ROCK GLACIERS ON MILLER MOUNTAIN NEAR COOKE CITY, MONTANA

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Introduction

The Miller Mountain area was last glaciated by part of the mountain ice sheet covering much of the Yellowstone region during the Pinedale Glaciation which ended about 13,000 years ago (Pierce, 1979). Landforms of the area include glacial troughs, aretes, horns, cirques, and numerous periglacial features. Miller Mountain, elevation 3263 m, is located in the Absaroka Range approximately 5 km northwest of Cooke City, Montana, and 2 km east of the northeast corner of Yellowstone National Park. Aretes run west, southeast, and northwest from the summit.

Along the east, north, and northwest faces of Miller Mountain are at least six rock glaciers. Rock glaciers are defined as accumulations of blocky detritus extending downslope from talus cones or glaciers; rock glaciers creep due to deformation of internal ice (Wahrhaftig, 1987). The purpose of this study was to study the morphology of the rock glaciers, to gain an understanding of the processes involved in their formation, and to determine if these features are still actively undergoing deformation as a result of these processes.

Clockwise from northwest to southeast, the informal names of the rock glaciers are Sunset, Bull of the Woods, Weasel, Midway, Highrock, and Whitebark (Figure 1). The rock glaciers, which lie against the valley walls of Miller Mountain, are talus-fed lobate rock glaciers with the exception of Sunset, which is a tongue-shaped rock glacier (Wahrhaftig and Cox, 1959). Due to time and resource constraints field work was focused on Whitebark and Sunset rock glaciers.

The supply of debris for the rock glaciers is fractured Eocene Absaroka volcanic rocks. At the base of Miller Mountain is the Heart Mountain "Fault " (Elliot, 1979). The volcanic rocks are underlain by Cambrian and Ordovician carbonates and shales (Figure 2).

General observations, rough surveys, and minor excavations were the primary methods of data gathering. Excavations were made in an attempt to study the soils and the internal characteristics of the rock glacier debris. Field data was supplemented with data from topographic maps and aerial photographs. Survey instruments included a total station and an inclinometer.

Description

The rock glaciers all posses typical rock glacier morphology including transverse and longitudinal ridges, deep furrows, and conical pits. Large boulders (up to 3 m in diameter) litter the rock glaciers. On Weasel rock glacier in particular, spalling and fracturing has reduced many of what were once large boulders to rubble. The front slopes of the rock glaciers vary significantly but are as steep as 43° on Sunset rock glacier. Slope angles in furrows and on sides of ridges are as much as 37 ° on Whitebark rock glacier. These steep angles suggest that the conical pits and furrows are locally active and may be the result of ongoing collapse of debris into subsurface crevasses and channels (Potter, 1972). Channels in the subsurface ice may be due to thermal erosion by meltwater or percolating summer precipitation. Downward movement of fines has resulted in rock glacier surfaces that are mostly coarse debris and in a concentration of fines just below the surface.

In the upslope direction there is a trend from moraine to rock glacier to talus. The outer landforms tend to have gentler slopes, more soil development, vegetation such as trees and grass, and a generally smaller clast size. Upslope there is little soil development, vegetation is restricted to lichens, and mean clast size increases. On some rock glaciers, there are lobes of different ages; these lobes can be distinguished on the basis of weathering, soils, vegetation, color, clast size, surface morphology, and overlapping relationships.

There is much evidence for the presence of internal ice. An excavation into the bottom, west side of a furrow located near the terminus of Midway revealed the following sequence: 30 cm of matrix-free coarse cobbles at the surface; 30 cm of wet finer cobbles with a fine-grained matrix; 20 cm of matrix-free coarse cobbles; ice crystals starting to form a matrix at 80 cm. The bottom of this furrow contained shallow pools of standing water overlying ice-cemented debris. On Weasel rock glacier ice-cemented debris and/or debris-free ice were found near the bottom of the pits and furrows; standing water was ponded on top of the ice. On Sunset ice-cemented debris was found at the talus/rock glacier transition. There were also longitudinal ridges of debris-covered snow, apparently from mass wasting. Standing water (temperature 1° C) was present in the bottom of the deep conical depression on Whitebark. Water could be heard running beneath the surface debris of Weasel. It is assumed that this is the result of meltwater lying on ice or an ice-cemented surface. Just downslope of Whitebark rock glacier were two separate springs with water temperatures of 1°C. In contrast, Miller Creek (approximately 150 m downslope) had a temperature of 11

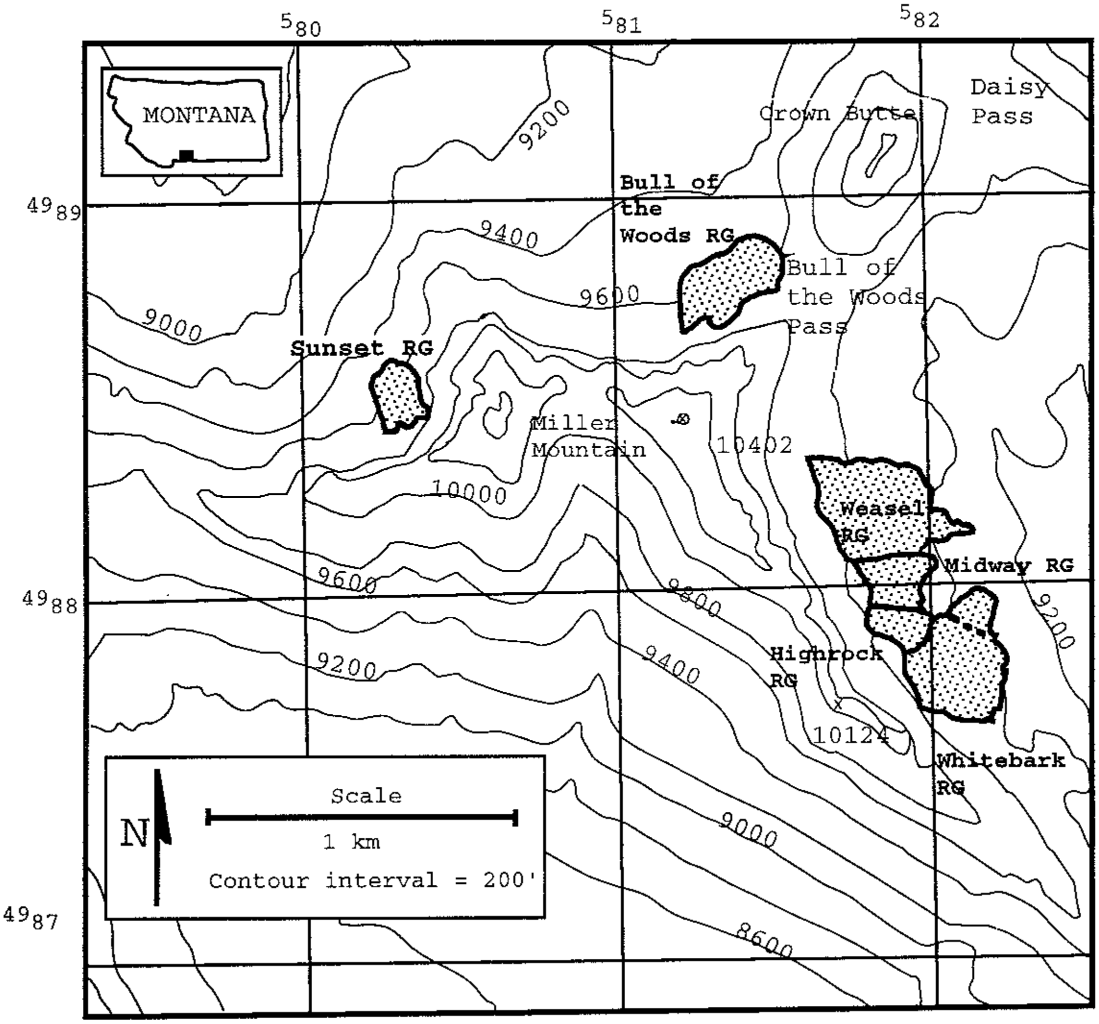

Figure 1: Location of Miller Mountain rock glaciers.

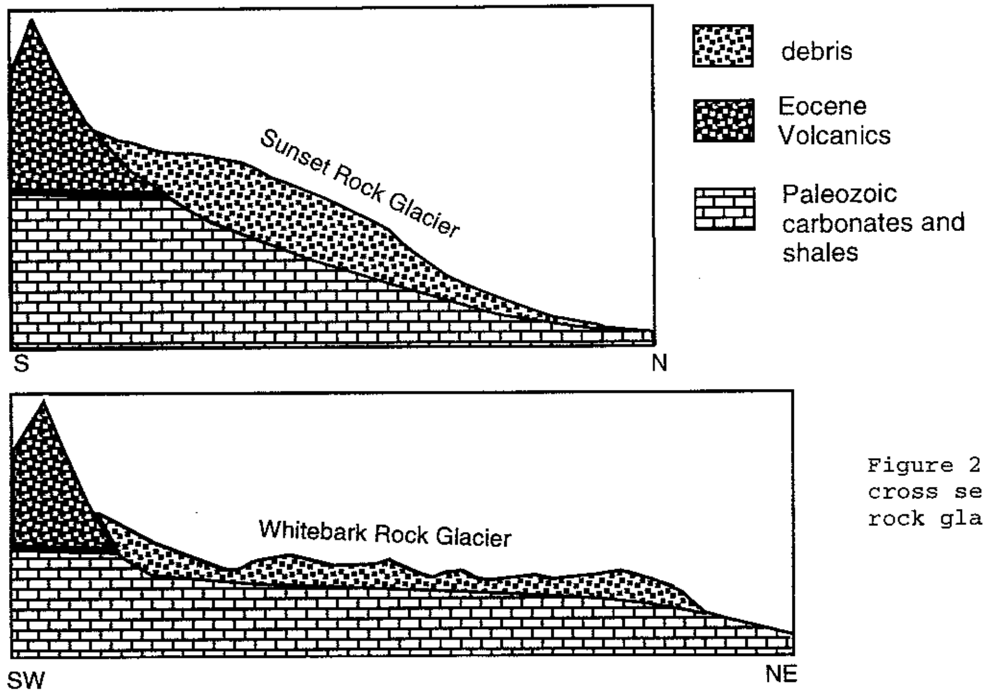

Figure 2: Diagrammatic cross sections of two rock glaciers

°C. The presence of interstitial ice is not indicative of activity. Present steep morphology may be the result of ongoing stagnation or the result of creep processes.

Processes

Sunset is steeper and thicker than the other rock glaciers (Table 1). Calculations indicate a shear stress of 2.3 bars for Sunset rock glacier. Its front slope of as much as 43° is very unstable. Based on calculations for Whitebark, Midway, and Weasel, it appears that the shear stress in these 3 rock glaciers is too low to allow deformation of internal ice (Table 1). This implies that they are inactive rock glaciers and that the processes which originally formed them are no longer operating. In order for shear stress to reach values of 1 bar (the minimum shear stress needed to deform pure ice) the thickness and/or slope would have to be greater. The presence of an ice core would thicken the rock glacier, possibly providing the right conditions for flow. Front slope angles also support the conclusion that these 3 rock glaciers are inactive.

Rock Glacier	Whitebark	Highrock	Midway	Weasel	Bull of the Woods	Sunset
Length (m)	215	140	210	305	165	190
Status	Inactive	Inactive	Inactive	Inactive	Inactive	Active
Width (m)	290	135	160	265	330	140
Length:Width	0.74	1.04	1.31	1.15	0.50	1.36
Area (m^2)	72,800	18,200	28,000	82,600	53,200	23,800
Thickness (m)	11	------	18	26	------	40
Volume (m^3)	8.1×10^5	------	5.0×10^5	2.1×10^6	------	9.52×10^5
Surface Inclination	5 °	------	7 °	5.5 °	------	10 °
Shear Stress (bars)	0.17	-----	0.39	0.46	------	2.3
Elevation (m)	2895	2925	2925	2950	2955	3030
Aspect	NE	NE	NE	NE	N	NW
Front Slope (steepest)	35 °	36 °	42 °	39 °	-------	43 °
Mean Front Slope Angle	27.7 °	------	-------	-------	-------	38.2 °

Table 1: Rock glacer data

Conical pits on Weasel and Whitebark suggest that perhaps these rock glaciers were once ice-cored. Pits as deep as 11m on Whitebark and 26 m on Weasel are difficult to explain without the former presence of an ice core or lenses of ice which melted.

Part of the supply for these rock glaciers was probably morainal debris left during deglaciation. However, most of the supply is from mass wasting of the steep sides of Miller Mountain. The mass wasting likely includes large rockfalls. Removal of lateral support as the mountain ice sheet retreated at the end of the Pleistocene caused unloading and destablization of valley walls and likely resulted in large mass wasting events. The presence of a ridge-top depression on the east peak of Miller Mountain suggests that lateral spreading and large rockfalls continue to the present.

Small rockfalls are an active and significant contributor to the talus which feeds the rock glaciers. Falling rocks were heard and seen many times every day in the field. Potter (1972) noted that rockfalls are most frequent during the first few weeks of spring, and in later summer and fall as nightly freezing increases frost wedging.

Climate

It is known that active rock glaciers require a periglacial climate with negative mean annual air temperatures. This implies the possibility of discontinuous permafrost. Thus the presence of active rock glaciers is indicative of permafrost (Barsch, 1988).

Potter (1972) used data from Crandall Creek and Yellowstone Lake weather stations (the closest weather stations to Miller Mountain) to derive an equation for temperature change with elevation. This equation [T= (2281 m - elevation in m)/95.3m/°] yields a mean annual temperature range from -6.7 to -7.9 °C for the elevations of the rock glaciers. However, temperatures in mountainous regions are known to vary dramatically making such data very approximate. Aspect can also have a dramatic affect on local temperature.

Age

Measurements of the thickness of weathering rinds showed little promise as the rates of clast disintegration are high. The largest rind sizes (8 mm) were present on all portions of Midway rock glacier suggesting that either the entire rock glacier is of the same age or that rinds of all sizes exist in debris across the rock glacier due to the degree of fracturing and excessive spalling . Merely picking up some of the rocks would cause disintegration.

Soils on the outer portion of Whitebark rock glacier are moderately developed with A horizons as thick as 18 cm and very thin B horizons, whereas soils midway upslope have 10 cm A horizons and no B horizons. There is no soil development near the top of Whitebark.

Vegetation follows a similar trend to the soils. One very large tree (estimated to be 300 years old) and several small trees grow on the outer ridge of Whitebark. Grasses exist in areas of soil accumulation on the lower half of the rock glacier. Only lichens grow at higher elevations.

Lichen growth on these rock glaciers seems to be more dependent on aspect than on any other factor. Lichen size seems to be limited by clast size. The clasts disintegrate so quickly that lichens of significant size has no chance to grow. There are no local areas of known age disturbance to develop a lichen growth curve. Thus absolute age determination using lichen age dating methods was not possible.

Perhaps the strongest argument for an approximate age of the rock glaciers is the presence of deep conical pits which appear to be ice stagnation features resulting from the melting of an ice core or thick ice lenses. This would suggest a late Pleistocene age for the formation of rock glaciers since this was the most recent time that significant ice existed in the area.

Conclusions

The rock glaciers at Miller Mountain probably formed late in the Pleistocene and may have once had ice cores, but it is unlikely that they still do. There was likely a transition from an active glacier to a stagnant glacier to an active ice-cored rock glacier to an inactive rock glacier.

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