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MULTIPLE CYCLES OF CRYOPLANATION ON SUGARLOAF MOUNTAIN, MARYLAND

Abstract

Sugarloaf mountain, a monadnock in southernmost Frederick county, Maryland, is formed by an anticlinorium containing Lower Cambrian (?) quartzites and interbedded phyllites. Quartzite ledges forming Sugarloaf Peak, underlying structural terraces on the south and west flanks of The Peak, and exposed along the crest of Stewart Hill were riven by frost at several times during the Pleistocene. Tors and summit plateaux lie atop these shattered ledges; talus, cryoplanation terraces, and boulder streams occur below them. The development of such extensive periglacial landforms in an area far south of the Wisconsinan ice border was enabled by the favorable lithology, attitude, and aspect of these ledges.

INTRODUCTION

LOCATION

Sugarloaf mountain stands on the High Piedmont in southernmost Frederick county, Maryland at N39°15'00", W77°22'30", three miles north of the village of Dickerson (Fig. 1). The area is shown in detail in Fig. 2, modified from the Buckeystown, Poolesville, and Urbana 7½' series quadrangles, USGS. About ten square miles are included.

TOPOGRAPHY

The Sugarloaf massif consists of a U-shaped ridge three miles in length and one in width. This ridge rises gradually from the High Piedmont and, ascending first northeastward, then southeastward, and finally southwestward through an irregular succession of lesser eminences, culminates in Sugarloaf Peak, an acre of level ground standing 1280 feet above the sea and about 700 feet above the adjacent Piedmont. Both the major and the minor topographic features of the massif are closely controlled by structure and lithology.

From a distance, the slopes of the massif appear to be smooth and rounded. Closer examination reveals many quartzite ledges and pinnacles puncturing, as it were, the larger outlines of the massif. These topographic anomalies are the subjects of this paper.

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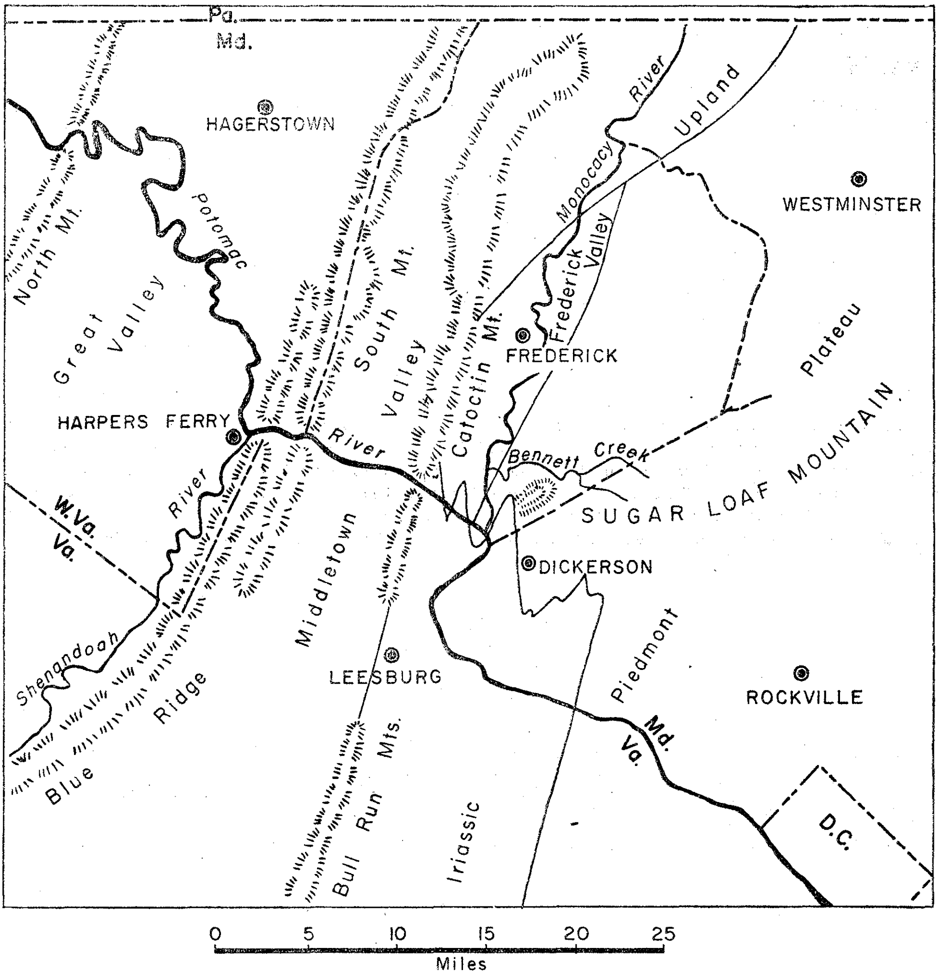

Fig. 1. Regional setting of Sugarloaf Mountain, Maryland (modified from STOSE *et al.*, 1946, p. 4)

PALEOCLIMATE

The larger outlines of the Sugarloaf massif must have been established during the Tertiary, for Sugarloaf is a monadnock on the (Tertiary) Piedmont surface. It is to be interpreted, then, as the product of a climate similar to that of the Present, only somewhat more warm and moist and, therefore, one in which chemical weathering and erosion were relatively more important than they now are.

Sugarloaf mountain lies within the continental humid temperate region of North America, in the belt of westerlies. Annual precipitation at Frederick, Maryland, the nearest weather station, averages 40¾ inches, distributed evenly throughout the year. There are an average of 179 frost—free and 105 freezing days, and 81 days

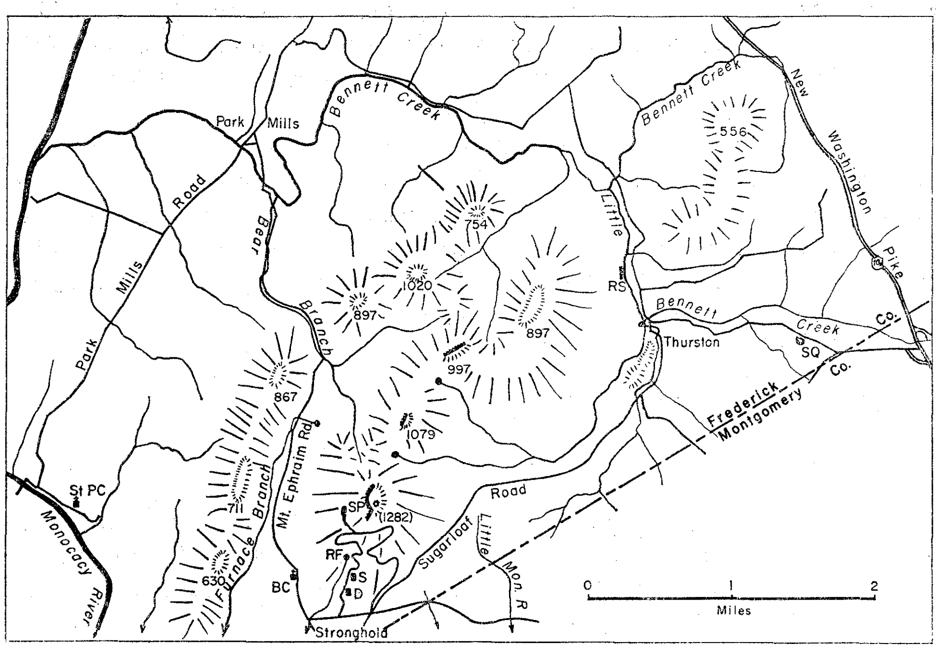

Fig. 2. The Sugarloaf Area, showing features discussed in the text

on which the air temperature crosses the freezing point. Mean monthly temperatures range from 32.5° F in January to 76.6° F in July.

Interrupting the rounded topography developed under the continental humid temperate climates of the late Tertiary and interglacial Pleistocene are many anomalous local landforms. Tors, summit plateaux, shattered cliffs, talus, cryoplanation terraces, and boulder streams — all these were created during the glacial Pleistocene by a climate at those times boreal — to tundra-like in severity.

Although the Wisconsinan tundra zone, as mapped by DILLON (1956, Fig. 11) long was thought to be essentially conterminous with the zone in North America in which periglacial features occur (SMITH, 1962, p. 336), recent investigations show that this interpretation was too restrictive. BRUNNSCHWEILER (1962, 1964) postulates the former existence of a tundra climate in the Sugarloaf area on the bases of landforms and of relict soil phenomena and reports (1964, p. 224) congelifractates to occur in the vicinity of Leesburg, Virginia, across the Potomac (south) from Sugarloaf. Faunal evidence shows that a tundra—transitional taiga forest probably existed in the Sugarloaf area from about 22,000 to 13,000 years BP (GUILDAY, 1971, p. 234). CLARK (1968) recently described several new occurrences of sorted patterned ground in the central Appalachians.

The questions, „Why are there so many fewer periglacial phenomena south of the Pleistocene terminal moraines in North America than there are in Europe?" and, in view of this, „Was there a periglacial realm in eastern North America?"

were summarized recently in HEDGES (1972). Most of the periglacial landforms and other evidence for the former existence of tundra climates in the Central Atlantic states have been found at relatively high elevations in the central Appalachians. Very few are known to exist in the Piedmont.

Cryogene phenomena probably developed in this region only in areas where local conditions such as altitude, lithology, aspect, and/or exposure were especially favorable. The topographic elements on Sugarloaf mountain herein ascribed to a periglacial genesis probably owe their existence to a combination of lithology, structure, and aspect which left these portions of the landscape especially vulnerable to weathering under periglacial conditions.

GEOLOGY

STRATIGRAPHY*

The rocks of which the Sugarloaf massif is composed have been referred to five Lower Cambrian formations, in ascending order the Stronghold, Sugarloaf Mountain, Park Mills, Urbana, and Dennis. All are strongly quartzitic, with the exception of the Urbana.

The Stronghold and Sugarloaf Mountain quartzites comprise the Sugarloaf group. These rocks customarily are regarded as being equivalent to the Weverton sandstone of Catoctin and South mountains. Phyllites probably occur between the beds of quartzite, although they rarely are exposed. The eastern portion of the massif is underlain by rocks of the Sugarloaf group.

That part of the Sugarloaf massif lying west of the Sugarloaf fault (i. e., Stewart Hill), the valleys of Bennett and Little Bennett creeks, and the headwaters of the Little Monocacy, are underlain by the Park Mills, Urbana, and Dennis formations of the Thurston group. These phyllites and interbedded quartzites traditionally have been correlated with Harpers phyllite of the Blue Ridge.

STRUCTURE

The Sugarloaf massif is a faulted anticlinorium overturned to the west. The topography of the mountain is inverted and is closely controlled by structure. Sugarloaf Peak is synclinal, lesser peaks to the north and west occur on the truncated

*THOMAS' (1952) geologic analysis of the Sugarloaf massif is the most detailed yet presented. Most earlier viewpoints can be reconciled with it; the few which cannot are based upon errors of interpretation easily explained without contradicting THOMAS' scheme. This discussion assumes the correctness of THOMAS' exposition.

A detailed critique of the often conflicting geological literature on the Sugarloaf area is presented in my manuscript report to Stronghold, Inc. (Dickerson, Md., 20753), "Geography, Geology, and Geomorphology of the Sugarloaf Massif." A copy of that report also is on deposit with the Maryland Department of Geology, Mines, and Water Resoures, Baltimore.

axes of steeply-plunging secondary folds, and Stewart Hill is held up by the near-vertical western limb of the major anticline. The valleys of Bear Branch and of Furnace Branch, in the center of the massif, follow the Sugarloaf fault.

GEOMORPHOLOGY

SUGARLOAF ANTICLINORIUM

Sugarloaf mountain is a monadnock, a smoothly-moulded erosional upland standing above the High Piedmont. It owes its survival to the durability of the quartzites which form its peaks. The larger features of the mountain were developed under the continental humid temperate climates of the late Tertiary and interglacial Pleistocene. Structural control of the topography is nearly perfect.

Smooth, concave slopes which rise abruptly from the valley floors and rounded, soil-mantled summits are typical of the central Appalachians (KEITH, 1893, p. 377). Where bedrock outcrops occur, one nearly always finds as the local cause (a) a stream undercutting a bank, (b) karsting and suberosion, or (c) relict periglacial activity.

This landscape is a late-mature topography in which, slopes steeper than the repose angle of the mantle having been extinguished by the accumulation of weathering debris from above, the entire landscape has been covered by a protecting blanket of vegetation and is being softened and flattened by solution.

The solution of quartzite and of other silicate minerals in the Appalachians occurs at an appreciable rate. REED, BRYANT, and HACK (1963, p. 1186) reported that the Linville river, North Carolina is removing silica in solution so rapidly that the elevation of its entire basin could have been reduced by 35 feet since the end of the Miocene, by the solution of silica alone. Closed depressions in North Carolina quartzites equivalent to the Sugarloaf Mountain quartzite are reported by the same authors to have formed by solution. An opferkessel and several boulders of spheroidal weathering, presumably formed since the close of the Wisconsinan glacial stage, occur on Peak 997[1]. A general review of solutional landforms on silicate terraines is given in HEDGES (1969).

Thus, slope angles lower than the angle of repose now are more closely related to the solubility of the underlying rocks than to their mechanical strength. Quartzite outcrops in the Sugarloaf massif owe their existence to climatic perturbations which temporarily weakened the vegetal cover, allowing the steepest slopes to be stripped of their mantle by running water and the underlying quartzites thereafter to be attacked by frost and other mechanical agencies.

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[1] Peak numbers refer to summit elevations, shown in Fig. 2.

PERIGLACIAL ANOMALIES

The anomalous landforms which now interrupt the basic humid-temperate slopes of the Sugarloaf massif are characteristic of regions now possessing tundra climates and, also, of temperate regions lying slightly beyond the Wisconsinan terminal moraines. Tors, summit plateaux, shattered ledges, talus, cryoplanation terraces, and block streams are developed upon nearly all of the peaks and along the south and west flanks of the east ridge. Each of the ledges mapped by SCOTFORD (1951) exhibits some degree of periglacial weathering and erosion.

Peak 867 yet retains an unbroken exposure of the anticlinal crest in Park Mills quartzite along Stewart Hill (Pl. 1). The face of the exposure is smooth, except for a few exfoliation scars, and, at the top, curves over into the east limb of the anticline. That there is relatively little debris at the base of the outcrop suggests that frost attack is not too effective until the ends of the strata are exposed and water has easy access between the layers.

For proof that these features are relict and are not developing under the present climatic regime, we need only to observe their weathered, stable aspect. There are no fresh breakage surfaces either on the ledges or on the blocks of talus. All rock surfaces are encrusted with lichens. The boulder streams are overgrown with large, erect trees.

Tors

The level, soil-covered summit plateaux of the Sugarloaf massif often are pierced by monuments and hogbacks of unreduced quartzite. Some of the monuments are rounded (*cf.* Peak 1020). Others (*cf.* Bell's Chapel area) are strongly shattered and are surrounded by debris-laden pediments. Hogbacks are best developed on Stewart Hill south of Peak 867. These tors are strongly reminiscent of the gritstone tors of the English Pennines (PALMER and RADLEY, 1961) and of the castle rocks of southwestern Wisconsin (BLACK, 1969, pp. 77—78).

Monuments composed of vertical beds probably are the exposed ends of minor folds plunging down the flanks of the anticlinorium. JONAS (1937, p. 382) aptly described similar features, saying: „Steep-fold areas tend to weather out on the surface into a series of nearly vertical, sharply pointed pinnacles which have the appearance of sagging tombstones in a neglected graveyard."

Tors are the residuals, the „monadnocks" lingering above the penultimate surface of periglacial erosion in areas where the summit plateau is incompletely formed.

Summit plateaux

The quartzite crests of the ridges in the Sugarloaf massif normally are very gently rounded, regardless of the attitude of the underlying beds. On the east, they break sharply into a mountainside sloping about 20°. On the west ,they end quite abruptly at a shattered ledge standing at about 55°.

The plateau surfaces are thinly mantled with soil, through which monuments and hogbacks of quartzite protrude. These plateaux occur at varying absolute elevations and slope longitudinally along the irregular crestlines of the ridges. They are cut into the same quartzites which form the tors above them and the shattered ledges below them. No lithologic, structural, or topographic causes for them are to be found.

The most satisfactory explanation of these features is that they are old cryoplanation terraces dating from pre-Wisconsinan stages of the Pleistocene. When the climate is periglacial, the phyllite is relatively more resistant to weathering than is the quartzite, due to the ability of the phyllite quickly to break down and to orm a protecting layer of soil. Cryoplanation thus begins where the phyllite/quartzite contact intersects the land surface and bevels stratigraphically upward acrfoss the east-dipping layers of quartzite.

When the climate changes to interglacial, the quartzite becomes relatively more resistant due to its lesser solubility and massive character. Slopes underlain by phyllite then are preferentially lowered, leaving the cryoplanation terrace high above the new topographic elevation of the phyllite/quartzite contact. During subsequent periglacial stages, renewed cryoplanation initiates new terraces at the successively lower elevations of the outcrop of the phyllite/quartzite contact and a stepped topography is developed. Old terraces are extended during later stages of periglacial denudation. Residual summit hogbacks and monuments eventually are bevelled off and the highest surviving terrace becomes a plateau, laterally flat but longitudinally conforming to the varying elevation of the former outcrop line of the phyllite/quartzite contact. Pl. 2 shows the summit plateau and tor on Sugarloaf Peak.

Shattered ledges

Nearly all outcrops of quartzite in the Sugarloaf massif have been severely shattered. The ends of the individual beds are broken and great slabs and pillars stand partly detatched from the main mass of quartzite. Some exposures consist wholly of jumbled blocks. The impression gained is not unlike that in a quarry just after a shot has been fired. Closer examination reveals, however, that the surfaces of the stones thus rent asunder have been pitted and furrowed by long exposure to the elements.

The tor which rises above the summit plateau is about 150 feet from the break in slope between the plateau and the mountainside. Considering the summit plateau to have been initiated during the penultimate cycle of cryoplanation, and assuming the two cycles to have been equally long, then the ledge of which the tor is the surviving remnant must have retreated 75 feet during each cycle. Retreat of the other ledges probably was on the same order of magnitude. Pl. 3 shows the shattered ledge and talus at Sugarloaf Peak.

Talus

The bases of all of the higher ledges are obscured by talus accumulations. Talus below the White Cliffs of Sugarloaf Peak stands at about 35°, near the angle of repose for coarse detritus. The individual blocks in the talus aprons are weathered and their formerly sharp corners have been rounded by mechanical disintegration. The deposits now are being invaded by trees. Clearly, they are inactive at the present time. Nothing is being added to them from the ledges above and nothing is being subtracted from them to the block streams beyond.

Block streams

The lower margins of the talus aprons ravel out into block streams which become thinner downslope and at length blend into a general sparse scattering of quartzite float which occurs all over the mountain. Visible block streams generally are confined to the terraces, although small fragments often may be found beneath the forest litter on the mountainside.

The transition from talus to block stream occurs where sufficient fines have accumulated between the boulders to retain a supply of moisture adequate for frost heaving or solifluction (DEMEK, 1969, p. 120). Blocks embedded in fines are reported to have moved over slopes as low as 2° (SMITH, 1949, p. 210. citing BÜDEL), a declivity much lower than those of the terraces in the Sugarloaf massif[2].

The block streams, like the talus, are weathered and have been overgrown by vegetation. They clearly are relict features incapable of having been produced under modern conditions.

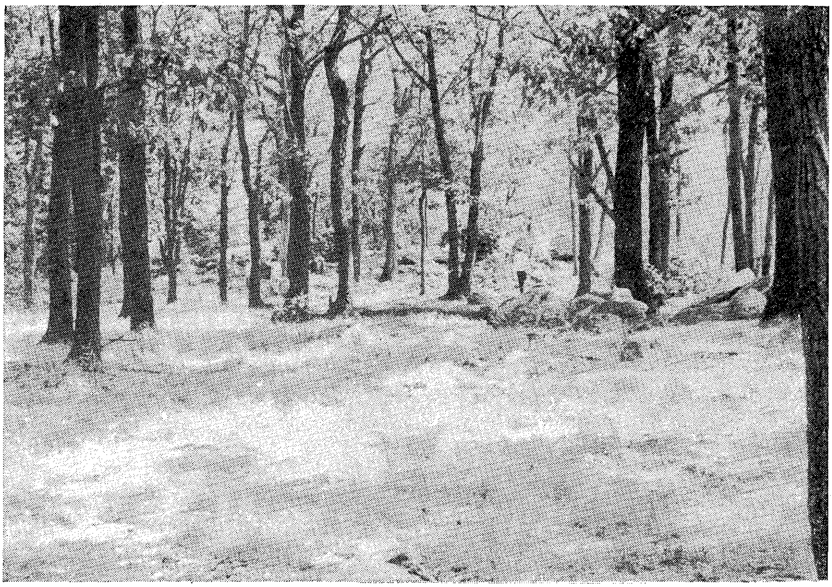
Cryoplanation terraces

Geologists who have studied Sugarloaf mountain postulate a layer of phyllite to intervene between the base of the White Cliffs and the low quartzite ledge at the outer edge of the terrace below the White Cliffs, although this phyllite is „poorly exposed". Their feeling, presumably, is that the terrace must be a structural bench and, therefore, a relatively less resistant rock should underlie it. The STOSES (1946, pp. 71—72) refer to an „upper cliff maker" and a „lower ledge maker" separated by 70 feet of softer quartzite and banded slate.

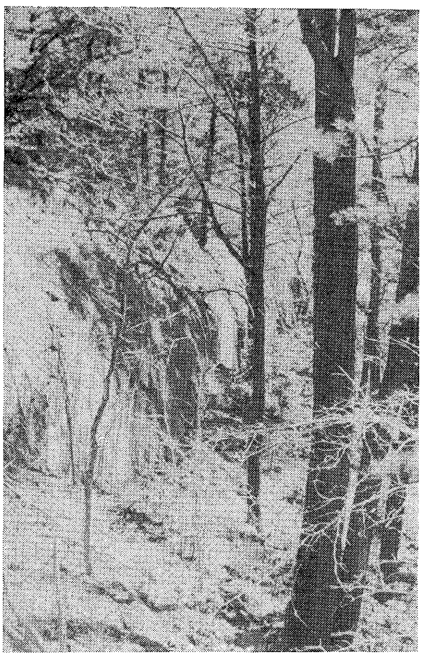
If only the innermost 75 feet of the terrace were developed by cryoplanation, as estimated earlier (p. 239), then the outer 300 feet would be structural in origin. Although covered now by blocks derived from the shattered ledge and from the

[2]Measured slope angles on Sugarloaf Peak are one-half degree on the summit plateau, 12° adjacent to the summit (below that, 20° on the east flank), 56 1/2° on the White Cliffs, 35 1/2° on the talus, and 5 1/2° on the terrace (actually, on the surface of the debris overlying the terrace).

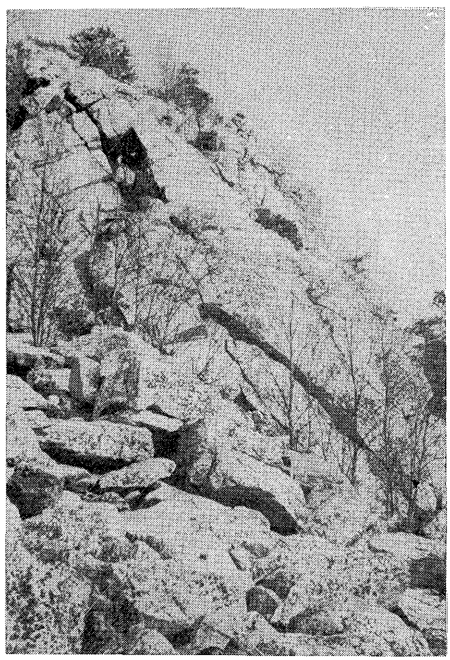
On Peak 1079, the talus stands at 36° and the terrace at 8°; there is no exposed ledge. On Peak 997, the cliff stands at 58°, the talus at 36°, and the terrace at 10°. On Peak 897, the talus stands at about 35° and the terrace at 9°; there is no exposed ledge.



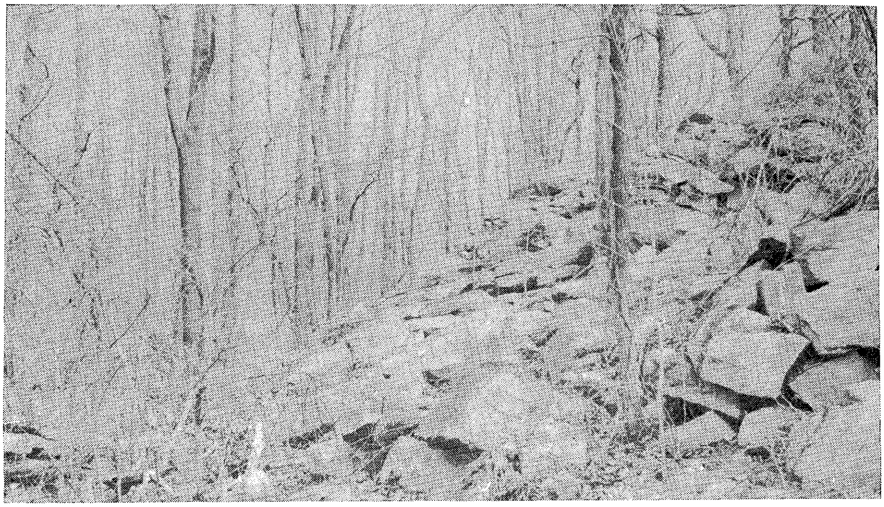
Pl. 1. Summit plateau and tor, Sugarloaf Peak



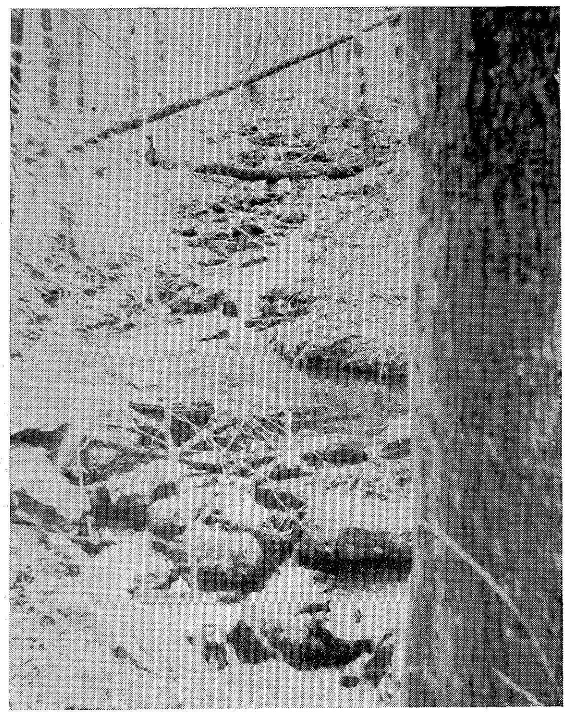
Pl. 2. Exfoliated, unbreached anticlinal arch, peak 867



Pl. 3. Shattered ledge and talus, White Cliffs of Sugarloaf



Pl. 4. Shattered ledge, talus, and terrace, South Mountain, Maryland, north of Crampton Gap



Pl. 5. Block-clogged channel of Bear Branch, Sugarloaf Massif

summit tor, this bench probably is underlain by phyllite beds between Sugarloaf Mountain quartzite nos. 2 and 3, not by quartzite.

A more clear-cut example of cryoplanation terrace than are those on Sugarloaf may be seen along South mountain from Crampton Gap northward to Lambs Knoll, 15 miles northwest of and 300 feet higher than Sugarloaf mountain. South mountain in this area consists of east-dipping Weverton sandstone overlying shale, a situation geologically similar to that at Sugarloaf. The crest of South mountain lies at the east side of the summit, just as the tor on Sugarloaf Peak lies at the east edge of the summit.

The summit of South mountain includes there morphologic elements: a west--facing ledge 20 to 30 feet high composed of shattered Weverton sandstone, more or less concealed by weathered talus, with a rocky terrace at the base of the talus (Pl. 4). The terrace bevels from west to east stratigraphically upward across the beds of sandstone, some of which protrude slightly through the surface of the terrace soil. Close beneath the crest, on the west side of the mountain, is a second shattered ledge, talus, and terrace[3].

The volume of rock removed during the development of the terrace below the White Cliffs of Sugarloaf may be estimated by projecting the terrace beneath the talus until it intersects the cliff and by projecting the mountainside from the top of the cliff to the presumed outer edge of the cryoplanation terrace. The solid figure enclosed by this triangle, extended 100 feet parallel with the cliff, includes 380,000 cubic feet.

If the depth of the rock debris on the cryoplanation terrace be six feet and two-thirds of that is solid material, and if the terrace and the cliff be projected beneath and behind the talus until they meet and two-thirds of the overlying talus volume is solid material, then along each 100 linear feet of the White Cliffs there remain 75,000 cubic feet of debris. It is evident that only about one-fifth of the former rock volume is present on the terrace. The remainder, plus an unknown quantity of debris resulting from the extension eastward of the summit plateau during the ultimate cryoplanation cycle into the higher ledge now represented by the tor, has been carried across the terrace and delivered to the lower slopes of the mountain. Some of this rock waste reached and now partly fills the channels of Furnace and Bear branches (Pl. 5).

AGE OF THE TOPOGRAPHY

No former baselevel surface above that of the Piedmont is identifiable in the Sugarloaf Mountain area. The Sugarloaf massif as a topographic feature, then, is at least as old as the Tertiary. Wolman (1967, p. 386) states the pre-agricultural

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[3]Shattered ledges, talus, terraces, and block streams occur on other parts of South mountain, also Keith (1894, pp. 1, 3) mentions examples near Harpers Ferry, West Virginia. Lesley (1892, p. 185) notes examples in southern Pennsylvania and Maryland. Well-developed talus may be seen in the Black Rocks area north of Route 70, east of Hagerstown, Maryland.

rate of erosion in the Middle Atlantic region to have been one meter in 50,000 years. 14,000,000 years, thus, were required to lower the land from 1280 feet (the elevation of Sugarloaf Peak) to 500 feet (the elevation of the Piedmont plateau adjacent). This length of time is slightly greater than all of geologic time since the end of the Miocene.

Minor topographic features in the Sugarloaf massif are of Wisconsinan or later ages. The summit plateaux, probably initiated during the Illinoian glacial stage, were greatly extended (on the east) and attenuated (on the west) by renewed cryoplanation during the Wisconsinan stage. Pre-Illinoian cryogene phenomena, if present, have yet to be identified on Sugarloaf.

At points other than the White Cliffs, not over 50 feet of humid-temperate erosion occurred on Sugarloaf mountain between the penultimate and ultimate periglacial episodes. Probably, this represents Sangamon denudation. The Sangamon interglacial stage lasted about 200,000 years (ERICSON, *et al.*, 1964, p. 711). WOLMAN'S estimate that about a meter of material is removed in 50,000 years accomodates only one-third of the amount which seems to have disappeared from the Sugarloaf massif during the Sangamon. In steeply-sloping areas such as this, however, the rate may well have been much higher than the average. Post-Wisconsinan denudation has not exceeded 15 feet.

SUMMARY

The characteristically rounded, continental humid-temperate topography of Sugarloaf mountain upon close examination is seen to have been widely though superficially modified by episodes of periglacial climate during the glacial Pleistocene. Periglacial landforms occur in a typical assemblage which includes, in descending order: tor, summit plateau, shattered ledge, talus, terrace, and block streams. Two periglacial episodes, probably Illinoian (tor and summit plateau) and Wisconsinan (ledge, talus, terrace, and block streams) in age, are represented.

These relict, discordant features are found only on south- or west-facing outcrops of quartzite where anticlinal axes have been breached, exposing the ends of the beds. The development of extensive periglacial landfroms in an area far south of the Wisconsinan ice border and at relatively low elevations was made possible by the favorable lithology, attitude, and exposure of these outcropping quartzites.

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Professor FRANK AHNERT (University of Maryland) first brought to my attention the morphologic puzzles of Sugarloaf mountain. Much useful information was provided during the course of the study by DONALD A. MCCORMACK (Executive Secretary, Stronghold, Inc.). My dear friend, DR. MARY T. HOWARD (Federal City College), expressed an abiding interest in this study and was instrumental in its being successfully concluded.

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