When Should Absence of Evidence Be Evidence of Absence? A Case Study from Paleogeology

Matthew Brewer

Abstract

According to what I call the Probabilistic View, absence of evidence is evidence of absence when finding evidence is highly expected. However, this view fails to make sense of the practice of using absence of evidence in the paleosciences, where finding evidence is typically not highly expected. Using a case from paleogeology, I offer a novel account of when absence of evidence should be evidence of absence, which I call the Pragmatic View: appeals to absence of evidence as evidence of absence are warranted because they offer a scaffold to investigate auxiliary hypotheses related to the hypothesis in question.

1. Introduction

A common aphorism says that "absence of evidence is not evidence of absence." The phrase's proscription is intuitively plausible: the mere fact that we lack evidence for a hypothesis does not warrant us to infer that the hypothesis in question is false. Perhaps some evidence exists that we have not yet discovered, or perhaps all the evidence that existed at one time has been destroyed. Interpreting absence of evidence as evidence of absence is often characterized as a kind of faulty reasoning. For instance, Carl Sagan and Ann Druyan popularized the phrase "absence of evidence is not evidence of absence" when they included it in a list of logical and rhetorical fallacies (Sagan and Druyan 1995). Indeed, the history of science is replete with cases which demonstrate how conflating absence of evidence with evidence of absence might lead us to false conclusions. Consider the case of the coelacanth fish, one of many so-called "Lazarus taxa" known to paleontologists: long thought to have gone extinct in the Cretaceous period due to its absence from the fossil record, a living coelacanth specimen was later caught in 1938 near the coast of South Africa (Smith 1939). Prima facie, and due to cases like these, it seems that we are right to refrain from interpreting absence of evidence as evidence of absence.

The case of the coelacanth fish is recognized as a context in which appeals to absence of evidence as evidence of absence were unwarranted. Nevertheless, scientists often do interpret absence of evidence as evidence of absence in other contexts. In this paper, I offer a novel defense of practices that appeal to absence of evidence as evidence of absence, especially in the context of the paleosciences.

In Section 2, I review the history of the phrase "absence of evidence is not evidence of absence," to show that it has roots in geological practice that give us insights into a more nuanced understanding of the phrase. Such nuances were articulated later by philosophers of

science, when they expressed the Probabilistic View of absence of evidence. In Section 3.1, I consider a case from contemporary paleogeology that is not adequately captured by the Probabilistic View, namely, timing the onset of plate tectonics on Earth. While finding evidence in this case is not highly expected, appeals to absence of evidence as evidence of absence persist. In Section 3.2, I articulate the Pragmatic View to understand this practice, and thereby argue there are overlooked reasons for which practitioners should treat absence of evidence as evidence of absence. Appeals to absence of evidence as evidence of absence are justified because they provide a scaffold for subsequent investigations of the auxiliary hypotheses related to the hypothesis in question.

2. The Probabilistic View and Its Historical Antecedents

The question when to treat absence of evidence (henceforth AoE) as evidence of absence (henceforth EoA) is an old problem with roots in geological practice that have thus far gone unappreciated. While this question is a general problem for all historical disciplines that test their theories based on incomplete trace evidence, the history of geology sheds helpful light on the nuances of the proscription "absence of evidence is not evidence of absence."

The distinction between AoE and EoA was first identified in the late nineteenth century.[1] The earliest known occurrence of the phrase "absence of evidence is not evidence of absence" was in 1895, when it was invoked in a paper by the geologist Thomas Sheppard (Sheppard 1895; Goranson and O'Toole 2014).[2] Glaciology was a burgeoning subfield of geology at the time (Schroder 2023), and one open question was how to explain the presence of so-called "erratics,"

[1] See Wright 1887 and Housman 1891 (Goranson and O'Toole 2014).
[2] A close approximation of the phrase also appears in another paper published in the same year by the geologist William Sollas (Sollas 1895; Goranson and O'Toole 2014).

or apparently foreign rocks that conspicuously differ from local rocks. Leading theories of the time said erratics were deposited by moving glaciers, but the mechanisms for how this occurred were not yet clear, and alternative theories were still entertained by geologists even late into the nineteenth century.

Sheppard wrote to *The Glacialists' Magazine* to respond to a letter published the previous year in *Nature*, wherein Henry H. Howorth proposed some erratics in England were not deposited by glaciers, but instead by "Danish pirates" who had used them as anchors for their ships (Howorth 1894). Howorth appealed to the absence of a particular kind of evidence for glaciers: so-called "terminal moraines," or large collections of sediment that accrue at the front of a moving glacier, marking the end of its advance. If the erratics in England were transported by a large glacier, Howorth asked, "where is the terminal moraine, or anything like a moraine, left by this monster?" (p. 79). In reply, Sheppard pointed out that a possible moraine had already been identified; nevertheless, he also warned, "[e]ven if no moraine existed, it does not follow that there was no Ice-sheet: it has been remarked by Mr. Dugald Bell that 'absence of evidence is not evidence of absence'" (p. 132). Thus, the geologist Dugald Bell is credited as among the first to use the phrase.

While Sheppard did not provide a citation for Bell's remark, one can better understand Bell's view of AoE as EoA by considering his published works. Contrary to what one might expect given Sheppard's attribution, in one of his papers published in 1897, Bell in fact violated the very phrase he is credited with coining and instead treated AoE *as* EoA. To understand why, some further background on the state of glaciology in the late nineteenth century is in order.

Geologists of the time largely agreed that erratics were deposited by glaciers, but they were divided among competing theories that specified different mechanisms for how such glacial

deposition might have occurred. According to one "submergence" theory, erratics were deposited when melting glaciers drifted on water above submerged land. According to an alternative theory, the land was not submerged and instead the glaciers moved directly across the land itself.

In his 1897 paper, Bell appealed to the AoE for submergence as evidence that submergence did not occur; in other words, he treated AoE as EoA. Bell described the AoE as "conspicuous," because "*if* the sea had reached the level supposed, […] it should have left traces of itself in innumerable localities all over the country" (Bell 1897, p. 28). Not just one line of evidence was missing, but rather, many were absent. Bell remarked, "[w]hen some of these evidences are wanting, others are sure to be found, if the sea has really been there." This is especially the case if the sea had covered a wide area, as then we would expect more traces to be left behind by its presence. Bell dismissed the very few pieces of evidence cited by others as evidence for submergence, "the very paucity and distribution of which" suggested to him that they were noise "due to another cause" (p. 30). Thus, he appealed to the abundance of evidence that *would* be expected had submergence occurred to justify his treatment of the AoE as EoA. Bell also argued against alternative explanations for the AoE. He dismissed as untenable explanations that posited that evidence for submergence was subsequently removed by glaciation (p. 29).

A closer look at the history of the phrase "absence of evidence is not evidence of absence" has revealed its nuances. AoE is not EoA, *except* in cases wherein evidence for the hypothesis in question is highly likely to occur and be found**.**

Surprisingly, such nuances were not fully articulated until after the turn of the millennium by Elliott Sober in his detailed treatment of the status of AoE as EoA (Sober 2009). Sober offers a Bayesian argument showing that in cases wherein finding evidence is highly likely, AoE is

strong EoA. Nevertheless, the phrase "absence of evidence is not evidence of absence" persists because in many cases finding evidence is highly unlikely. In such cases, *not* finding evidence only very *weakly* favors the negation of the hypothesis in question. While the phrase is technically false, "[w]hen something makes a small difference," Sober explained, "it often seems harmless to say that it makes no difference" (p. 89).[3]

Efraim Wallach has also argued that AoE can be EoA under circumstances which are often found in archaeology (Wallach 2019). According to Wallach, "[a] necessary condition for inference from absence of evidence to have respectable plausibility is that evidence is highly expected" (p. 2). He explained that most archaeological traces (human artifacts) are unique kinds of evidence insofar as they are strong and distinct. Human settlements produce an abundance of material remains which are easily distinguishable from their environment. These traces also have a high degree of what Wallach called survivability: inorganic artifacts are not likely to perish.

Sober and Wallach both subscribe to what I am here calling the Probabilistic View: AoE is strong EoA only under conditions wherein finding evidence that would confirm the hypothesis in question is highly likely according to our background knowledge, or in other words, finding evidence is highly expected. Such a case is exemplified by Bell's arguments against submergence. The Probabilistic View also says that when evidence is not highly expected, AoE provides some (although in many cases practically negligible) support for the negation of the hypothesis in question. Thus, the aphorism "absence of evidence is not evidence of absence" is technically false though often approximately true according to the Probabilistic View.

[3] Sober compares the evidential strength of AoE in cases wherein finding evidence is unlikely to the degree to which observing non-black non-ravens confirms the proposition "all ravens are black."

While the Probabilistic View is a useful account for understanding the role of AoE in scientific reasoning, in the following section, I argue that it is incomplete, because it does not capture an important class of cases of scientific practice. In such cases, evidence is *not* highly expected; nonetheless, I argue that scientists are warranted to treat AoE as EoA. In Section 3.1, I examine a case from current research in paleogeology — specifically the search for when plate tectonics began on Earth — that uses AoE arguments, despite the evidence not being highly likely. I then use this example in Section 3.2 to articulate what I call the Pragmatic View of AoE as EoA.

3.1 Absence of Evidence for Plate Tectonics

A central debate in contemporary paleogeology is, "when did plate tectonics begin on Earth?" There is no consensus regarding this question among geologists, with proposed dates ranging billions of years, from the Neoproterozoic era (ca. 538 million to 1 billion years ago) (e.g., Hamilton 2011) to the Hadean era (ca. 4 billion years ago, Earth's oldest era) (e.g., Hopkins et al. 2008). Much of the disagreement stems from the fact that geologists interpret trace evidence for the operation of plate tectonics in Earth's past differently. Specifically, they disagree regarding how to interpret the *absence* of certain lines of evidence for the operation of plate tectonics in Earth's past.[4] Some treat the AoE as EoA, while others contend evidence was once present but subsequently destroyed. A few words about some important lines of evidence for the past operation of plate tectonics are in order.

[4] Richard A. Watson has pointed out that geologists frequently make inferences from the absence of certain geologic features (Watson 1982).

Certain features in the geologic rock record are thought by some (e.g., Stern 2023) to form only under conditions of plate tectonics. Such features include blueschist (a type of rock), ophiolite, and ultra-high pressure (UHP) rocks. Blueschist and UHP rocks are thought to form under special temperature and pressure conditions that occur only when one tectonic plate slides or "subducts" beneath another. Ophiolites are thought to be oceanic crust previously thrust onto the surface of continents by the movement of plates. Given that such features might require plate tectonics for their formation, many geologists interpret their presence as strong evidence for the operation of plate tectonics.

Importantly, these lines of evidence for plate tectonics are only present in the rock record during and after the Neoproterozoic.[5] Some geologists, such as Robert Stern (2018; 2023), have taken the absence of these rocks in the geologic record prior to the Neoproterozoic as EoA and inferred that plate tectonics did not initiate prior to the Neoproterozoic.

If geologists are right to treat AoE as EoA in this case, then the Probabilistic View does not provide a full account of AoE as EoA, as there are reasons to doubt that definitive evidence for processes deep in Earth's past can ever be *highly* expected. Philosophers of the historical sciences are well-aware of this problem (e.g., Turner 2007; Currie 2018). As geologists investigate further back in time, the frequency of discoverable traces that might serve as evidence for hypotheses about the past generally decreases. Thus, on the Probabilistic View, it seems unlikely that AoE could ever be *strong* evidence for hypotheses about the Earth's deep past. On this view, AoE only ever very *weakly* supports hypotheses in such investigative contexts. It seems that when timing the onset of plate tectonics, AoE should be negligible as EoA. In my view, the Probabilistic View fails to fully appreciate the importance of appeals to

[5] Except for a few older ophiolites, which might be interpreted as noise.

AoE when timing the onset of plate tectonics. As I will argue below, geologists often have compelling reasons to treat AoE and EoA, which requires that we go beyond the Probabilistic View.

3.2 The Pragmatic View

There are at least three primary reasons why geologists treat the AoE as EoA, even when it is not highly probable that such evidence would be found had it existed. First, they may treat AoE as EoA because doing so provides a theoretical scaffold (Chapman and Wylie 2016; Currie 2018) needed to investigate new lines of inquiry. For example, it may allow them to ask, "What does the evidence tell us about the hypothesis in question (aside from the fact it is more likely to be true)?" or, "What new implications might be inferred from the evidence in question?" Second, a scientist might also ask, "How secure are the theories licensing us to treat some traces as evidence for a given hypothesis?" In other words, "What auxiliary hypotheses must we assume in order to secure the theoretical link between the evidence and the hypothesis?" And, third, "What alternative hypotheses must we reject or introduce?" Appeals to AoE for plate tectonics as EoA provides a framework for such subsequent investigations. We can see these reasons at work in the case of the onset of plate tectonics.

Consistent with the Probabilistic View, Stern argues that we can expect evidence for plate tectonics in Earth's deep past by addressing what he calls the "preservation problem," or the question whether evidence *would have* been preserved had plate tectonics been operative for a given time in Earth's past. Stern argues that the key traces of plate tectonics discussed above (blueschist, ophiolites, and UHP rocks) would have been preserved had plate tectonics been operative prior to the Neoproterozoic.

For our purposes, we will consider two arguments employed by Stern to show that evidence for plate tectonics prior to the Neoproterozoic would have been preserved had it been operative. His first argument assumes that blueschist, ophiolites, and UHP rocks are each differently affected by erosion, a process which destroys evidence over time (Stern 2018). Stern contends that if each line of evidence is affected differently by erosion, and if erosion had such an impact that evidence is not preserved, then we would not expect to observe correlations in the frequencies of these traces across time. But geologists do in fact observe such correlations in the rock record; therefore, erosion was not so impactful that evidence was not preserved. However, one might object, if it can be shown that some other destructive processes (or perhaps a single catastrophic process) were operative and that they had significant but *equivalent* effects on all traces such that they masked the *different* signals in the frequencies caused by erosion.

Stern's second argument assumes that if evidence is adequately preserved for two bookended periods in Earth's history, then we can also assume that evidence would have been adequately preserved in any intervening periods (Stern 2023). Thus, an AoE between two periods of adequate preservation is not likely due to poor preservation, but instead a genuine absence (i.e., EoA). Stern argues that other lines of evidence for plate tectonics from the earlier Orosirian period (ca. 1.8 to 2 billion years ago) are adequately preserved, and evidence from the later Neoproterozoic period (ca. 538 million to 1 billion years ago) is also adequately preserved; thus, we can be confident that evidence from the intervening Mesoproterozoic period (ca. 1 to 1.6 billion years ago) would also have been preserved had plate tectonics been operative. He concludes that the Earth has experienced multiple episodes of plate tectonics (one that initiated during the Orosirian, and the current episode that initiated during the Neoproterozoic), punctuated by a "boring" period of relatively little tectonic activity during the Mesoproterozoic.

One might also object here, by pointing out that Stern relies on a "uniformitarian" assumption about the preservation of evidence, insofar as he assumes destructive processes are uniform across time. By contrast, it is possible that causes *unique* to the Mesoproterozoic destroyed all evidence of plate tectonics during that period; for instance, perhaps some catastrophic event might have occurred.

To show why appeals to AoE as EoA in paleogeological reasoning are justified, even when such evidence is not likely to be found, I wish to highlight the new opportunities for inquiry that were prompted by Stern's appeals to the AoE as EoA. Let us call my view the Pragmatic View. According to the Pragmatic View, AoE should be treated as EoA because doing so provides a scaffold for researchers to investigate the auxiliary hypotheses related to the hypothesis in question. To consider Stern as an example, his arguments make assumptions in the form of auxiliary hypotheses, the investigation of which may be fruitful for geologists. For instance, a geologist may wish to investigate whether the effects of a given destructive process are in fact uniform across time. Geologists might also wish to investigate whether different lines of evidence are in fact affected differently (or perhaps uniformly) by destructive processes. Stern's treatment of AoE as EoA provides a strong warrant for the investigation of such auxiliary hypotheses.

Those who wish to maintain that plate tectonics initiated long before the Neoproterozoic and even before the Orosirian are also presented with new opportunities for inquiry: they will need to respond by providing a theoretical or empirical explanation for the AoE despite the operation of plate tectonics.[6] To take blueschist as an example, numerous geologists have

[6] This procedure might be compared to the procedure experimentalists follow when they respond to failed predictions by identifying sources of error.

proposed potential explanations for its absence from the geologic record prior to the Neoproterozoic. Some maintain that blueschist formed prior to the Neoproterozoic, but conditions were not conducive to its preservation. Perhaps blueschist was eroded (Gibbons and Mann 1983), or perhaps because the Earth was hotter, plate tectonic processes in the past recycled the Earth's crust at a faster rate, destroying blueschist in the process (Nisbet and Fowler 1983). Others maintain that plate tectonic processes do not necessarily form blueschist, and conditions were relevantly different prior to the Neoproterozoic such that blueschist did not form (Maruyama et al. 1996; Palin and White 2015). Exploring the implications of these and other auxiliary hypotheses related to the hypothesis that plate tectonics was operative prior to the Neoproterozoic might deepen geologists' understanding of the history of the Earth. Geologists might investigate whether they have other theoretical or empirical reasons to prefer one (or perhaps multiple) of the auxiliaries, or to accept the alternative. Perhaps one of the candidate auxiliary hypotheses also explains other features of the Earth's deep past more adequately than the others.[7]

If the Probabilistic View is taken to its extreme, then geologists might not conduct such investigations, as the probabilistic strength of AoE as EoA in the context of Earth's deep past is mostly (if not always) very *weak*. As Sober pointed out, things that seem to make little difference are sometimes ignored. Some practicing geologists (e.g., Palin et al. 2020) have invoked the phrase "absence of evidence is not evidence of absence," because they hold that Earth's deep past "may simply be too far-removed to envisage" (p. 26). However, AoE is worthy of treatment as EoA in paleogeology according to the Pragmatic View.

[7] One way in which geologists might investigate a hypothesis and its auxiliaries, even when evidence is absent, is by conducting computer simulations.

Indeed, by ignoring AoE as EoA, scientists risk ignoring productive avenues of inquiry into auxiliary hypotheses. Auxiliary hypotheses are conditionals, of the form "If H [our initial hypothesis] is true, then evidence y will be observed." To formulate and test auxiliary hypotheses, scientists must conditionally endorse an initial hypothesis over other conceivable alternatives. AoE as EoA provides the initial warrant (perhaps the only warrant) for provisionally investigating the implications of some hypotheses that might otherwise be neglected (namely, those supported by EoA).

Moreover, because adequately testing hypotheses against alternatives requires the detailed specification of relevant auxiliaries, treating AoE as EoA provides a theoretical scaffold for geologists to more fully investigate alternatives to initial hypotheses under investigation. As Sober has noted himself, hypothesis testing is a "contrastive activity" (Sober 1994). Practicing scientists do not test a hypothesis against its simple negation, but instead, alternatives are specified. Hypotheses about the onset of plate tectonics should be tested against a range of possible alternatives conjoined with different auxiliary hypotheses. Contrastive testing is most powerful when auxiliary hypotheses are spelled out explicitly, as doing so allows scientists to make more specific predictions by anticipating possible distorting or confounding effects (i.e., sources of error). In this way, understanding a wider range of alternatives and their auxiliaries advances scientists' understanding of the target under investigation. Such tests would not be possible without treating AoE as EoA, as the development of detailed auxiliaries occurs only after conditionally accepting a hypothesis as true for the purposes of investigation. Conditionally accepting AoE as EoA allows Stern to consider auxiliaries relevant to the preservation of evidence (briefly described above). Others might attempt to refute Stern by specifying a wider range of relevant alternatives, each with its own set of auxiliary hypotheses, against which his

hypothesis might be contrasted using Bayesian techniques. As this case shows, treating AoE as EoA thus allows scientists to build a rich theoretical scaffold to make genuine progress towards a more adequate representation of the Earth's deep past.

Furthermore, for AoE to ever amount to *strong* EoA, then the Pragmatic View may be necessary. AoE is made stronger as EoA when scientists investigate auxiliaries but fail to identify possible alternative explanations for the AoE. Cristian Larroulet Philippi has previously pointed out the importance of background knowledge about causal mechanisms when making inferences from an AoE (Larroulet Philippi 2022, p. 163). Without a scaffold of knowledge about the relevant casual mechanisms at play, we cannot be confident that we have ruled out possible alternative explanations for the AoE. Yet, this scaffold can only be constructed if AoE is provisionally treated as possible EoA in the first place, as this enables scientists to explore the auxiliary hypotheses and implications that must be accepted if the AoE is to amount to strong EoA.

I should point out that the Pragmatic View of AoE does not deflate our view of evidence, at least relative to the Bayesian understanding of evidence. Sober's understanding of evidential confirmation is subjective, insofar as he holds that "evidence can modify *one's degrees of belief* in various hypotheses [emphasis added]" (Sober 2009, p. 65). Bayesian probabilities quantify a scientist's willingness to make a bet on the truth of a hypothesis; in other words, they quantify the degree to which an agent is inclined to act as if a proposition is true (Ramsey 1926 [1990]). According to my Pragmatic View, practitioners should treat AoE as EoA, which is to say, they should act as if hypotheses supported by AoE as EoA are true, as this assumption provides a scaffold for subsequent tests of relevant auxiliaries. Such tests might lead to the later confirmation or disconfirmation of the hypothesis supported by the AoE. Insofar as the

Pragmatic View says scientists should act as if hypotheses supported by AoE as EoA are true, it is no more subjective than the standard Bayesian view of confirmation.

4. Conclusion: When Should Absence of Evidence Be Evidence of Absence?

Philosophers of science have shown that the aphorism "absence of evidence is not evidence of absence" is technically false. According to the Probabilistic View, AoE provides some EoA, but in many cases, wherein evidence is not highly expected, the phrase is approximately true. I have detailed an episode from the history of glaciology to show that philosophers of science expressing the Probabilistic View are articulating assumptions at play in geological reasoning of the late nineteenth century.

While the Probabilistic View has its merits, I have shown that it fails to capture the importance of appeals to AoE as EoA in cases wherein evidence is not highly expected to be found, such as in the case examined here, namely, the geological practice of timing the onset of plate tectonics. According to my Pragmatic View, AoE should be treated as EoA, because doing so provides a theoretical scaffold for scientists to further investigate auxiliary hypotheses (in particular, hypotheses describing the connection between past events and trace evidence). Treating AoE as EoA allows scientists to conditionally treat a hypothesis as true for the sake of subsequent investigations of its auxiliaries. The specification of such auxiliaries allows for more informative contrastive testing of an initial hypothesis against alternatives. In many cases, AoE guides practitioners by focusing their investigations on alternatives and auxiliaries which might explain the absence of evidence. If scientists did not treat AoE as EoA, then there would be comparatively little warrant for such investigations. Yet, such investigations allow scientists to

make genuine progress towards more refined theories containing a greater number of auxiliary hypotheses that more adequately describe the history of the Earth.

References

Bell, Dugald (1897). "The 'Great Submergence' Again: Clava." *Geological Magazine* 4, no. 1: 27-30.

Chapman, Robert, and Alison Wylie (2016). *Evidential Reasoning in Archaeology*. London: Bloomsbury.

Currie, Adrian (2018). *Rock, Bone, and Ruin: An Optimist's Guide to the Historical Sciences*. Cambridge: MIT Press.

Gibbons, Wes, and Andy Mann (1983). "Pre-Mesozoic lawsonite in Anglesey, northern Wales: Preservation of ancient blueschists." *Geology* 11, no. 1: 3-6.

Goranson, Stephen, and Garson O'Toole (2014). "completing "absence of evidence...,"" March 29. ADS-L (American Dialect Society listserv). https://listserv.linguistlist.org/pipermail/ads-l/2014-March/131659.html.

Hamilton, Warren B. (2011). "Plate tectonics began in Neoproterozoic time, and plumes from deep mantle have never operated." *Lithos* 123, nos. 1-4: 1-20.

Hopkins, Michelle, T. Mark Harrison, and Craig E. Manning (2008). "Low heat flow inferred from >4 Gyr zircons suggests Hadean plate boundary interactions." *Nature* 456: 493-96.

Housman, William (1891). "The Lenton Herd." *Live Stock Journal* 34, no. 915: 408.

Howorth, Henry H. (1894). "The North Sea Ice Sheet." *Nature* 50, no. 1282: 79.

Larroulet Philippi, Cristian (2022). "There is Cause to Randomize." *Philosophy of Science* 89, no. 1: 152-70.

Maruyama, Shigenori, Juhn G. Liou, and Masaru Terabayashi (1996). "Blueschists and Eclogites of the World and Their Exhumation." *International Geology Review* 38, no. 6: 485-594.

Nisbet, Euan G., and Christine Mary R. Fowler (1983). "Model for Archean plate tectonics." *Geology* 11, no. 3: 376-79.

Palin, Richard M., M. Santosh, Wentao Cao, Shan-Shan Li, David Hernández-Uribe, and Andrew Parsons (2020). "Secular change and the onset of plate tectonics on Earth." *Earth-Science Reviews* 207, 103172: 1-41.

Palin, Richard M., and Richard W. White (2015). "Emergence of blueschists on Earth linked to secular changes in oceanic crust composition." *Nature Geoscience* 9: 60-64.

Ramsey, Frank P. (1926 [1990]). "Truth and Probability." In *Philosophical Papers*, edited by D. H. Mellor, 52-109. Cambridge: Cambridge University Press.

Sagan, Carl, and Ann Druyan (1995). *The Demon-Haunted World: Science as a Candle in the Dark*. New York: Ballantine Books.

Schroder, Julie (2023). "The Remarkable Reverend Henry W. Crosskey, the Erratic Blocks Committee, and the Crosskey Collection of Glacial Erratic Specimens." Birmingham Erratic Boulders Project. https://erraticsproject.org/henry_crosskey/.

Sheppard, Thomas (1895). "On the Occurrence of Scandinavian Boulders in England." *The Glacialists' Magazine* 3, no. 1: 129-32.

Smith, James L. B. (1939). "A Living Fish of Mesozoic Type." *Nature* 143: 455-56.

Sober, Elliott (1994). "Contrastive empiricism." In *From a biological point of view: Essays in evolutionary philosophy*, 114-35. New York: Cambridge University Press.

——— (2009). "Absence of evidence and evidence of absence: evidential transitivity in connection with fossils, fishing, fine-tuning, and firing squads." *Philosophical Studies* 143: 63-90.

Sollas, William J. (1895). "An Experiment to Demonstrate the Mode of Flow of a Viscous Fluid." *The Quarterly Journal of the Geological Society of London* 51: 361-68.

Stern, Robert J. (2018). "The evolution of plate tectonics." *Philosophical Transactions of the Royal Society A* 376, no. 20170406: 1-21.

——— (2023). "The Orosirian (1800–2050 Ma) plate tectonic episode: Key for reconstructing the Proterozoic tectonic record." *Geoscience Frontiers* 14, 101553.

Turner, Derek (2007). *Making Prehistory: Historical Science and the Scientific Realism Debate*. New York: Cambridge University Press.

Wallach, Efraim (2019). "Inference from absence: the case of archaeology." *Palgrave Communications* 5, no. 94: 1-10.

Watson, Richard A. (1982). "Absence as Evidence in Geology." *Journal of Geological Education* 30, no. 5: 300-01.

Wright, William (1887). "The Empire of the Hittites." *Journal of the Transactions of the Victoria Institute, or Philosophical Society of Great Britain* 21 (January 3): 55-72.