Figure 1. Picture of Mount Stuart, North Cascades, Washington. Photo by Tom Foster, provided by Nick Zentner.

Mt Stuart, Washington State: Beware Occam's Razor

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

Geology logline: *Paleomagnetic evidence, starting with a 1972 study of the Mount Stuart batholith, indicates significant northward movement of parts of the North American Cordillera starting ca. 100 Ma.*

Cognitive science logline: *Attentional limits that allow us to function in a world with many potential distractions provide opportunities and dangers when science encounters new information.*

"ENTITIES ARE NOT TO BE MULTIPLIED WITHOUT NECESSITY"
ONE STATEMENT OF OCCAM'S RAZOR
(FROM PONCIUS, 1639)

In 1972, a short paper by Myrl Beck and Linda Noson provided data that caused unease in our understanding of the North American Cordillera that continues today (Beck and Noson, 1972). The data came from a paleomagnetic study of the granitic Mount Stuart batholith, Washington (Fig. 1). The paleomagnetic study indicated that the batholith had been located 3000 km south (at the latitude of northern Mexico) shortly after it intruded into host rocks (ca. 100 Ma), relative to its current position in North America.

Here is a short review of the basics of paleomagnetism: The magnetic minerals in rocks can record the geomagnetic field. Igneous rocks acquire this paleomagnetic signal when they cool through ~500 °C (i.e., the Curie temperature) if they contain titanomagnetite (a common magnetic mineral in granites); sedimentary rocks acquire a paleomagnetic signal shortly after they are deposited. The magnetic and geographic poles align when averaged over thousands of years; consequently, the inclination of the paleomagnetic signal is horizontal (0°) at the equator and vertical (±90°) at the poles. If the rock containing magnetic minerals did not move af-

*basil@geology.wisc.edu
[1]University of Wisconsin–Madison, Madison, Wisconsin 53706, USA
[2]Temple University, Philadelphia, Pennsylvania 19122, USA

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ter the paleomagnetic signal was acquired, then there is a predictable relationship between the paleomagnetic orientations and the latitude. However, if the rock moved to a new latitude, it would have retained its original paleomagnetic inclination, which differs from the expected magnetic inclination at its new latitude.

The Mount Stuart batholith has a shallower paleomagnetic inclination than would be expected if it had been attached to northwest Washington State at 100 Ma (Fig. 2). A key challenge to interpreting paleomagnetic results in plutonic rocks is that paleohorizontal cannot be assumed from the current horizontal orientation. However, subsequent paleomagnetic data sets from the Mount Stuart region have determined the original horizontal plane using bedding planes, interlayered sedimentary and volcanic rocks, and paleomagnetic tests for quality (e.g., Wynne et al., 1995). Moreover, younger (ca. 70 Ma) Cretaceous rocks show less latitudinal offset, indicating that the paleomagnetic data record consistent and coherent northward transport of the terranes (Fig. 2). In aggregate, the paleomagnetic results from multiple sites—which have been remeasured, and for which the reproducibility of the results were demonstrated using different techniques and methods (e.g., Housen et al., 2003)—are generally consistent with the 1972 results from the Mount Stuart batholith (e.g., Enkin et al., 2006). Most of northwest Washington State, coastal British Columbia (BC), and some coastal parts of Alaska—which is collectively known as the Insular superterrane—have moved significantly northward (see the paleomagnetic review by B. Housen in Tikoff et al., 2023). The debate about the location of the Insular superterrane at ca. 100–55 Ma is known as the Baja-BC controversy (e.g., Cowan, 1994), because parts of British Columbia (BC) might have been located at the latitudes of Baja California (Baja).

Why are these data so problematic? Most models for the tectonic development of western North America call on orthogonal—or "straight in"—convergence. In the western United States, convergence involved orthogonal subduction of the Farallon plate, with proposed shallow subduction starting at ca. 80 Ma and linked to the formation of the eastern Rocky Mountains (Dickinson and Snyder, 1978). In western Canada, it involved orthogonal collision of two island arcs (the westernmost of which was the Insular superterrane; e.g., Monger et al., 1982). These two-dimensional models of orthogonal convergence were developed after the paleomagnetic data were published and were thus in conflict with the evidence for northward motion. Further, the Insular superterrane was very likely adjacent to North America in the Late Cretaceous: Geological evidence indicates that it collided at ca. 100 Ma with North America at some latitude (e.g., Rubin et al., 1990). If the accreted terranes (e.g., Insular superterrane) required thousands of kilometers of movement after this collision, these models might be invalidated (Fig. 3).

This essay addresses a topic of ongoing debate (e.g., Busby et al., 2023) in order to explore cognitive processes. In full transparency, one of the authors has been an active participant in this debate for years (hint: It is not the psychologist). We think, however, that the history of inferences about the movement of the Mount Stuart batholith offers a cognitive window through which to notice and incorporate new information into one's world view.

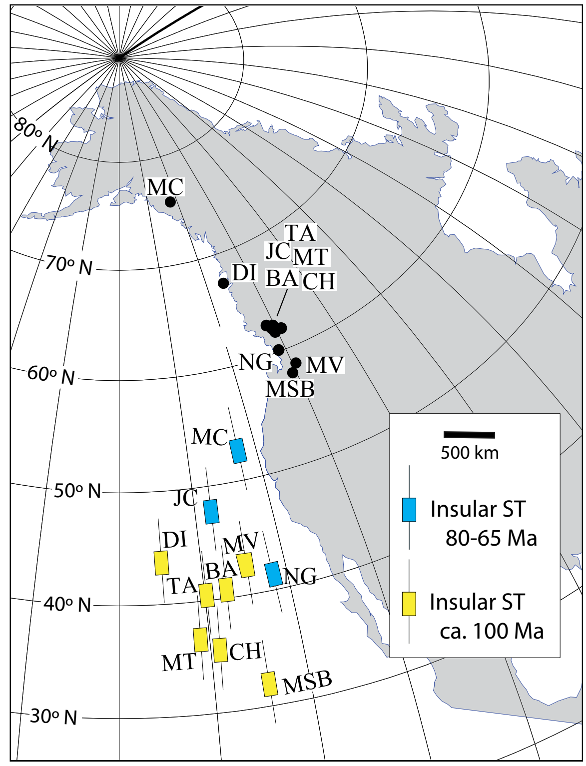

Figure 2. Reconstructed locations based on paleomagnetic data for sites from the Insular Superterrane (ST) in the mid-Cretaceous (ca. 100 Ma; yellow) and latest Cretaceous (80–65 Ma; blue) using Cretaceous North American reference poles from Tikoff et al. (2023). Paleolatitudes and 95% confidence limits from the paleomagnetic means are plotted (box plus whiskers). Insular Superterrane paleomagnetic sites are: BA—Battlement-Amazon volcanics and sediments; CH—volcanics and sediments of Churn Creek; DI—Duke Island ultramafics; JC—Jamison Creek volcanics and sediments; MC—MacColl Ridge; MSB—Mount Stuart batholith; MT—Mount Tatlow volcanics and sediments; MV—Methow valley remagnetized strata; NG—Nanaimo Group sediments; TA—Tete Angela volcanics and sediments. Data compiled by B. Housen; figure modified from Tikoff et al. (2023).

We start with an important analogy between the everyday duties of the mind and the science of geology. In both cases, one is typically confronted with limited, partial, and incomplete information, upon which one must act. Field geologists, whether they walk the high deserts of Chile, where there are almost complete surface exposures, or slog through the bogs of Ireland to find the next outcrop, know they work from incomplete observations of Earth. What may be less obvious is the same is true of every scene you look at. As we noted in Tikoff and Shipley (2024), the visual system is always filling in the occluded parts of objects. If the reader looks around, they will note that closer objects hide parts of more distant objects, and the fronts of objects hide their backs. The mental processes that complete the partially occluded objects have two components: (1) a detection that completion is needed, and (2) a filling in with the likely missing structure. What might be happening in the mind when new evidence becomes visible/available? In this

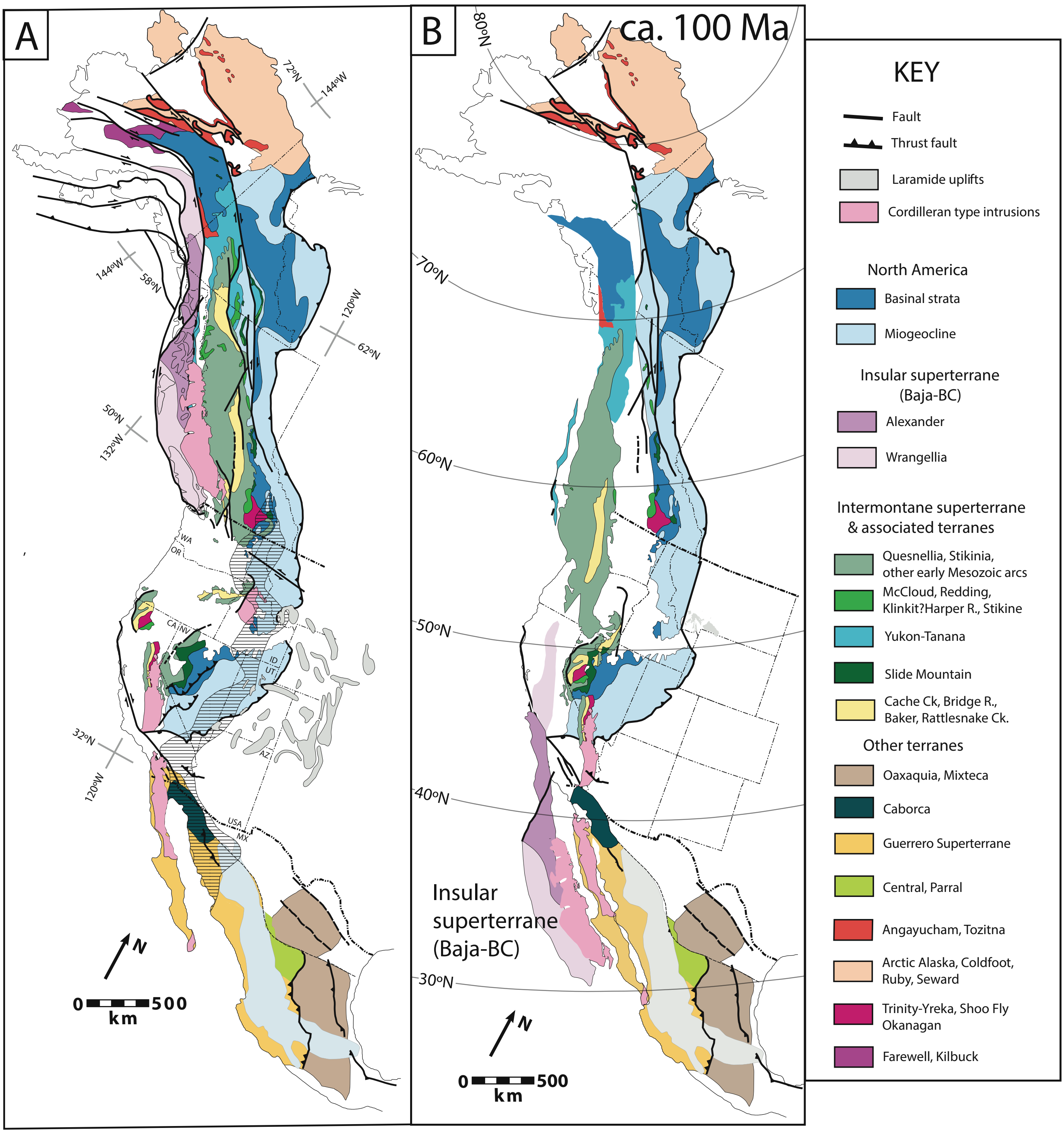

Figure 3. Terrane map for the western margin of North America: (A) now and (B) at 100 Ma. Mount Stuart batholith is located at the southern end of the Insular superterrane (pink and purple colors). BC—British Columbia; Ck—Creek; R—River; WA—Washington; OR—Oregon; CA—California; NV—Nevada; ID—Idaho; UT—Utah; AZ—Arizona; MX—Mexico.

essay, we address both how new evidence may or may not be noticed and, if noticed, how new evidence may be combined with other evidence from the world.

NOTICING

The dictionary of the American Psychological Association defines attention as "a state in which cognitive resources are focused on certain aspects of the environment rather than on others." The concept of attention is a recognition of the mind's limits to take in information as well as limits on the number of ideas it can hold and consider. If we do not attend to something, we literally do not see it or hear it, even when our eyes or ears are pointed right at the thing. The psychologists Robert Becklin and Ulric Neisser demonstrated this point by having participants monitor simple events, such as the ball passes during a basketball game (Neisser and Becklen, 1975). This was no ordinary game because, once the action started, a person in a gorilla suit walked among the players. Most participants did not report anything out of the ordinary when asked if they noticed anything unusual. Experts faired only a little better, with more than 80% of radiologists failing to notice a gorilla appearing in a lung X-ray they were viewing for lung nodules (Drew et al., 2013). If you need a simple demonstration to convince yourself, try watching two movies at the same time or listening to two conversations at the same time. You can abstract information from one, but you must guess (by filling in) the contents of the other.

Our attention can be guided by our goals, but it is also guided unconsciously by the world. Some events in the world, such as objects moving, automatically draw attention. Automatic attention likely had some survival value for early humans, for whom motion in the world may have signaled the presence of a dangerous animal. Attention is also drawn by unexpected events. Surprises are cases where our mental model of the world failed, revealing itself to be incomplete because it did not accurately anticipate what would happen next, and therefore must require updating.

What we notice requires attention, and therefore we do not notice when we are not noticing. Stated another way, you cannot tell when you are ignoring something. Consider the case of drivers talking on a cell phone, even when they are not holding the phone. The research on accidents and driving simulators is clear; the level of reaction time impairment while using a cell phone is equivalent to driving with blood alcohol levels three times the legal limit in the UK. Why do most drivers feel they are OK on the phone? Because the mind does not notice the errors it was making, in the form of not attending to stop signs, red lights, and pedestrians. If you need additional convincing, watch the public safety message from Transport of London (2017).

How are traffic accidents similar to failures to notice paleomagnetic orientations? The human mind functions well when working with a single event stream, analogous to a single theory. If your theory is that the Mount Stuart batholith has not moved, then your observation-gathering goals will be structured by that theory, and thus attention will be paid to observations that are consistent with stasis. So, in the absence of the paleomagnetic data, orthogonal convergence might be seen as the simplest model for the tectonic development of western North America. Further, there is no strike-slip fault with that much documented offset. The apparent continuity of rocks in the North American Cordillera likely led to their being mentally grouped together (see discussion on lumping and splitting; Tikoff and Shipley, 2025) and thus hypothesizing that nothing had moved by significant amounts up or down the margin of North America.

Once multiple paleomagnetic studies were published, why did not people reevaluate their understanding? We offer four possibilities. One possibility is that the shallow inclination values were seen as consistent with a large-scale series of normal faults that modified the values to shallower angles from their original expected steep values for the region (e.g., Butler et al., 1989). If you want to understand this effect, consider a stack of books on your bookshelf when the bookend is released: If an oblique line were drawn on a page of every book (our analogy for a paleomagnetic vector), then that inclined line in space would become nearly horizontal as the books slumped next to each other nearly parallel to the shelf. This alternative interpretation is fair for paleomagnetic results from intrusive igneous rocks. However, this source of uncertainty in interpretation is absent in paleomagnetic data in which paleohorizontal is constrained by bedding in fine-grained sedimentary rocks (e.g., Wynne et al., 1995).

A second possibility is that the paleomagnetic data were relegated to the do-not-know-what-to-do-with-it mental folder. The problem is that the do-not-know-what-to-do-with-it mental folder tends to slide into the mental recycling bin. Which is unfortunate, because the do-not-know-what-to-do-with-it mental folder may contain noncompliant data or, alternatively stated, data with negative salience (Nelson et al., 2024; see upcoming essay #10 on Sage Hen flat, California). Unless used, or brought into focus by a reviewer, noncompliant data tend to be forgotten because they do not fit with the larger mental model of the region.

A third possibility is the nonvisual nature of paleomagnetic data. Paleomagnetic signals are not available to perception, as they literally cannot be seen. Most geologists are highly influenced by visual observation through both training and experience. Visual cues are powerful attractors to the geological mind. In contrast, non-perceptional data cannot as easily remind geologists to keep them in mind as they move toward being forgotten (see Shipley and Tikoff, 2025).

The fourth possibility is that the paleomagnetic data were being actively ignored. This issue was raised by the geologist Darrel Cowan (D. Cowan, 2024, pers. comm.): "I'm convinced that most geologists working on late Mesozoic and early Cenozoic California geology and tectonics concluded that none of the transport models added any insights to their understanding, so basically ignored them." This hypothesis reflects how any given model works better if a particular type of data is ignored. This approach, however, delays the necessary reckoning, by either adjusting the model in a way that it can accommodate the data or discarding the old model for a new one. As a historically relevant example, consider the way that geological data from the Southern Hemisphere supporting long-distance continental drift (e.g., du Toit and Reed, 1927) were ignored by much of the geological and geophysical community.

If expectations and attentional focus cause unexpected findings to be missed, how does progress occur? Surely writing a scientific paper requires utilizing single-minded focus. Coming across and noticing inconsistent data require less-goal-oriented exploration, in this case, reading papers that may not seem directly relevant to one's research program. Detection of conflicts between theory and inconsistent data can occur in the review process, when reviewers can advocate alternative theories. Working with multiple possible theories requires heterogeneity of papers read and data remembered. Thus, progress requires workflows for detecting inconsistent data and connecting them to theories.

INCORPORATING NEW EVIDENCE

Once one accepts the possibility that the Mount Stuart batholith has moved, why might some models have proposed paths shorter than the one suggested by the paleomagnetic data? If one charts a history of how far the Mount Stuart batholith has been proposed to have moved since ca. 100 Ma, one sees a distinct linear upward trend starting from zero. As tectonicists wrestled with the problem of aligning data to models, they proposed increasingly greater amounts of northward movement: none (Dickinson and Snyder, 1978) to 1000 km (Butler et al., 2001; Wyld et al., 2006) to 1600 km (Umhoefer and Blakey, 2006; Sauer et al., 2019). The slow acceptance of increasingly farther Insular superterrane movement likely reflects a desire to minimize the imagined distances traveled. It is also, however, evidence that people are reluctant to change their mental models. A critical reader might argue that in the absence of clear evidence for margin-parallel movement, such as a fault with a known offset, the simplest path is the shortest one. In effect, why propose anything more complicated than needed to explain the facts at hand? This idea, familiar to the practice of science, has been codified as "Occam's Razor." From Ptolemy to Ernst Mach, scientists and philosophers have argued that, "Entities must not be multiplied beyond necessity" (the actual words were Entia non sunt multiplicanda praeter necessitatem: Poncius, 1639).

Thus, one way to understand the slow evolution of the models is that Occam's razor acted as an intrinsic dampening force, only yielding as much movement as absolutely required by the data. A case in point was the estimate proposed by Wyld et al. (2006) of ~1000 km of offset of the Insular superterrane, which was the product of integration of all known fault offsets after 100 Ma in the Pacific Northwest of the United States and in the Canadian Cordillera. It is likely that unknown faults could have added kilometers of offset to the movement of the Insular superterrane, because all fault offsets are minimum estimates. That is, the study by Wyld et al. (2006) is the least-offset (most fixist) permissible model.

From the perspective of incomplete and uncertain knowledge, it is worth noting another application of simplicity in proposed paths between two points. In vision, when an object is shown at two locations in succession, the visual system fills in a path between the locations. This happens with movies, in which a series of static images are brought to movement by our visual system filling in the missing path. Notably, despite there being an infinite set of possible paths between two locations, we see only one, and that one is the shortest one. Tectonic motions are constrained by surrounding plates to move along a restricted set of paths, and some of those likely fit into the mind more easily than others (we will return to this in a future essay on the Falkland Islands).

The history of science is very clear on this point: It is hard to change a human (scientist's) mind. The question is: Why? Certainly, science is an inherently conservative enterprise in which new models have the burden of proof. That explanation, however, is insufficient for the rejection of the paleomagnetic data that are 50 years old and very consistent. We offer four possibilities. First, our mental models guide what we attend to, so that we may not notice inconsistent information. Further, even if we notice something is contradictory, we may "weigh" the consistent evidence higher than the inconsistent evidence. Second, we judge a mental model as right or wrong based on the ease of thinking it. A long-held and familiar model tends to feel correct and thus is unlikely to change. The third reason has to do with scientists' mental models of themselves. Everyone has a mental model of their mind, or a sense of self, known as an ego in psychology. If one's model of the mind is rational and competent, errors are inconsistent with that model. As described above, inconsistent data tend to be overlooked or ignored. Alternatively, one can adopt a model of the mind that embraces uncertainty and being the type of person who can be wrong. This approach allows mental models of the world to change.

The last possibility is that the complexity of Earth does not align well with the ways in which the mind constructs inferences from observations. There is general agreement that Earth is a complex system, so it should be expected that it does not always behave in simple ways. Simplicity is not, in itself, evidence for Earth processes. The title for this essay, "Beware Occam's Razor," is intended to convey the reasoning fallacy of calling on simple models to explain complex systems. One's perceptual and cognitive processes also follow the simplicity principle at the core of Occam's razor. This bias may be part of why minimal offsets—whether related to Cordilleran tectonics or continental drift—seem correct: It makes them easy to think and hard to see the alternatives. Thus, the appeal to simplicity reflects the way the mind works with incomplete data that impedes—for good and ill—changes to our minds.

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