THE END OF THE LITTLE ICE AGE, MENDENHALL GLACIER, JUNEAU, ALASKA

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INTRODUCTION

The geomorphology of a surrounding glacier provides clues to past ice activity. With careful study of these landforms and their patterns, it may be determined if the glacier margin was advancing, retreating, or stationary, and if the ice was stagnant or active. There are a variety of depositional and erosional glacial landforms surrounding Mendenhall Glacier and Mendenhall Lake (Figure 1). The glacial trough of the Mendenhall Glacier, and Mendenhall Lake basin were likely excavated throughout the Pleistocene. In addition to the terminal moraine complex, there are a variety of depositional and erosional landforms in the recently deglaciated area. Depositional landforms include lateral moraines, kames, and possible kame terraces and eskers. Erosional landforms include striations, grooves, stoss-and-lee forms, and spectacular p-forms.

The purpose of this study was to map the glacial landforms surrounding Mendenhall Lake, calculate retreat rates of Mendenhall Glacier for the last century, and compare changes in retreat rate to tree ring width in the area. With this information, a more detailed history of Mendenhall Glacier during its last century of retreat can be known.

MENDENHALL LAKE

The formation of the Mendenhall Lake basin likely started about 2 million years ago at the beginning of the ice age. Weaknesses in the low-grade metamorphic bedrock (foliation, fractures) made the lake basin area more susceptible to the erosional forces of the glacier. Through glacial plucking, as well as glacial abrasion and meltwater erosion, the bedrock lake basin was excavated.

During the retreat of the Mendenhall Glacier at the end of the Little Ice Age, the glacier paused at what is now the south end of Mendenhall Lake and deposited an extensive moraine complex that ranges in age from about 1769 to 1916 AD (Lawrence, 1950; Miller, 1975). As the Mendenhall Glacier retreated during the subsequent warmer climate, the moraine complex dammed meltwater from the glacier. The meltwater crossed this dam of drift, and flowed down Mendenhall Valley to form the Mendenhall River channel. Modern lake formation began about 1900, as the glacier retreated from its last major moraine in the moraine complex. The glacier continued to retreat and exposed more of the bedrock basin, which filled with meltwater to form Mendenhall Lake. As the glacier front retreats, the lake becomes longer by expansion to the north. However, as the Mendenhall River slowly cuts through the moraines, the lake may become smaller as its level drops. Wave action on the lake has cut low bluffs and deposited beaches and spits.

GEOMORPHOLOGY

DEPOSITIONAL LANDFORMS

Moraines

The moraine complex responsible for the dam at the south end of Mendenhall Lake is approximately 5 kilometers long and 1.5 kilometers wide and is made of four large moraines (Figure 1a). Lawrence (1950) first used dendrochronology, and later Miller (1975) used radiocarbon dating and more dendrochronology to place the formation of the moraines from 1769 to 1916 AD. Throughout the moraine complex are kames and kettles.

front. In a saturated, malleable basal till, shearing forces are constantly moving and rotating these clasts causing great amounts of clast-to-clast contact. It would seem this contact is capable of abrading clasts into smooth spheres. This process would only be responsible for rounding the boulders, however, isolating them on a kame terrace requires an additional step.

When the glacier recedes and deposits a basal till, the rounded boulders are contained within the mass. The boulders are later exposed when a meltwater channel overrides the deposit and winnows out the smaller clasts. When the meltwater has removed all but the biggest clasts, these large boulders are left as lag, perched on a kame terrace.

For smaller clasts less than 50 cm in diameter, it is likely they are rounded very efficiently beneath the glacier in a network of subglacial fluvial channels. A large quantity of meltwater is present at the base of the Herbert Glacier, supplying the outlet stream with a discharge greater than 14 m^3/s (Sawyer, 2001). This meltwater is under large pressure gradients underneath the glacier, and this produces high water velocities. These high velocities produce high turbulence and turbidity, which in turn creates high viscosities. A highly viscous, fast moving slurry of water and sediment is an ideal environment to round clasts very fast (Benn and Evans, 1998).

CONCLUSIONS

The unique set of landforms and sediments in the basin at the Herbert Glacier ice front appear to have formed through a set of interrelated processes. Under the Herbert Glacier, deforming basal till efficiently and effectively rounds large boulders and smaller clasts alike. This basal till is then winnowed by subglacial and subaerial meltwater streams that isolate the large boulders, further round the smaller clasts, and also deposit kame terraces. After deposition, these rounded clasts are also available to be deposited in other landforms within the basin.

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Along the east side of Mendenhall Lake are prominent lateral moraines along the valley wall, and smaller moraines in a drift complex that is directly on the shoreline (Figure 1a). The prominent lateral moraines were deposited approximately 30 years ago, and the smaller moraines in the drift complex were deposited less than 20 years ago.

During the retreat of the past few decades, the rock rib directly in front of Mendenhall Glacier has been exposed. The last ice to flow over the rock rib was at a gap near its center. This small ice lobe deposited a small arcuate moraine complex (Figure 1a). The 10 moraines range in size from 14 to 68 m long, 1 to 16 m wide, and 0.3 to 3 m high. Earlier ice flowed over the entire rock rib, so there must be a specific reason as to why the moraine complex is so localized. Sediment distribution within the ice lobe could have been concentrated in certain areas, and as this ice lobe retreated, the sediment was deposited to form this moraine complex. There also could have been changes in the retreat rates of the ice lobe, so the moraines developed in the areas where the ice was for the longest amount of time. The moraine complex could also have been more widespread at some time during glacial retreat, but meltwater through the rock gap could have washed away the rest of the sediment.

Kames

At the southwestern corner of the Mendenhall Glacier in July 2000 a small kame was being deposited (Figure 1b). A small, supraglacial stream cut a channel directly down the side of the ice and deposited sand and pebbles directly on the striated bedrock next to the ice margin. Older kames can be found along the shore of Mendenhall Lake and in the moraine complex damming the lake.

Drumlinoids

Within the large moraine complex are a few oval features perpendicular to the moraines. They are best classified as drumlinoids (rather than drumlins or flutes) because of their intermediate length to width ratios (Figure 1a).

EROSIONAL LANDFORMS

Striations

The low-grade metamorphic rocks in the vicinity of Mendenhall Lake have abundant striations (Figure 1c). The best preserved striations are where the rock rib has been most recently deglaciated. Cross-cutting striations are abundant in the vicinity of the small moraine complex on the south side of the rock rib. Their pattern suggests southward ice flow when the ice was more extensive, followed by radial ice flow when the lobe was building the moraines. The cross-cutting striations could be a result of different ice advances, or a change in ice flow direction during an ice advance (Bennett and Glasser, 1996).

P-forms

P-forms are also widespread on the rock outcrops near Mendenhall Lake. They are concentrated on the proximal side of the rock rib. The p-forms of the Mendenhall Glacier can be described as channels, which are similar to the shape of a meltwater channel and are more common on the rock rib; knobs or bowls, which are round features that are either convex or concave; or as grooves, which are similar to channels but less sinuous (Anderson and Borns, 1994). The channels and grooves are generally 1 to 5 m in length and less than a meter in width and depth. The knobs or bowls are less than 2 m in diameter.

While the origin of p-forms is unknown, there are three main hypotheses. The first is glacial abrasion, by which a glacier accumulates debris in certain areas, and uses these tools to carve p-forms. The other two hypotheses are similar in their use of water as an eroding agent, either a hyperconcentrated mixture of till and water eroded the features, or just meltwater produced the p-forms (Bennett and Glasser, 1996). Since Mendenhall Glacier is a fairly "clean" glacier, it is probably likely that the p-forms were formed by a hyperconcentrated mixture of till and water or meltwater.

Stoss-and-lee forms

Present along the valley sides and plentiful on the rock rib are stoss-and-lee forms ranging in size from a few meters long to a hundred meters in width and height. Along the southwestern corner of the glacier are two large stoss-and-lee forms a hundred meters high with small valleys excavated between them. Smaller stoss-and-lee forms, only a few meters in size, are present on both the proximal and distal sides of the rock rib.

MENDENHALL GLACIER RETREAT RATES

RETREAT RATES

The retreat rates from 1910 to 2000 were established using Knopf's 1912 map of the 1910 ice margin, the USGS Juneau (B-2) map of the 1948 ice margin, Miller's 1975 map of the 1962 ice margin, air photos from 1984 and 1996, and GPS data collected during July 2000. Three reference points were located on the eastern, southern, and western parts of the Mendenhall Lake shoreline. The distances between the reference points and ice margin positions were used to calculate retreat rates. Position 1 is along the east side of Mendenhall Lake, position 2 is directly south of Mendenhall Lake, and position 3 is along the west side of Mendenhall Lake.

The resulting data shows first a decrease and then an increase in the rate of retreat of the Mendenhall Glacier (Table 1). This change is most dramatic to the west (position 3), the area most influenced by the rock rib directly in front of Mendenhall Glacier. As the glacier retreated over the rock rib, it thinned and stagnated, prompting the sharp decrease in retreat from 1948 to 1984. Because of the rock rib's high heat absorption, the retreat rate sharply increased as the rock rib was exposed. The data from positions 1 and 2 also show a decrease in retreat from 1948 to 1984, although it is less dramatic. Along the eastern shoreline, there was the most uniform retreat; not influenced by the rock rib, the ice remained active.

TREE CORES

Tree ring width was calculated by measuring the length of a section of tree rings (e.g., measuring the rings from 1962 to 1984) and then dividing the length by the number of rings in the section (Table 2). Tree cores were collected at four different sites. Two tree-coring sites were near the Mendenhall Glacier, one along the left lateral moraine on the East Glacier Trail, and another along the right lateral moraine on the West Glacier Trail. Other tree cores were collected near the bridges of both the Eagle and Herbert Rivers, which are major meltwater streams downvalley of the Eagle and Herbert Glaciers.

An interesting trend is noted when retreat rates are compared to tree ring widths (Figure 2). The lowest retreat rate from 1962 to 1984 correlates with the smallest mean tree ring width from 1962 to 1984. Since a cooler climate means thinner tree rings, the decrease in tree ring width is indicative of a drop in temperature, which would also decrease the retreat rate of the glacier (Wiles et al., 1996). Similarly, the highest retreat rate (1910 – 1948) correlates with the thickest tree rings; both may be due to warmer climate, but the high retreat rate may be a result of increased calving in the deepest and widest part of Mendenhall Lake.

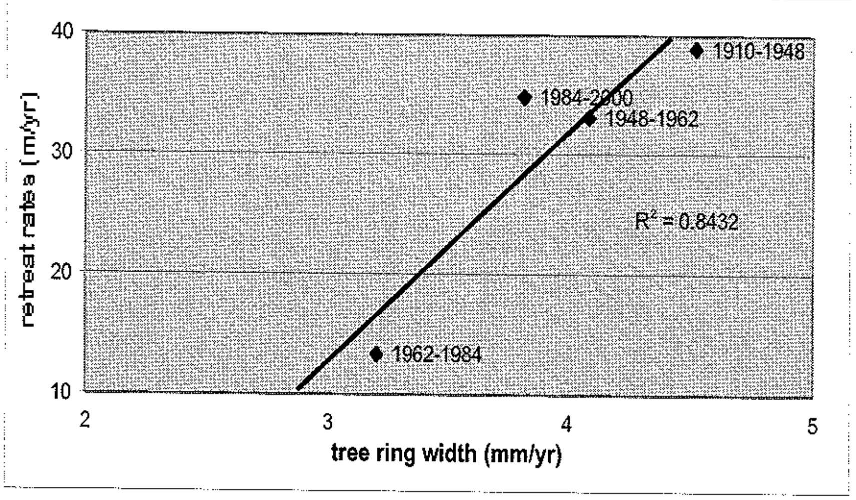
Table 1. Mendenhall Glacier retreat rates (m/yr)

	1984 - 2000	1962 – 1984	1948 - 1962	1910 - 1948	1910 - 2000
Position 1 (east)	33.0	18.8	24.0	30.0	23.9
Position 2 (west)	35.4	12.5	37.7	45.0	34.2
Position 3 (south)	36.1	8.6	37.7	41.7	31.2
Mean	33.3	13.3	33.1	38.9	29.8

Table 2. Average tree ring width (mm/yr)

# of cores	1984 - 2000	1962 - 1984	1948 - 1962	1910 - 1948	1910 - 2000
14	4.17	X	X	X	X
9	4.79	3.78	X	X	X
5	3.00	3.02	5.50	X	X
2	3.31	2.82	2.68	4.52	3.60
Mean	3.82	3.21	4.09	4.52	3.60

Figure 2. Tree ring width vs. retreat rate



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UNDERSTANDING GLACIER SLIDING FROM SUBGLACIALLY DEPOSITED SILT SKINS

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INTRODUCTION

Glacial advances and retreats, prominent factors in global climate and sea level change, are controlled by climate and a combination of processes including ice deformation, basal sliding, and subglacial hydraulic systems. Evidence of the effects of these processes is preserved in the landforms and deposits left behind. Examining deposits recently uncovered by retreating glaciers is one method of studying subglacial processes and glacier sliding. Features of subglacial deposits, including their distribution, morphology, and chemistry, provide specific clues about the interaction of ice, the bedrock it flows over, and subglacial water. Morphology of subglacial deposits is a key to understanding the larger aspects of glacier systems, and how they, in turn, have affected global climate throughout Earth history (Paterson, 1994).

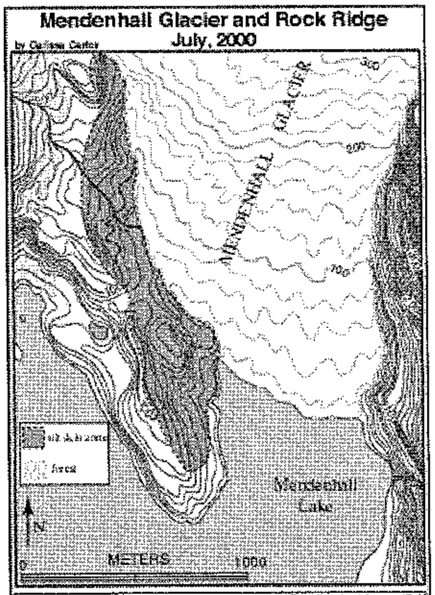

Fig. 1 ROCK RIDGE DEPICTING SILT SKIN ZONES

Based on 1998 Juneau (B-2) NW Quadrangle Map and GPS data taken in July, 2000

Map depicting zones where silt skins are found on the Mendenhall rock ridge. Ice was at western extent of silt skin zone approximately 20 years ago.

Location and Sample Description

In the past two decades, the retreating Mendenhall Glacier in Juneau, Alaska has exposed a bedrock ridge spotted with patchy coatings of calcite-cemented clay to sand-sized lithic grains (Fig. 1). These coatings, referred to here as 'silt skins', range from 0.5 to 20 mm in thickness and display two distinct morphologies: striated and corrugated. Striated silt skins are thin, located mainly on stoss slopes, and preserve local striation direction. Thicker, corrugated skins form on lee slopes and consist of parallel micro-ridges elongated in the local downslope direction (Fig. 2a). Micro-ridges are constructional features enhanced by erosional processes; wavelengths generally range from 1 to 10 mm.

METHODS

Field Work

I collected silt skin data by mapping their distribution on the bedrock ridge, recording Global Positioning System (GPS) locations, and collecting skin, rock, ice, and water samples. I made transects at regular intervals over the entire rock ridge normal to the ice front. Transects consisted of 8 to 12 measurement points; at each point I collected a GPS location, measured local slope, and local striation direction. Additionally, I estimated a percentage cover value for silt skins by placing a one-meter square frame on the rock face exposing a local maximum cover, and then making an estimate using a 'Comparison Chart for Estimating Percentage Composition'. At collection localities, I noted orientation-, striation-, and local downslope-direction on individual samples.

I also used a GPS receiver to map the ice front, denote the extent of an area of high skin density, and determine the 'zero skin line' where coatings are no longer preserved.

Additionally, I gathered three ice samples, including a basal sample from the ice front on the western side of the glacier, a basal sample from the ice front at approximately mid-glacier, and one mid-ice sample from the ice front at mid-glacier. I traversed to the West Side of the glacier and collected a subglacial water sample by crawling under the ice.