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ROCK GLACIERS ON THE WEST SLOPE OF SOUTH BALDY MAGDALENA MOUNTAINS SOCORRO COUNTY NEW MEXICO

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INTRODUCTION

South Baldy is a prominent peak in the central portion of the Magdalena Range approximately 128 km southwest of Albuquerque and 28 km west of Socorro, New Mexico (fig. 1). Access is provided by U.S. Highway 60 and U.S. Forest Service Road 235 (Water Canyon Road). The junction of U.S. 60 and Water Canyon Road is approximately 17 km east of Magdalena and 24 km west of Socorro. From this junction the distance to the South Baldy area is 18 km. The six rock glaciers described in this paper are on the west flank of South Baldy and are accessible by foot from the mountain crest (fig. 2).

The Magdalena Mountains are a north-trending fault-block range some 40 km long and as much as 18 km wide. The range is bounded on the northeast by La Jencia Basin, on the south by a series of washes tributary to Rocky Arroyo, and on the west by the intermontane valley of Milligan Gulch. The Magdalena Mountains abruptly rise some 1285 m from a basal elevation of approximately 2000 m; their crest has an altitude of about 3000 m. South Baldy is the highest peak with a summit elevation of 3287 m.

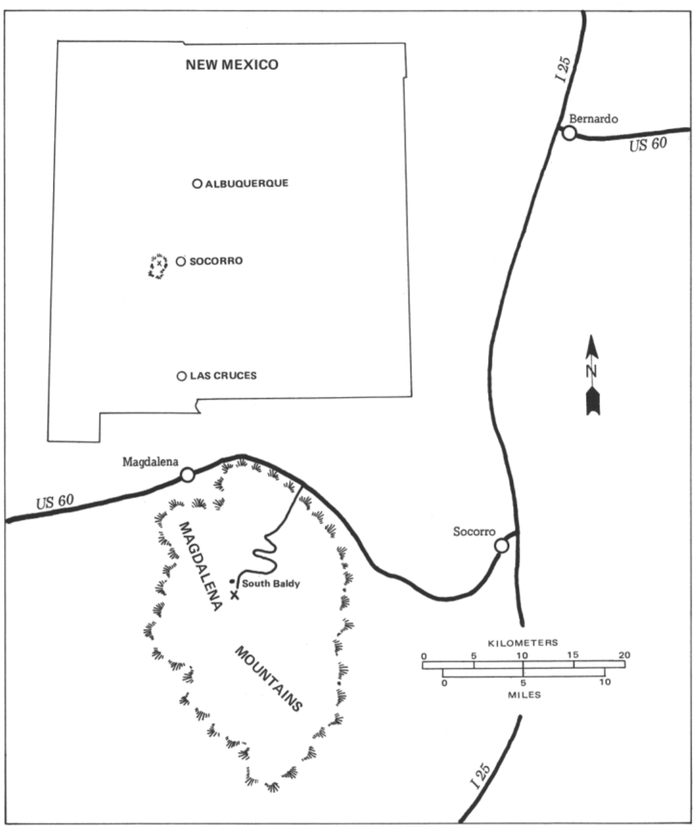

Figure 1. Location of South Baldy in the Magdalena Mountains, west of Socorro, New Mexico.

The northern portion of the Magdalena Mountains, north of Water Canyon, consists of Precambrian igneous and metamorphic rocks overlain on the crest and western slope by Paleozoic sedimentary rocks. Tertiary volcanic rocks overlie Paleozoic rocks in the northern part of the range and comprise all of the bedrock exposures south of Water Canyon, including South Baldy. The debris composing the rock glaciers is derived mainly from rhyolitic ash-flow tuffs.

Mass wasting is one of the dominant geomorphic processes operating in the Magdalena Mountains. Much of the exposed bedrock is intensely fractured by intersecting, steeply dipping joint sets. The closely spaced fractures allow surface water to penetrate the bedrock where it is subjected to repeated freeze-thaw cycles. The resultant ice wedging has produced extensive talus slopes throughout the mountains. Many of these slopes have undulating surfaces consisting of many small ridges and furrows. Ridges are parallel to the contour, indicating down slope movement which may be due to frost creep or solifluction. Soil slumps, solifluction lobes, and snow avalanche chutes also are common, especially at higher elevations.

The town of Magdalena, at an elevation of 1993 m, has the closest weather station maintaining continuous long-term weather records. Thirty-year normals for the period of 1941-1970 indicate a mean annual temperature of 11.3°C (U.S. Department of Commerce, 1973). January

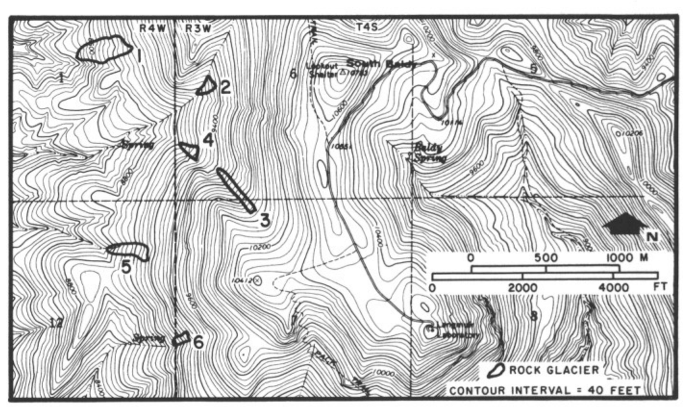

Figure 2. Topographic map showing location of rock glaciers on the west slope of South Baldy in the Magdalena Mountains. Numbered locations indicate rock glaciers discussed in the text. Map base is the U.S. Geological Survey topographic map of the South Baldy, New Mexico, 7.5 minute quadrangle.

is the coldest month with a mean temperature of 0.9°C; July is the warmest month with a mean temperature of 22.1°C. For the same period the average annual precipitation was 26.44 cm, with 60 percent of the total occurring during the three months of July, August, and September. Interpretation of climatic data presented by Tuan, Everard, and Widdison (1969) indicates a vertical temperature gradient of — 0.9°C/100 m and a vertical precipitation gradient of + 3.49 cm/100 m for the Magdalena area. Utilizing these figures, the following crude approximations of the current climatic conditions were determined for the South Baldy area: mean annual temperature 0.2°C; mean January temperature — 10°C; mean July temperature 11°C; mean annual precipitation 76 cm; and mean total precipitation for July, August, and September 46 cm.

DESCRIPTION

Rock glaciers are periglacial mass-movement deposits that commonly form in alpine regions and often are associated closely with glacial deposits. Potter (1972, p. 3027) defines a rock glacier as "a tongue-like or lobate body usually of angular boulders that resembles a small glacier, generally occurs in high mountainous terrain, and usually has ridges, furrows and sometimes lobes on its surface, and has a steep front at the angle of repose." Wahrhaftig and Cox (1959) distinguish two principal types of rock glaciers in the Alaska Range based on shape, ratio of length to width, and topographic position. Lobate rock glaciers are as broad or broader than they are long, and are single or multiple lobes that originate at the base of talus cones. Tongue-shaped rock glaciers are longer than they are broad and form when lobate rock glaciers from the sides and back of a cirque coalesce, and the resulting mass flows down-valley.

Wahrhaftig and Cox (1959), in their studies in the Alaska Range, set a standard for the terminology of the gross features and surface microrelief of rock glaciers which is followed here. The front of a rock glacier is the steep face that marks the down-valley end. The sides are abrupt embankments, which generally diminish in height up-valley, and the head is the place where the rock glacier merges with the talus that feeds it. Lateral moraine ridges are prominent embankments which border the sides and are referred to in this paper as lateral ridges. Microrelief features on the rock glaciers on South Baldy are characterized mainly by longitudinal and transverse ridges and furrows. Longitudinal ridges and furrows usually extend the greater part of the length of a rock glacier and parallel the apparent direction of flow. Transverse ridges and furrows, perpendicular to the apparent direction of movement, are generally convex downslope. Transverse ridges commonly die out against longitudinal ridges or bend sharply to merge with them.

The rock glaciers on South Baldy are at the head of gullies eroded on the west slope of the mountain with an average elevation of about 2800 m (fig. 2). The altitudes of the heads as determined from the U.S. Geological Survey topographic map (fig. 2) range between 2735-3030 m and the fronts between 2570-2870 m. The average slope of the terrain underlying the rock glaciers is approximately 24°. The rock glaciers are tongue-shaped, with lengths of 120-400 m and widths of 30-150 m (fig. 3). Heads terminate at talus on the steep mountain slopes, and the sides rise as embankments 2-5 m high. Fronts slope 20-30° and are 5-50 m in height. Lateral ridges extend along the sides, are 5-15 m wide and about 1-5 m above the surfaces of the rock glaciers (fig. 4).

The surfaces of the rock glaciers slope toward the frontal faces at 5-12°. They have well-developed longitudinal and transverse ridges and furrows over much of their extent (fig. 5, 6). Crests of the ridges usually are 1-3 m above the floors of the adjacent furrows. Some areas are characterized by a hummocky topography due to many randomly distributed ridges and furrows with a relief of 1-3 m. Prominent transverse ridges are at the crests of the frontal faces, and depressions with

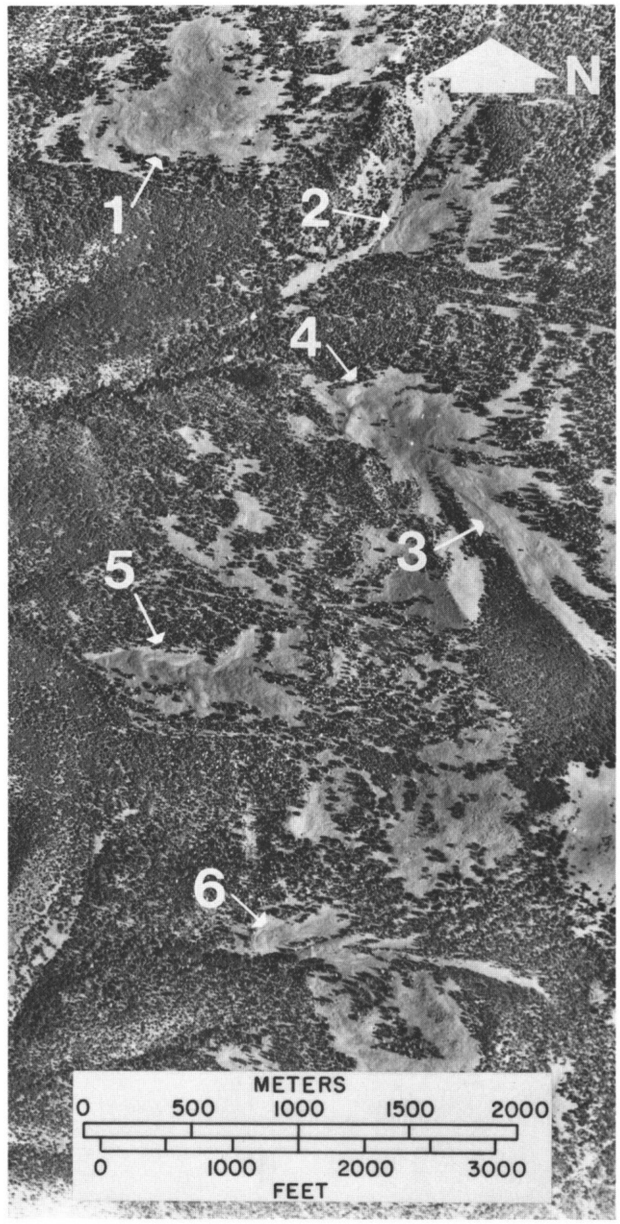

Figure 3. U.S. Department of Agriculture Forest Service aerial photograph (CIB-1774-131) showing physiographic expression of the rock glaciers on the west slope of South Baldy in the Magdalena Mountains. Locations of the rock glaciers are shown in Figure 2.

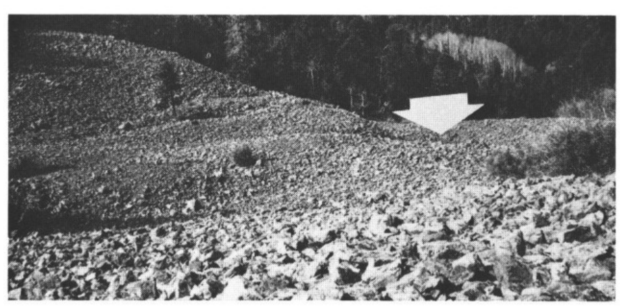

Figure 4. Gross features and surface microrelief on rock glacier 4 (fig. 2). View is to the southwest from the north side. Lateral ridge in foreground curves to form transverse ridge at the crest of the frontal face at the right. Depression behind transverse ridge is indicated by arrow. Longitudinal ridges and furrows are on the surface.

Figure 5. Longitudinal ridges and furrows developed on rock glacier 3 (fig. 2). Fine debris transported by water is in the furrows, whereas larger boulders cap the ridges.

maximum depths of 6 m often are directly behind these ridges. Transverse ridges and furrows are developed on some frontal faces, resulting in hummocky surfaces with a relief of 1-3 m.

The surface debris of the rock glaciers is stable and is composed of angular to subangular blocks and slabs of rhyolite, which range between 15-180 cm in diameter and average 30-60 cm. Subangular to subrounded fragments less than 25 mm in length probably were transported by water. Lichen commonly covers 40-80 percent of the exposed faces, and all but freshly exposed rock surfaces are oxidized. Over most surfaces the fragments are flat and randomly distributed with no preferred orientation. No exposure of an interior of a rock glacier was found, so the composition below the surface is unknown. Soil development is restricted, but groves of trees and shrubs project through the debris at some localities.

AGE AND CORRELATION

The rock glaciers on South Baldy are believed to be equivalent to the late Pleistocene (Wisconsin) or Neoglacial deposits in the Rocky Mountain region described by Richmond (1965) because they still retain pronounced constructional relief and are little affected by weathering. Richmond (1963, p. E123—E125) recognized two substages of late Pleistocene glaciation on Sierra Blanca Peak located 180 km southeast of South Baldy in southern New Mexico. Bull Lake glaciation is marked by two terminal moraines at 3000 m and 3170 m in a canyon extending northeast from a cirque. The moraines bear a mature soil about 100 cm thick. are considerablv dissected. and boulders both in and on the till

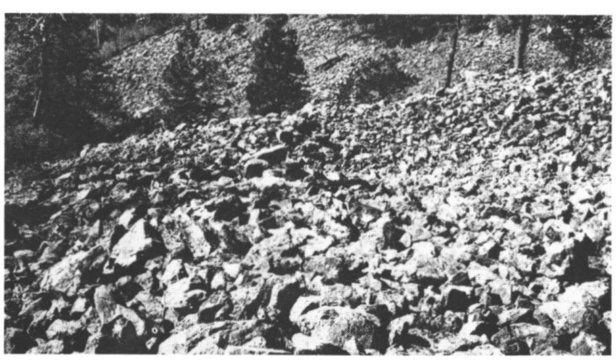

Figure 6. Transverse ridge and furrow on lobe at crest of frontal face of rock glacier 4 (fig. 2). Transverse ridge bends to form lateral ridge in middle ground.

are deeply weathered. Pinedale glaciation is characterized by three terminal moraines between 3200-3450 m on the steep slopes leading into the cirque. These moraines are little dissected and bear an immature soil about 25 cm thick. The cirque floor is between 3480-3510 m. Talus along the headwall is covered by soil, grass, and trees. No deposits having the characteristics of Neoglacial moraines, rock glaciers or protalus ramparts are described.

A moraine and protalus ramparts of Neoglacial age occur in cirques above 3230 m in the White Mountains of east-central Arizona about 235 km west of South Baldy (Merril and Pewe, 1972). The moraine is at about 3350 m and is composed of fresh boulders, with essentially no soil development. Protalus ramparts are in cirques which were not occupied by glaciers during the Neoglaciation, but no rock glaciers are described.

The absence of rock glaciers of Neoglacial age in the cirques on Sierra Blanca Peak and in the White Mountains suggests that the climate in the region during this time was not favorable for their development and further suggests that the deposits on South Baldy formed in the late Pleistocene. The rock glaciers may be equivalent to the Pinedale moraines on Sierra Blanca Peak, since both have undergone little physical and chemical alteration, and both have abundant lichen on the exposed surfaces of their debris. The scarcity of soil on the rock glaciers may be attributed to the lack of fine material which would provide a base for soil-building processes.

ORIGIN

Tongue-shaped rock glaciers may either be cemented with interstitial ice or contain buried glacial ice (White, 1976). Potter (1972, p. 3027) refers to rock glaciers that contain considerable debris cemented by interstitial ice as ice-cemented rock glaciers, and those composed of relatively clear glacial ice that is covered by debris as ice-cored rock glaciers. Wahrhaftig and Cox (1959, p. 412-413) believe that the interstitial ice in ice-cemented rock glaciers forms from compacted snow, by the freezing of water derived from rain and melting snow, and ground water that rises beneath the rock masses and freezes on contact with the air. The debris component provides protection from both the sun's rays and wind during the accumulation of the interstitial ice, and a supply of boulders is fed from the cliffs near the head by ice wedging. Movement may be due to deformation of the interstitial ice under pressure, the weight of the talus behind, or some interaction between the permafrost and ground water inside the rock glacier (White, 1981, p. 134).

White (1976, p. 79-80) believes that there are differences in the surface relief of ice-cored and ice-cemented rock glaciers and presents criteria for distinguishing the two types. Ice-cored rock glaciers are characterized by saucer- or spoon-shaped depressions between the base of cirque headwalls and rock glaciers, longitudinal furrows along both sides, central meandering furrows, and conical or coalescing steep-sided collapse pits. Ice-cemented rock glaciers are identified by longitudinal and transverse ridges. The rock glaciers on South Baldy are thought to have moved by the flow of interstitial ice because they have longitudinal and transverse ridges and lack the diagnostic features of ice-cored rock glaciers. In addition they occur 550 m below the average elevation of the late Pleistocene (Wisconsin) orographic snow line in southern New Mexico (Richmond, 1965, fig. 3), which precludes movement due to a core of glacial ice.

Barsch (1977, p. 234) proposes a model for the formation of ice-cemented rock glaciers below talus in the Swiss Alps which may be applied to the deposits on South Baldy. The production of talus blocks in the cliffs above the talus increases the weight of the debris at the base of the cliffs. The lower part of the talus cemented by interstitial ice then becomes unstable when the threshold of the critical shear stress is overcome, resulting in a lobate rock glacier which begins to creep away from the cliff. As the lobate rock glacier continues to move, it is confined by the valley walls and develops down-valley into a tongue-shaped rock glacier. If talus production persists and snow and water are available for the formation of interstitial ice, additional debris will be added to the tongue-shaped rock glacier developing down valley.

Gully heads eroded in rhyolite were the source for the rock glacier debris on South Baldy. The rhyolite is a fine-grained igneous rock of rather uniform texture cut by closely spaced joints and fractures. As a result, blocks and slabs were dislodged easily by ice-wedging action, producing a large volume of talus. The debris accumulated at the base of the gully head and became cemented by interstitial ice. When the ice-cemented debris began to move away from the gully head, it was confined by the sides, and a tongue-shaped rock glacier developed. In one of the gullies talus production was abundant, resulting in the generation of two rock glaciers (fig. 2, 3). Rock glacier 3 formed at the head of the gully and was supplied by debris from the headwall. Rock glacier 4 developed down-slope from rock glacier 3, and formed from talus that was produced along the side walls and accumulated on the gully floor.

CLIMATIC INTERPRETATION

Inactive and fossil rock glaciers have paleoclimatic significance because they indicate former lower temperatures or greater precipitation or both (Washburn, 1973, p. 198). Specifically, they are evidence of former periglacial conditions, since they indicate colder climates and permafrost. The formation of a rock glacier requires a climate which allows the dislodgement of talus by intense freeze-thaw action. Optimum conditions for ice wedging at the present time appear to be a moist climate with frequently recurring freeze-thaw; this process also occurs in dry climates but apparently more slowly (Flint, 1971, p. 271). Active rock glaciers which owe their movement to interstitial ice imply the presence of permafrost and a periglacial climate of sufficient intensity to permit ice to exist and deform under pressure (White, 1981, p. 134).

Brakenridge (1978) presents evidence that the full glacial climate (27,000-13,000 years ago) in the American Southwest was cold and dry. Relict snow lines and cryogenic deposits are explained by a 7-8°C annual cooling, with total annual precipitation very much like that of the present. Interstitial ice observed in the late spring in a large inactive rock glacier in the San Mateo Mountains, located 48 km southwest of South Baldy (Blagbrough and Farkas, 1968, p. 822-823), indicates that precipitation in the region at the present time is adequate for ice preservation and suggests that lower temperatures alone are essential for rock glacier movement.

The rock glaciers on South Baldy formed under a periglacial climate during the late Pleistocene characterized by much diurnal freezing and thawing and indicate a zone of discontinuous permafrost at about 2800 m on the west slope of the mountain. Temperatures were low enough for interstitial ice to develop and for the deformation of the ice to take place under pressure. The mean annual temperature probably was near freezing, and the annual precipitation may have approximated that of the present.

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