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Abstract

Fossil, tongue-shaped rock glaciers of Wisconsin(?) age occur at the heads of canyons at an elevation of approximately 7,950 ft on Carrizo Mountain. The rock glaciers are 250–1,200 ft long and 200–400 ft wide. They have abrupt fronts, lateral ridges that delineate the flanks, and depressed areas extending from the crests of the fronts to the heads. They are composed of blocks and slabby clasts of igneous rock with lengths of 2–3 ft. Isolated areas on the rock-glacier surfaces are covered by an azonal soil of decomposed organic material approximately 6 inches thick. The rock glaciers moved by flow of interstitial ice; their formation 3,050 ft below the Wisconsin orographic snow line in southern New Mexico is attributed to the overlying debris, which protected the ice from wind and solar radiation. The interstitial ice indicates a Wisconsin periglacial climate with a mean annual temperature near freezing and a zone of discontinuous permafrost at approximately 7,950 ft on the mountain slopes.

Fossil rock glaciers on Carrizo Mountain, Lincoln County, New Mexico

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Introduction

Rock glaciers, which commonly occur in alpine regions near the snow line, are periglacial, mass-movement deposits that are composed of coarse to fine rock debris. Two principal types of rock glaciers were distinguished based on shape, topographic position, and ratio of length to width (White, 1981, pp. 132–134). Tongue-shaped rock glaciers are elongated masses of rock debris that are longer than they are broad. They usually occur in cirques or along valley floors. Longitudinal ridges and furrows that usually extend the greater part of their length and usually lay parallel to the direction of movement commonly occur along their sides. Longitudinal ridges often bend to form transverse ridges that are perpendicular to the direction of flow. Lobate rock glaciers are composed mainly of unsorted talus, and they are broader than they are long. They occur singly or in groups along valley walls, and they are usually an extension of talus. Most lobate rock glaciers have a few transverse ridges and furrows on their surfaces.

Two principal theories for the origin and movement of rock glaciers have been developed and both appear to be valid. Wahrhaftig and Cox (1959, pp. 412–413) proposed that rock glaciers owe their movement to the flow of interstitial ice that may form from compacted snow, from the freezing of water derived from melting snow and rain, or from ground water that rises beneath the rock masses and freezes on contact with the air. The debris component provides protection from both the sun and wind during the accumulation of the interstitial ice. The action of frost-wedging supplies additional boulders from the steep cliffs near the head of the rock glacier. Giardino (1983) proposed that the movement of rock glaciers cemented by interstitial ice may be the result of an interaction between fine-textured debris and an increase in hydrostatic pressure and lubrication within the rock glaciers. The second principal theory considers rock glaciers to be the debris-covered tongues of true glaciers that formerly occupied the floors of cirques (Richmond, 1952; Flint and Denny, 1958; Outcalt and Benedict, 1965). According to this theory the surface debris, thought to have been dropped onto a glacier by frost-wedging from the cirque walls, rests upon a core of till. Rock glaciers that contain considerable debris cemented by interstitial ice are referred to as ice-cemented rock glaciers, and those composed of relatively clear glacier ice covered by debris are referred to as ice-cored rock glaciers (Potter, 1972, p. 3027).

White (1976, pp. 79–80) presented criteria for distinguishing ice-cored and ice-cemented rock glaciers using surface features. Ice-cored rock glaciers are distinguished by saucer- or spoon-shaped depressions between the base of the cirque headwalls and the rock glaciers, longitudinal furrows along both sides, central meandering furrows, and conical or coalescing, steep-sided collapse pits. Ice-cemented rock glaciers are characterized by well developed longitudinal and transverse ridges.

Barsch (1977, p. 232) distinguishes three types of rock glaciers based on activity and ice content. Active rock glaciers show actual movement due to interstitial ice or core ice. Inactive rock glaciers no longer show any movement but still contain ice. Fossil rock glaciers are free of ice; they sometimes show collapse structures and have no evidence of recent movement.

Fossil, ice-cemented rock glaciers such as those on Carrizo Mountain are important in the reconstruction of ancient Quaternary environments because they are evidence of former periglacial climates, they indicate zones of discontinuous or sporadic permafrost, and they suggest approximate elevations of timberline. Presently active rock glaciers that move by the flow of interstitial ice in the ☞

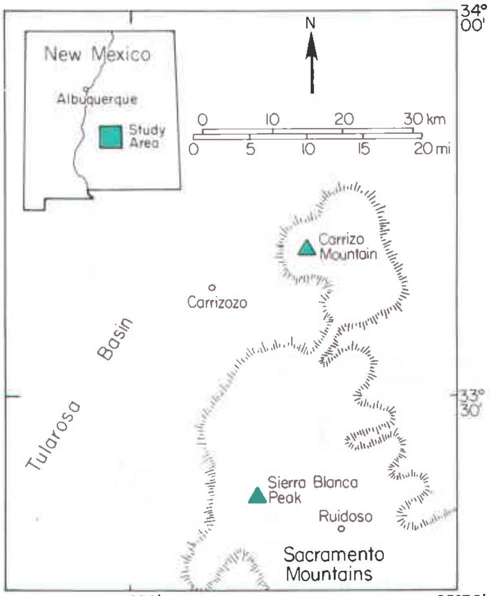

FIGURE 1—Location map of Carrizo Mountain, northeast of Carrizozo, New Mexico.

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Alaska Range (Wahrhaftig and Cox, 1959) and in the Colorado Front Range (White, 1971) are in areas where the mean annual temperatures are below freezing and where there is discontinuous and sporadic permafrost. However, the climate conditions under which these periglacial deposits formed are not clearly understood and they may have been distinct from the current conditions that allow these rock glaciers a little movement. Presumably, the formation of rock glaciers requires a climate that allows the dislodgement of blocks and slabs by intense freeze–thaw action, but wet and relatively warm conditions with much diurnal freezing and thawing may be more favorable for rock fall than a cold and dry climate.

Fossil, ice-cemented rock glaciers imply the presence of former permafrost and a periglacial climate of sufficient intensity to permit ice to exist and deform under pressure (White, 1981, p. 134). They are well defined, characteristic forms for the upper part of the periglacial (subnival) zone and can be used to determine the lower limit of the upper periglacial zone (Barsch and Updike, 1971). They also can be used to calculate the approximate elevation of the ancient timber line on a mountain slope and to determine the amount of timber-line depression because the upper periglacial zone is above timber line (Barsch and Updike, 1971, p. 241).

Location, physiography, and general geology

Carrizo Mountain is located approximately 10 mi northeast of Carrizozo, north of Sierra Blanca Peak in the Sacramento Mountains (Fig. 1). It has an elevation of 9,605 ft and is nearly an isolated dome approximately 5 mi in diameter. It rises approximately 3,000 ft above the Tularosa Basin on the west, and it is separated from other mountains on the north, northeast, and southeast by broad saddles with altitudes of 6,000–7,500 ft. The steep mountain slopes are dissected by canyons containing intermittent streams that flow mainly in the spring when snow melts and in the summer during afternoon thunderstorms. The heads of the canyons have floors that slope at about 12° and talus-covered walls that rise 1,000–1,500 ft above the floors.

The core of Carrizo Mountain is a steep-sided stock of probable Oligocene age that intrudes the Mesaverde Formation of Upper Cretaceous age (Petrl and others, 1984). It is composed of two steeply dipping, vertically oriented rhyolite bodies with an intervening quartz monzonite. The stock is partly bounded by faults on the north and northwest sides; small plugs and numerous dikes occur on the east and southeast flanks. Quaternary deposits on the slopes and around the base of the mountain include pediment gravels, alluvial fans, talus, and alluvium.

Three of the five life associations generally present throughout the region are on Carrizo Mountain (Martin 1964); their altitude distribution is controlled largely by slope exposure. The piñon–juniper association grows to elevations between 7,200 and 8,800 ft on the mountain slopes. The transition association characterized by ponderosa pine occurs above the piñon–juniper zone and is terminated by the spruce–fir association on the crest of the mountain. No climatic records are available for Carrizo Mountain, but the natural vegetation shows that the climate is more humid and temperatures are lower than in the adjacent lowlands. Carrizozo, in the Tularosa Basin at an altitude of 5,450 ft, has an average annual temperature of about 56° F and an average annual precipitation of 13 inches. Carrizo Mountain may receive between 16–20 inches of precipitation per year, and the average annual temperature is probably 40–55° F.

Description

Rock glaciers on Carrizo Mountain are at the heads of canyons and have elevations of 7,500–8,100 ft on the northwest, 7,800–8,000 ft on the west, and 8,300–8,500 ft on the south slope (Fig. 2). They are tongue-shaped and have lengths of 250–1,200 ft, widths of 200–400 ft, and possible thicknesses of 50–150 ft. Their heads terminate at talus on the headwalls of canyons, and their sides rise as steep embankments separated from the sidewalls by small gullies 10–50 ft deep. The fronts of the rock glaciers slope about 30° and are commonly 50–200 ft high. A single longitudinal ridge parallels each side (Fig. 3). These ridges have lengths of 100–500 ft, widths of 30–200 ft, and slope toward the front at about 15°. They head against talus and, in most instances, curve to form transverse ridges at the crests of the fronts (Fig. 4). Where transverse ridges are lacking, the longitudinal

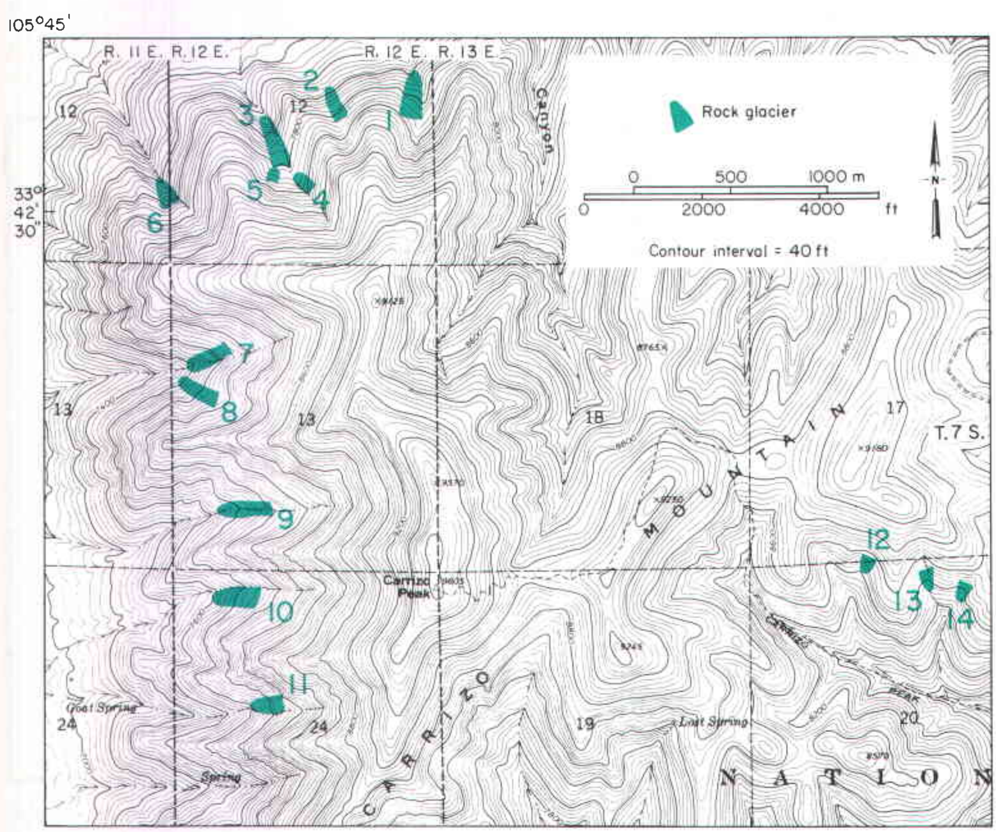

FIGURE 2—Topographic map showing location of rock glaciers on the slopes of Carrizo Mountain. Base map is the U.S. Geological Survey's topographic map of White Oaks south $7^{1}/_{2}$ min quadrangle.

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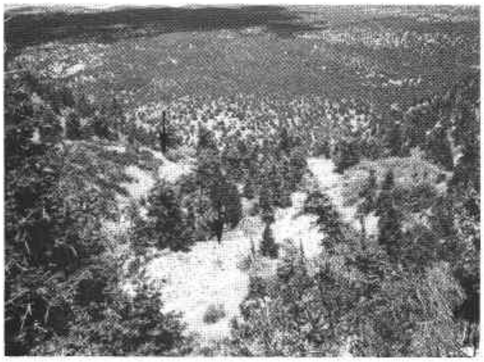

FIGURE 3—Rock glacier 1 on the northwest slope of Carrizo Mountain (*see* Fig. 2). View is to the north from the canyon head. Lateral ridges (arrows) delineate the flanks and are separated by a wide depressed area with trees in the center.

FIGURE 4—Rock glacier 5 on the west side of canyon on the northwest slope of Carrizo Mountain (*see* Fig. 2). View is to the northeast from west wall of canyon. The two lateral ridges bend to form a transverse ridge at crest of front on the right. The depressed area is between the lateral ridges.

ridges are separated by gaps along the crests of the fronts.

Depressed areas between the two longitudinal ridges generally extend from the crests of the fronts to the canyon heads, with lengths of 100–650 ft, widths of 50–200 ft, and depths of 10–50 ft. They range in form from wide, spoon-shaped hollows to narrow, V-shaped gaps that slope from the headwalls at about 12°. Topography with a relief less than 20 ft in the depressed areas is due to the presence of longitudinal and transverse ridges and furrows and many randomly oriented ridges and furrows.

The debris on the surfaces of the rock glaciers is stable and is composed of angular to subangular blocks and slabby clasts of igneous rock with lengths that range between 6 inches and 6 ft and average 2–3 ft. Subangular to subrounded fragments less than 1 inch in length appear to have been transported by water. Lichen commonly covers 40–80% of the exposed faces, and all but freshly exposed rock surfaces are oxidized. On most surfaces the fragments are flat and randomly distributed with no preferred orientation. No exposure of an interior of a rock glacier was observed and no coarse-above-fine sorting of the debris was visible in the fronts; therefore, the composition below the surface is unknown. A dark brown, azonal soil with a maximum thickness of 6 inches covers isolated areas on the surfaces of the rock glaciers. It is formed by decomposed organic material, which fills spaces between the debris, and it covers some of the blocks and slabs. Trees and shrubs grow on the soil and project through the talus at some localities.

Some rock glaciers (Fig. 2, nos. 3, 7, 8, 9) are composed of two talus tongues, both of which have steep fronts, lateral ridges, and depressed areas (Fig. 5). The upper tongue appears to have overridden the head of the lower. Both tongues have about the same degree of preserved surface features and about the same amount of area covered by soil and vegetation, which suggests that they formed during a single periglacial time. Three rock glaciers (Fig. 2, nos. 3, 4, 5) are in a canyon on the northwest slope of the mountain (Fig. 6). Rock glacier 3, the largest, is on the canyon floor, and the two smaller deposits extend from talus above. Rock glacier 5 encroaches upon the head of rock glacier 3, and rock glacier 4 is separated from the head of rock glacier 3 by talus. Physiographic relationships indicate that the two smaller rock glaciers are younger than the larger, but soil development and vegetation suggest that all three deposits formed during the same periglacial episode.

Age

No glacial deposits that could be used to establish a chronology are known to be present on Carrizo Mountain. Wisconsin moraines of Pinedale and Bull Lake age occur at altitudes of 9,850–11,300 ft below a cirque on Sierra Blanca Peak located 23 mi south of Carrizo Mountain (Richmond, 1963). The cirque floor is between 11,400–11,500 ft in

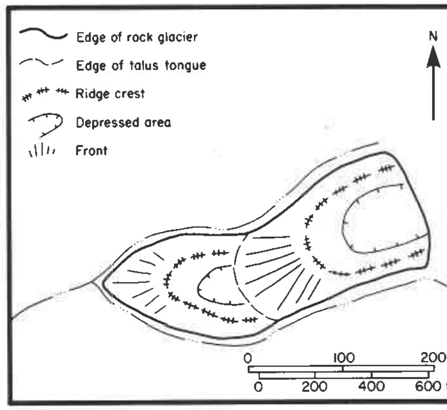

FIGURE 5—Sketch map of rock glacier 7 taken from U.S. Forest Service aerial photograph EDF–3–76. The rock glacier is on the west slope of Carrizo Mountain (*see* Fig. 2) and is composed of two talus tongues, each of which has a steep front, lateral and transverse ridges, and a depressed area. The upper tongue appears to have overridden the head of the lower.

elevation; talus along the headwall is covered by soil, grass, and trees. No glacial or periglacial deposits of Neoglacial age are described; however, moraines of Neoglacial age do occur below the lips of and in cirques above 11,200 ft in the Sangre de Cristo Mountains of northern New Mexico (Richmond, 1963).

Moraines of Bull Lake age on Sierra Blanca Peak bear a mature soil that is approximately 3 ft thick. They are dissected considerably and boulders both in and on the till are weathered deeply. Pinedale moraines are dissected slightly and have an immature soil that is approximately 10 inches thick. The Neoglacial moraines in the Sangre de Cristo ☞

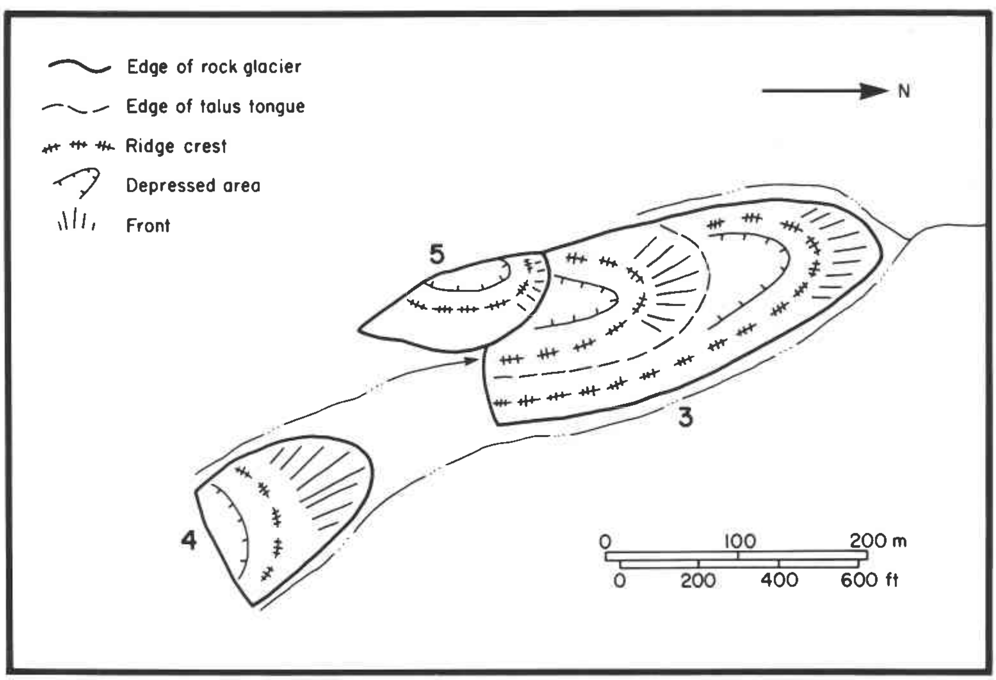

FIGURE 6—Sketch map of rock glaciers 3, 4, and 5 taken from U.S. Forest Service aerial photograph EDF-3-76. The rock glaciers are in a canyon on the northwest slope of Carrizo Mountain (*see* Fig. 2). The large rock glacier on the canyon floor is composed of two talus tongues; physiographic relationships indicate that it is older than rock glaciers 4 and 5.

Mountains have azonal soils up to 8 inches thick in areas where fine material is exposed.

The rock glaciers on Carrizo Mountain are thought to be equivalent in age to either the Wisconsin or the Neoglacial deposits in New Mexico described by Richmond (1963) because they have well defined constructional relief and have undergone little weathering. The rock glaciers could be the same age as the Neoglacial moraines in the Sangre de Cristo Mountains because both have azonal soils less than 10 inches thick. However, the suitability of correlating soils on rock glaciers with those developed on moraines should be taken into account (J. B. Benedict, written comm. 1984). The rock glaciers on Carrizo Mountain are composed of blocks and slabby clasts with voids between the debris so that some time lag was involved in acquiring the fines needed for soil formation. The Neoglacial moraines in the Sangre de Cristo Mountains had fines exposed at the time of deposition that provided an immediate base for soil-building processes. Because the soils on the rock glaciers and the moraines are similar, the rock glaciers could be older (Wisconsin) because of the time involved in the accumulation of fines. The absence of Neoglacial deposits in the cirque on Sierra Blanca Peak suggests that the climate in southern New Mexico during the Neoglaciation was not suitable for the formation of periglacial deposits and supports a Wisconsin age for the rock glaciers on Carrizo Mountain.

Origin

The rock glaciers on Carrizo Mountain are believed to have moved by the flow of interstitial ice because they have well defined longitudinal and transverse ridges that are characteristic of ice-cemented forms, and they lack the central meandering furrows, longitudinal furrows, and collapse pits of ice-cored forms. In addition, Wisconsin glacier development in southern New Mexico was restricted to the cirque at approximately 11,450 ft on Sierra Blanca Peak, eliminating the possibility of movement due to core ice. The subdued ridges, soil and vegetation, and lichen-covered talus on the rock glaciers indicate that they are fossil forms that have been inactive for a considerable amount of time.

The steep walls of the amphitheaters formed by rhyolite and quartz monzonite are the source for the rock-glacier debris. The igneous rock is fine grained and of uniform texture and, because it is cut by fractures and faults, blocks and slabs were dislodged easily by frost-wedging, which resulted in a large amount of rock-fall talus. The debris accumulated at the base of the headwall and became cemented by interstitial ice. When the ice-cemented debris began to move away from the canyon's head by the creep of interstitial ice, it was confined by the canyon walls and a tongue-shaped rock glacier developed. In some of the canyons talus production continued and sufficient snow and water were available for the formation of interstitial ice, which resulted in the generation of a second rock-fall talus tongue that overrode the head of the first.

Climate

The rock glaciers on Carrizo Mountain formed during a time when temperatures were lower than current temperatures and the periglacial zone was depressed considerably throughout southern New Mexico. They indicate a zone of discontinuous permafrost near the lower limit of the upper periglacial zone at an elevation of approximately 7,950 ft, which is approximately 3,050 ft below the average altitude of the Wisconsin orographic snow line in southern New Mexico (Richmond, 1965, fig. 3). Permafrost was present in the rock glaciers at altitudes of approximately 7,750 ft on the northwest, 7,850 ft on the west, and 8,400 ft on the south slope of the mountain. These variations in elevation suggest that the direction in which the rock glacier faced was a factor affecting its development because north-facing slopes receive a minimum of solar radiation, whereas those with a southern orientation have maximum exposure to the sun. Even though the debris component provided protection from solar radiation, slope exposure still influenced the formation and preservation of the interstitial ice.

The rock glaciers on Carrizo Mountain indicate that the Wisconsin timber line was located at approximately 7,950 ft, which is within both the modern piñon–juniper and transition life associations of Martin (1964). The altitude approximates the elevation of the full-glacial Wisconsin timber line for the latitude of Carrizo Mountain (about 34° N.) calculated by Brakenridge (1978, fig. 1). The modern timber line is present on Sierra Blanca Peak at approximately 12,000 ft (Martin, 1964), which suggests that life zones on Carrizo Mountain were depressed approximately 4,050 ft during the Wisconsin. This amount of lowering closely approximates the maximum 4,000-ft late Pleistocene biotic-zone depression in the southwestern United States indicated by pollen analysis (Martin and Mehringer, 1965, p. 451). However, it is somewhat greater than the 3,100–3,300-ft depression during the late Wisconsin of ponderosa pine in the San Andres Mountains on the west side of the Tularosa Basin (Van Devender and Toolin, 1983, p. 51).

The rock glaciers on Carrizo Mountain formed at approximately 3,050 ft below the Wisconsin orographic snow line in southern New Mexico, which demonstrates the importance of the debris component in the formation and maintenance of interstitial ice. Ice-cored rock glaciers must originate in glaciated terrain near the firn limit. Ice-cemented rock glaciers can form below the orographic snow line because their ice is protected by the debris component, whereas glacier ice is exposed to the sun and wind. On Carrizo Mountain, late Pleistocene temperatures were low enough for the development of interstitial ice in talus at approximately 7,950 ft, but on Sierra Blanca Peak the combined factors of low temperatures and adequate snow fall conducive to the accumulation of exposed glacier ice in a protected locality were present at only approximately 11,450 ft.

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