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Late Pleistocene Periglacial Geomorphology (Rock Glaciers and Blockfields) at Kendrick Peak, Northern Arizona

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INTRODUCTION

Statement of the Problem

In the semi-arid and arid southwestern United States quite a distinct number of mountains have been glaciated during Wisconsinan time. Despite the fact that an even greater area above the Wisconsinan timberline has been part of the periglacial zone, the study of the periglacial environment has been neglected through long periods of scientific research in the southwestern United States.

In many cases the knowledge of the Wisconsinan snowline gives no correct picture of the late Pleistocene changes in these arid and semi-arid mountains because we do not know, for the most part, the elevation of the present snowline. It would be, therefore, of great help if we could approximate in these mountains the depression of other geomorphic zones or, at least, of the periglacial zone during Wisconsinan time. To establish the lowering of the periglacial zone we must look for distinctive periglacial features. Very well defined and distinctive periglacial forms are rock glaciers. Active rock glaciers have been described from nearly all major mountain systems of the world.

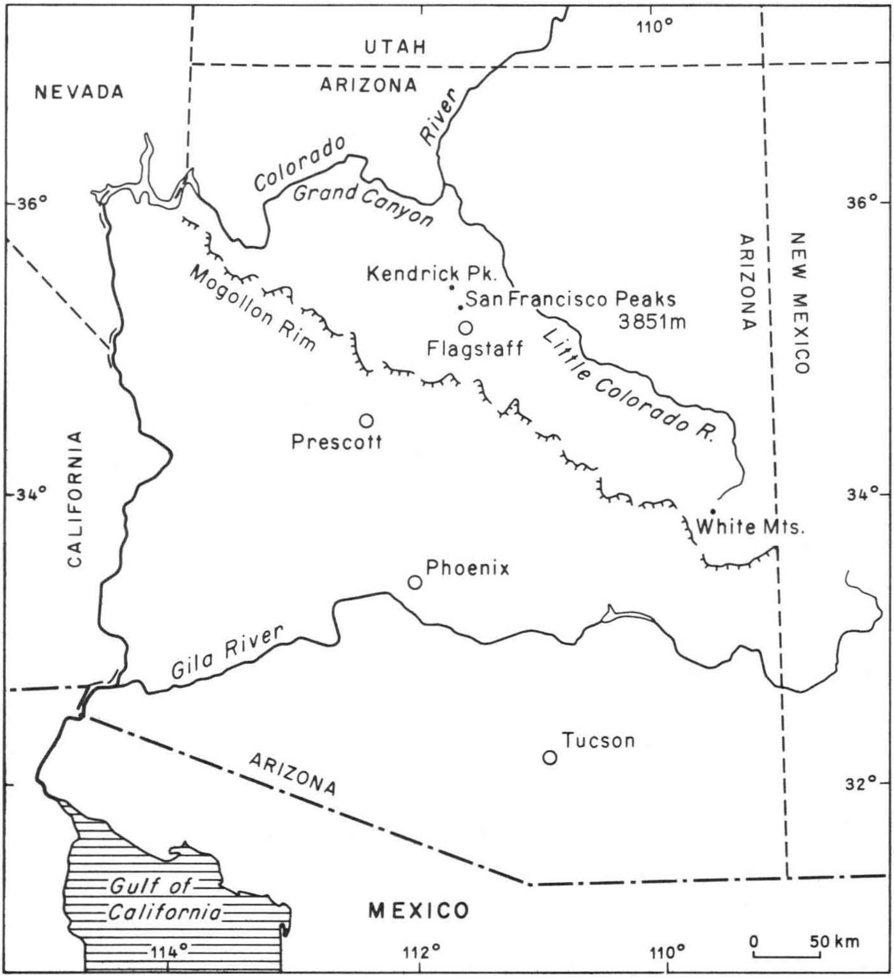

Figure 1.--Index Map of Arizona.

Definition of a Rock Glacier

A rock glacier is a large, tongue- or lobe-shaped mass of rock waste which is exclusively covered by a layer of big boulders. A rock glacier is limited by steep slopes of some 35 - 40 degrees. The surface shows a well-developed relief of furrows and ridges mostly perpendicular to the direction of flow. The downslopes movement varies between 0.1 and 4.0 m per year (Barsch, 1969a). The movement itself is generally due to interstitial ice, e.g., the frozen interior of the rock glacier (Wahrhaftig and Cox, 1959; Barsch, 1969b). The rock glacier, therefore, do not belong to the glacial, but to the periglacial environment. They are related to permafrost and they can be looked upon as a well-defined characteristic form for the upper parts of the periglacial zone (Barsch, 1969b).

A fossil or inactive rock glacier has, for the most part, lost its frozen interior. It sometimes shows collapse structures but no signs of recent movement. It is subject to erosion. First, the steep front and side slopes become gentler and at these slopes the well-known stratification (boulders in the top layer and gravel, sand, and silt gathered in the lower layer) is mantled by boulders from the top layer. Sometimes parts of the fine material in the interior have been washed out. According to the age and to the resistance of the rock types, the boulders are more or less weathered and the surface relief of furrows and ridges has been subdued. Therefore, it is often difficult to recognize a "fossil" rock glacier in the field. Especially small rock glaciers are often described as other forms, e.g., protalus ramparts (Blagbrough and Breed, 1967). According to Barsch (unpublished material), the questioned forms on Navajo Mountain, Southern Utah, should be considered as inactive rock glaciers beneath talus slopes.

Selection of the Study Area

A good area in which to look for fossil rock glaciers of Wisconsinan age, for their lower limit, and for their relation to the snowline during the time they have been active is a mountain which was not high enough to support glaciers during Wisconsinan time, but which was high enough to bear, in relation to the Wisconsinan snowline, a full periglacial environment.

A mountain which fulfills all these conditions is Kendrick Peak in Northern Arizona. It has not been glaciated, but its height (3,175 m / 10,418 ft.) approached the regional Wisconsinan snowline recently calculated to be 3,330 m (11,100 ft.) by Updike (1969).

GEOGRAPHICAL SETTING

Location

Kendrick Peak in northern Arizona is located on the southwest margin of the Colorado Plateau province, at approximately 115°50' west longitude and 35°25' north latitude (Figure 1). It lies about 28 km northwest of Flagstaff, Arizona. The peak is part of the San Francisco volcanic field, one of the most prominant physiographic features in the southwestern United States. Kendrick Peak occupies a central position in this field in which it is the second largest cone. The San Francisco Peaks are only 10 km to the southeast. Their highest peak is Humphreys Peak at

3,851 m. The summit of Kendrick Peak has an elevation of 3,175 m, approximately 900 m above the surrounding plains. The mountain proper covers an area of about 46.6 sq. km.

Climate

There are no direct measurements of meterologic data for Kendrick Peak itself available. The temperature is only recorded in Flagstaff at 1,950 m (6,500 ft.) elevation. The mean annual temperature for a 50-year period at this station is 7.6°C (45.6°F). The coldest month is January with -2.8°C (27°F), the warmest one is July with 18.3°C (65°F) (Green and Sellers, 1964). If we assume a temperature gradient of 0.5 to 0.6°C/100 m, we can estimate a mean annual temperature of 1.3 - 2.3°C at 3,000 m at the Kendrick Peak.

Precipitation has been recorded at the San Francisco Peaks. According to Colton (1958), the mean annual precipitation at 3,000 m elevation is approximately 83.8 cm (33 in.) (recorded in the Interior Valley). The range is from 27.2 to 115.4 cm (10.73 to 45.44 in.) per year. Most of the precipitation from the end of September to the end of May the following year falls as snow. It seems very probable that Kendrick Peak receives a similar amount of precipitation, especially in snow. Snow patches can be observed until the end of June in the spruce and fir forests around Kendrick Peak.

Vegetation Life Zones

We are here in the classical areas in which Merriam (1890) established his ecological life zone concept. Despite the fact that the life zone concept is perhaps too simple for use in forestry, it is still of good value for a short characterising of vegetation and climate.

At Kendrick Peak only three of the upper life zones are present. They are the Transition zone with Ponderosa pine, the Canadian zone with Douglas fir, and the Hudsonian zone with Engelmann spruce. All the foothills and the lower parts of the mountain itself up to 2,450 - 2,600 m are covered with a pure Ponderosa forest (exceptions are some park areas in the plains around the mountain with natural grassland). The mixed coniferous forest with Douglas fir and other species (in the lower part Ponderosa pine, in higher parts bristlecone pine and Engelmann spruce) covers most of the mountain up to 2,900 to 3,000 m. Only the uppermost parts and the high north-facing slopes show fine stands of Engelmann spruce and here occurs the pure Hudsonian life zone.

BEDROCK GEOLOGY

Kendrick Peak is an outstanding silicic volcano of the San Francisco volcanic field. It is a composite cone of five eruptive stages. Robinson (1913) made a reconnaissance of the area and concluded that the lavas, in order of eruption, are rhyolite, pyroxene dacite, hypersthene dacite, andesite, and basalt. Robinson's rhyolite has a silica composition of about 69% and in this report it will be termed a rhyodacite. The sequence shows a definite trend toward increasing silica difficiency which may be taken to indicate a silicic to mafic differentiation.

The rhyodacite forms the main cone as well as an extensive flow to the northwest. The unit consists of crystalline, spherulitic, and black glassy flows with associated flow breccias. The rock is characteristically micro-crystalline with scattered phenocrysts of biotite and plagioclase. Commonly the rock outcrop is very friable, particularly in weathered exposures and jointing generally occurs in blocks less than 50 cm diameter.

The pyroxene dacite and hypersthene dacite are the surface bedrock types on the lower slopes and divides on most sides of the mountain. These rocks seem to have flowed out from central vents over the large rhyodacite mass. Although the flows are extensive on the main cone, they appear thin because of the frequent exposure of the underlying rhyodacite, particularly in canyon walls. Megascopically, the two lavas are difficult to distinguish from each other, both being compact and having phenocrysts of feldspar and occasional pyroxenes of augite or hypersthene. The pyroxene dacite ranges from light to medium grey to brown whereas the hypersthene dacite is uniformly dark grey to black. These dacites generally have the most wide-spaced jointing of the Kendrick Peak lavas with blocks ranging in excess of 3 m diameter. Chemical weathering is less efficient in these dacites than in the rhyodacite due to the denser, fine-grained crystallinity of the dacites.

The andesite occurs only at a few localities on the upper slopes of the main mountain mass, the largest of these being a conical mass resting directly on the rhyodacite at the summit of the mountain. The andesite is the most compact and dense rock of the mountain and has the greatest resistance to chemical weathering. This is due, in large part, to the paucity of phenocrysts and greatest relative abundance of mafic minerals (the predominant of these being augite). Jointing varies from massive blocks 1 to 3 m in diameter to typically flaggy-jointed blocks 6 - 10 cm in thickness and less than 1 m diameter.

The basalt was erupted from parasitic vents along the lower flanks of the main mountain. The basalts in all cases were found to overlie the more silicic lavas. The rock is a typical olivine basalt characteristic of the calc-alkaline volcanic field. The silica content is about 48% and olivine and augite are the main mafic minerals present. Our investigations seem to indicate that the basalt may be considerably younger than, and independent from, the intermediate volcanic eruptions on the mountain.

According to Robinson (1913, p. 58), 21.7 cubic km of rhyodacite were erupted at Kendrick Peak, whereas only 4.5 cubic km of the dacites and andesites were extruded. Such relative abundances of lava-types and the apparent trend from silicic to mafic lavas distinguishes Kendrick Peak from any other volcanic center in the San Francisco volcanic field.

INVESTIGATION AND RESULTS

During the summer of 1968, a reconnaissance was made of the area by Updike, being primarily concerned with the volcanic geology and with the possible occurrence of Pleistocene glacial deposits which could be correlated to those noted in the San

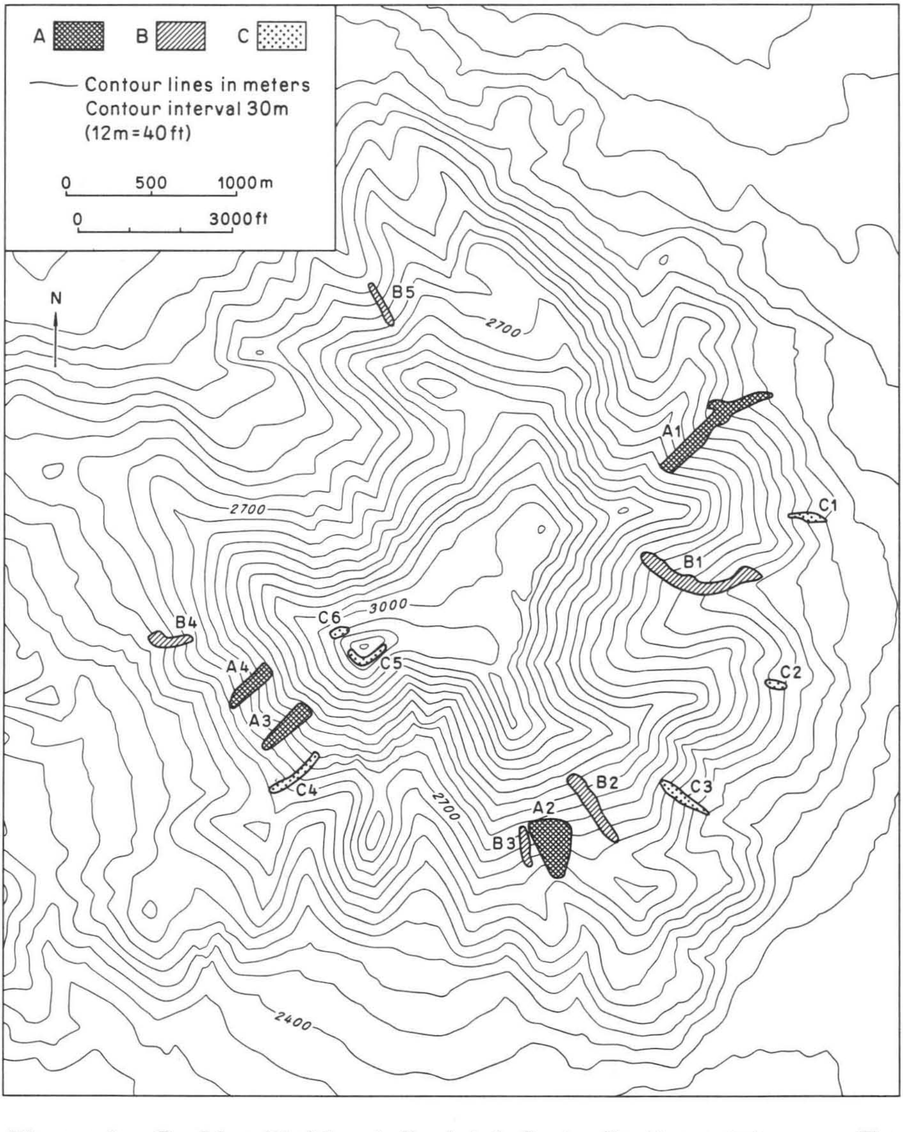

Figure 2.--Boulder Fields at Kendrick Peak, Northern Arizona. The 3,000 m Contourline Equals 10,000 Feet of Elevation. Legend:
A - Inactive Rock Glacier
B - Intermediate Forms
C - Blockfields

Francisco Peaks (Atwood, 1905; Sharp, 1942; Updike, 1967, 1969; Updike and Péwé, 1970a). Updike found no evidence of glaciation, but extensive periglacial deposits were observed and briefly studied.

Detailed investigation by Barsch and Updike was conducted during the summer of 1969. Study was made of all major canyons and slopes of the mountain with primary interest being in the surficial deposits and the associated distribution of parent lithologies in the bedrock. Close examination of boulder bields on all sides of the mountain showed that some of these features have a well-developed surface relief which indicates former downslope movement.

As stated earlier, inactive rock glaciers can be identified as tongues or lobes of boulders with particular topographic forms. We, therefore, mapped all accumulations of boulders around Kendrick Peak and we refer to them in a descriptive sense as boulder fields.

A reconnaissance was made of the area by airplane prior to detailed mapping. The maps were constructed directly in the field with the assistance of a Thommen altimeter, Meridian clinometer, Brunton compass, and steel tape. The Kendrick Peak $7\frac{1}{2}$ minute U. S. Geological Survey topographic map was used as a base map.

In addition to the mapping all information concerning the state of development of the boulder fields and their present-day surface relief were gathered. Fifteen large boulder fields were mapped (Figure 2). All of them, except C-4, have no vegetation cover. They all consist of angular boulders and no fine material occurs on their surface. Their surface relief, however, varies considerably from one unit to another. We, therefore, divided these 15 boulder fields into three classes or groups. All data are presented in Table 1.

The first group is composed of those boulder fields on which a very well-developed, prominant relief of furrows and ridges occurs. The major ridges have generally steep front slopes often up to 85% (38 degrees). The ridges are tongue-shaped and include, in many cases, depressions 2 to 5 m deep (maximum ca. 8 - 10 m). In some cases the depressions may be interpreted as collapse structures. Because the boulder fields of group 1 meet all criteria, we refer to them as inactive rock glaciers (see Conclusion).

The best-developed boulder field in group 1 is Kendrick Tank rock glacier (Figure 3). It was initiated beneath a blocky talus slope in the head of a small valley. All the boulders were derived from dacite. The rock glacier begins at 2,730 m elevation with a sudden transition from the uniform talus slope to a well-developed surface relief with ridges and terrace-like features. The ridges which do not cross the entire rock glacier are often terminated by very prominant scarps (slope: 70 - 80 %). At 2,635 m elevation a very prominant scarp (85%, height ca. 10 m) forms the lower end of the very well-developed surface relief. Down-valley from this scarp the ridges and furrows on the bouldery surface are much more subdued, but still the lobate form of the ridges is easily recognized. Weathering seems to have been more intensive in the lower part than in the upper. In many cases, the primary flow structures in the rock are weathered out, and the boulder size seems to be modified by intensive frost cracking.

Table 1: Boulder Fields (Rock Glaciers, Intermediate Forms and Blockfields) at Kendrick Peak, Northern Arizona

	Name	Map-Symbol	Length (m)	Width (m)	Exp.	Elevation Upper (m)	Elevation Lower (m)	Diff. in Elevation (m)	Slope %	Angle degree
Group 1:	Kendrick Tank regl.	A1	900	70-75	NE	2730	2485	245	23	10
	Crowley Tank regl.	A2	360	60-240	S	2760	2615	145	40	18
	Newman Hill regl.	A3	360	50-100	SW	2850	2690	160	45	20
	Newman Spring regl.	A4	325	50-85	SW	2820	2670	150	46	21
Group 2:		B1*	460	80	S-SE	2750	2610	140	30	14
		B2	480	50-80	SE	2835	2670	265	55	25
		B3	240	50	S	2760	2655	105	42	19
		B4	260	60	W	2695	2595	95	37	17
		B5	290	50	NW	2670	2565	105	36	16
Group 3:		C1	240	25-50	E	2555	2485	70	29	13
		C2	145	35-40	E	2630	2580	50	35	16
		C3	335	25-60	SE	2700	2550	150	45	20
		C4	360	30-50	SW	2770	2640	130	36	16
		C5**	50	265	SW-SE	3090	3060	30	60	27
		C6**	60	120	NW	3060	3010	50	83	37

*B1 is composed of several units sloping down from the south facing slope of a small valley. The above cited values represent the upper part of B1.

**C5 and C6 are small blockfields around the small knob of Kendrick Peak. That explains their special form and the special values in Table 1.

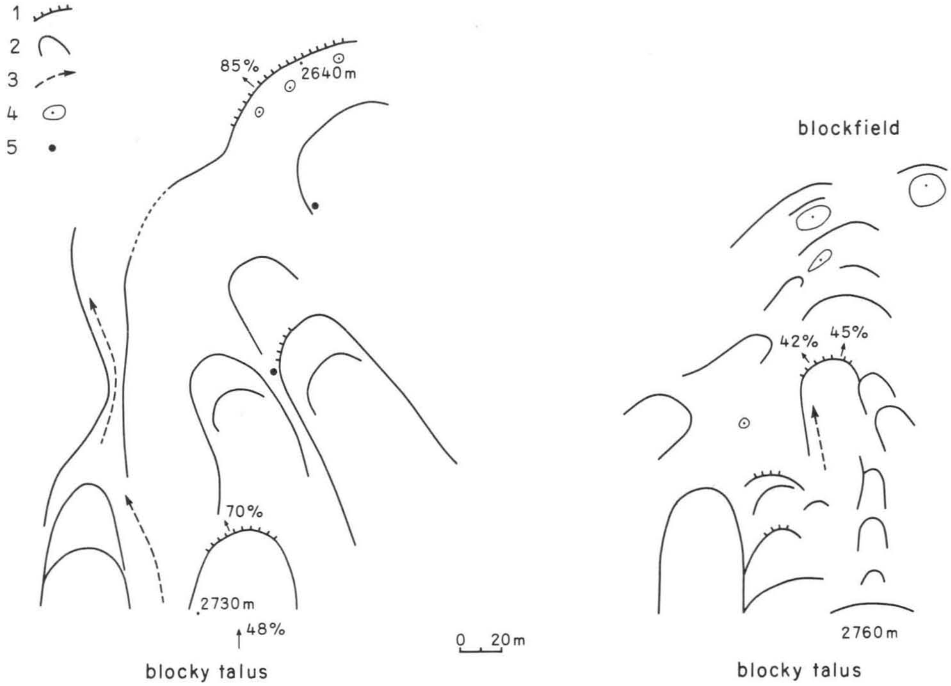

Figure 3.--Kendrick Tank (A-1, left) and Crowley Tank (A-2, right) Rock Glacier at Kendrick Peak, Northern Arizona. Legend:

1 - Steep Slope
2 - Ridge, Lobe
3 - Furrow
4 - Closed Depression
5 - Tree

Below 2,540 m the boulder field is no longer convex in relation to the surrounding terrain, but concave. The lower end of this boulder field is at 2,485 m. In the forest which surrounds the lowermost part of the rock glacier we have found an accumulation of big boulders.

We can, therefore, distinguish three parts on the Kendrick Tank rock glacier: (1) an upper part with a very prominent relief, (2) a middle part with less developed relief, and (3) a lower part with a very poor relief and with a concave form in relation to the surrounding terrain.

Another well-developed boulder field of group 1 is Crowley Tank rock glacier (Figure 3). It was developed out of a steep talus slope and its upper part has a slope angle of 47%. Beginning at 2,760 m, a very distinctive surface relief appears. In this part we found three lobate ridges adjacent to each other. Despite the mappable relief, no prominent scarps were developed. In the lowermost part, however, large depressions are present and the blocky layer extends into forest. On Crowley Tank rock glacier we could not find any sign of the differentiation described from Kendrick Tank rock glacier.

In Figure 4 we present the mapped surface relief of Newman Spring rock glacier. It has the steepest average slope with 46% (21°) of all rock glaciers at Kendrick Peak. The uppermost part of this boulder field shows a slope angle of 53% (24°). Despite this extreme steepness, it has a fine relief with several very distinctive lobate ridges and with very deep depressions in its lower part. A characteristic feature of Newman Spring rock glacier is its color in the lower part. The northwest side is light-colored, caused by dominance of dacite (ca. 80%) over other rock types. The southeast side is darker, caused by the presence of andesite (more than 60% of the boulders). The boulder field has a particularly steep, elongated form, but there is no question that it is a well-developed rock glacier with distinctive relief.

The most interesting member of group 1 is Newman Hill rock glacier. It consists, for the most part, of one large terminal lobe formed by a single, prominent ridge. The front slope of this ridge is 40 - 50 m high and has a slope angle of 50% (23°). The depression behind this ridge is about 10 m deep in relation to the front ridge, and 12 - 14 m towards the side ridges. Most of the ridges are built up of, and covered by, large boulders, and only on the steep front slope was fine-grained material exposed.

The second group consists of boulder fields which have only a poorly developed relief. The ridges and furrows are smooth, steep front scarps are missing, and the depressions are shallow. The difference from forms of group 1 is obvious, but gradational. In all cases it was possible to map the surface relief. We refer to them as intermediate forms, because they seem to form, at least in relation to their surface, a transition between group 1 and 3.

A good example representing this group is B-1. It is a large boulder field covering nearly the entire floor of a small valley and consists of boulders which have moved from the head wall and the northern wall of the valley. The direction of the downslope movement of the boulders lies between south and southeast. Small lobes, as well as ridges and small terrace-like features, have developed in the directions of flow. They form

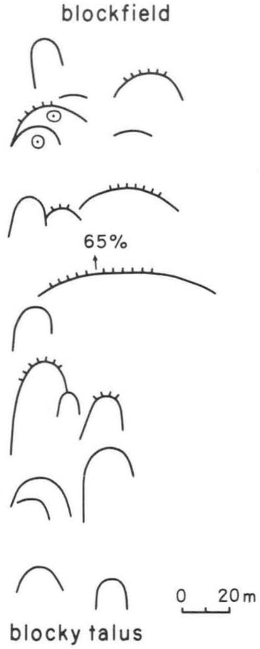

Figure 4.--Newman Spring Rock Glacier (A-4) at Kendrick Peak, Northern Arizona. Legend: See Figure 3.

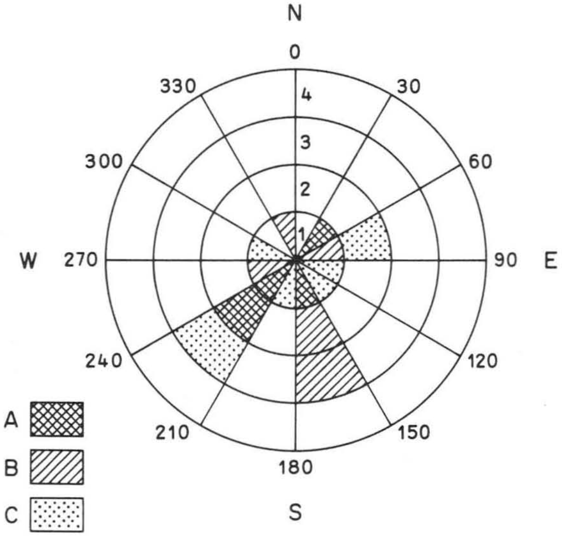

Figure 5.--Orientation of Boulder Fields at Kendrick Peak, Northern Arizona. Legend:
A - Rock Glaciers
B - Intermediate Forms
C - Blockfields

a well-developed row at the base of the northern valley slope. The surface relief is fairly well developed, but it is still much poorer than on members of group 1 and in all cases clearly smaller than those of group 1.

The third group, in contrast, is made up of boulder fields with no surface relief. There is no part on a unit of group 3 where we find furrows, ridges, or depressions. The boulder fields of this class are each a sheet-like accumulation of boulders with no fine material and with a lack of vegetation. Thus far, they conform with the definition of a blockfield given by Caine (1966), but the slope angle of 13 to 20 degrees (29 - 45%) is too steep according to his definition in which he introduces as an upper limit for the slope an angle of 15 degrees. Such a limitation is rather artificial. We refer, therefore, to the units of group 3 as blockfields.

As an example of this group, we cite C-3. It is a long and narrow blockfield with a relatively steep slope of 45%. On its surface no relief, neither furrows nor ridges, can be observed. This type of boulder field approximates features described in Europe and other parts of the world as Blockstreams, "Blackstrome" or "Blockmeere" (e.g., Schott, 1931; Fezer, 1953; Rother, 1965; Caine and Jennings, 1968).

The boulder fields of type A, B, or C were observed to occur on vitually all sides of the mountain. However, the greatest concentration of major features were formed on the east, south, and southwest sides of the peak (Figure 5 and Table 2). The large units were all found to follow the axis of topographic depressions (commonly canyons). It was also noted that the south-facing walls of these canyons were more favorable for the production of large amounts of talus, provided that bedrock was homogeneous and the canyon was properly oriented (i.e., east-, west-, or south-facing).

The boulder fields also seem correlative to particular elevations in relationship to their exposure. Table 2 shows that the units in the southern quarters have their lower limit at a higher elevation than those facing north or directly east or west. The difference between the lower limit of inactive rock glaciers facing northeast and ones facing southwest is nearly 200 m. There are not enough data for a statistical analysis, but it is striking that in two cases the highest lower limit is on units facing southwest.

A direct comparison of the lower limits of the boulder fields demonstrates that the members of groups 1 and 2 are clearly limited to higher elevations. If we, therefore, compare the average values for all south-, southwest-, and southeast-facing boulder fields, we find that the difference between groups 1 and 2 is very small and that rock glacier and intermediate forms occupy the same range of elevations. On the other hand, there is a clear interval of approximately 65 m down to the lower limit of blockfields in this sector. This step is about 35% of the difference in elevation of the lower limit of rock glaciers on northeast and southwest-facing slopes.

Table 2: Average Lower Elevation (m) of the Mapped Boulder Fields in Relation to Exposure

	E	NE	NW	W	SW	S	SE	Average SW S SE
Group 1:	----	2485	----	----	2680*	2615	----	2658
Group 2:	----	----	2565	2595	----	2655	2670	2663
Group 3:	2483*	----	----	----	2640	----	2550	2595

* Average of two values

Table 3: Difference in Elevation Between the Wisconsinan Snowline (3,330 m) and the Upper and Lower Limit of the Inactive Rock Glaciers at Kendrick Peak, Northern Arizona

Rock Glacier	Symbol	Exposure	Upper Limit (m)	Lower Limit (m)
	A-1	NE	600	845
	A-2	S	570	715
	A-3	SW	480	640
	A-4	SW	510	660
		Average:	540	715

CONCLUSION

The boulder fields of group 1 show all features characteristic of active rock glaciers today, i.e., surface relief of furrows and ridges, steep front and side scarps, large closed depressions, a bouldery mantle, and aerial extent. Their present-day relief can only be explained as former flow structures, which have also been described from active rock glaciers (Wahrhaftig and Cox, 1959; Barsch, 1969a). In addition, the fact that deep depressions in the lower extent of some boulder fields of group 1 can only be explained as collapse features, favoring a rock glacier interpretation. A major collapse indicates the former presence of considerable amounts of interstitial ice necessary for the movement of active rock glaciers (Wahrhaftig and Cox, 1959; Barsch, 1969a, 1969b). We conclude, therefore, that the boulder fields of group 1 at Kendrick Peak are inactive rock glaciers which must have formed during times when snowline was much lower than today.

If we consider the boulder fields of group 1 to be inactive rock glaciers, it is subsequently necessary to discuss the relationship of the boulder fields of groups 2 and 3 to these rock glaciers. The members of group 2 occur at more or less the same elevations as the rock glaciers and weathering of exposed boulders is identical. Therefore, despite their more gentle surface relief, the group 2 deposits cannot be subjectively considered older than the group 1 boulder fields. It is very probably that they are of the same age as the rock glaciers. Their more poorly-developed, present-day surface relief perhaps has been more modified or else was never very prominent. We prefer the latter assumption, because the boulder fields of group 2 are mainly situated in areas where the production of blocky talus was more limited than at those places occupied by the inactive rock glaciers of group 1. Their evolution to well-developed rock glaciers was, therefore, handicapped, because the formation of rock glaciers not only depends upon rigorous periglacial climate, but also upon a sufficient production of blocky talus. The boulder fields of group 2, therefore, are believed to be inactive, incipient rock glaciers.

Considerable differences exist, not only in elevation, but also in surface relief, between the rock glaciers of groups 1 and 2 and the boulder fields of group 3. The formation of the group 3 boulder fields resulted from different processes than the rock glaciers. They form a sheet-like cover below their source areas, but they do not show any flow structures. The movement of these boulders was surely due only to solifluction, rock creep, and normal gravity talus production. The amount of interstitial ice was very low, perhaps absent, because no collapse or flowage structures have been found. In many areas the boulders have been moved in a matrix of fine grained material, which has partially been removed by surface and subsurface drainage (described as "piping" by Smith, 1968). This is indicated by the fact that the blockfields have, for the most part, no side scarps towards the surrounding terrain, and the slopes surrounding the blockfields generally show a fine matrix containing many boulders. Soil and forestation have developed in these adjacent areas. The blockfields thus formed at lower elevations, under a less intensive periglacial environment than the rock glaciers. The prominent bouldery appearance of these deposits is probably not related to frost-induced sorting, but the result of secondary denudation by removal of the fine fraction. As Smith points out (1968,

p. 203-204), piping, or the removal of the fine fraction from periglacial deposits by running water in the interstices may be part of the periglacial sequence in an area, being related to the melting of interstitial ice. It seems quite plausible that the units of groups 1 and 2 have also been subjected to surficial modification and accentuation by this process. Boulder fields of nearly the same appearance as our type C have been described from New South Wales, Australia, by Caine and Jennings (1968) as blockstreams. The authors assume that these blockstreams are too small and too thin to be the relics of rock glaciers. Their age is considered, according to a radio carbon date, to be younger than 35,000 B.P.

The rock glaciers and the other boulder fields at Kendrick Peak have been formed during times when snowline was considerably depressed, probably correlative to the glaciation of the San Francisco Peaks (Atwood, 1905; Sharp, 1942; Updike, 1967, 1969; Updike and Péwé, 1970b). The freshness of the surface relief and the well-preserved general form of the rock glaciers at Kendrick Peak indicates a relatively young age. It seems, therefore, reasonable to assume a Wisconsinan age for them. At present it is not possible to give a more precise age (i.e., early or late Wisconsinan).

The interpretation that the boulder fields of groups 1 and 2 are Wisconsinan rock glaciers has several climatic implications. Active rock glaciers are considered as a characteristic form of the upper periglacial zone (upper subnival) (Barsch, 1969b). We must, therefore, consider their relation to the snowline during Wisconsinan time. Updike (1969) reports a snowline of 3,330 m (11,100 ft.) as an average for seven cirques in the Interior Valley of the San Francisco Peaks during the Wisconsinan. A similar value can probably be considered for Kendrick Peak.

The average lower limit of the rock glaciers at Kendrick Peak is about 700 m below the Wisconsinan snowline. Similar limits below snowline have been reported from New Mexico (John Blagbrough, 1969, oral comm.). The inactive rock glaciers of Wisconsinan age there are situated 600 - 900 m below the snowline of the same period. In comparison, the present lower limit of rock glaciers in the Swiss Alps lies about 400 m below the present snowline (Barsch, 1969a, 1969b), and in the Alaska Range the same limit is 120 - 360 m below the present snowline (Wahrhaftig and Cox, 1959). This seems to indicate a particular climatic difference between the former periglacial zone in the southwest and the present periglacial zone in the mountains of higher latitudes. The difference probably is due to more intensive radiation and to a greater aridity in the southwestern United States. Both factors have a greater impact on glaciers than on rock glaciers, because the interstitial ice in rock glaciers is protected from direct radiation and sublimation by the blocky mantle of debris. The so-called "Balch ventilation," i.e., freezing by Balch ventilation, (Thompson, 1962) is common to all rock glaciers or other boulder fields, but it seems that the effect is more important in regions with an intensive radiation climate.

The inactive rock glaciers at Kendrick Peak were formed well below snowline during Wisconsinan time. They have, therefore, to be considered as a periglacial and not a glacial feature. Their movement is due to interstitial ice and not to glacier ice. The latter could not have been formed below snowline, in an area lacking glaciation. Therefore, we do not find data which could favor an interpretation of the inactive rock glaciers of Kendrick Peak as debris covered glaciers (e.g., Kesseli, 1941; Richmond, 1952; Outcalt and Benedict, 1965; Potter, 1967; type 3 of Barsch, 1969a). The same is true for the San Mateo Mountains, New Mexico, according to Blagbrough and Farkas (1968) or for the Escudillo Mountains, Arizona, according to Barsch (unpublished material). All these rock glaciers moved downslope with the aid of interstitial ice, but the amount of interstitial ice varied from one rock glacier to another. For instance, the Newman Hill rock glacier must have contained a considerable amount of interstitial ice as the large depression in its terminus shows.

The average lower limit of the rock glaciers at Kendrick Peak lies at about 2,600 m which also delinates the lower limit of the upper periglacial (subnival) zone during Wisconsinan time. The present timberline at the San Francisco Peaks is at about 3,500 m. The depression of the timberline during the Wisconsinan must have been approximately more than 1000 m. That means timberline must have been at an elevation in which we find today the Ponderosa life zone. Most of the present Canadian life zone was part of the Wisconsinan upper periglacial (upper subnival) zone and was influenced by a vigorous periglacial environment.

The active rock glaciers in the Alps exist in a climate with an average annual temperature of -2 to -3°C. At present, the mean annual air temperature at Kendrick Peak (at 2,650 m) is about 3.1°C (this assumes a gradient of 0.5° C/100 m from Flagstaff to Kendrick Peak). To establish a climatic regime at this elevation favorable for the development of rock glaciers similar to those of the Alps, the mean annual air temperature must have been depressed about 5°C. This value, at best, shows the approximate range we must assume for the depression of the mean annual temperature at Kendrick Peak, with no consideration for the other variables involved in the regime of a rock glacier. We consider that the accumulation of additional data on other areas within the Pleistocene periglacial environment of the Southwest will be most profitable in the interpretation of the Quaternary climate of the southwestern United States.

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