Periglacial mass Movement deposits of late Wisconsinan age, Gallinas Mountains, Lincoln County, central New Mexico

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*John W. Blagbrough**

Abstract

Block streams, block slopes, and rock glaciers are periglacial mass movement deposits above 2,400 m (7,874 ft) in the Gallinas Mountains composed of angular blocks and slabby clasts of rhyolite. Block streams are on the floors of gullies and ravines that slope from 20° to 30° and have average lengths of approximately 150 m (492 ft) and average widths of 60 m (197 ft). Block slopes are present on mountain flanks and on the walls of ravines with slopes greater than 20°, extend parallel to the contour for hundreds of meters, and have no visible rock source or cliff above. Their surfaces are characterized by lobes and tongues of rubble, implying downslope movement of the debris. Tongue-shaped rock glaciers sloping at 15–20° are below block streams and block slopes on the floors of gullies and ravines, and have average lengths of 155 m (509 ft) and average widths of 50 m (164 ft). They have well-to-poorly defined flanks and fronts and well-developed longitudinal, transverse, and oblique ridges and furrows.

The periglacial mass movement deposits indicate a late Wisconsinan climate characterized by frequent freeze-thaw cycles, mean annual temperatures below 0°C, which favored the formation and preservation of permafrost, and a geocryogenic region above 2,400 m (7,874 ft). The mean annual precipitation was sufficient for soil saturation that resulted in the downslope movement of block-slope and block-stream rubble, probably by gelifluction. Surfaces of two ages on an extensive block slope indicate two late Wisconsinan periglacial episodes separated by a period when warmer and drier conditions prevailed.

Introduction

The purpose of this paper is to 1) describe the periglacial mass movement deposits in the Gallinas Mountains; 2) establish their age by correlation with late Wisconsinan climatic events in the Estancia Basin in central New Mexico and in the Capitan Mountains in south-central New Mexico; and 3) point out their climatic significance. White (1981) sets a standard for the nomenclature and identification of non-catastrophic alpine mass movement forms that are used in this study. In the Gallinas Mountains these forms include block streams, block slopes, and rock glaciers.

White (1981) defines a *block stream* as a narrow linear body of blocky debris extending farther downslope than across. These forms are on mountainsides or in the heads of ravines on the steepest slopes available either below or above timberline. Their thicknesses range from a few meters to approximately 10 m (33 ft). The longest axes of their tabular blocks may be oriented either parallel or normal to the slope direction or swing in a series of lobes with steep upslope dips.

Block slopes are present in both alpine and polar regions, usually above timberline, and are commonly associated with glacial and periglacial features (White 1976). Richmond (1962), in his studies in the La Sal Mountains of Utah, refers to these deposits as frost rubble sheets and rubble lobes. White (1981) defines a block slope as a sheetlike accumulation of large rock fragments on a mountain slope with an angle greater than 10°. They are more extensive along a mountain slope parallel to the contours than downslope and have no visible source rock such as a cliff or ledge at their head. Block slopes are an accumulation of debris over bedrock only a few meters thick. The blocks on the surface are larger than those at depth and are joined together or interlocked. The fragments may show a fabric with the long axes of the blocks aligned parallel to the slope direction indicating downslope movement. Debris on block slopes that have traveled long distances show a strong fabric, whereas rubble without such a fabric is derived from the bedrock beneath (White 1976, p. 91).

The origin of block streams and block slopes in alpine areas implies complex processes that may occur under periglacial conditions (Richmond 1962; Washburn 1980; White 1976). These include the generation of blocky debris and fine fragments by weathering and frost wedging; the movement of the debris by solifluction, gelifluction, or frost creep, resulting in a texture indicating downslope movement; and the subsequent removal of the interstitial matrix by washing or piping. This sequence of events explains the fabric of the deposits and suggests that motion once did occur when finer fragments between the blocks provided the means (White 1976).

Because active block steams and block slopes are widely distributed in alpine and polar regions, the presence of relict deposits in middle latitude highlands has been widely interpreted as recording former periglacial climates. However, Flint (1971, p. 277) notes that these deposits do not necessarily indicate a former frost climate unless they are associated with features that do indicate frozen ground. White (1976) and Washburn (1980) suggest that relict block steams and block slopes are reasonable evidence for former frost wedging resulting from frequent freezing and thawing cycles. Washburn (1980, p. 220) further points out that the production of large fragments in block deposits seems to be favored by deep penetration of freezing into jointed bedrock, and the widespread existence of large blocks of rubble probably is dependent on the low temperatures of periglacial environments, as well as frequent freeze-thaw cycles.

Rock glaciers are deposits of periglacial mass movement and products of glaciation that have been noted in many alpine regions throughout the world (Giardino and Vitek 1988). White (1981) defines a rock glacier as a tongue-shaped or lobate accumulation of unsorted, coarse-to-fine rock debris that moves down valley or away from a valley wall. Two principal types of rock glaciers are recognized based upon shape and topographic position (Wahrhaftig and Cox 1959; White 1981). Tongue-shaped rock glaciers are elongated masses of rock debris longer than they are broad that are common in cirques and on valley floors. Lobate rock glaciers are masses of unsorted debris that are as broad or broader than they are long and are present singly or in groups along valley walls as extensions of talus cones or talus aprons. Frost wedging supplies the debris for the development or rock glaciers and indicates a climate characterized by frequent recurring freeze and thaw (Washburn 1980, pp. 271–274).

Rock glaciers may move by the creep of glacial ice inside (ice-cored), by the recrystallization and creep of interstitial ice within the fine debris (ice-cemented), or by sliding at the base of the frozen debris within (White 1981). Ice-cored rock glaciers are distinguished by saucer- or spoon-shaped depressions between the base of the cirque head walls and the rock glacier, longitudinal furrows along both sides, central meandering furrows, and conical or coalescing, steep-sided collapse pits (White 1976). Ice-cemented rock glaciers are characterized by well-developed

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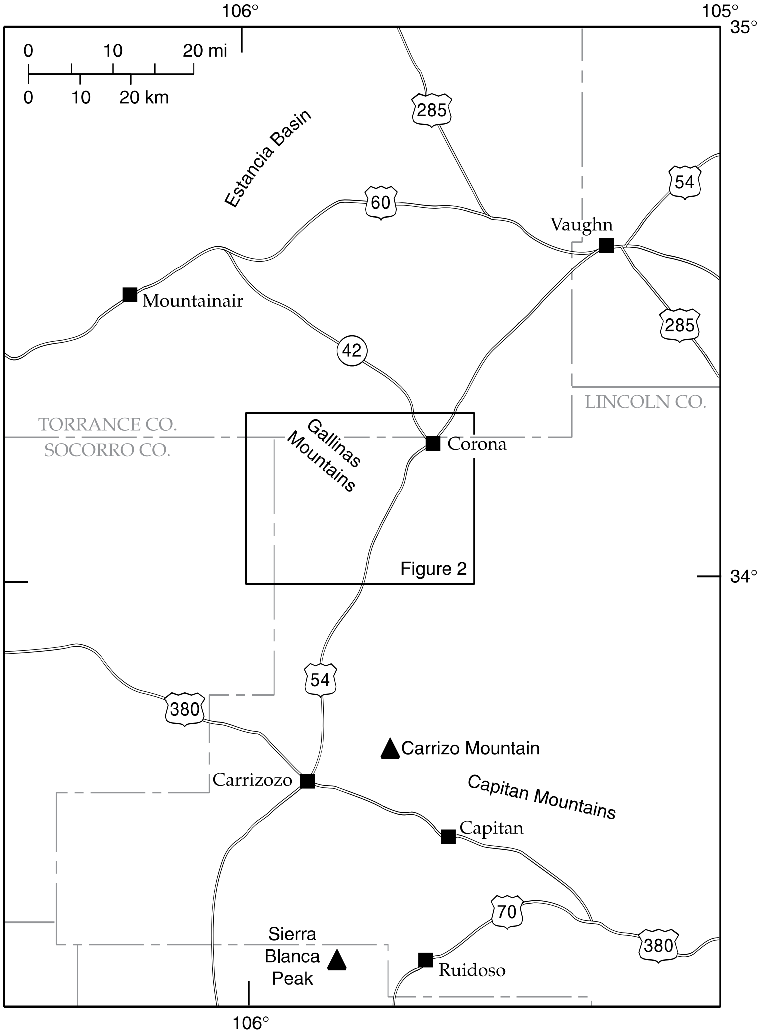

FIGURE 1—Location of the Gallinas Mountains, Capitan Mountains, Carrizo Mountain, and Sierra Blanca Peak in central and south-central New Mexico.

longitudinal and transverse ridges and heads that merge with the debris-covered slopes above. Active ice-cemented rock glaciers indicate the presence of sporadic permafrost (Corté 1987) and mean annual temperatures at ground level from 0° to –1°C (Péwé 1983).

Corté (1987) differentiates three geocryogenic (periglacial) zones in the central Andes (latitude 33° S). The parageocryogenic zone (500–3,200 m; 1,640–10,498 ft) is below the lower limit of sporadic permafrost (3,200 m). Above 3,200 m is the geocryogenic region with two zones. The lower Y zone (3,200–5,000 m; 10,498–16,404 ft) is permafrost with active layers and above 5,000 m is the intense geocryogenic Z zone with negligible thawing. Gelifluction occurs in both the parageocryogenic zone and the lower Y zone of the geocryogenic region, whereas rock glaciers are confined to the latter zone.

Geographic and geologic setting

The Gallinas Mountains are in the northwest corner of Lincoln County and cross over into the southern part of Torrance County in central New Mexico (Fig. 1). The mountains are accessible by 19 km (12 mi) of graded road that runs westward from US–54 approximately 6 km (4 mi) south of the town of Corona. They extend in a northwest direction for approximately 16 km (10 mi) and have a width of approximately 8 km (5 mi; Fig. 2). The main upland has an altitude of approximately 2,400 m (7,874 ft); the highest altitudes of 2,633 m (8,638 ft) at Gallinas Peak and 2,613 m (8,573 ft) at West Turkey Cone are in the northwest end of the range. The steep northern and eastern slopes of Gallinas Peak and the northern slope of West Turkey Cone rise approximately 450–455 m (1,476–1,493 ft) above the alluvium below and are cut by gullies and ravines with maximum depths of approximately 150 m (492 ft; Fig. 3).

The Gallinas Mountains are formed by a core of Precambrian granite overlain by approximately 600 m (1,969 ft) of Permian clastic sediments (Abo Formation, Yeso Formation, and Glorieta Sandstone) intruded by alkalic and subalkalic hypabyssal rock consisting mainly of porphyritic trachyte and rhyolite (Perhac 1970). Doming and faulting accompanied the igneous activity. The faults have a distinct northwest and northeast strike pattern, the former being the most prominent. Gallinas Peak and West Turkey Cone are part of a laccolith of light-colored, fine-grained porphyritic rhyolite. Isolated outcrops of Permian sedimentary rocks are visible along the flanks of the intrusion. Extensive areas of the upper slopes of Gallinas Peak and West Turkey Cone are covered by sheets of blocky debris that obscure the bedrock below.

Three of the five life zones ("associations" of conspicuous plants) recognized in the region by Martin (1964) are in the Gallinas Mountains, where their distribution is controlled largely by altitude and slope exposure. The desert grassland association is near the mountain base below 2,150 m (7,053 ft) and is succeeded by the piñon-juniper association on mountain slopes at altitudes between 2,150–2,250 m (7,053–7,382 ft). The transition association characterized by ponderosa pine is above the piñon-juniper association usually at altitudes greater than 2,250 m (7,382 ft), and it covers large areas of the upper slopes of Gallinas Peak and West Turkey Cone.

The town of Corona, at an altitude of 2,026 m (6,647 ft), is the closest weather station to Gallinas Peak with long-term weather records (Kunkel 1984). Forty-seven-year normals indicate a mean annual temperature of 10.5°C, and a 46-year record indicates an average annual precipitation of 39.2 cm (15.4 in) with approximately 50% of the total occurring during July, August, and September. Van Devender et al. (1984) suggest a mean annual temperature lapse rate in south-central New Mexico of 0.72°C/100 m. Using this value and the weather data from Corona, the following approximation of current temperature conditions was determined for the Gallinas Mountains: 7°C for the upper slopes at approximately 2,400 m (7,874 ft) and 6.5°C for the summit of Gallinas Peak. Using the weather data from Corona and altitudinal increases in precipitation for New Mexico (Tuan et al. 1969, fig. 14), a mean annual precipitation greater than that for Corona is implied for the Gallinas Mountains above 2,400 m (7,874 ft).

Description

Block streams, block slopes, and rock glaciers are periglacial mass movement deposits on Gallinas Peak and West Turkey Cone (Fig. 4).

Block streams

Block streams are on slopes of 20–30° in gullies and ravines eroded in the flanks of Gallinas Peak and West Turkey Cone

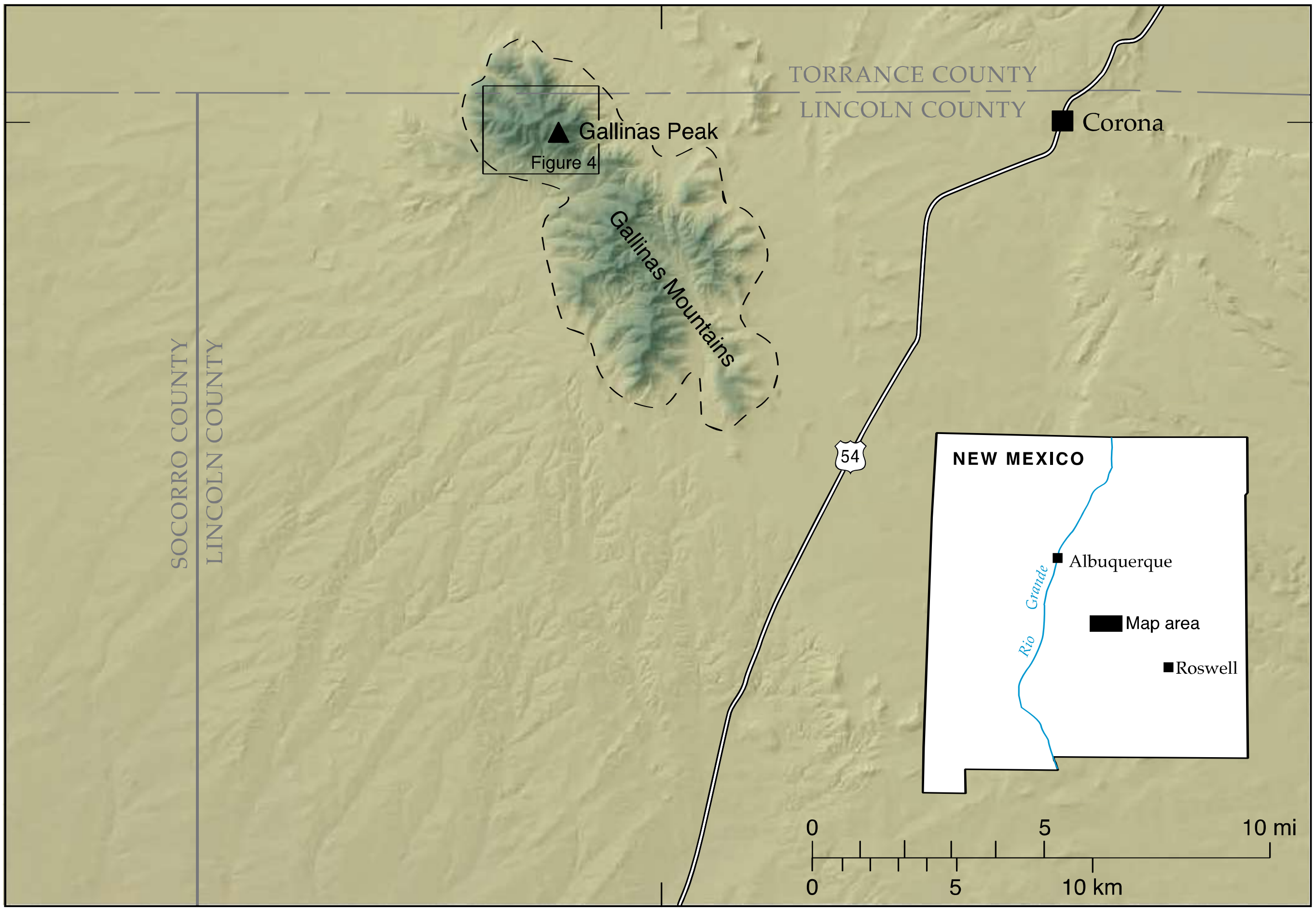

FIGURE 2—Location of Gallinas Mountains in central New Mexico.

above 2,350 m (7,710 ft). They have lengths of approximately 90–230 m (295–755 ft) and average widths of approximately 60 m (197 ft). Some forms have no apparent source rock such as a cliff or ledge, whereas others extend into gullies and ravines from the base of block slopes.

Some block streams have irregular or hummocky surfaces formed by ridges, furrows, and lobes with a maximum relief of approximately 1.5 m (5 ft). Ridges normal to the apparent direction of movement are convex downslope. Other forms are scoured in many places by small channels that extend downslope for the entire length of the deposit.

Angular to subangular blocks and slabby clasts of rhyolite with lengths of 15–60 cm (6–24 in) make up most of the debris. Smaller fragments, less than 15 cm (6 in) in length, fill voids between the larger blocks. Tabular blocks may have their longest axes oriented either parallel to or normal to the slope. The rubble is stable, and lichen covers 40–80% of exposed faces. Trees and shrubs project through the debris in isolated groves that cover approximately 5% of the surfaces.

Block slopes

Block slopes are present as extensive sheets a few meters thick on the flanks of Gallinas Peak and West Turkey Cone above 2,400 m (7,874 ft) and are either exposed as debris-covered slopes or are partly obscured by soil and vascular plants. They extend parallel to the contour, some for hundreds of meters, and have widths of approximately 200 m (656 ft). They have no exposed bedrock at their heads and are on slopes of 20–30°. Most block slopes appear to thin to a feather edge and have well-to-poorly defined flanks. Block slopes are best exposed as mappable units on the east side of Gallinas Peak and the southwest flank of West Turkey Cone.

A well-defined block slope on the east side of Gallinas Peak extends along the contour for approximately 500 m (1,640 ft) and downslope for approximately 300 m (984 ft; Fig. 3). Its head terminates at the crest of the peak, and a rock glacier and block stream project into gullies from the base (Fig. 4, no. 5). The flanks in many places are delineated by lateral ridges, which rise approximately 1 m (3 ft) above the forest floor (Fig. 5). Channels with maximum depths of approximately 1 m (3 ft) are parallel to the slope, and some scour the entire width of the deposit.

Lobes and tongues of rubble character-

FIGURE 3—East flank of Gallinas Peak showing periglacial mass movement deposits (block slope on the left, block stream on the right). Summit of the peak is approximately 500 m (1,640 ft) above the alluvium in the foreground.

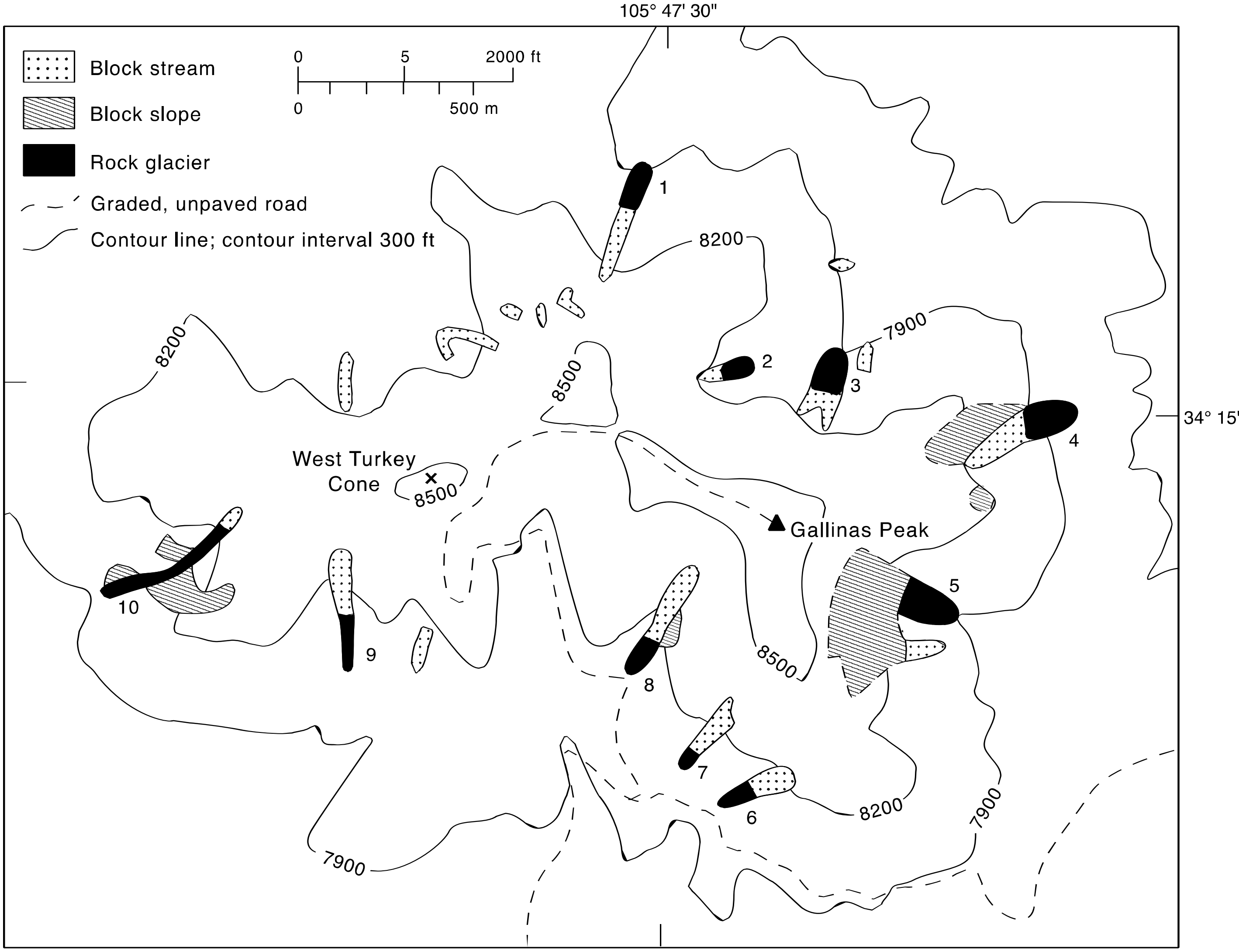

FIGURE 4—Location of periglacial mass movement deposits on Gallinas Peak and West Turkey Cone.

FIGURE 5—North flank of a younger block slope on the east side of Gallinas Peak defined by a lateral ridge that rises approximately 1 m (3 ft) above a tree-covered older block slope surface. View is to the north. Photograph by Francis G. Varney.

FIGURE 6—Rubble tongue on block slope on the east side of Gallinas Peak showing lateral ridges that bend to form an arcuate ridge at the crest of the toe. The depressed area is in the foreground. View is to the east.

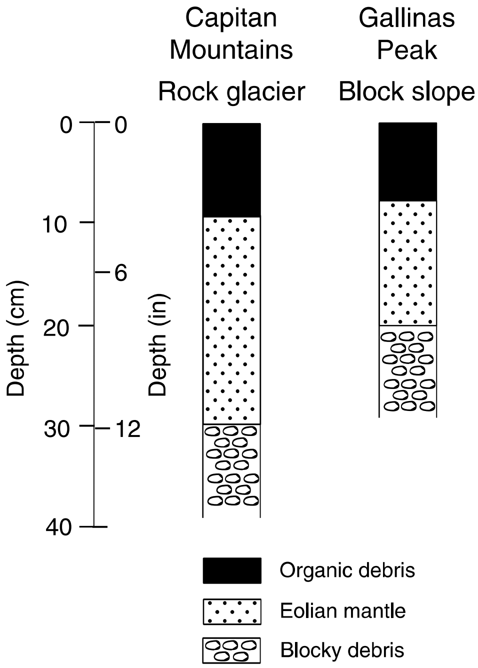

FIGURE 7—Comparison of a generalized profile of soil from the older surface of the block slope on the east side of Gallinas Peak with a profile of an older rock glacier in Sawmill Canyon on the south side of the Capitan Mountains in south-central New Mexico.

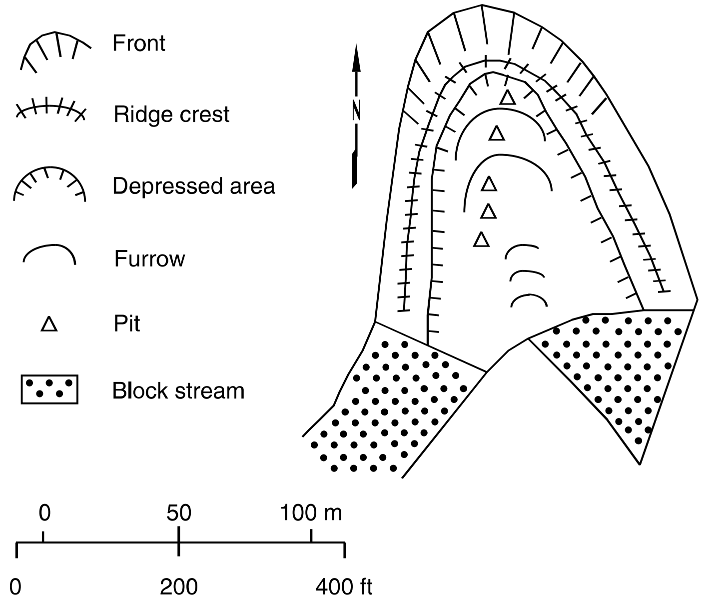

FIGURE 8—Sketch map of rock glacier 3 on the north side of Gallinas Peak showing the steep front, lateral and transverse ridges, and depressed area, and furrows and pits in the depression.

ize the surface of the block slope, creating irregular, hummocky, or wavy surfaces that presumably resulted from the downslope movement of localized masses of debris. Lateral ridges that bend forming an arcuate ridge at the toe define some rubble tongues (Fig. 6). A depression extends from the base of the arcuate ridge to the head and is flanked by the lateral ridges. The maximum breadth of the tongues at their heads is approximately 20 m (66 ft), and their maximum length downslope from head to toe is approximately 40 m (131 ft). The crests of the lateral ridges extend approximately 3 m (10 ft) above the surface of the block slope, and the arcuate ridges are approximately 4 m (13 ft) in height.

The rubble of the block slope is formed predominantly by angular to subangular blocks and slabby clasts of porphyritic rhyolite with average lengths of 30–60 cm (12–24 in) and maximum lengths of approximately 1 m (3 ft). Interstitial fines are lacking except at localities where soil is present. Fragments at the surface are mostly oriented at random except along the flanks and toes of rubble tongues where the long axes of the fragments may be aligned parallel to the apparent direction of movement. The debris is stable, and lichen covers 30–60% of the exposed faces. The poorly developed fabric over most of the block slope infers that its rubble has traveled only a short distance and was locally derived.

The block slope appears to be of two ages. Over approximately 75% of its extent it is nearly devoid of vascular plants, has well-developed constructional relief, and contains pockets of dark brown soil approximately 3 cm thick formed by decomposed to partly decomposed organic debris mixed with sand and silt (Fig. 7). On older surfaces, vascular plants and soil obscure the debris, and the constructional relief is subdued. The soil is formed by approximately 20 cm (7.7 in) of dark-gray loess mixed with organic debris overlain by a horizon of decomposed to partly decomposed organic debris approximately 3 cm (1 in) thick.

Rock glaciers

Ten tongue-shaped rock glaciers are on the floors of ravines at an average altitude of approximately 2,440 m (8,005 ft) on the flanks of Gallinas Peak and West Turkey Cone. They have average lengths of approximately 155 m (509 ft) and average widths of 50 m (164 ft; Table 1). The average altitude of their heads is approximately 2,465 m (8,087 ft), and the average altitude of their toes is approximately 2,415 m (7,923 ft).

The forms on the north and east sides of Gallinas Peak are characterized by steep fronts, well-defined flanks, and heads that originate at the base of block streams or block slopes (Fig. 8). Flanks rise as steep embankments and are separated from the walls of ravines by gullies 5–15 m (16–49 ft) deep. Fronts are 15–30 m (49–98 ft) high and slope at approximately 30°. Lateral ridges 3–5 m (10–16 ft) high are along the flanks. They slope at 15–20° and bend to form transverse ridges at the crests of the fronts (Fig. 9).

Depressed areas that slope at approximately 15° are between the lateral ridges and extend from the bases of the transverse ridges to the heads. Hummocky topography with relief of 1.5–4.5 m (5–15 ft) in the depressed areas is due to many longitudinal, transverse, and oblique ridges and furrows (Fig. 10). Tongues of debris from the slopes above extend into the depressed areas of the two rock glaciers on the east side of Gallinas Peak, suggesting downslope movement of rubble after the formation of the depressions.

Conical pits are in the depressed areas and on lateral ridges of the forms on the north side of Gallinas Peak. They have diameters of 3–6 m (10–20 ft) and sides that slope inward at approximately 30°, and they are 1.5–4.5 m (5–15 ft) deep. Some pits on lateral ridges form irregular lines parallel to the long axis of the rock glacier.

The forms on the south sides of Gallinas Peak and West Turkey Cone are less well defined and may represent an early stage in rock-glacier development. Toes either

TABLE 1—Comparative altitudinal and morphological data for the 10 rock glaciers in the Gallinas Mountains.

	meters	feet
Average altitude of fronts	2,415	7,923
Range in altitude of fronts	2,370–2,455	7,776–8,054
Average altitude of heads	2,465	8,087
Range in altitude of heads	2,410–2,510	7,907–8,235
Average length	155	508
Range in length	70–4,225	230–13,862
Average width	50	164

FIGURE 9—Rock glacier 4 on the east side of Gallinas Peak showing lateral ridges that bend to form a transverse ridge at the crest of the front, and the depressed area. Debris in the foreground is at the toe of a block stream. View is to the east.

FIGURE 10—Rock glacier 5 on the east side of Gallinas Peak showing lateral and transverse ridges and hummocky topography in the depressed area. Tongues of debris from the base of the block slope in foreground extend into the depression. View is to the east.

FIGURE 11—Rock glacier 8 in a ravine on the south side of Gallinas Peak showing poorly defined lateral ridges and depressed area. Debris at the left extends from block slope on the east side of the ravine, and the toe thins to a feather edge. View is to the south.

thin to a feather edge or are defined by frontal faces approximately 3.5 m (11 ft) high that slope at approximately 15°. Flanks either merge with the debris of block slopes on ravine walls or are delineated by poorly defined lateral ridges with maximum heights of approximately 3 m (10 ft; Fig. 11). Depressed areas are either shallow or absent.

Longitudinal, transverse, and oblique ridges and furrows with a relief of 1–2 m (3–7 ft) result in a hummocky topography on many surfaces. Tongues and lobes of debris extend from block slopes on ravine walls onto some surfaces. Conical pits are near the toes of some forms and round-to-oval shaped with sides that slope inward at approximately 25°. They have maximum depths of approximately 2 m (7 ft) and surface diameters of approximately 2 m (7 ft).

The rock glaciers in the Gallinas Mountains are formed by interlocking angular to subangular blocks and slabby clasts of porphyritic rhyolite with average lengths of approximately 1.5 m (4.9 ft). Smaller fragments less than 15 cm (59 in) in length fill voids between the larger debris. Subangular to subrounded fragments less than 1.5 cm (0.6 in) in diameter probably were transported by water. In general, the debris on the ridges is larger in size than that in the depressed areas. Most fragments show some oxidation and have undergone frost shattering while on the surface of the deposits.

The debris is stable, and lichen covers 40–80% of the exposed faces. Much of the rubble is a jumbled mass with no apparent orientation of the blocks and slabby clasts. However, some blocks are elongated parallel to the slope of the deposit, and some platy slabs are vertical and aligned parallel to the apparent direction of movement.

A dark-brown soil 2.5–7.5 cm (1.0–2.0 in) thick fills voids between the debris in isolated pockets. The soil is formed by decomposed to partly decomposed organic material mixed with sand and silt. Trees and shrubs grow in the soil and project through the debris over 5–15% of the surfaces.

Age

Age inferences for the periglacial mass movement deposits in the Gallinas Mountains, given in Table 2, use as references the rock-glacier deposits in the Capitan Mountains in south-central New Mexico (Blagbrough 1999), climatic data from the Estancia Basin in central New Mexico (Allen and Anderson 1993, 2000; Anderson et al. 2002), and the glacial and rock-glacier deposits on Sierra Blanca Peak in southern New Mexico (Richmond 1986; Shroba 1991).

Rock glaciers of two ages are distinguished in the Capitan Mountains using the preservation of topographic expression and soil development. The older rock glaciers are moderately dissected and show good preservation of their tongue-shaped form and gross features (fronts, lateral ridges, and depressed areas). Longitudinal and transverse ridges and furrows are either poorly defined or unrecognizable on aerial photographs. They bear a dark-gray eolian mantle 20–30 cm (7.7–12 in) thick overlain by a horizon approximately 7.5 cm (3.0 in) thick formed by decomposed organic material mixed with sand and silt. The older rock glaciers are thought to have been active during the glacial maximum high stand of Lake Estancia (ca 20–15 k.y. B.P.) and may be equivalent in age to the younger Pinedale moraine on Sierra Blanca Peak. The loess probably was deposited under warmer and drier conditions during the low stand of Lake Estancia (ca 15–14 k.y. B.P.).

The younger rock glaciers in the Capitan Mountains have a well-preserved tongue-shaped form and are less dissected than the older rock glaciers. Their gross features and longitudinal and transverse ridges and furrows are well defined. They bear pockets of soil similar in thickness and composition to the upper soil horizon on the older rock glaciers. The younger rock glaciers were probably active during the younger high stand of Lake Estancia (ca 14–12 k.y. B.P.), which occurred near the close of the late Wisconsinan and may be equivalent in age to the older rock glacier on Sierra Blanca Peak.

The rock glaciers and block streams mapped in the Gallinas Mountains and the younger surface of the block slope on the east side of Gallinas Peak are thought to be equivalent in age to the younger rock glaciers in the Capitan Mountains because these deposits bear pockets of soil formed by decomposed to partly decomposed organic material mixed with sand and silt. In addition they are little dissected, have well-preserved forms, and have distinct constructional relief. The difference in thickness of the eolian mantle in the two areas (Fig. 5) may be attributed to the variance in the slope declivity of the rock glaciers and block slope. Removal of the loess by surface runoff would be more intense on the steeper block slope (20–30° slope) than on the rock glaciers (10–20° slope).

TABLE 2—Tentative correlation of late Wisconsinan pluvial, glacial, and periglacial events in central and south-central New Mexico.

Estancia Basin (Allen and Anderson 2000)	Sierra Blanca Peak (Richmond 1986, Shroba 1991)	Capitan Mountains (Blagbrough 1999)	Gallinas Mountains (this report)
Minor high stand (ca 11–10 k.y. B.P.)	younger rock glacier		slope stabilization
Desiccation (ca 12–11 k.y. B.P.)	loess		
Younger high stand (ca 14–12 k.y. B.P.)	older rock glacier	younger rock glaciers	rock glaciers block streams block slopes
Low stand (ca 15–14 k.y. B.P.)	loess	loess	loess
Glacial maximum high stand (ca 20–15 k.y. B.P.)	younger Pinedale moraine	older rock glaciers	block slope

Climate

The rock glaciers in the Gallinas Mountains delineate a late Wisconsinan zone of sporadic permafrost and the lower limit of the geocryogenic region of Corté (1987) at approximately 2,400 m (7,874 ft) on the slopes of Gallinas Peak and West Turkey Cone (Fig. 12). This altitude closely approximates the lower limit of permafrost in the Capitan Mountains (2,430 m; 7,972 ft) and on Carrizo Mountain (2,370 m; 7,776 ft; Blagbrough 1994). The parageocryogenic zone of Corté (1987) was below 2,400 m (7,874 ft), lacked permafrost, and was characterized by seasonal freezing and thawing. The rock glaciers are present near the reconstructed late Wisconsinan 0°C isotherm (Blagbrough 1994) and, as a result, their development was greatly influenced by slope orientation. East- and north-facing slopes have less exposure to the direct rays of the sun than south-facing slopes. As a result, forms with well-defined fronts, flanks, and lateral ridges were able to develop on northern and eastern exposures where interstitial ice existed for longer periods of time than on south-facing slopes where less well-defined tongues of debris were generated under more marginal conditions.

The angular rubble composing the block streams and block slopes in the Gallinas Mountains indicates a late Wisconsinan climate characterized by frequent freeze-thaw cycles, resulting in the generation of large volumes of blocky debris by frost wedging. The large size of the rubble and its wide distribution imply a cold periglacial climate that resulted in the deep penetration of freezing into the jointed bedrock. A late Wisconsinan zone of sporadic permafrost at approximately 2,400 m (7,874 ft) suggests that permanently frozen ground probably existed above, implying that gelifluction may have been the dominant process for the downslope movement of the rubble. The mean annual precipitation was sufficient to promote the soil saturation necessary for downslope movement of the rubble and to provide the necessary moisture for frost wedging.

The snow cover was thin and of short duration, which favored intense frost wedging and gelifluction. The presence of sporadic permafrost approximately 1,000 m (3,281 ft) below the orographic snow line on Sierra Blanca Peak suggests that the rock glaciers formed under a cold, dry continental climate (Blagbrough 1994). Within the geocryogenic region, seasonal freezing and thawing in the upper horizon of the permafrost resulted in downslope movement of debris by gelifluction.

The block slope on the east side of Gallinas Peak indicates two late Wisconsinan periglacial episodes separated by a period when warmer and drier conditions prevailed. The climate of the older episode was characterized by frequent freeze-thaw cycles, cold temperatures, and sufficient precipitation to promote soil saturation. A change to warmer and drier conditions resulted in slope stabilization accompanied by the accumulation of a loessal mantle over much of the deposit. A return to cooler and wetter conditions initiated a younger periglacial episode, which brought about subsequent movement of the block slope over much of its extent, resulting in the destruction of the loessal mantle where movement occurred.

The younger periglacial episode favored the movement of block slopes and block streams over extensive areas of Gallinas Peak and West Turkey Cone. Mean annual temperatures were low enough (from 0 to –1°C) for the formation of interstitial ice in rubble at the heads of some ravines and the creep of the ice resulted in the generation of rock glaciers. A change to warmer conditions at the close of the late Wisconsinan caused the melting of the interstitial ice and the formation of depressed areas and conical pits. After the melting of the interstitial ice, downslope movement of debris continued, resulting in the accumulations of tongues of rubble in the depressed areas of the two rock glaciers on the east flank of Gallinas Peak.

Warmer and drier conditions at the close of the late Wisconsinan apparently brought about slope stabilization in the Gallinas Mountains. The scouring of the block streams and block slopes by water erosion and the removal of their interstitial matrix by washing or piping also may have commenced at this time. The pockets of soil composed of organic debris on the younger periglacial deposits probably formed mainly during the Holocene. The presence of partially decomposed organic debris indicates that the process continues at the present time.

Conclusions

The periglacial mass movement deposits in the Gallinas Mountains and the Capitan Mountains (Blagbrough 1991, 1999) and on Carrizo Mountain (Blagbrough 1984) indicate a late Wisconsinan geocryogenic

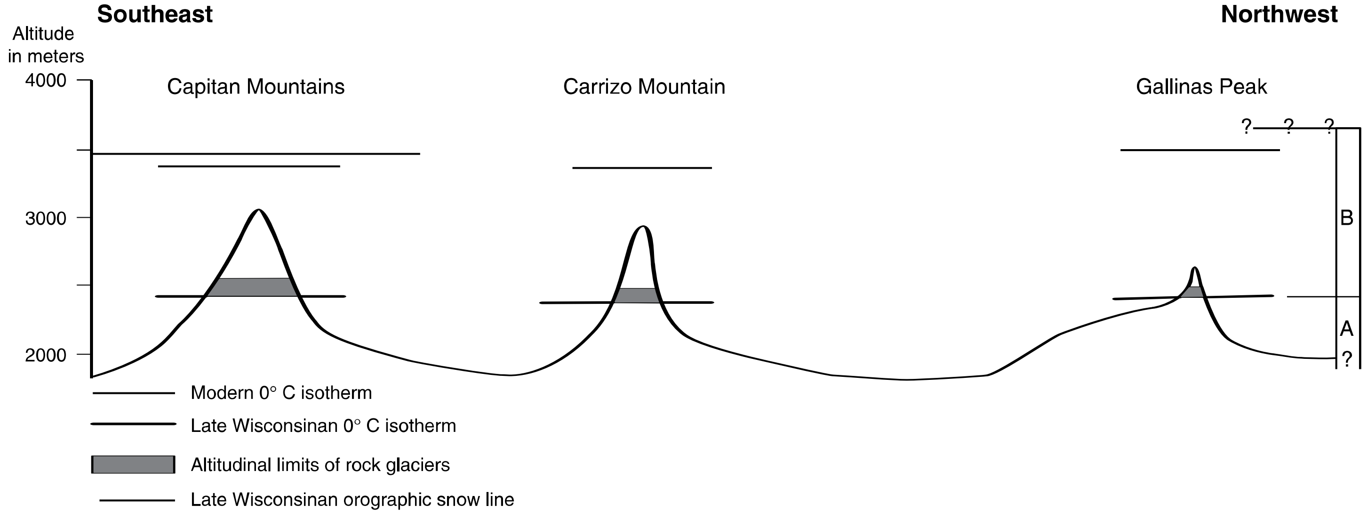

FIGURE 12—Generalized topographic profile from Gallinas Peak in the northwest to the Capitan Mountains in the southeast showing rock glaciers, the altitude of the modern and late Wisconsinan 0°C isotherm, the geocryogenic region and the parageocryogenic zone of Corté (1987), and the late Wisconsinan orographic snow line. Rock glaciers are determined by the average altitude of their heads and fronts in the Capitan Mountains (Blagbrough 1991, 1999), on Carrizo Mountain (Blagbrough 1984), and on Gallinas Peak. The altitude of the modern and late Wisconsinan 0°C air isotherm is from Blagbrough (1994). The altitude of the orographic snow line is determined by the altitude of the cirque floor on Sierra Blanca Peak (Richmond 1963). **A**—parageocryogenic zone; **B**—lower zone of geocryogenic region.

region in central and south-central New Mexico with an upper horizon of active permafrost. The lower limit of permafrost and the geocryogenic region was at approximately 2,400 m (7,874 ft) as determined by the average altitude of rock-glacier fronts. Within the parageocryogenic zone, below the lower limit of permafrost, rock glaciers are absent and block slopes and block streams are poorly developed. The regional geocryogenic zone with active permafrost extended as high as 3,650 m (11,975 ft) as indicated by the upper limit of talus (block slopes) on Sierra Blanca Peak (Richmond 1963). The mean annual temperature within the geocryogenic region was below 0°C, diurnal freezing and thawing resulted in the generation of large volumes of debris, and seasonal thawing in the upper horizon of the permafrost caused the downslope movement of the debris by gelifluction.

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A farewell to John Blagbrough

*David W. Wentworth**

Dr. John Blagbrough, who passed away July 10, 2004, was a long time member of the Albuquerque Geological Society and the New Mexico Geological Society. He shall be remembered as a good friend of many of us, an excellent geologist, and an outstanding human being. He can also be described as a typical part of what has been called America's Greatest Generation.

John was born on December 17, 1924, and raised in Skaneateles, a village in the Finger Lake district of upstate New York, where he and his family experienced the Great Depression. He attributed his frugal nature, however, to his Vermont ancestors and not the depression. He graduated from Skaneateles Central High School in 1942. I spent a few years at the same school soon after John left, and I know that he had a couple of very demanding, no nonsense type teachers that helped shape his personality. We would often talk about them in later years.

After spending two semesters at nearby Syracuse University, he entered the navy in the summer of 1943 several months short of his 19th birthday. He and many other young men at the time were forced to grow up in a hurry. John was assigned to the Seabees and eventually sent to the South Pacific. He ended up moving north to the island of Tinian where the Seabees built the large airfield used by the B-29s that dropped the atomic bombs. When he got there the area was still not secured, and he had a scary experience with the enemy while patrolling in a cane field in a remote part of the island.

After being discharged from the navy he went back to Syracuse University and graduated in 1950 with a B.S. in geology and went on to receive an M.S. in geology in 1952. He wrote a thesis on glaciology for his M.S. degree under Dr. Earl T. Apfel, a prominent glaciologist. Dr. Apfel was another demanding teacher with high expectations who helped shape John's approach to scientific challenges.

John spent several years with the Atomic Energy Commission in the 1950s. He did geological field work as part of a massive uranium exploration program, mainly on the Colorado Plateau, as part of the country's weapons procurement program. He spent much time in remote camps and worked outcrops never before studied in any detail. During the first uranium boom in the late 1950s and early 1960s he worked for Tidewater Oil Company, which was exploring for subsurface uranium deposits in the western part of the Grants mineral belt.

In 1961 he entered the University of New Mexico where he worked on a Ph.D. degree under Dr. Sherman Wengerd. He received the degree in 1965. His dissertation was titled "Quaternary geology of the northern Chuska Mountains and Rock Valley, northeastern Arizona and northwestern New Mexico." As a result he developed a keen interest in paraglaciation. While at UNM John advised a number of young graduate students on how to be successful in their work. He made suggestions, encouraged them, and helped edit their work.

In the late 1960s John did various consulting work out of Albuquerque. In 1971 he obtained a retainer from Pechiney Development, a French company that was establishing a uranium exploration program in the United States, and consulted for them for over 10 years. His specific knowledge of uranium occurrences on the Colorado Plateau allowed him to make recommendations that would save the company considerable effort and money.

John began writing professional papers on paraglaciation in the middle 1980s and continued to do so until his death. These were mainly on mountain ranges in south and central New Mexico. These papers were published by the New Mexico Bureau of Geology and Mineral Resources in *New Mexico Geology* (v. 6, no. 4, pp. 65–68; v. 16, no. 4, pp. 65–71; and v. 21, no. 3, pp. 57–65).

Dr. Blagbrough was a product of a liberal education and had a number of interests outside of geology including history, politics, economics, climatology, and genealogy. He knew how to measure and get along with all sorts of people, and his science was always well thought out, detailed, and honest. He also enjoyed a good controversy. He knew how to write concise professional papers, and his editing skills were greatly in demand from some of us who have less talent along these lines.

John will be missed by his many friends, and I will greatly miss our monthly lunches and conversations.

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