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GSA TODAY

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The Case for a Long-Lived and Robust Yellowstone Hotspot

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SCIENCE

Cover: Photo taken near the summit of the Steens Mountain shield volcano in SE Oregon where the western escarpment reveals a stacked sequence of Steens Basalt flows and flow lobes, with feeder dikes exposed on the left side of the foreground ridge and on the right side of the background ridge. See related article, p. 4–10.

GSA NEWS

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The Case for a Long-Lived and Robust Yellowstone Hotspot

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ABSTRACT

The Yellowstone hotspot is recognized as a whole-mantle plume with a history that extends to at least 56 Ma, as recorded by offshore volcanism on the Siletzia oceanic plateau. Siletzia accreted onto the North American plate at 51–49 Ma, followed by repositioning of the Farallon trench west of Siletzia from 48 to 45 Ma. North America overrode the hotspot, and it transitioned from the Farallon plate to the North American plate from 42 to 34 Ma. Since that time, it has been genetically associated with a series of aligned volcanic provinces associated with age-progressive events that include Oligocene high-K calc-alkaline volcanism in the Oregon backarc region with coeval adakite volcanism localized above the hot plume center; mid-Miocene bimodal and flood-basalt volcanism of the main-phase Columbia River Basalt Group; coeval collapse of the Nevadaplano associated with onset of Basin and Range extension and minor magmatism; and late Miocene to recent bimodal volcanism along two coeval but antithetical rhyolite migration trends—the Yellowstone–Snake River Plain hotspot track to the ENE and the Oregon High Lava Plains to the WNW.

INTRODUCTION

Most workers agree that rhyolite migration along the Yellowstone–Snake River Plain hotspot track is driven by mantle upwelling and basaltic magmatism, but they disagree on the mechanism of mantle ascent. Proponents of a shallow-mantle origin for the Yellowstone hotspot have suggested a variety of mechanisms that include rift propagation (Christiansen et al., 2002), the lateral migration of lithospheric extension (Foulger et al., 2015), and eastward mantle flow driven by sinking of the Farallon slab (Zhou et al., 2018). Other workers attribute the hotspot trend to plate motion over a deep-seated mantle plume (e.g., Hooper et al., 2007, and references therein), an origin reinforced by recent seismic tomography that resolves the Yellowstone hotspot as a high-temperature, low-density conduit that extends through the lower mantle and is sourced at the core-mantle boundary (Nelson and Grand, 2018; Steinberger et al., 2019). An energetic plume is suggested by peak excess temperatures of 650–850 °C through the lower mantle (Nelson and Grand, 2018), and by an estimated range in volume flux through the upper mantle of 15 $m^3 s^{-1}$ to 31 $m^3 s^{-1}$ (Camp, 2019). Here, we examine the enduring strength and evolution of this feature by summarizing and connecting previous studies to reveal a linear progression of magmatic provinces lying along the track of a fixed Yellowstone hotspot that has been active at least since 56 Ma.

PROVENANCE AND KINSHIP OF SILETZIA TO THE YELLOWSTONE HOTSPOT

Debate on the earliest manifestation of the Yellowstone hotspot has focused on traditional models that equate the generation of continental flood-basalt provinces to melting of starting plume heads at the base of continental lithosphere (e.g., Campbell, 2005). This paradigm has led several workers to conclude that the Yellowstone starting plume head arrived at ca. 17 Ma, contemporaneous with the earliest flood-basalt eruptions of the Columbia River Basalt Group (Pierce and Morgan, 1992; Camp and Ross, 2004; Shervais and Hanan, 2008; Smith et al., 2009). Duncan (1982), however, was an early supporter of an older Yellowstone hotspot responsible for Paleocene to Eocene volcanism that created an oceanic plateau, now preserved as mafic rocks accreted to the Coast Ranges of Oregon, Washington, and Vancouver Island—the Siletzia terrane. Although alternative models for the origin of Siletzia have been proposed, including continental margin rifting (Clowes et al., 1987; Wells et al., 1984); slab window magmatism (Babcock et al., 1992; Madsen et al., 2006); and microplate accretion (McCrory and Wilson, 2013), proximity to a hotspot seems to be required to produce the large volume of basalt. Such an origin is supported by a variety of more recent studies; for example: (1) plate reconstruction models supporting the location of a Paleocene to Eocene Yellowstone hotspot in position to produce Siletzia offshore of the northwestern U.S. (Engebretson et al., 1985; McCrory and Wilson, 2013; Wells et al., 2014; Müller et al., 2016); (2) field and geochronological data constraining the composition, age, and timing of Siletzia's accretion (Wells et al., 2014; Eddy et al., 2017); (3) volume calculations of 1.7×10^6 km^3 to 2.6×10^6 km^3 for the unsubducted part of the Siletzia terrane (Trehu et al., 1994; Wells et al., 2014), classifying it as a large igneous province typical of other oceanic hotspots (Bryan and Ernst, 2008); (4) elevated $^{187}Os/^{188}Os$ in Siletzia mafic lavas and $^3He/^4He$ on olivine phenocrysts, consistent with a mantle plume source (Pyle et al., 2015); (5) trace-element and Sr-Pb-Nd-Hf isotopic data delineating a heterogeneous mantle source with a plume component similar to early Columbia River Basalt Group lavas (Pyle et al., 2015; Phillips et al., 2017); and (6) mantle potential temperature calculations that are well above ambient mantle and consistent with melts derived from a hot mantle plume (Phillips et al., 2017).

Murphy (2016) suggested a still earlier period of offshore magmatism, with the Yellowstone swell entering the Farallon trench at ca. 80–75 Ma and contributing to the Laramide orogeny. The cause of the Laramide orogeny remains controversial and is not addressed here.

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HOTSPOT CHRONOLOGY

We have compiled volcanic fields previously interpreted to be related to Yellowstone hotspot magmatism across the northwestern U.S. on Figure 1, including a reconstructed Siletzia in the Eocene, in an attempt to document the magmatic progression across the forearc and through the Cascadia backarc region. Also plotted are the locations of the hotspot at 40.5 Ma from McCrory and Wilson (2013) and a proposed hotspot track using the plate motions of Matthews et al. (2016) and assuming a fixed hotspot. The magmatic provinces are aligned with the proposed hotspot track and have a monotonic age progression similar to, but not identical to the model, which we will return to later.

Here we describe a history of progressive crustal melting manifested in the series of aligned tectonomagmatic stages in Figure 1B, ranging from rifting and oceanic-island-basalt–like (OIB) lavas in the forearc, to adakitic backarc magmatism, voluminous flood basalt, and rhyolitic volcanism. These events, we suggest, record the progressive effects of a long-lived Yellowstone hotspot as it propagates from beneath oceanic lithosphere, across continental lithosphere of accreted terranes, to its current position beneath the North American craton.

Volcanism and Accretion of Siletzia (ca. 56–49 Ma) and Establishment of a New Subduction System (ca. 48–45 Ma)

Radiometric ages constrained by field mapping, global nannoplankton zones, and paleomagnetic correlations demonstrate that Siletzia was formed from 56 to 49 Ma and

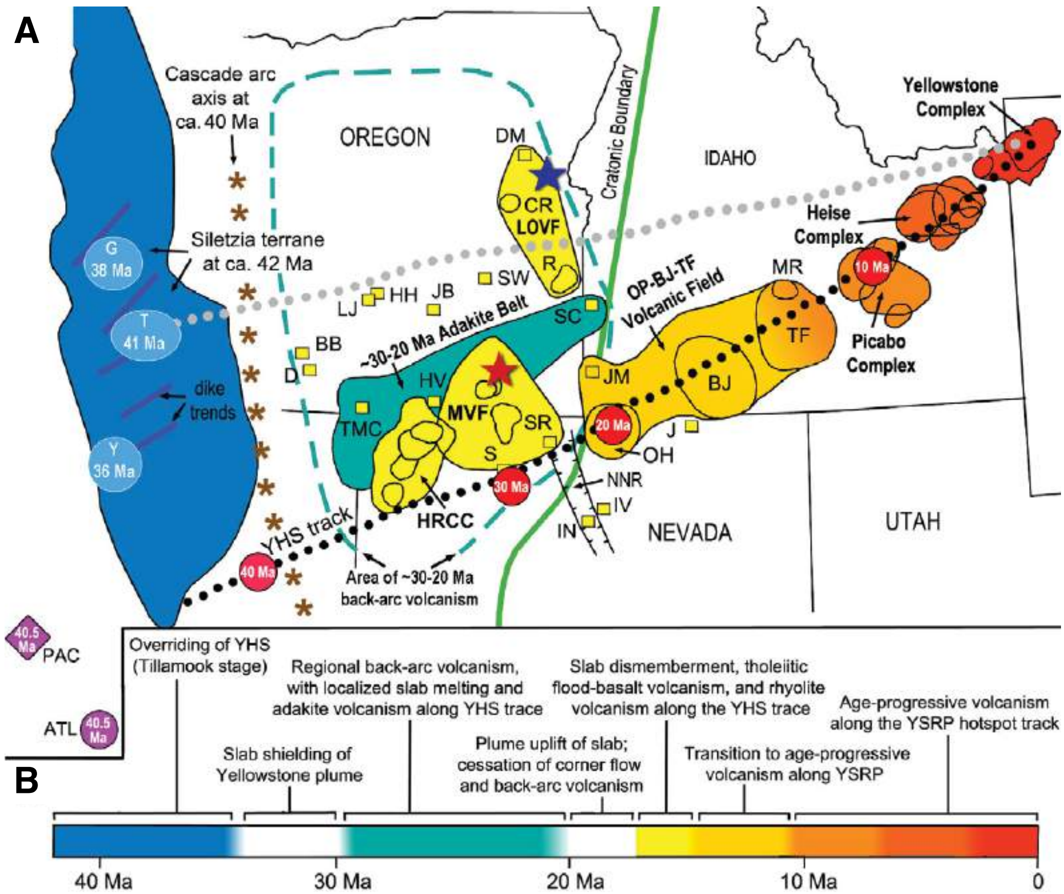

Figure 1. (A) Evolution of the Yellowstone hotspot (YHS) track relative to the North American plate. Siletzia is restored to its relative position at ca. 42 Ma when the YHS was overridden by the accreted Siletzia terrane, now part of North America. Ancestral Cascades arc location at ca. 40 Ma is modified from Wells and McCaffrey (2013). Colored locations east of Siletzia correspond to progressive sites of crustal melting along the hotspot track since ca. 30 Ma, without removal of Basin and Range extension. Purple diamond and circle are locations of YHS with respect to N. America at 40.5 Ma from McCrory and Wilson (2013) in Pacific (PAC) and Atlantic (ATL) hotspot frames; red dots are projected YHS locations using plate motion of Matthews et al. (2016) and assuming a fixed YHS. Black and gray dotted lines are possible YHS tracks modified from Wells et al. (2014). NNR—northern Nevada rift; YSRP—Yellowstone–Snake River Plain. Calderas, felsic volcanic fields, and lava centers from Shervais and Hanan (2008), Benson et al. (2017), and Anders et al. (2019), with colors corresponding to color-code ages in panel B. Mafic fields in the Coast Range: T—Tillamook; Y—Yachats; G—Grays River. Felsic volcanic fields: LOVF—Lake Owyhee Volcanic Field; MVF—McDermitt Volcanic Field; HRCC—Field of the High Rock Caldera Complex; OP-BJ-TF—Owyhee Plateau–Bruneau Jarbidge–Twin Falls Volcanic Field. Individual calderas shown in irregular oval polygons: MR—Magic Reservoir; OH—Owyhee-Humboldt; BJ—Bruneau-Jarbidge caldera; TF—Twin Falls caldera; R—Rooster Comb caldera; CR—caldera at Castle Rock; DM—Dooley Mountain; JM—Juniper Mountain. Contemporaneous felsic centers shown as yellow boxes: SC—Silver City; LJ—Little Juniper Mountain; HH—Horsehead Mountain; JB—Jackass Butte; SW—Swamp Creek Rhyolite; TMC—Twenty Mile Creek Rhyolite; BB—Bald Butte; D—Drum Hill; HV—Hawks Valley–Lone Mountain; S—Sleeper Rhyolite; SR—Santa Rosa–Calico; IN—Inzenhood; IV—Ivanhoe; J—Jarbidge. The two stars represent alternative sites for the plume center at 17–16 Ma, the blue-star location supported by some workers (e.g., Glen and Ponce, 2002; Shervais and Hanan, 2008; Wolff and Ramos, 2013), and the red-star location supported by others (e.g., Camp and Ross, 2004; Pierce and Morgan, 2009; Benson et al., 2017). (B) Timeline of tectonomagmatic events along the YHS track.

accreted to North America at 51–49 Ma (Wells et al., 2014, and references therein). Accretion may have been partly contemporaneous with underplating of older parts of a greater Siletzia in the backarc region of SE Washington and adjacent Oregon (Gao et al., 2011; Schmandt and Humphreys, 2011). Trench development west of the accreted terrane was established at 48–45 Ma (Wells et al., 2014). Subduction initiation at this time is consistent with upper plate extension and post-accretion magmatism of a regional tholeiitic sill complex in the northern Oregon Coast Range (Wells et al., 2014) and with the onset of sporadic arc volcanism in the ancestral Cascades from ca. 45–36 Ma (DuBray and John, 2011).

Overriding of the Yellowstone Hotspot by the North American Plate (ca. 42–34 Ma)

At ca. 42 Ma, the leading edge of the North American plate began to override the hotspot at the site of the newly formed trench (Simpson and Cox, 1977; Wells et al., 2014). This event marks the beginning of regional margin-parallel extension, widespread dike injection, and post-accretionary hotspot magmatism of enriched mid-oceanic ridge basalt (EMORB) and OIB of the Tillamook episode from 42 to 34 Ma (Chan et al., 2012; Parker et al., 2010; Wells et al., 2014), exemplified in the Tillamook Volcanics, Yachats basalt, and Grays River Volcanics (Fig. 1). Location of the overridden hotspot at this time therefore appears to have been in the general vicinity of southern Oregon and northern California, but perhaps slightly north of the calculated hotspot track approximated in Figure 1 (black dotted line). Well-documented clockwise rotation and northward migration of the forearc have since moved Siletzia and the Tillamook Volcanics as much as 300 km to the north (Beck, 1984; Wells et al., 2014).

Slab Uplift and Volcanism in the Oregon Backarc Region (ca. 30–20 Ma)

Continued flux of the plume tail should have accumulated a significant mass of hot plume material shielded beneath the Farallon slab from 42 to 30 Ma (e.g., Coble and Mahood, 2012). Plume arrival in the Oregon backarc generated a broad region of high-K calc-alkaline volcanism and a coeval but more localized belt of adakite volcanism from ca. 30–20 Ma (Fig. 1) (Camp et al., 2017). Mafic rocks of this episode display depletion in Nb and enrichment in the H_2O-soluble elements Rb, Ba, K, and Pb, a chemical signature that requires melting of a hydrated mantle source. Camp et al. (2017) attribute source enrichment to plume-induced uplift and heating of the slab resulting in the liberation of H_2O into the overlying mantle wedge, thus lowering solidus temperatures and promoting partial melting of hydrated mantle beneath the Oregon backarc from 30 to 20 Ma (Fig. 1).

Thermomechanical erosion of the Farallon slab is suggested by the ENE-trending belt of 30-to-20 Ma adakite, thought to be derived from slab melting of oceanic crust (Fig. 1). The low solidus temperature of this mafic source makes it highly susceptible to thermal erosion and melt generation above the feeding plume tail, where maximum temperatures are maintained (Campbell, 2005). The adakite belt lies parallel to plate motion and has been described as an older extension of the Yellowstone–Snake River Plain hotspot track to the east (Camp et al., 2017).

Volcanic Hiatus in the Backarc Region (ca. 20 Ma to 17 Ma)

Calc-alkaline and adakite volcanism in the backarc region waned dramatically at 22 Ma and ceased at 20 Ma. Thus began a 3–5-m.y. volcanic hiatus that is well established in eastern Oregon and northernmost Nevada (Coble and Mahood, 2012, and references therein). Coble and Mahood (2012) attribute this hiatus to continued plume uplift of the Farallon slab leading to the cessation of corner flow in the overlying mantle wedge. The hiatus separates two distinct magmatic perturbations in the backarc region: (1) the older period of calc-alkaline magmatism from 30 to 20 Ma, where mafic rocks were derived from a wet mantle source; and (2) a younger period of tholeiitic flood-basalt to bimodal magmatism from 17 to 15 Ma, where mafic rocks were derived from a dry mantle source.

Slab Rupture and Tholeiitic Flood Basalt to Bimodal Volcanism (ca. 17–15 Ma)

The volcanic hiatus ended at ca. 17 Ma with fissure eruptions of the voluminous main-phase lavas of the Columbia River Basalt Group, all of which share a plume-like component based on trace-element and isotopic data (e.g., Wolff and Ramos, 2013). The main phase generated 93% (194,000 km^3) of the Columbia River Basalt Group volume in ca. 600,000 years (Kasbohm and Schoene, 2018). This narrow age-range overlaps with the age of bimodal eruptions along the northern Nevada rift from 16.5 to 15.0 Ma (John et al., 2000) and with high-volume rhyolite eruptions in SE Oregon and NW Nevada from 16.5 to 15.5 Ma (Fig. 1) (Coble and Mahood, 2016; Benson et al., 2017). The oldest rhyolites at 16.5–16.1 Ma (i.e., HRCC, MVF, SR, S, HV, and J on Fig. 1) and the most voluminous rhyolite fields (~5000 km^3; HRCC and MVF on Fig. 1) lie in a narrow belt adjacent and parallel to the projected Yellowstone hotspot track (Fig. 1). In total, this 17–15 Ma event of flood basalt and bimodal volcanism produced a N–S system of coeval dike swarms, rhyolitic calderas and large, mid-crustal keel dikes expressed as linear aeromagnetic anomalies (Glen and Ponce, 2002) that extend from eastern Washington to central Nevada and perhaps into southern Nevada (Pierce and Morgan, 1992), the Nevada–Columbia Basin Magmatic Belt (Fig. 2) of Camp et al. (2015).

Liu and Stegman (2012) attribute the Nevada–Columbia Basin Magmatic Belt to slab tearing along a N-S hinge line beneath eastern Oregon, followed by upwelling and melting of subslab asthenosphere. Other workers prefer a modification of this process with slab rupture near the eastern hinge of plume-driven uplift (Coble and Mahood, 2012; Camp et al., 2015), tearing N-S in much the same manner as envisioned by Liu and Stegman (2012). Extension of the Nevada–Columbia Basin Magmatic Belt into NE Oregon and SE Washington (Fig. 2) may have also been augmented by the northward deflection of spreading plume material against the thick cratonic boundary (e.g., Sleep, 1996; Camp, 1995), and/or by the long-distance lateral migration of dikes from centralized magma chambers farther south (Wolff and Ramos, 2013).

Slab dismemberment beneath eastern Oregon is consistent with seismic studies that resolve a truncated subducting plate that terminates at ~300 km depth, with fast anomalies farther east interpreted as Farallon slab remnants (e.g., Obrebski et al., 2010). The intervening slab hole lies directly beneath the axial trend of the older (30–20 Ma) adakite hotspot track and the younger continuation of the Yellowstone–Snake River Plain hotspot track (e.g., figure 3f of Obrebski et al., 2010).

Plume Relationship to Regional Tectonics (17–15 Ma)

The events at 17–15 Ma occurred during a time when western North America was evolving from a convergent to a transform

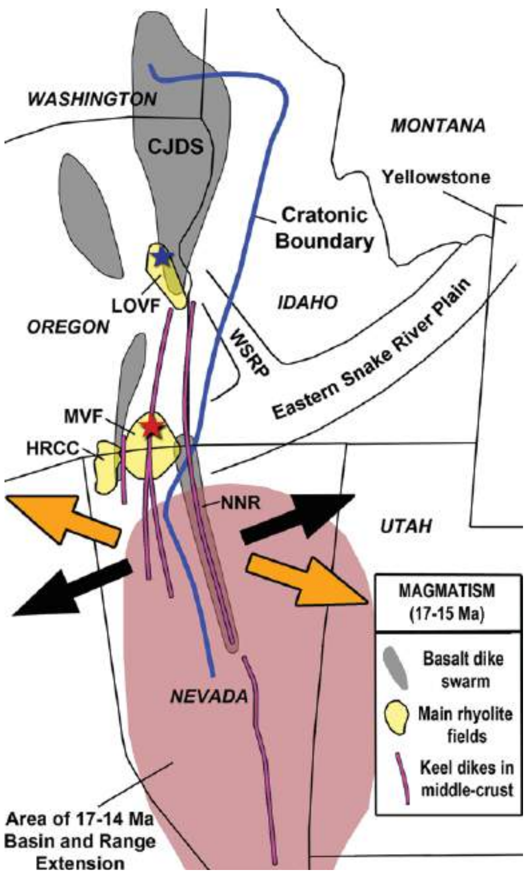

Figure 2. Palinspastic reconstruction of bimodal volcanism along the Nevada–Columbia Basin magmatic belt from ca. 17–15 Ma, with southernmost extension based solely on aeromagnetic data. See Figure 1 for definition of red and blue stars and volcanic fields HRCC, MVF, LOVF, and NNR. Orange arrows depict the orientation of mid-Miocene Basin-and-Range extension; black arrows depict the overall dilation direction of coeval mid-Miocene dikes. CJDS–Chief Joseph dike swarm, where 85% of the Columbia River Basalt Group volume erupted. Area of 17–14 Ma extension from Colgan and Henry (2009). WSRP—Western Snake River Plain.

setting. Basin-and-Range extension began at 17–16 Ma (Colgan and Henry, 2009) when torsional stress was fully imposed on the continental interior due to plate-boundary tectonics (Dickinson, 1997).

Could the initiation of continental extension at 17–16 Ma be the root cause of coeval flood-basalt and related magmatism in the Nevada–Columbia Basin Magmatic Belt (e.g., Dickinson, 1997)? Such a scenario conflicts with two observations: (1) the greatest eruptive volume was in the area of least extension (e.g., the Chief Joseph dike swarm; CJDS on Fig. 2), while the smallest eruptive volume was in the Basin-and-Range region of far greater extension (e.g., the NNR on Fig. 2); and (2) early crustal extension in the northern and central Basin-and-Range generated structural elements with NNE trends, but coeval magmatic intrusion along the Nevada–Columbia Basin Magmatic Belt generated dikes with NNW trends, a 45° difference (e.g., Colgan, 2013). Camp et al. (2015) and Morriss et al. (2020) attributed the source of these magmatic trends instead to a bottom-up process of forceful dike injection due to high magma overpressure unrelated to regional stress.

Could plume impingement be the main cause of Basin-and-Range extension? This also seems unlikely, based on the well-documented influence of plate-boundary conditions on regional stress and the influence of high gravitational potential energy on the uplifted orogenic plateau, the Nevadaplano. On the other hand, plume underplating may well have played a role in crustal extension through thermal weakening and mantle traction at the base of the lithosphere (Pierce et al., 2002), thus providing a catalyst for extension of the high plateau that was already under stress and on the verge of regional collapse (Camp et al., 2015).

Transition from Broad-Based Volcanism to an Age-Progressive Hotspot Track (ca. 14–10 Ma)

In the long-lived plume scenario, the Yellowstone plume head arrived prior to Siletzia accretion, and not during the onset of flood-basalt volcanism. The plume component in the main-phase Columbia River Basalt Group eruptions is instead attributed to the large volume of plume material that collected beneath the Farallon slab by flux of the feeding plume tail from ca. 34–17 Ma. Slab rupture and adiabatic rise of this accumulated mantle generated bimodal eruptions of flood basalt and rhyolite from 17 to 15 Ma, the latter driven by basalt injection and melting of fertile crust near the center of the Nevada–Columbia Basin Magmatic Belt (e.g., Coble and Mahood, 2016; Benson et al., 2017).

Silicic volcanism remained dispersed until ca. 14 Ma when rhyolitic eruptions became more focused along the Yellowstone–Snake River Plain in SW Idaho (Fig. 1). Here, bimodal eruptions from ca. 14 Ma to 10 Ma are thought to be associated with the transition from volcanism above the broad accumulation of plume material to volcanism above the narrow plume tail, as the former was overridden by continental lithosphere of the North American craton (Pierce and Morgan, 1992; Shervais and Hanan, 2008). A systematic ENE progression of younger inception ages for rhyolite fields in the central Snake River Plain began between 12.5–10.8 Ma, with the plume tail establishing a well-defined hotspot-migration trend by ca. 10 Ma (Pierce and Morgan, 1992, 2009).

Coeval Rhyolite Migrations along Opposing Trends (10 Ma to Recent)

Anders et al. (2019) calculated a migration rate of 2.27 ± 0.21 cm/yr along the Yellowstone–Snake River Plain trend since 10.41 Ma, which is close to independent estimates of plate motion along the same ENE trend (Fig. 3). This is consistent with a fixed Yellowstone hotspot over this timeframe, similar to the classic Hawaiian-type model of plate motion above a stationary plume tail.

Contemporaneous silicic migration since 10 Ma occurs across the Oregon High Lava Plains from SE Oregon toward the Newberry volcano east of the Oregon Cascades arc (e.g., Jordan et al., 2004). This WNW trend (Fig. 3) is antithetical to the Yellowstone–Snake River Plain trend and is often cited as evidence against a plume origin (e.g., Christiansen et al., 2002; Foulger et al., 2015). Several workers attribute the High Lava Plains trend to mantle upwelling associated with slab rollback (e.g., Long et al., 2009; Ford et al., 2013), but this may be difficult to reconcile with evolving seismic data that reveal a shortened and highly fragmented slab in this region (Long, 2016). Slab fragmentation is described by Hawley and Allen (2019) as a propagating tear responsible for westward mantle flow beneath the High Lava Plains trend. Following Jordan et al.

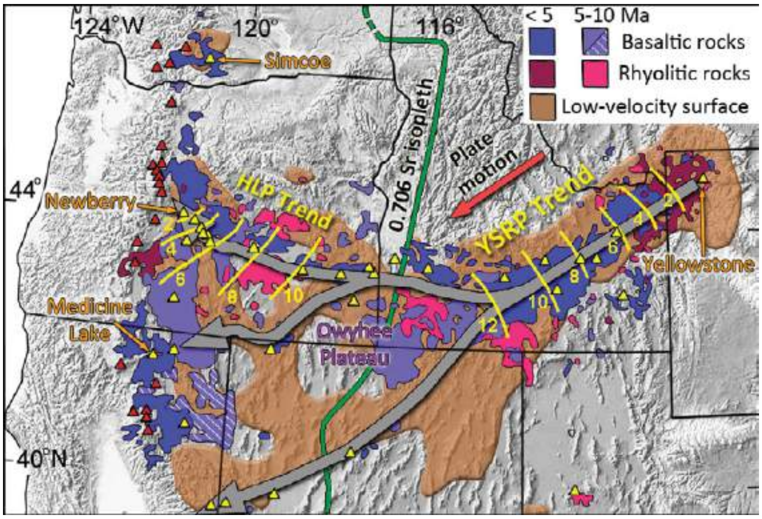

Figure 3. Volcanic rocks younger than 10 Ma superimposed above sublithospheric low-velocity surface of Wagner et al. (2010). Yellow lines are isochrons for rhyolite volcanism along the Yellowstone–Snake River Plain (YSRP) and High Lava Plains (HLP). Red triangles are Holocene volcanoes of the high Cascades; yellow triangles are areas of Quaternary volcanism in the Cascadia backarc region largely corresponding with seismic low-velocity channels of plume-modified mantle flow; channel axes approximated by gray arrows. Modified from Camp (2019).

(2004), Wells and McCaffrey (2013) calculated that the High Lava Plains progression migrated westward due to mantle counterflow at the slab subduction rate until it hit the slab at 5 Ma, when it slowed to the rollback rate, driven by forearc rotation. Camp (2019) described an alternative model of westward mantle flow driven by plume flux sheared in the direction of plate motion but augmented by rapid, thermally driven buoyancy flow across the cratonic boundary of North America. According to this model, Miocene-to-recent flow of plume-modified mantle generated a broad seismic low-velocity feature described by Wagner et al. (2010), which emanates from the Yellowstone hotspot and currently underlies the Snake River Plain and High Lava Plains volcanic rocks (Fig. 3). Quaternary flow at the top of this larger feature is evident in the identification of finger-like channels of low seismic velocity at 75 km depth coincident with the dispersed alignment of young volcanic centers that extend from Yellowstone to the Cascades volcanic arc (Fig. 3).

Magmatic Timing versus Plate Motions

The magmatic progression nicely follows a linear trend between the predicted Yellowstone hotspot location at 40 Ma and its present location (Fig. 1), but magmatism between 17 and 10 Ma lags 5–10 m.y. behind the predicted appearance from the fixed hotspot track. Accounting for Basin-Range extension could reduce some, but not all, of the misfit, and the time required for the Yellowstone hotspot to escape from beneath the slab curtain also could have contributed substantially to the delay. Jordan et al. (2004) suggested an additional mechanism, where plume material was deflected west of the hotspot location after ca. 20 Ma as it rose obliquely against the base of shallowing lithosphere, ponding beneath thinner lithosphere west of the cratonic boundary. Finally, the uncertainties in the plate models and the possibility of Cenozoic true polar wander (Woodworth and Gordon, 2018) may be significant at this scale. Although formal uncertainties are not typically provided, the differences in the 40± Ma position of the Yellowstone hotspot may give some idea of the variability in models.

SUMMARY

The combined evidence suggests that Yellowstone plume-lithosphere interaction may have been more significant than previously thought, contributing to a linear age-progression of tectonomagmatic events and aligned volcanic provinces since 56 Ma. These include: (1) late Paleocene to Eocene volcanism and accretion of the Siletzia oceanic terrane; (2) rifting and OIB-like forearc magmatism at 42 Ma following establishment of a new trench west of the accreted terrane as the leading edge of North America overrode the Yellowstone hotspot; (3) Oligocene eruption of high-K calc-alkaline lavas in the Oregon backarc region resulting from plume uplift and heating of the Farallon slab, leading to volatile release and melting of the mantle wedge; (4) coeval Oligocene adakite volcanism during thermomechanical erosion of the slab and melting of oceanic crust; (5) slab rupture resulting in adiabatic rise and melting of a plume source component found in Miocene tholeiitic flood basalts of the Columbia River Basalt Group and the Nevada–Columbia Basin Magmatic Belt; (6) active mantle upwelling beneath the Nevadaplano that may have aided in plateau collapse and Miocene initiation of Basin-and-Range extension; (7) Miocene-to-recent bimodal volcanism and rhyolite migration along the Yellowstone–Snake River Plain hotspot track to the ENE; and (8) westward sublithospheric flow of plume-modified mantle, resulting in Miocene-to-recent bimodal volcanism with rhyolite migration along the Oregon High Lava Plains to the WNW.

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26–30 October

GSA 2020

CONNECTS ONLINE

Letter from the GSA 2020 Connects Online General Chair

Dear attendees,

I'm sure you would have preferred to attend the meeting in person in Montréal, just as the Local Organizing Committee and I would have loved to welcome you to our great city and showcase the exciting geology of the region. It was clearly a disappointment to abandon the extensive planning for an in-person conference, and the shift to an entirely online meeting presented many challenges. Nevertheless, I would like to highlight the successes of the meeting, which included 225 technical sessions, five Pardee Symposia, four Feed Your Brain lunchtime lectures, 17 short courses, four virtual field trips, and 99 non-technical events. While the ongoing pandemic may have limited participation, there were 2,798 presentations and 6,007 attendees registered for the conference.

I would like to offer our sincere appreciation to all of you for contributing to these successes and finding the time to participate, despite the difficulties. Your patience and efforts in the face of the logistical and technical stumbling blocks ensured that the meeting was a venue for productive scientific exchanges and diffusion of cutting-edge science.

The Geological Society of America meeting this year offered many glimpses of the future of virtual conferences, while also providing many lessons. It is inescapable that in the post-pandemic world, virtual meetings will be more commonplace, not only because they allow us to significantly reduce our carbon footprint, but also because they are more inclusive. For one, they allow people who cannot travel to international conferences to contribute to the advancement of geosciences. The high number of registered participants at GSA 2020 attests that this was the case this year. The reliance on pre-recorded presentations may have caused some consternation among busy participants trying to juggle their time and commitments, but this format also allowed all presenters the time and space to craft their talks in advance, resulting in high-quality sessions across the board. The chats and panelist discussions also democratized exchanges by allowing more people to share ideas in a respectful way. Moreover, the Montréal meeting was exemplary in the diversity of participants and in the number of sessions led with aplomb by early career researchers. What we all missed most, however, was actively exchanging ideas with others. Whether they'll be face-to-face or virtual, future meetings will have to foster collaborative knowledge-building to a maximum because only by working together will we be able to tackle the even more complex future scientific challenges. But that being said, I do hope to see you all in person soon, perhaps next year in Portland and definitely in Montréal for GSA Connects 2027!

Wishing you all to continue driving our science
while taking care of your health and that of others,

Félix Gervais
GSA 2020 General Chair
Associate Professor at Polytechnique Montréal

Thanks to the GSA 2020 Connects Online Organizing Committee

Félix Gervais: General Chair

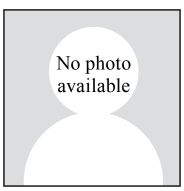
Kevin Mickus: Technical Program Chair

Amy Brock-Hon: Technical Program Vice-Chair

Brian Cousens: Field Trip Co-Chair

Kristyn Rodzinyak: Field Trip Co-Chair

William Minarik: K–12 Chair



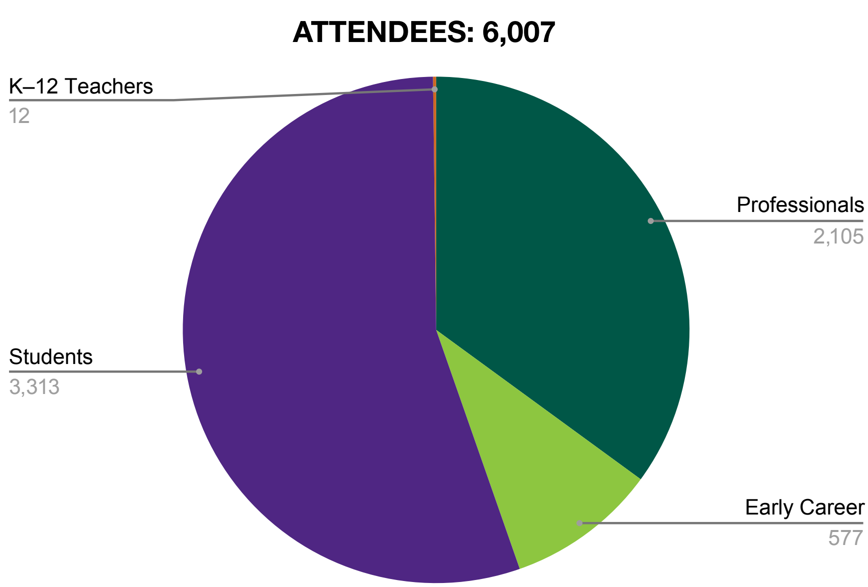
James Kirkpatrick: Student/Early Career Professionals Chair

Fiona Darcy: Community Education Chair

Galen Halverson: Local Geology Program Chair

By the Numbers

- Attendees: 6,007
- Professionals: 2,105
- Early Career Professionals: 577
- Students: 3,313
- K–12 Teachers: 12
- Mentors: 94
- On To the Future Scholars: 38
- Countries Represented: 66 (17% of attendance, up from 10% when in person)
- Abstracts: 2,798
- Short Courses: 17
- Virtual Field Trips: 4
- Exhibiting Organizations: 55



Thank You to All the Mentors Who Volunteered Their Time at GSA 2020 Connects Online

Mentors are integral to GSA's meetings and are a source of motivation and support for students and early career professionals as they seek advice and information related to their academic and career pathways. The following are programs mentors presented along with selected comments from mentees.

- Cover Letter Workshop
- Geoscience Workforce Outlook Presentation
- Career Panel
- Creating a Résumé for Industry
- Careers in Industry Panel
- Selling Yourself at GSA: Learn How to Network and Leave a Lasting Impression
- Networking Event
- Early Career Panel
- An Introduction to USAJOBS
- Careers in Government Panel
- Women in Geology Panel
- Creating a Curriculum Vitae
- Careers in Academia and Teaching Panel
- Diversity, Equity, and Inclusion Networking Event
- Creating a Résumé for Non-Traditional Employment
- Non-Traditional Careers Panel

"Great mentors and sessions."

"Awesome event with professionals who were great speakers who clearly cared about helping people reach their potential. Thanks so much!"

"I have attended these events at past GSAs and this one was the best. Each panel had a very good representation of all the career avenues that exist. I especially liked how the careers in academia included people that specialize in each of the different educational settings (K–12, 2 year, 4 year, R1). Great job GSA!"

If you missed these events at GSA 2020 Connects Online, please check GSA's webinar library at **https://www.geosociety.org/webinars** for recordings.

THE GEOLOGICAL SOCIETY OF AMERICA®
KARST DIVISION

Exploring New Frontiers in Cave and Karst Science

AUTHORS
Jason S. Polk, Chair, GSA Karst Division
Dan Jones, Secretary, GSA Karst Division
Ben Tobin, Treasurer, GSA Karst Division

The GSA Karst Division, established in 2014, encompasses a thriving group of interdisciplinary researchers, students, and explorers. The maturation and expansion of cave and karst science in recent years is evident in the "New Frontiers" sessions recently held at GSA 2020 Connects Online, which highlighted emerging and intriguing scientific work underway. Here, we discuss new and innovative areas in which karst science is currently expanding and celebrate recognition of these efforts exemplified in the naming of 2021 as the International Year of Caves and Karst, organized by the International Union of Speleology.

At a global scale, the critical zone is where rock meets life at Earth's surface, from treetop to groundwater. Critical zone processes are a substantial focus for the earth-science community, though surprisingly little emphasis has been placed on karst areas; however, the National Science Foundation recently funded a new research coordination network (RCN) focused on critical zone processes in carbonate terrains, which is bringing together multidisciplinary researchers to focus on some of the most pressing issues related to carbon cycling, biogeochemical processes, and human-environment interactions involving climate change through surface-subsurface connections.

Karst hydrogeology has long focused on contaminant transport, but as our understanding grows, researchers are making new advances in identifying and modeling the behavior of emerging contaminants in karst aquifers. Rapid infiltration and discharge, coupled with long-term storage capabilities, make karst groundwaters especially susceptible to anthropogenic contaminants. Growing research on the sources and fate of microplastics in karst aquifers, having been the focus of only a single published manuscript to date, is offering important new insights into the behavior of these ubiquitous contaminants in karst groundwaters and their impacts on sensitive cave ecosystems. Research is also expanding on emerging contaminants, including fluorescent whitening compounds, PFOS and other perfluorochemicals, hormones, pharmaceuticals, personal-care products, as well as antibiotic-resistant bacteria in groundwater, bringing them to the forefront of our attention as groundwater resources face critical vulnerabilities from numerous stressors.

Cave geobiology and geomicrobiology is one of the most rapidly growing interdisciplinary subfields of karst research. Recent discoveries include insights into bedrock corrosion and speleothem formation, such as microbial contributions to carbonate precipitation in moonmilk and recognition of the role of iron-reducing microorganisms in the formation of unusual iron ore caves in Brazil. We've unearthed new antibiotic resistance properties of cave bacteria and are starting to apply microbiological techniques for managing cave resources, which are providing excellent approaches to combat unsightly, harmful photosynthetic *lampenflora* biofilms in show caves. Continuing advances in DNA sequencing technology are enabling far more extensive microbial community characterization, and new genomic techniques are enabling researchers to better link genes and geochemistry in karst settings. The New Frontiers session presentations included applications of cutting-edge genomics technologies to shed new light on cave communities and improve genome recovery of novel microorganisms from cave biofilms.

We continue to look beyond the confines of Earth in ways never before possible, providing clues to the prevalence of lava caves on the moon and Mars. These caves represent new opportunities to access the Martian subsurface and hunt for signatures of life, past or present, and may eventually provide shelter for human habitation. New robotics technologies are actively being developed to explore these extremely challenging terrains, and, here on Earth, researchers are redoubling efforts at robotic- and human-guided exploration of analogue lava caves. The NASA Decadal Survey featured many new white papers addressing the subsurface than in previous years, and efforts to advance subsurface studies using innovative geophysical and geomicrobiological methods hold promise for the future.

Traditionally, karst science has fostered and embraced a diverse collective of scientists, cavers, and communities passionate about these unique landscapes. Now, more than ever, we celebrate that inclusiveness both in our research foci and delivery, which is evident through advances in how we interact and involve the community. We have transitioned successfully to offer novel virtual field studies courses and produced data-driven visuals using geocognition to ensure understanding and learning about karst. Creative research in ethnogeology is elucidating the importance of caves to societies around the world, highlighting how human society relates to natural resources and their role in communities, which proves important to the management of caves and karst in the broader context of globalization. Together, our efforts demonstrate how karst researchers are championing the power of interdisciplinary collaboration. We can be confident that future pioneers will draw upon a collection of ideas, cultures, paradigms, and science that truly represent our best efforts to ensure a lighted path for cave and karst research toward a better world.

CALL FOR NOMINATIONS

2021 GSA Awards & Medals

GSA selects individuals based on track record and commitment to integrity and promise to continue living up to the ethical standards embodied in GSA's Code of Ethics & Professional Conduct in addition to their many accomplishments. For details, see the October issue of *GSA Today* or go to **https://www.geosociety.org/awards.** The deadline for medal, award, and recognition nominations is **1 Feb.**

Penrose Medal
Arthur L. Day Medal
Young Scientist Award (Donath Medal)
Florence Bascom Geologic Mapping Award
The Bromery Award for Minorities
Doris M. Curtis Outstanding Woman in Science Award
GSA Distinguished Service Award
GSA Public Service Award
Honorary Fellow

Also Coming Up:

John C. Frye Environmental Geology Award
Deadline: 31 Mar.

In cooperation with the Association of American State Geologists, GSA makes an annual award for the best paper on environmental geology published either by GSA or by one of the state geological surveys. **Please send your nominations to** GSA Grants and Awards, P.O. Box 9140, Boulder, CO 80301-9140, USA; or send digital documents to awards@geosociety.org.

For more information, go to **www.stategeologists.org/award/frye.**

Call for GSA Fellowship Nominations

Deadline: 1 Feb. 2021

Nominate a deserving colleague with the honor of GSA Fellowship. GSA members are elected to Fellowship in recognition of distinguished contributions to the geosciences. See the election requirements at **https://www.geosociety.org/Fellowship.**

How to Nominate

The primary nominator, who must be a current GSA Fellow, (1) writes a letter of support; (2) collects two additional letters of support (one must be from a Fellow; both must be GSA members); (3) obtains nominee's current CV or résumé (two-page limit); and (4) completes online nomination form and uploads letters and CV/résumé at **https://www.geosociety.org/FellowNoms.**

The Geological Society of America®

GEOCAREERS

GeoCareers Programs at the 2021 Section Meetings

CAREER WORKSHOPS

Geoscience Career Workshop Part 1: Career Planning and Networking.

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

Geoscience Career Workshop Part 2: Geoscience Career Exploration.

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

Geoscience Career Workshop Part 3: Cover Letters, Résumés, and CVs.

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

MENTOR PROGRAMS

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

Northeastern: Online Meeting
Shlemon Mentor Program: Sunday, 14 March
Mann Mentors in Applied Hydrology Program: Monday, 15 March

Southeastern Section: Online Meeting
Shlemon Mentor Program: Thursday, 1 April
Mann Mentors in Applied Hydrology Program: Friday, 2 April

Joint North-Central South-Central Section: Online Meeting
Shlemon Mentor Program: Sunday, 18 April
Mann Mentors in Applied Hydrology Program: Monday, 19 April

Cordilleran Section: Online Meeting
Shlemon Mentor Program: Wednesday, 12 May
Mann Mentors in Applied Hydrology Program: Thursday, 13 May

Northeastern Urban Award for Non-Traditional Students

Students interested in attending the Northeastern Section Meeting (**https://www.geosociety.org/ne-mtg**) are encouraged to apply to this award covering educational costs, dependent care, abstract fees, and meeting registration. Apply by 1 Feb. at https://forms.gle/qKWwkkSpPGSxyJFM8.

THE GEOLOGICAL SOCIETY OF AMERICA®

2021 GSA Section Meetings

Northeastern

14–16 March
Online Meeting
https://www.geosociety.org/ne-mtg

The skyline of Hartford, Connecticut, as seen from across the Connecticut River. Image by Jimaro Morales from Pixabay.

Southeastern

1–2 April
Online Meeting
https://www.geosociety.org/se-mtg

William J. Samford Hall, Auburn University. The George F. Landegger Collection of Alabama Photographs in Carol M. Highsmith's America, Library of Congress, Prints and Photographs Division.

Joint North-Central/South-Central

18–20 April
Online Meeting
https://www.geosociety.org/nc-mtg

Downtown Springfield Park Central Square. Photo courtesy of the Springfield, Missouri, Convention and Visitors Bureau.

Cordilleran

12–14 May
Online Meeting
https://www.geosociety.org/cd-mtg

Volcanic geology of the Virginia Mountains, Nevada. Photo courtesy of Dr. Philipp Ruprecht, UNR faculty member.

Rocky Mountain

25–27 M…
POSTPONED
…ollins, Colorado
https://www.geosociety.org/rm-mtg

Pineridge Natural Area. Image by Jan Alexander from Pixabay.

A Foretaste of GSA Memoir 216:

Revising the Revisions: James Hutton's Reputation among Geologists in the Late Eighteenth and Nineteenth Centuries

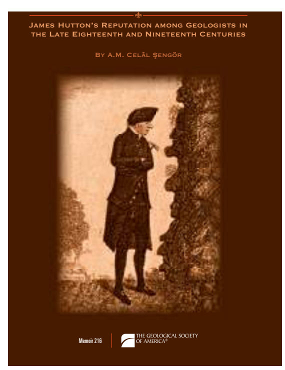
A.M. Celâl Şengör, *İTÜ Maden Fakültesi, Jeoloji Bölümü ve Avrasya Yerbilimleri Enstitüsü, Ayazağa 34469, Istanbul, Turkey; sengor@itu.edu.tr*

In *Revising the Revisions: James Hutton's Reputation among Geologists in the Late Eighteenth and Nineteenth Centuries* I tackle the problem resulting from a recent trend among some historians of geology of considering the Scottish polymath James Hutton's (1726–1797) *Theory of the Earth* (Hutton, 1785, 1788, 1795, 1899) the last of the "theories of the earth" genre of publications that had begun developing in the seventeenth century and to regard it as something behind the times already in the late eighteenth century and which was subsequently remembered only because some later geologists, particularly Hutton's countryman Sir Archibald Geikie (1835–1924), found it convenient to represent it as a precursor of the prevailing opinions of the day. The problem stems from the observation that the available documentation, published and unpublished, from the late eighteenth century to the date of publication of Geikie's widely read book *Founders of Geology* in 1897, shows that Hutton's theory was considered as something completely new by his contemporaries, very different from anything that preceded it, whether they agreed with him or not, and that it was widely discussed both in his own country and abroad—from St. Petersburg through Europe to New York. By the end of the third decade in the nineteenth century, many very respectable geologists began seeing in him "the father of modern geology" even before Sir Archibald was born. To present some of these documents, I have reviewed in Memoir 216 a small part of the available literature of geology from 1785 to 1897 in the Austrian, British, and Russian Empires, France, Germany, Switzerland, Italy, and the United States, and I have selected passages discussing Hutton's ideas, his legacy, and his relevance to the current problems in geology at the times the documents I cite were written. Despite the small selection, the book required citing more than 600 references and reading or skimming many more.

This review of the literature clearly shows that the revisionists' ideas are not correct. So, the question becomes why some historians of geology wrote things that belittle Hutton's importance. The answer to this "why" is not easy to produce and even harder to demonstrate. Among the most important of the answers to this question, I discuss especially four.

1. The revisionist historians' misconception of what science, and, specifically, geology, is about. They seem to consider observations and methods of observation to be the main core of geology, rather than its theories; i.e., they think knowledge rather than understanding is the core of science.
2. Historians of geology, particularly those with a social science background, seem not adequately informed about the literature of geology for the periods they write about.
3. One reason for the inadequate usage of the literature of geology is clearly the slackening standards of peer review, especially in private presses, including all the university presses.
4. Finally in at least one case, the religious feelings of one author clearly caused him to favor his co-religionists against Hutton, against all credible evidence.

Memoir 216 was conceived as an antidote to some of what I think are unfounded claims about James Hutton's impact on geology and the nature of geology itself.



Revising the Revisions: James Hutton's Reputation among Geologists in the Late Eighteenth and Nineteenth Centuries
By A.M. Celâl Şengör
MWR216, 150 p., plus indices, 9780813712161, US$70.00; member price US$49.00

Buy at the GSA Store: rock.geosociety.org/store.

Welcome New GSA Members

The following new members joined between 14 Feb. and 14 Sept. 2020 and were approved by GSA Council at its fall meeting.

PROFESSIONALS

Abraham Remilekun Adeniyi
Moses Oluwaseun Adeoye
Rajendran Sobha Ajin
Steven Banham
James Barton
Jason Randall Baugh
Cynthia Baumann
Zackary V. Bishop
John Bailey Bobbitt
Russell Boulding
Doug Brugge
Kat Cantner
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Vanessa Colás
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Elizabeth Cottrell
Rex Edward Crick
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Albert Vidal Dias III
Frederic Dias
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Gerry Drake
Sue C. Ebanks
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Tim J. Fedak
Maureen Feineman
Karen M. Fischer
John Andrew Fleming
Beth Forrest
Virgilio Arenas Fuentes
Jessica Michelle Garcia
Rupert Dujon Green
Heather Noelle Gregory
Yu Jeffrey Gu
Jay Gunderson
Jacob Timothy Guy
Timothy Hampel
Janice Lee Hornburg
Stephen Patrick Horton
Katharine Horzmann
Munir Humayun
Andrew Ireson
William Ishmael
Derek Jackson
Matt Justice
Mary Kang
Ritu Kansal
Riaz Hossain Khan
Timothy Kozmyk
Shanker Krishna
Alfred Lacazette
JD Lancaster
Philip Charles Laporta
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Wenkun Qie
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Isabel Rivera-Collazo
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Justin Roth
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Dustin Trail
Justin Edward Tully
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Claudio Vita-Finzi
Michael J. Walter
James Wanslow
Tom Wentzler
Patricia J. White
Marie-Claude Williamson
Diane Winter
Kenneth W. Wisian
Amber Wittner
Adrienne J. Woods
Karl C. Wozniak
Alex Zagorevski
Martina Zucchi

EARLY CAREER PROFESSIONALS

Olusola Adekanle
Mayowa Agunbiade
Kabiru Akingbein
Richard Alfaro
Kali L. Allison
Scott Annis
Rodrigo Osmar Arrocha
Lavanya Ashokkumar
Candice Ceilidh Bedford
Susanne Benz
Cindy M. Bergeron
Robert Ian Beumer
Tyler Bexton
William Zachary Billings
Samuel Birch
Valentina Bocanegra
Zachary Boles
Lydian Boschman
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Thornton Brooksbank Jr.
Garrett Drew Brown
Bill Burger
James Michael Carlson
Gadrielle Chen
Huxian Chen
Etienne Clabaut
Thomas M. Cullen
Salvatore D'ambrosio
Aaron Darling
Dominique David-Chavez
Joel Davis
Thomas Dols
Idowu Emumejakpor
Edwin Ero
Rebeca Espinosa Cortes
Carly Faber
Mingshi Feng
Kevin Florence
Adam Fradkin
Shawn Gagnon
Hadi Ghofrani
Addis Gonzalez
Bryan Gordon II
William Kurt Green
Ciarra Solina Greene
Ana Mafalda Guimaraes Ferreira
Ashley Paul Gumsley
Gp Gurumurthy
Erik Bryce Hansen
Eric Delonte Harper II
Kimberly Heallen
Jack Heltzer
Diana Hernandez Garcia
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Kayode Joseph Igbasan
Ana Maria Carmen Ilie
Allison Elizabeth Keator
Gehendra Kharel
Dylan Kinser
Sam Knapp
Ardiansyah Koeshidayatullah
Abiodun Olufemi Komolafe
Kowalski M. Kowalski
Emmanuel Abayomi Ladapo III
Thomas Neil Lamont
Lydia Marie Landau
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Yong Li
Nagissa Mahmoudi
Margaret Martindale
Patricia Martínez-Garzón
Gabrielle Matheson
Kumiko Matsui
Jeremy Maurer
Genna Beth Mcdonagh

Michael K. Mckeon
Brian Merritt
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Regan Nicole Milner
Daniel Morón-Alfonso
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Catherine Nakalembe
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Samuel William Oldham
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Jiahui Qian
Sabina Rakhimbekova
Jagat Rathod
Daniel Ray
Everett Jacob Reyna
Aaron K. Rice
Tyler E. Ricketts
Marina C. Rillo
Laura R. Ringeisen
Tommy Rodengen
John Rollins
Matthew Roseboom
Tumpa Saha
Farid Saleh
Isah Salisu
Venkadesh Samykannu
Christopher M. Sanders
Margaret Sanders
Matthew Schmidt
Marie Catherine Sforna
Griffin Shelor
Kevin Jacob Soffera
Juan Pablo Solano-Monge
Julie Sorfleet
Mason Odell Stahl
Haijing Sun
Perumala Sunder Raju
Dawid Szymanowski
Giulia Tartaglia
Tashina L. Taylor
Maryalyce J. Therrien
Kendra Tyler
Vivian Wallace
Ruijia Wang
Matthew Warke
Aaron Witter
Renzo Paolo Yaringaño
Joaquin Zamora Sr.

STUDENTS

(Listed by Professional Interest)

Archaeological Geology

Stephanie Alexandra Alvarenga
Caleb Cavender
Katherine Dowling
Vivienne Maxwell
Rachel Lily Mignona
Megan Colleen Plummer
Steven Porson
William S. Pratt Jr.
Ariel Colucci Russell
Faye Skinner

Biogeosciences

Osama Alian
Josh Anadu
Gabriel Zeballos Castellon
Bryan Antonio Chamba
Pablo A. Chester Paquis
Gregory Connock
Audrey Cook
Michael Cyrier
Thomas Peter Diragi
Shawn P. Dunaway
Leigha Eby
Tian Gan
Megan Goldsmith
Caleb Richard Hammer
Joseph A. Hansen
Michelle Juliana Jimenez
Brendell Re Arlbra Jones
Maura Kanner
Sarah Khoury
M. Kelsey Lane
Ziheng Li
Jiaqi Liang
Raissa Marques Mendonca
Teresa Mccarrell
Athena Nghiem
Lizzie Paulus
Yu Pei
Sophia Michael Pinter
Joseph Martin Platt
Juliet Ye Fang Ramey-Lariviere
Tom Reershemius
Dalton John Renner
Hannah Rigoni
Edwin Rodriguez-Dzul
Leah Davis Rubin
Neha Sharma
Noelle Steen
Andy Tan
Yu Kai Tan
Alexa Terrazas
Qi Wang
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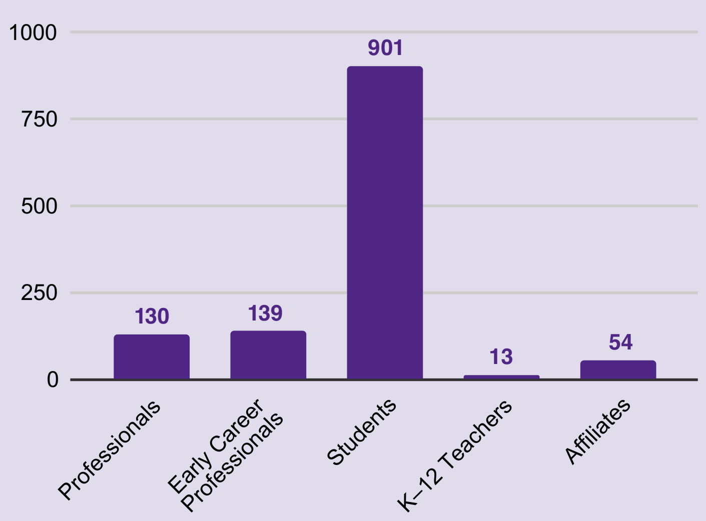
Climatology/Meteorology

Jon Delsordo
Karim Lakhani
Jonathon Charles Lewis
Andres Mendoza
Caroline Grace Mlaska
Sarah Grace Payne
Brandon Ryan
Gregory A. Scofield
Martha Jane Sorenson
Ananya Srivastava
Jacob Ryan Whitlock

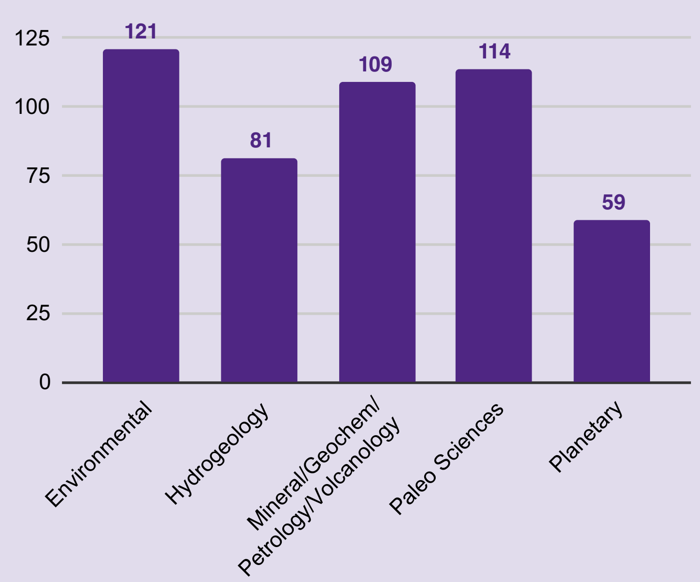
Economic Geology

Babak Asli
Celine M. Beaucamp
Joy Carter
Justin Claiborne
Alex Coronado
Charles Coronado
Sanjukta De
Winifred Duncan
Leah Evans

NEW MEMBERS BY MEMBER TYPE



TOP PROFESSIONAL INTERESTS OF NEW STUDENT MEMBERS



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Jared William Hansen
Tanner James Havens
Russell Paul Hayden
Jarrett James Humpula
Jake Anthony Jefferson
Isabella Phoebe Lucia
Andrew Maendel
Kei Quinn
Jorge Rene Sanz
Majid Soleymani
Jan Joseph Villarin
Gretchen Wambach
Samuel Curtis Warren

Energy Geology
Ayaka Abe
Mohammed Almustafa
Eirika Arnardottir
Claire Elizabeth Bartlett
Brittany Bray
Daniel Campos
Jayeeta Chakraborty
Dan Peter Constantin
Dallas Dalton Cook
Aaron Benjamin Escobar
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Victoria Alexis Treto
Destany Vargas
John Michael Vosika
Kimberly Sue Waltermire
Yang Wang
Kenneth B. Watson
Hyatt Webb
Robert Wencel
Adrian Alan Wiggins
John Worrall IV

Engineering Geology
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Celina Chang
Md Jariful Amin Chowdhury
Caroline Cook
Theresa Czech
Naya Deykes
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Da’juan Jamar Wilson

Environmental Science
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Megan Wedal
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Art Willoughby
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Vaugh W. Wodchis
Samantha Rae Wolf
Sherry Yueh Xu
Jessica Yates
Wei Zhi

Geography
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Julie Edwards
Damaliz Gonzalez-Santiago
Caitlin Guerin
Anu Khadka
Coghlin Kumler
Daniel J. Melnick
Karen Ramirez
Nathan Rice
Carlos Suarez-Plascencia

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Stephanie Lachance
Zihui Lei
Uchenna Emmanuel Nwoke
Kevin Roback
Jessica Louise Rydquist
Macon Augustus Wooley

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Sam Haim
Oscar Ariel Pedersen
Joseph Powell
Kyla Vaught-Shouse
Olivia Wren
Yuqian Zhao

Geophysics/Tectonophysics
Amin Abbasi Baghbadorani
Stephanie Marie Adams
Benedict Aduomahor
Natalie Alvarez
Hannah M. Ambrosino
Carlo Emanuel Azuara
Hannah Bahrami
Matthew Walter Bogumil
Trey J. Brink
Francesca Davis Burkett
Mario Castaneda
Mikayla Lee Clark
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Holly Fortener
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Mckenna Margaret Riggen
Ashley Rivera
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Casey Edward Ruplinger
Elizabeth Mae Schaeffer
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Daniel Shi
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Hannah Tilley
Maylani Velazquez
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Jingchuan Wang
Megan Ward-Baranyay
Sarah Wells-Moran
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Qicheng Zeng

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GSA depends on the volunteer efforts of many science editors, associate editors, and editorial board members to ensure the timeliness and quality of our publications.

GSA thanks the editors whose terms ended 31 Dec. 2020 for their service to the Society and to the science: **James G. Schmitt,** *Geology*; **Dennis Brown,** *Geology*; and **Brian G. Katz,** *Environmental & Engineering Geoscience*.

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New and Updated Position Statements

In November 2020, GSA Council approved a new position statement titled "U.S. Flood Risk Management." Minor revisions to three statements were also approved: "Public Investment in Earth Science Research," "Role of Government in Minerals and Energy Resources Research," and "Visas for Foreign Scientists and Students." Summaries of the statements are below; full versions of all position statements are online at **https://www.geosociety.org/positionstatements.** GSA members are encouraged to use the statements as geoscience communication tools when interacting with policy makers, students, colleagues, and the general public.

U.S. Flood Risk Management

Across the U.S. and worldwide, flooding is the deadliest and most costly natural disaster. The rising costs of flooding result from continued development of flood-prone land and modifications to river and coastal systems, amplified by climate change. By most metrics, the U.S. is losing the fight to manage the nation's flood risk. Science provides tools for quantifying flood risk, estimating future conditions, balancing human uses of floodplains with ecosystem services, and identifying effective mitigation strategies. The Geological Society of America recommends policies that move the U.S. toward long-term resilience, focusing on pathways toward sustainable floodplain management and flood-risk reduction.

Public Investment in Earth Science Research

Strong and growing public investments in Earth-science research promote the general welfare of all citizens; ensure the health, vitality, and security of society; and provide sound stewardship of Earth. Investments are needed from all levels of government to address such issues as energy and mineral resources, water resources, climate change, and natural hazards. Public funding for Earth-science research forms the basis for training and educating the next generation of Earth-science professionals.

Role of Government in Minerals and Energy Resources Research

Sound scientific knowledge should guide decision making about the exploration, development, and stewardship of finite energy and mineral resources. Sustaining and enhancing that knowledge requires more public investment in energy and mineral resource research, education, and stewardship.

Visas for Foreign Scientists and Students

GSA endorses a United States visa system that supports international scientific exchange and cooperation. Government visa policy is especially important to the earth sciences because:

1. Earth science is inherently an international endeavor because it is not possible to understand Earth by studying only those parts of the planet that fall within the boundaries of a single country.
2. Progress in Earth science requires international field research, participation in international conferences, access to international research facilities, and other activities that involve international exchange and cooperation.
3. Delays in issuing visas to Earth scientists responding to natural disasters—such as earthquakes, tsunamis, volcanic eruptions, and floods—can result in loss of life, loss of property, and loss of scientific opportunities. Earth scientists can help prevent some natural hazards from becoming natural disasters through international exchange and collaboration.



Scientists in Parks

Scientists in Parks provides all aspiring professionals—especially those underrepresented in science—with a unique opportunity to work on important real-world projects while building professional experience and a life-long connection to America's national parks.

Spring/summer 2021 opportunities are now posted—Apply by 24 Jan.

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Learn more from the national parks about the program and related opportunities at **https://go.nps.gov/scientistsinparks.**

Questions? Contact us at sip@geosociety.org.

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(https://www.geosociety.org/jobs) for up-to-the-minute job postings. Job Board ads may also appear in a corresponding monthly print issue of *GSA Today*. Send inquires to advertising@geosociety.org, or call +1-800-427-1988 ext. 1053 or +1-303-357-1053.

Geosciences Future Faculty Postdoctoral Program, College of Geosciences, Texas A&M University

The College of Geosciences at Texas A&M University in College Station, Texas, invites applications for two (2) Geoscience Future Faculty (GFF) Postdoctoral Research Associate Fellowships. The goals of the GFF Postdoctoral Research Associate Fellowship are to advance interdisciplinary research, increase diversity within the geosciences and develop future leaders. The College of Geosciences is committed to creating a diverse and inclusive climate for faculty, staff, and students. We seek a postdoctoral fellow with a demonstrated track record of a commitment to diversity, equity, and inclusion.

The College of Geosciences is one of the nation's most comprehensive Earth-system colleges and is committed to the discovery, advancement and application of knowledge fundamental to understanding our planet and its resources for a sustainable future. Our disciplinary research and educational excellence are built on cutting-edge analyses and observations, numerical simulations and theoretical studies, and field-based data collection at all spatial and temporal scales. We welcome applicants with research interests connected to one of our four departments- Atmospheric Sciences, Geography, Geology & Geophysics, and Oceanography. In addition, individuals with backgrounds in other related disciplines i.e. chemistry, physics, biology, environmental science, or mathematics and an interest in applying their skills to research topics within the Geosciences are encouraged to apply.

The postdoctoral position is awarded for two years and includes a generous support package comprised of a stipend ($60,000/yr) for a 12-month appointment, research funds ($15,000/yr, including relocation support), plus health-care benefits. For more details, on eligibility and application visit the full program details at: https://tamus.wd1.myworkdayjobs.com/TAMU_External/job/Post-Doctoral-Research-Associate-Fellow_R-033512.

Assistant Professor (Tenure-Track), Fluvial/Hydrology/Watershed Assessment, Missouri State University

The Department of Geography, Geology, and Planning at Missouri State University invites applicants for a tenure-track Assistant Professor to begin in August 2021. We seek a geoscientist with expertise in fluvial/soil geomorphology, physical hydrology, and/or watershed assessment and management. A Ph.D. in geography, geology, or a related discipline must be earned by August 2021.

Duties include maintaining a successful research program in collaboration with Ozarks Environmental and Water Resources Institute, which is housed in our department (https://oewri.missouristate.edu). The successful candidate will teach undergraduate and graduate courses related to their expertise. The candidate must also demonstrate the ability to incorporate GIS or remote sensing into their teaching and research.

The full position announcement is available at: https://bit.ly/MSUGeog21.

The department houses 21 full time faculty, 4 BS majors, and an MS program (https://geosciences.missouristate.edu/). MSU is an urban university in Missouri's 3rd largest metro area and enrolls more than 26,000 students from every state in the US and around the world.

Apply online at https://jobs.missouristate.edu/postings/51429. Applicants must upload a cover letter, CV, unofficial transcripts, teaching statement, research statement, and a list of 3-5 references (letters not required at time of application).

First date of review is 01/05/2021 and will continue until the position is filled. Official transcripts and criminal background check required at time of hire. Missouri State University is an EO/AA/M/F/Veterans/Disability/Sexual Orientation/Gender Identity Employer and Institution.

Open Rank Faculty Position in Geoscience or Environmental Science, University of Texas Arlington

The University of Texas Arlington (UTA) is spearheading a new, multi-disciplinary hiring initiative in support of our strategic plan, Bold Solutions | Global Impact.

UTA is uniquely positioned to address the epic challenges that face our growing urban regions. By leveraging our expertise in the critical areas outlined in the strategic plan, the University is poised to help emerging megacities like the Dallas–Fort Worth Metroplex become sustainable economic and cultural centers that raise the prospects for prosperity and enhance quality of life.

One of UTA's goals is to increase the representation of historically underrepresented faculty, including underrepresented minority faculty in general and women faculty in STEM fields. Increasing the representation of faculty members who understand, and have overcome, race, gender-based, and ability barriers and biases is vital to the success and well-being of our students. Diversity is critical to academic excellence. As research demonstrates, diverse teams are more innovative, productive, and solve complex problems faster. UTA is committed to preparing all students to live and work in an increasingly global, diverse, and interconnected world by exposing them to a wide array of ideas, experiences, cultures, and individuals.

We are looking for strong tenure track faculty who will contribute in their in geoscience or environmental science area to the unprecedented excellence research, teaching, and community engagement taking place in the College of Science.

Applicants should have a doctoral degree in geoscience or environmental science. Candidates in their early career must demonstrate strong potential to develop a research program supported by external funding, while more established candidates must demonstrate active, externally funded research agendas.

Application Procedure. Review of applications will begin immediately and continue until the position is filled. Applicants must apply online at https://uta.peopleadmin.com/postings/13077.

A complete application includes: 1) curriculum vitae, 2) summary of current and proposed research (max. two pages), 3) Statement on diversity, equity and inclusion, and 4) names and email addresses of three references.

Question regarding this position may be directed via email to Dr. Majie Fan, College of Science Search Committee (Email: mfan@uta.edu) or the administration of the Department of Earth and Environmental Sciences (Courtony Hill, Email: courtony.hill@uta.edu).

OPPORTUNITIES FOR STUDENTS

Graduate Student Opportunities (M.S.), Ohio University. The Department of Geological Sciences at Ohio University invites applications to its research thesis-based M.S. degree in Geology for the Fall of 2021. The Geological Sciences faculty at Ohio University collaborate in three research clusters: paleobiology and sedimentary geology, solid earth and planetary dynamics, and environmental and surficial processes. Prospective students are encouraged to contact faculty directly to discuss potential research topics. Qualified students are eligible to receive teaching assistantships that carry a full tuition scholarship and a competitive stipend. For program and application information, visit the department website at http://www.ohio.edu/cas/geology/graduate or contact the graduate chair, Dr. Daniel Hembree (hembree@ohio.edu). Review of applications begins February 1, 2021.

Graduate Student Opportunities (Online M.S.), Ohio University. The Department of Geological Sciences at Ohio University invites applications to its online, non-thesis M.S. degree in Geology for the Spring or Fall of 2021. The program includes courses on research methods, paleobiology and sedimentary geology, Earth materials and planetary geology, and environmental and surface processes. The program is designed for students planning to enter or already in the geoscience workforce (industry, government, non-profit) that do not require research experience as well as K–12 educators seeking additional training in the geosciences. For program and application information, visit the department website at http://www.ohio.edu/cas/geology/graduate or contact Dr. Xizhen Schenk (xschenk@ohio.edu).

Graduate Student Opportunities in Geosciences at Baylor University. The Department of Geosciences at Baylor University invites applications for full-time Ph.D. and M.S. students starting in August 2021. Admission to the program includes 5 years of support for Ph.D. students and 2 years of support for M.S. students through graduate assistantships and fellowships, a full tuition waiver, 80% health insurance subsidy, annual travel funding for conference attendance, and research funding for graduate students on a competitive basis. Candidates should have at least an undergraduate degree in geology, geophysics, or in a related area and excellent analytical and writing skills. Students holding a BS degree may apply directly to the Ph.D. program.

Faculty research covers a broad spectrum of Earth sciences, with strengths in biogeosciences, energy geoscience, hydrological and surface processes, lithospheric processes, paleoclimate, and solid Earth and planetary sciences. For more information about the Department of Geosciences, our research areas, and the graduate program please visit www.baylor.edu/geosciences.

Applications are due by January 15, 2021, with a priority application deadline of December 1, 2020. Details about the application process and the priority deadline can be found here: https://www.baylor.edu/geosciences/index.php?id=952059. Applications to the Department of Geosciences must be submitted online here: https://grad.baylor.edu/apply/. Please contact our Graduate Program Director for more information or with questions at geosciences@baylor.edu.

M.S., Ph.D., in Earth Sciences (Full-Tuition and Stipends), Syracuse University. The Department of Earth and Environmental Sciences at Syracuse University invites applications for full-time M.S. and Ph.D. students starting in August 2021. Interdisciplinary research opportunities leading to M.S. and Ph.D. degrees include: biogeochemistry, computational geophysics, environmental geology, geomorphology, global environmental change, hydrogeology and hydrology, isotope geochemistry, paleobiology, paleolimnology, petrology, sedimentology, tectonics, and thermochronology. For more information on our programs: https://thecollege.syr.edu/earth-sciences-department/graduate-programs-earth-sciences/.

Ph.D. and M.S. students are supported by full-tuition scholarships and stipends through teaching assistantships, research assistantships, and/or fellowships. The Department only admits students that have identified faculty advisors, so it is recommended you contact potential advisors in your field of interest either before or after application. For more information on our faculty and research groups: https://thecollege.syr.edu/earth-sciences-department/research/.

Applications for Fall 2021 admission are strongly encouraged by January 15, 2021. To apply: https://thecollege.syr.edu/earth-sciences-department/graduate-programs-earth-sciences/application-information/.

Two NSF-Funded Ph.D. Assistantships to Study Beaver Dam Analogues Impacts on Floodplain Hydrology. Syracuse. We are seeking two Ph.D. students to start May or June 2021 for an NSF project focused on understanding the hydrologic impacts of beaver dam analogues in semi-arid landscapes using a combination of fieldwork (Wyoming), numerical modeling, and UAV image analysis. If interested, please contact Dr. Christa Kelleher (Syracuse University, Earth and Environmental Sciences) or Dr. Philippe Vidon (SUNY-ESF, Sustainable Resources Management) ahead of the application deadline (Jan 15, 2021) with a current CV, information about your interest in pursuing a graduate degree, and research or other relevant experience.

Graduate Student Opportunities at Case Western Reserve University. Students with backgrounds in geology, physics, chemistry, biology, engineering, and related fields are encouraged to apply for our Ph.D. and MS programs in Earth, Environmental, and Planetary Sciences. Areas of active research in the Department include planetary geology and geodynamics, planetary materials, high-pressure mineral physics and geochemistry, core and mantle processes, environmental science, sedimentary geology, and sediment transport. For more information, please visit http://eeps.case.edu or write to eeps-gradinfo@case.edu. Financial assistance is available. Application deadline: 1/15/2021.

Graduate Assistantship, New Mexico Highlands University. Graduate assistantships are available for students wishing to pursue a Master of Science beginning Fall 2021 term. The Environmental Geology Program strengths are in Environmental Science, Geographic Information Systems (GIS), Water Resource Science, and classic Geology.

The NSF-Funded Paleomagnetic-Rock Magnetic, Powder X-Ray Diffraction, Field Instrumentation, and Water Chemistry labs support wide-ranging analytical research. We are particularly interested in students with interests in volcanology, geophysics, geochemistry, water resource science, geomorphology, GIS, and petrology.

The NMHU campus in Las Vegas, New Mexico, is situated at the boundary of the Great Plains and the Rocky Mountains and is located near several world-renowned geologic features (Rio Grande Rift). A low student:faculty ratio and state-of-the art laboratory facilities provide students with a superior learning experience. The graduate assistantship includes a nine-month stipend and tuition waiver per academic year. Application review begins the first Friday in February. For more information, contact Dr. Michael Petronis at mspetro@nmhu.edu. For disabled access or services call 505-454-3513 or TDD# 505-454-3003. AA/EOE Employer.

Earth Evolution, Emergence, and Uniformitarianism

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Emergent phenomenon describes the propensity for any high-energy, far-from-equilibrium system to self-organize in ways that cannot be predicted from knowing its individual components (Ablowitz, 1939; Pines, 2014). Emergence is closely related to self-organization, complexity, and evolution. Animals, ecosystems, spiral galaxies, hydrothermal systems, hurricanes, and civilizations are some of the many examples of emergent phenomena, where low-level rules give rise to higher-level complexity. Entirely new properties and behaviors "emerge," without direction and with characteristics that cannot be predicted from knowledge of the constituents alone. The whole is truly greater than the sum of its parts. Yes, the second law of thermodynamics is real, but it can take a long time for the system to stop dissipating energy. In the case of long-lived, high-energy systems like convecting silicate planets with a significant fraction of primordial heat trapped inside and with slowly diminishing contributions from radioactive decay, entropy may have to wait billions of years to shut down the party.

Morowitz (2002) outlines the emergence of 28 things, beginning with the Big Bang and ending with civilization. The self-organization of organic molecules to make life may be the most spectacular example of emergence. Earth's climate, hydrosphere, and nutrient cycle all are emergent phenomena. These are in fact co-emergent systems, evolving together in ways that presently cannot be predicted. Those who have tried to predict the stock market or the course of the COVID-19 pandemic know the futility of trying to foresee what will happen next in these emergent systems. The tectonic styles of convecting silicate bodies in our Solar System are also examples of emergent behavior. Such behavior is expected for these high-energy, far-from-equilibrium systems as their interiors cool and their lithospheres respond by becoming thicker, denser, and stronger. Strong temperature gradients between the cold, rigid exterior and the hot, convecting interior cause density inversions coupled to large nonlinear variations of rock strength and viscosity that together drive emergent behavior, manifested in the lithosphere as tectonics.

Although emergent behavior is today impossible to predict, it can leave evidence that allows the history of an emergent system to be reconstructed and quantitatively understood. This is as true for planets as it is for civilization. Is it possible to discern emergent behavior in the tectonic behavior of active bodies in the Solar System? Yes, but it is easier for smaller, dying planets than for more vigorous, larger ones (Earth, Venus), where evidence for earlier tectonic styles is often obliterated by newly emergent ones. Mars is a good example of a slowly dying planet, because its small size has enhanced cooling of its interior over its 4.56 Ga lifetime. Mars' crustal dichotomy preserves evidence of three successive emergent tectonic styles: (1) creation of the primitive crust now preserved in the southern hemisphere; (2) crustal rejuvenation (best exposed in the northern lowlands) by widespread volcanism possibly related to giant impact and subsequent mantle convection (e.g., Golabek et al., 2011); and (3) strongly focused long-term magmatism and tectonics caused by localized mantle plumes, manifested by large volcanoes in the Tharsis and Valles Marineris regions.

Plate tectonics—Earth's unique lithospheric manifestation of mantle convection—is almost certainly an example of emergent behavior of a still-vigorous convecting planet. This conclusion was recently highlighted by Brown et al. (2020), who compiled and analyzed thermobaric ratios (temperature/pressure, *T/P*) for Paleoarchean to Cenozoic metamorphic rocks and used this to identify times when significant shifts in mean *T/P* occurred. The variations in Earth's thermobarometric ratio must reflect changes in Earth's convective and tectonic style that can usefully be called emergent. Consistent with this conclusion, numerical modeling investigation even of very simplified mantle convection systems with Earth-like rheology shows emergent behavior, such as spontaneous appearance and self-organization of various tectonic plate boundaries; growth, aging, and subduction of oceanic plates; and generation of a global plate mosaic (e.g., Tackley, 2000). Lenardic (2018) explored this point further, arguing that any convecting Earth-like silicate body would experience multiple emergent transitions between different planetary tectonic regimes, reflecting changes in lithosphere strength and planetary internal energy with time. Indeed, numerical models reveal that several different global geodynamic regimes in Precambrian time likely preceded modern plate tectonics (e.g., Gerya, 2019). Multi-stable behavior allows, in particular, for the possibility that plate tectonics could emerge, transition to another mode, and re-emerge along a planet's cooling path.

Because the emerging tectonic regime will obliterate much of the evidence for earlier regimes, we will have to be clever to figure out how plate tectonics evolved on Earth and even more clever to figure out what other tectonic styles emerged before this. We have argued elsewhere that the modern episode of plate tectonics emerged when a very strong mantle plume ruptured all-encompassing but gravitationally unstable lithosphere (Gerya et al., 2015), and one of us has repeatedly argued on different lines of evidence that this happened in Neoproterozoic time (Stern, 2018). These ideas are controversial but beg the question: why hasn't the conceptual framework of emergent tectonics gained more currency in our science?

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One problem may be our (mostly implicit but still pervasive) attachment to the principle of uniformitarianism,"The present is the key to the past" and its offspring, actualism "The present, punctuated by occasional catastrophes, like bolide impacts and snowball Earth, is the key to the past" (Windley, 1993). Uniformitarianism was very useful when eighteenth- and nineteenth-century geologists were debating the age of the Earth with clergy claiming it was 6,000 years old, but that was then, and this is now. Does our allegiance to the old philosophy stop us from addressing questions that need to be asked?

Gould (1965) distinguished substantive and methodological uniformitarianism. Substantive uniformitarianism considers that ancient Earth processes (e.g., orogeny, sedimentation, erosion) were the same as now operating. In contrast, methodological uniformitarianism states the obvious: that the laws of physics and chemistry pertain to all of Earth's history. Gould (1965) concluded that substantive uniformitarianism was "…false and stifling to hypothesis formation…" and is "…an incorrect theory [that] should be abandoned" (p. 223). There is still an important role for substantive uniformitarianism in our efforts to reach and teach students and the public. Perhaps in 1965 it appeared that the battle with creation pseudoscience was over, but not in 2020, at least in the United States. Substantive uniformitarianism is still useful for teaching lower-division undergraduates and in battles with creationists, for example, to show why and how the Grand Canyon was carved in a few million years by the Colorado River flowing through a plateau lifted up by mantle convection, not in a few days by Noah's flood. But within the scientific community, substantive uniformitarianism poisons scientific discussions about how plate tectonics came to be Earth's dominant convective mode.

Modern earth sciences use methodological uniformitarianistic approaches for both discovering and understanding emergence based on numerical modeling that uses fundamental physical laws for investigating behavior of complex geological systems. This emergent trend in earth sciences reflects the maturing of the discipline from a descriptive qualitative to a predictive quantitative science and opens the door to clearer thinking about emergent phenomena on Earth. In this respect, modeling combined with observations offer a good way to better calibrate our intuition for emergence, as well as to test if a geological system of interest is prone to emergent behavior and what are the main physical parameters controlling it.

We think that encouraging thinking about the role of emergence in all earth systems should be part of the way for the geosciences to advance in the twenty-first century. The field of emergence is much broader than the earth sciences, with entire institutes studying a wide range of emergent phenomena; for example, the Santa Fe Institute, https://www.santafe.edu/about. At present, the emergence of planetary tectonic styles is not being considered by these researchers, and it should be. How can we help make this happen? A good first step would be for more geoscientists to learn about emergence; the Wikipedia entry "emergence" is a good place to start. Second steps include teaching about emergence in our classes and considering it in our research.

Embracing emergence for understanding Earth's history not only can inject excitement into our science, the philosophy can pay psychic benefits. We are facing a very uncertain future, but thinking about emergence can perhaps reassure us that all futures are uncertain except for low-energy systems (e.g., dead planets and dead people). Which would you rather be part of, a low-energy system with a certain future or a high-energy system with an unpredictable future but with the promise that something will emerge, some time in the future? We know which planet we want to be on!

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GSA Statement on Diversity and a Challenge to the Society, Geoscience Departments, and the Geoscience Community at Large

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INTRODUCTION

On 1 June 2020, the Geological Society of America (GSA) posted the following message on its message board:

> This past week we witnessed a sadly familiar scene in the United States with the senseless death of George Floyd in Minneapolis. He joins other victims of overt racism and systemic discrimination. We all feel the pain, anger, and sadness of these tragedies, but it is particularly acute for our African American members, their families, and other People of Color. GSA stands with all of our colleagues facing these injustices and is committed to challenging and changing the biases that lead to discriminatory practices against People of Color.
>
> We condemn discrimination and harassment in any form, and are actively working to promote the ideals and principles of our position statements on *Diversity in the Geosciences Community* and *Removing Barriers to Career Progression for Women in the Geosciences*. GSA's Code of Ethics and Professional Conduct gives process to our vision and purpose for representing the best that our science can be.
>
> The pain of recent events motivates us to push harder to advance diversity, equity, and inclusion in the geosciences. Addressing systemic oppression requires both immediate and long-term efforts while humbly acknowledging that the geosciences remain one of the least diverse academic disciplines in the sciences. In the weeks and months ahead, GSA leadership will be furthering our efforts toward building a more diverse, respectful, and inclusive space for all science, and scientists, to thrive. We ask the GSA membership to join us and to challenge us to make a real difference.

We applaud GSA for making a public statement regarding these painful events; however, we want to focus on two significant statements in this message. First, the acknowledgment that geoscience remains one of the least diverse science discipline. Secondly, the call to challenge GSA to make a real difference.

THE PROBLEM

GSA, and the geosciences in general, continue to gloss over the fact that we remain far behind even other STEM disciplines in our diversity (Fig. 1; also see Bernard and Cooperdock, 2018). Whereas this was stated in the 1 June note, nowhere in the official GSA position statement on Diversity in the Geosciences Community is this fact acknowledged. Instead, GSA pleads ignorance of the magnitude of the problem: "There is a lack of quantitative and qualitative understanding of the current status of diversity-related issues and conditions in and associated with GSA." This statement is made in spite of the fact that the National Science Foundation, the American Geosciences Institute (AGI), the *Journal of Geoscience Education*, and even GSA itself have been publishing data and articles for more than 40 years that point this out (e.g., Gillette, 1972; O'Connell and Holmes, 2011; Stokes et al., 2014). GSA can and must do better, and we all need to take a long hard look at our discipline, our Society, and ourselves.

Geoscience is the least diverse discipline in science. There are many reasons why this is the case, and attempts at solving this issue have not been successful (NSF, 2001; Bernard and Cooperdock, 2018; Dutt, 2020). The total number of underrepresented minority (URM) geoscientists is unacceptable. Rarely have 20 or more Ph.D.s been earned by Black geoscientists in any given year nationwide. Rarely has that number been above 40 for M.S. degrees in a year. Fewer than 4% of tenured or tenure-track faculty are URM in the top 100 U.S. earth science departments (Nelson, 2017). We must provide more opportunities for URM students to see themselves reflected in the face of the professor in front of the classroom and as representative role models and leaders in their field. Most of the GSA position statement on diversity is boilerplate and lacks specific actions. It talks about embracing diversity, but much of the document focuses on geoscience education and outreach to policy makers. The Society can and should take concrete positions ***and actions*** on diversity, equity, and inclusion and lead by example.

COMMIT TO REAL CHANGE

The Society and our discipline cannot continue to overlook this issue, particularly as it pertains to Black, Latinx, and First Nations communities. Even AGI, which has done more than any of the U.S. geoscience societies to address this issue still softens the problem: "Outside of the representation rate of Black and African American geoscience graduate students, the representation rates of racial and ethnic underrepresented groups in the geosciences are similar to STEM-wide trends, indicating diversity issues in the geosciences are not unique" (Wilson, 2018). To begin with, Black representation is worse in geoscience than other STEM disciplines. Secondly, this statement has been used by STEM disciplines for decades to throw up their collective hands and not address the issues. GSA, geoscience departments, and geoscientists must accept these facts before we can move forward to create real change.

The negative health and environmental impacts of geoscience industries, such as energy and mineral resource extraction, production, and disposal disproportionally fall on URM communities. Decades, and in some cases centuries, of zoning laws and

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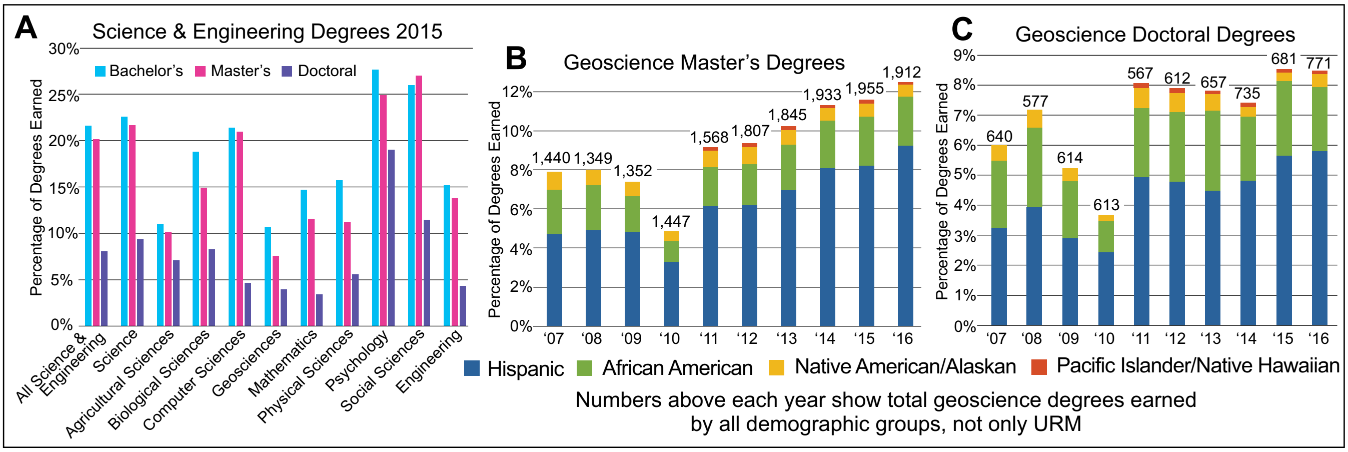

Figure 1. (A) Percentage of STEM degrees earned by underrepresented minorities, (B) Percentage of geoscience M.S., and (C) Ph.D. degrees earned by underrepresented minorities (URM). Figures after Wilson (2019) and total geoscience M.S. and Ph.D. degrees in panels (B) and (C) from the U.S. Department of Education, National Center for Education Statistics (https://nces.ed.gov/programs/digest/d19/tables/dt19_325.72.asp?current = yes).

redlining bring us to a present day where the intersection of geoscience and society is likely more important to everyday life in URM communities than other demographics. In fact, a range of geoscience issues, including natural hazards, water quality and quantity, and climate change are all inextricably linked to topics of race, equity, justice, and marginalization of URM communities. These are the communities GSA, and all of us as geoscientists, should be doing everything in our power to help to train (and retain) as the next generation of geoscientists, and diverse voices are critical in the search for just and equitable solutions. Yet, where is there any mention of real partnership with Historically Black Colleges and Universities (HBCUs), Hispanic Serving Institutions (HSIs), the Hispanic Association of Colleges and Universities (HACU), or Tribal Colleges and Universities (TCUs) in GSA's actions or position statement? Where is there any mention of real partnership with organizations such as the National Association of Black Geoscientists (NABG), American Association of Blacks in Energy (AABE), Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS), Society of Mexican American Engineers and Scientists (MAES), GeoLatinas, American Indian Science and Engineering Society (AISES), Geoscience Alliance, or National Consortium for Graduate Degrees for Minorities in Engineering and Science (GEM)? Real and meaningful two-way partnerships that produce actions, and that do not only exist on paper, are critically needed.

We strongly encourage GSA, geoscience departments, and geoscientists to take leadership roles on a range of issues to begin to commit to real and lasting change. A few examples of such actions could include:

- Advocating for immediate and significant increases in the number of URM faculty in geoscience departments nationwide through inclusive and equitable hiring practices (e.g., Tatum, 2003);
- Creating real two-way partnerships with HBCUs, HSIs, the HACU, and TCUs;
- Creating real partnerships with organizations such as NABG, SACNAS, MAES, GeoLatinas, AISES, GEM, Geoscience Alliance, and others;
- Creating inclusive mentoring programs, perhaps with these organizations;
- Advocating for the removal of GRE requirements to geoscience graduate programs and adopting a "holistic" evaluation process (Kent and McCarthy, 2016);
- Either directly paying for, or advocating for the removal of, graduate school application fees for URM students (similar to the American Geophysical Union's Bridge Program);
- Mandating diversity in panels and plenary lectures at meetings as well as in awards;
- Ensuring that the burden of creating this change and revising the position statement and actions of GSA and the geoscience community do not fall exclusively on URM members of GSA—these are issues that must be addressed by the entire executive leadership of the Society, as well as all members;
- Identify and remediate systemic roadblocks to diversity within geoscience curricula;
- Identify and promote best practices and successful programs that succeed in engaging, empowering, and promoting URM geoscientists; and
- Listen deeply to the experiences of URM geoscientists and commit to meaningful change.

This is only an initial list, and we all need to continue to develop more direct and concrete actions. An online petition, "Geoscientists: Call for a Robust Anti-Racism Plan for the Geosciences" (http://chng.it/gZ28ZNHcnS), and the resources at https://500womenscientists.org/updates/2020/6/1/take-action inspired this article, and they include a more comprehensive list of actions in which we all can and should engage. We sincerely thank the organizers of the petition and strongly encourage all geoscience societies, and all geoscientists, to read the petition and consider adding their support. GSA can, should, and must take a leadership role in this issue, and it is only through the concerted efforts of the executive and membership of the Society, geoscience departments across the country, and all of us as geoscientists that we can begin to be the change we so desperately need.

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Editor's Note: GSA has made several diversity-related updates since this paper was first written. The latest information is online at https://www.geosociety.org/diversity. Of note, a leadership retreat on diversity, equity, and inclusion (DEI) was held in August 2020 that included GSA's Executive Committee, GSA staff, and 20 invited diversity leaders in the geosciences. That discussion, led by facilitator and expert trainer Dr. Nita Mosby-Tyler of The Equity Project LLC, identified activities likely to have a measurable and lasting impact. Additional details, including priorities and the existing DEI initiatives in GSA's strategic plan, are online.

J. David Lowell Field Camp Scholarships

GSA and the GSA Foundation are proud to announce that J. David Lowell Field Camp Scholarships will be available to undergraduate geology students for the summer of 2021. These scholarships will provide students with US$2,000 each to attend the field camp of their choice. Applications are reviewed based on diversity, economic/financial need, and merit.

Application deadline: 19 Mar.

Learn more at **https://www.geosociety.org/GSA/Education_Careers/Field_Experiences/GSA/fieldexp/home.aspx.** Questions? Contact Jennifer Nocerino, jnocerino@geosociety.org.

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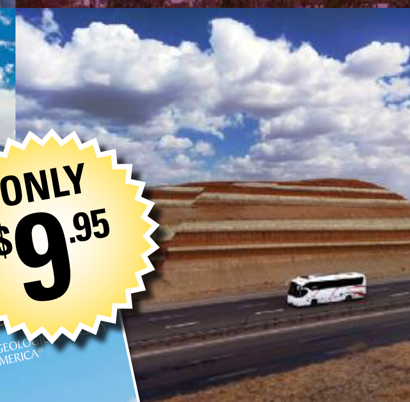

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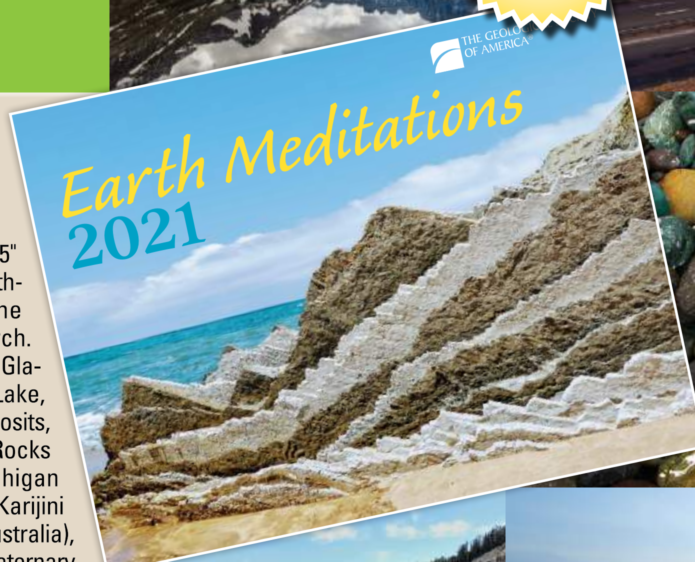
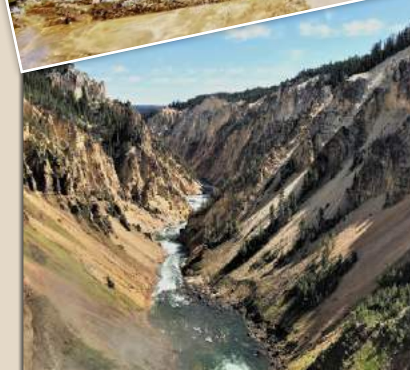
This 12-month, 9.5" × 12.5" calendar showcases breath-taking submissions to the GSA calendar photo search. Featuring images of Many Glacier Lodge, Swiftcurrent Lake, Montana (USA), flysch deposits, Zumaia (Spain), Pictured Rocks National Lakeshore, Michigan (USA), Hamersley Gorge, Karijini National Park (Western Australia), and horizontal Pliocene–Quaternary sequences along Zanjan-Mianeh highway (Iran), this serene calendar will freshen up your space.

- Dates of many noteworthy eruptions & earthquakes
- Birthdates of notable geoscientists
- Dates of GSA events & deadlines





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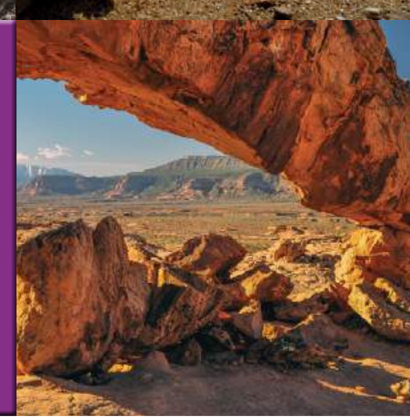

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We Thank You

The True Sense of Community That is GSA, Reflected in Our Donors

Throughout 2020, a year of unprecedented uncertainty, you, donors to the GSA Foundation, rallied together in the true sense of community that is embodied by GSA. You demonstrated how much we care about our students and their wellbeing, their futures, and their vital role as the next generation of geoscientists addressing topics impacting people, the environment, societies, and economies around the planet.

Every year, the GSA Foundation is extremely thankful to all of our friends and donors who contribute time, resources, ideas, and financial support toward the Geological Society of America's programs. In the face of remarkable challenges that cascaded over the course of the past year, we were even more humbled and inspired by your generous outpouring of support for ongoing endeavors such as On To the Future and field camp opportunities—and especially for what we witnessed with the launch of GSA CARES, the GSA COVID-19 Assistance and Relief Effort for Students. Within just four weeks of the call to match each of GSA's and GSAF's contributions to this fund, you exceeded the US$50,000 goal with nearly US$82,000 in gifts to help to as many students as possible. This allowed GSA to distribute more than US$181,000 to our student members who applied for aid. We received hundreds of responses from student recipients, and this is one of many that captures just how significantly your support is felt and appreciated:

"In this new world where everything seems to be dark and worrying, in this new world where all hope seems lost, GSA cares and still cares. When the only thing I have left is my future career to shape, receiving financial aid to help me achieve my educational goals means the world to me."

We at the GSA Foundation are honored to know and work with each of you, and to be reminded of why we do what we do, especially at a time when the world needs good. Thank you for your demonstration of our community of support.

Photo by Adam Jaime on Unsplash.

www.gsa-foundation.org

Call for Short Course and Technical Session Proposals

It's time to plan for **GSA Connects 2021 in Portland, Oregon, USA,** on 10–13 October. We challenge you to propose a Short Course and/or a Technical Session that reflects your expertise and pushes the boundaries of the discipline. Share your science with your community, teach your colleagues, and promote discussion of the incredible regional geology.

Exchange the geology by organizing and chairing a Technical Session.

Technical Session deadline: **1 Feb. 2021**

Proposals are being taken for Pardee Keynote Symposia and Topical Sessions. Please make your selection on the proposal submission form.

https://gsa.confex.com/gsa/2021AM/cfs.cgi

Share the geology as an instructor of a Short Course.

Short Course proposal deadline: **1 Feb. 2021**

Courses run the Friday and Saturday before the meeting and are typically a half day to two full days.

https://gsa.confex.com/gsa/2021AM/shortcourse/cfs.cgi

A MESSAGE FROM GSA's EXECUTIVE DIRECTOR

Dear Colleagues,

As you know, GSA is committed to the ideal of scientific discovery, rigor, diversity, and integrity.

I invite you to prepare a proposal for a Technical Session for GSA Connects 2021 that reflects your expertise and research but also pushes the boundaries of the discipline. Without expanding our horizon, we will not move the geosciences forward and keep our relevance. I challenge you to also broaden your reach to those you collaborate with by including diversity in all ways—discipline, career progression, and individuals.

Thank you for considering sharing your science and work at GSA Connects 2021.

—Vicki S. McConnell

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