Abstract:
A rock glacier one mile long, 200-500 feet wide, and ranging in elevation from 8,500 to 9,950 feet, descends from the northeastfacing cirque of Lone Mountain at the head of West Fork of the West Gallatin River. The majority of material comprising the rock glacier is slabby, angular, andesite porphyry with average maximum diameter of eight inches. A very small percentage of debris consists of angular silicious siltstone boulders.

In mid-August interstitial ice was present at depths of four feet near the upper limit of the rock glacier, twelve feet near the middle, and two feet at the downvalley terminus.

As determined by morphology and stability, the rock glacier can be divided into three parts, possibly representing three episodes of neoglacial activity. The lower part with a relatively smooth slope (average slope 17 degrees) and a gently convex, downvalley terminus is covered by lichens, some grass, and a few trees. The middle part consists of several imbricate lobes, whose downvalley termini are abrupt and steep (40 degrees), displaying no lichen growth.

The upper part with an average slope of seven degrees and a 40 degree frontal scarp has a permanent snowfield at the upvalley end. Lichen growth near the frontal scarp is minor, and completely lacking nearer the snowfield. The surface is characterized by longitudinal and transverse ridges, separated at regular intervals by shallow furrows. The fresh, abrupt, downvalley scarps, diminished lichen growth toward the upper end, and overturned lichen-covered rocks indicate instability in the middle and upper areas.

In presenting this thesis in partial fulfillment of the requirements for an advanced degree at Montana State University, I agree that the Library shall make it freely available for inspection. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by my major professor, or in his absence, by the Director of Libraries. It is understood that any copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Signature Jimmy Goolsby

Date May 26, 1972

EAST ROCK GLACIER OF LONE MOUNTAIN,
MADISON COUNTY, MONTANA

by

JIMMY EARL GOOLSBY

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

Earth Science (Geology)

Approved:

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MONTANA STATE UNIVERSITY
Bozeman, Montana

June, 1972

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This writer is extremely grateful to Professor John Montagne of the Department of Earth Sciences, for his help both in the field and in the writing of this report. He served both as principle investigator of the geology portion of the grant and faculty advisor to the writer. His help and encouragement made this study an enjoyable as well as an educational experience.

Thanks are also extended to Clifford Montagne who helped to introduce this writer to the area around Lone Mountain.

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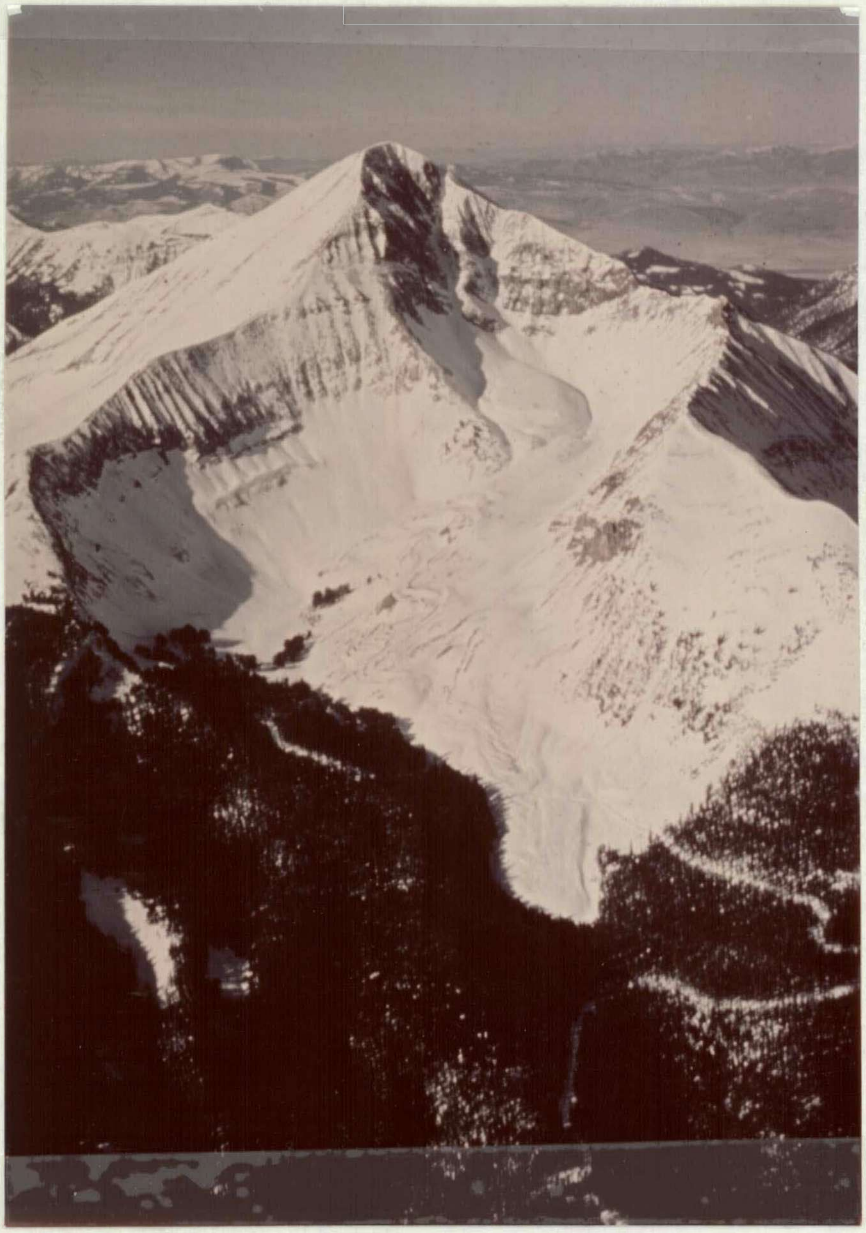

Figure No. 1. Large east facing composite cirque of Lone Mountain containing the East Lone Mountain Rock Glacier. Lowest lobe of rock glacier extends into tree area in foreground.

INTRODUCTION

This thesis concerning Lone Mountain and the East Rock Glacier of Lone Mountain was written because of the growing public interest in the natural phenomena of the area. Kehew (1971) and Montagne (1971) helped to create public interest in the rock glaciers of Lone Mountain by mentioning them in their theses which were completed during the preceding year. At that time Montagne suggested that the "active rock glacier" be studied in more detail.

This report is based on field work conducted on Lone Mountain during parts of July through October, 1971. Funds were furnished by the National Science Foundation R A N N Program Project No. 29908X. The grant was jointly administered by the Center for Planning and Development, the Endowment and Research Foundation and Department of Earth Sciences of Montana State University. The grant supports an interdisciplinary study of the West Fork Basin and Gallatin Canyon which will establish environmental base lines for comparison as the canyon is further developed. The grant project is entitled The Impact of a Large Recreational Development on a Semiprimitive Environment. Professor John Montagne, Montana State University, was the principle geologic investigator for the project and this writer was funded as his research assistant.

Scope and Method of Study

Field mapping was completed on U. S. Forest Service aerial photograph E I 0-13-222 magnified to a scale of 11 inches per mile or approximately 1:5751. All portions of the East Rock Glacier were traversed and observed many times. Pits were dug into the rock debris to check depth to running water and ice. All important aspects of the rock glacier were noted and photographed, measurements were taken, and rock orientation studies were attempted. By noting differences in lichen growth and surface morphology, relative ages were deduced.

Objectives of the Study

The objective of this research was to make a detailed study of the high-level erosional processes of Lone Mountain with special emphasis on the East Rock Glacier. The question of origin, time of origin, content, and stability of the rock glacier were important in guiding the field research during 1971. The results of this study should be helpful in developing public-use policy regarding Lone Mountain and its vicinity.

Location and Geologic Setting

The following references supplied general information in writing this section of the thesis; and, they should be consulted for more detail concerning the area geology: Montagne, 1971; Thornbury, 1965; McMannis and Chadwick, 1964; Hall, 1961; Swanson, 1950.

East Lone Mountain rock glacier (Figure No. 1), 111° 26' W Long. 45° 17' N Lat., which is the focal point of this thesis is located in the northeast and the lower east-facing cirques of Lone Mountain, Madison County, Montana. Lone Mountain is located on the west boundary of the West Fork Basin of the Madison Mountain Range which is within the Northern Rocky Mountain Province. North of Lone Mountain the east trending Spanish Peaks Fault (a high angle reverse fault with at least 10,000 feet of displacement) forms the north boundary of the West Fork Basin. Pre-Cambrian metamorphic rocks are exposed on the upthrown north side of the Spanish Peaks Fault; and on the downthrown south side, within the West Fork Basin, softer Cretaceous sedimentary rocks are exposed. The Lower Basin Syncline, paralleling the Spanish Peaks, forms most of the West Fork Basin.

Lone Mountain, at an altitude of 11,166 feet, forms part of the drainage divide between the Gallatin River to the east and the Madison River to the west.

Lone Mountain is a multiple horizon laccolithic intrusion or in simpler terms, a "Christmas tree laccolith." The dominant rock material is andesite porphyry which forms thick sills that are crosscut by some younger basalt porphyry intrusions. The sedimentary rock material is silicious siltstone containing thin interbedded black shale units. These rocks are Cretaceous in age. Some minor faulting has occurred throughout the complex.

Fan, Cedar, and Pioneer Mountains to the southwest are similar to Lone Mountain in composition. Together with the Lone Mountain complex these intrusives, consisting of andesite-dacite porphyry, cover an area of approximately 50 square miles. All the material is intruded into Upper Cretaceous sedimentary rocks and the ratio of intrusives to sedimentary rocks is probably about one to one. The total thickness of intrusive rock in a single column is in excess of 2,000 feet. (Swanson, 1950)

The Upper Cretaceous units and the intruded sills were all folded during Spanish Peaks faulting, indicating late or post Cretaceous age of the intrusions and the post intrusive age of the Spanish Peaks Fault. Thus, according to Hall, (1961) the Spanish Peaks Fault is post-Late Cretaceous, possibly as young as Oligocene.

Previous Work and Terminology

Theories concerning the origin of rock glaciers are varied. For the most part these theories have been reviewed by Wahrhaftig and Cox (1959) and Potter (1967), and the following summary is taken primarily from their treatments of the subject.

Cross and Howe (1905, p. 25) considered the common, streamlike rock glaciers to be unusual types of moraines. Howe (1909, p. 52) later wrote that rock glaciers were the debris of violent landslides.

Capps (1910, p. 364) believed that water from melted snow and rain sank into the debris at the lower edge of glaciers and was frozen, gradually filling the interstices with ice up to a point where melting equalled freezing. Movement was then caused by the melting of the ice followed by freezing and expansion of the water. Tyrrell (1910, p. 552-553) agreed in part with Capp's theory but suggested that originally the source of water was from springs, and that the concentric ridges characteristic of the surface of rock glaciers developed by downward sliding of the rocks after melting of ice during the spring.

Chaix (1923, p. 32) regarded rock glaciers as terminal moraines filled with mud and clay. He believed that the interstitial mud acted as a lubricant and, aided by freezing and thawing, caused the debris to move down-slope. Kesseli (1941, p. 226-227) believed rock streams to be of glacial origin, and thought the wave patterns on their surface were formed as a result of deformation under the weight of overriding ice. He suggested that if rock glacier movement occurred it was due to a tendency to creep after deposition or to a remaining ice core. He did not believe that creep could have been responsible for initiating the rock glaciers. Richmond (1952) believed rock glaciers to be residual from small glacial advances and that the surface morphology retained the essential configuration and structure of the ice.

Wahrhaftig and Cox (1959, p. 401, 406, 433, and 514) concluded that the movement of rock glaciers is the result of the flow of interstitial ice. Thompson (1962, p. 212) concurred.

Potter (1967, p. 4, 21-22) found the internal composition of a moving rock glacier in the Absaroka Range of Wyoming to be clean ice. White (1971) and Benedict (1965) found the same situation, clean ice-cored rock glaciers, in the Colorado Front Range.

Wahrhaftig and Cox (1959) have stated that "theories of thier (rock glaciers) origin are almost as numerous as the reports of their occurrence--evidence of the challenge that these interesting forms have presented to the imaginations of geomorphologists." The preceding statement seems to indicate that there is still much to be determined concerning rock glacier origin.

Terminology

In this thesis the term rock glacier will be used for any feature fitting the following description: a rock glacier is a tongue-like body of loose rock rubble, resembling an actual ice glacier, originating in high mountain catchment basins, and showing evidence of either past or present movement. This definition can be used to identify rock glaciers from distances in the field or by examination of aerial photographs. Rock glaciers that contain considerable debris cemented by interstitial ice will be called ice-cemented rock glaciers, and rock glaciers that are composed of relatively clean glacier ice mantled by debris will be called ice-cored rock glaciers. These terms and their definitions were proposed by Potter (1967, p. 4).

Relation of Stratigraphy to Rock Sliding

As has already been mentioned, Lone Mountain is a multiple horizon laccolithic intrusion. Approximately 50 percent of the mountain is composed of andesite porphyry (the major intruding material) and the other 50 percent is comprised of Upper Cretaceous beds of alternating sandstone, silicious siltstone, and black shale. Since fern leaves have been found within the stratigraphic sequence, it is possible that the sedimentary rocks of Lone Mountain are part of the Albino Formation, described in this area by Kehew (1971) and Hall (1961).

The andesite porphyry seems to weather (mechanically) at a relatively rapid rate on Lone Mountain mostly because frost heaving has increased the natural fracturing tendency of this rock type. Most of the slopes formed on the andesite are at the maximum angle of repose for loose rock of that size and shape (40 degrees). Where the andesite is the capping rock material along a ridge, it forms a knife edge with a 40 degree slope on either side. The andesite breaks up into relatively small flat pieces and is carried downhill by steady creep processes.

The sedimentary rocks composed mostly of resistant silicious siltstone stand out as cliff faces or benches wherever they outcrop. The siltstone weathers very slowly and where it is found overlying either a thin shale unit or one of the more rapidly weathering igneous rocks of Lone Mountain it may form an overhang. Of course this situation is condusive to rock slides.

The overhanging of silicious siltstone near the east terminus of the south-facing north wall has been the cause of a major rockslide (Figure No. 2). A block of overhanging siltstone is presently perched at the head of the previous rock slide.

Snow Avalanche

Snow avalanches are believed to be a common occurrence in the east cirque of Lone Mountain. Large snow cornices were observed along the north-facing ridge and peak of Lone Mountain during the late spring of 1971.

Snow breccia, which is an indicator of snow slab avalanches, was abundant within the east cirque on July 10, 1971 (Figure No. 3). The trees within the cirque show evidence of having been in the path of snow avalanches. A large percentage of the trees have been broken off at similar heights. Snow avalanches, breaking off parts of the trees that were not buried by snow at the time of the avalanche or avalanches are responsible for this phenomena. Erratic debris such as trees is widely scattered in some areas indicating an avalanche path (Figure No. 4).

Occurrence of snow avalanche in mountainous terrain is very common. In some areas avalanches can be controlled by dynamiting or shelling likely points of origin. Snow avalanches within the east