Figure 1. Photograph of a channel caused by catastrophic flooding of Glacial Lake Missoula, Dry Falls, Washington. Photo by Tom Foster, provided by Nick Zentner.

Channeled Scablands, Northwest U.S., and Runnable Mental Models

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

Geology logline: *How a catastrophic series of floods were recognized by J Harlen Bretz and Joseph Pardee to have formed the Channeled Scablands of eastern Washington State, USA.*

Cognitive science logline: *Runnable mental models, mental simulations of geological processes applied to specific events, are used by many geologists in evaluating hypotheses.*

The Channeled Scablands of Washington State are well known in the geologic community for having been the source of a significant debate: What was the origin of a series of landforms that occur in eastern Washington, northern Idaho, and westernmost Montana? This debate was a familiar one to geologists. Did these features form through the types of surficial processes that are observed to be occurring today operating over a long time, or did they occur through a catastrophic event?

The community-accepted model in the 1920s and 1930s is that the Channeled Scablands occurred through typical fluvial erosion and hillslope movement, possibly enhanced by glacial melt, an idea that represented a deep commitment to uniformitarian processes. That is, whatever processes are active in forming a landscape at the present were likely the same ones that acted continuously in the past and occurred over long periods of time (e.g., Lyell, 1830). The analogy from the present to the past only works, however, if geological processes do not substantively change over time. Thus, many geologists were likely approaching this Channeled Scablands landscape from the viewpoint of uniformitarianism.

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

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The catastrophic model for channeled scablands is often associated with a single person—J Harlen Bretz. He proposed that the source of the Channeled Scablands was a cataclysmic outpouring of water that he named the Spokane Flood. Although Bretz originally proposed another source for the water, he came to accept one supplied by Joseph Pardee. Pardee worked for the U.S. Geological Survey, and he recognized that the outpouring resulted from the sudden (and repeated) demise of Glacial Lake Missoula (Pardee, 1942). Over two thousand cubic kilometers of water flowed over the landscape during the short outbursts, picking up and depositing material to form a variety of erosional and depositional landforms. These include rock basins (giant "potholes"), inner channels, subfluvial cataracts, and erosional grooves (Fig. 1; e.g., Baker, 1978). For those with a sense of the power needed to form these shapes, it is a landscape of awe: What else but a massive flood could have left these traces?

The debate ultimately resolved in favor of the catastrophic floods: At present, it is thought that there were close to 100 floods that ranged in duration and magnitude (O'Connor et al., 2020). When thinking about catastrophic events, the question often arises: "Why have geologists been so committed to uniformitarian thinking?" Here, we pick up that question by asking, "How did J Harlen Bretz and Joseph Pardee figure out the catastrophic floods?" The answer is: They could not rely on the existing concepts to explain their data. Consequently, they had to come up with a new hypothesis. Knowing that the hypothesis was viable required constructing a runnable mental model.

A mental model is constructed of mental representations of objects with their respective properties (e.g., Gentner and Stevens, 1983). We have added "runnable" to a foundational cognitive science concept of mental models to distinguish representations of something from a representation that can be tested by mentally simulating "what happens if." The "runnable" term indicates how a mind can evaluate a new hypothesis, by simulating the hypothesized events to "see" if the result resembles the observed state of the world. A runnable mental model has two key components consisting of objects (patterns) and events (processes). Moreover, runnable mental models can capture processes that are complex and occur over significant amounts of time.

To adequately capture the complexity of runnable mental models used in the geological sciences, we turn to the analogy of a theater production: Running a mental model is like a play. The objects are the actors and stage, and the events are the script (Tomkins, 1962; Schank, 1990). From a cognitive science perspective, actors and stage are two different things (Epstein et al., 2003). Actors are spatially localized things that have shape and boundaries; stages are the spatial relations between multiple objects. The script is an event, in which subevents play out (Cohn-Sheehy et al., 2022). We now watch the play of the catastrophic Spokane flood. The stage includes Glacial Lake Missoula, a retreating ice margin, and a landscape that has seen this all before. The actors are water, sediment, and bedrock. The script is fast and furious water movement over about a week, where the various actors have to respond to changed circumstances. In this analogy of a play, it is hopefully clear how a runnable mental model simulates how geologic processes transform landforms and/or the rock record over time.

How are runnable mental models of geological processes created? Generally, our memory of events is the foundation for mental animations. Memories can be abstracted from the details of each specific event to capture the regularities across events. These types of abstracted memories are sometimes referred to as schemas, in that they retain the schematic structure of an event without the details that vary from one occurrence to the next. Schemas are, essentially, aggregated memories. A schema allows the mind to think about an event as a single thing that has no clear objective beginning or end. Having developed an event schema, one can conceive of events that have never been encountered by applying the schema to new objects. For example, having learned a birthday party schema, a child may playfully stretch the schema to envision a party with animals as guests, who of course would be wearing party hats and eating cake to align with the birthday party schema. Schemas, similar to analogies, can be a cognitive engine for hypothesis generation.

HOW DOES THE MIND KEEP TRACK OF BOTH INDIVIDUAL EVENTS AND ALSO COMBINE ACROSS THEM TO EXTRACT CONSISTENT REGULARITIES AND PARTS THAT VARY?

Understanding how one creates schemas has been a challenge in cognitive science: How does the mind keep track of both individual events and also combine across them to extract consistent regularities and parts that vary? How are the variations across events separated from the consistent properties without decomposing the whole into every individual event? A relatively recent proposal by Jeff Zacks and colleagues (Cohn-Sheehy et al., 2022) is that the mind organizes memories using the overall structure of the large event schema and keeps track of where within the schema subevents may differ. For example, one has a general schema of birthdays, but also memories that some birthdays had games, but others did not, and many had candles, but the number varied. The same richness certainly applies to geologists thinking about processes (e.g., mountain building) with local variations (e.g., shaped by preexisting structures).

The objects and schema of our mental models may be formed from the memories of observed objects and events, but they need not be. Humans have the capacity for thinking about things that are other than reality, imagining and communicating *hypothetical counterfactuals*. These hypothetical counterfactuals allow us to assimilate objects and events we have not directly experienced. Rather, they can be provided by others who have seen them, inferred from indirect observation, or visualized with the application of technology that extends our senses. The schemas for these models come from another mind, not unlike the memories of models we build from reading fiction. The memories that form runnable models may be of directly experienced objects and events in the world or models of the world, or indirectly experienced objects and events, either from an external visualization or an internal mental

Figure 2. Photograph of West Bar on the Columbia River near Trinidad, Washington. The landforms are giant current ripple marks caused by catastrophic flooding. Photo by Tom Foster, provided by Nick Zentner.

simulation. A symbolic mind has the capacity to create powerful new ideas that can be shared to form the basis of runnable models in the community. This capacity is necessary for learning and practice in much of the geosciences because the important objects and events often cannot be directly seen, including those associated with catastrophic floods.

The concepts of erosion and deposition are, to a geologist, schemas. One can observe, in a typical river, how water erodes sand grains from one location and deposits them in another, thus forming ripples. A schema of erosion and deposition could be applied to a new situation. In the case of the Channeled Scablands, it needed to be applied to a place where there was a lot of water (and we mean a lot, i.e., over 25 cubic kilometers of water per hour) running over the landscape, picking up and depositing sediment as it flowed. Without the ability to apply these schemas and produce a runnable mental model, Bretz would never have invoked a Spokane Flood as a cause of the observed landforms.

Consider the utility of runnable models using the words of a geologist (V. Baker in a 2024 interview with N. Zentner, Ice Age Floods A–Z, Episode S, starting at 1:14:30). When Bretz was frustrated with colleagues about not accepting the catastrophic flood hypothesis, he would say that if he could just take them to the Wallula Gap overlook, they would accept the hypothesis. V. Baker describes the reaction of a geologist, who originally opposed the catastrophic flood hypothesis, at one of these overlooks in the Channeled Scablands: "Once he actually saw the relationships…there is no way that anything could happen but a catastrophic flood to make that landscape. It just screams at you if you look at it." Landscapes do not scream at nongeologists; the Channeled Scablands landscape just exists for most people who do not understand basic processes and patterns associated with sediment transport in water (e.g., people who do not have a schema). Figure 2 shows West Bar along the Columbia River, the location that to us most screams "catastrophic flood." Bretz was effectively saying that a geologist—given the right vantage point—would necessarily produce a runnable mental model that would require massive water volumes. In the case of the Channeled Scablands, that runnable model requires schemas of erosion and deposition. Without a perspective informed by memories of Earth processes, a person is just sightseeing. Explanation and acceptance of almost all process-based models in the geological sciences require some form of runnable mental model.

WITHOUT A PERSPECTIVE INFORMED BY MEMORIES OF EARTH PROCESSES, A PERSON IS JUST SIGHTSEEING.

The features of the Channeled Scablands landscape had the power to change minds on a wholesale level. In this sense, it is similar to Siccar Point, Scotland (e.g., Shipley and Tikoff, 2024b), insofar as the displayed geometry is sufficiently compelling to change one's worldview. If the landscape was so compelling, why did it take so long for the idea to emerge in the history of visits to this landscape? We speculate that the delay lay in the challenge of creating an internally consistent runnable mental model. Bretz and Pardee had to, singularly or jointly, connect the ideas of sediment deposition and erosion in typical river systems to the movement of house-sized rocks during catastrophic floods.

Once Bretz and Pardee began offering their account of what happened, others could attempt to run a mental model to see if they came to the same conclusions. Steven J. Gould, in his book *The Panda's Thumb*, reports that participants of a geological field trip to the Channeled Scablands run in 1965 sent Harlen Bretz a note that said, "We are all catastrophists now" (Gould, 1980, p. 202). The participants on the 1965 field trip were effectively saying that their runnable mental models confirmed that the Spokane floods could (and did) yield these landforms. Once an individual's mental connections have been stretched to align the analogy from familiar processes to the hypothesized ones, it becomes easier for subsequent geologists, who are challenged only to recognize the appropriateness of the analogy. Once a community begins to agree on the explanation for an observation, in this case the landforms of the Channeled Scablands, then not everyone needs to run the mental model to check the interpretation. In both cases, mental resources are conserved, as there is no necessity to pause to run a model in order to check the validity of the reasoning.

Often, testing the details of the explanation offered by a runnable mental model requires more precision or capacity than the mind can provide. Scientists can turn to a different type of runnable model, perhaps a computational model or a physical model (e.g., a stream table). In developing these physical and computational models, however, scientists likely begin with a runnable mental model. Scientists and educators often avail themselves of physical models to bring Earth-scale processes into the classroom and laboratory, in order to observe them and develop or refine a runnable mental model.

The importance of runnable mental models is also highlighted by the centrality of illustrations in the geological literature. It is typical for a scientific paper to contain a final figure that provides a time-progressive view of a particular geological process. Within this figure, there are the hypothesized relevant objects and the hypothesized manner in which they change over time. It is left to the reader to construct the mental model and run it. Animations can reduce the burden of mental animation and also provide the content for a memory that can be used to extract an event schema. The well-known visualizations (https://animations.geol.ucsb.edu/index.htm) of Tanya Atwater for the Cenozoic tectonic development of California (following Atwater, 1970) reflect how animations can support scientists' minds.

How do all of these pieces fit with the concept of multiple working hypotheses (discussed in Shipley and Tikoff, 2024a)? It is likely that any spatial hypothesis was evaluated with a runnable mental model. When employing multiple working hypotheses, each hypothesis is associated with a separate runnable mental model. Prior to 1920, there was a runnable mental model for normal fluvial processes to shape the Channeled Scablands; Bretz provided a description of a new runnable mental model that required a catastrophic flood. Other scientists needed to produce their own runnable mental model of the catastrophic flood upon encountering Bretz's account. Then, they could compare the catastrophic flood hypothesis to the previously existing hypothesis, to see how well each runnable mental model accounted for the observed landforms in the Channeled Scablands.

Moreover, runnable mental models can be updated, for example, when Bretz accepted that there was more than a single Spokane flood. Each mental model is supported by some combination of schemas (aggregated memories from the real world or theoretical approaches) and analogies. Both schemas and analogies are used to evaluate both the observations (patterns) and the potential explanations for the observations (processes). The conviction of the rightness of a mental model is correlated to the rightness of the schema or the analogy.

To emphasize these points, we return to the theater analogy used above. Two unresolved alternative working hypotheses (e.g., normal fluvial processes vs. catastrophic flooding) are two different scripts. Needless to say, character (e.g., landform) development and interaction between the characters (e.g., water, sediments, erosion) occur differently in the different plays. The preferred play has a more plausible explanation for the position (and state of being) of the players and stage elements at the end of the play; the preferred runnable mental model is the one that better explains the features observed in the world.

We end by noting that the mind leaves traces of its action in the history of science. That is, scientific discoveries are necessarily historical. In the era of strict uniformitarianism, in which all runnable mental models were necessarily constructed from current events, Bretz made a notable achievement to mentally simulate (e.g., create a runnable mental model of) a catastrophic flood. Further, Bretz and Pardee facilitated acceptance of the potential role of other catastrophic events in Earth's history—one example being the acceptance of a meteorite impact as an explanation for the extinction event at the end of the Cretaceous. However, historians of science have noted that transitions in scientific consensus from one model to another do not occur in an instant. The slow pace of change reflects multiple aspects of the nature of human minds in scientific communities, including the challenging effort of building runnable mental models.

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REFERENCES CITED

*** denotes suggested further reading**

Atwater, T., 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geological Society of America Bulletin, v. 81, p. 3513–3535, https://doi.org/10.1130/0016-7606(1970)81[3513:IOPTFT]2.0.CO;2.

Baker, V.R., 1978, Large-scale erosional and depositional features of the Channeled Scabland, *in* Baker, V.R., and Nummedal, D., eds., The Channeled Scabland: Washington, D.C., National Aeronautics and Space Administration Planetary Geology Program, p. 81–115.

*Baker, V.R., 2008, The Spokane Flood debates: Historical background and philosophical perspective, *in* Grapes, R., Oldroyd, D., and Grigelis, A., eds., History of Geomorphology and Quaternary Geology: Geological Society, London, Special Publication 301, p. 33–50, https://doi.org/10.1144/SP301.3.

*Baker, V.R., 2023, Hypothesizing Mega-Flooding 100 Years Ago: J Harlen Bretz and the Cataclysmic Late Pleistocene Mega-Flooding Origin of the Channeled Scabland: International Commission on the History of Geological Sciences (INHIGEO) Website Anniversaries in Geo-History: International Union of Geological Sciences (IUGS) E-Bulletin 196, April 2023, 4 p., https://www.inhigeo.com/anniversaries.html.

Cohn-Sheehy, B.I., Delarazan, A.I., Crivelli-Decker, J.E., Reagh, Z.M., Mundada, N.S., Yonelinas, A.P., Zacks, J.M., and Ranganath, C., 2022, Narratives bridge the divide between distant events in episodic memory: Memory & Cognition, v. 50, p. 478–494, https://doi.org/10.3758/s13421-021-01178-x.

Epstein, R., Graham, K.S., and Downing, P.E., 2003, Viewpoint-specific scene representations in human parahippocampal cortex: Neuron, v. 37, p. 865–876, https://doi.org/10.1016/S0896-6273(03)00117-X.

Gentner, D., and Stevens, A., 1983, Mental Models: Hillsdale, New Jersey, Lawrence Erlbaum Associates, 352 p., https://doi.org/10.4324/9781315802725.

Gould, S.J., 1980, The Panda's Thumb: More Reflections in Natural History: New York, W.W. Norton and Company, 343 p.

Lyell, C., 1830, Principles of Geology: London, John Murray, 528 p.

O'Connor, J.E., Baker, V.R., Waitt, R.B., Smith, L.R., Cannon, C.M., George, D.L., and Denlinger, R.P., 2020, The Missoula and Bonneville floods—A review of ice-age megafloods in the Columbia River basin: Earth-Science Reviews, v. 208, https://doi.org/10.1016/j.earscirev.2020.103181.

Pardee, J.T., 1942, Unusual currents in Glacial Lake Missoula, Montana: Geological Society of America Bulletin, v. 53, p. 1569–1600, https://doi.org/10.1130/GSAB-53-1569.

Shipley, T.F., and Tikoff, B., 2024a, Lake Bonneville shorelines, Utah, and the role of the mind in the practice of geology: GSA Today, v. 34, no. 9, p. 26-29. https://doi.org/10.1130/GSATG101GM.1.

Shipley, T.F., and Tikoff, B., 2024b, Siccar Point, Scotland, and the role of mental models: GSA Today, v. 34, no. 11, p. 36–40. https://doi.org/10.1130/GSATG103GM.1.

Schank, R.C., 1990, Dynamic Memory: A Theory of Reminding and Learning in Computers and People: Cambridge, UK, Cambridge University Press, 272 p.

Tomkins, S.S., 1962, Affect, Imagery, Consciousness: Volume I, The Positive Affects: New York, Springer Publishing Company, 588 p.

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