Megaflood incision of the Grand Coulee, Channeled Scablands of eastern Washington

Introduction: The Channeled Scablands is a striking landscape that captures a remarkable moment in Earth's history when enormous quantities of glacial meltwater poured across the region. These glacial floods carved deep canyons, referred to as coulees, into basalt bedrock within the otherwise subdued topography of the Columbia Plateau. The most impressive of these, Grand Coulee, is the largest flood-carved canyon on Earth at 200 m deep and nearly 100 km long. Once thought to be glacially-carved, the recognition that Grand Coulee formed due to the upstream erosion of what must have been one of the largest known waterfalls on Earth [1] brought about a revolution in geological thinking by proposing that catastrophic events—rather than slow, uniformitarian processes—can dominate the evolution of Earth's surface. Though a catastrophic flood origin of the Grand Coulee is now accepted, many questions still remain regarding the size and number of floods that carved it [1]. **I propose to use cosmogenic nuclide exposure dating to measure the retreat rate of the Grand Coulee waterfall, and to combine field evidence of sediment transport with numerical flood models to constrain the discharge of the outburst floods that carved Grand Coulee.** This approach will address longstanding questions concerning the role of catastrophic events in shaping Earth's surface, make inferences about the hydrology of early Mars (which contains canyons similar in form to Grand Coulee). Additionally, my project will highlight the process of scientific discovery to the public via Grand Coulee's status as a National Natural Landmark and a key feature on the Ice Age Floods National Geologic Trail.

Questions: The project will address two fundamental questions regarding the role of catastrophic floods in eroding Grand Coulee. **Question 1**: Did Grand Coulee form geologically instantaneously during a single flood, or by flooding throughout the last ice age or even earlier glaciations? **Question 2**: What was the magnitude of the flood(s) that carved Grand Coulee and how did flood volume change as the landscape evolved via canyon incision?

Research Plan: I propose to integrate field, geochronological, and numerical modeling methods to unravel the geomorphic history of the Upper Grand Coulee, under the advisement of Dr. Isaac Larsen at the University of Massachusetts. **Question 1** will be addressed using primarily geochronological methods. Determining exposure ages along the length of the canyon rim of Upper Grand Coulee will constrain the location of the waterfall as it retreated upstream. I have collected samples of fluvially-transported granite boulders and flood-carved basalt surfaces from the study area for exposure dating [2]. Granites will be processed for ^{10}Be dating in the UMass Cosmogenic Nuclide Laboratory, and basalts will be dated using ^{3}He in labs of collaborators. If the waterfall experienced gradual retreat in response to multiple floods, we expect to find a decrease in exposure ages of flooded basalt surfaces with distance upstream. Alternatively, similar ages of flooded basalt along the rim of Upper Grand Coulee would support a more rapid landscape response driven by a single flood or several floods occurring in rapid succession. **Question 2** will be addressed by field and numerical methods. I will use a 2D, depth-averaged shallow water hydraulic script to numerically simulate floods of varying magnitudes in Grand Coulee, with discharges ranging from the minimum required to barely inundate the canyon floor, to that which fills the canyon to the brim. This script will be run on the Massachusetts Green High Performance Computing Center, a supercomputer accessible from UMass. Field measurements will be used to determine which of these modeled discharges is most consistent with the geochronological evidence. I measured boulder dimensions on depositional bars in Grand Coulee, and will use these to constrain the threshold bed stresses and flood discharges required for their transport. Similarly, field measurements of basalt columns and physics-based estimates of bed stresses required to erode the bedrock channel floor will be used to constrain the canyon-forming discharge [3]. These discharge constraints will allow me to assess whether Grand Coulee was filled to the brim by floods, as is often assumed in flood reconstructions, or whether smaller, but still exceptional, floods carved the canyon. Moreover, the geochronology will allow me to independently assess the predictions of my modeling, as the dating will indicate whether the appropriate paradigm of incision requires huge, brim-full floods or smaller floods.

Intellectual Merit: The evidence to support extensive flooding in the Channeled Scablands is overwhelming, but it remains a challenge to quantitatively constrain the pace and timing of the evolution of the bedrock landscape and the coevolution of flooding and canyon incision [3]. Our understanding and interpretation of the roles that floods of varying magnitudes may have played in generating the topography of the Channeled Scablands therefore remains far from complete. By addressing the magnitude of the floods that carved Grand Coulee, my work will address long-standing questions regarding the balance between catastrophic and gradual processes in shaping topography. There is great value in constraining the discharge of megafloods: large freshwater releases can alter ocean circulation and trigger abrupt climate change [4], so understanding the magnitude of paleo-floods is key to understanding Earth's past climate and sensitivity for future climate change, given current ice melting in polar regions. Additionally, understanding the processes and formation rates of Grand Coulee can yield insight into the evolution of the much larger Martian Outflow Channels and contribute to a clearer picture of the volume of water that flowed on the surface of early Mars, where direct dating is not yet possible.

Broader Impacts: The story of the megafloods is exciting, coherent, and illustrative of the nature of scientific research, and outreach on this topic can motivate the next generation of scientists. In fact, watching a documentary on the Channeled Scablands played a major role in my own decision to pursue graduate research. Outreach will therefore be a significant broader impact of this work. I participate in UMass' Graduate Women In STEM's Science Café, and already have multiple Channeled Scablands presentations scheduled at a local middle school, through which I hope to ignite interest in science and make research relatable. I will also work with Eureka!, a branch of Girls, Inc., which runs summer programs at UMass for pre-college girls from an underserved community. I will play a leading role in developing a series of local discovery-based field trips to introduce girls to earth science, which is largely absent in the standardized state curriculum. Floods from ice and landslide dam failures are hazards worldwide, and the quantitative methods for estimating flood discharge developed in my work can be directly transferred to smaller floods, and thereby used to assess geohazards using paleoflood evidence and to predict risks from future flooding scenarios. As the usefulness of scientific research is limited until it is communicated to policymakers and members of the public, I will post project updates to my field blog to convey the research process, discuss my findings, and provide a personal perspective of geoscience. I also intend to collaborate with other researchers to develop a field trip to the Scablands at a national conference to showcase current research on the megafloods, and will work with state parks in the Grand Coulee area to develop interpretive displays to communicate the story of the Scablands' dynamic past to the public.

References [1] Bretz, J. 1932. *American Geog. Soc.* 15. **[2]** Lal, D. 1991. *Earth and Plan. Sci. Letters.* 104, 424-439. **[3]** Larsen, I. and Lamb, M. 2016. *Nature.* 538, 229-232. **[4]** Barber, D.C., et al. 1999. *Nature.* 400, 344-348.