Sources of Supraglacial Debris on Emmons Glacier, Mount Rainier, WA

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Abstract

Debris covering glacier ice can have a significant impact on surface mass balance. Understanding the regional sources of debris, especially from any rockfall and rock avalanches, as well as understanding the local character of the debris cover, are necessary in order to understand patterns of glacier melt, retreat, and preservation. We use satellite imagery and field measurements of clast size and angularity to help define and describe debris units on Emmons Glacier on Mount Rainier, WA. Emmons Glacier is the largest glacier by area on Mount Rainier, with a thick and extensive debris cover over the lower glacier that may include contributions from a 1963 rockfall off Little Tahoma Peak, which at the time covered most of the lower glacier with debris. Using satellite imagery we identified seven different supraglacial sediment units using color and texture differences that are visible at the scale of meters to tens of meters. Field measurements of clast angularity and size were collected at 51 sample sites across the debris cover between 2016 and 2021. These field data were used to test the remotely sensed debris-unit boundaries, and to evaluate the sources of the debris within supraglacial sediment units. Sediment units closer to the glacier margins are more angular, more weathered and include a higher proportion of fine-grained sediment than units located closer to the glacier centerline, suggesting deposition of rockfall on the glacier surface; past measurements of glacier surface velocities suggest that ice beneath these units, which make up ~ 60% of the debris cover by area, flows very slowly if at all. Supraglacial sediment in the center of the glacier is less weathered, includes less fine-grained material, and likely originates from glacial erosion and transport of bedrock material that is ablating out at the surface. Our work suggests ongoing glacier flow and delivery of sediment in the central portions of the glacier, but most of the debris cover across the lower glacier is dominated by highly weathered, rockfall-derived debris that shows little indication of continued delivery of supraglacial sediment by glacier flow.

Introduction

- Studying debris character and debris sources is important because the thickness of debris cover can impact ablation rate by insulating the ice, or, in areas of very thin debris where heat can transfer through to the ice, decreasing the albedo of the surface and increasing melting (e.g., Østrem, 1959; Nicholson & Benn, 2006; Anderson & Anderson, 2018).
- Studying debris sources, especially from rockfall and avalanches, helps us understand how portions of the glacier may quickly become insulated from melt, and how that impacts glacier evolution.
- In this work we apply the knowledge that clasts transported supraglacially tend to be more angular than those transported subglacially (Hambrey & Ehrmann, 2004).
- Most literature indicates that basally transported debris will have a higher concentration of silt and clay, but there's significant evidence that weathering of rockfall can also cause this silt and clay on some glaciers (Owen et. al., 2003).

Study Area

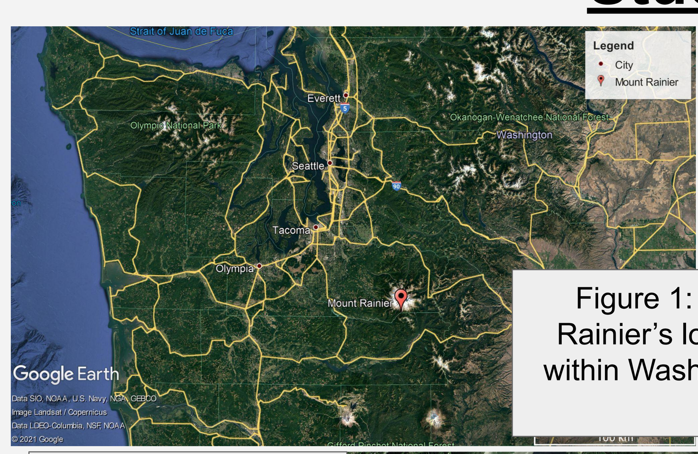


Figure 1: Mount Rainier's location within Washington State.

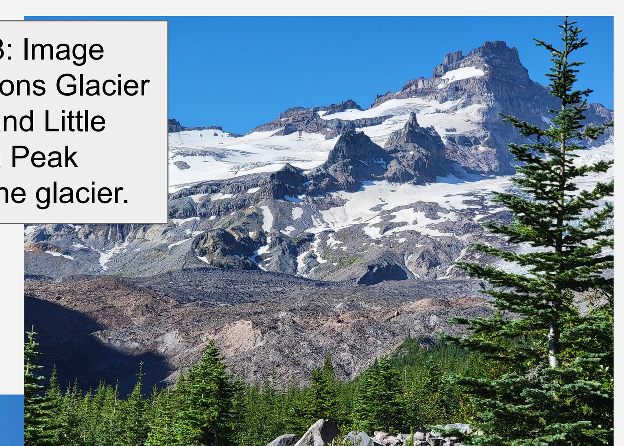


Figure 3: Image of Emmons Glacier debris and Little Tahoma Peak above the glacier.

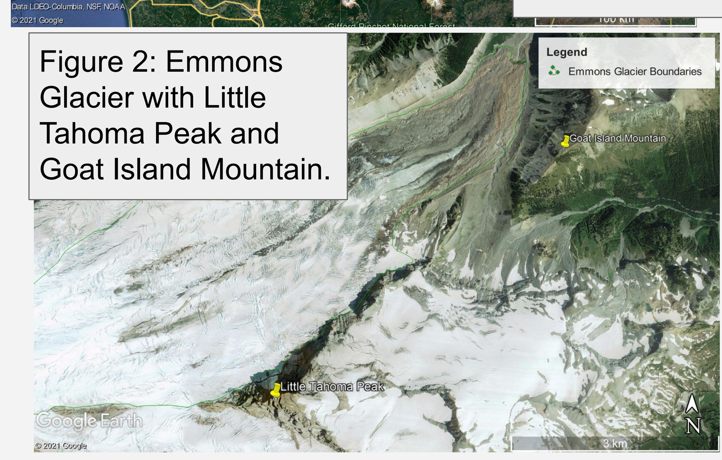


Figure 2: Emmons Glacier with Little Tahoma Peak and Goat Island Mountain.

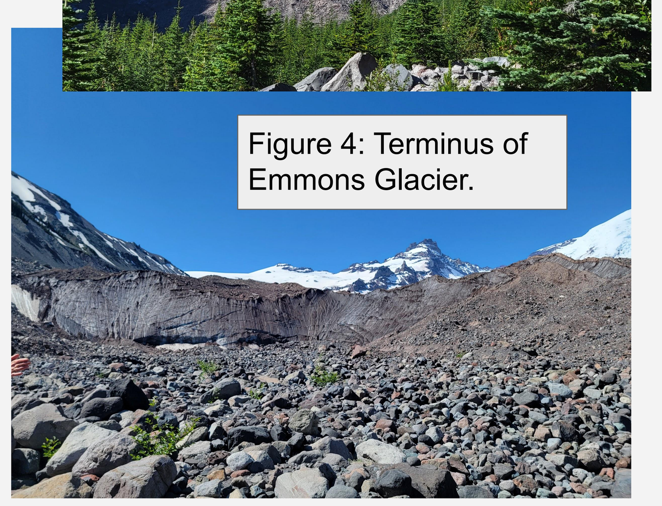


Figure 4: Terminus of Emmons Glacier.

- Mt. Rainier, the tallest peak in the Cascade Range, is an active volcano located in Washington State (Figure 1). It has 28 named glaciers and large snowfields (Sisson et al., 2011).
- Emmons Glacier (Figures 2, 3, 4) is the largest on Mt. Rainier, and one of two that gained ice volume between 1970-2007/2008 (Sisson et al., 2011).
- In 1963, a rockfall occurred off Little Tahoma Peak (Figure 3), landing on Emmons and causing several avalanches, covering the glacier with debris (Crandell & Fahnestock, 1968).

Methods

- Using satellite imagery, debris units on the glacier were mapped based on visible color and texture differences.
- Clasts for data collection were selected by imposing a predetermined spacing method in the field, including crosshairs (Figure 5) and grids in different field seasons.
- The crosshairs method was set up as seen in Figure 5, with data collected at each point where lines intersect (at the center and 1 m and 2 m away in each cardinal direction.
- For each clast, angularity, using the Powers Roundness Scale (Powers, 1953) and clast size were recorded (Figure 6).
- If, at a data collection point, the debris was fine-grained, a 1 cup sample of that debris was taken instead of clast measurements.
- In the lab, the moisture content of the samples was determined by drying and weighing them.
- Samples were sieved using geologic sieves.
- Unit averages were found for the angularity on the Powers scale, a-axis size, moisture content, and the % of sediment from the samples that was <63µm, or smaller than sand (Wentworth 1922).

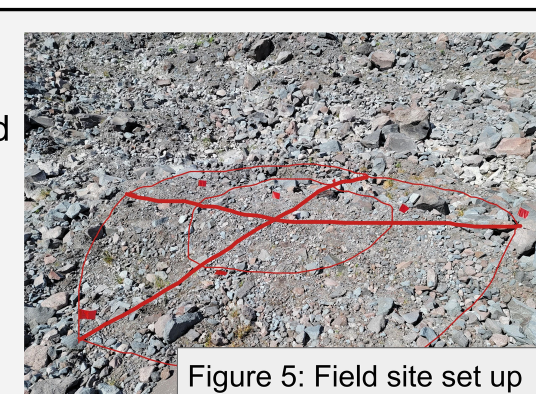


Figure 5: Field site set up in crosshairs pattern

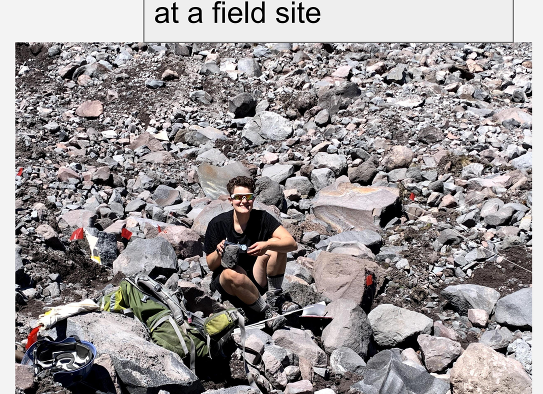


Figure 6: Collecting data at a field site

Results

Seven units (Figure 7) were defined based on Google Earth satellite imagery, focusing on color and texture differences. Between 2016-2021, 51 sites were studied on the glacier surface. Data from all the sites within each unit were compiled and averaged, then used to characterize and interpret for each unit.

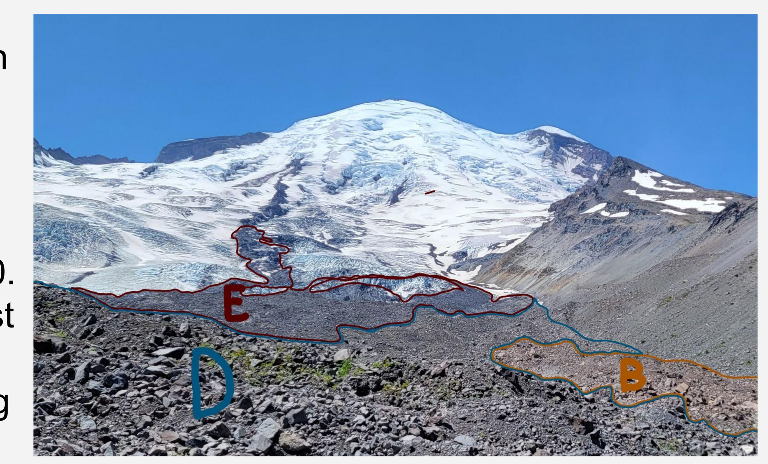


Figure 9: Units B, D, and E, looking southwest towards the summit of Mt. Rainier. On the right side of the image is the lateral moraine that runs along the glacier's north side.

Units A, B, D, F, and G are on the margins of the glacier. These units all show signs of weathering, and have stayed stagnant in Google Earth timelapse imagery since 1980.

- Units A and B are the most angular units, each with very angular clasts making up just under 15% of the total (Figure 8). Unit B showed much more color from oxidation that Unit A, with approximately the same amount of fine-grained sediment in both units.
- Unit D (Figure 9), Unit F, and Unit G are far less angular than other units. Moraines next to these units are situated more directly above them than in other units, where a gully separates the moraine from the glacier.
- Unit F has the highest percentage of fine sediments (Figure 10), followed by Unit G. Both of these units have significantly more fine sediments than Units A and B.

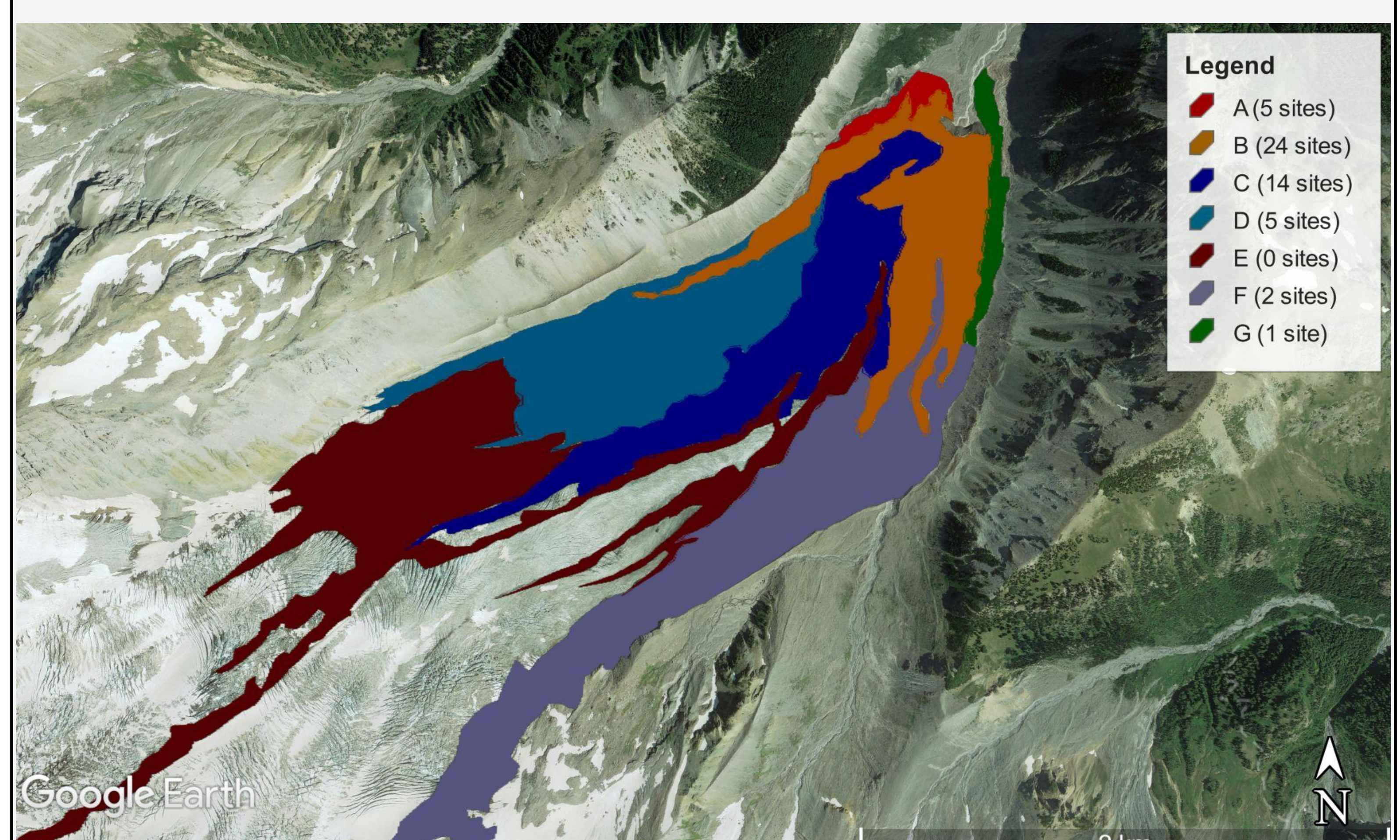


Figure 7: Unit map of debris on Emmons Glacier

Units C and E are in the central region of the glacier that is more dynamic than the marginal units, which in some cases may be stagnated. Ice flow continues to move ice and expose clean ice in the central region up to the boundary of Unit E.

- All information on Unit E is from satellite imagery and distant field observations, as no study sites were established in the unit due to the difficulty and lack of safety accessing it in the field.
- Unit C (Figure 11) debris is more angular than debris in units D, F, and G, but less angular than in units A and B (Figure 8).
- Unit C has less fine-grained sediment than any other studied unit (Figure 10).

Figure 11: The boundaries between Units B, C, and E, looking east across the glacier.

Results

Figure 8: Note that as there were no study sites in Unit E, there is no data for it.

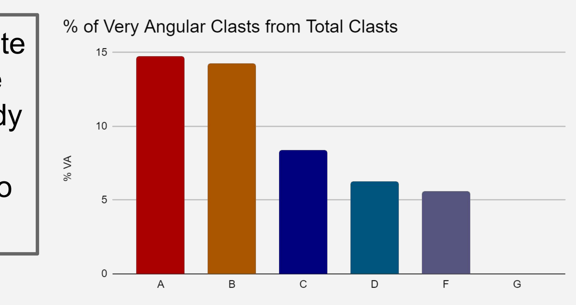
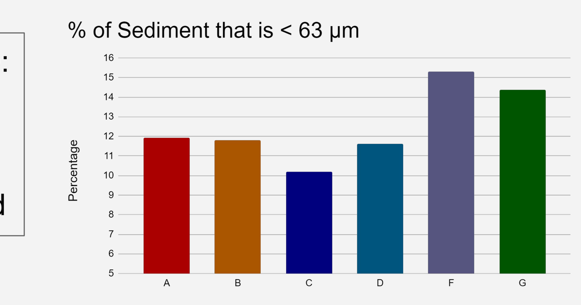


Figure 10: % of sediment smaller than sand



Discussion

- Mid-glacier units, (C and E) are likely a product of bedrock erosion and subglacial/englacial transport. Unit E comes directly from the bedrock outcrops that can be seen above it, while Unit C is transported further.
  - Allstadt et. al. (2015) found that the interior of Emmons Glacier (Units C and E) has a much higher velocity than the margins of the glacier, using snapshot measurements of ice-surface velocity in a given year. Satellite imagery of the glacier surface over the past 40 years also indicates that the central region is still flowing.
- Marginal units (A, B, D, F, and G) appear to mostly be debris from rockfall. A and B have the high angularity expected in a rockfall unit. Units D, F, and G may have rocks that fell onto the glacier from moraines, which would account for their lower angularity.
  - These marginal units displayed clear signs of weathering, including color from oxidation (particularly noticeable in Unit B), and clasts that had crumbled in place from freeze-thaw processes. This weathering resulted in the higher percentage of finer sediments <63 µm found in these units, which is broadly consistent with the pattern explained by Owen et. al. (2003), where glaciers with large permanent debris cover may have more fine-grained sediment due to weathering than fine sediments from basal transport.
- Sources of uncertainty in our interpretations include:
  - Lack of quantitative or conclusive field data on weathering.
  - Bedrock debris isn't transported englacially or subglacially for a long distance, making its characteristics less distinctive.
  - Limited sample collection sites in some units mean that it is not possible to generalize results across the area of that unit.
- We did not find conclusive evidence of rockfall from the 1963 rockfall detailed by Crandell and Fahnestock (1965) on the glacier, but it is very likely that Unit A and Unit B consist of debris from it.
- Moore (2018) details the importance of debris cover for ablation control. It is likely that rockfalls from nearly 60 years ago are still impacting Emmons Glacier's ablation rates. This is likely a reason for the lower ablation rates experienced by Emmons Glacier as compared to other glaciers on Mount Rainier.

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