Geoscience at the Confluence

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Greetings and welcome to GSA Connects. These meetings are a rush of activity. There's more to do than one can do—I appreciate you being here today as we come together to celebrate the accomplishments of our members as well as to reflect upon the Society and our science.

Here's an update on the Society. It was nearly a year ago that Melanie Brandt joined GSA as its executive director and CEO. Melanie is fabulous; she's brought energy and new ideas to the Society. Although Melanie's not a geologist, her experience growing professional societies is impressive. I've learned much from working with her on GSA business, plus I've gained a new perspective on corporate vernacular. For example, I now know stuff like whether or not "the juice is worth the squeeze." Spoiler alert: It isn't. I'm also fortunate to collaborate with Debbie Marcinkowski, executive director of the Foundation, as they work tirelessly to support GSA's mission.

The Society is focused on diversifying, retaining, and energizing its membership, we're expanding our international activities, and we have new publication projects in the works to amplify GSA's public presence. If you want to talk more about GSA's plans, be in touch.

We're in Pittsburgh at the confluence of the Allegheny and Monongahela Rivers which join to become the mighty Ohio River. These are important American rivers. The Allegheny River arises, in part, from the glaciated terrain of northern Pennsylvania and New York. To learn more about this watershed, and one of America's last big dams, I encourage you to attend tomorrow's Pardee session titled, "Land of Our Ancestors, Submerged by a Lake of Betrayal." Two hundred kilometers south of here, beneath the high ridges of an old landscape, the Monongahela's tributaries commence, tumbling through gorges of impressive whitewater on their northward journey to Pittsburgh.

Pittsburgh owes its existence to this confluence of rivers. These watery ribbons form a transportation network across the rugged landscape of the Appalachian Plateau. This confluence was long traversed by First Nations people; later, European settler colonists crossed the Appalachians and came down these rivers. In the nineteenth century, the mineral wealth hidden in the region's Paleozoic strata was discovered, extracted, and put to work. Pittsburgh, the Steel City, became a major industrial hub because it sits at the confluence of rivers, enabling the easy ingress of raw materials and egress of the products from which to forge an empire.

Today, I want to talk about something that I've been ruminating over for some time: the idea of confluence in a broader sense. You know how when you hear a particular song, you're immediately transported to that confluence of a specific time and place?

Curiously enough, I first heard "Age of Aquarius" by the 5th Dimension on a cassette tape while driving an old four-speed manual Chevy pickup truck across the flanks of Utah's Aquarius Plateau. Every time I hear that song it takes me back to that time and place. It was 1987, I was in a field course that roamed over the Colorado Plateau—it's the place where young geologists can go to actually "see" geology. And for me, that experience was transformative.

The magical power of confluence in time and place that certain songs create strikes me as being an equally powerful concept in geology. Today, I'm going to build on this idea of confluence. Geology is a science at the confluence. As a field of study, whether its academic or applied, geology sits at the confluence of time and place. And in many ways, this makes the geosciences unique.

Aerial view of Pittsburgh, Pennsylvania, 1902. Created by T. M. Fowler & James B. Moyer. Courtesy of the Library of Congress.

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For me, and I expect for many of you here, that mix of time and place is what attracted us to the science. The temporal nature of geology, with its focus on the past, but also firmly rooted in the present with an eye to the future, is compelling stuff.

What follows are narratives about my path to, and career in, geology. I hope these stories aren't boorish yarns from an aging scientist, but rather an arc that celebrates learning, excitement, and discovery. As a student it was clear to me that there were discoveries to be made in the geosciences, and three decades later I feel the same way. Discovery, at this confluence of time and place, perhaps contextualized by a good story or two, makes our science both engaging and relevant.

During my first semester in college, pretty much as a lark, I took an introductory geology course. That class, taught by Heather Macdonald, changed my life. It was an early class, 8 a.m. early, but Heather's a gifted teacher who made the geology cool enough for me to wake up for it every day. The course's lab component was traditional, in an old-school way, meaning there were piles of rocks in boxes plus a dizzying array of topographic maps that we were tasked with analyzing and hopefully understanding. No doubt some of you experienced something similar in your geological upbringing.

One particular lab exercise involved using the topographic map of the Mammoth Cave 15 ft quadrangle in Kentucky to answer questions on a worksheet; the idea was to get us to recognize the karstic nature of this terrain with its caverns, disappearing streams and sinkholes. In the northern reaches of that map the Green River meanders across the terrain. Seeing it on this map, I can hear John Prine singing about [the river] in his song "Paradise."

There's that confluence again. Not just the confluence of time and place in the geological record, or in the time machine of hearing an old song, but in the confluence of music and memory and storytelling and the study of geology that connects me deeply to this discipline. Never underestimate the power of a musical interlude to move a lecture forward or perhaps reawaken a fading audience.

John Prine's "Paradise" also transports me back to my adolescence as a summer camper at Nature Camp, where it was sung many times. We were witty, so we commonly changed the lyrics from "Mr. Peabody's Coal Train" to "Mr. Coalbody's Pea Train," and it still makes me giggle. The song itself laments environmental degradation caused by strip mining. As a first-year geology student, it was this confluence of "seeing" the terrain on an old map and Prine's classic ballad that demonstrated geology's importance. The character of a landscape is determined by its geology; its stratigraphy and its structure make all the difference. In Kentucky's humid climate, Mississippian limestones melt away to form caverns and blind valleys while nearby, in younger Pennsylvanian strata, coal is plentiful enough—here, as Prine notes, "with the world's largest shovel they tortured the timber and stripped off the land" to reach the black pay dirt, all to stoke the fires of "progress."

As we look to the future, it's clear that our collective demand for Earth materials is escalating. Two years ago, at Barb Dutrow's Presidential Address, she demonstrated how minerals matter. Mining, an inherently extractive process, is only going to grow; we may not want the world's largest shovels to dig out coal anymore, but we're smitten with spodumene crystals and the lithium held within. How, as stewards of this planet, can we mine for a sustainable future? Geoscientists and GSA have a responsibility to both lead the effort to discover the critical minerals that'll power a greener future and find the solutions that ameliorate mining's pernicious side effects.

As a young faculty member, I took my first field course to Fish Lake, a place that I'd been introduced to as a student back in 1987. Fish Lake is Utah's largest alpine lake, situated in a broad valley at 9,000 ft above sea level. Here we'd hike to the top of the Pelican Canyon moraine with its broad view of the lake. Few of my students realized that we were on a moraine; so much for all that learning from topographic maps back in the lab. As an educator, I can attest that place-based experience counts for a lot. After discerning the origin of the moraine, I'd lob question upon question at my students: When did the moraine form? When did Fish Lake form? How was the valley created?

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I thought my pedagogy plenty clever, but after a few field course visits to Fish Lake, I realized that many of those questions had never been properly answered. This landscape looked tectonically "young," but the Colorado Plateau and its adjoining High Plateaus aren't known for their seismicity. So began a research quest to understand the landscape history and tectonics of the High Plateaus.

With support from the National Science Foundation, we took our first full cohort of undergraduate researchers to the Fish Lake Plateau in 2005. We tramped across the high country, working out its volcanic stratigraphy while mapping more graben than I can recall. From the comfort of a pontoon boat, my friend Scott Harris surveyed the bathymetry of Fish Lake. Mild-mannered Dave Marchetti sampled boulders on moraines and terraces for cosmogenic exposure age dating. It may not have been the age of Aquarius, but it was an age of discovery and there was joy in that discovery.

Scott's mapping revealed that Fish Lake's waters hid a second older moraine complex. Exposure ages provide the chronology of >400,000 years of tectonic, fluvial, and glacial activity on this landscape, including young fault scarps that cut 20,000-year-old moraines. This research, conducted by a handful of faculty and a score of undergraduates, brought forth new knowledge about Utah's enigmatic High Plateaus. Research that's been published in the professional literature and discussed at GSA meetings. I'd like to see GSA work with researchers to broaden the audience and amplify the scope of their new geoscience discoveries. This is important, as in an era of declining trust in science and fact, geoscientists must work to be out in the public, explaining our science and its relevance for our future on this planet. And as a Society we must better support the early career geoscientists who do outward-facing and impactful science. Relying primarily on the H-index as a metric of scientific success and productivity is problematic—we can and should do better.

Virginia is well-watered and covered by greenery, effectively warding off geologists from west of the 100th Meridian. However, its geological terranes are compelling. When I first conceived of this talk, I struggled as to what snippet of Virginia geology to share—should it be glimpses of a Snowball Earth preserved in

700-million-year-old glaciogenic rocks, or a Taconian mélange formed as Gondawanan arcs crashed onto North American shores?

Ultimately, I chose an ongoing research project at Highland, an antebellum plantation in the eastern Blue Ridge foothills near Charlottesville. Highland was, for a time, home to America's fifth president, James Monroe. Collectively, what do we remember of James Monroe? Perhaps the Monroe Doctrine, viewed by many as a forward-looking policy that effectively turned the western hemisphere into the United States's sphere or a policy that fomented U.S. hegemony, leaving a legacy of poor countries throughout Central and South America. Monroe was a William & Mary student but dropped out to fight in the American Revolution. He was the youngest of the Founding Fathers, and he was a slave owner. His two-term presidency ran from 1817 to 1824; that's two hundred years ago, and it's known to historians as the Era of Good Feelings. Perhaps one day my GSA presidency will have that same moniker.

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The duo formerly known as Mandolin Orange [reflects] on American history [in the song "Wildfire."] "It should've been different; it could have been easy"—from the American Revolution to the Civil War. And to my way of thinking, that sentiment still resonates today as we reckon with our national history.

Last year at Monroe's old plantation, the 27 students in my Field Methods course undertook a semester-long project to study the bedrock geology, geomorphology, and landscape history at Highland. Our goal was to connect deep time with human time in this historic place.

The geology at Highland falls short of spectacular. The property is primarily underlain by meta-basaltic greenstones of the Catoctin Formation, but outcrops are few and far between as the landscape is typically covered by a distinctive reddish soil. However, these ultisols are flush with base cations yielding highly fertile silty loams. It's no accident that three American presidents had large plantations sited on the Catoctin Formation rather than on the poor soils developed on the ubiquitous phyllites and schists of the Piedmont.

About 570 million years ago, the Catoctin basalts flooded a barren Ediacaran landscape. Ultimately these flows were the harbinger of a new ocean basin—the Iapetus Ocean, which tore Laurentia apart as it grew. In central Virginia, the pillow lavas and breccias at the top of the Catoctin Formation provide the critical evidence of Iapetus's watery advance.

Yet, it's not all greenstone at Highland; interlayered within the metabasalt are sheets of metamorphosed arkosic sandstone and siltstone. These fluvial deposits are derived from the erosion Grenvillian granitic rocks in highlands to the west. The stratigraphy hints at the dynamic interplay between rifting, sedimentation, and volcanism.

Highland is a different kind of historic destination, in contrast to Washington's Mount Vernon, or Jefferson's Monticello—there is no big house of the "great" man to be seen or toured. For years there was controversy about the lack of the big house at Highland. Monroe sold the property in 1825 and a later owner constructed the still-standing Victorian-era farmhouse. To the casual visitor, Highland seems a confusing mishmash of multi-era architecture.

But in 2016, archaeologist Sara Bon-Harper and her team discovered the foundation of Monroe's original house, built in 1799. The foundation of that structure endures, a foot or two below the surface, more or less in the front yard of the Victorian-era farmhouse. We now know that a fire destroyed the original house. What remains of Monroe's house is primarily its stone foundation, and much of that foundation is meta-arkose, locally derived arkose. The arkose's tendency to form rectangular blocks, bound by joint and vein sets, makes it well-suited for foundation stone.

Hidden in a grove of red cedars, and just a few hundred meters from the old foundation, William & Mary students discovered the remnants of a quarry cut into a regularly jointed but massive meta-arkose. Petrographic analysis of samples from the foundation and the old quarry are identical. We're stoked to have located the source of the foundation stone. Joy in discovery and, in this case, connecting deep time to the early days of the American Republic—to me, that's geoheritage.

Here's a toolmark created during the quarrying of that arkose. Whose labor created that toolmark? Who quarried these stones and transported those blocks to the house site? James Monroe's work at Highland was done by enslaved people, and that's a big part of the story at nineteenth-century sites across the southern United States. Subjugation and freedom, prosperity and poverty—geology has played its role in this dichotomy throughout history. It's incumbent upon today's geoscientists to use a critical lens to discover those linkages and to tell stories such as this. Geoheritage is having its moment, but for geoheritage to gain traction beyond the geologically inclined, we need to intentionally bridge that gap between deep time and human history.

Long past tenure, I realized that I'd spent my career studying continental rocks. Yes, we're rooted to the continents, but the world is a big place. I thought it'd be worthwhile to examine rocks and structures formed elsewhere on Earth. Ophiolites fit the bill, as these enigmatic bits of oceanic crust and mantle are vastly different from anything I'd ever studied. A decade ago I made my first pilgrimage to see ophiolite, in the Al Hajar of northern Oman. Here the world's largest and best-preserved ophiolite is well-exposed.

Oman is a unique country. It's ancient and traditional in so many ways, but it's also a country that's raced into modernity over the past three decades. Oman's renaissance is financed by oil and gas pumped from beneath its interior deserts; once again the confluence of deep time and place come together to forge civil change.

My original research goal was to examine the basal thrust zone. It's a massive fault upon which the ophiolite was emplaced onto crustal rocks as the Tethys Ocean closed during the Cretaceous. Hot rocks from the mantle were juxtaposed over seafloor sediments and lavas, heating and deforming those rocks into a metamorphic sole glued to the base of the ophiolite.

While traversing to our field sites, we'd encounter a weird rock—a reddish orange rock that held up craggy hills and rocky fins. This rock "got in the way" as we climbed over and around it to reach the metamorphic sole. The rock is listwaenite, and at first, listwaenite was of no interest to me. It's a troublesome rock; even its spelling causes angst. Regardless of how it's spelled, listwaenite is a carbonated peridotite composed of the minerals magnesite, dolomite, quartz, and hematite.

Where does listwaenite form? Some researchers maintain that listwaenite developed in the mantle wedge during the emplacement of the ophiolite and thus represents a sink for carbon in the deep Earth. Yet Oman's listwaenite is almost always exposed at the base of the ophiolite, and as our research demonstrates, associated with upper-crustal extensional fault zones that post-date ophiolite obduction. Here, the geological structure, with serpentine-rich peridotites in tectonic contact above Mesozoic carbonate rocks, provides a readily available source of carbon-rich fluids to course through dilational fault zones, effectively "listwaenitizing" peridotites.

Why does listwaenite matter? Well, it's a fully carbonated peridotite that snatched carbon from the hydrosphere, sequestering carbon back into the rock record. Could this geological process be replicated in real time, such that the vast ophiolite could form a viable sink for atmospheric carbon? That's an important geo-engineering challenge, but success could yield substantive gains that work to lower atmospheric CO_2 levels. Geoscientists need to be a part of this effort, blurring the line between academic and applied research for the greater good.

Thanks for staying with me throughout this free-ranging talk. Your forbearance with my anecdotes is appreciated. My take home message is this: geoscience, situated at the confluence of time and place, is the science that deciphers the past, understands the modern processes that shape our planet, and brings perspective to a rapidly changing world. Let's take joy in, and celebrate, our collective geoscience discoveries. But let's also lean in and lift up to amplify our voices so as to broaden the reach and relevance of the geosciences, as I believe that's imperative for a sustainable future on Earth.