Research Summary:

The Yellowstone hotspot produces thermal, magmatic, and topographic features that have been progressively uplifting and then subsiding a path through the Rocky Mountains over the past 17 million years. Magmatism and ground deformation are attributed to a mantle plume currently reaching the crust under the northwest corner of Wyoming (Fig. 1). Given that Yellowstone is one of the most conspicuous and accessible continental hotspots on Earth, it presents an excellent research opportunity. The eastern leading edge of the hotspot is hypothesized to have a gradient of differential uplift, with peak uplift rates of 0.1 – 0.4 mm/yr along the Yellowstone Crescent of High Terrain (YCHT) [1, 2]. These broad estimates are based on geoid anomalies, long-wavelength topography, and geomorphic observations, but have not been verified empirically. We generally know little about the Quaternary-timescale deformation pertinent to the geodynamics of hotspots.

Along with regional uplift, late-Cenozoic climate trends may have also contributed to increasing river erosion in the Rocky Mountain region. Global cooling can drive incision through increased glacial and snowmelt driving more variable and competent hydrologic regimes [e.g. 4, 5, 6]. Studies have identified significant late-Cenozoic erosion throughout the Bighorn Basin [7, 8], with faster erosion rates from 0.6 Ma to present [9], but these incision rates still need to be explained. Previous work in the region has focused on tectonic drivers of erosion [e.g. 10, 11] and generally lacks the geochronology to distinguish the roles that uplift and Quaternary climate each play. A goal of my research is to address this research need and determine to what degree Shoshone River incision has been driven by late-Cenozoic hotspot uplift versus climate change.

The eastward-draining Shoshone River provides an optimal data transect to quantify uplift and tilting rates interpreted from the terrace record. The Shoshone drainage’s relatively modest glacial extent, especially along the North Fork (Fig. 2), provides a long fluvial transect along which to isolate tectonic and climate impacts. I will test the hypothesis of previous workers [1, 2, 3] that Shoshone River terraces converge downstream due to differential uplift along the YCHT or alternatively, that the pattern indicates climate is a major driver. The design of this research is to use luminescence dating of terrace deposits and field correlation to document incision patterns and rates so conceptual models of deformation and drivers of incision can be tested (Fig. 3).

Research Objectives and Methodology:

1. **Document spatial patterns of correlated Shoshone River terraces in longitudinal-profile context.** J. Hoover Mackin’s classical work on the Shoshone terraces east of Cody recorded an apparent pattern of downstream convergence across the Bighorn Basin [3]. However, the upper reaches of the Shoshone are a missing component of the terrace dataset representing the upper half of the drainage system. We expect the terrace patterns upstream of Cody will help distinguish between two endmember predictions for a hotspot-uplift or climate-driven scenario (Fig. 3). Terraces converging downstream would indicate tectonic uplift in the headwaters, while terraces increasing in concavity over time would indicate climate-induced changes to the flow regime [4].
I plan to build upon previous mapping by adding new data upstream of Cody, utilizing aerial imagery and Digital Elevation Models (DEMs) iteratively with field observations. Elevations of deposits and landforms at select transects will be obtained from GPS surveying in the field.

2. **Luminescence date 12 samples from terrace deposits.** Despite the previous work on these terraces [2, 3], there are no numerical ages available to test what Mackin and others have proposed. During a field visit in September, I collected three samples, two along the upper South Fork and one in the town of Cody. I anticipate collecting four additional samples downstream of Cody to verify ages of previously mapped terraces and determine incision rates through time. The remaining five samples will be collected along the North and South Forks to determine how terraces there correlate with those downstream of Cody. In the North Fork, I’ve identified one terrace exposure to be sampled and will focus the rest of my search in the Wapiti Valley area upstream of Buffalo Bill Reservoir (Fig. 2).

I have training and access to USU’s Luminescence Lab to complete sample analysis. This chronology, combined with the results of Objective 1, will enable calculation of river incision rates across the long profile and through time. If there indeed is a signature of tectonic tilting in the terrace profiles, calculation of incision rates will provide quantitative constraints of deformation.

3. **Conduct terrain analysis using MATLAB’s TopoToolbox [12] and the Topographic Analysis Kit (TAK) [13].** I will produce maps and long-profile analysis of normalized channel steepness ($k_{sn}$) and chi values ($\chi$), which are steepness indices that have been shown to be sensitive to tectonic drivers [14, 15, 16]. They are derived from Flint’s stream power erosion law [17] that relates channel slope to drainage area. My maps and long-profile plots will help indicate whether the upper drainages of the Shoshone River are being differentially uplifted and tilted by the Yellowstone hotspot. This component of my M.S. research is not included in the scope of this funding request.

**Significance:**

In addition to better understanding the geodynamic system and the role of climate in river erosion, identifying the history and rates of deformation can help with understanding regional geologic hazards. With this research, I aim to quantify uplift rates on the leading edge of the hotspot margin. This will better constrain crustal movements and increase our understanding of how the earth’s surface is responding to this mantle plume. Confirming the rate at which the dynamic topography is changing provides context for Yellowstone hotspot magmatism and seismicity hazards and helps more confidently predict their future trajectory.
**Budget and Budget Justification:**

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- Two extended field visits are proposed for Summer 2024 to obtain terrace luminescence samples and map terraces. This includes travel from Logan, UT to Cody, WY and travel around field sites (two 1,050 mile trips at the Utah State University (USU) Geoscience department vehicle mileage rate of $0.75/mile for a total of $1,575); the USU per diem rate (ten full days at $57/day and four travel days at $42.75/day for a total of $741); and camping fees at Buffalo Bill State Park (12 nights at $31.98/night for a total of $383.76).
- Luminescence samples will be collected and analyzed to provide terrace ages. I will process my samples at USU’s Luminescence Lab at a discounted internal-student rate (12 samples at $500/sample for a total of $6,000).

I currently have research-assistantship funding for support during this project, but that funding does not include field or analytical expenses. I am relying on this RMS-SEPM scholarship and other student grant opportunities to support the items listed above in my budget.
Figure 3: Conceptual diagram illustrating the two endmember hypotheses for drivers of river incision, along with their characteristic erosion patterns over time and longitudinal profile. The upper diagram shows the anticipated terrace pattern given uplift in the headwaters, and the lower diagram shows the expected terrace pattern with erosion due to climate fluctuations.
References:


