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. Debris insulates the ice, decreasing melting, or, in areas of very thin debris where heat can transfer through to the ice, decreases the albedo of the surface and increases 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.

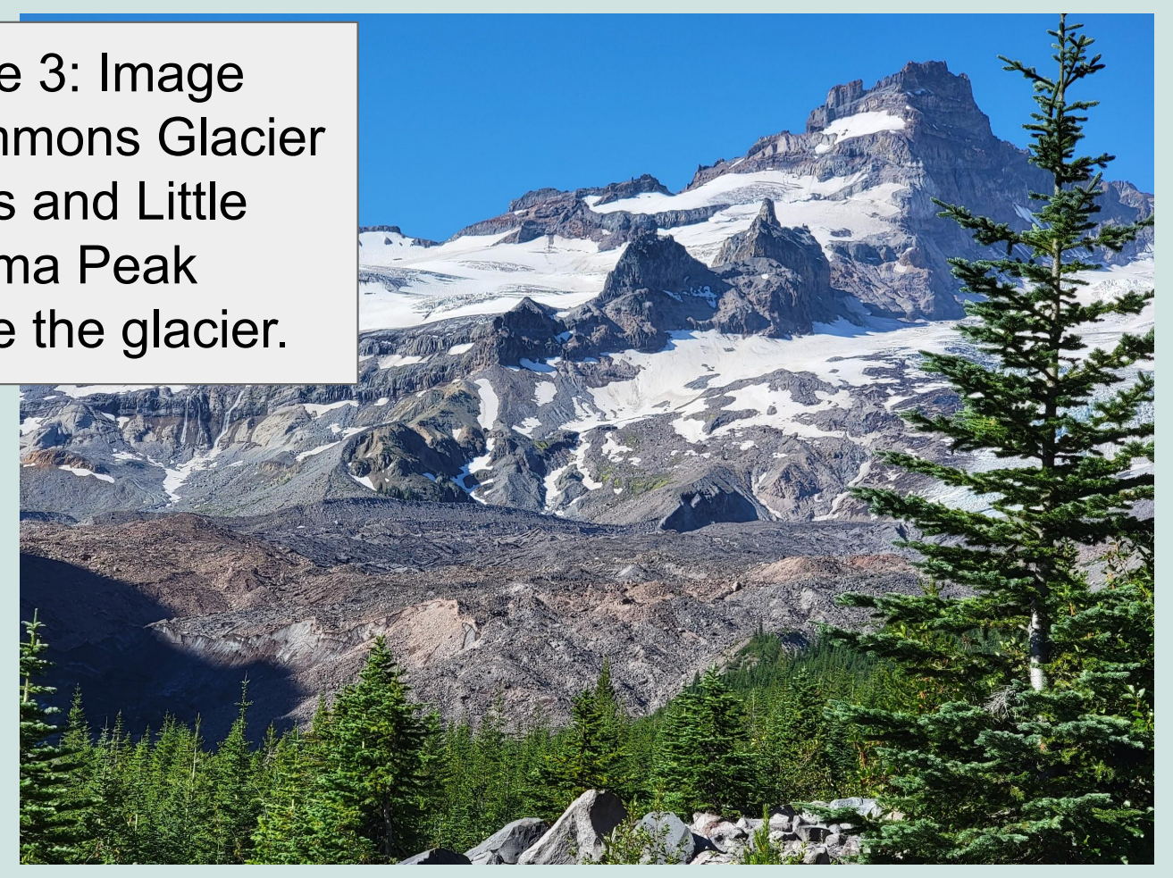

Figure 3: Image of Emmons Glacier debris and Little Tahoma Peak above the glacier.

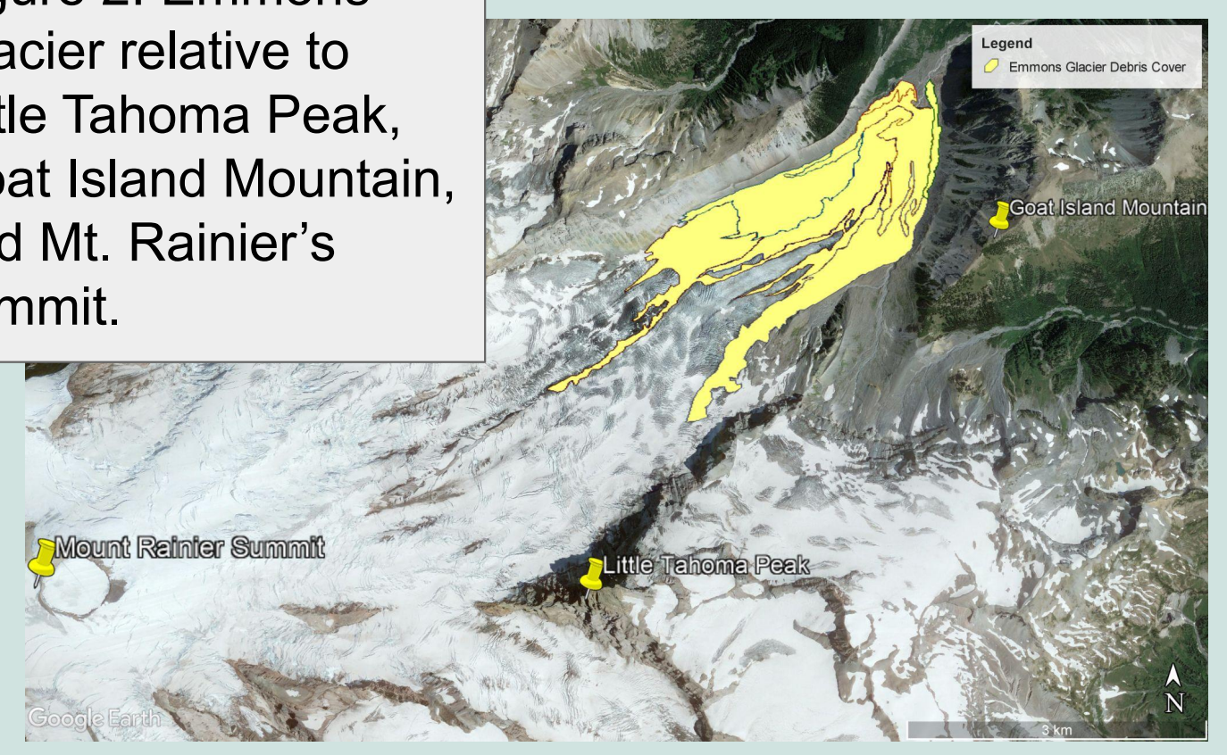

Figure 2: Emmons Glacier relative to Little Tahoma Peak, Goat Island Mountain, and Mt. Rainier's summit.

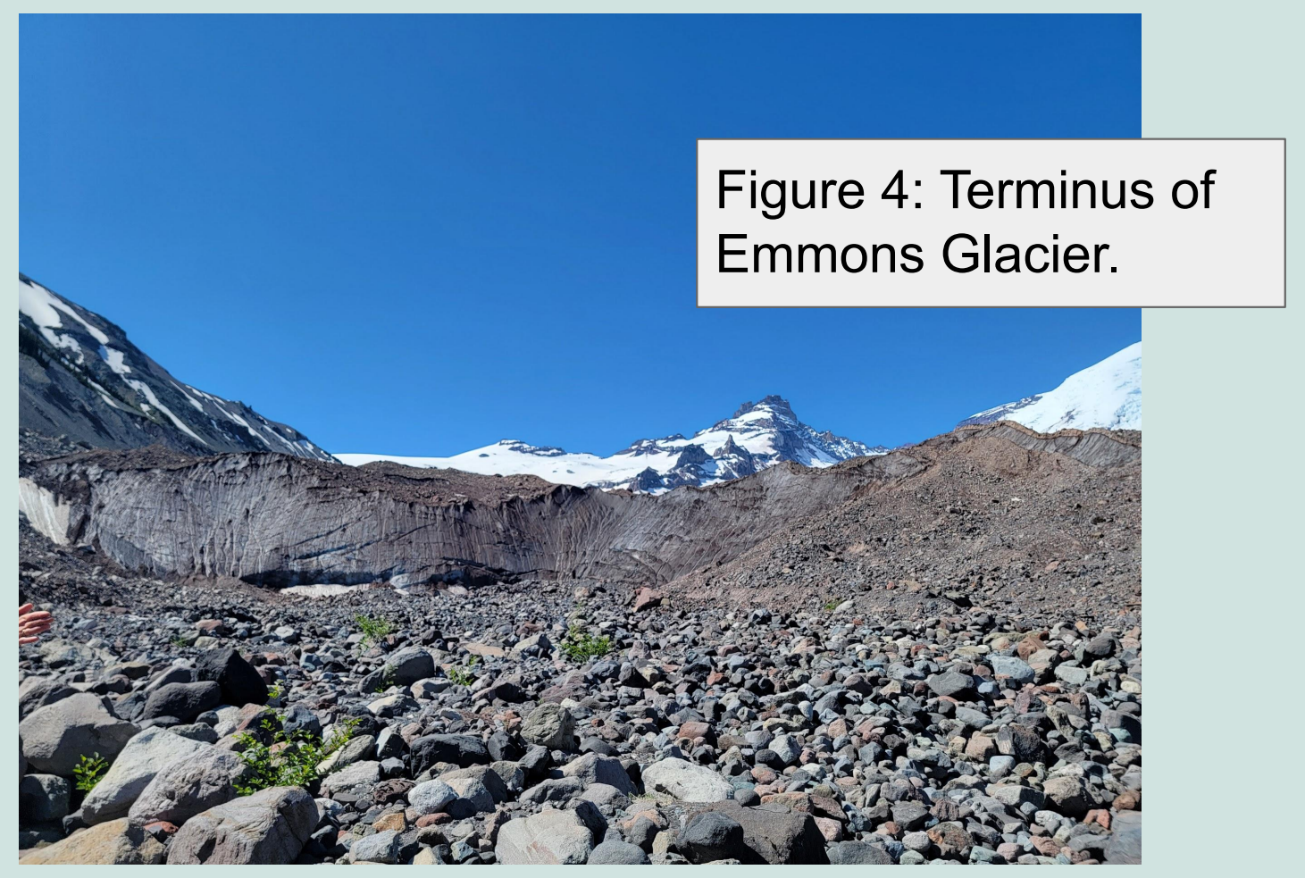

Figure 4: Terminus of Emmons Glacier.

- 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 Google Earth 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 spacing method in the field–both crosshairs (Figure 5) and grids were used in different field seasons.
- In 2021, 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.
- Fine-grained samples were sieved using geologic sieves.
- Unit averages were found for: angularity on the Powers scale, a-axis size, and the % of sediment per sample <63µm, or smaller than sand (Wentworth 1922).

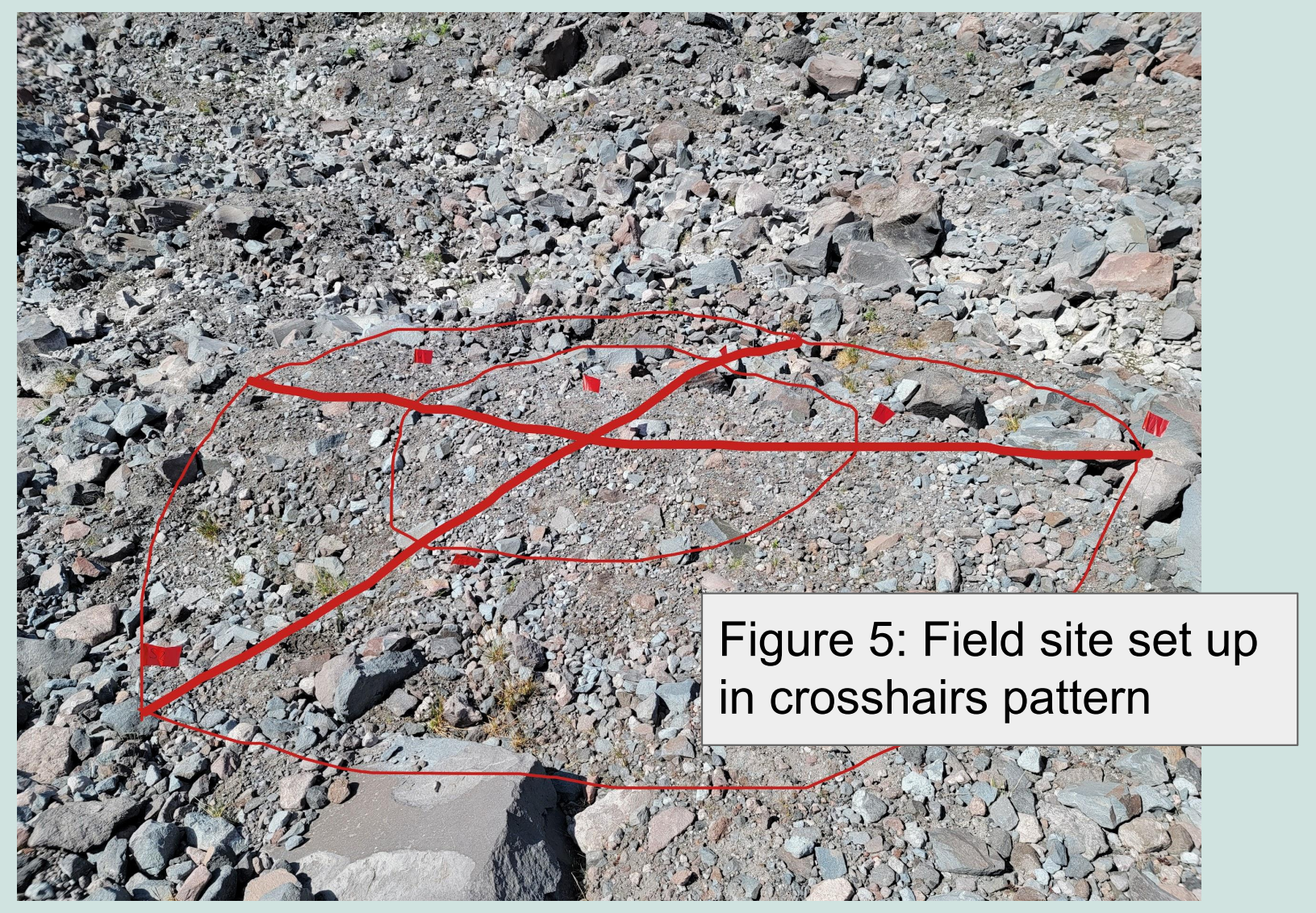

Figure 5: Field site set up in crosshairs pattern

Results

Seven units (Figure 7) were defined based on 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 (Figure 12), 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 are all rockfall debris that have been slowly transported supraglacially and weathered.

- Units A and B are the most angular and are very similar units in all but weathering. Unit B shows more evidence of both freeze-thaw weathering and oxidation than Unit A–clasts showed more red coloring in Unit B and in several locations, had crumbled in place (Figure 8).
- Unit D (Figure 9) is less angular than the other marginal units. It may consist of a mix of supraglacially transported rockfall and subglacially transported bedrock, as the unit above it is made of recently exposed bedrock debris, so parts of this may have travelled into this unit.
- Unit F has the highest percentage of fine sediments, followed by Unit G and Unit D. All three of these units have significantly more fine sediments than Units A and B, evidence of different weathering and different sources of rockfall.

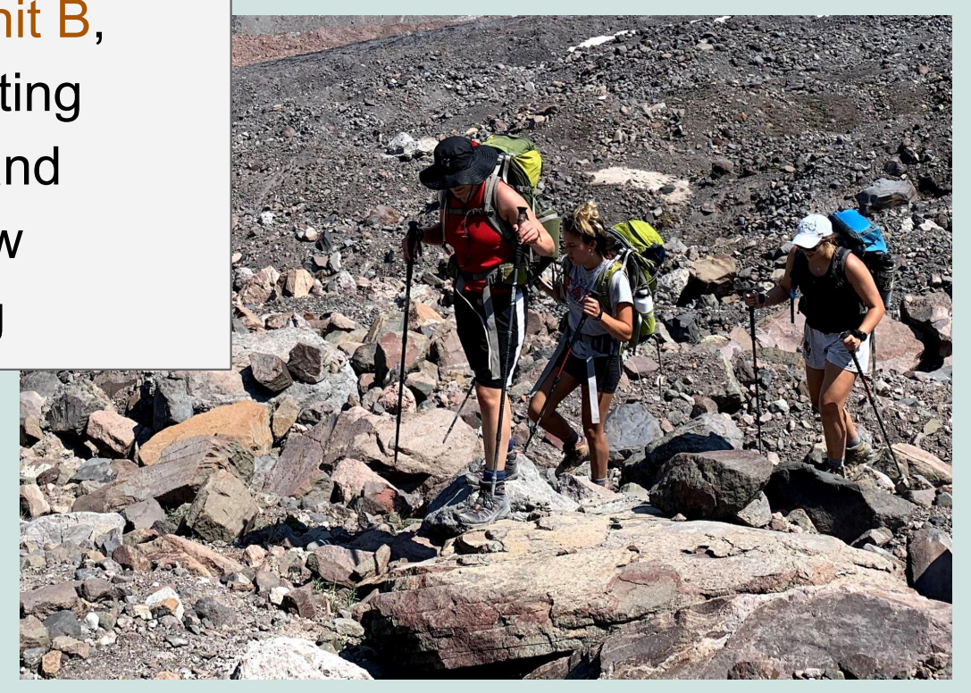

Figure 8: Debris cover in Unit B, demonstrating oxidation and freeze-thaw weathering

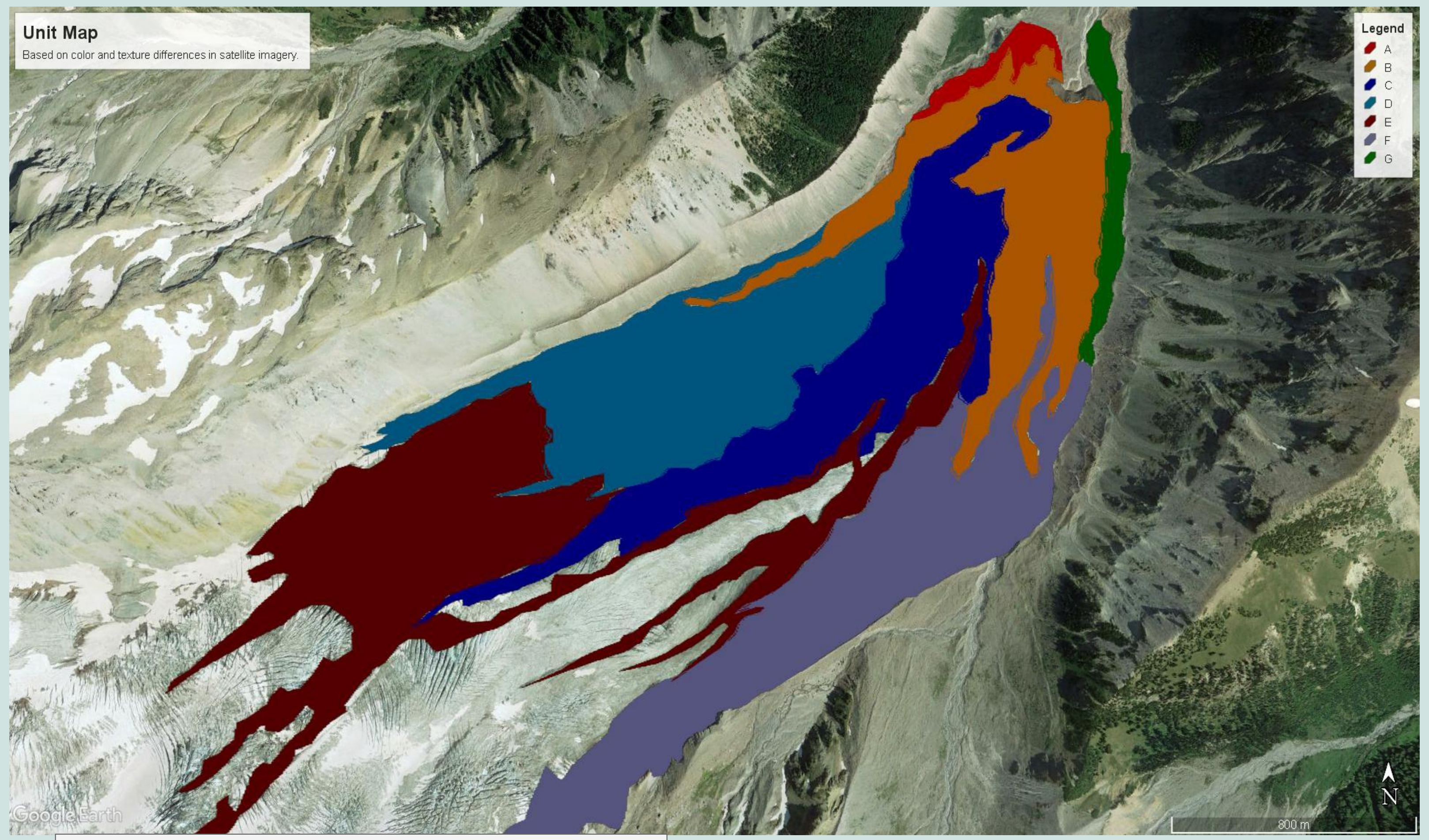

Figure 7: Unit map of debris on Emmons Glacier

Units C and E are in the central region of the glacier. These units are from basally transported debris, which was pushed upwards in the ice and melted out upon reaching the equilibrium line between the accumulation and ablation zones of the glacier.

- Unit E is bedrock that has been recently picked up by the glacier and then entered the debris cover. An exposed "tongue" of bedrock can be seen far up the glacier, part of the source of this unit. This is Interpreted from satellite imagery and distant field observations, as no study sites were established in the unit.
- Unit C (Figure 10) is also made of subglacially transported bedrock, though it is older than debris in Unit E.

Figure 10: The boundaries between Units B, C, and E, looking east across the glacier.

Discussion

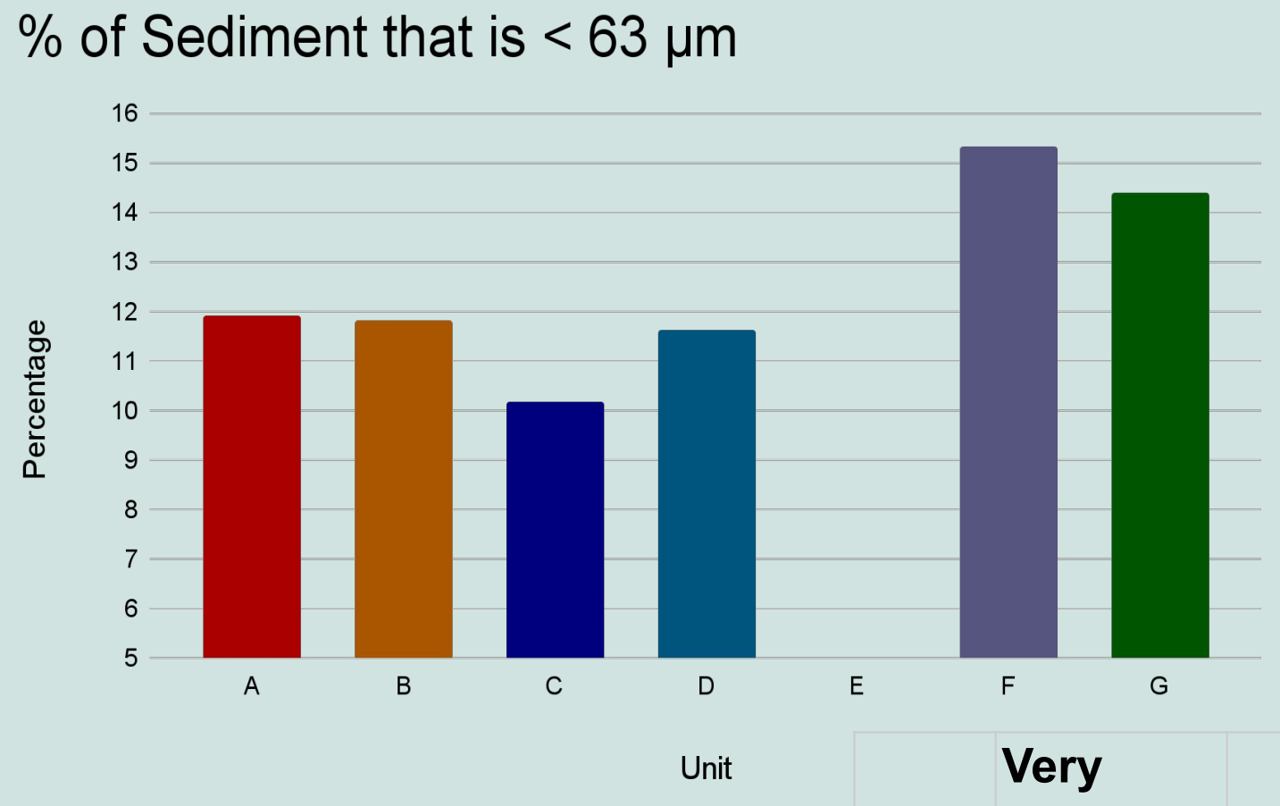

Figure 11: A graph indicating the percentage of sediment in samples that was < 63 µm. Note that as there were no study sites in Unit E, there were no samples collected there.

Figure 12: A table with collected data on angularity and average size of measured clasts in each unit. Note that as there were no study sites in Unit E, there is no data for it and that the very rounded category has been omitted, as no clasts in any unit were in this category

Unit	Very Angular (%)	Angular (%)	Semi-Angular (%)	Semi-Rounded (%)	Rounded (%)	Max. A-Axis (mm)	Avg. A-Axis (mm)
A	14.72	29.67	31.78	17.17	6.67	1620.00	245.01
B	14.19	44.29	24.58	16.42	0.00	4000.00	239.88
C	8.33	35.35	34.27	22.05	0.00	1000.00	175.67
D	6.19	35.94	36.35	11.30	8.00	595.00	196.67
E	--	--	--	--	--	--	--
F	5.56	30.95	63.49	0.00	0.00	128.00	61.26
G	0.00	33.33	33.33	33.33	0.00	128.00	50.89

- We found that finer sediments <63 µm were a product of weathering in rock units on Emmons Glacier, concentrated in rockfall units (Figure 11). Most literature suggests that fine sediments would be more concentrated in basally transported units, but this inverse pattern follows Owen et. al. (2003). They attributed the difference to debris cover, specifying high-elevation glaciers, but Emmons also has a larger amount of debris than others.
- Allstadt et. al. (2015) found that the interior of Emmons Glacier has a much higher velocity than the margins of the glacier. The boundary between these two flow rates approximately matches the boundary between rockfall and basally transported units, meaning that only basally transported debris has been added recently, while the rockfall is older and more stagnant.
- We did not find conclusive evidence of rockfall from the 1963 rockfall detailed by Crandell and Fahnestock (1965) still on the glacier, but it is very likely that some of the rockfall units are from this event. Since the only recent debris is basal, rockfall units must be older, likely stretching back at least to this event.
- Moore (2018) details the importance of debris cover for ablation control. The likelihood of rockfalls from nearly 60 years ago remaining in the debris cover of Emmons Glacier indicates how long one event can impact glacial retreat. It also suggest a reason for the difference between Emmons Glacier and most other glaciers on Mount Rainier in ablation, if Emmons Glacier is one of the only ones with such a large rockfall event contributing to its modern debris cover.

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