New Mexico Geological Society

Downloaded from: http://nmgs.nmt.edu/publications/guidebooks/42

Late Pleistocene rock glaciers in the western part of the Capitan Mountains, Lincoln County, New Mexico: Description, age and climatic significance

John W. Blagbrough, 1991, pp. 333-338

in:

Geology of the Sierra Blanca, Sacramento, and Capitan Ranges, New Mexico, Barker, J. M.; Kues, B. S.; Austin, G. S.; Lucas, S. G.; [eds.], New Mexico Geological Society 42nd Annual Fall Field Conference Guidebook, 361 p.

This is one of many related papers that were included in the 1991 NMGS Fall Field Conference Guidebook.

Annual NMGS Fall Field Conference Guidebooks

Every fall since 1950, the New Mexico Geological Society (NMGS) has held an annual Fall Field Conference that explores some region of New Mexico (or surrounding states). Always well attended, these conferences provide a guidebook to participants. Besides detailed road logs, the guidebooks contain many well written, edited, and peer-reviewed geoscience papers. These books have set the national standard for geologic guidebooks and are an essential geologic reference for anyone working in or around New Mexico.

Free Downloads

NMGS has decided to make peer-reviewed papers from our Fall Field Conference guidebooks available for free download. Non-members will have access to guidebook papers two years after publication. Members have access to all papers. This is in keeping with our mission of promoting interest, research, and cooperation regarding geology in New Mexico. However, guidebook sales represent a significant proportion of our operating budget. Therefore, only *research papers* are available for download. *Road logs*, *mini-papers*, *maps*, *stratigraphic charts*, and other selected content are available only in the printed guidebooks.

Copyright Information

Publications of the New Mexico Geological Society, printed and electronic, are protected by the copyright laws of the United States. No material from the NMGS website, or printed and electronic publications, may be reprinted or redistributed without NMGS permission. Contact us for permission to reprint portions of any of our publications.

One printed copy of any materials from the NMGS website or our print and electronic publications may be made for individual use without our permission. Teachers and students may make unlimited copies for educational use. Any other use of these materials requires explicit permission.

LATE PLEISTOCENE ROCK GLACIERS IN THE WESTERN PART OF THE CAPITAN MOUNTAINS, LINCOLN COUNTY, NEW MEXICO: DESCRIPTION, AGE AND CLIMATIC SIGNIFICANCE

JOHN W. BLAGBROUGH
P.O. Box 8063, Albuquerque, New Mexico 87198

Abstract—Seventy-six tongue-shaped rock glaciers of probable late Wisconsin age occur below talus at the heads of canyons and ravines at an average elevation of about 2485 m in the western part of the Capitan Mountains. They have abrupt fronts and steep sides often delineated by lateral ridges which curve to form transverse ridges at the crests of the fronts. Longitudinal and transverse ridges and furrows are common surface features. Their debris is stable and lichen covers 20–90% of exposed faces. A dark brown, weakly developed soil formed by decomposed organic material has a maximum thickness of 15 cm and occurs as isolated pockets that cover 10–15% of the surfaces. The rock-glaciers have surface features that indicate they are ice-cemented (permafrost) forms that moved by the flow of interstitial ice. They denote a climate with a mean annual temperature below freezing, characterized by much diurnal freezing and thawing which resulted in the generation of large volumes of talus. The average elevation of the fronts (2430 m) delineates the approximate lower limit of Late Wisconsin alpine permafrost and the upper periglacial (subnival) zone.

INTRODUCTION

Rock glaciers are periglacial mass-movement deposits that have been reported in many mountain ranges in western North America (Péwé, 1983a). Potter (1972, p. 3027) defined a rock glacier as a tongue-shaped or lobate body composed of angular debris that resembles a small glacier, with ridges, furrows and lobes on its surface and a steep front at the angle of repose. White (1981) distinguished two principal types of rock glaciers based upon shape and topographic setting. Lobate rock glaciers are composed mainly of unsorted talus and are as broad or broader than they are long. They occur as single or multiple lobes at the base of talus along valley walls. Tongue-shaped rock glaciers are elongated masses of rock debris longer than they are broad. They originate in cirques or on valley floors near the valley heads.

Rock glaciers are either masses of debris cemented by interstitial ice (ice-cemented rock glaciers) or small glaciers that are mantled by debris (ice-cored rock glaciers) (Potter, 1972, p. 3027). Tongue-shaped rock glaciers may be either ice-cemented or ice-cored, whereas lobate forms are always ice-cemented (White, 1976, p. 81). Ice-cored rock glaciers are distinguished by saucer- or spoon-shaped depressions between the base of cirque headwalls and rock-glacier heads, longitudinal furrows along both sides, central meandering furrows, and conical or coalescing collapse pits (White, 1976, p. 79–80). Ice-cemented forms lack depressions at their heads and have continuous talus and avalanche slopes feeding onto their heads (Luckman and Crockett, 1978, p. 542). They also are characterized by well-developed longitudinal and transverse ridges (White, 1976).

Active ice-cemented rock glaciers are good indicators of perennially frozen ground and inactive remnants indicate ancient permafrost in alpine areas (Péwé, 1983b). Permafrost exists at high altitudes where the mean annual air temperature at ground level is 0°C or less, especially if the snow cover is thin or of short duration and the lower altitudinal limit of alpine permafrost coincides roughly with the 0° to −1°C air isotherm (Péwé, 1983a). Permafrost distribution in the alpine environments include areas where it is everywhere present (continuous), areas where it is less extensive (discontinuous), and localities where it is only rarely encountered (sporadic).

Harris (1981) placed ice-cemented rock glaciers in the colder parts of the discontinuous permafrost zone. White (1979) noted that they have value in establishing the vertical limits of the upper periglacial (subnival) zone. Barsch and Updike (1971) believed that the front elevations of ice-cemented rock glaciers roughly coincide with the lower limit of the upper periglacial zone. They further suggested that the average front altitudes of active rock glaciers should roughly correspond with the lower limit of active sporadic permafrost. White (1979) presented evidence that internal ice supply, up-slope talus input, and bed gradient, in addition to front ambient temperature, operate to control front activity of rock glaciers. He concluded that, even though active rock glaciers are by definition permafrost bodies, the fronts may not give useful indications of the average elevations of the lower limits of sporadic permafrost.

Corte (1987) listed several climatic conditions favoring the formation and movement of rock glaciers. Among these are a mean annual temperature less than 0°C, clear skies that promote nightly freezing and daily thawing, enough moisture in the ground for cyrofraction and gelifluction, and reduced snow cover to facilitate ground freezing and cyrofraction. He noted that increased snow favors the formation of glaciers, whereas less snow means more cyrofraction and the greater production of debris for developing rock glaciers. A colder climate also may restrict the formation of rock glaciers because it promotes the preservation of the snow cover and may result in fewer days with diurnal freezing and thawing.

GEOGRAPHIC AND GEOLOGIC SETTING

The Capitan Mountains are located in Lincoln County, New Mexico, about 80 km northwest of Roswell (Fig. 1). The range extends in an east-west direction for about 32 km and is 6.5—8 km wide (Fig. 2). West Mountain is a nearly isolated upland separated from the main part of the mountains by Capitan Pass, with a summit elevation of 2272 m. The study area is in the Encinoso and Capitan Pass quadrangles (U.S. Geological Survey $7^{1}/_{2}$-min quadrangle maps) and includes the western

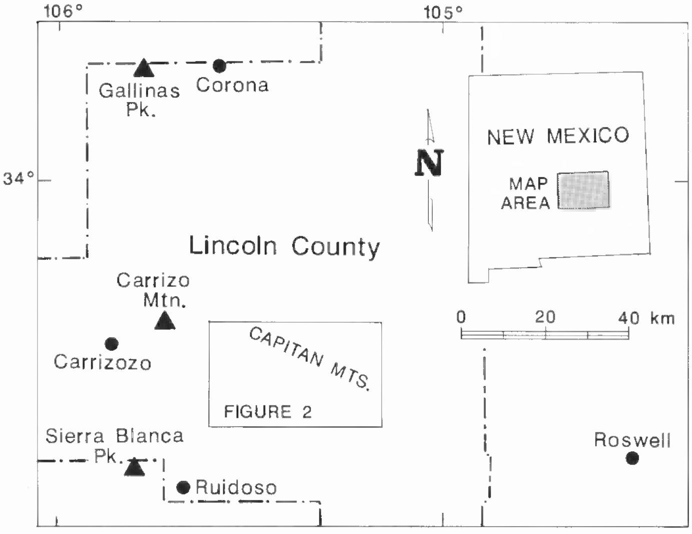

FIGURE 1. Location of Capitan Mountains in south-central New Mexico.

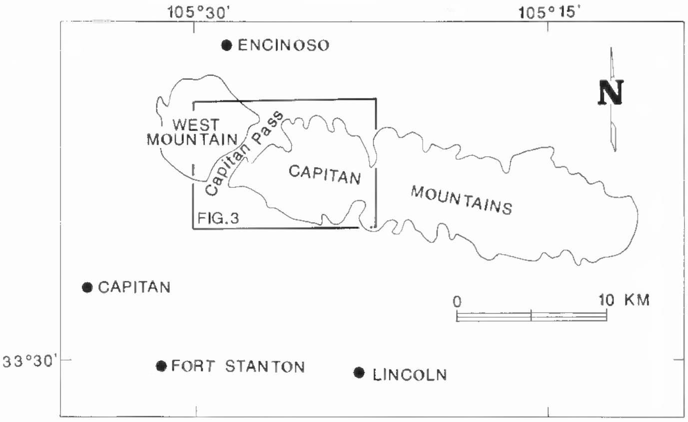

FIGURE 2. Location of the study area in the Capitan Mountains. Base map is U.S. Geological Survey's topographic map of the Roswell quadrangle, 1:250,000 scale series.

section of the main part of the mountains and the eastern end of West Mountain.

The crest of the range has elevations of about 2600–3050 m and rises approximately 900 m above the surrounding terrain. The northern and southern flanks are cut by many steep-walled canyons that have maximum depths of about 300 m. Intermittent streams in the canyons provide the main drainages and usually flow in the spring when snow in the mountains melts and in the summer during afternoon thunderstorms. Numerous small canyons and ravines are tributary to the large canyons.

The Capitan Mountains were formed by an intrusion of Tertiary age, which may be either a laccolith or a stock (Kelley, 1971). Overall, the intrusion is a fine-grained leucocratic quartz syenite and ranges in composition from granite to quartz monzonite. The rock is medium- to fine-grained and only slightly porphyritic. Strata of the Yeso Formation (Permian) are in contact with the intrusion at the eastern end of the range. The western end has a roof pendant formed by west-dipping beds of the Rio Bonito Member of the San Andres Formation (Permian); outliers of this roof pendant occur along the crest of the mountains. Beneath the flanking sediments of Quaternary age, the Yeso is probably in contact with the intrusion everywhere but at the western end.

Rockfall talus covers extensive areas of the steep mountain slopes. Most talus forms smooth, concave slopes. A few talus sheets have undulating surfaces consisting of many small ridges and furrows. The ridges and furrows are parallel to the contours, indicating movement down slope that may be due to frost creep or solifluction. About 120 rock glaciers of late Pleistocene age occur at the base of steep talus on the north and south slopes of the range at an average elevation of 2560 m (Blagbrough, 1976). No glacial deposits of Wisconsin age are known to occur and none are expected because the crest of the range is about 300 m below the Wisconsin orographic snow line in southern New Mexico as defined by Richmond (1965, fig. 3).

Vegetation zonation in the Capitan Mountains occurs along an elevation gradient of about 1200 m from desert grassland near the base to spruce-fir association on the crest (Martin, 1964). The piñon-juniper association grows to an elevation of about 2200 m on the lower slopes. The transition association occurs between 2200–2700 m and the spruce-fir association is above 2750 m on the upper slopes and crest of the mountains.

There are no long-term measurements of meteorological data for the Capitan Mountains. However, the natural vegetation indicates the climate is controlled largely by elevation, with precipitation increasing and temperature decreasing upward. The slopes probably receive between 50–75 cm of precipitation annually and the crest more than 75 cm (Tuan et al., 1969).

Fort Stanton (1897 m), located 13 km south of the Capitan Mountains, has the closest weather station maintaining long-term weather records. Normals for the 43-yr period of 1931–1974 indicate a mean annual temperature of 11.2°C (Kunkel, 1984). January is the coldest month with a mean temperature of 1.5°C; July is the warmest month with a mean temperature of 21°C. Van Devender et al. (1984) indicated a mean annual lapse rate in south-central New Mexico of 0.72°C/100m from Alamogordo (1326 m) in the Tularosa Basin to Mountain Park (2048 m) and Cloudcroft (2652 m) in the Sacramento Mountains. Utilizing this value, the following crude approximations of current temperature conditions were determined for the Capitan Mountains: 8°–5°C for the slopes (2300–2750 m) and 3°C for the crest (3000 m).

DESCRIPTION

Seventy-six tongue-shaped rock glaciers were identified on U.S. Forest Service aerial photographs (scale 1:15,840) and plotted on U.S. Geological Survey topographic maps (scale 1:24,000) (Fig. 3). Their lengths, widths, orientation, and the elevations of their fronts and heads were determined from the topographic maps. Thirty-three were studied in the field and observations were noted as to size of debris, soil and vegetation cover, slope and height of fronts, and dimensions of ridges and furrows.

Forty-seven rock glaciers on the north side of the mountains are on slopes facing north, northwest, and northeast; 29 on the south flank are on slopes facing south, southeast, and southwest (Fig. 4). About 51% have compass orientations that range between N 300°–60° and 36% have exposures between S 120°–240°. The rock-glacier heads range between 2305–2815 m in elevation and average 2503 m on the north and 2596 m on the south side of the mountains (Table 1). Fronts occur between 2244–2635 m and average 2399 m in elevation on the north and 2482 m on the south side of the range.

The rock glaciers are at the heads of ravines and small tributary canyons, and on the floors of major canyons. Those in ravines and tributary canyons are the extensions of talus at the drainage-heads. They have lengths of 55–300 m and average widths of about 70 m. Rock glaciers on the floors of major canyons are composed of talus that accumulated along the base of the sidewalls and headwalls. Many have surface relief indicating that they developed from lobate rock glaciers that coalesced on canyon floors. They have lengths of 295–1560 m and average widths of about 80 m.

The rock glaciers have steep fronts 5–60 m high that slope about 30° (Figs. 5, 6). Heads merge with talus on mountain slopes and central areas slope downstream about 15°. Sides rise as steep embankments 5–10 m high that, in places, are separated from talus by gullies. On many rock glaciers, the flanks are delineated by lateral ridges that stand 1–5 m above central areas and bend to form transverse ridges at the crest of fronts (Fig. 7). Depressed areas often extend from the base of transverse ridges to the heads and are 1–5 m below lateral ridges.

Longitudinal and transverse ridges and furrows with an average relief of about 3 m are common surface features on most rock glaciers. They produce a hummocky topography in most depressed areas. Conical pits with a mean depth of about 3 m and oblique ridges and furrows that strike at about 45° to the apparent direction of movement are less often developed.

The rock glaciers are composed of angular to subangular blocks and slabby clasts, derived from fine-grained igneous rock and the Rio Bonito Member, that range in diameter from 15 cm to 2 m and average about 60 cm. Many smaller fragments are less than 30 cm in diameter. The debris on the lateral ridges usually is larger than that on the frontal faces and the central areas above the frontal faces. On most rock glaciers, the debris is a jumbled mass with no apparent orientation of blocks. On some surfaces, platy slabs are nearly vertical and are aligned parallel to the apparent direction of movement. Most fragments are oxidized and some have undergone frost-shattering. The debris is stable, and lichen covers 20–90% of the exposed faces.

Soil and vascular plants cover 10–15% of the rock-glacier surfaces. The soil is dark brown and weakly developed with a maximum thickness of 15 cm. It occurs as isolated pockets and is formed by decomposed organic material filling voids between the blocks and slabby clasts. Trees and shrubs grow in the soil and project through the debris on some rock glaciers.

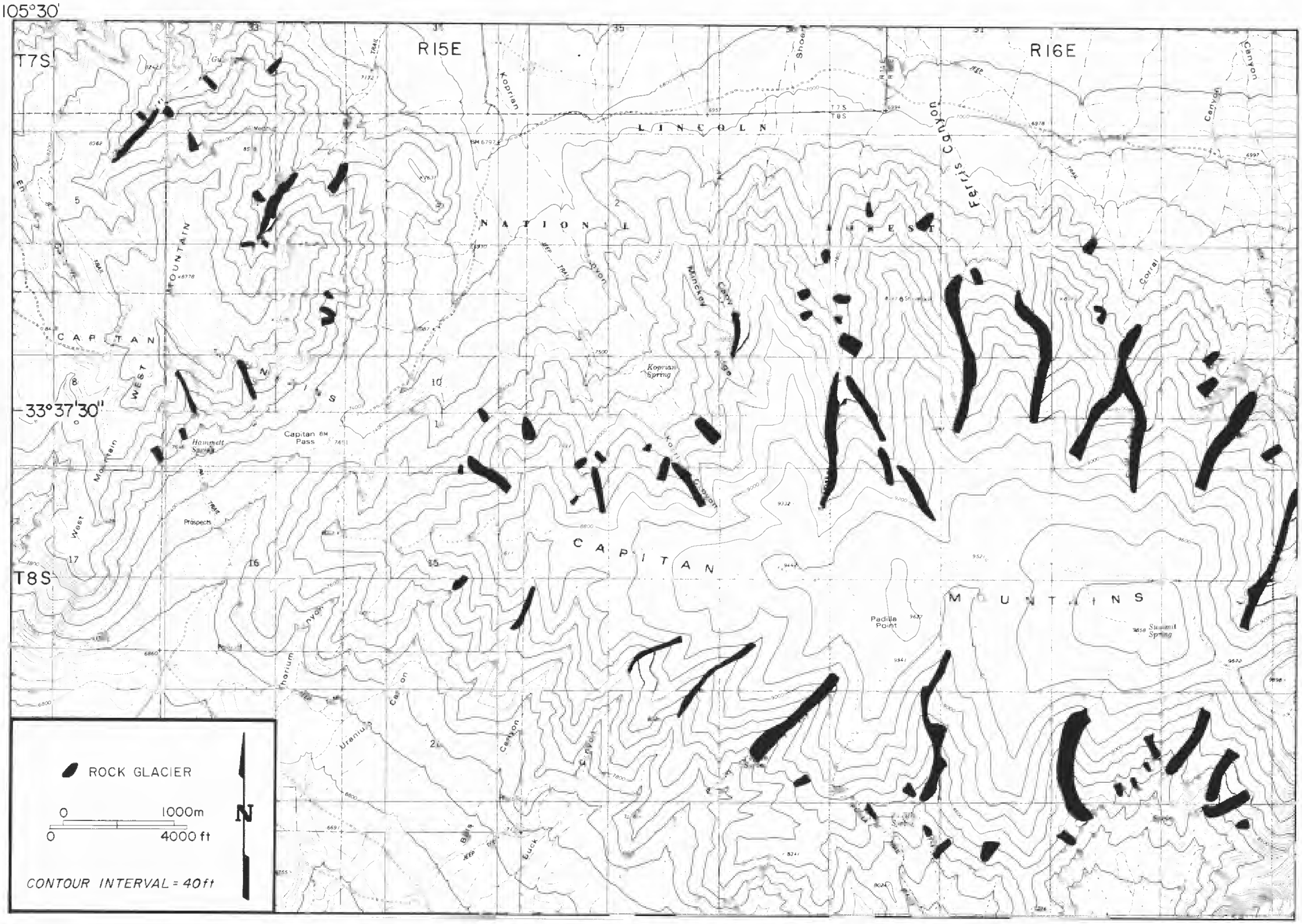

FIGURE 3. Topographic map showing location of rock glaciers in the study area. Base maps are the U.S. Geological Survey's topographic maps of Capitan Pass and Encinoso 7½-minute quadrangles.

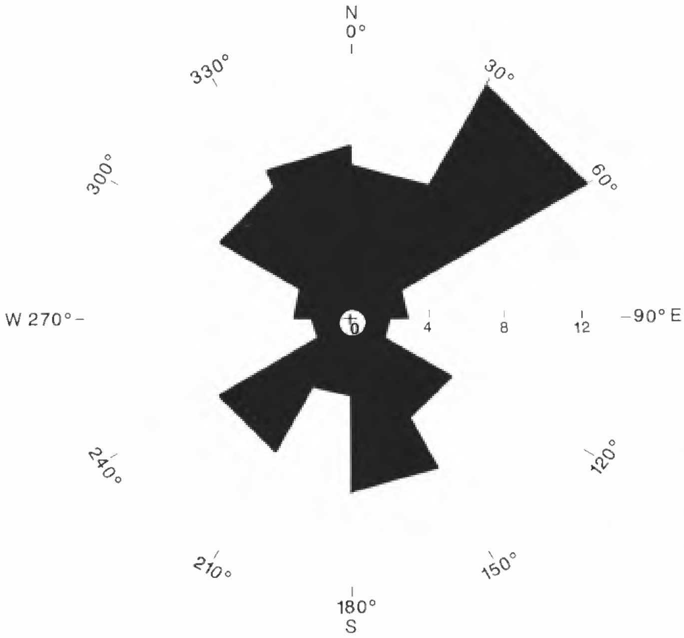

FIGURE 4. Rose diagram of rock-glacier compass orientation frequency in the Capitan Mountains.

FIGURE 5. Front of rock glacier in the east branch of Koprian Canyon on the north side of the Capitan Mountains. View is to the south. The front is about 25 m high and slopes 30°.

TABLE 1. Comparative altitudinal and morphological data for rock glaciers in the Capitan Mountains.

	All Rock Glaciers	Rock Glaciers North Side	Rock Glaciers South Side
Number	76	47	29
Mean Elevation of Fronts (m)	2430	2399	2482
Range in Elevation of Fronts (m)	2244-2635	2244-2565	2378-2635
Mean Elevation of Heads (m)	2538	2503	2596
Range in Elevation of Heads (m)	2305-2815	2305-2793	2425-2815
Mean Length (m)	347	358	319
Range in Length (m)	55-1560	55-1560	70-1105

FIGURE 6. Oblique aerial photograph of rock glacier in the west branch of Ferris Canyon on the north side of the Capitan Mountains. View is to the south. The rock glacier has a steep front about 75 m high, lateral ridges along the flanks, and longitudinal and transverse ridges and furrows on the surface.

FIGURE 7. Surface of rock glacier in gully northwest of Hammett Springs on the southeastern slope of West Mountain. View is to the southeast. The transverse ridge at the crest of the front curves to form lateral ridges along the sides. A depressed area with hummocky topography is between the transverse ridges.

Older rock glaciers occur east of the study area on both the north and south slopes of the mountains. They are moderately dissected and show preservation of their tongue-shaped forms and gross features such as steep fronts, flanks, lateral ridges, and depressed areas. Longitudinal and transverse ridges and furrows are either subdued or unrecognizable on aerial photographs. Soil and vascular plants cover 50–85% of their surfaces. The soil is composed of about 25 cm of loess overlain by 5–15 cm of decomposed organic material.

AGE

Richmond (1963, 1986) described glacial and periglacial deposits on Sierra Blanca Peak, located about 45 km southwest of the Capitan

Mountains. Bull Lake and Pinedale moraines occur down-valley from a cirque on the north flank of the peak. The cirque floor is between 3475–3500 m in elevation and talus along the headwall is covered by soil, grass, and trees. No moraines of Holocene age were noted. The Bull Lake moraines bear a mature soil about 90 cm thick. They are dissected considerably and boulders both in and on the till are weathered deeply. The Pinedale moraines are dissected slightly and have an immature soil about 25 cm thick. The Bull Lake moraines probably are Illinoian in age and the Pinedale moraines may be equivalent to the outer moraines of late Wisconsin age that occur at many localities in the Southern Rocky Mountains (Richmond, 1986, pl. 12).

A long, narrow, blocky deposit along the valley bottom characterized by transverse ridges and a loessial mix was mapped as a Pinedale rock glacier by Shorba (1977). The deposit extends through the Pinedale moraines and partway through the Bull Lake moraines and may have formed during recessional episodes of the Pinedale glaciation. A small rock glacier of early Holocene age occurs at the cirque headwall.

Glacial and periglacial deposits of Holocene age occur below the lips of and in cirques at about 3400 m on Wheeler Peak and Lake Peak in the Sangre de Cristo Mountains of northern New Mexico (Richmond, 1963). They are correlative with the Temple Lake and Gannett Peak Stades of the Neoglaciation and postdate the Altithermal interval (Richmond, 1965). The Temple Lake deposits include small moraines and rock glaciers in cirques. These deposits have thin soils up to 20 cm thick and tundra and spruce vegetation. The Gannett Peak Stade is characterized by fresh moraines and rock glaciers above deposits of the Temple Lake Stade. The Gannett Peak deposits have no soil and only a few sparse plants.

Soil on the rock glaciers in the study area suggest that they are equivalent in age to the Temple Lake moraines in the Sangre de Cristo Mountains because both features have similar soil profiles. However, the practice of utilizing soils on rock glaciers with those developed on moraines for correlation purposes may not be reliable (J. B. Benedict, personal comm., 1984). Rock glaciers usually are composed of coarse talus with voids between the debris so that some time is required in acquiring fines necessary for soil formation. Moraines have fines exposed at the time of deposition that provide an immediate basis for soil-building processes. Because of the lag time involved in the acquisition of fines, the rock glaciers are thought to predate the Holocene. Their sharp surface relief and well-preserved form indicate a late Wisconsin age.

Many of the rock glaciers east of the study area appear to be older than the late Wisconsin forms because of the extensive soil and vascular plant cover and because weathering has either subdued or obliterated their ridges and furrows. In addition, soil profiles indicate that a period of loess accumulation occurred before the formation of the late Wisconsin rock glaciers. The degree of weathering suggests that the older rock glaciers may have formed during the Bull Lake glaciation.

CLIMATE

The rock glaciers in the Capitan Mountains are thought to be ice-cemented (permafrost) forms because they have contiguous talus extending onto their heads and because most forms have well-developed longitudinal ridges and furrows. Péwé (1983a, b) presented a model that establishes the relationship between latitude and altitude of existing alpine permafrost and alpine permafrost of Wisconsin age in the Cordillera of North America. According to the model, the latitudinal gradient of the lower limit of existing permafrost rises to the south about 80 m per degree of latitude and the lower limit of Wisconsin alpine permafrost is about 1000 m below that of existing permafrost. The lower limit of existing alpine permafrost for the latitude of the Capitan Mountains is about 3475 m and the lower limit of Wisconsin alpine permafrost is about 2475 m (Péwé, 1983b, fig. 9-14).

The average elevation of the rock-glacier fronts in the Capitan Mountains is about 2430 m (Table 1). This value closely approximates the average elevation of rock-glacier fronts of late Wisconsin age on Carrizo Mountain (2370 m) about 25 km west (Blagbrough, 1984, fig. 2) and on Gallinas Peak (2413 m) about 75 km northwest of the study area (J. W. Blagbrough, unpubl., 1990). These occurrences indicate a regional average lower altitudinal limit to rock-glacier activity in south-central New Mexico during the late Wisconsin that is 45–105 m less than the lower limit of alpine permafrost defined by Péwé (1983b, fig. 9-14).

Comparing the average elevation of rock-glacier fronts on the south and north flanks of the Capitan Mountains the difference is found to be 84 m. This figure closely approximates the 62 m altitudinal difference between southerly and northerly oriented active rock-glacier fronts in the San Juan Mountains of southwestern Colorado (White, 1979). White attributed this small altitudinal variation between southerly versus northerly exposures mainly to the insulation provided by the talus component, especially if the upper debris matrix is thick.

The mean annual temperature at the average elevation of the rock-glacier fronts in the Capitan Mountains is calculated to be about 7°C using the climatic data mentioned previously. Fig. 8 suggests that the mean summer temperature for the months of June, July, and August is at about 16°C. Mean temperatures during the winter months of December, January, and February are near-freezing or below. These values imply that the mean winter temperature favors the preservation of interstitial ice at the present time and that lower summer temperatures during the Late Wisconsin were essential for the maintenance and creep of the ice.

Leopold's (1951) reconstruction of the Late Wisconsin climate in the Estancia Basin, located 97 km northwest of the Capitan Mountains, suggests a lowering of the mean July temperature about 9°C, and the mean January temperature about 2.8°C. This interpretation is in general accord with packrat-midden data from the northern Chihuahua Desert (Spaulding et al., 1984). A postulated decline of 9.7°C in the mean August temperature during the Late Wisconsin is indicated by the modern affinities of fossil foraminifera from pluvial Lake Estancia (Bachhuber and McClellan, 1977). This is coupled with a suggested decline in winter temperatures of less than 3°C (Spaulding et al., 1984). If similar depressions prevailed in the Capitan Mountains, it is possible to reconstruct a rough approximation of the march of the mean monthly late Wisconsin temperatures at the average elevation of the rock-glacier fronts (Fig. 8). According to this curve, mean monthly temperatures

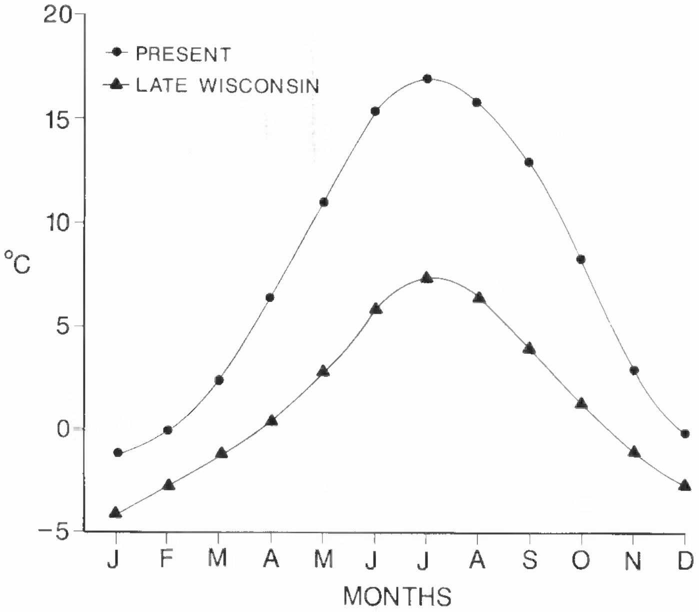

FIGURE 8. The present and late Wisconsin temperature march at the average elevation of the rock-glacier fronts in the Capitan Mountains. The present temperature march is based upon mean monthly temperatures at Fort Stanton (Kunkel, 1984) adjusted to lapse rates for the average elevation of the rock-glacier fronts (2430 m). The late Wisconsin march is determined by subtracting the summer and winter temperature depressions in the Estancia Basin (Leopold, 1951; Bachhuber and McClellan, 1977) from the modern mean summer and winter temperatures at the average elevation of the rock-glacier fronts.

were below freezing for about five months of the year and the mean summer temperature was at about 6.5°C. Apparently the lower summer temperatures coupled with the protection from solar radiation provided by the debris component favored annual preservation and creep of interstitial ice.

Utilizing the data presented in this study and the glacial features on Sierra Blanca Peak described by Richmond (1963, 1965, 1986), it is possible to make certain generalizations about the alpine climate in the area of the Capitan Mountains and Sierra Blanca Peak during the late Wisconsin. The average lower limit of alpine permafrost was about 2440 m, which corresponded roughly with the 0° to −1°C air isotherm (Fig. 9). The orographic snow line was at about 3355 m.

The upper periglacial (subnival) zone in the Capitan Mountains extended from about 2440 m to the crest (3000 m). Within this zone, the mean annual temperature was at freezing or below and the climate was characterized by much diurnal freezing and thawing resulting in the generation of large volumes of talus. Snow cover during the winter probably was thin and of short duration, and sufficient moisture promoted freeze-thaw action and the formation of interstitial ice.

Colder temperatures and more abundant snowfall on Sierra Blanca Peak resulted in the formation of an alpine glacier in the cirque at about 3490 m on the north slope. Three terminal moraines of late Wisconsin (Pinedale) age occur below the cirque at altitudes of 3200, 3325, and 3445 m, indicating three glacial stades. The colder climate, with fewer days marked by diurnal freezing and thawing, coupled with a thicker snow cover of long duration apparently restricted the generation of talus and the development of rock glaciers in the cirque.

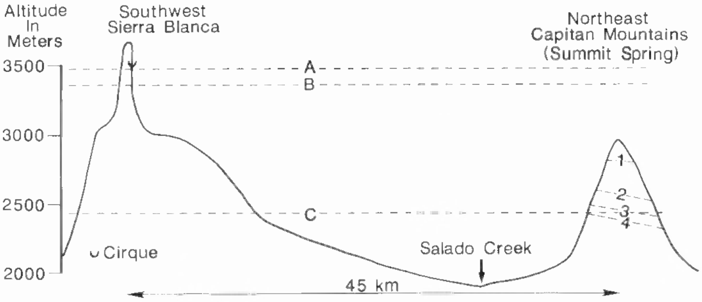

FIGURE 9. Diagrammatic cross section through the Capitan Mountains and Sierra Blanca Peak showing the vertical distribution of late Wisconsin glacial and periglacial features. The average elevation of the rock-glacier fronts (2430 m) determines the lower limit of alpine permafrost. The zone of rock-glacier activity is delineated by the maximum elevation of the heads and the minimum elevations of the fronts on the north and south sides of the mountains (Table 1). Glacial data is from Richmond (1963, 1965). A, modern lower limit of alpine permafrost; B, late Wisconsin orographic snow line; C, late Wisconsin lower limit of alpine permafrost. 1, maximum elevation of rock-glacier heads; 2, average elevation of rock-glacier heads; 3, average elevation of rock-glacier fronts; 4, minimum elevation of rock-glacier fronts.

ACKNOWLEDGMENTS

The author would like to extend his appreciation to S. E. White for his advice and encouragement during the early stages of the study. Thanks also are due W. O. Hatchell, who assisted in the field, and L. L. Sprague, who provided an aerial reconnaissance of the Capitan Mountains. Critical reviews of the manuscript by John W. Hawley, William O. Hatchell, and Sidney E. White are also gratefully acknowledged. Much of the support for the field investigations was provided by the Geological Society of America research grant 1239-69.

REFERENCES

Bachhuber, F. W. and McClellan, W. A., 1977, Paleoecology of marine foraminifera in the pluvial Estancia Valley, central New Mexico: Quaternary Research, v. 7, p. 254–267.

Barsch, D. and Updike, R. G., 1971, Late Pleistocene periglacial geomorphology (rock glaciers and block fields) at Kendrick Peak, northern Arizona: Arizona Geological Society Digest, v. 9, p. 225–243.

Blagbrough, J. W., 1976, Rock glaciers in the Capitan Mountains, south-central New Mexico: Geological Society of America, Abstracts with Programs, v. 8, p. 570–571.

Blagbrough, J. W., 1984, Fossil rock glaciers on Carrizo Mountain, Lincoln County, New Mexico: New Mexico Geology, v. 6, p. 65–68.

Corte, A. E., 1987, Rock glacier taxonomy; *in* Giardino, J. R., Shroder, J. F., Jr. and Vitek, J. D., eds., Rock glaciers: Boston, Allen and Unwin, p. 27–39.

Harris, S. A., 1981, Distribution of active glaciers and rock glaciers compared to the distribution of permafrost landforms, based on freezing and thawing indices: Canadian Journal of Earth Science, v. 18, p. 376–381.

Kelley, V. C., 1971, Geology of the Pecos country, southeastern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 24, 75 p.

Kunkel, K. E., 1984, Temperature and precipitation summaries for selected New Mexico locations: Las Cruces, New Mexico Department of Agriculture, 190 p.

Leopold, L. B., 1951, Pleistocene climate in New Mexico: American Journal of Science, v. 249, p. 152–168.

Luckman, B. H. and Crockett, K. J., 1978, Distribution and characteristics of rock glaciers in the southern part of Jasper National Park, Alberta: Canadian Journal of Earth Science, v. 15, p. 540–550.

Martin, W. C., 1964, Some aspects of the natural history of Capitan and Jicarilla Mountains, and Sierra Blanca Peak region of New Mexico: New Mexico Geological Society, Guidebook 15, p. 171–176.

Péwé, T. L., 1983a, Alpine permafrost in the contiguous United States: a review: Arctic and Alpine Research, v. 15, p. 145–156.

Péwé, T. L., 1983b, The periglacial environment in North America during Wisconsin time; *in* Porter, S. C., ed., Late Quaternary environments of the United States, v. 1, The late Pleistocene: Minneapolis, University of Minnesota Press, p. 157–189.

Potter, N., Jr., 1972, Ice-cored rock glacier, Galena Creek, northern Absaroka Mountain, Wyoming: Geological Society of America Bulletin, v. 83, p. 3025–3057.

Richmond, G. M., 1963, Correlation of some glacial deposits in New Mexico: U.S. Geological Survey, Professional Paper 450-E, p. E121–E125.

Richmond, G. M., 1965, Glaciation of the Rocky Mountains; *in* Wright, H. E., Jr. and Frey, D. C., eds., The Quaternary of the United States: Princeton, Princeton University Press, p. 217–230.

Richmond, G. M., 1986, Stratigraphy and correlation of glacial deposits of the Rocky Mountains, the Colorado Plateau, and the ranges of the Great Basin; *in* Šibrava, V., Bowen, D. Q. and Richmond, G. M., eds., Quaternary glaciation in the Northern Hemisphere: New York, Pergamon Press, p. 99–127.

Shorba, R. R., 1977, Soil development in Quaternary tills, rock glacier deposits, and taluses, southern and central Rocky Mountains [Ph.D. dissertation]: Boulder, University of Colorado, 424 p.

Spaulding, W. G., Leopold, E. B. and Van Devender, T. R., 1983, Late Wisconsin paleoecology of the American Southwest; *in* Porter, S. C., ed., Late-Quaternary environments of the United States, v. 1, The late Pleistocene: Minneapolis, University of Minnesota Press, p. 259–293.

Tuan, Y. F., Everard, C. E. and Widdison, J. G., 1969, The climate of New Mexico: Santa Fe, New Mexico State Planning Office, 197 p.

Van Devender, T. R., Betancourt, J. L. and Wimberly, M., 1984, Biogeographic implications of a packrat midden sequence from the Sacramento Mountains, south-central New Mexico: Quaternary Research, v. 22, p. 344–360.

White, P. G., 1979, Rock glacier morphometry, San Juan Mountains, Colorado: Geological Society of America Bulletin, v. 90, part II, p. 924–952.

White, S. E., 1976, Rock glaciers and block fields, review and new data: Quaternary Research, v. 6, p. 77–97.

White, S. E., 1981, Alpine mass movement forms (noncatastrophic): classification, description, and significance: Arctic and Alpine Research, v. 13, p. 127–137.