SUSPENDED SEDIMENT LOAD OF PROGLACIAL MELTWATER SYSTEMS

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INTRODUCTION

The Mendenhall, Herbert and Eagle Glaciers' close proximity and shared accumulation zone allow for a unique opportunity to study variations between the three glacial systems. One immediately noticeable difference lies in their meltwater system morphology; these differences affect the suspended sediment load and sedimentation along their respective courses to the sea.

The Eagle Glacier empties its meltwater via a small river confined by steep bedrock walls into a system of two lakes connected by a small channel. The Eagle River then drains the lower lake and empties into the sea a five km downstream (Figure 1, Carson et al., this volume). The Herbert Glacier has a large river emptying from a conduit on glacier right, which winds down between the glacier front and bedrock before forming a large delta as it widens out into a braided channel, then joins the Eagle River 4 km downstream (Figure 1, Carson et al., this volume). The Mendenhall Glacier terminates directly into Mendenhall Lake, a large body of water, which likely traps much of the sediments being eroded by meltwater. The Mendenhall River drains the lake to the south and takes the water to Gastineau Channel (Figure 1, Carson et al., this volume).

Each system has unique drainage characteristics, and the presence (or lack) of sediment-trapping lakes ought to affect the amount of suspended sediment in each system. Also, changes in discharge influence the suspended load. Increased discharge might allow for higher sediment transport, but if the glaciers produce a fixed volume of sediment, then a greater volume of meltwater will create a dilution of suspended load.

I studied variations in suspended sediment concentration at different locations along each of the three drainage systems, taking into account variations in stage and sediment mineralogy, as well as examining the grain size distribution of suspended sediment as a function of the location from which is was sampled. I hope to characterize the suspended sediment load along the proglacial meltwater systems of the Mendenhall, Herbert and Eagle Glaciers, and to understand any differences observed between the three.

METHODS

My general observations of the field area include: stream morphology, identification and description of sediment trapping lakes, stream gradients, size of deltas and lakes, and description of possible meteoric water inputs into the proglacial system.

I took water samples of approximately 280 ml by submerging a sample bottle in the maximum possible current (whenever stream samples came from a stream) until it filled. Due to extremely cold water temperatures, sampling locations were restricted to riverbanks and lakeshores, thus values may not be representative of actual suspended load, but they can be compared with one another.

The locations of sample sites were selected to be representative of the different hydrologic environments. So, whenever applicable, samples were taken: at the mouth of the major glacial outlet stream, up and downstream from any delta or lake, from major meteoric water inputs, up and downstream from those major meteoric inputs, and from the main river of the meltwater system before it emptied into the sea. I also set up stage meters at various downstream locations along the path of each of the three glacial meltwater systems, usually at or close to sampling sites.

For each sample, the following information was recorded: date and time at which sample was taken, the sample site location, and the stage of the water level at the time of sampling. Stage was measured to be the vertical distance between a fixed marker and the water surface. Samples were taken every two hours, or sooner if significant changes in stage were observed. I recorded the position of all sample sites and stage meters using Global Positioning System (GPS), which I placed on a geo-referenced map of the field area using ArcView software.

Each water sample collected was filtered using a 0.45 _m filter paper to isolate the suspended sediment for further analysis. I also measured the volume of water from which the sediment sample was extracted. Once dried, the filter papers with their sediment samples were massed to the nearest tenth of a milligram; I calculated the mass of sediment in the sample by subtracting the average mass of a filter paper from the previously measured combined mass

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of the filter and sample. Concentration of suspended load was derived by dividing mass of sediment by the volume of water from which it was extracted to give a value in g/l.

From the approximately 100 samples collected, a number were chosen from each sample location that represent the range of observed stages for further analysis. The general mineralogical composition of the samples were determined using x-ray diffraction on the samples, and the grain size distribution was measured using a laser particle size analyzer. Grain size distributions were examined by plotting diameter against volume percent in an Excel graph.

I defined the relationship between stage and concentration of suspended load for each sampling location, examining any possible explanations for variations both within and between the three systems. Using the XRD results I determined the basic mineralogy of the suspended sediments from the three systems and how it changes as a function of distance downstream from the glacier. Using a laser particle size analyzer, I examined the grain size distributions of the same group of samples, paying particular attention to the effects of sediment traps and distance from the glacier on the distribution of particle sizes.

SUSPENDED SEDIMENT CONCENTRATIONS

Concentration of suspended sediment varies widely from 0 in virtually all meteoric and supraglacial water to 1.270 g/l in the upper Herbert River. Along the Eagle Glacier system for the subglacial river, the lakes and their outlet, an increase in stage is marked by an increase in the concentration of suspended sediment. However, the exact relationship cannot be quantified because a change in stage does not result in a proportional or regular change in suspended load. The variation in stage is such that it merely indicates an increase or decrease in amount of flow or water storage. Also, concentration of suspended load generally decreased with further distance downstream.

A major problem was discovered with the stage measurements at the meltwater conduit of the Herbert Glacier. The stream flowed from underneath a steep wall of stagnant ice, which over the course of the month of July was slowly being melted away by the constant flow of the stream. This caused the stream to shift toward its left bank creating an apparent drop in stage on the right bank, thereby causing stage readings to be imprecise and rendering the stage meters useless by the end of the month. At all other locations along the Herbert meltwater system both a decreased in stage and an increase in downstream distance were accompanied by a decrease in suspended sediment load concentration.

GRAIN SIZE ANALYSES

Grain size distribution for the Eagle meltwater system tends to be fairly uniform below the delta in Upper Eagle Lake. Samples taken from the lake, its outlet, and the lower river were composed primarily of fine silt and clay sized particles. Water from the lower portion of Eagle River at the highway bridge suspends only medium to fine silt and some clay sized grains. Both at high and low stage, lake water tended to have only a small portion of its suspended

Fig. 1: Grain Size Distribution Mendenhall Glacier

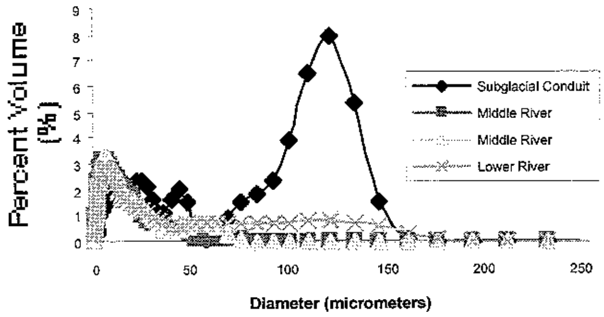


Fig. 2: Grain Size Distribution Eagle Glacier

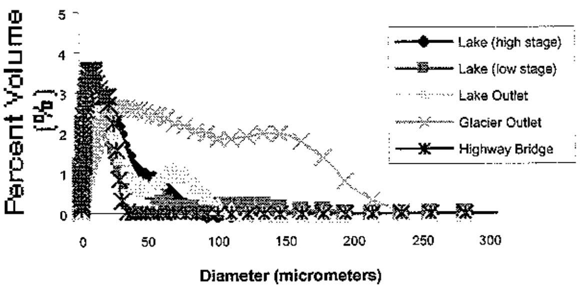


Fig. 3: Grain Size Distribution Herbert Glacier

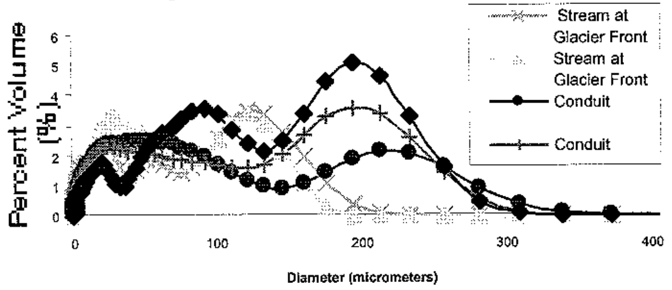
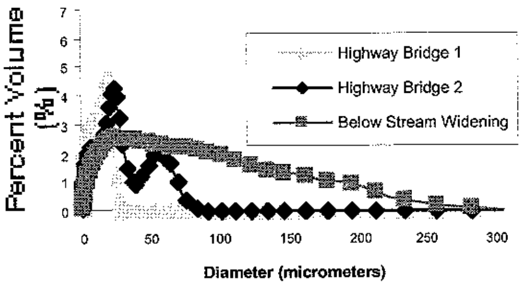


Fig. 4: Grain Size Distribution Herbert Glacier



Figures 1-4 show grain size distributions along the meltwater channels of the Mendenhall, Eagle and Herbert Glaciers.

particles between medium silt and fine sand sizes. At lower stage the lake was able to hold a very small proportion of medium sized sand grains, which was not observed in the lake at high stage.

For clay and silt sized sediments, the outlet from the lower lake has virtually identical grain size distribution to that of the lake. However, overall it displays a bimodal distribution because of a slight peak in the very fine sand sized particles at 70 _m (Prothero and Schwab, 1996). This could be due to occurrence of erosion at the outlet as the lake water gains momentum rushing into the channel. It might also be because the outlet drains water from the center of the lake, where larger grain sizes are in suspension relative to the banks, where lake water samples were taken.

Water leaving the glacier shows an entirely different grain size distribution; particle diameters are as large as 260 micrometers. Distribution is bimodal with peaks at 25 and 145 _m. The high velocity subglacial meltwater is able to carry medium sized sands in suspension, but between the point where the river exits its confining bedrock walls, widens into its delta, and enters the lake, the larger grains fall out of suspension. The result of dropping these grains is a suspended load with the grain size distribution observed in the lakes. It would seem that the two lakes act as a trap for sediments greater in size than very fine sand. These lakes allow the settling out of all such larger grains, leaving primarily silt and clay sized rock flour to be transported through the meltwater system out to sea.

Glacial meltwater output from the Mendenhall Glacier is virtually impossible to monitor because it terminates in Mendenhall Lake; any subglacial inputs into the lake are entirely inaccessible. However, I attained one sample from a subglacial conduit that surfaced on glacier left at a bedrock contact, so I must assume that it is indicative of Mendenhall Glacier's input into the lake.

This sample is composed almost entirely of fine-grained sand (between 75 and 150 _m diameter), with a small, but significant portion of clay and silt sized sediments (Prothero and Schwab, 1996). The upper section of Mendenhall River, just below the lake's outlet, carries suspended sediment with equivalent grain size distribution to that of the Eagle River. Thus Mendenhall's subglacial meltwater carries some fine sand-sized particles but not ones as large those carried by the Eagle's meltwater. Mendenhall Lake acts as a sediment trap for the grains larger than very fine sands, just as the Eagle Lakes do.

The section of the Mendenhall River by the lower bridge is also able to suspend a significant proportion of medium sized sand grains. Tidal influence could be significant on the Mendenhall River because it empties into the sea and has a low gradient, also, samples were not treated with deflocculant prior to being run through the laser particle size analyzer. Thus, the medium sand grains (100-200 _m in diameter) observed in the lower reaches of the river are likely due flocculation of clays in suspension caused by saltwater intrusion at high tides (Peijrup, 1988).

All samples taken near the primary meltwater conduit of the Herbert Glacier show similar distributions with peaks at diameters of about 30 and 200 _m, and maximum diameters of about 350 _m. Samples taken slightly downstream from the conduit display similar distribution to this, but have the second peak at 125 _m, and the maximum diameter at 225 _m. The lower section of the Herbert River by the highway bridge carried sediments of similar grain size to the Eagle River but with bimodal distribution showing two slight peaks in the very fine silt sizes.

Once the Herbert River moves outside of its confining bedrock walls and into the outwash plain the peak at 125 _m disappears and the distribution becomes much more uniform. The maximum grain size for this location is around 300 _m. Although the Herbert Glacier meltwater system did contain a sediment trapping lake as recently as 1982 (Figure 1, Carson et al., this volume), it no longer does. However, grain sizes larger than 30 _m settle out of suspension and are deposited by the time the meltwater makes its way downstream to the highway bridge.

Indeed, comparing samples taken from the Herbert conduit to those taken just 100 m downstream proves that the flattening of the stream gradient after it curves to flow parallel to the glacier front causes virtually all sediments larger than 250 _m to fall out of suspension. Similarly, the widening of the river just downstream from the glacier causes a large proportion of grains with diameters greater than 100 _m. It seems probable that the Herbert River's wide, braided channel and numerous sandbars are what trap the remaining large particles (>30 _m) that make it past the significant drop in river gradient leaving only very fine silt and clay sized sediments.

X-RAY DIFFRACTION

X-ray diffraction analysis showed little variation in mineralogy between the three systems. I had difficulty distinguishing between muscovite and illite since the latter can easily replace the former. So as in other studies (Zenger, 1969), I have assumed that all muscovite includes whatever illite content there may be. All samples analyzed showed very strong peaks for muscovite and illite, quartz, feldspar, hornblende, and chlorite, usually with muscovite being the dominant peak.

Three samples from the Eagle Glacier system were run for XRD analysis: one from the meltwater stream coming directly out from beneath the glacier, the second from the lower lake, and the third from the main river by the highway bridge before it empties into the sea. The relative intensity of quartz and feldspar peaks is highest in the sample taken from the stream coming directly out from under the glacier, and their peaks drop in relative intensity as one moves downstream. Conversely, muscovite and illite content displays the opposite trend; it is found in lowest proportions near the glacier, increasing in relative abundance in the downstream direction. Chlorite also increases in proportion with downstream distance, while hornblende stays relatively constant throughout.

The Herbert and Mendenhall Glaciers' meltwater systems exhibit similar trends in mineralogy as observed in the Eagle system: dominant muscovite peak, large quartz peak, lesser peaks of hornblende and chlorite, and a low feldspar peak. In a downstream direction, muscovite content increases significantly, while feldspar content decreases dramatically. Also, going downstream, relative abundance of quartz drops slightly and is coupled with a slight rise in chlorite.

I only analyzed one meteoric input stream, Montana Creek, for mineralogy but found the same minerals as in the glacial meltwater. However, the chlorite content of the sample was much higher than in any of the glacial meltwater samples; muscovite content is also fairly high. Quartz and hornblende amounts are comparable to levels in glacial meltwater samples, whereas feldspar is only found in very low concentrations in Montana Creek.

The similarity between the mineralogy of the suspended load in the three glacial systems is a good indication that the bedrock underlying the three glaciers is virtually the same. The mineralogy of the sediments is consistent with the observed bedrock composition of granodiorite and mixed metamorphics (Gehrels et al., 1992). Also, similarity between mineralogy of sediment in glacial meltwater and that of Montana Creek indicates that this meteoric stream is probably eroding older glacial sedimentary deposits, which would have higher sheet silicate contents as in the lower reaches of the streams.

Quartz grains tend to be larger than any of the other minerals present in the samples because quartz is more resistant to weathering. The decrease in quartz content the further one moves downstream is likely a result of these larger, thus more massive grains settling out of suspension. Once removed from the super-cooled temperatures of subglacial waters, feldspar is particularly susceptible to chemical weathering. The high surface area to volume ratio of the small grain sizes observed would also accelerate chemical weathering (Prothero and Schwab, 1996), which would account for the decrease in feldspar content at increasing downstream intervals.

Smaller particles and sheet silicates such as clays and micas settle far more slowly, which allows them to stay in suspension all along the course of the meltwater channels. So, the settling out of quartz and the weathering of feldspar coupled with the propensity of chlorite, illite and muscovite to stay in suspension explains the increase in relative abundance of these three minerals the further downstream one is in each of the three glacial systems as well as greater abundance in the meteoric stream. Overall, the high proportion of chlorite is not all that surprising since the glaciers lie over and erode the metamorphosed marine sediments of various accretionary terrains and the coastal plutonic complex (Gehrels et at., 1992).

CONCLUSIONS

No major differences are found between the three systems, except that the lakes in the Eagle and Herbert Glaciers tend to be particularly effective in trapping sand sized sediments. Dilution of suspended sediment load does not occur with increased discharge of meltwater. Concentration of suspended load in the three glacial systems increases with increased stage, but not with any regularity or predictable pattern

Although Mendenhall and Eagle lakes act as very effective sediment traps filtering out larger grain sizes and decreasing the total suspended load, the same process occurs in the Herbert meltwater system without the aid of lakes. It is a more gradual process, however, that cannot be pinpointed to a specific location or area along the drainage. The fact that the distribution of the smaller sized grains is virtually the same for all samples taken is an indication that the rock-flour produced by the glaciers has a relatively standard distribution.

The overall bedrock composition underlying each of the three glaciers must be relatively similar in order to yield virtually identical mineralogy of suspended sediment. Changes in suspended load mineralogy are due primarily to the hydrology of the meltwater system. Quartz tends to settle out of suspension while micaceous minerals do not; feldspar also settles out or is removed from the system by chemical weathering.

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