SEDIMENTOLOGICAL DESCRIPTION AND PROCESS INTERPRETATION OF GLACIOGENIC LANDFORMS AT THE HERBERT GLACIER ICE FRONT

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INTRODUCTION

Recent rapid recession of the Herbert Glacier, an outlet glacier of the Juneau Icefield, has revealed a striking set of glacial, sub-glacial, and proglacial landforms and sediments. The Herbert Glacier has receded 3.5 km in the last 235 years since its Little Ice Age maximum stand (Lawrence, 1950), and for the past 15 years has been receding at a rate of 20 m per year. This recent recession has uncovered a small basin approximately 300 m north/south and 350 m east/west located at the current (July 2000) ice front.

Multiple kame terraces ring the walls of the ice marginal basin and are graded to several past meltwater outlets. These terraces, and most other deposits in the basin, including moraines, other ice contact stratified drift, and the sediment melting out from under the ice, are composed entirely of rounded granitic clasts. In remarkable contrast to these subglacial clasts are very few, angular, iron-stained metamorphic rocks that are seen in supraglacial transport. Large (>2 m diameter) well-rounded boulders are scattered throughout the basin on kame terraces, in moraines, and mixed with till. There is also a 20 m stratigraphic section exposed in the steep northern basin wall. This section is composed of two tills and a suite of stratified drift units. The lower till is highly weathered and contains large subangular clasts of tonalite, while the upper till is unweathered and composed of smaller (< 30 cm) subrounded to rounded clasts of tonalite.

The principle goals of this project are to examine the dynamics responsible for rounding the clasts in the basin, especially the larger boulders, and to map and describe the origin of the multiple kame terraces. Multiple hypotheses have been informally suggested as explanations for the rounding of the large boulders, most of which could be used to explain the rounding of the smaller clasts as well. The boulders could come pre-rounded as corestones. They could be rounded by direct ice transport. They could be rounded by subglacial fluvial transport at the bottom of moulins (Connor, 2000) or in a network of subglacial fluvial channels. They could be rounded in subaerial fluvial process in either normal flow regimes or catastrophic jökulhlaup events. They could also be rounded in a subglacial deforming till (Fleisher, 2000). Each of these hypothesis will be examined for validity.

METHODS

A GIS surface expression map of the Herbert Glacier ice front and surroundings was created in ArcView using GPS data (Figure 1). GPS data points were collected in the field at the contacts between different surface features including bedrock, ice, stagnant ice, river channel, braid plain, moraine, and kame terraces. Features were differentiated based on clast lithology, size and shape, outcrop pattern, and general appearance. These data were then transferred into ArcView, and from them a map of ice, bedrock, river channel, and geomorphic features, was created. To provide a third dimension to the map, topographic profiles of the basin were also created.

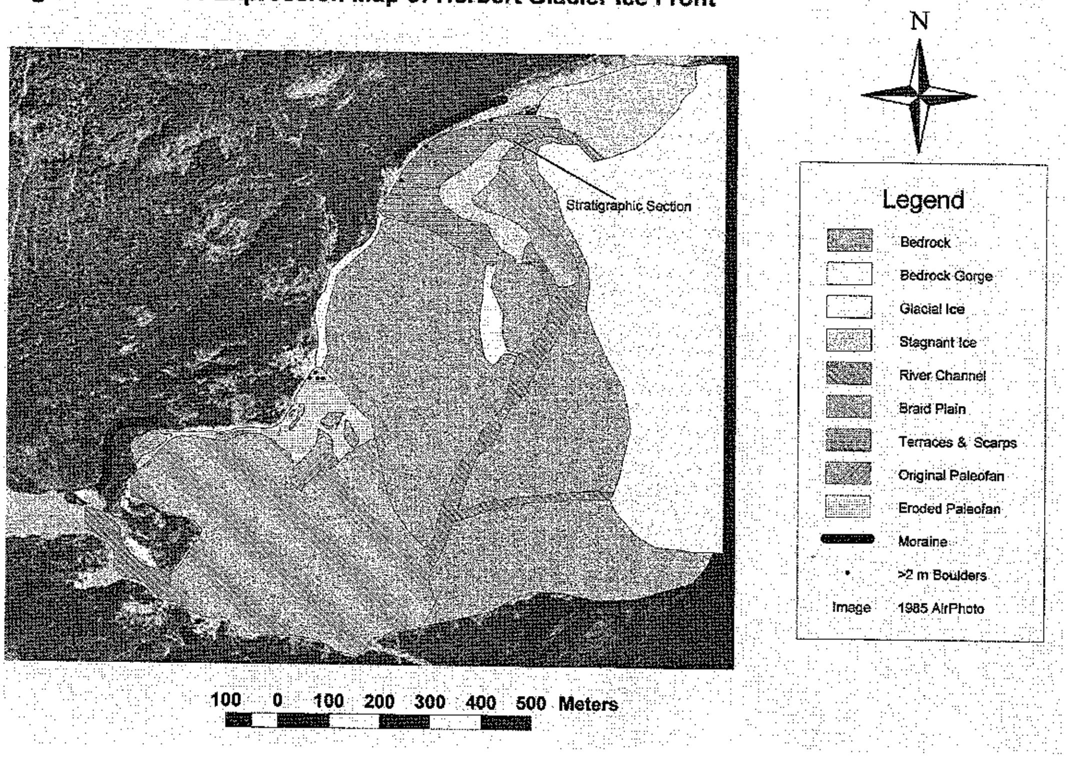
A plot comparing the seven kame terrace slopes was produced by a combination of GPS and altimeter/barometer data (Figure 2). This plot was also used to compare the slopes of multiple terraces grading to a single outlet.

Quantification of the rounding, lithology and size of clasts on the kame terraces was done by seven pebble counts. For each pebble count, a 30 m tape was placed on the tread of a kame terrace following the trend down its slope and the size, lithology, and degree of rounding of each rock at every 0.5 m was tabulated. Rocks that spanned 0.5 m intervals were counted as one rock and not tabulated twice. Total sample size was 274 rocks.

Tranter, M., Sharp, M. J., Brown, G. H., Willis, I. C., Hubbard, B. P., Nielsen, M. K., Smart, C. C., Gordon, S., Tulley, M., Lamb, H. R. (1997). "Variability in the chemical composition of in situ subglacial meltwaters." Hydrological Processes 11: 59-77.

The paleohydraulic methods of Baker (1974), Williams (1983), and Costa (1983) were used to determine the necessary velocity and water depth to transport the large boulders by fluvial processes. The Baker (1974) method is a theoretical approach based on critical shear stress equations. The Williams (1983) and Costa (1983) methods use empirical relations between grain size and velocity, stream power, and bed shear stress to determine paleoflow characteristics. In an effort to determine if fluvial transport is a viable process for rounding the boulders, the values produced from each method were compared to reasonable assumptions of flow characteristics based on field evidence.

Figure 1. Surface Expression Map of Herbert Glacier Ice Front



RESULTS

The slope of the kame terraces varied between 1.3 and 3.0 degrees. Where multiple terraces graded to a single outlet, the terrace with a higher up-valley outcrop had a steeper slope than the lower terrace.

Eighty-eight percent of the clasts examined in the kame terrace deposits were rounded to subrounded. Rounded clasts were defined as having equant axes, rounded corners, and no facets, while subrounded clasts were defined as having relatively equant axes, rounded corners, and one facet or less. No relationship was found between the degree of rounding and physical location on a terrace or terrace number. There is also no relationship between clast size and degree of rounding. There is a relationship between clast lithology and degree of rounding, however. The dominant subglacial rock type, tonalite, was never found to be angular, while the supraglacial metamorphic rocks were never more rounded than subangular.

Paleohydraulic calculations:

Method	Water Depth (m)	Flow Velocity (m/s)
Baker (1974)	2.8	10
Williams (1983)	1.8	2.8
Costa (1983)	4.3	6.9

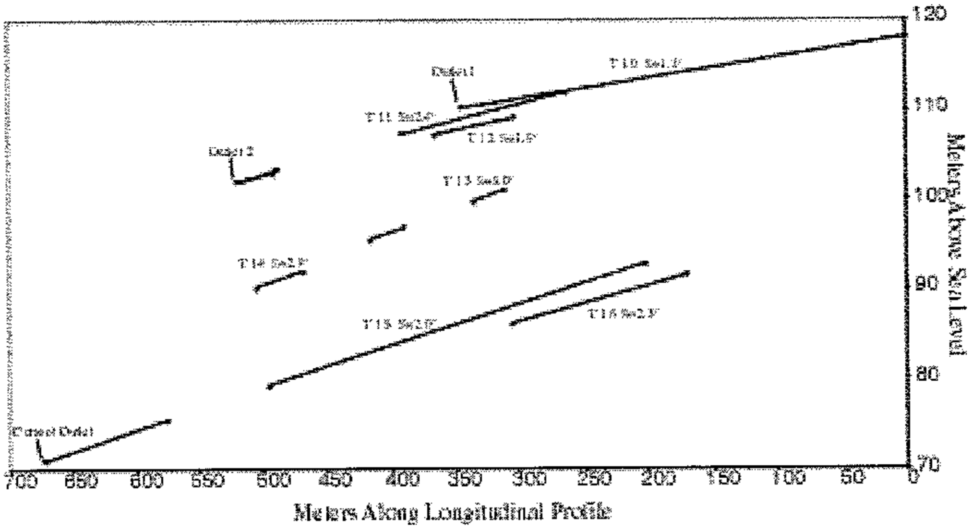


Figure 2. Longitudinal profile comparing kame terrace slopes graded to multiple bedrock outlets.

DISCUSSIONS

Terrace Formation

Multiple kame terraces form when an ice-contact stream attains lower base-level controls. A new control could be a lower bedrock outlet, exposed by retreating ice, or it could also be the result of removing a debris plug from the current outlet. When a plug is catastrophically removed or a new bedrock low is exposed, the meltwater stream begins incising the old terrace and depositing a lower terrace. If this happens successively through time, multiple terraces and their erosional scarps will be preserved, just as observed in the ice front basin. Judging by the fact that there are seven preserved kame terraces in the basin, which has only been exposed in the past 15 years, this process operates on a yearly scale at the Herbert Glacier.

Rounding Processes

Because both the large boulders and small clasts are in depositional proximity to each other, it is likely that related processes are responsible for rounding them. It is unlikely that either size of rounded clasts are core-stones because they are simply too great in number. It is also unlikely that they have been rounded by direct ice transport because that usually creates facets on the rocks. For the larger clasts greater than 1 m, it is implausible that they have been rounded at the bottom of moulins because of the shear amount of water and abrading particles necessary for this type of process. It is also questionable that the large boulders are jökulhlaup deposits because there is no other sedimentological or geomorphic evidence supporting this scale of flooding.

Normal flow regime rounding of the larger clasts also appears to be discounted by the results of the paleohydraulic calculations. The three methods each produced depths and velocities of water not observed in the field. The meltwater stream emanating from the glacier does not exceed 2 m in depth and on average does not flow faster than 1 m/s (Sawyer, 2001). It is possible that there have been higher flows but these calculations were made during the summer at the peak of discharge in the ablation season. It is therefore unlikely that fluvial processes alone are responsible for rounding the large boulders. In consideration of all these restrictions, it is most probable that a deforming basal till rounds the large boulders.

This is the best hypothesis because there is field evidence for support. These large boulders, along with many smaller rounded clasts, are observed in basal tills that have melted out from the receding ice 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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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.