Introduction to the Series

Thomas (Tim) F. Shipley and Basil Tikoff

In the essay series "Places that Reveal the Geological Mind," we are going to explore what goes on in a mind at the cutting edge of disciplinary practice and when first learning geology. We have selected a series of places on Earth that reveal both geological processes and the mental processes that extract knowledge from rocks. Thomas (Tim) Shipley, a professor of cognitive science, has now been working with geologists and geoscience educators for over two decades. Funding from the NSF-sponsored Spatial Intelligence and Learning Center catalyzed leaving his familiar cognitive science community behind to try to understand how another scientific community thinks. Basil Tikoff, a professor of geology, has been a willing collaborator in the effort to link cognitive science and geology. The appeal, originally, was to understand spatial learning in a field that requires high levels of spatial thinking. It became apparent that understanding how one knows the natural world revealed aspects of spatial thinking that were not recognized by the cognitive science community. This series is the product of their ongoing collaboration.

WHY—AND WHAT—PLACES REVEAL

> *We have just travelled 1300 km in a day and a half to spend an hour or so looking at a shallow bay. We four sat for an hour contemplating a collection of dark mounds of bacteria and sediment, while a trickle of tourists walked by, paused for a few moments, and then moved on. After an hour of sitting, looking, and thinking, we left. It was 1300 km back to where we needed to go. At the time, I remember thinking this experience was somehow important … despite not really having a clear idea of what had just happened.*
>
> *I can think of no psychologically notable person, place, or thing that I would want to see so much that I would be willing to spend a day and a half in a car to get there, spend a few hours looking and then get back in the car for the day and half trip back! Neither Freud's study, nor any other trace of an important event in the history of psychology, has the power to call me across a continent.*
>
> —from Tim Shipley's notes on a field trip to Shark Bay, Australia, 2015

The brief travelogue remarking on the distance travelled to see stromatolites may not strike a geologist as unusual or particularly notable, as the need to visit rocks in faraway places is familiar and fundamental to the practice of geology. That need does not have any analogue in psychology or in most other disciplines. Psychologists, for example, could be sitting anywhere when they look at and think about their data. Tim found the experience bewildering because he had no sense of the geologists' motives: why did they need to be here and what were they thinking here? This led him to think about (1) what information a mind can assimilate in a place to be used to understand the past and (2) how geological regularities in specific places change the minds of the observers, both as individuals and as a community. The "aha" moment of the trip was the realization that how geologists think necessarily included consideration of the places in the world that are deeply tied to that thinking.

The field of geology is predicated on the relationship between place and meaning. Because of this relationship, Shark Bay, Australia, calls to geologists. The known properties of present-day stromatolites are the key to the fossil stromatolites, and the fossil stromatolites are critical to an appreciation of the mind-bending longevity of life on Earth. Siccar Point, Scotland, similarly calls to geologists; the angular unconformity there tells us about the enormity of geological time, just as it informed James Hutton and John Playfair. And, because of those individuals, Siccar Point is the place where humans figured it out (Hutton) and managed to communicate it to others (Playfair). The evidence and insight that specific places provide comes from the way the human mind creates meaning, and that meaning is developed through how the mind works. Thus, places can reveal thinking. In this context, specific places are important for some combination of three reasons: They are where something got figured out, they provided critical pieces of a puzzle that allows us to determine Earth history, and they tell us something particularly clearly about Earth processes.

OVERVIEW OF THE SERIES

Over the course of twelve essays, we will take the reader to places around the world. Some places are well known, such as those featured in the top 100 International Union of Geological Sciences (IUGS) geological heritage sites (Hilario et al., 2022), and others less so. In each essay, we discuss how the science of the locale reveals something of the way the mind understands the geology, focusing on one aspect of how the mind works as currently understood by cognitive science.

We begin at **Lake Bonneville, Utah,** where variations in the elevation of abandoned lake shorelines challenge the mind for an explanation, and G.K. Gilbert advances the method of multiple working hypotheses as a way to avoid cognitive bias. We draw cognitive insights on how geologists use their minds from his 1886 scientific report.

Our second essay is about **Shark Bay,** a locale associated with the earliest visible fossil evidence of life, to consider one of the mind's most powerful tools: using analogies to reason about the unknown from the known.

In the third essay, we use the angular unconformity at **Siccar Point** to illustrate the use of mental models. Geologists have an extensive library of mental models of the things

Stromatolites at Shark Bay, Australia.

THE OVERARCHING THESIS OF THE ESSAY SERIES IS THAT BY EXPLORING THE ROLE OF THE MIND AS IT DEEPLY GRAPPLES WITH THE NATURAL WORLD, WE MAY LEARN MORE ABOUT BOTH.

they have seen, and these are the working parts of the scientific mind needed to reason from traces of past events. From individual experiences, generalized models are formed. These mental models are capable of recognizing geologically important features despite their manifestly diverse forms.

We return to G.K. Gilbert and Utah in the fourth essay about the **Henry Mountains,** to discuss how new mental models—such as the idea for a laccolith—are developed.

In essays five and six, about the **Channeled Scablands** of eastern **Washington** and the **Grand Canyon of Arizona,** we consider the mental processes that animate mental simulations of geological processes and how such runnable models might change with new data.

In the next three essays, we discuss the nature of perception and knowing, how we know what is around us in the world, including the cognitive processes that make perception work. We start with an essay on noticing and how the mind unconsciously fills in gaps when objects and events are incomplete, discussing Mesozoic terrane motion and specifically the **Cretaceous Mt. Stuart batholith.** We move on to an essay on the **Burgess Shale, British Columbia, Canada,** about the importance of seeing and thinking in three dimensions. We end this theme discussing the distinction between perceiving and knowing, and how instruments extend human senses, using the observation of CO_2 on **Mauna Loa, Hawai'i.**

The planned final triplet of essays takes a broader perspective on the science. The tenth essay, about the **Sage Hen Flat** pluton in **California**, discusses trust and new ways to communicate uncertainty that allow multiple minds to share information. The next essay, about the **Falkland Islands,** makes a case that the mind works best when it can engage in both goal-directed exploration and play. Our final essay is about the **Massif Central in France.** We use the controversy about plutonism vs. neptunism—which was resolved at this locale—to discuss the importance of multiple minds working on a problem together. This type of collaborative work reflects an important aspect of the way humans think, which is at odds with common conceptions such as the idea that the mind is like a computer. That is, the way in which we think about the mind influences how it gets used.

The overarching thesis of the essay series is that by exploring the role of the mind as it deeply grapples with the natural world, we may learn more about both.

LETTING DISCIPLINES MERGE

Why bring together disciplines whose subject matter seems as distant as their respective buildings on most college campuses? First, a good scientist wants to manage risk. Knowing the limitations of the mind can help adjust practice to reduce the risk of mental errors. For example, cognitive biases often impede advances in theory. In the first essay, we address this topic directly, **discussing geological and cognitive approaches to avoiding bias,** why these approaches work, and why intuitively appealing alternative approaches do not work (Soll et al., 2015). While this practical advice may appear to have an "eat your vegetables" quality, it is grounded in evidence-based findings to motivate the readers to reflect on their current practices, both as individuals and as a community. Second, **a good scientist wants to maximize opportunities.** Understanding the strengths of the mind and how complex reasoning works can increase the likelihood of creative insights. For example, analogical thinking is central to reasoning about the past. In our second essay, we discuss how analogical thinking can be promoted at all levels, from the first encounters with geology to practitioners working on complex problems (Gentner et al., 2001). Realizing the full potential for opportunities afforded by linking geology and cognitive science requires "handshaking protocols" that allow translations of concepts between the cognitive and geological sciences; however, cognitive theories are impoverished in addressing the complexity of how geologists think about the world (Resnick and Shipley, 2013). Third, the fundamental reason for writing these essays—and why we hope they will be read—is that in the

aggregate they **make a case for a powerful approach to knowing the world.** We are proposing a way of thinking that embraces the reciprocity between how the world shapes the mind and how the mind shapes our understanding of the world. Once you start seeing the role of the mind in geology you will not be able to unsee it, just as a geologist cannot unsee abandoned shorelines or U-shaped valleys.

WE ARE PROPOSING A WAY OF THINKING THAT EMBRACES THE RECIPROCITY BETWEEN HOW THE WORLD SHAPES THE MIND AND HOW THE MIND SHAPES OUR UNDERSTANDING OF THE WORLD.

View of Emerald Lake from Burgess Pass in Yoho National Park, British Columbia, Canada.

By encompassing Earth and mind together, we can begin to do science in a holistic way. When we build bridges between the natural and social sciences, a new science can and likely will develop. That new science field—neither cognitive science nor geological science—allows us to break unseen barriers and see new opportunities. We illustrate this claim here using the example of uncertainty in field observations (e.g., Tikoff et al., 2023). A field scientist's uncertainties about their observations are valuable data for the community, because they will enhance trust in shared data, increase participation by those unable to visit the field site to assess data quality, and aggregate knowing so a community can appropriately weigh and use collective data to improve theories. Uncertainty might be recorded in a field notebook, but recording and sharing that uncertainty is not part of disciplinary practice so that valuable data is lost to the vagaries of memory. Why? Likely because the contents of the mind were not seen as within the purview of a natural scientist.

Because the essays address geoscientists' thinking at a given time and how it evolved, they bear some resemblance to a "history of science" analysis, but they diverge in important ways. First, the essays focus on the alignment of a place and the workings of a mind that understands the geology of the place. Second, we use the specific examples to make broader points about how our minds make sense of the world, often unconsciously. Due to the focus, many details about the geology of the specific location and the cognitive science cannot be included. To make up for this admitted shortcoming, we provide suggestions for further reading.

Finally, a word about the writing process for these essays. Some essays began by selecting a cognitive process and then identifying a destination that could serve as a sort of type locale for that thinking. Other essays started by selecting a location, then working through the cognitive story it told. In either case, Basil would write the geology summary and Tim would contribute follow-up writing about the cognitive science. After that, the free-for-all of writing and revision leaves it hard to unmix the ideas to confidently identify who had the preponderance of input on any particular essay. To accommodate the linguistic necessity of author orders, the essays alternate who is listed as first author. Finally, for each essay, we include one sentence loglines to summarize the main point for both the geology and the cognitive science.

The series, overall, makes the case that better science will arise from more closely attending to the processes of the world and the processes of the mind. We hope you will find this dual Earth and mind-studying-Earth perspective both interesting and useful.

REFERENCES CITED

Gentner, D., Holyoak, K.J., and Kokinov, B., eds., 2001, The Analogical Mind: Perspectives from Cognitive Science: Cambridge, Massachusetts, MIT Press, 541 p.

Resnick, I., and Shipley, T.F., 2013, Breaking new ground in the mind: An initial study of mental brittle transformation and mental rigid rotation in science experts: Cognitive Processing, v. 14, p. 143–152, https://doi.org/10.1007/s10339-013-0548-2

Soll, J.B., Milkman, K.L., and Payne, J.W., 2015, A user's guide to debiasing, *in* Keren, G., and Wu, G., eds., The Wiley Blackwell Handbook of Judgment and Decision Making: Chichester, UK, John Wiley & Sons, https://doi.org/10.1002/9781118468333.ch33.

Tikoff, B., Shipley, T.F., Nelson, E.M., Williams, R.T., Barshi, N., and Wilson, C., 2023, Improving the practice of geology through explicit inclusion of scientific uncertainty for data and models: GSA Today, v. 33, no. 7, https://doi.org/10.1130/GSATG560A.1.

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.