[AMERICAN JOURNAL OF SCIENCE, VOL. 256, FEBRUARY 1958, P. 111-127]

STATISTICAL STUDY OF TOPOGRAPHY, SHEETING, AND JOINTING IN GRANITE, ACADIA NATIONAL PARK, MAINE

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ABSTRACT. Both field and laboratory data are used to show the relationship between topography and structure in a mountainous area of subaerial erosion that was reshaped by glacial ice. A statistical method is employed to assist in relating effects of stream and glacial erosion, as controlled by sheeting and jointing, upon homogeneous granite. This method allows one to depict a topographic surface, in terms of slope directions and inclinations, by a simple diagram similar to petrofabric-type diagrams.

Two such diagrams representing the present topography are prepared, one from map data and one from field data. Another diagram based on sheeting in the granite is shown to represent rather accurately the preglacial topography. A comparison of preglacial and postglacial topographies indicates three principal changes due to ice action; (1) a shift in main valley trend from N10°E-S10°W to N15°W-S15°E, (2) an increase in easterly and westerly slope areas and slope angles, and (3) the formation of asymmetrical ridge-and-valley cross sections. Additional diagrams of selected portions of the slope profile are employed both to evaluate the method and to further the topographic analysis.

Data on jointing of the granite, when plotted in a rosette diagram, reveal three principal and one subordinate joint sets. The control of each set upon topography is clearly brought out in the analysis.

In terms of the symmetry concept, the ice advance was oblique to the topographic symmetry plane and glacial erosion was adequate to transform the monoclinic pattern to one of triclinic symmetry.

INTRODUCTION

This study is an attempt to interrelate jointing, sheeting, and the topographic effects of stream and glacial erosion. A relatively new statistical method of analysis is employed with the hope of determining its effectiveness as a quantitative as well as qualitative research tool. The area selected for this study represents a small physiographic unit within Acadia National Park in the southeastern part of Mount Desert Island, Maine (fig. 1). It is underlain by petrographically uniform medium-grained granite, and is believed to constitute an ideal area for this type of investigation.

Field studies were made principally by C. A. Chapman and J. P. Wehrenberg during the summer of 1950, and were supported by a generous grant from the University Research Board, University of Illinois. T. T. Quirke, Jr. (1951) and R. L. Rioux (1955) continued the investigation in the laboratory. Subsequent field and laboratory work by C. A. Chapman required some modification of these earlier studies, and the significant findings in all the above investigations are embodied in this paper. Professors G. W. White, P. R. Shaffer, and W. M. Merrill have offered many helpful suggestions. In addition to all above, the writers are greatly indebted to various members of the National Park Service for their cooperation and assistance in connection with this project.

TOPOGRAPHY

Mount Desert Island is an exceptional feature in this region of Maine primarily because of its high relief and rugged profile. A large part of the island is dominated by the Mount Desert Range which trends N 65° E (fig.1). This range is dissected into a series of peaks and ridges by U-shaped

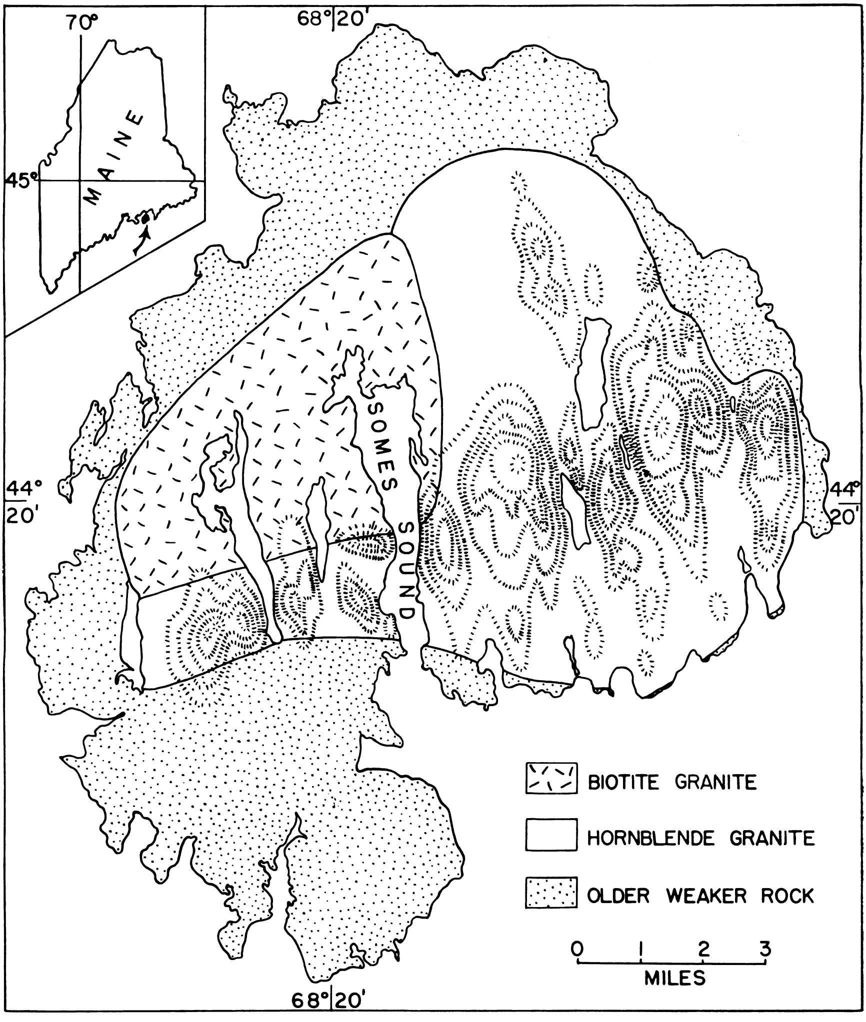

Fig. 1. Index map and simplified relief and geologic map of Mount Desert Island. Acadia National Park includes, in part, most of the area of hornblende granite.

valleys which trend approximately N 15° W (fig. 2). Four of these peaks rise above 1100 feet, and Cadillac Mountain (1530 feet) is the highest point within 20 miles of the Atlantic coastline of the United States (Wood, 1924). Raisz (1929) relates the extensive lowland of the island to the New England peneplane, and he considers the mountain range a monadnock on that erosional surface.

Shaler (1889), Bascom (1919), and Raisz (1929) treat in detail the various physiographic features, but Raisz (1929) gives the most modern and complete account of the physiography and reviews the previous literature. All these earlier workers noted the presence of a dominant master joint set trend-

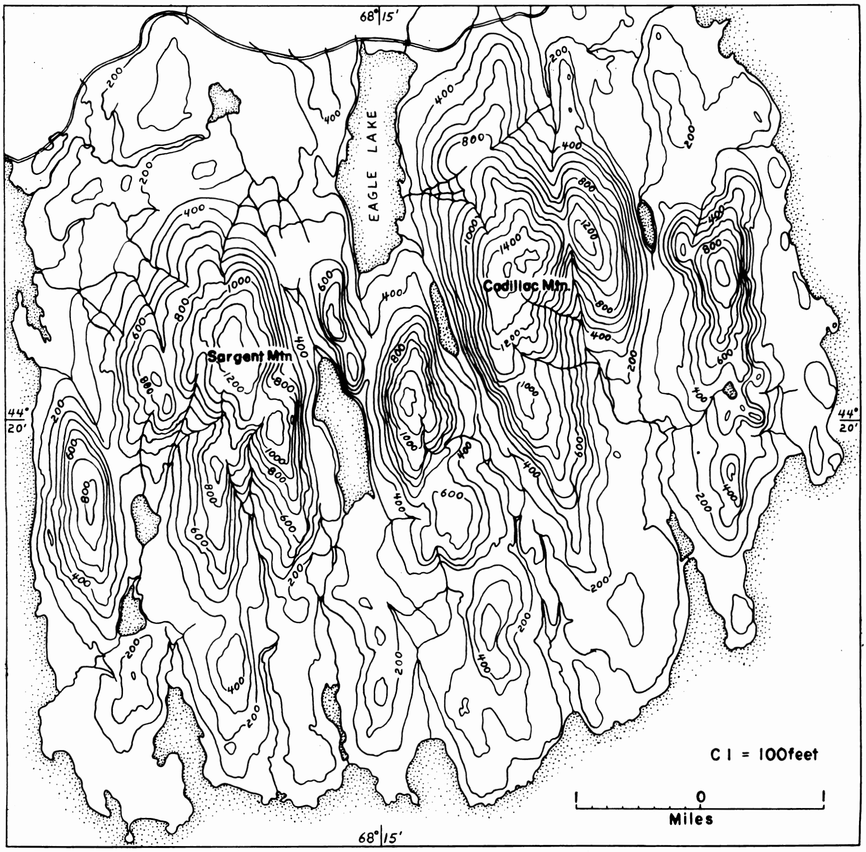

Fig. 2. Topography of southeastern part of Mount Desert Island modified from the United States Geological Survey topographic map of Acadia National Park.

ing roughly N-S and a promient diabase dike set with a similar trend. Since these two features approximately parallel the dominant valleys of the region, these authors attributed the valley trend to the structural control of either joints, or dikes, or both. Chadwick (1939, 1944), on the other hand, concluded that the valleys were controlled by the positions of roof pendants and inclusions of weaker rock and by keystone faults.

No systematic study of jointing and diking had been made of this area, and the above conclusions are based on very general observations. Detailed field work for the present study, however, does show a definite relation between topography and jointing, but three very prominent joint sets were discovered to complicate the interrelation. On the contrary, field observations do not substantiate the earlier conclusion of dike control on topography. For example, basic dikes are as abundant on high ridges as in valleys. A special effort was made to test the roof pendant and inclusion theory, but no evidence in its favor could be found. Contrary to the statements of Chadwick (1939, 1944), inclusions in the granite were not observed to be more abundant in the valleys. The granite contact, furthermore, apparently cuts straight across the valleys and is not deflected as shown on Chadwick's map.

It is believed that the roof pendant theory occupied a foremost position in Chadwick's mind, because of his interpretation of the sheeting structure in the granite. He attributed the sheeting to cooling, and believed it formed parallel to the granite walls and roof. Consequently, he visualized a roof pendant or downward extension of the granite roof rock in each valley region. In other words, he felt that the present topography virtually conforms with the original roof of the granite "bathylith". As will be shown later, such an interpretation of the sheeting is incorrect; and, consequently, the pendant theory is unsupported. Evidence either for or against the keystone fault hypothesis was not found.

The bedrock geology of Mount Desert Island was first mapped by Shaler (1889) and a modified map was later published by Chadwick (1939). All investigators of this island recognized the existence of a central core of granite, which held up the hills and mountains, and a marginal zone of weaker rocks which formed the low coastal fringe. The fringe rocks are composed of volcanics, siliceous sediments, gabbro-diorite, gneiss, and schist. Intruding these older rocks is the core, generally considered a petrologic and structural unit of hornblende granite. The present study shows, however, that a younger and finer grained biotite granite body is to be distinguished from a larger mass of coarser grained hornblende granite (fig. 1). The knowledge of the existence and distribution of these two petrographic types now enables us to explain certain unusual topographic features of the island.

The Mount Desert Range shows a gourd-shaped outline with the narrow neck pointed westward (fig. 1). This shape has been controlled in large part by the disposition of the hornblende and biotite granites. The hornblende granite is apparently a highly durable rock, due perhaps to its more interlocking texture; and it constitutes the more elevated areas of the island. The biotite granite, on the other hand, has a sugary texture which probably accounts for its high susceptability to weathering and tendency to underlie low ground.

The crestal zone of the mountain mass has an overall trend of approximately N65°E. West of Somes Sound, in the neck of the gourd, the range runs about N70°E coincident with the narrow westward prolongation of the hornblende granite. Though highly symmetrical, this portion of the range shows slightly steeper southerly than northerly slopes.

East of Somes Sound the crestal zone trends about N80°E, and appears to be offset to the north about one mile. This apparent offset in the region of Somes Sound is believed due to the disposition of the two granite masses and not to faulting. Had the biotite granite never intruded, the crestal zone would have extended westward across Somes Sound without apparent offset to the south. The crestal zone east of Somes Sound occupies a rather normal position, that is, about half way between the northern and southern limits of the granite mass. Long gentle ridges trail off to the southern contact, and poorly defined ridges trail off to the northern contact. These latter are generally steep in their higher elevations, and west of Eagle Lake they are interrupted by an extensive lowland which isolates McFarland Mountain and Youngs Mountain (northwest of Eagle Lake) from the main mountain mass. This lowland was developed by westerly flowing streams which cut back readily across the easily eroded biotite granite. This headward extension of stream valleys eastward has created a pronounced asymmetry to the main mountain range and developed extensive areas of steep, generally northerly slope.

It seems evident, therefore, that the general outline of the Mount Desert Range was controlled by the disposition of a more resistant hornblende granite relative to a weaker granite and the older fringing rocks.

GLACIATION

Evidence of glaciation is abundant in the area. The large transverse valleys are typically U-shaped and many contain rock basin lakes. Boulders up to twenty feet across are widely distributed and a number are precariously perched on the mountain slopes. Some of the largest of these erratics are composed of a coarse granitic rock quite foreign to the island and must have been transported at least 20 to 25 miles.

Shaler (1889) and Raisz (1929) have studied the glacial striations, grooves, and roches moutonnées. They concluded that ice within the valleys moved parallel to present valley trends; whereas ice in the upper levels, which covered the mountain range, moved in a more southeasterly direction. Field work upon which the present paper is based corroborates these earlier findings. Raisz (1929) in the course of field studies was unable to find any supporting evidence for multiple glaciation in this area.

It is agreed by numerous investigators that prior to Pleistocene time the hornblende granite mass formed an elongate range trending roughly perpendicular to the main advance of the ice sheet. The effects of glaciation upon this monadnock are briefly but most admirably described by Raisz (1929, p. 141).

> . . . We have to imagine the mountains at this time as a maturely disscected range with an uneven crest and with deep valleys and dividing spurs on both flanks. The ice ascended the valleys of the northern flank and spilled over the crest, at first, of course, in the saddles, whence long icy tongues descended upon the southern lowlands.
>
> For a long time the ice carved its spillways deeper and deeper into the saddles until it had cut sufficiently deep for more effective discharge, despite the increasing thickness of the ice. Such is the origin of the deep glacial troughs which give so unusual an appearance to the Mount Desert range. Only when the thickness of the ice exceeded the height of the mountains were the crests buried under a slowly moving ice sheet several thousand feet thick.
>
> At this stage the ice movement changed its direction. This is recorded in the asymmetry of the mountains and in the form of the ice-carved ledges. In the beginning, the ice was guided by the direction of the valleys, which was transverse to the main crest and coincided with the direction of the north-south dikes. When the ice extended above the mountain tops, it could not be controlled further by the topography, but followed its own general direction of flow, which was more to the southeast.

THE SSO DIAGRAM

The analysis which follows is based upon a statistical method devised by Chapman (1951 and 1952), and involves the preparation and comparison of statistical slope orientation diagrams (SSO diagrams). For each diagram the direction and inclination of slope are measured at several hundred uniformly spaced points on a topographic map to obtain a representative sample of the orientation of the various slopes of an area. For this study the 1942 edition of the Mount Desert Island, Maine topographic map with a scale of 1:31680 and a contour interval of twenty feet was used. Points were selected by means of a square grid the spacings of which were governed roughly by the number of points desired. Slope measurements were determined at each grid intersection on the map by means of a protractor and slope scale. Each measurement, thus, represents the orientation in space of a plane tangent to the topographic surface at the point of measurement.

Using what is essentially equivalent to radial coordinate paper, with the origin at the center and north established at the top of the sheet, each set of slope measurements may be plotted as a point. The angle of slope (inclination) is indicated by the distance of the point from the origin or plot center. This distance increases as slope angle increases. The direction of slope is indicated by the azimuth of the radial line (isogonic line) on which the point appears. A horizontal slope is represented by a point at the plot center. A slope inclined 89° due east is represented by a point near the edge of the plot at the three o'clock position (i.e. on the N90°E isogonic line). Since slopes greater than 30° are uncommon, only the central part of the plotting sheet is needed. In the present study, the outermost circle of each diagram represents the loci of 30° slope angles. For convenience this circle is called the 30° isoclinal line. In addition the 10° and 20° isoclinal lines are shown.

The resulting plot is similar to the stereographic projection of crystal faces or the point plot used in preparing a petrofabric diagram. It should be noted, however, that normally radial coordinate paper is practical only where slope angles do not exceed about 25°. For the most accurate work the standard equal area projection net should be used (Chapman, 1952, p. 433). This type of net was actually employed in this study; the plot was made on the upper hemisphere in each case.

The density distribution of points over all parts of the plot is next determined and expressed by means of contour lines precisely as in a petrofabric diagram. The result is a statistical slope orientation diagram (SSO diagram).

The elements of the SSO diagram are analogous to those of the petrofabric diagram (Chapman, 1952, p. 438). A few of these need brief explanation. A concentration of points extending diametrically across the diagram and indicated by an elongation of the contour outline in that direction is known as a partial girdle. Such a pattern indicates a linear topography with valley-and-ridge trend perpendicular to the girdle length.

The clustering of slopes (points) between two relatively closely spaced concentric circles constitutes a small circle girdle. If such a girdle is discontinuous, it is called a partial small circle girdle. These girdles are roughly concentric with the projection (plot), and their presence generally indicates a high percentage of relatively steep slope and a low percentage of slope at a slightly lower angle of inclination.

The concentration of points within a small area is known as a maximum. A well-defined maximum is common near the plot center and represents a high percentage of gentle or horizontal slope.

For the detailed analysis we will be concerned with that part of the island shown in figure 2. Figure 3 represents a plot of 481 slope values obtained from that portion of the topographic map. To test the adequacy of sampling, two additional SSO diagrams, not included here, were prepared using alternate points on the grid, or 240 and 241 poles respectively. These two diagrams were similar in all major respects to figure 3, thus testifying to the validity of the sample and suggesting that one-half the number of measurements used in figure 3 would have produced a representative diagram.

The most obvious features displayed by figure 3 include a central maximum and a partial girdle trending roughly east-west. The central maximum indicates a high percentage of relatively flat ground, the partial girdle indicates a dominant set of roughly N-S ridges and valleys. The most frequent slope directions for slopes steeper than 5° are not diametrically opposed, but lie roughly along the N 90° E and S 65° W isogonic lines. This relation imparts triclinic symmetry to the diagram, and merely shows that one set of slopes strikes N-S and inclines eastward whereas the other set strikes N25°W and inclines WSW. The relation indicates a series of valleys with walls converging to the north, whereas intervening ridges taper to the south. This feature, brought out so clearly on the SSO diagram, is poorly shown on the topographic map. The average valley trend is about N15°W-S15°E.

The diagram indicates a noticeable absence of moderate and steep northerly and southerly slopes. For slope angle values above about 7°, easterly slopes are, on the whole, a few degrees steeper than westerly slopes. This asymmetry of ridge-and-valley cross section is poorly shown on the topographic map.

The maximum concentration (mode) is at the center of the diagram, and a comparatively large amount (about 20 percent) of the topographic surface is underlain by slopes with inclinations of less than 5°. The 6-12 percent con-

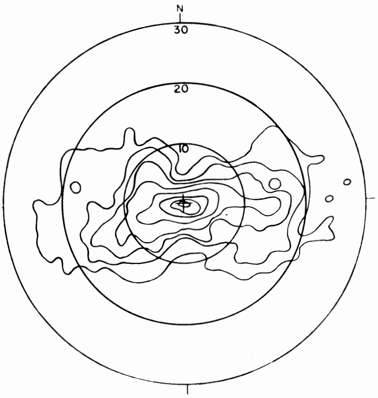

Fig. 3

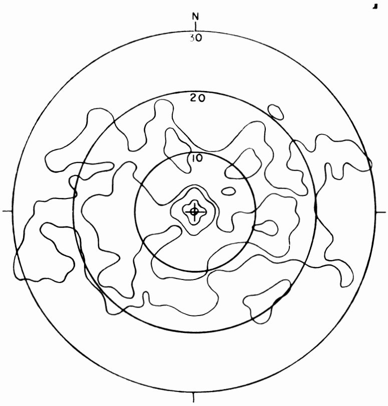

Fig. 4

Fig. 3. SSO diagram based on map data; 481 poles; contours 1-2-3-4-6-8-10-12% per 1% area of 30° circle.

Fig. 4. SSO diagram based on field data; 539 poles; contours 1-2-3-4-5% per 1% area of 30° circle.

tour lines surrounding the central maximum are conspicuously off-centered to the south and reveal a predominance of southerly slopes for these low angle values.

Figure 4 represents a plot of 539 slope values obtained by actual field measurements. Each measurement was made with a brunton compass and represents the slope for an area about 300 feet in diameter. These data were gathered as part of a detailed structural and petrologic study of the granite and before the concept of the SSO diagram was developed. Consequently, the method of sampling was not as systematic as it might have been. It was felt, however, that 539 readings should produce a representative diagram, since somewhat less than half that number is adequate when topographic map values are used. Figure 4, however, lacks continuity, and the 539 readings are apparently insufficient here where field measurements of slope are used. It is concluded that an SSO diagram prepared from topographic map data will show greater regularity and continuity in regional slope relations due to smoothing out of contours. A similar diagram prepared from field data tends to bring out the slight irregularities in slope, as well as the regional slope. A scattering of poles (points) and a large number of relatively weak maxima result. In spite of this, figures 3 and 4 show many striking similarities. Figure 4 shows the roughly E-W partial girdle, the central maximum, and the paucity of north slopes. The relatively high concentration of southerly slopes is probably due to the fact that a large number of field traverses were run along the southward trailing ridges. Had more E-W traverses (across the topographic grain) been run, a better diagram would have been obtained.

SHEETING

Sheeting is well developed over most of the hornblende granite area, and in general this structure roughly conforms with the present topography. The numerous departures from parallelism, however, are of great significance and need more detailed consideration.

Over the ridges and mountain summits sheeting is gently arched and nearly parallel to topographic slope. At lower elevations and particularly along steep valley sides. sheeting is inclined less steeply than the slope. This divergence of sheeting and topography is usually greatest on the steepest slopes, and it is commonly made apparent by a conspicuous series of inclined steps in the sheeting layers. Locally the step-like features are poorly formed, and the slope appears to transect the sheeting layers more smoothly.

Along the more asymmetrical ridges, such as Cedar Swamp Mountain and Jordan Ridge (the two ridges extending south from Sargent Mtn.), the relations of sheeting and slope are of special importance. Here sheeting is truncated at a low angle on the western slope and at a high angle on the eastern slope. So pronounced is this difference that the ridge crest lies some distance to the west of the crest in the sheeting arch. Such relations indicate that the ice tongue in the valley to the east cut back the eastern slope of the ridge nearly to its former crest. The ice in the valley to the west, however, failed to cut as deeply and steeply into the western flank of the mountain ridge. As a result asymmetrical ridges formed.

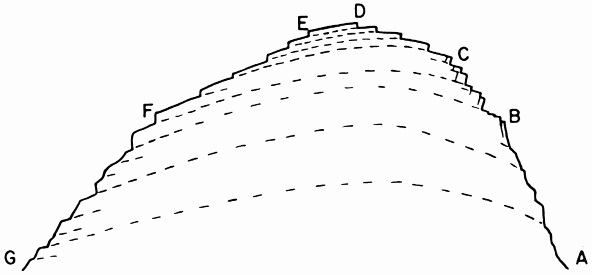

Fig. 5. Diagrammatic cross-profile of asymmetrical ridge, as viewed looking northward, showing relation of sheeting to topography.

Such a ridge is shown in figure 5. The steep western slope (F-G) shows the common relation of truncated sheeting and step structure. Steep eastern slopes (A-B) may show higher angle of truncation, but generally sheeting is difficult to observe here. Higher eastern slopes (B-C) are less steep and have been somewhat disintegrated by glacial ice and later frost action. Breaking down of such slopes appears to have been controlled largely by steep joints. On high western slopes (E-F) sheeting dominates over jointing in the control of slope angle. Gentler slopes, consequently, are encountered here. Near the crest (D-E) slope conforms with sheeting which is nearly flat. East of the crest somewhat steeper slopes (C-D) have formed by steps across nearly horizontal sheeting.

On the northwest slopes of the larger mountains, sheeting is nearly parallel to topography. In some places it dips a bit more steeply and in others a bit less steeply than the local slope. Some of the highest angles of sheeting truncation were observed on southeastern slopes where relatively gentle sheeting is exposed in the steep slopes. In the small hills known as The Bubbles (southeast of Eagle Lake), sheeting is nearly horizontal and is cut off at a high angle by the steep hillsides.

The above relations serve to indicate that most of the sheeting is preglacial in age. In a few places, however, it appears that a sheeting has formed parallel to the ice cut surfaces and is, therefore, glacial or post-glacial in age.

The relations between sheeting and topography, as well as the fact that sheeting surfaces appear closely spaced on ridges and more widely spaced further down the ice-cut slopes, favor the theory that sheeting in the hornblende granite developed in response to unloading, and is not controlled by the contacts of the granite body. This problem has been considered in some detail is an excellent paper by Jahns (1943).

Figure 6 represents a plot of 577 readings on sheeting. These data were gathered along the same series of unoriented traverses used in measuring the slope values involved in figure 4. Figure 6, however, shows excellent continuity and is considered to be a fairly accurate representation. This may appear somewhat surprising at first when it is realized that the data for figures 4 and 6 are not only essentially equally numerous but were obtained from the same stations. The reason for the greater continuity of figure 6, where the number of poles plotted is nearly the same, is due to the more uniform or more regional nature of sheeting as compared with that of local slope. Consequently, notably fewer sheeting measurements are required for a representative diagram.

With slight modification, figure 6 is believed to represent the topography immediately prior to glaciation. Some data used in this diagram represent postglacial sheeting, but the number of such readings is believed to be relatively small. It is to be noted that the diagram represents only bedrock topography and very little is broad valley bottom. The greatest difference between sheeting slope and preglacial slope is to be found in the lower parts of the glacial valleys. Here the sheeting probably inclines a bit more gently than did the old preglacial slopes directly above it. This effect, however, is in part compensated for by the inclusion of some postglacial sheeting data. A truly representative diagram would probably show a slightly stronger girdle development with the outer contour not exceeding the 22-23° isoclinal line (circle) in the easterly and westerly directions.

The preglacial as compared with the present topography is considered to have been slightly less linear, because the east-west girdle of figure 6 is only weakly developed. This girdle, more accurately, trends about N80°W-S80°E and indicates an average stream line of N10°E-S10°W. The more nearly radial symmetry of figure 6 as compared with figure 3 indicates that easterly and westerly slopes were such more gentle prior to glaciation, whereas northerly and southerly slopes were slightly steeper.

In contrast to figure 3, figure 6 shows symmetry of easterly and westerly slope angles and a symmetry plane extending N10°E-S10°W across the diagram. Northerly and southerly slope angles, however, are asymmetrical. Extensive gentle slopes to the south and few gentle slopes to the north are shown by the off-centering of the 3-4-6-8-10 percent contours, and the somewhat greater abundance of steeper northerly slopes is shown by the slight off-centering of the 1-2 percent contours. This relation eliminates the possibility of an east-west symmetry plane and establishes a monoclinic symmetry for the diagram.

Raisz (1929, p. 141 and 155) felt that the topography immediately prior to glaciation was in the mature stage of development. Based on a comparison of SSO diagrams of other areas (Chapman, 1951), the writers conclude that the sheeting diagram (fig. 6) indicates an advanced stage of maturity for the Mount Desert Range prior to glaciation.

The differences between figure 6 on the one hand and figures 3 and 4 on the other, reflect general changes in topography produced by glaciation. The three most obvious changes appear to have been:

1. A shift in average trend of valley and ridge from N10°E-S10°W to N15°W-S15°E.
2. An increase in easterly and westerly slope areas and slope angles (in part at the expense of northerly and southerly slopes) due to the obliteration of earlier headwater areas by deeply carving tongues of glacial ice.
3. The development of an asymmetrical cross section for many valleys and ridges.

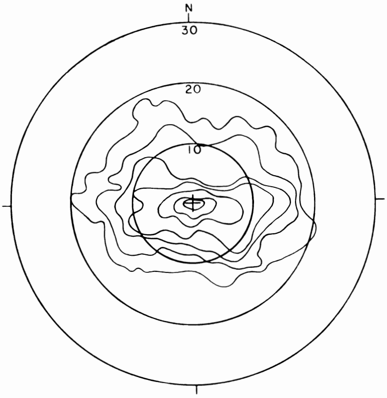

Fig. 6

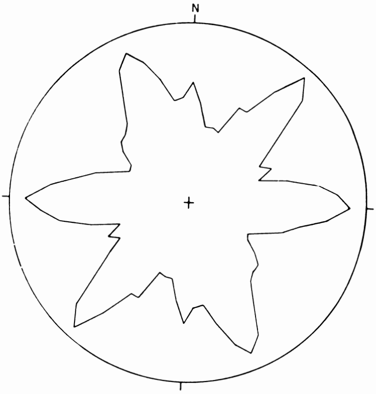

Fig. 7

Fig. 6. SSO diagram based on sheeting data; 577 poles; contours 1-2-3-4-6-8-10% per 1% area of 30° circle.

Fig. 7. Joint diagram based on 854 joint measurements. Radius of circle represents 40 joint measurements.

JOINTING

In addition to the studies of slope and sheeting, detailed observations on jointing were made in the granite area. About 3000 readings were taken, each representing the average attitude of roughly 20 nearly parallel joints. Joints were recorded as good, medium and poor; and the approximate spacing of each joint set was noted. These data were gathered at the same stations as those from which sheeting and slope data were obtained.

Jointing is a wide spread phenomena but is by no means uniform. Joints are sparse on steep valley slopes as compared with slopes at higher elevations. They are also less prevalent on broad rounded ridges than on the sharp narrow ones. The significance of these various relations can not be discussed here, but it will suffice to say that these studies indicate that jointing has in part controlled topography and topography in turn has had a control upon jointing. As between sheeting and topography, the interdependence of jointing and topography is convincingly demonstrated.

Figure 7 is a rose-diagram representing the strike of 854 separate joint measurements. Since most joints are steep to vertical, poles of joint planes were not used; but joint strikes, to the nearest 5°, were plotted.

Three distinct joint sets appear to make up the joint system of the area. These sets trend E-W, N40°E and N25°W. A more subordinate set trends N-S and destroys the otherwise well-developed orthorhombic symmetry pattern of the diagram. Comparing this diagram with figure 3, one notes a parallelism between the strike of westerly slopes and the N25°W joint set and the strike of easterly slopes and the N-S joint set. In other words, the east valley walls parallel the N-S joints and west valley walls parallel N25°W joints. The significance of this relation will be considered later.

TOPOGRAPHIC ANALYSIS

The present topography is believed to have resulted from stream and glacial erosion which were controlled largely by structural trends (sheeting and jointing patterns) within the granite. In order to evaluate and determine more quantitatively the interrelations of these factors, several additional SSO diagrams were prepared. These diagrams represent selected portions of the slope profile and bring out the contribution of each part to the composite picture seen in figure 3. Only the three most significant of these, however, will be considered.

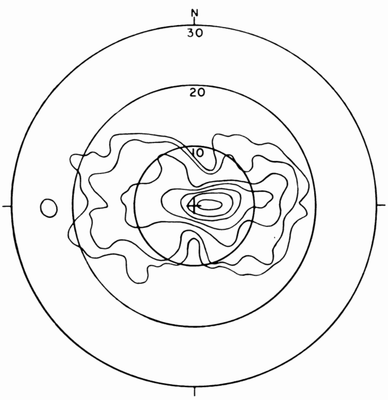

Fig. 8

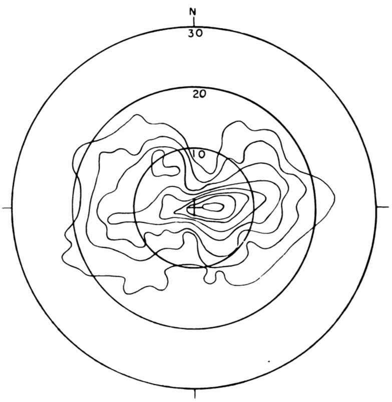

Fig. 9

Fig. 8. SSO diagram of highest slopes: 319 poles; contours 1-2-4-6-8-10-12% per 1% of 30° circle.

Fig. 9. SSO diagram of highest and next highest slopes; 565 poles; contours 1-2-3-4-5-6-7-8% per 1% area of 30° circle.

Figure 8 represents a plot of 319 slope poles obtained from the uppermost slopes of the highest ridges and mountain tops. As compared with figure 3 this diagram shows diametrically opposed slope direction concentrations, only moderate dispersion of slope direction, and marked asymmetry for gentle slopes (revealed by off-centered maximum).

Figure 9 represents a plot of 565 poles. It is a composite diagram and includes the poles of figure 8 in addition to those of the contiguous, slightly lower and steeper slope areas. In this diagram dispersion of slope direction is greater than in figures 3 and 8. An off-centered maximum for low slope angles is as pronounced as in figure 8. Like figure 3 but unlike figure 8, the suggestion of a slope direction concentration in the S65°W isogonic zone is apparent.

Figure 10 represents a plot of 718 poles obtained from the steepest slope areas which lie at elevations generally below those represented in figure 9. This diagram shows a lower dispersion of slope direction for the higher slope angles. The dominant slope directions, revealed by prominent maxima, are N85°E and S65°W.

Figures 8 and 9, in contrast to figures 3 and 4, show a strong maximum off-centered to the east about 2°. This striking difference appears to have the

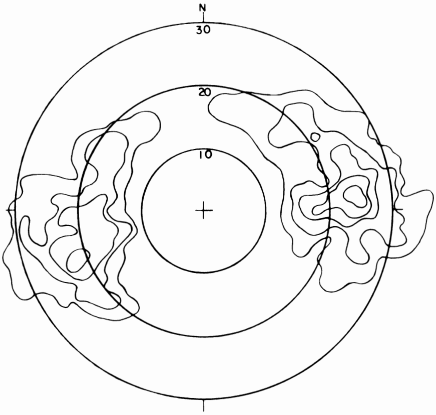

Fig. 10. SSO diagram of steepest slopes; 718 poles; contours 1-2-3-4-5% per 1% area of 30° circle.

following explanation. The gentle slopes (less than 10°) in figures 8 and 9 represent mountain and ridge tops only and reveal the asymmetry of glacial erosion at these high elevations. Corresponding slopes of figures 3 and 4, however, represent both mountain and ridge tops and valley floors; and the asymmetry at higher elevations is compensated by a reversed asymmetry at lower elevations. The asymmetry of mountain and ridge tops is, therefore, camouflaged in the more general type of diagram such as figures 3 and 4. The asymmetry of valley floors is due probably to deeper channelling by glacial ice in the western half of the valleys. In figure 3, which is based on map data, asymmetry of valley bottoms may be due in part to piling up of debris at the foot of east valley walls and the cleaning out of debris from the base of the west valley walls.

The effects of glaciation on the higher slopes, therefore, can best be determined by comparing figures 8 and 9 with figure 6 (sheeting).

Figure 8 shows an east-west girdle with slope direction concentrations nearly coincident with those for the gentler slopes of figure 6. This indicates there has been little or no change in the strike direction of the higher slopes due to ice action. The glacial effect appears to have been predominantly a rather uniform stripping essentially parallel to sheeting. The asymmetry of slope direction, as revealed by the off-centered maximum, however, shows that gentle easterly slopes have been increased greatly in area over gentle westerly slopes. This asymmetry appears to have been accomplished by high-level ice which moved southeasterly across the ridges and stripped the granite in layers parallel to sheeting. The stripping of any particular sheeting layer began at the free face of the steep U-shaped valley walls immediately to the east. Aided by joints, successive sheeting layers were stripped back toward the ridge crests to the west; and extensive stripping caused a westward migration of ridge crests and the consequent development of extensive areas of gentle slopes (C-D of fig. 5). The prominent N-S and N25°W joint sets facilitated this stripping and prevented a "rotation" of resulting ridge crests and newly cut slopes. The same maximum offset to the east is shown in figure 9.

Let us now consider the somewhat steeper slopes, generally at slightly lower elevations, at the northern ends of the hills. Figure 6 shows a rather uniform distribution for slopes with slope angles of about 7°-17° and slope directions of N45°W-N45°E. Figures 3 and 9, however, show a conspicuous bulging of contours into the NNW octant and a marked reentrant in the north direction. These relations indicate an abundance of NNW slopes, relatively few NNE slopes, and a paucity of north slopes. This shift in distribution of slopes is attributed to the effects of glacial ice on the north ends of the hills.

By comparison there has been relatively less flattening of NNW slopes than either north or NNE slopes by glaciation. This is probably due to the advance of ice from the NNW upon elongate N-S hills and the stripping of granite layers parallel to well developed sheeting planes. Stripping from NNW slopes may not have been extensive, because the free face from which stripping could be initiated was greatly limited. Only slight change in orientation of such slopes, therefore, could have resulted. The NE slopes, however, were differently affected. Lying very close to the steep freshly-cut west valley walls, where an extensive free face occurred, these slopes were subjected to extensive stripping which was undoubtedly greatly augmented by the N40°E and N25°W joint sets. This trimming back of slopes occurred in part at the expense of north slopes, and consequently north slopes were reduced in area. The significant change was perhaps the apparent clockwise rotation of generally northeasterly slopes; and the net effect was to greatly reduce the area of north slopes, to slightly reduce the area of NNE slopes, and to greatly increase the area of ENE slopes.

Let us next consider the effect of glacial action on the southern parts of these elongate hills. Figure 6 indicates a very uniform distribution for slope directions between S45°E and S45°W prior to glaciation. Figure 9, however, shows a distinct bulging of contours in the SSE octant indicating a relative increase in area and average inclination for SSE slopes. The diagram also shows a paucity of south slopes and a reduction in area of SSW slopes as compared with figure 6. These relations are essentially diametrically symmetrical with those of the northern counterparts.

The SSE slopes were most favorable for plucking action, because they lay on the lee side. The well developed sheeting, combined with the N40°E and N80°E joint sets, permitted extensive quarrying and the formation of stepped slopes which incline somewhat more steeply than the sheeting itself. The pronounced loss of south slope area is due in part to the cutting back of SSE slopes. Also responsible is the extensive slicing off of the southwest portions of the elongate hills. This action will be considered shortly.

The concentration of slopes in the N85°E isogonic zone of figures 6, 8, and 9 indicates little modification of slope direction for west valley walls by glacial action. The faint development of a slope concentration in the S70°W isogonic zone of figure 9, however, suggests considerable change in direction of east valley walls during glaciation. This is brought out more strikingly in figure 10 which represents only steep slopes. Figure 10 shows the strongest diametrical asymmetry with principal slope directions N85°E and S65°W.

Such relations indicate a well-developed linear valley pattern trending N15°W-S15°E with a conspicuous flaring of steep valley walls to the south. Incidentally this diagram shows also the greatest asymmetry in angle of slope with easterly slopes steeper than westerly slopes, and it brings out clearly the asymmetry of the ridge-and-valley cross profile. Figure 10, therefore, represents that portion of the slope profile which primarily determines the asymmetry of the general diagram (fig. 3).

The concentration of WSW slopes is believed to be due to the truncation of the southwestern portion of original north-south ridges. The cutting back of these southwestern slopes was accomplished by the valley ice which possessed a more easterly drift in the southeastern portions of the valleys. The easterly drift was due to a gradual mergence of the southward moving valley ice currents at low levels with the more southeasterly movement of the higher portions of the ice sheet. The faceting of these slopes was aided in large part by stripping along sheeting layers, but quarrying from the southern ends of the hills was in part a necessary prerequisite and accompanying mechanism. This quarrying action provided a free face which could be worked backward (in an up-ice direction) along sheeting planes. Stripping of successive sheeting layers was greatly facilitated by the N40°E and N80°E joint sets which helped to maintain a free face roughly perpendicular to ice flow.

The bevelling of sheeting layers on east valley walls was more pronounced in the southern parts of valleys where the easterly drift of ice was greatest. To the north, however, these surfaces gradually merge with the steep north-south slopes cut by the deeply eroding valley ice currents. An easterly drift of the upper ice is thus reflected in the modification of the east valley walls. Ice action on SW slopes, therefore, was similar but much more extensive and severe than on NE slopes.

The marked constriction of contour pattern along the N-S line of figures 3, 8, and 9, as compared with figure 6, is due in part to the reduction of north and south slope areas, as already described. It is also due in part to the destruction of considerable north and south slope area in the crestal region of the mountain range due to the formation of through-going glacial valleys. This dumbell-shaped contour pattern expresses not only the absolute loss of north and south slope areas but also the marked increase in areas of steep slope in the general easterly and westerly directions.

Figures 4, 8, 9, and 10 all show greater dispersion of slope direction for western slopes, between 10°-20°, than for corresponding eastern slopes. This difference does not appear from the topographic map to be due primarily to greater scalloping of westerly slopes. It seems more probable to indicate that eastern hillsides are straighter and more continuous, whereas western hillsides are arcuate in ground plan. Such asymmetry of outline supports the idea that abrasion and stripping by overriding ice were effective on the western half of hills, whereas, the eastern half was cut back intensely by valley ice currents.

SUMMARY AND CONCLUSIONS

The SSO diagram has proved to be an effective tool in the topographic study of this area. As shown by a comparison of figure 3 with three others (not included here) of the same area but obtained by slightly different methods, independent plots yield diagrams similar in all major respects. In addition it has been shown that SSO diagrams reveal elements of topography not readily discernible from the topographic map. The picture presented by a topographic map alone is often misleading; unusual features, which may not be dominant features, often lead to poor interpretations of slope relationships. These diagrams simplify comparison of topography with such structural features as sheeting and jointing.

Since the area involved is small and the features relatively homogeneous throughout, the SSO diagrams should well represent this topographic unit. The use of an enlarged copy of the topographic map helped to reduce possible errors in slope measurement. It is known that reducing the number of poles by one-half did not alter the diagrams in many cases. Below a certain minimum number of poles, however, a diagram shows marked discontinuity and poorly portrays true slope relations. No method, other than experimentation, was attempted to determine this statistical minimum. It should be noted that SSO diagrams constructed from maps are no more accurate than the maps themselves. Although we might expect slope data obtained in the field to give the most reliable diagram, it has been shown in this study that many more field measurements are necessary to obtain a statistical sample, because of the high dispersion of slope values. It also appears that if somewhat random traverses are used in the collection of field data, they would best be run about transverse to topographic trends. Data on more regional features, such as sheeting, may be plotted from field measurements without a comparatively large number of readings.

Sheeting, which is shown to be controlled by the preglacial topography, is believed to have formed in response to unloading. A statistical plot of sheeting, therefore, is considered to represent rather closely the topographic character of the Mount Desert Range immediately prior to glaciation. A comparison of preglacial and postglacial topographies shows a conspicuous change in trend of valley and ridge, a marked increase in areas of easterly and westerly slopes, and the development of asymmetrical ridge-and-valley cross sections.

The trend of prominent ridges and valleys of this area is attributed to stream and glacial erosion and structural controls in the form of jointing and sheeting. The original valley sites were determined by preglacial streams whose trends were about N10°E-S10°W. Ice moving through these valleys actively scoured deep channels, due to concentrated flow, and removed the headwater areas of small streams in the crestal zone of the mountain range. Unusual long valley profiles thus resulted. Distinctly asymmetrical ridges and valleys were formed by quarrying activities of the ice as the greatly thickened glacier moved south-southeasterly across the mountain range. The coincidence of glacial and certain structural trends permitted extensive erosion of the southwestern portions of the elongate hills. This attack on southwesterly slopes was accomplished by a quarrying action along sheeting surfaces as the N25°W and N40°E joint sets formed block structures in the path of the overriding ice. Severe plucking occurred on SSE slopes to provide a free face for more effective stripping on the southwesterly slopes. This stripping resulted in the development of extensive S65°W slope areas along the east valley walls. The overriding ice sheet was ineffective in modifying the trend of west valley walls, perhaps due to the control of N-S joints. There was, however, considerable reduction of slope inclination at higher levels. The asymmetry of valley-and-ridge cross profile was due in large part to abrasion along the stoss side and plucking along the lee side.

A marked linear topographic grain, trending N10°E-S10°W, had formed on rather homogeneous granite of the Mount Desert Range in pre-glacial time. The topography was bilaterally symmetrical with respect to this linear trend, and it may be considered to have possessed monoclinic symmetry. Pleistocene glaciation appears to have been directed toward the south-southeast at a marked angle to the N10°E-S10°W symmetry direction of the topography. So effective was this oblique attack by glacial ice that the monoclinic symmetry pattern of the old topography was supplanted by one of triclinic character.

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