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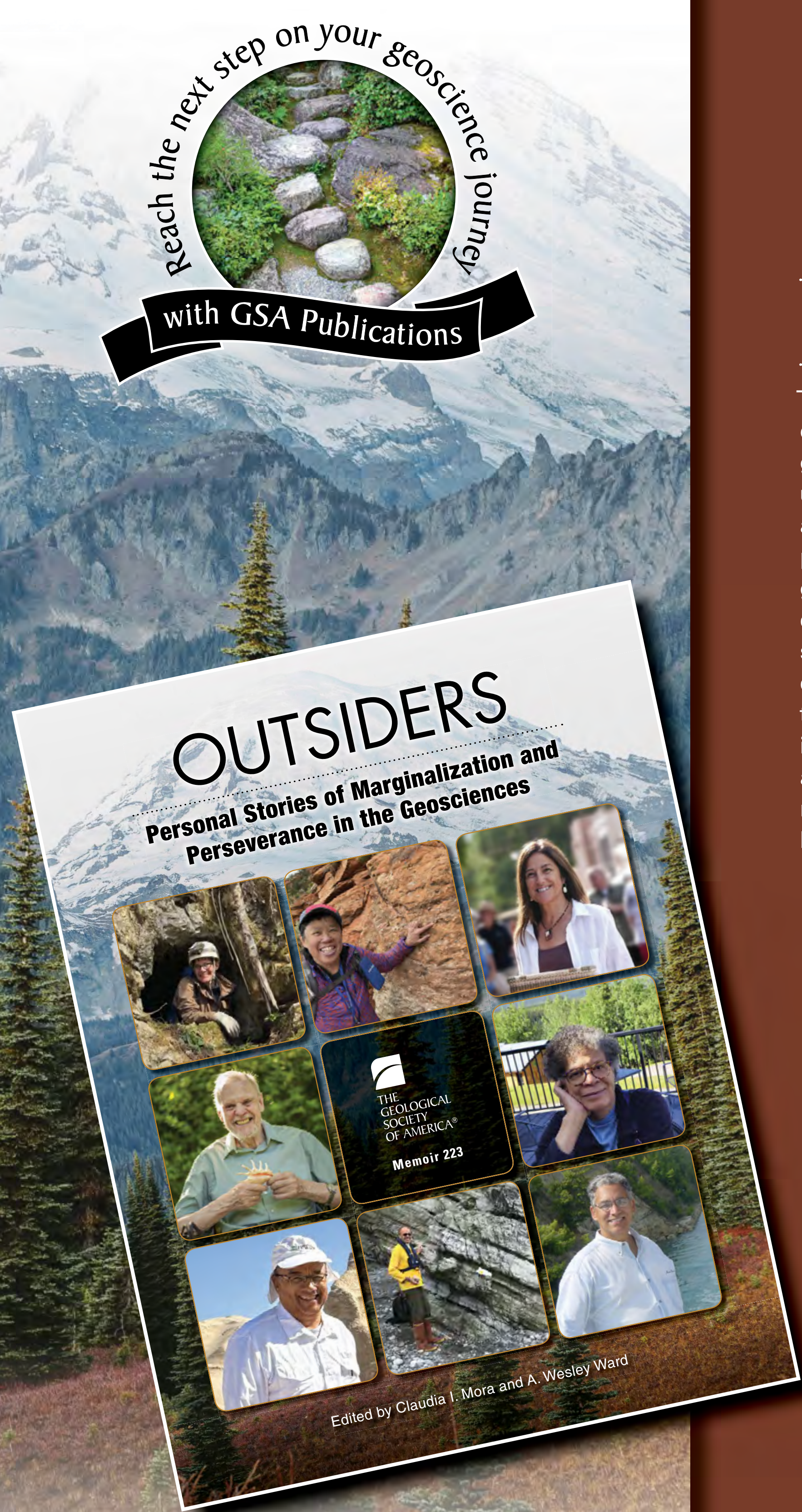

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The iconic Galápagos vista, looking west from the summit of Bartolomé Island to Santiago Island.

Figure 1. Several puys in the Auvergne district, France. Photo by Sarah Trevino.

Auvergne District, France: How Places, People, and Ideas Influence the Mind

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

Geology logline: *The recognition of volcanoes and basalt flows of the Auvergne district, France, resulted in the rejection of the Neptunist model of the Earth proposed by Abraham Werner. Yet some geological thinking influenced by the Neptunist model—looking for worldwide patterns of deposition—remains and is useful.*

Cognitive science logline: *Collective understanding builds among minds over time as individuals contribute their experience to form ideas, which no one might have had on their own. This collective understanding, in geology, is guided by the information from the world—particularly places that have influenced the geological mind.*

> *"Let us consult nature herself, who usually leaves recognizable traces of her operations… [Consultons la nature elle-même, qui laisse ordinairement des traces reconnoissables de ses opérations,…]"*
>
> ***—N. Desmarest (1753, p. 97; English translation adapted from Taylor, 2001a, p. 44)***

The Auvergne district has an outsize influence in the history of geology, in large part because it is one of the most accessible volcanic fields in western Europe. These volcanoes of central France first erupted ~100,000 years ago and stopped ~10,000 years ago. The Auvergne volcanic district is also known as the Chaîne des Puys, with a "Puy" referring to a rounded hill (Fig. 1). When geologists first worked in the Auvergne district, Neptunism was the dominant model

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for thinking about the Earth. The Neptunists believed that all rocks observed at the surface today were a result of deposition from ocean water. The idea was advocated by German geologist Abraham Werner, a mineralogist of some distinction and a charismatic lecturer. He was responsible for attracting students from all over Europe to the Academy of Freiburg, Germany. Werner attempted to provide a stratigraphic order that would work anywhere on Earth. In this model, all rocks were formed as chemical precipitates or clastic sedimentary deposits in a worldwide ocean.

The geology school at Freiburg had previously introduced a universal system for classifying minerals (Werner, 1774). Werner's attempt to classify deposition applied a similar strategy to rocks at the scale of the Earth. The competing worldview at that time was that of the Plutonists, whose proponents included James Hutton. Plutonists interpreted igneous rocks as the result of cooling magmas.

Nicolas Desmarest was one of the first geologists to study the Auvergne district. He started working in the region in the 1760s, published on it in 1771 (Desmarest, 1771), and finally produced a geological map in 1806 (Fig. 2). In a narrative of science that focuses on individual discovery, Desmarest has a credible claim to be the first person that did geology in a manner that would be recognizable to contemporary practitioners (Oldroyd, 1996; we note that a reasonable case could also be made for Nicolas Steno or James Hutton). Desmarest recognized that the Puys were volcanoes, and that molten rocks flowed from these edifices. He identified the basaltic rocks, observed cross-cutting relations and differential weathering to determine a chronology of the basalt flows, and constructed a plausible sequence of events (e.g., a history) that would explain his observations.

Desmarest's work influenced the Plutonist versus Neptunist debate at the time. When Desmarest was asked about which camp he fell into, he apparently told others to "go see for yourself." And they did, including Charles Lyell, George Scrope, and—most importantly—Werner's star student, Leopold von Buch. In the Auvergne, von Buch was convinced that Neptunism was incorrect, at least as to the origin of basalt. The geology of the Auvergne district itself was sufficiently convincing that the region is called the "Graveyard of Neptunism."

Or so goes the story. The reality is more complex and more nuanced. Desmarest was an outstanding geologist, but it was not only his contributions that pushed the debate to its conclusion. We have often focused on a single geologist (e.g., G.K. Gilbert, H. Whittington) in a "great geologist" approach for this essay series, because it simplifies the narrative. The same is true for the role of the mind; we have simplified the cognitive science narrative to focus on a point for each essay. The downside of such an approach is that it promotes a simplistic understanding of the Earth and the mind and suggests that scientific progress is linear. To atone for our past narratives and to address these issues, the main theses of this essay are: (1) science is done by communities, not individuals; (2) science practice is influenced by prior researchers and their mental models; and (3) places are foundational to geological thought. We end this final essay with an articulation of a cognitive science–informed perspective of geology.

#1: SCIENCE IS DONE BY COMMUNITIES

The history of geologists' understanding of the Auvergne illustrates how ideas emerge from being passed among minds. Consider our modern understanding of who contributed to that understanding. Desmarest reasoned about temporal sequences using the apparent ending and continuation of linear distributions of basalts, a form of spatial reasoning now referred to as cross-cutting relationships. Antoine Lavoisier, who would go on to achieve renown for his work in chemistry, saw differentiation in rocks (e.g., mudstone versus sandstone) and linked rock chemistry to the environmental conditions where the rocks formed. Scrope observed that smoother basalt flows were connected to vents and rougher basalt flows were not connected to vents. Using this evidence, he suggested that the former basalts had experienced less weathering and were younger.

The ideas from the Auvergne were not the only ones relevant to the Auvergne. Ideas from the mining district around Freiburg, Germany, were particularly influential. Despite pursuing a theory that was grounded in a Noachian flood, in which a single event caused layering from the erosion of primitive original rocks, Johann Gottlob Lehmann nevertheless observed discrete layers that align with major stratigraphic boundaries. Even absent a theory of deep time, he could perceive part of the story the rocks were telling him, and that there was a significant change at the Paleozoic–Mesozoic boundary.

In the Auvergne, we can see that many scientists had useful contributions; Desmarest did not figure out the Auvergne in a solo effort. What has gotten lost in a narrative of science—which emphasizes testing, rejecting, and accepting theories—is the way ideas intermingle. The role of communities in science has been highlighted in a variety of ways including cognition distributed across a social group (Hutchins, 1995; Giere, 2002), and science communities as a type of community of practice (Wenger, 1998; Kienle and Wessner, 2005).

Given the role of the community, why do scientific narratives tend to focus on the individual? To answer this question, we focus on an insight from the social sciences: How we think about the mind influences how it is used. For the past 250 years, there has been an analogy of the mind being like a machine (de La Mettrie, 1749). As part of the cybernetic revolution of the 1960s, with the earliest public gleanings of how computers work, the analogy gets updated to the mind being like a computer. This approach will bias the believer toward an "industrial" model of thinking: Input from the world, in the form of perception, is processed, the result is sent on for yet more processing, and still more processing, until a final output in the form of an idea or action emerges (Neisser, 1976). Moreover, it implies that the mind will work at its best alone, without interruption.

Yet science is not built piece by piece. Despite the mechanical/computational narrative of the mind, no scientist moves smoothly from data collection or theoretical calculation (input) to generating a fully formed final interpretation (output). Multiple authors have made the case that this approach is flawed for experts in the workplace (e.g., Epstein, 2019) and students in classrooms constructing knowledge in pieces (e.g., diSessa, 1993). This essay series too argues against the assumptions that underly it (Shipley and Tikoff, 2025). The isolation of ideas in the mind of a single person may be analogous to seeing discrete objects and discrete events, reflecting a tendency to segment the world into packets to aid thinking and communicating. To credit individual scientists reflects a particular way of thinking about the way the mind works, and misses the point that science is the most effective and profound group effort in human history. One approaches doing science as a one-mind job at the peril of missing the opportunity to do even better science with multiple minds.

A better analogy for science and the mind is a conversation where a good idea emerges from the passing of ideas back and forth between participants. Here, the participants could even be the same person at different points in time, such as when one writes notes for a future self to support reengaging with the ideas to come to a new understanding. The conversation acts both as a test to filter for ideas that are not working and a way to construct new ideas. Both the filtering and constructing are distributed among the conversationalists. Thus, despite a human propensity to focus on discrete objects, a single isolated mind is not the best "scale" to understand new ideas. To understand this concept, we make an analogy to ecology. Within an ecosystem, the order often exists at a systems level, rather than the level of an individual organism or species. That is, studying any single organism or even species, which may be highly salient features of the system, nevertheless misses the point. Rather, the most fundamental regularity exists at the interactions among species (e.g., a negative feedback loop in predator-prey systems).

Even in our community narrative of understanding the geology of the Auvergne, our credit to individuals is suspect. Narratives of science commonly hold out an individual scientist as the person with a critical insight. This approach often reflects a gross simplification. Kuhn (1963) makes this point about who discovered oxygen: A credible case can be made for Joseph Priestly, Lavoisier, or Carl Wilhelm Scheele. The focus on a uniquely responsible person misses the point—it was all of them, and many others. We emphasize that this approach does nothing to diminish our esteem for any individual scientist, including Desmarest. It does suggest, however, that they are perhaps better regarded as human milestones (to use a rock-based analogy) along a path to our current understanding.

#2: SCIENCE PRACTICE IS INFLUENCED BY PRIOR RESEARCHERS AND THEIR MENTAL MODELS

We are unambiguously influenced by past researchers, how they chose to study, and the places that they chose to investigate (e.g., Oreskes, 1999). This situation occurs, at least in part, because prior research influences mental models and disciplinary practice, and hence the training of scientists. An informative example from the history of natural science contrasts the work of Linnaeus and Buffon. Although Linnaeus is well known to science students, his approach arguably interfered with recognizing the complexity of the natural world. He had worked to advance biology by the application of careful, but rigid, categories. His categories were guided by religious theories that were not tied to information in the world (Roberts, 2024). In contrast, Buffon's approach to natural history (Buffon, 1749–1767) was to make careful observations and withhold classification until constellations of observations began to cohere into patterns. Desmarest was influenced by Buffon's approach of letting the world inform categories (Taylor, 2001b).

A historical summary of the era might offer a simplistic idea that Plutonism was correct and Neptunism was incorrect. After all, the Auvergne district is the "Graveyard of Neptunism." The story, however, is more complicated. Science is not a competition, akin to a sporting event. The language of competition—"winners" and "losers"—reveals a tendency for black-and-white, winner-takes-all thinking. Even if the theories held by early Neptunists were incorrect, their approach yielded significant contributions to geology, because the theories did not prevent useful observations. We now know that there are worldwide patterns of sedimentary deposition, an idea recognized and popularized by Laurence Sloss (the so-called Sloss cycles; Sloss, 1963). Sedimentological records, including observations originally made by Neptunists, allowed the development of a worldwide sea-level curve that goes back to the Mesozoic (Haq et al., 1987).

We make a more specific ecological analogy to emphasize this point. Just as removing all predators does not benefit a prey species in the long term, so too discarding theorists and entire theories likely detrimental to science. We see, in the history of geological thinking about the Auvergne, evidence of parts of ideas coming together and moving into disciplinary practices so completely that today they barely register as a theory. By acknowledging how ideas merge, we may avoid ignoring the parts of competing theories that are fractionally correct.

The downfall of Neptunism reflects two aspects of science that contribute to both its successes and failures. First, when Werner extrapolated, he went far beyond the data to offer a theory. The extrapolation addressed aspects of the world for which it simply did not apply. Second, his model did not change after problematical observations came to light. It is important to recognize that both defects are the downside of a strength of the mind. Categorizing and building models requires extracting regularities from variability, and doing so requires going beyond what is at hand. The extraction of regularity in model building requires ignoring some of the variability, implicitly assigning it to be either noise or minor to-be-explained-later aspects of a model. Sometimes noise is just noise, and perseverance is warranted; other times, variability is the motivation to construct a better model. The scientific challenge lies in correctly discerning signals, or partial signals, when faced with this uncertainty.

The "bundling" of ideas, because they were jointly held by an individual, is another consequence of our focus on individual scientists. In the Neptunism versus Plutonism debate, the associated theories were Catastrophism versus Uniformitarianism, respectively. Because Neptunism was associated with a catastrophic flood, it makes sense that it is associated with Catastrophism. But the story goes beyond the scientific into the social considerations. Because Hutton was both a Plutonist and a Uniformitarianist, those two viewpoints are often associated, but they are not logically dependent on each other. Consequently, a person can be correct about one theory and wrong about another (or more right about one theory and less right about another). This lumping or bundling of theories is a pattern observable in the history of geology. Awareness of mentally bundled theories provides an opening to recognize and retain the correct parts in order to facilitate progress.

One might argue that Plutonism/Uniformitarianism "won" in the 1800s. However, the adherence to this unimodal approach was arguably to the collective detriment of geology. Consider the difficulty of acceptance of ideas that called on catastrophic events, including floods in the Channeled Scablands (J Harlan Bretz, J. Pardee, and others) or the end-Cretaceous meteorite impact (W. Alvarez, L. Alvarez, F. Asaro, H. Michel, and others). To insist that a particular viewpoint is the only way to address a problem impedes scientific progress because, among other reasons, it stifles creativity by shutting down conversation.

#3: PLACES ARE FOUNDATIONAL TO GEOLOGICAL THOUGHT

Choose any historical contingency and follow it, and you will see potential for an altered development of scientific ideas. If Desmarest, with his intense curiosity, had found something else to study, he would not have worked on the Auvergne. Whatever made Lavoisier chose chemistry over geology could have worked in the opposite direction and would have altered the course of both fields. On a personal level, almost all scientists recognize that their careers were altered by subtle and seemingly arbitrary personal decisions (e.g., Greene, 2015). Our individual destinies are controlled, more than we care to admit, by blind chance.

However, in our view, replace any individual or theory and a community of minds capable of extracting information from the world will converge on similar models of the world. This conclusion is at odds with observers of science who focus on the influence of social interactions in construction

A
B


Figure 2. Part of the key (A) and part of the map (B) of the Auvergne district by N. Desmeret (1771). From the collection of Bibliothèque nationale de France, as reproduced by Szaniawska (2018); available under Creative Common License 3.0.

of meaning (e.g., Latour and Woolgar, 1986); this viewpoint downplays the availability of Earth's patterns that directly inform the mind of the causal processes. Scientists do not add meaning; rather, they discern the patterns that can be noticed as a record of a process. It is statistically true that the patterns are unlikely to be noticed if theory does not predict them. But critically, once the pattern is seen, it cannot be unseen, regardless of the popularity of extant theories. This emphasizes the power of empirical, place-based data to correct errors in theory.

For the geological mind, thinking to understand the geological history of a place and the place itself are intrinsically and intricately linked. The locale constrains plausible interpretations and offers evidence for new ideas. While preconceptions can moderate both processes, geologists would have eventually figured it out, regardless of the interpretations of earlier workers. For example, if the Auvergne district was inaccessible, determining the relative chronology of different lava flows would have been worked out somewhere else where the same patterns occur. Nature leaves its traces, as per Desmarest's point, and these traces have an order that allows conclusions independent of belief systems. These places—particularly exemplars—can reveal previously unrecognized processes and change minds. In the Auvergne, we can see belief systems change in response to observations, such as in the case of von Buch.

This literal and metaphorical grounding is not a property of all sciences. Consider, in contrast, the history of economic behavior, where arguably introducing a theory that humans respond to economic incentives created the conditions where the theory became true (see Schwartz, 1986; Graber and Wengrow, 2023). Believing that humans respond to economic incentives led to imposing systems of economic incentives, which led to people responding to incentives that had not previously controlled their behavior. In the social sciences, one could credibly argue that humans can invent their own reality; in the natural sciences, to accept the same statement is a route to catastrophe.

The importance of places in geology is the equivalent of the importance of reproducible experiments in the experimental sciences. They are the empirical foundations from which science proceeds. Places can be revisited with new ideas and analytical tools, in the same way that more precise experiments can be run. Places are essential to our understanding of Earth.

TOWARD A COGNITIVE SCIENCE–INFORMED PERSPECTIVE OF SCIENCE

In this section, we address both naïve perspectives on conducting science and criticisms of scientific discovery. Our perspective on science—gained by working on the interface of natural science and cognitive science—argues against two contradictory models: (1) scientific knowledge is an accumulation of truth through the application of the scientific method (scientific determinism); and (2) scientific knowledge is the society of scientists' agreed-upon socially constructed beliefs (social constructivism). We argue that neither is correct, but similar to Neptunism and Plutonism, there are attributes of both that are useful.

Scientific determinism is incorrect for a variety of reasons, many of which were discussed in this essay series. First, studies in the history of science indicate that there is no single scientific method (e.g., Oreskes, 1999). Second, human perception is not wholly accurate (e.g., Shipley and Tikoff, 2025). Third, the social milieu in which scientists work affects their preconceived notions. The mind is not a precise machine uninfluenced by others, but neither does understanding of the world come completely from others. Fourth, other minds may guide what patterns are noticed. Consequently, it takes a long time to change people's minds (Oreskes, 1999; Tikoff and Shipley, 2025).

Social constructivism is based on the idea that all knowledge is socially constructed. The reasons to adopt social constructivism are all the problems listed above for scientific determinism. Social constructivism fails as a model, however, because scientists in the natural sciences are not wholly constrained by surrounding beliefs. Each essay in this series describes a different example of a place that allowed geologists to understand Earth, regardless of their *a priori* beliefs.

Scientific knowledge as a social construct fails because Earth—and nature more generally—does not change its processes in response to what humans believe. In this respect, we return to Desmarest's quote at the beginning of the essay. It illustrates his belief in a process of science, and his thinking that science is self-correcting because erroneous bias cannot survive input from the world. Perception provides the patterns that conform, or not, to expectations. When the patterns of the world do not conform to our beliefs, the mind changes to align with the world. Although this change may take some time, it does occur.

In summary, both scientific determinism and social constructivism individually fail. But there is a middle path that lies at the intersection of the social and natural sciences.

Throughout this essay series, we have investigated individuals or small groups of people who have made major conceptual leaps that led to new understanding, based on observations in a place. There is a commonality to those investigators: They were intellectually flexible, creative, and had insights that relied on the nonlinearity of the human mind. While the essays often dealt with the limitation of the mind, we have also tried to illustrate the capacity of minds to develop clear insights about the world. Moreover, in the arena of scientific research, multiple minds can cooperate to build a powerful idea to see something new about an area that has been present for eons.

One of the many ways in which the human mind is wonderful lies in its ability to take a small number of observations and infer patterns. The unexpected success of this process is the accuracy of the conclusions, given the paucity of input. This achievement relies on a capacity to link ideas and observations that, on the surface, bear little resemblance but share enough structure that allow alignment of past experiences to the present sparse input. Furthermore, this process is not dependent solely on memory. Rather, when confronted with novel situations, the mind can use the available patterns to make accurate inferences and interpretations. These thinking skills support both individual action and group communication. The human capacity to find patterns endows a community of minds with creativity, collaborating to build ideas that are bigger than any single mind could achieve (Woolley et al., 2010).

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Postscript: Our Individual Reflection on the Places and Minds

HOW PLACE INFLUENCES THE GEOLOGICAL MIND: A PSYCHOLOGIST'S VIEW

"The mountains are calling and I must go, and I will work on while I can, studying incessantly."

—J. Muir (1873)

Places keep on giving. Geologists revisit places to ask new questions and revisit old questions. The observations of previous generations of geologists are still useful, despite changes in theories; pre-tectonics maps are still valuable for the practice of the science. Geologists are both figuratively and literally grounded by "place."

As we wrote these essays, I mused about whether psychology had an analog to place. In the end, I think that there is no equivalent touchstone for my field. There are studies that were done 50 years ago and more that are considered important, but you cannot go find those people who were the participants in those studies to ask a new question. Even if you could find a few of the people that participated in the study, they are no longer the people that they once were. As cognitive scientists, we do not have the equivalent of 100-year-old maps that we cite in our work. Furthermore, psychology data are closely bound to the theory that generated them and as such tend not to survive theoretical revolutions. In that way, the psychology of 50 years ago is not as useful as the geology of 50 years ago. By connecting thinking to places, I hoped to offer some observations about how the mind works that will transcend specific minds and specific theories of how minds work.

I have worked with geologists for over 20 years, and it has transformed my perception of the world. Twenty years ago, mountains and islands just were. Now those places ask "why?" You, expert geology readers, will be adept at asking of the Earth "why is this the way it is?" With the aid of the geology community, I aimed to expand the scope of this simple interrogative to see where together we can improve both the sciences of the mind and of the Earth. I did not intend to wag my finger and point out all the suboptimal reasoning the human mind might engage in, but rather to look for opportunities to avoid the mind's pitfalls and use the mind's strengths toward advancing science.

Along the way I hoped to convey a sense of my own wonder. I have been moved by geologists as they experience wonder, seeing this world anew with eyes informed by knowing past worlds. Wonder, the eminent psychologist William James suggested, formed the roots of philosophy. It allows the discipline to see the world anew as it "breaks up caked prejudices" (James, 1911). In my experience in the mountains "wondering" with geologists, I have learned a lot that I did not know about the mind. I find it particularly fascinating that, to a first approximation, psychology has no satisfactory explanation for how geologists answer their most fundamental "how" and "why" questions.

HOW PLACE INFLUENCES THE GEOLOGICAL MIND: A GEOLOGIST'S VIEW

"There is only this solid sense of having had or having been or having lived something real and good and satisfying, and the knowledge that having had or been or lived these things I can never lose them again. Home is what you can take away with you."

—W. Stegner, about his adopted hometown of Salt Lake City (Stegner, 1969, p. 168–169)

For me, this essay series ends where it began: by the shorelines of Lake Bonneville outside of Salt Lake City. I was born and grew up there. In the valley of my childhood, horizonal lines—stripes on the mountains—were visible from nearly everywhere, to the east on the Wasatch front and to the west on the Oquirrh Mountains. I find it satisfying that the shorelines of my youth were the topic of one of the most influential papers on geological thought (Gilbert, 1886). If the shorelines are subconsciously part of who I am and my home, then so too are the geological reasoning and awareness of my own thinking when I consider how the shorelines formed and were uplifted.

As a geologist, however, I also have attachment to the other 11 places that we have written about. Geological exemplars and type localities embody something about the profession of geology. They are places where geologists, as a community, figured out something important about the world. Or, really, it is the place in the world where a pattern is significantly clear, that one can discover something that is more difficult to think elsewhere. Perhaps Siccar Point, Scotland, is the easiest place to make this point. I, similar to most geologists, have an attachment to this location. I recognize it immediately in a photograph. I felt compelled to go visit it. It was amazing when I got there (but that is a very steep slope).

But why do I feel an attachment to Siccar Point or the Auvergne? Tim suggested that perhaps there is a community-based "response to discovery" that is still there. The geological investigations that occurred in any of these exemplars have influenced the field of geology, and hence the training of a geologist. For example, many geologists are taught the concept of an angular unconformity—with its implications for geological time—based on a photo of Siccar Point. Because perception is tied to cognition, you remember not only the angular unconformity but you also remember having the insight about what that means. That is, it is a place—even if you only saw a picture of it—where you expanded your mind. Having your mind expanded is a compelling case for "having lived something real and good and satisfying," to use W. Stegner's (1969) words. And what I know after working with cognitive scientists is that you really do take it away with you. The geological exemplars and their interpreted processes are available to geologists anytime in the form of a mental model or a runnable mental model. If home is really what you can take away with you, then visiting one of these places is, in some ways, like visiting home. It makes geoscientists at home in the world, which is a superb side benefit for a profession.

But why should other geologists engage with cognitive science? I will make two arguments, one practical and one motivational. Here is the practical argument: Science for the sake of discovering something new about the world will likely be eclipsed by science needed to maintain a habitable planet. Scientists need to become better communicators if we are going to survive any of the potential catastrophes, many of which are self-inflicted by the human race. That goal requires knowing about the world and what goes on in the mind as it makes sense of the world and then communicating it all in an understandable way that we are not yet doing (e.g., using salience; Nelson et al., 2024). Here is the motivational argument: It allows you to do better science. To immerse yourself in the interplay between the science and the do-er of the science is to achieve yet another level of science. It provides another layer of satisfaction and will probably stop a few costly mistakes. The closest analog that I have to working with Tim is doing geological fieldwork. The immediateness of research-oriented fieldwork—with its physical and mental challenges—allows one to do “something real and good and satisfying” and know it while you are doing it. The same is true, at least for me, for understanding what is going on in the mind while doing science.

I now accept that my thinking—both consciously and unconsciously—is affected both by my past and the nature of the human mind with its strengths and limitations. Since I started working with my cognitive scientist colleague Tim, it has been a slow, hesitating, and long journey to acceptance and understanding of how my practice of geology is affected by the foibles of the human mind. I can summarize the experience in the words of an acquaintance from East High School in Salt Lake City, describing her experiences in life: It has been humbling, in a generally positive sort of way.

CONCLUSION (FROM BOTH OF US)

Thank you, reader, for joining some or all of our worldwide tour of places that have influenced the geological mind. We have made a case in this essay series for considering both the mind and the world. We argue, for the geological mind, that they are intrinsically and intricately linked. Knowing the mind’s strengths and weaknesses will hopefully both make you a better scientist and make the journey more enjoyable.

ACKNOWLEDGMENTS FOR THE ESSAY SERIES

We would like to give our sincere thanks to the following people: Cathy Manduca for bringing us together, although she likely did not imagine how it would change us. Nora Newcombe and NSF for investing in a science of learning that robustly supported connecting geological science to spatial thinking in cognitive science. Alix Davatzes for supporting Tim’s trip to the Pilbara and Shark Bay and reading numerous versions of essays (especially numerous versions of the Shark Bay essay) as we figured out how to communicate what the Earth and mind were telling us. Ellen M. Nelson for joining us in figuring out what a future that combined natural and social sciences would look like, in addition to proofreading all of the essays, taking photos, and making illustrations. Marie Dvorzak, the University of Wisconsin-Madison Geology librarian, for her consistent support and helping us find historical articles. Steve Whitmeyer for supporting what turned out to be a bit of a writing retreat in Ireland as we struggled with how to combine world and mind in our earliest essay. Bob Dott for instilling the importance in understanding a small amount of the history of the field for current practitioners.

To all the other geologists (Nicole, Mike, Kim, Heather, Steve, Steve, Nick, Sarah, and more) who over the years generously gave their time and taught Tim a little more geology, and the psychologists of SILC (Nora, David, Dedre, Susan, Susan, Kinnari, Ilyse, Cristina) who taught Basil a bit of cognitive science.

Deepu Murty helped with our exploration of curiosity. Jeremy Wolfe, Zach Hambrick, and Laura Novick offered valuable guidance on priority when contemplating what psychology research to share with scientists outside of psychology.

We thank both GSA (particularly Bridgette Moore and *GSA Today* editors Jim Schmitt and Peter Copeland) and NAGT for this opportunity. Katie Busser at GSA was particularly helpful with final polishing and meeting our monthly deadlines.

The final word goes to Anne Egger, who deserves the kind of gushing thanks authors offer their editors upon completion of books. She was responsible for motivating this essay series and acted as the editor, including finding reviewers for these articles. She provided multiple edits for each essay, was able to see through the problems of each essay to its potential, and kept us on track. She guided us to see the value in the critical feedback and accepted our decisions on how to handle the narrative. Thus, she deserves credit for all the ways the essays are better and none of the blame for the remaining problems. We both sincerely thank her and acknowledge her significant intellectual contribution.

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NAGT

THE GEOLOGICAL SOCIETY OF AMERICA®

This essay series is a joint effort of the National Association of Geoscience Teachers (NAGT) and the Geological Society of America (GSA). Anne Egger, Executive Director of NAGT, served as the associate editor.

One Month Until GSA Connects 2025

19-22 October | San Antonio, Texas, USA

Important Dates

- **Cancellation Deadline:** 12 September
- **Housing Reservation Deadline:** 24 September
- **Standard Meeting Registration Rate Deadline:** 2 October
- **Late Meeting Registration Opens:** 3 October
- **Connects Icebreaker:** 18 October
- **Connects 2025:** 19-22 October

Registration

Standard registration rates end 2 October—**reserve your place today!**

GSA offers a 50% discount on annual meeting registration fees for individuals who are both residing in and are citizens of low and low-middle-income countries as classified by the World Bank. The 50% discount does not apply to the K–12 Professional or Guest registration classes.

connects.geosociety.org/register

Hotels

GSA has selected several hotels within close proximity of the Henry B. González Convention Center. Make your reservation by 24 September to get exclusive GSA rates!

connects.geosociety.org/travel/hotels-transportation

Getting to—and Around—San Antonio

Whether you're arriving by plane, train, or automobile, San Antonio offers plenty of convenient options to get you where you need to go—and plenty of ways to explore once you're here.

By Air

San Antonio International Airport (SAT) is the city's primary gateway and just a short drive from downtown and the iconic River Walk. Prefer a scenic route? Fly into Austin-Bergstrom International Airport (AUS), about 80 miles north, and enjoy a Texas road trip on your way to San Antonio.

By Train

Amtrak service is available via the San Antonio Station at 350 Hoefgen Ave., located near Sunset Station and minutes from the Alamo and the River Walk. The station serves the Texas Eagle route, connecting San Antonio with major cities including Austin, Dallas, and Chicago.

Getting Around Town

Once you've arrived, getting around is easy. Take a leisurely stroll along the River Walk, catch a VIA Metropolitan Transit bus, rent a bike or e-scooter, or cruise through downtown aboard a historic river barge taxi. Rideshare services and rental cars are also widely available for exploring beyond the city center.

To plan your travel and see all the transportation options available, **visit www.visitsanantonio.com/**.

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or contact **shortcourse@geosociety.org** / **fieldtrip@geosociety.org**.

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For Members of GSA's Associated Societies

GSA is proud to partner with 88 Associated Societies (AS) around the world—and to recognize their ongoing contributions to geoscience, we're offering a **15%** registration discount for all AS members.

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Contact your society for their unique discount code and enter it when registering for GSA Connects 2025.

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GSA is committed to making global scientific exchange more accessible. If you're from an upper-middle-income, lower-middle-income, or low-income country (based on economic classifications of the World Bank), you're eligible for deeply discounted registration rates—**50%** off for participants from upper-middle-income countries and **75%** off for participants from lower-middle- and low-income countries.

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Check eligibility at **geosociety.co/MembershipDues**

Fill out this form before registering: **geosociety.co/ConnectsDiscountCodeRequest**

You'll receive a unique discount code via email within 1–2 business days.

Use the code during registration to unlock your discount!

Questions? Contact **gsa_international@geosociety.org**.

Schedule at a Glance

PRE-MEETING

Events include field trips, short courses, and a variety of business and social events.

Pre-meeting in-person events in San Antonio will take place 14–18 October.

Short courses begin online Friday, 10 October, and in person Friday, 17 October.

Field trips begin Tuesday, 14 October.

SATURDAY, 18 OCTOBER

- Icebreaker Reception: 5–7 p.m.

SUNDAY, 19 OCTOBER

- Oral Technical Sessions: 8 a.m.–noon
- All-Day Poster Sessions: 8 a.m.–5:30 p.m., with presenting authors at their posters from either 9–11 a.m. or 3:30–5:30 p.m. Presentation times will be listed in the program.
- GeoCareers Day: 9 a.m.–1 p.m.
- GeoCareers Corner: 9 a.m.–5 p.m.
- Pre-Event Reception: 11:15 a.m.–noon
- GSA Presidential Address and Awards Ceremony: Noon–1:30 p.m.
- Oral Technical Sessions: 1:30–5:30 p.m.
- Pardee Keynote Symposium: 2:30–5:30 p.m.
- Exhibit Opening Reception: 4:30–7 p.m.
- Innovation Spotlight Stage: 4:30–7 p.m.
- Women in Geology Reception: 5:30–7 p.m.
- Night at the Museum: Briscoe Western Art Museum: 7:30–9:30 p.m.

MONDAY, 20 OCTOBER

- Oral Technical Sessions: 8 a.m.–noon
- All-Day Poster Sessions: 8 a.m.–5:30 p.m., with presenting authors at their posters from either 9–11 a.m. or 3:30–5:30 p.m. Presentation times will be listed in the program.
- GeoCareers Corner: 9 a.m.–5 p.m.
- Exhibits: 10 a.m.–6:30 p.m.
- Innovation Spotlight Stage: 10 a.m.–6:30 p.m.
- Noontime Lecture by Former Mayor of San Antonio Ron Nirenberg: 12:15–1 p.m.
- Pardee Keynote Symposium: 1:30–5:30 p.m.
- Oral Technical Sessions: 1:30–5:30 p.m.
- Afternoon Reception in the Exhibit Hall: 4:30–6:30 p.m.
- Alumni Receptions: Evening hours

TUESDAY, 21 OCTOBER

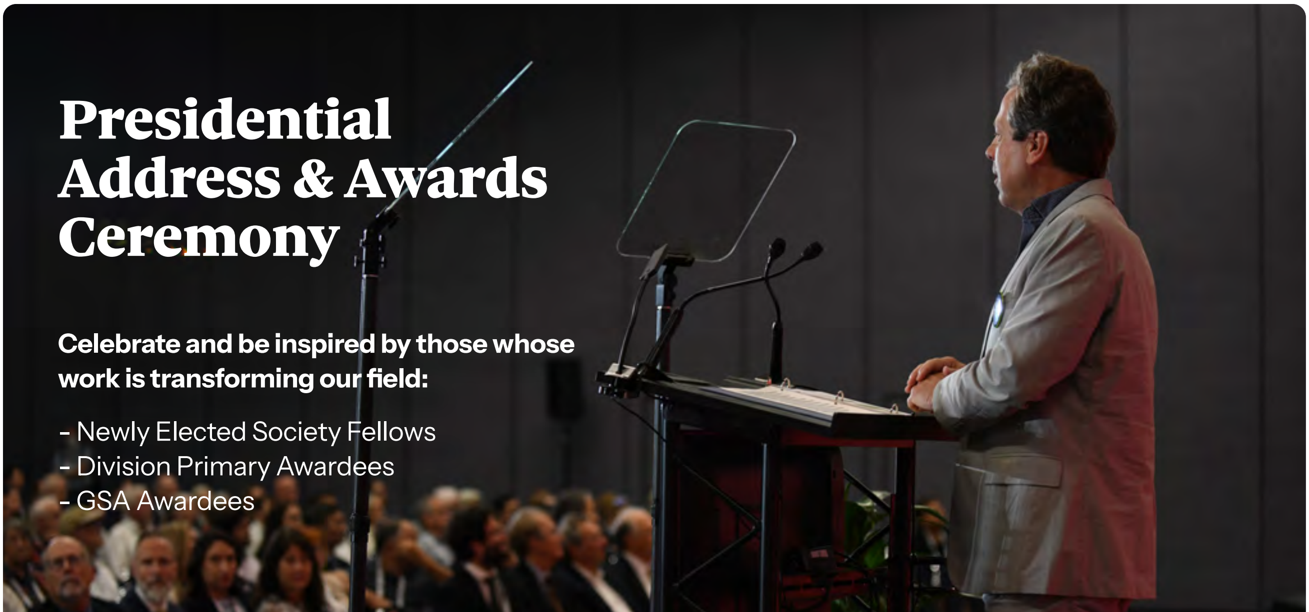
- Pardee Keynote Symposium: 8–11:30 a.m. and 1:30–5:30 p.m.
- Oral Technical Sessions: 8 a.m.–noon
- All-Day Poster Sessions: 8 a.m.–5:30 p.m., with presenting authors at their poster from either 9–11 a.m. or 3:30–5:30 p.m. Presentation times will be listed in the program.
- GeoCareers Corner: 9 a.m.–5 p.m.
- Exhibits: 10 a.m.–6:30 p.m.
- Innovation Spotlight Stage: 10 a.m.–6:30 p.m.
- Michel T. Halbouty Distinguished Lecture by Dr. Michael H. Young: 12:15–1:15 p.m.
- Oral Technical Sessions: 1:30–5:30 p.m.
- Afternoon Reception in the Exhibit Hall: 4:30–6:30 p.m.

WEDNESDAY, 22 OCTOBER

- Pardee Keynote Symposium: 8 a.m.–noon
- Oral Technical Sessions: 8 a.m.–noon
- All-Day Poster Sessions: 8 a.m.–5:30 p.m., with presenting authors at their posters from either 9–11 a.m. or 3:30–5:30 p.m. Presentation times will be listed in the program.
- Exhibits: 10 a.m.–2 p.m.
- Innovation Spotlight Stage: 10 a.m.–2 p.m.
- Noontime Lecture by Dr. Elizabeth Rampe: 12:15–1:15 p.m.
- Oral Technical Sessions: 1:30–5:30 p.m.

POST-MEETING

Post-meeting field trips run from Wednesday, 22 October, through Saturday, 25 October.



Presidential Address & Awards Ceremony

Celebrate and be inspired by those whose work is transforming our field:

- Newly Elected Society Fellows
- Division Primary Awardees
- GSA Awardees

Sunday, 19 October
Noon
Stars at Night Ballroom
Henry B. González Convention Center

Emcee: Melanie Brandt, Executive Director & CEO
Closing Remarks: President-Elect Glenn Thackray

Pre-Event Reception

Join us at 11:15 a.m. in the Ballroom lobby.

Enjoy complimentary food & beverages before the ceremony.

Presented by: President Nathan A. Niemi
Title: Beyond the Compass: Redefining Field Education in Geoscience

At Connects 2025, GSA spotlights themes of transition, dissolving borders, and reaching for the stars—ideas that resonate deeply with the evolving landscape of geoscience field education. Shifting student interests, rapid technological advances, and persistent barriers to participation are reshaping what experiential field training can and should be. Inspiring the next generation to confront the complex geoscience challenges facing society has never been more critical

2025 President's Medal Recipient: OpenTopography Facility — opentopography.org

Ramon Arrowsmith, Arizona State University
Chris Crosby, EarthScope
Viswanath Nandigam, San Diego Supercomputer Center, UC San Diego
Chelsea Scott, Arizona State University

OpenTopography facilitates efficient access to topographic data, tools, and resources to advance our understanding of Earth's surface, vegetation, and built environment. It is operated collaboratively by the San Diego Supercomputer Center at UC San Diego, the EarthScope Consortium, and the School of Earth and Space Exploration at Arizona State University. Core support comes from the NSF Division of Earth Sciences.

Don't Miss Out!

Add These Ticketed Events to Your Registration

GeoCareers Day
Sunday, 19 October | 9 a.m.–1 p.m.
$20; includes lunch

Paleontological Society (PS) Business Meeting and Awards Reception Buffet
Sunday, 19 October | 6:30 p.m.
$80

Night at the Museum: Briscoe Western Art Museum
Sunday, 19 October | 7:30 p.m.
$50: Professionals; $35: Early Career Professionals; $25: Students

Association for Women Geoscientists (AWG) Awards Breakfast and Networking Event
Monday, 20 October | 6:30 a.m.
$50

Mineralogical Society of America Awards Lunch
Tuesday, 21 October | Noon
$88

MGPV / MSA Joint Reception
Tuesday, 21 October | 6 p.m.
$10

Planetary Geology Division Annual Banquet and Business Meeting
Tuesday, 21 October | 7 p.m.
$75

Noontime Lectures

GSA Presidential Address and Awards Ceremony
Sunday, 19 October
Noon–1:30 p.m.

Whiskey's for Drinking and Water's for Fighting: How San Antonio Stays Ahead of the Battle Coming to Texas
Noontime Lecture by Former Mayor of San Antonio Ron Nirenberg
Monday, 20 October
12:15–1 p.m.

Comparing Life-Cycle Environmental Impacts and Costs of Electricity Generation Systems
Tuesday, 21 October
12:15–1:15 p.m.
Michel T. Halbouty Distinguished Lecture by Dr. Michael H. Young

Noontime Lecture by Dr. Elizabeth Rampe
Wednesday, 22 October
12:15–1:15 p.m.

Join Us for the Popular "Success in Publishing" Workshop!

Date: Sunday, 19 October
Time: 10–11:30 a.m.
Location: GeoCareers Corner

Back for its 13th year, this popular workshop is designed to demystify the publishing process for early career researchers. Whether you're working on your first manuscript or looking to strengthen your publishing skills, join GSA science editors Nancy Riggs and Robinson Cecil—both recipients of GSA's Distinguished Service Award—for a practical and engaging session.

What you'll gain:

- Strategies to structure your manuscript for clarity and impact
- Tips for designing effective figures and tables
- Guidance on journal selection and submission
- A better understanding of the peer review process
- Insight into how reviewing can enhance your own writing and career

https://www.geosociety.org/GSA/GSA/Pubs/WritersResource.aspx

Calling All OTF Alumni – Join Us at Connects!

Heading to GSA Connects 2025? Don't miss the OTF and Diversity Reception!

We'd love to see our OTF alumni in the audience for our annual OTF and Diversity Reception, where our new OTF awardees will be recognized. Come mingle with our new cohort and support the OTF program!

Date: Tuesday, 21 October
Time: 6–7:30 p.m.
Location: Henry B. González Convention Center

We hope you'll make time to attend and help us represent the strength and spirit of our alumni community!

2025 Michel T. Halbouty Distinguished Lecture

Michael H. Young, University of Texas-Austin
Date: Tuesday, 21 October
Time: 12:15 p.m.
Location: Stars at Night Ballroom, Henry B. González Convention Center

Comparing Life-Cycle Environmental Impacts and Costs of Electricity Generation Systems

What are the all-in costs, environmental and economic, of expanding and running an electrical grid for Texas, and how might these costs change over the next 30 years? Can we quantify trade-offs among society's goals of providing reliable and affordable energy, mitigating climate change, and ensuring affordability for consumers? We achieve these goals through comparative life-cycle assessments (LCA) of different generation systems that include 18 different environmental pathways, including greenhouse gases (CO_2-eq) and local emissions (particulate matter, SOX, NOX); land and water use and pollution; biodiversity and ecosystem impacts; and others. These LCA analyses consider extraction of natural resources (gas, minerals, etc.), manufacturing of generation equipment, power plant operations, and end-of-life options (e.g., landfilling or recycling of equipment).

We show in our study how environmental impacts manifest along global supply chains for materials (e.g., lithium, cobalt, etc.) that support energy development at different times during the 30-year lifespan of the facilities. And, we connect every operating facility, using different generation mixes, to a nodal-scale, grid dispatch model that allows us to track grid reliability (goal #1), improvements in environmental performance (goal #2), and differences in consumer cost of electricity (goal #3). The results show the complicated nature of impacts along the global supply chain of materials needed for energy development and while electricity is generated, and they point to areas where impacts can be mitigated through innovation and action

> *"By seeking to understand the environmental and economic impacts of both climate and human activity, Michael has forwarded our understanding of the water/energy nexus, soil/water/plant interactions, and connections between water resources, arid and semi-arid landscape development, and human interactions. A fellow of both GSA and the Soil Science Society of America, Michael believes in bridging divides between scientific disciplines and encourages these endeavors by his students and colleagues."*
>
> —Robert M. Reed

Explore the Geoscience Frontier with GSA Field Trips

https://connects.geosociety.org/program/field-trips

Step into the landscape and experience geology firsthand with GSA Connects 2025 field trips! This year's lineup brings you from the Permian reef of Guadalupe Mountains National Park to the carbonate platforms of the Trans-Pecos, the seismic fault zones of central Texas, and the K/Pg boundary along the Brazos River. Dive into topics like cave monitoring, energy production, planetary analogs, geoarchaeology, and hydrogeology—all covered by top researchers and educators.

Whether you're interested in tectonics, volcanology, paleoclimate, sedimentology, or sustainable resource use, there's a trip for every interest and career stage. Many trips offer CEUs and are designed with students and early career professionals in mind—at accessible prices and incredible scientific value.

Grant Support Available for Students and Early Career Professionals

Field trip grants are available thanks to the generous support of Chevron, the Witte Museum, the Kansas Geological Society, the Paleontological Society, and GSA's Scientific Divisions. These grants help make participation possible for students and early career attendees who want to get out in the field.

Apply now at https://forms.gle/MeKy9gt6qjQxcMMn8.

Level Up at GSA Connects 2025 with a Short Course!

https://connects.geosociety.org/program/short-courses

Advance your career with high-impact, hands-on learning. GSA short courses offer in-depth training led by experts across a wide range of geoscience topics—from field mapping and data analysis to science communication and geotourism. GSA short courses are the fastest way to sharpen your skills, grow your network, and stay current in the geosciences. Whether you're looking to explore digital outcrops, map landslides with LiDAR, or dive into the geochemistry of critical minerals, there's a course for you.

Student members save 50% on most courses— some are even free! Courses are held in person and online, with CEUs available for all. Spots fill fast, so don't miss your chance to join experts and peers in these dynamic, career-boosting sessions.

STUDENTS:

Student Volunteer Program

https://connects.geosociety.org/register/volunteer

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

Not a student member yet?

Join now at https://www.geosociety.org/GSA/gsa/membership/student.aspx to take advantage of this opportunity and more!

Student memberships are only $25/year.

Be a Mentor!

Meet with students to hear their stories, and share your own. Whether you are early or mid-career, or recently retired, you have wisdom that will help young geoscientists find their paths. GSA Connects offers many ways to get involved:

- 1:1 Résumé/CV Review
- 1:1 Mentoring Sessions
- GeoCareers Day Table Mentor
- Women in Geology Program Mentor

Sign up at https://bit.ly/3USbUNI.

The Geological Society of America®

GEOCAREERS

https://connects.geosociety.org/networking/geocareers

GSA's GeoCareers program, one of GSA's most successful initiatives, helps students and early career professionals explore career options, build skills, and connect with mentors and employers.

GeoCareers Day

Sunday, 19 October | 9 a.m.–1 p.m.
$20 (includes lunch)

If you are entering the job market, supporting someone who is, or just want more information on the types of nonacademic geoscience careers available in industry or with the federal government, you'll want to attend this series of events. Registration is required—sign up under "Ticketed Events" when you register for the meeting online.

- Geoscience Career Workshop
- Company Connection
- Mentor Roundtables
- GeoCareers Panel Luncheon

GeoCareers Corner

Sunday–Tuesday,
19–21 October | 9 a.m.–5 p.m.
Open to All Attendees

Everyone registered for GSA Connects 2025 is welcome to visit the GeoCareers Corner, where you'll find one-on-one mentoring, career presentations, special networking events, and a space to pause and relax in the midst of a busy conference.

- Career Presentations
- 1:1 Résumé Review Sessions
- 1:1 Mentoring
- Early Career Professional Coffee
- Geology Club Meet-Up
- Women in Geology Program
- Post or View Job Listings

Connect with Publications Staff at GSA Connects 2025!

Representatives from our publications department will be at GSA Connects 2025 to serve as resources for our authors, reviewers, and editors. Take advantage of being in-person to get your pubs-related questions answered.

- Talk to a Science Editor or staff member about your publication in progress
- Ask us about microcredentialing
- Grab some giveaways
- Sign up to be a reviewer
- Learn about authorship and editorship with GSA's journals and books
- Take a selfie for GSA social media to promote your research

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Visit geosociety.co/GSAPublications

Come find our booth in the HQ Pavilion

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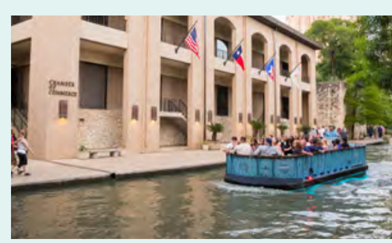

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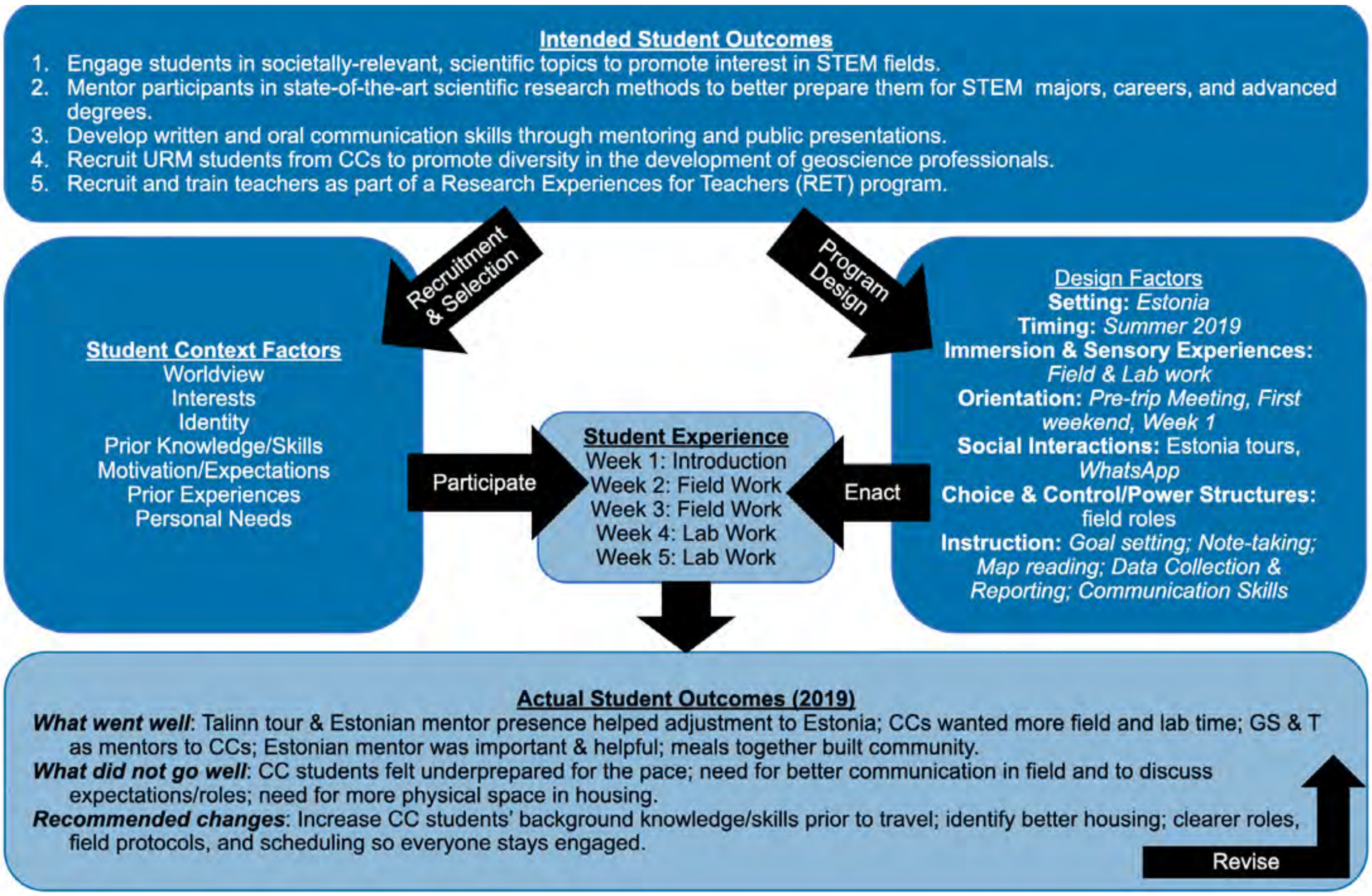

Figure 1. Aligning components of the IRES Estonia Project to the UFERN model.

Leveraging the UFERN Model to Improve International Research Experiences for Undergraduates

N.D. LaDue,[*,1] C.L.B. Manning,[1] and N. Stansell[1]

ABSTRACT

The Undergraduate Field Experience Research Network (UFERN) is an interdisciplinary community of physical and social scientists interested in undergraduate field-based learning (O'Connell et al., 2022). Based on social and behavioral research on learning, a group of UFERN community members collaborated to develop the UFERN model to facilitate successful undergraduate field experiences. The model focuses on how intended student outcomes (e.g., knowledge, skills), the student contextual factors (e.g., worldview, interests, identity, prior knowledge, motivation), and program design factors (e.g., setting, orientation, interaction) influence the students' experience and program outcomes (Fig. 1). Below, we describe how we used the UFERN model to improve and document the efficacy of an International Research Experience for Students (IRES) in Estonia (IRES Estonia).

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[1] Department of Earth, Atmosphere, and Environment, Northern Illinois University, DeKalb, Illinois 60115, USA.

[2] Supplemental Material. Text S1. Pre-trip survey administered one month prior to travel. Text S2. Post-trip survey administered two months after return from Estonia. Please visit https://doi.org/10.1130/GSAT.S.29936744 to access the supplemental material, and contact editing@geosociety.org with any questions.

CITATION: LaDue, N.D., Manning, C.L.B., and Stansell, N., 2025, Leveraging the UFERN model to improve international research experiences for undergraduates: GSA Today, v. 35, p. 22–24, https://doi.org/10.1130/GSATG614GW.1.

2019 Cohort	2022 Cohort
3 weeks field, 2 weeks lab	3 weeks field, 1 week lab
2 CC, 1 Teacher, 2 GAs	2 CC, 1 Teacher, 2 GAs
Ages 19-44 years, M=30 years	Ages 21-36 years, M=27 years
4 women, 1 man	3 women, 2 men
4 White, 1 Latina	3 White, 2 Latina

Figure 2. IRES program attributes and participant demographics.

CONTEXT

This IRES focused on assessing short- and long-term impacts of climate change in the Baltic region through investigation of water chemistry and lake sediments (e.g., pollen, isotopes). During the proposal development process, the PI, co-author Stansell, established partnerships with two regional community college (CC) geoscience faculty at Hispanic Serving Institutions (HSIs) to reach diverse, science-interested students early on their academic path (Weathers et al., 2024; Outcome 4). Engagement in undergraduate research is a predictor of success for students of color (NASEM, 2019), and this collaboration provided greater access to research experiences for CC students (Hewlett, 2018). Earth science teachers were recruited through relevant society social media posts (e.g., National Earth Science Teachers Association; Outcome 5). CC faculty advertised the opportunity in their classes, directly encouraged interested students to apply, and provided letters of recommendation. Applicants provided unofficial transcripts, a résumé, and a personal statement about how IRES Estonia would benefit their education and career goals. Stansell selected each participant for this experience.

This IRES included a short field and lab experience with a small, diverse team (Fig. 2). The 2020 COVID-19 pandemic caused the cancellation of the 2020 and 2021 field seasons. Participants selected for the 2021 field season were invited to participate in the 2022 field season.

APPLYING THE UFERN MODEL

We leveraged the UFERN model (Fig. 1) after the 2019 program to assess and improve the IRES Estonia program for future years. The goals of the project were the five intended student outcomes. To assess goals 1, 2 and 3, we gathered the participants' initial context factors using a survey assessing participants' future goals (Lopatto, 2007), science identity, and sense of belonging in science (Findley-Van Nostrand and Pollenz, 2017; Supplemental Material File S1[2]). The design factors of IRES Estonia included the setting (e.g., City of Estonia, fieldwork), the timing (e.g., summer, field and lab work), orientation to the experience (e.g., pre-trip meeting and survey, first weekend tours of Estonia to learn cultural norms), informal social interactions (e.g., WhatsApp, meals cooked and eaten together), power structures (e.g., scientists, graduate students, undergraduate students, teachers), and a variety of instructional models (e.g., skills training with Excel, map reading, field notetaking; Fig. 1). An orientation meeting reviewed the travel and lodging (prepaid by the grant) and the daily agenda. Stansell arranged for stipends ($500 per week) to be released prior to travel to ensure students could purchase necessary clothing and cover travel incidentals. An Estonian Ph.D. student in Stansell's lab provided cultural support for the IRES participants during the first few days in Estonia. Once in the field, the students learned protocols for map reading, field notetaking, water sample collection, ground penetrating radar, and lake core drilling. The research team also engaged in local traditions (e.g., saunas). In the laboratory, students were taught how to format spreadsheets and analyze data. Students were invited to continue their research project ($100 weekly stipend) for the subsequent academic year.

The 2019 evaluation pre-trip surveys indicated that all participants had high levels of interest, motivation, and science identity that were maintained on the post-trip survey. While in Estonia, participants completed a weekly Google form to evaluate their level of comfort, the pace of the program, and any challenges they encountered. LaDue summarized and anonymized the feedback to Stansell each week. Two months after returning, each participant completed a post-trip survey (Supplemental Material File S2) and one-on-one interview (LaDue or Manning). Interview findings were summarized to inform program improvement. Based on 2019 assessment data, we categorized the actual student outcomes to identify priority areas for improvement. Participants were enthusiastic about the cultural and field-based research experience. The CC students indicated that the pace was too fast, and they wanted more lab time and background knowledge and skills. Stansell learned that CC students needed more support using common science tools (e.g., spreadsheets). Interviews indicated friction around roles and responsibilities related to significant age differences (i.e., perceived power structures) between students and the teacher that were exacerbated by cramped European-style lodging accommodations (i.e., cultural norms). Stansell engaged in UFERN workshops between the first and second field seasons to learn ways to manage field teams with diverse backgrounds.

From the 2019 field season, we learned that student context factors should drive the design factors (O'Connell et al., 2022). Therefore, the 2022 field plan focused on the need for better lodging, more clearly defined roles, and specific tasks to keep everyone engaged in the fieldwork (Fig. 1). More spacious lodging allowing for more alone time was arranged. Stansell started each field day with a discussion of roles and responsibilities, distributing duties based on experience (e.g., 2022 teacher with a hydrogeology M.S.). To enhance students' prior knowledge, the summer 2022 students participated in an online seminar class with Stansell in spring 2022.

One-on-one interviews held after the 2022 field season revealed that the changes made to the program had a positive impact on the actual student outcomes. The pre-trip seminar built rapport with PI Stansell and between the graduate and CC students. Participants reported that the weekend of cultural activities upon first arriving in Talinn (led by the Estonian graduate student) were essential to orient them and that the roomier lodging was comfortable. Clear daily goal setting and discussion of roles helped participants stay engaged throughout fieldwork. These findings support Jolley et al.'s (2018) research on the benefits of student-centered, situated fieldwork.

SUMMARY

The UFERN model enabled us to examine each interacting component of the program and to identify which changes were most critical. We identified the need to address power imbalances, role clarity, and culture-based expectations. Reevaluation using the model for the 2022 cohort demonstrated that improvements were effective. We recommend that program developers consider using the UFERN model to facilitate planning and evaluation.

This project met its intended goals: All four CC students continued their research after their field season, yielding three undergraduate theses and two national conference presentations. Three graduated as geology majors from four-year universities and one is currently a master's student. The pandemic interruption between cohorts allowed for a pre-fieldwork seminar to facilitate CC students' content knowledge and critical relationship building prior to travel. Future project developers should consider these strategies to improve their project outcomes.

ACKNOWLEDGMENTS

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MANUSCRIPT RECEIVED 4 OCTOBER 2024
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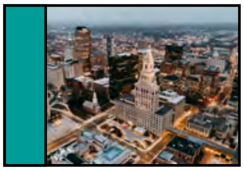

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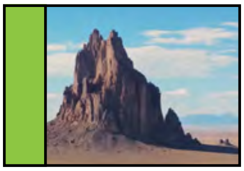

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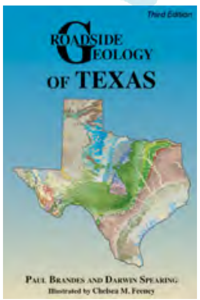

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Paul Brandes and Dar Spearing; Illustrated by Chelsea M. Feeney

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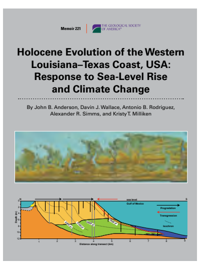

Holocene Evolution of the Western Louisiana-Texas Coast

John B. Anderson, Davin J. Wallace, Antonio B. Rodriguez, Alexander R. Simms, and Kristy T. Milliken

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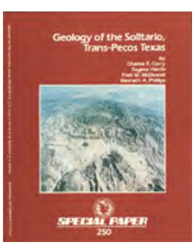
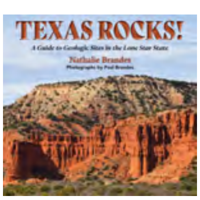


Geology of the Solitario, Trans-Pecos Texas

Charles E. Corry, Eugene Herrin, Fred W. McDowell, and Kenneth A. Phillips

This volume describes the stratigraphy, fossils, igneous and sedimentary lithology, volcanology, structural geology, geochemistry, geochronology, and geophysical surveys of the Solitario and vicinity. *PDF only.*



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Nathalie Brandes; Photographs by Paul Brandes

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O. Richard Norton; Illustrated by Dorothy S. Norton

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Keep an eye out for the upcoming Field Guide 74 and the Texas Geo-Sites Map, both associated with 2025 Connects and related field trips!

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Figure 1. The iconic Galápagos vista, looking west from the summit of Bartolomé Island to Santiago Island. Both islands belong to the northeastern Kea trend, sourced from average lower Pacific mantle (Harpp and Weis, 2020; see text). Credit: Lon Abbott.

The Galápagos Islands: Scientific Insights from the Core-Mantle Boundary to the Atmosphere

Lon D. Abbott,[*,1]

On a misty July morning I stood on the rim of the Galápagos Islands' Sierra Negra caldera watching a group of Darwin's finches flitting about, musing about the outsized influence these diminutive birds have had on the history of scientific thought. Few geoheritage sites can rival the significance of the Galápagos (Fig. 1), the chain of volcanoes in the Pacific Ocean 900 km west of Ecuador that inspired a scientific paradigm: Darwin's theory of evolution.

One sentence in Charles Darwin's 1845 second edition of Voyage of the Beagle neatly sums up the enormous influence of the variety of beak shapes displayed by the 17 closely related local finch species on his thinking about evolution: "Seeing this gradation and diversity of structure in one small, intimately related group of birds, one might really fancy that from an original paucity of birds in this archipelago, one species had been taken and modified for different ends" (Darwin, 1845).

THE FIRST WORLD HERITAGE SITE

The Galápagos are listed as the first UNESCO World Heritage and were inscribed in 1978. To make the World Heritage list, a site must possess "Outstanding Universal Value" (OUV) in at least one criterion. The Galápagos

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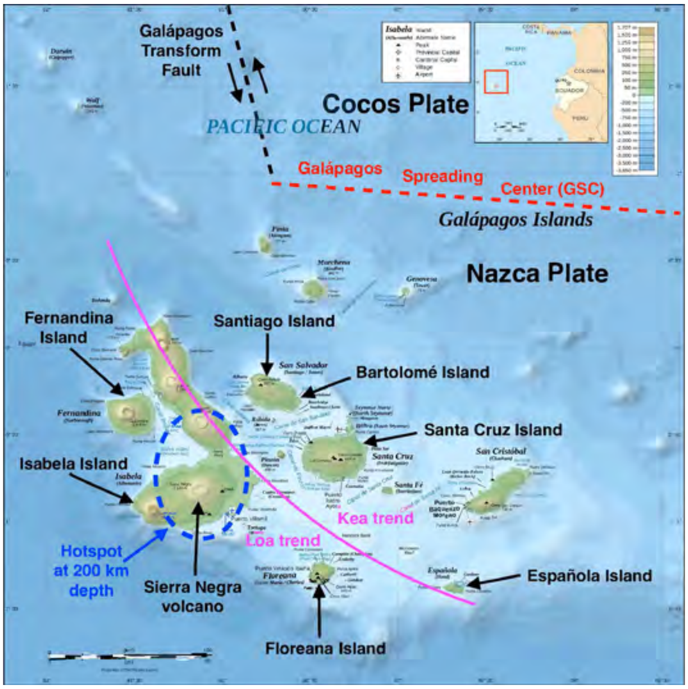


Figure 2. Map of the Galápagos Islands. The boundary between the more enriched Loa and less enriched Kea trends, marked in pink, is after Harpp and Weis (2020). The approximate hotspot footprint at 200 km depth is after Villagómez et al. (2014). Credit: Eric Gaba/Wikimedia Commons.

possess OUV in all four UNESCO criteria for natural sites. They were of course inscribed under Criterion IX, which focuses on ecological and biological processes. But their geology was also deemed of global significance under Criterion VIII—as an "outstanding example representing stages of earth's history." The citation notes that "almost no other site in the world offers protection of such a complete continuum of geological and geomorphological features" (UNESCO, 2025). I had arrived in the Galápagos days earlier with a group of undergraduate geology students and professors from the University of Colorado and Ecuador's Escuela Superior Politécnica del Litoral (ESPOL) to explore those features, which are primarily young (3 Ma and younger) basaltic shield volcanoes and cinder cones built by magma from the Galápagos hotspot.

SIERRA NEGRA: NOT YOUR TYPICAL BASALTIC SHIELD VOLCANO

Like the Hawai'ian Islands, the Galápagos (Fig. 2) were built by voluminous basaltic eruptions fed by a hotspot. In each case, massive shield volcanoes (with low, <10° slope angles) erupted atop a hotspot, forming an island that tectonic plate movement eventually shifted off the hotspot, making room for a new, younger island to grow. Consequently, the oldest islands in both groups stand farthest from the hotspot. The Galápagos formed on the Nazca Plate, which is moving east at 51 km/My, so the southeastern-most island, Española, is the oldest at ~2.8 Ma (Rojas-Agramonte et al., 2022). Isabela and Fernandina Islands, ~230 km NW of Española, straddle the modern hotspot. Fernandina has been built by eruptions from one shield volcano, whereas Isabela, the biggest Galápagos island, consists of six shields that grew together.

Given the many Hawai'i–Galápagos similarities, it's tempting to assume that the geologic evolution of the Galápagos mirrors that of the more intensively studied Hawai'ian Islands. But closer examination of the Galápagos also reveals significant differences, from the architecture and behavior of individual volcanoes to archipelago-wide evolution. These Galápagos distinctions offer insights into how hotspot-producing mantle plumes interact with tectonic plates.

Active Galápagos shield volcanoes possess an atypical architecture produced by their equally unusual eruptive styles. Isabela Island's Sierra Negra, which erupted in 2005 and 2018, is the best-studied Galápagos shield and illustrates the type. Hawai'i's Kilauea, the archetypical shield volcano, provides a useful comparison. Both volcanoes have a large summit depression—the central caldera (Figs. 3A and 3B). But Kilauea also has two prominent rift zones extending outward from the caldera (Fig. 3C), an architectural element Sierra Negra and other Galápagos shields lack. Instead, Galápagos shields possess networks of smaller fissures inside the caldera rim's circumference (Figs. 3A and 3D) and radially oriented fissures (like spokes on a wheel) outside the caldera (Maerten et al., 2023; Ortiz et al., 2024). Kilauea's 2018 eruption illustrates a typical shield eruptive sequence. Deeply sourced lava filled the caldera, then drained into the rift zones, triggering 500 m of caldera subsidence. By contrast, Sierra Negra erupted lava from some of the circumferential and radial fissures during both the 2005 and 2018 eruptions (Geist et al., 2008; Bell et al., 2021).

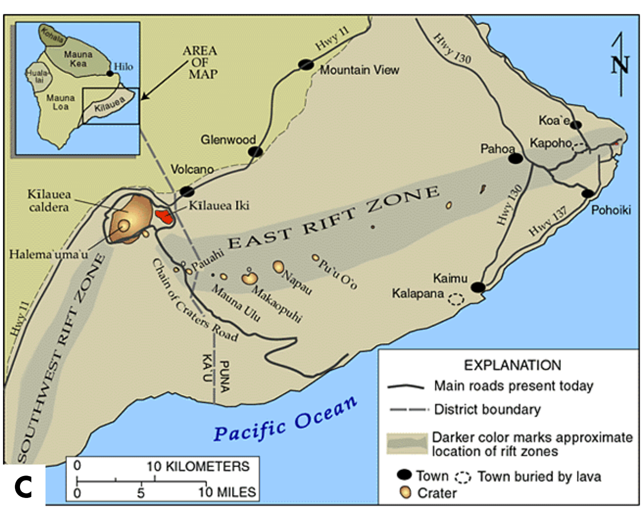
Between eruptions, Kilauea's caldera experiences minimal uplift and few earthquakes, indicating that little magma is rising through its plumbing system. The situation at Sierra Negra is quite different. Its caldera rose 5 m in the years before the 2005 eruption and 6.5 m between 2005 and 2018, accompanied by frequent earthquakes. These inflation episodes document the filling, between eruptions, of a sill-like magma chamber 2 km beneath the caldera. The caldera subsided modestly during each eruption, but long-term uplift exceeded subsidence, making Sierra Negra a resurgent caldera. Resurgence is common in high-silica calderas but absent on typical basaltic shields (Geist et al., 2008; Bell et al., 2021). Clearly, Sierra Negra and the other Galápagos shields don't behave like their Hawai'ian archetypes.

WHEN PLUME MEETS RIDGE: LITHOSPHERIC THICKNESS INFLUENCES VOLCANIC STYLE

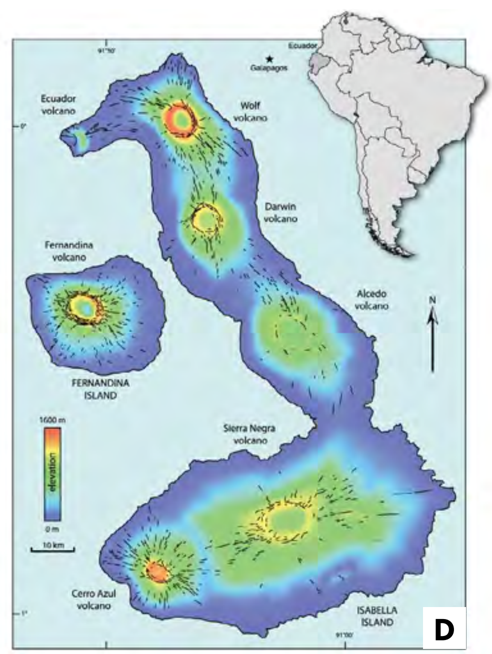
The distinction between Hawai'ian and Galápagos volcanism doesn't stop there. Hawai'ian volcanoes exhibit a predictable geochemical evolution that Galápagos volcanoes lack. Over a span of ~1 My, as they migrate over the hotspot, Hawai'ian volcanoes experience an alkalic (high potassium and sodium) "preshield" phase, evolve to a tholeiitic (less potassium and sodium) "shield" phase, experience another alkalic "postshield" phase, and then, after being dormant for up to 2.5 My, they commonly erupt again (the "rejuvenated" phase). Galápagos volcanoes, by contrast, experience just the tholeiitic shield phase (Harpp and Weis, 2020). Why the difference?

A

B



C



D

Figure 3. Comparison of the volcanic architecture of the Galápagos' Sierra Negra and Hawai`i's Kilauea shield volcanoes. (A) Photo of the Sierra Negra caldera. The fresh black lava covering the caldera floor was erupted in 2005. The small black ridge paralleling the arcuate, vegetated caldera rim is one of the circumferential eruptive fissures. Credit: Lon Abbott. (B) This aerial photograph of the Kilauea caldera and the smaller Halema'uma'u crater nested inside it was taken in 1997. The caldera later subsided 500 m during the 2018 eruption. Credit: J. Kauahikaua, U.S. Geological Survey. (C) Map of the Kilauea caldera and the prominent rift zones that extend to the east and southwest from the central caldera. Credit: U.S. Geological Survey. (D) Map of the active Isabel and Fernandina Island volcanoes from Maerten et al. (2023). The black lines are the eruptive fissures, which cluster around the circumferences of the central calderas and radiate away from the calderas like spokes on a wheel.

Even more puzzling, there isn't an evolutionary link between the western Galápagos' active, caldera-forming shields and the older, eastern Galápagos islands downstream from the hot spot. The eastern shields don't have calderas now and they never did (Wilson et al., 2022). Why didn't they host calderas when they were located atop the hotspot plume, as the active western Galápagos volcanoes do today (Figs. 3A and 3D)?

The explanation for these Hawai‘i–Galápagos and intra-Galápagos differences appears to be the relative proximity of the hotspot plume to a mid-ocean ridge during volcanism. The lithosphere is vanishingly thin at mid-ocean ridges and thickens away from them. That's because rigid lithosphere and convecting asthenosphere are compositionally identical; asthenosphere, by definition, becomes lithosphere when it cools below ~1350 °C. Hawai‘i's mid-plate location means its islands grow on thick oceanic lithosphere. But the Galápagos lie just 150–300 km south of the Galapagos Spreading Center (GSC), the divergent plate boundary between the Nazca and Cocos plates (Fig. 2), so their lithosphere is much thinner.

Hawai‘i's thick lithosphere can support the geochemical evolution seen at Hawai‘ian volcanoes, but the thin Galápagos lithosphere cannot (Harpp and Weis, 2020). Thin lithosphere also means the ambient regional stress is comparatively weak. By contrast, the high magma pressures in and around the active Galápagos calderas dominates the local stress field, resulting in their unusual pattern of circumferential and radial eruptive fissures (Maerten et al., 2023). The stress situation was different, though, >1 Ma when the eastern Galápagos islands began to grow. The GSC has repeatedly shifted southward, toward the Galápagos, including during construction of the eastern islands. Wilson et al. (2022) suggested that the ultra-thin, GSC-adjacent lithosphere on which the eastern Galápagos shields were built had such a weak stress field that it was incapable of focusing magma, precluding development of the long-lived plumbing systems necessary for caldera formation. Furthermore, the GSC currently siphons magma away from the Galápagos plume; such magma theft was likely more pronounced when the ridge was closer to the plume, meaning the eastern shields formed in a magma-starved environment, further inhibiting caldera development (Harpp and Geist, 2018).

THE HAWAI‘IAN AND GALÁPAGOS HOTSPOTS: FRATERNAL TWINS BORN FROM THE PACIFIC LLSVP

Both Hawai‘i and the Galápagos hug the edge of the Pacific Large Low Shear Velocity Province (LLSVP), a vast region of low seismic velocity above the core-mantle boundary. LLSVPs are enigmatic; geophysicists debate whether they possess higher- or lower-density material than the surrounding lower mantle. Understanding what they are and when they formed is a first-order challenge in geoscience (Duncombe, 2019). But the fact that most hotspots cluster around their edges suggests they play an essential role in plume dynamics.

Most scientists think the material in LLSVPs differs compositionally from the adjacent lower mantle. This supposition was validated by the discovery that Hawai‘i's two parallel volcanic trends, the Loa and Kea (named for the two biggest volcanos on Hawai‘i's Big Island), are geochemically distinct. The SW (Loa) trend is fed by a thin filament of material rising from the Pacific LLSVP, whereas the source for the NE (Kea) trend is average lower Pacific mantle, which is less "enriched" than the LLSVP-derived magma. In this context, "enriched" means that lavas from this source have high Rb/Sr, U/Pb, Th/Pb, and low Sm/Nd and Lu/Hf ratios (Weis et al., 2011). Such parallel, chemically distinct filaments were soon discovered feeding other plumes, but not the Galápagos. It appeared that the Galápagos and Hawai‘ian plumes differ fundamentally.

The Galápagos' proximity to the GSC produces a complex geochemical milieu. But a 2020 study cut through that complexity and detected the parallel Loa and Kea compositional trends in the Galápagos. The western and southern islands of Fernandina, Isabela, and Floreana carry the enriched Loa signature, and the Kea trend is found on the northern and eastern islands. Hawai‘i and the Galápagos share a common magma generation mechanism after all. But the geochemical signatures of the enriched, Loa magmas are different for Hawai‘i and the Galápagos, suggesting internal heterogeneity within the Pacific LLSVP (Harpp and Weis, 2020).

MORE GALÁPAGOS INSIGHTS: FROM SOIL FORMATION TO OCEANIC AND ATMOSPHERIC CIRCULATION

The study of Galápagos geology has also yielded important insights beyond the fields of volcanology and tectonics. Understanding soil formation processes is necessary to maximize food production. Paque et al. (2024) quantified the influence of climate and rock porosity on the rate of soil production for Santa Cruz Island (Fig. 2). The island's windward side provides an ideal natural laboratory thanks to its uniformly young (20–165 ka) basaltic rock coupled with a strong rainfall gradient from <200 mm/yr on the arid coast to 1600 mm/yr on the shield volcano's crest. The authors analyzed soil formation processes using ten pairs of low-porosity lava and high-porosity scoria samples collected along a transect through the precipitation gradient. Where mean annual precipitation is <600 mm/yr, in situ basalt weathering is a sluggish 0.5 tons/km^2/yr, and the soil contains 1.7 times more atmospheric dust than in situ rock weathering products. The degree of soil development increases with increasing precipitation, as revealed by soil depth, pH, and mass-loss coefficients. Above a precipitation threshold of 1000 mm/yr, in situ rock weathering dominates. Rock porosity is another important control; at high-precipitation sites, soil developed on high-porosity scoria is ten times thicker and exhibits a 10-fold greater mass loss (due to chemical weathering) than basalt soils.

The Galápagos Islands rise in the eastern equatorial Pacific, a key location for global climate regulation. This is primarily because of the presence there of the "cold tongue" (CT), a zonal band of minimum sea surface temperature. The CT is produced by trade wind–induced coastal upwelling along the west coast of South America combined with equatorial upwelling caused by Ekman divergence (Karnauskas et al., 2006). Those authors state: "It would be difficult to overemphasize the importance of the CT in global hydrological and geochemical cycles" because of the key role it plays in tropical cloud formation, precipitation patterns, oceanic nutrient delivery, and carbon cycling (p. 1266). The general circulation models (GCM) used for climate modeling prior to 2006 produced a "too cold" CT, resulting in unrealistic models of tropical cloud and precipitation patterns.

The Galápagos present a barrier to the equatorial current system, likely influencing CT behavior, but none of the contemporary GCMs in 2006 included the Galápagos. Karnauskas et al. (2006) tested whether the absence of the Galápagos in GCMs caused their too-cold CT. Sure enough, they discovered that the Galápagos obstruct the Equatorial Undercurrent, resulting in a warmer sea-surface temperature than would otherwise exist. Inclusion of the Galápagos in GCMs eliminated the CT cold bias.

As our group traveled through the Galápagos, we saw tortoises, iguanas, and more finches, reminding us repeatedly of the Galápagos fauna's legendary significance for Darwin's development of evolutionary theory. Our tour of the islands' unique geology educated us to other, less celebrated but tremendously important scientific insights of planetary scale, ranging from the core-mantle boundary's chemical composition to the fundamental controls on oceanic and atmospheric circulation. The Galápagos possess a truly extraordinary biological and geological heritage that amply justifies their status as the first-ever World Heritage Site.

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Jigsaw Emplacement on Granite

GEOLOGY THROUGH THE LENS

This puzzle-like feature was observed on a granite outcrop during tin exploration within the Younger Granite Complex of Jos Plateau State, Nigeria.

Daniel John Izam is a Mineral Exploration Geologist from Nigeria.

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