THE BLACK ROCK FOREST

BULLETIN No. 8

HENRY H. TRYON, *Director*

GLACIAL GEOLOGY
OF THE
BLACK ROCK FOREST

By

C. S. DENNY

CORNWALL-ON-THE-HUDSON, NEW YORK

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INTRODUCTION

The Black Rock Forest, a privately own tract, is situated on the northwest side of the Hudson Highlands, a few miles west of the Hudson river, in the towns of Cornwall and Highland, New York (See Tryon, 1930). As a part of its research program the Forest has undertaken various ecological, pedological, and geological studies of which this report is a part. The purpose of this study has been two-fold: (1) to determine the relationship between the glacial deposits and the timber types; and (2) to discover whether repeated cutting and burning of the forest has induced changes in the subsoil since colonial times by acceleration of the geological processes.

The Wisconsin ice sheet covered this portion of New York state (See Fig. 8) and extended as far south as northern New Jersey (See Bayley and others, 1914). The amount of weathering which the glacial deposits in the Forest have undergone leads to the conclusion that the last ice to pass over the Highlands was Early or Middle Wisconsin in age. The Highlands were never again covered by the continental glacier; nevertheless the near presence of ice in the Catskill mountains (Rich, 1935) must have produced a very rigorous climate in the vicinity of the Forest. It has been possible to show that the processes active under this "periglacial" climate [1] modified the surface features which were the direct result of glaciation; and that the mineral soil on which the timber grows is a frost-heaved and weathered layer derived from the Early or Middle Wisconsin till and from the country rock of the region.

The report will first mention previous geological in-

[1] Refers to the area around the borders of the ice sheet and was first so used by von Lozinski in 1909 (See von Lozinski 1910).

vestigations that have been carried out in this region, and will then describe the topography. Next an account of periglacial phenomena from northern Europe and arctic regions will be given, so that in the discussion of the glacial deposits which follows, it will be possible (1) to show the similarity of such phenomena as described from other areas to the features found in the Forest; and (2) to show that the upper loose-textured material which everywhere overlies the till is of periglacial origin. Following a summary of the results obtained from this geological investigation, conclusions will be stated regarding the relation of geological processes, past and present, to the timber types.

The work was carried on for about six weeks during the early part of the summer of 1937 in the company of Dr. Hugh M. Raup of the Arnold Arboretum, who has been engaged in a botanical study of the Forest, and at whose suggestion the work was first undertaken. The writer is indebted to Dr. Raup for his assistance in the gathering of the data contained herein and for many helpful discussions of the problems involved during both the field work and the preparation of the manuscript. Dr. Kirk Bryan of Harvard University spent several days with the writer in the Forest and the surrounding region, and has been kind enough to criticize the manuscript. The Storm King School furnished a laboratory and equipment for the mechanical analyses. Finally, it is a pleasure for the writer to acknowledge his indebtedness to the owner and staff of the Black Rock Forest for the opportunity to carry on this study and for their assistance throughout its duration.

PREVIOUS GEOLOGIC WORK

The Forest lies entirely within the area of the pre-Cambrian rocks of the Hudson Highlands. The bed rock geology of the West Point Quadrangle has been mapped in detail by Berkey and Rice (1921) but this area includes only the southeast corner of the Forest. Considerable field work has been done in the Schunemunk Quadrangle by Colony and others but the results are as yet largely unpublished. The latest account of the area, together with a bibliography of the more important reports dealing with it, is to be found in Guidebook No. 9 of the XVI International Geological Congress (1933). So far as observed, the "Storm King granite" or a closely related type of igneous rock is the prevailing rock of the Forest. However no detailed study of the bed rock was attempted.

The glacial geology of the Highland area, including the Forest, has never been very extensively studied so far as the writer is aware. Brief mention of the glacial features of the Hudson Gorge has been made by Woodworth (1905), Johnson (1925), Thompson (1936) and others. Data regarding the glacial deposits to the north of the Highlands have been recorded by Woodworth (1905) and by Berkey (1911).

The soils of the Highland region were mapped by Crabb and Morrison (1914) for the U. S. Department of Agriculture. Recently Scholz (1931) made a study of the "Cove Soils" of the Forest. Most of the soils are of the "brown earth" type, although small areas "where a slightly podosolized profile had developed under hemlock stands," were noted. The profiles used extended to depths of a little over 25 inches, and the soils are classified as predominantly "clay loam" (clay content not over 30 per cent). Five typical profiles "show an important similarity in that the lower part of the soil profile is characteristically compacted." A columnar structure is locally present. This compacted layer is known as "hardpan." The humus content is rather uniform. Scholz states "that the soil mantle is deepest on upper slopes and hilltops and shallowest in the deep, V-shaped valleys and along the lower slope areas," and further that "on the steeper upper slopes and high ridge tops . . . the glacial till is ordinarily deepest." Scholz concludes that the abuse which the Forest has undergone has not greatly affected the soil, and that "there is no . . . convincing evidence of destructive surface erosion. Mechanical analysis data reveal only a slight tendency toward the physical translocation of clay and colloidal materials from upper soil horizons to lower ones."

TOPOGRAPHY

The Black Rock Forest lies on the north side of the Hudson Highlands. The area can be separated into two physiographic divisions: one, the "Highland" section, and the other, the "Northern Slope" section (See map, Fig. 1). The Highland section is an area of swamps and artificial ponds separated by low hills and rolling uplands. The relief is seldom over 200 feet with altitudes varying from about 1225 feet to the highest point in the Forest, Spy Rock, at an altitude of 1463 feet. Belonging to the Highland section but lying at somewhat lower altitudes are the lowland near the Upper Reservoir, Aleck Meadow and Glycerine Hollow. These valleys or "coves," as they are called in this region, are located in the northern and eastern part of the Forest and reach only to altitudes of 900 to 1000 feet. The Northern Slope section lies at altitudes of 420 to 1225 feet, and is characterized by steep, northwest slopes and deep ravines such as Black Rock Hollow.

Inspection of the topographic map of the Highland section shows that, with few exceptions, the ponds, swamps and ridges trend either northwest or northeast. This pattern is related to a system of joints in the country rock, as random observations have shown. That other zones of weakness in the rocks are present is suggested by the diverse trend of such valleys as that of Jim's Pond at the base of Eagle Cliff, and of Bog Meadow Pond. There is a tendency for the northwestern and southwestern slopes of the hills to be oversteepened. Many of the larger rock slides occur on such slopes. A few observations indicate that this asymmetry of slope is due to the northeasterly plunge of a linear structure in the crystalline rock of the Highlands. This structure leads to the formation of gentler, northeasterly ("dip") slopes. A similar relationship is general in the northern part of the Highlands and was noted by Thompson (1936) in the Storm King-Breakneck gorge.

Small, rounded, bed-rock knobs, 10 to 20 feet high, are very abundant in the Highland area (See Fig. 1). In places these knobs form the higher summits and are separated one from another either by a swamp or by a shallow swale partly filled with weathered till overlain by warp. These knobs resemble roches moutonnées in form although all traces of polish or of striae are absent. Exfoliation is removing thin plates of rock (See Plates XII and XIII). The surface of the ledges is very rough; large crystals of feldspar project one-half an inch or more above the surface (as on Eagle Cliff). Weather pits, 2 to 3 inches deep, and solution grooves parallel to the linear structure in the crystalline rock are common (as on Black Rock). Large talus blocks cover most of the steeper slopes in the Highland section, such as the west slope of the Hill of Pines, Rattlesnake, the hill to the east of Arthur's Pond, and Eagle Cliff. These talus slopes or "slides" are generally overgrown by forest except for the small "slide" on the west slope of Mt. Misery where some movement of small stones is in progress at the present time. On the gentler slopes scattered boulders lie upon warp, thin till and rock outcrop; as on the north slope of Mt. Misery, Black Rock, Rattlesnake and on the slopes surrounding Glycerine Hollow.

Of the eight ponds in or near the Forest, only one of them, Sutherland, is natural; the others are held in by dams. Each pond covers an original area of swamp or meadow. There are numerous large and small swamps many of which lie in basins carved out of bed rock. Everywhere the surface of the bed rock has glacial forms, but nowhere in the Highland section is there an area whose topography is that of a typical ground moraine. A possible exception is the southeast slope of Mt. Misery where a tiny swamp appears to be held in on all sides by weathered till. Elsewhere any original till over the glaciated bed rock has been largely removed by periglacial solifluction.

The Northern Slope section is characterized by steep slopes at higher altitudes developed on bed rock and by gentler slopes at lower altitudes where a thick blanket of glacial debris laps up on the Highlands from the northwest. The steeper slopes are covered, in many places, by talus or "slide rock." The surface of the thick glacial deposits is very smooth. Locally there are slight surface irregularities which might be remnants of ground morainal topography, but such features are here interpreted as the result of solifluction in the Periglacial Interval. The rather gently sloping, smooth surface of these deposits is dissected by numerous brooks which have carved out sharp, V-shaped ravines. These gulches may reach a depth of 30 to 40 feet, but have not been cut more than 10 feet into bed rock. The streams have steep gradients which, in detail, are broken by innumerable falls that separate reaches of gentler grade. Ramparts of boulders, deposited by great floods, are common, especially where the gradient is gentle. Locally there are very small terrace remnants along the banks of the stream, the surfaces of which are marked by old channel ways and boulder ramparts. In most places the ramparts and old channel ways are overgrown by large trees which show no evidence of having been disturbed by floods. However, locally trees are found whose growth has been disturbed by the piling in of boulders on their upstream side. The minor terraces occur at all elevations above the stream bed and do not appear to be remnants of a former stage in the erosion cycle, but the result of continued downcutting by the stream.

THE PERIGLACIAL CLIMATE

An anomalous feature of the topography, as previously described, is the absence of typical ground morainal topography on the surface of the thick glacial deposits; with nevertheless the presence, on the upland, of rock knobs (roches moutonnées) with a pseudo-glacial form. The writer believes that these anomalies are the result of processes active during deglaciation under the periglacial climate of that time. The probable importance of the periglacial climate for North American glacial geology was first mentioned by Bryan (1928) in a review of Kessler's book, "Das Eiszeitliche Klima." In the following section a brief account of periglacial phenomena as recognized in northern Europe and arctic regions will be given so that in the description of the Forest which follows, the similarity of forms in the Forest to those in the Arctic will be clearly brought out.

Following the excursion of the XI International Geological Congress to Spitzbergen in 1910 a series of papers appeared describing the soil forms which are there produced under the prevailing arctic climate. Solifluction is considered by Högbom (1914) to be one of the dominant erosive agents at work in that region, comparable in importance with running water or with ice (See also Andersson, 1906). Solifluction involves the down-slope movement of fragmental material more or less as a unit. According to Högbom (op. cit.) solifluction is the work of frost acting in two different ways: (1) by regelation or repeated freezing and thawing; and (2) by an increase in water-holding capacity of the surficial layer, caused by the presence beneath it of frozen subsoil, the "tjäle" of European workers. The solifluction layer becomes

loamy and plastic because intense frost weathering breaks up the material into small pieces.

Solifluction leads to the formation of rather smooth, uniform slopes covered with coarse and fine, fragmental material. Högbom (op. cit.) describes a steep mountain slope in Spitzbergen that is covered with large fragments, whereas on a gentler slope at its base originally coarse material has been broken into fine as the result of frost-weathering. The break-up favors solifluction on this gentler gradient, which process carries material down-valley and prevents the accumulation of debris at the base of the steep mountain slope.

In the mountains of Spitzbergen frost action has removed almost all traces of Pleistocene glaciation (Högbom, op. cit.). Smith (1910) records that in the Seward Peninsula region of Alaska "high-level gravels become so mixed with water-sorted material that the prospector could not recognize the presence of stream gravels. . . ."

Beginning with the publication of von Lozinski's paper in 1909 there has been a gradual recognition of the presence of fossil arctic soil forms in northern Europe outside of the limit of the last ice sheet. Here there is a surface layer which consists of a jumble of angular blocks of various rock types set in a loamy matrix. This layer is attributed to frost action and solifluction active during the glacial maximum (See Kessler, 1925; Woldstedt, 1929). Such a layer has been described under various names, including "warp," "trail," "head," and "rubble drift" (See Högbom, 1914; Denny, 1936). In this paper the term *warp* will be used.

In a recent paper von Lozinski (1933) has reviewed the subject of periglacial weathering and soil formation. He divides the "periglacial facies of mechanical weathering" into three categories, namely: (1) the periglacial facies of the rubble fields (Schuttfelder); (2) the periglacial facies of the "Palsen" fields ("Hummock fields"); and (3) the periglacial facies of the permanent ground frost or tjäle (formation by high ground water of a bluish-gray clay). The rubble field facies is the only one that has been recognized in the Forest. Von Lozinski shows that the original form of a frost-rifted block is sharply angular. Although periglacial frost action was effective on all types of rock, rubble fields can be preserved today only in rock of the more resistant types. Since the cessation of periglacial action the softer rocks have been reduced and rounded by post-glacial weathering. Vegetation has encroached over many rubble fields so as to obscure them from view. (See von Lozinski, 1910, and Schott, 1931.)

GLACIAL DEPOSITS

Method of Study

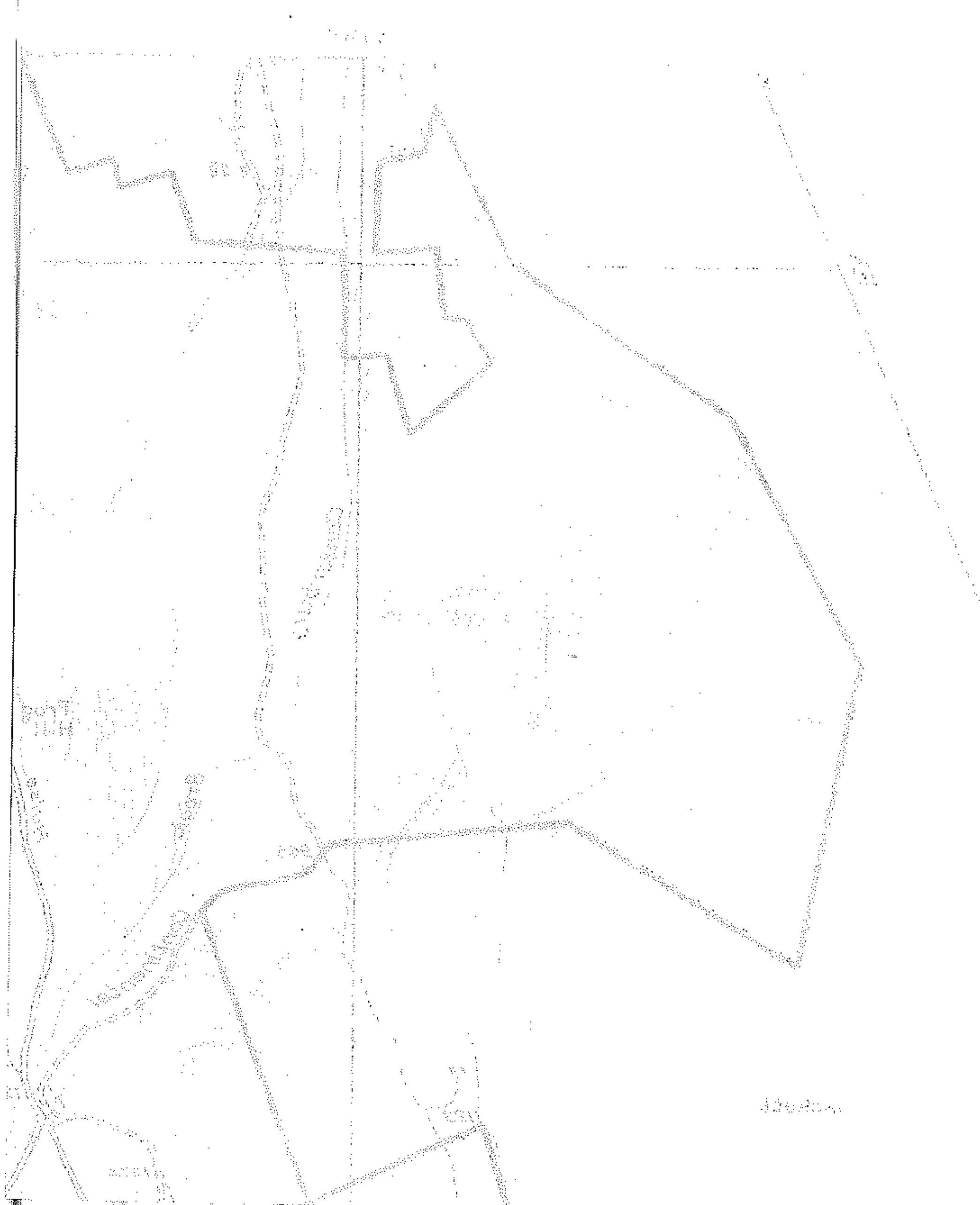
A general reconnaissance of the few natural exposures of glacial deposits within the Forest was followed by a campaign of digging pits at places considered critical. In all, 23 pits, whose location is shown on Fig. 1, were excavated to depths of from 1½ to 14 feet. An intensive study was made of 39 samples, each consisting of a cubic foot removed from the desired depth. Each sample was passed through a sieve with a five-eighths inch mesh and the fines discarded, because it was thought that a study of the coarse fraction alone would yield the desired results. If the material ran high in clay, water was poured on the sample to force it through the sieve. The stones, thus separated, were washed and then sorted according to the several rock types present. All particles retained on the sieve and therefore larger than five-eighths of an inch in diameter, but smaller than one foot in diameter are here called "stones." All larger fragments are called "boulders," and were not considered in sampling. The stones of the several rock types were counted, and their volume calculated by means of their displacement in water. The volume of stones per cubic foot in per cent and the percentage of the several types by number and by volume was calculated. The resulting data are given in the accompanying tables and discussed in detail in the following pages.

General Character

Till and warp are the only glacial deposits found within the confines of the Black Rock Forest. Water-laid sand and gravel are absent, although such materials and also glacial clay occur in the lowland to the north. In the Highland section the till and warp are thin and discontinuous. On a portion of the northern slopes the drift is thicker and more continuous, and an area covered by thick till overlain by warp has been mapped (See Fig. 1). Because the till and overlying warp have been weathered and iron-stained to a depth of from 6 to 12 feet, and because of the lack of good natural exposures, only one sample of absolutely unweathered till was collected, which was from the bank of Black Rock brook (No. 4a. Numbers refer to localities shown on Fig. 1.). However, unweathered blue-gray boulder clay was observed elsewhere in the undercut banks of Black Rock brook and also in those of Canterbury brook. Sixteen additional samples of till were gathered which are only moderately weathered.

The upper 1 to 4 feet of the weathered zone is loose and contains more boulders than the underlying till. It is a jumbled mass of pebbles and boulders in a yellowish-brown matrix of sand and clay. However, as shown by the detailed sections and pebble counts here recorded, it is largely derived from the underlying till. As it is now being weathered and destroyed by erosion, it must have been formed at a time previous to the present. As brought out in detailed studies it is a frost-heaved layer or warp, produced when frost action more intense than that of today was prevalent. Presumably this time lay within the Periglacial Interval. Both the warp and the underlying till have been somewhat weathered since that date. Wherever the glacial covering is less than 2 feet thick the weathered warp rests directly upon bed rock.

The nature of the till is determined by the general direction of movement of the continental ice and by the character of the underlying bed rock. As shown by glacial striae in the Forest and elsewhere, the ice moved from the north to the south and southeast. It is at once apparent that the situation of the Forest on the north-



would be subdivided into granite, gneiss, schist and so forth.

apparent that the situation of the Forest on the north

west side of the Hudson Highlands in the area of the pre-Cambrian crystalline rocks,[1] and adjacent to the boundary separating them from the Paleozoic sedimentary rocks in the lowland to the northwest determines the types of stone in the till of the Forest area (See Fig. 8). The till is a mixture of crystalline and sedimentary rocks, and in a given sample the proportion of crystalline rock increases with distance south of the boundary (except as noted below).

Thick Till on North Slopes

BLACK ROCK BROOK SECTION

In order to obtain a cross section from the surface down to completely unweathered till it was necessary to excavate an exposure to a depth of at least 10 feet. Such an excavation was made in the west bank of Black Rock brook at an altitude of about 490 feet (No. 4). By removing a maximum of about 4 feet of slumped material from the bank of the brook a 14-foot section was exposed which serves as the type for the area and which is shown in Plate I and Fig 2. A blue-gray boulder clay, the upper surface of which lies about 12 feet below the top of the bank, grades upward through 4 feet of yellowish-gray boulder clay into a yellowish-brown mass of pebbles and boulders of which the upper 4 feet is a somewhat weathered warp. The results of mechanical analyses of samples from each of the three zones are shown in Table No. 1.

The blue-gray boulder clay (No. 4a) is the parent material from which the upper zones have been largely derived. It is a hard and compact clay containing many pebbles and boulders. Most of the stones are striated

[1] Throughout this paper in descriptions of samples the term "crystalline rock" will be used to refer to all stones derived from the pre-Cambrian rocks of the Highlands, although in a strictly petrographic study the rocks would be subdivided into granite, gneiss, schist and so forth.

PLATE I. CUT IN WEST BANK OF BLACK ROCK BROOK AT AN ALTITUDE OF ABOUT 490 FEET (Loc. No. 4).

Three feet of weathered warp rests on weathered till. For explanation see Fig. 2. (*Photograph by H. H. Tryon*).

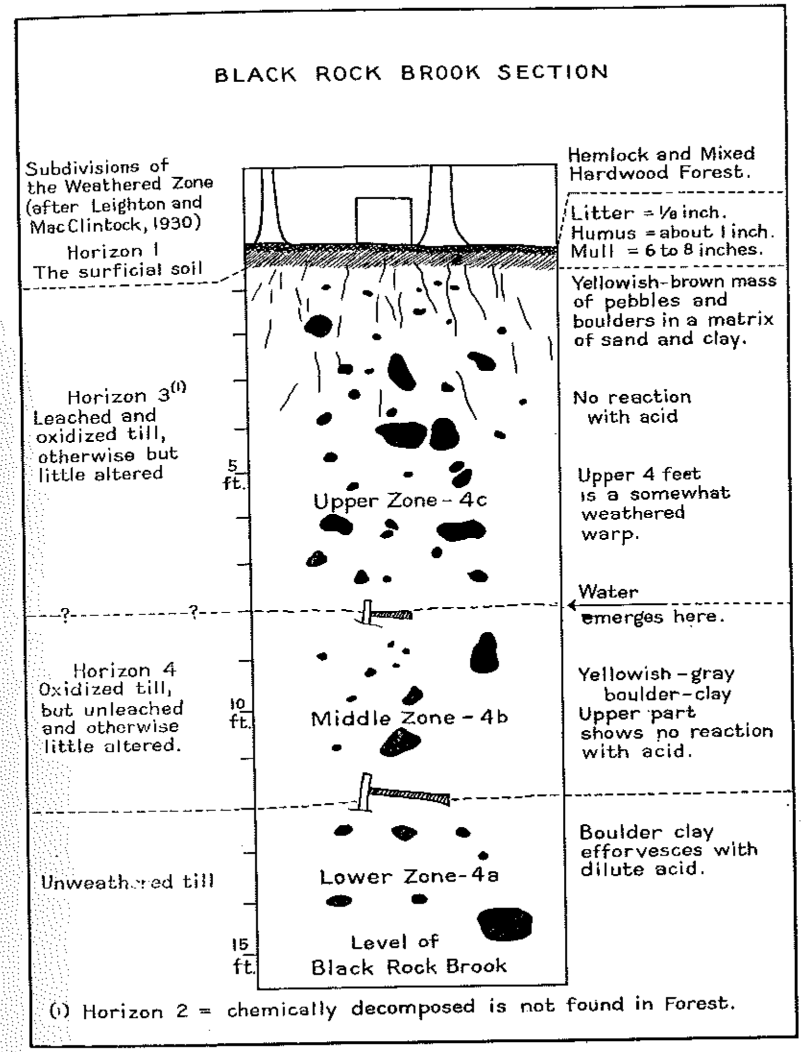


FIG. 2. SKETCH FROM PLATE I.

Four feet of weathered warp rests upon 8 feet of weathered till. Unweathered boulder clay outcrops at base of section.

TABLE No. 1

MECHANICAL ANALYSES OF SAMPLES FROM THE BLACK ROCK BROOK SECTION

	Percentage by volume		
	No. 4a Lower	*No. 4b Middle*	*No. 4c Upper*
Medium grained, blue-gray sandstone	44.4 (a)	46.2	......
Medium grained, greenish-gray sandstone	11.7 (b)	19.3	75.6 (a)
Fine grained, gray to yellow-brown, thin bedded, soft sandstone	......	0.4	8.3 (b)
Miscellaneous sandstone	4.6 (e)	1.6	......
Total sandstone	60.7	67.5	83.9
Slate	26.8 (c)	17.4	7.9 (c)
Crystalline rock	3.6 (d)	7.1	1.1 (e)
Quartzite	6.5 (f)	7.0	3.2 (f)
Chert	0.5 (g)	0.4	3.9 (d)
Conglomerate	0.1 (i)	0.05	......
Limestone	1.7 (h)	0.3	......
Red sandstone	0.1 (j)	0.2	0.09
Total	100.0	99.9	100.0
Percentage of stones per cubic foot	13.7	23.8	37.4
Depth (in feet) of sample below surface	14-15	9-11	5-6

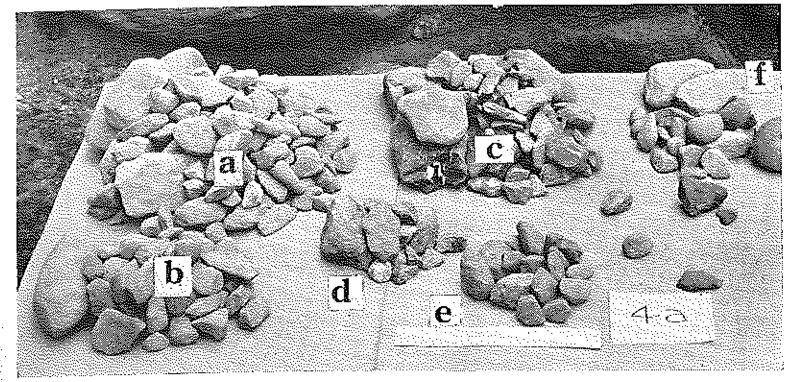


PLATE II. SAMPLE FROM UNWEATHERED BOULDER CLAY AT BASE OF SECTION (No. 4a).

Letters refer to Table No. 1. (*Photograph by H. M. Raup*).

and soled. Some of the "blue-gray sandstones" are "flat-iron" shaped. Their original form has been modified during transportation by the glacier. All of these rocks are clean and unweathered (See Plate II). The almost pure clay matrix effervesces vigorously with cold dilute hydrochloric acid, showing the presence in it of calcium carbonate.

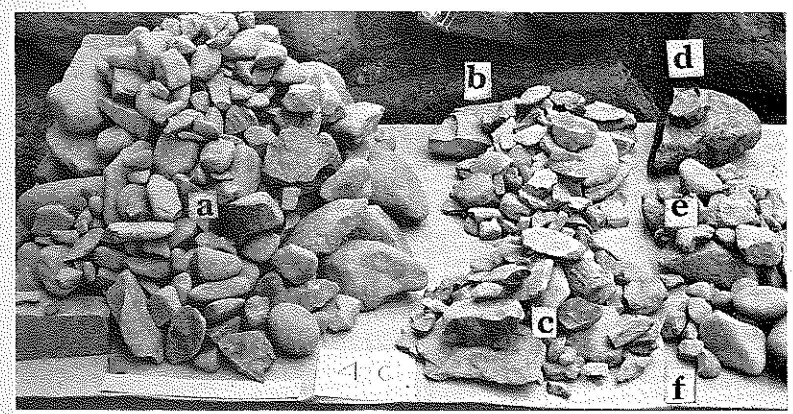


PLATE III. SAMPLE FROM WEATHERED ZONE ABOUT 5 TO 6 FEET BELOW THE SURFACE (No. 4c).

Letters refer to Table No. 1. (*Photograph by H. M. Raup*).

Table No. 1 shows the very close similarity in composition between the "lower" and "middle" zones. The compact, yellowish-gray boulder clay of the latter zone (No. 4b) exhibits the same texture as the unweathered boulder clay below. The matrix does not effervesce with cold acid in the upper part of this zone, but it does in the lower, showing that calcium carbonate has been removed only from the upper part of the "middle zone." The stones from this zone are very similar to those in the parent material ("lower zone") except that they are not as polished as those from below, nor were they as easy to clean. It will be noted that the percentage of stones per cubic foot has increased from 13.7 in the parent material to 23.8 in the middle zone. This may be an indication of variation in the parent material. No secondary deposit of calcium carbonate was noted.

The contact between the "middle" and "upper" zones is rather sharp, partly because at certain times water flows out on top of the clay. The yellowish-brown "upper" zone is a mass of pebbles and boulders in a matrix of sand and clay. It is loose-textured and easier to excavate than the clay. In the lower 4 feet the texture of the boulder clay still remains, but the upper 4 feet is a jumble of stones and finer material, and is probably best classified as warp. There is a high percentage of boulders in the 4 feet of warp. Plate I shows a large boulder of crystalline rock, about 1½ feet in diameter, lying 3 to 4 feet below the surface. The boulders shown in the lower left hand corner of the photograph also came from the "upper" zone. This abundance of boulders can be explained as the result of frost action and solifluction which has carried away much of the fine material originally present; and has brought down new boulders from the till or from the bed rock up the slope. Sample No. 4c comes from the lower 4 feet of the "upper" zone, i.e., below the warp. The greater volume of stones per cubic foot, 37.4 per cent (No. 4c), as compared with 23.8 per

cent and 13.7 per cent in No. 4b and a respectively, is due for the most part to the removal of fine material by weathering processes. For example, the action of water washes out the fines and causes a relative increase in the volume of stones per cubic foot. On the bottom of many of the stones there is a secondary deposit of clay and sand, probably brought in from above by descending water (illuviation), and very difficult to remove by washing. Many of the sandstones are soft and easy to break up (See Plates II and III) as is shown by the 8.3 per cent of "fine-grained, soft sandstone" (No. 4c). Similarly the percentage of slate greatly decreases from 26.8 in the fresh boulder clay (No. 4a) to 7.9 in the "upper zone" (No. 4c). These changes are probably the result of disintegration by weathering processes. No striae or polish are to be found on any of the stones except the resistant quartzites. The "greenish-gray sandstones" have a smoothed surface with rounded edges and resemble in form those from the parent boulder clay (No. 4a). The "medium-grained, blue-gray sandstones," present in the parent material, are absent above (in No. 4c). Many of the specimens of this sandstone from the "lower zone" (No. 4a) effervesce slightly with cold dilute hydrochloric acid, showing that they have a calcareous cement between the grains. Some of the larger specimens of "greenish-gray sandstone" (from No. 4c) when broken reveal, within an outer greenish-gray rind, 1 to 2 inches thick, a bluish-gray core which effervesces slightly with acid.

Apparently many of the "greenish-gray sandstones" of the "upper zone" (No. 4c) are merely the leached remnants of the "blue-gray sandstones" in the parent material (No. 4a). The crystalline rocks from the "upper zone" (No. 4c) are similar to those from below except for a yellow-brown stain. Some of the more schistose specimens break up easily.

In order to form a rough estimate of the amount of clay in these three zones, 200 grams of the matrix from each was shaken up in a bottle of water and let stand. The sample from the blue-gray boulder clay (No. 4a) cleared overnight. It contained a slightly greater volume of the finest settling portion (rock flour? [2]) than did either the "middle" or "upper" zones. The fines from the yellowish-gray clay (No. 4b) settled out in a slightly longer time than did those from the blue-gray clay (No. 4a), and the volume thereof was slightly less. However, the samples from the "upper zone" (No. 4c) was still cloudy a week later. A slightly smaller amount of the finest settling portion was present. The sample was yellow-brown in color, and the water over the fines remained colored and cloudy. This cloudiness is presumably due to the presence of colloidal clay derived by the weathering of the original till.

Leighton and MacClintock (1930) divide the weathered zone of glacial till into several horizons including: Horizon 1—the surficial soil; Horizon 2—chemically decomposed till; Horizon 3—leached and oxidized till otherwise but little altered; Horizon 4—oxidized till, but unleached and otherwise little altered. In the Black Rock brook section (See Fig. 2) the "upper zone" (No. 4c) corresponds most closely to Horizon 3, and the "middle zone" (No. 4b) to Horizon 4. Horizon 2 was not found in the Forest.

The Black Rock brook section is typical of the thick till on the lower north slopes of the Highlands. The section shows leaching of calcium carbonate down to a depth of 10 feet. A slight staining by iron oxide and presumable slight oxidation has descended to a somewhat greater depth, about 12 feet. In the upper 8 feet, sandstones with a calcareous cement have been leached and

[2] It is interesting to note that in the course of excavating this cut, as a result of the shoveling of the clay into the stream, the water took on a milk white color which persisted for a considerable distance downstream. The similarity with streams of glacial melt water was striking.

have become very soft. The more schistose crystalline rocks have become slightly weaker. The coarser-grained granites and gneisses are stained but otherwise not greatly altered. There has been some downward migration of fine material, but very little deposition of secondary calcium carbonate, probably owing to the relatively

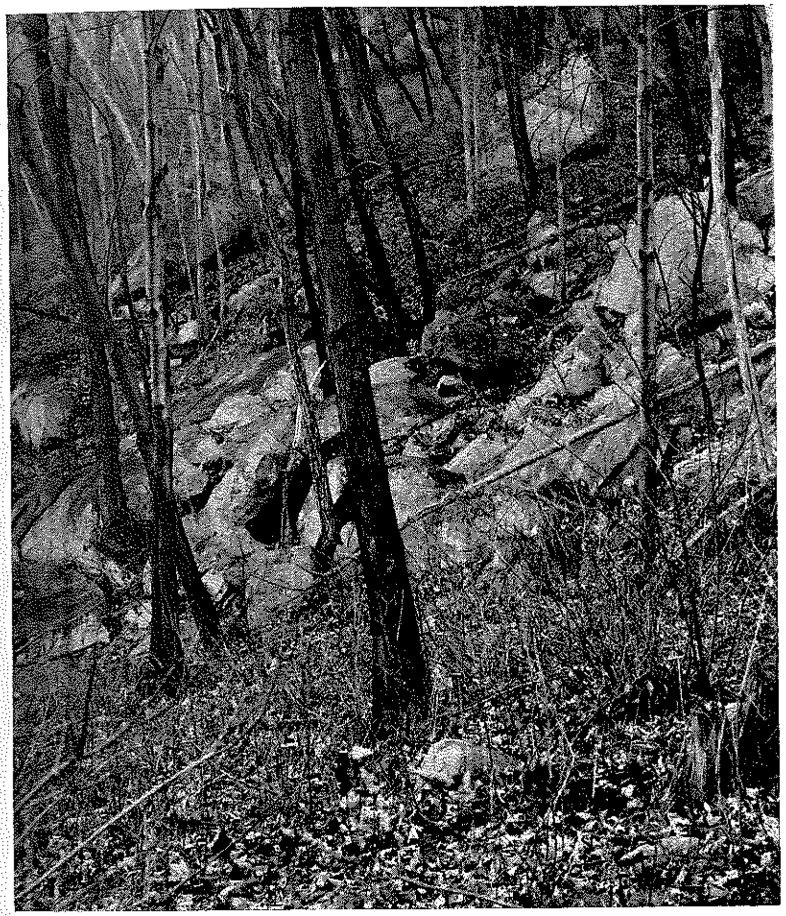


PLATE IV. BREAK IN SLOPE BETWEEN THICK TILL (in the foreground) AND STEEPER, TALUS-COVERED SLOPE OF BLACK ROCK.

Trees on slope incline slightly from the vertical in order to obtain as much light as possible. Northwest base of Black Rock to east of Hulse road, at an elevation of about 1100 feet. (*Photograph by author*).

small amount of carbonate in the original drift (See Table No. 1). Exposures of gravel in the lowlands to the north reveal a considerably greater percentage of limestone fragments and much secondary cementation. Cuts in till of the lowlands, as along Moodna Creek, show a depth of leaching of about 10 feet and resemble the Black Rock brook section.

Other Localities

The distribution of thick till overlain by warp on the north slopes of the Highlands is shown in Fig. 1. This till extends up to an altitude of almost 1200 feet in the sag to the northwest of Black Rock. In many places a sharp topographic break marks the inner margin of the till, and the steep bed rock slope changes abruptly to the gentler slope of the thick drift (See Plate IV). This is especially well shown in the valley of Canterbury brook. The accompanying section (Fig. 3) runs in a general northwesterly direction from the summit of Black Rock to the Forest boundary. The section shows thick till overlain by warp which is trenched by Canterbury brook

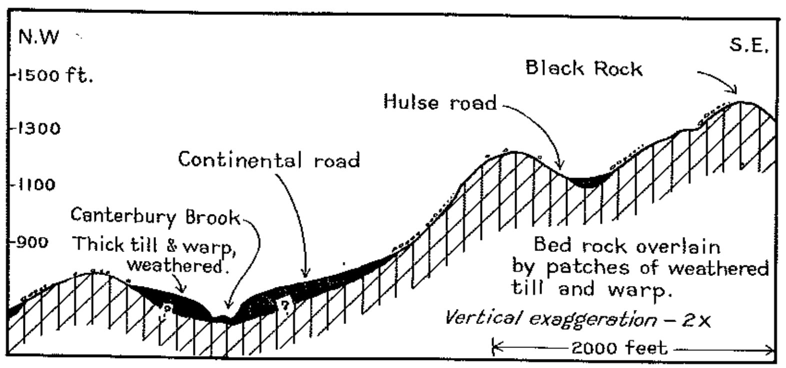


Fig. 3. CROSS-SECTION FROM BLACK ROCK NORTHWEST TO FOREST BOUNDARY.

Break in slope between thick till overlain by warp and steep bed rock face of the Highlands is clearly shown.

wherein scattered outcrops of bed rock are found. The dissection amounts to 30 or 40 feet, and as the brook has not encountered bed rock except at a few outcrops, the till must be thicker than 40 feet in many places.

The surface of the thick glacial deposits presents a remarkably uniform slope. Only slight irregularities occur. One of the most conspicuous of which is a flat terrace which runs east and west from Canterbury brook at an altitude of about 950 feet. This feature may be an "altiplanation" terrace. The surface of the thick drift is covered in some places by large sandstone boulders, 10 to 20 feet in diameter, and by masses of smaller sandstone boulders. The large sandstone boulders are numerous throughout the area of thick drift; the bed of Canterbury brook is full of them. In places the brook flows over a pavement of such boulders which reach 10 to 20 feet in diameter. Locally small pot holes, as much as 6 inches in depth, have been carved in these rounded boulders.

Glacial Deposits of the Highland Section

Throughout the Highland section the till is thin and is overlain by weathered warp. No absolutely unweathered till was found. The deepest cut (No. 14) extended to about 7½ feet below the surface and shows the till to be grayish-brown in color and rather more sandy in texture than the thick till on the northern slopes. Table 2 illustrates the percentage composition and the percentage of stones per cubic foot to be found in this till. Nos. 4a and b and No. 21 are in the Northern Slope section. The values are listed in order of increasing altitude of locality from which the sample was obtained. No regular change in composition with altitude is apparent. Most samples contain a predominance of sedimentary rocks except those from the southeastern part of the area. Several individual exposures will now be described to

TABLE No. 2

MECHANICAL ANALYSES OF SAMPLES OF FRESH OR OF MODERATELY WEATHERED TILL ARRANGED ACCORDING TO THE ALTITUDE OF THEIR RESPECTIVE LOCALITIES

Elevation in feet	No. of sample	Location of sample	Percentage by volume: Sandstone	Crystalline Rock	Slate	Miscel.	Percentage of stones per cu. ft.
530	4a	Black Rock Brook	60.7	3.6	26.8	8.9	13.7
530	4b	Black Rock Brook	67.5	7.1	17.4	8.0	23.8
675	2a	New Storm King Highway	17.8 (b)	81.5 (b)	0.1 (d)	0.6 (c)	36.3
675	2b	New Storm King Highway	7.5	92.5	...	0.1	19.4
725	21	Hulse Road	49.8	42.7	4.6	2.9	14.6
900	15a	Glycerine Hollow, south side	39.2	58.4	...	2.3	6.1
930	16	Glycerine Hollow, near base of north slope	52.4	44.4	1.3	2.1	9.7
1050	7a	Mt. Misery, north east slope	65.8	19.9	2.8	11.4	15.6
1070	3	Misery Cove, north slope of Hill of Pines	58.6	30.4	3.4	7.7	24.7
1120	9c	South east slope of Mt. Misery	2.3	97.7	0.1	...	19.9
1170	14a	Isaac Odell Place	77.9	8.5	11.1	2.5	2.7
1175	20a	Hulse Road	28.6	69.5	1.6	0.3	10.2
1180	22a	Junction of Continental and Jim's Pond Roads	36.2	58.8	3.7	1.1	19.4
1265	19	South west side of Arthur's Pond	90.5	1.9	3.2	4.5	31.2
1270	23a	North west end of Bog Meadow Pond	64.6	19.1	10.4	5.9	7.8
1310	1	North east end of Sphagnum Pond	91.0	2.2	4.2	2.8	23.3
1400	18a	Chatfield Trail, top of ridge	69.2	18.9	8.5	3.7	8.1
1410	10	Summit of Black Rock	69.1	25.8	3.9	1.2	16.5

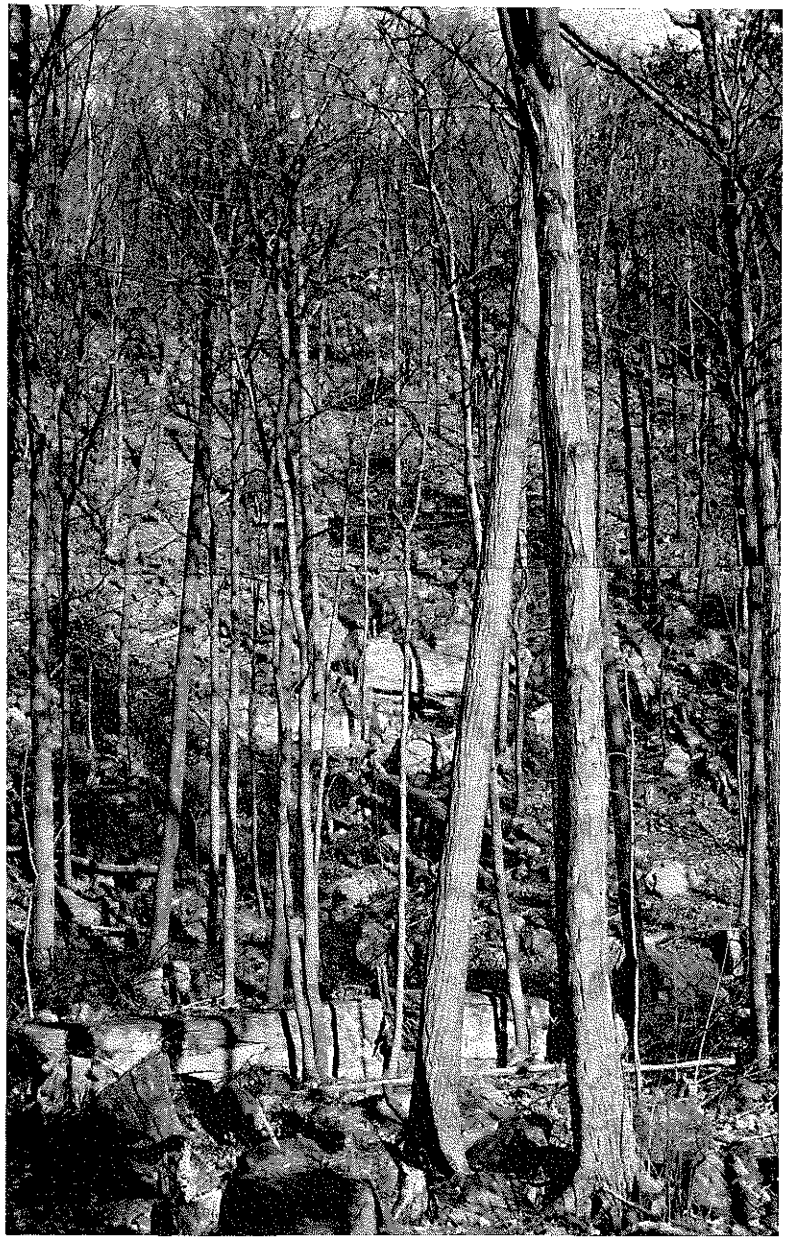


PLATE V. VIEW LOOKING NORTH FROM BOTTOM OF MISERY COVE TOWARD SOUTH SLOPE OF MT. MISERY, THE CREST LINE OF WHICH IS FAINTLY VISIBLE THROUGH THE TREES.

Shows talus formed during the Periglacial Interval. (*Photograph by author*).

illustrate the characteristics of till and warp found in the coves, on the slopes, and on the upland surface and hill tops.

The Coves

Misery Cove

Misery Cove is a small basin-like area south of Mt. Misery and north of the Hill of Pines. To the east a low divide made up, in part, of a rather thick mass of till, separates it from the Upper Reservoir valley. To the west the Cove opens out into Aleck Meadow. Bed rock overlain by thin patches of weathered till, warp and boulders forms the northern slope of the Hill of Pines. The steep southern slope of Mt. Misery is shown in Plate V. This photograph is a view looking north at the talus slope on the south side of Mt. Misery. In the foreground cove timber grows up between the boulders, which rest on the damp and swampy surface of the cove. In the background talus blocks of crystalline rock decrease in size up slope; and small masses of weathered till appear at the surface between some of the boulders. The crest line of Mt. Misery is faintly visible through trees. This talus or rock slide was formed during the Periglacial Interval. Only a few small stones are moving down slope at present.

The general configuration of the cove is shown in the accompanying north-south cross section (Fig. 4). Pit No. 3, on the south side, revealed 2 feet of weathered warp, composed of yellowish-brown, pebbly clay resting on a grayish-brown, sandy till, considerably weathered. Bed rock was not encountered. As one goes toward the north across the bottom of the cove, the stones on the surface increase in size and number until they form a veritable boulder pavement. On the north side almost no stones of sedimentary types are found.

On the south side of the cove (at "a") a pit was dug

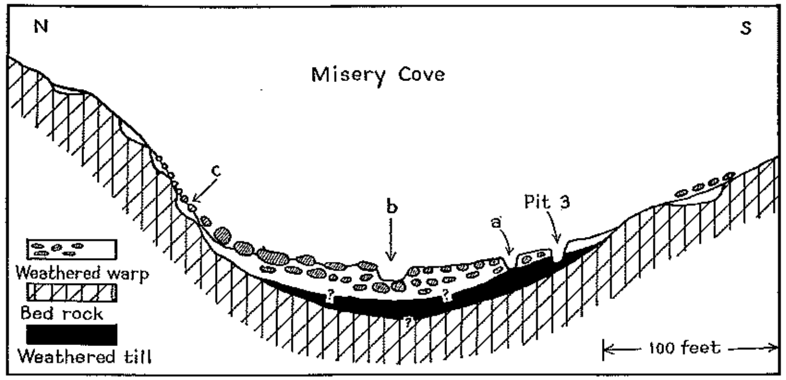


FIG. 4. DIAGRAMMATIC, NORTH-SOUTH CROSS-SECTION THROUGH THE BOTTOM OF MISERY COVE.

Plate V was taken looking to the north from pit "b". Thickness of glacial deposits exaggerated.

about 2 feet deep, which penetrated through the bouldery warp to the weathered till below. In the center of the cove an excavation (at "b") revealed boulders of crystalline rock to a depth of 3½ feet. A black layer of vegetable matter or peat filled the crevices between the boulders to a depth of 2 feet. Below the two-foot level arkosic sand was encountered containing fragments of partially disintegrated crystalline rock. The pit filled very rapidly with water. It appears that the cove trees grow on this peat accumulation and that the presence of standing water during a wet season has tended to increase the rate of disintegration of the underlying blocks of crystalline rock.

The cross section of the cove (Fig. 4) shows a mass of weathered till underlying the weathered warp and talus. This may not be present on the north side of the cove, but the evidence from Pits No. 3 and "a" indicates its presence on the south side.

The boulders of crystalline rock on the north side of the cove reach at least 10 feet in diameter and decrease in size up the slope of Mt. Misery. The slope is slightly over-steepened and has a faint basin-like form. The form

of the slope, and lithology and size distribution of the boulders indicate that they rolled down this slope after the till was laid down—perhaps after original irregularities had been erased by solifluction. A small pit on the slope (at "c") showed weathered till lying below the talus or "slide rock." The trees and shrubs growing on this slide show no evidence of disturbance by movement of the larger boulders during the last hundred years. A few of the smaller stones are moving slowly down slope at the present time. As this is one of the steepest slopes in the Forest and on it only small stones now move, the large stones must be attributed to movement at some previous period. As frost action greater than that of the present would promote movement of boulders over the slope, it is thought that most of the movement took place in the Periglacial Interval.

Pit No. 9 in the mass of rather thick till on the south slope of Mt. Misery to the east of the cove, contained 97.7 per cent of pebbles of crystalline rock. This is a much higher percentage of native rocks than No. 3 or other samples in the vicinity, and suggests that this thick mass of till was not laid down by the same part of the ice that deposited the cove till (No. 3). It is conceivable that Misery Cove was at one time filled by a local accumulation of ice or was occupied by a tongue of the advancing ice sheet. However no good evidence for either of these possibilities was discovered.

Glycerine Hollow

Glycerine Hollow is a circular cove located near the southeastern border of the Forest. It lies at an altitude of only 900 feet and is surrounded on three sides by rocky slopes overlain by thin patches of weathered till and warp. Bed rock crops out at the outlet of the cove in Cascade Brook and surrounds the cove on all sides, except for a small area on the southwest side where one pit was dug (No. 15), 5½ feet deep, which penetrated to a somewhat weathered and compact till. A swamp forms the floor of the cove. Although this area supports a good growth of timber, there appears to be no possibility of any thick till in the cove except in a rock basin beneath the swamp. A sample (No. 15a) of hard, sandy clay from the bottom of pit No. 15 contains only about 6 per cent of stones per cubic foot which include a rather high percentage of pebbles of crystalline rock, 58.4 per cent by volume. These crystalline pebbles have a soled form such as is characteristic of pebbles carried by glaciers. Their surfaces show but slight evidence of weathering. The surfaces of the sandstone pebbles are smooth but almost no striae were observed. The matrix of the till is a sticky bluish-gray, sandy silt or clay. The proportion of fine sand and silt in this sample is greater than in samples from the Northern Slope section. Patches and films of yellowish-brown clay (secondary?) occur in this horizon.

The upper 2 to 2½ feet of the section yielded a sample (No. 15b) with a high percentage of sandstone, 70.3 per cent by volume. This horizon is a loose mass of grayish-brown clay with a few pebbles which show the characteristic glacial form. Almost no sand grains were noted. The small and almost equidimensional pebbles of crystalline rock show rough surfaces and rounded edges. Smooth surfaces but almost no striae are characteristic of the sandstone pebbles. The variation in the percentage of foreign stones is probably an original characteristic of the till sheet. It is possible that the upper foot or so of the section is a recent stream deposit.

THE SLOPES

Mt. Misery

Mt. Misery (1268 feet) is located in the northeastern part of the Forest. The cross section of Fig. 5 is drawn from field observations and from the data obtained in 10

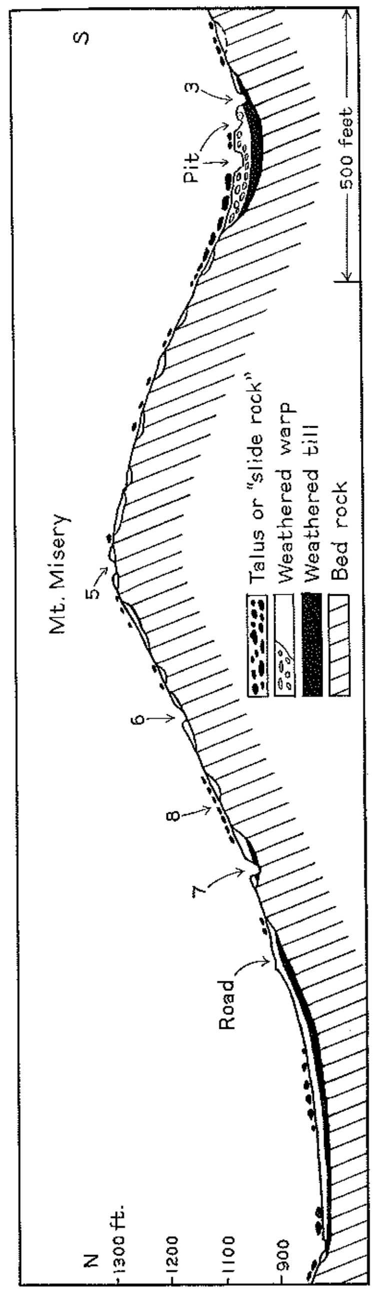


FIG. 5. NORTH-SOUTH CROSS-SECTION THROUGH THE SUMMIT OF MT. MISERY.
Numbers refer to pits described in text and shown on Fig. 1.

pits in the slopes. The relations found in this locality are thought to be characteristic of all the slopes in the Highland section of the Forest as pits on similar slopes yielded corresponding data.

Outcrops of bedrock occur at many places on the sides of Mt. Misery except on the lower southeast face where there is a relatively thick mass of sandy till (Pit No. 9). On the southwest side of the hill a small rock slide, relatively free from vegetation, is found. The south-facing slope is also steep and covered by talus or "slide rock" (See p. 27).

The glacial deposits lie on the slope in pockets between rock ledges. The orientation of the gneissic structure or banding in the country rock (linear parallelism) and of the several joint sets controls the form and distribution of the soil pockets.

On gentler slopes and on the summit, the upper 1 to 3 feet of material is a yellowish-brown, pebbly clay. This weathered warp rests either directly on the ledge or on hard and compact weathered till. The yellow or gray-brown matrix of this till does not effervesce with cold dilute hydrochloric acid and contains somewhat more sand than the overlying clay. On steeper slopes the warp instead of being a pebbly clay is a mass of angular boulders of crystalline rock which rests directly on the bed rock. There are all transitions between these two types of warp, depending, in part at least, on the declivity.

Table No. 3 presents data from four pits on the north slope of Mt. Misery (Nos. 5, 6, 7 and 8). The approximate location of the pits is shown in Fig. 5 (See also Plate VI). Samples Nos. 5, 6a, 6b and 7b are weathered warp and come from depths of from half a foot to 2 feet below the surface. These samples run relatively high in crystalline pebbles, the country rock of the area, and relatively low in sandstones and other categories of foreign origin. A hard, compact weathered till with a yellowish-brown color and containing patches of gray occurs at a

TABLE No. 3

MECHANICAL ANALYSES OF SAMPLES FROM MT. MISERY

Location of sample	*Percentage by volume*				*Percentage of stones per cu. ft.*
	Sandstone	*Crystalline Rock*	*Slate*	*Quartzite*	
Summit (No. 5), depth — 1 to 3 feet.	12.2	86.4	0.5	1.1	7.0
North east slope at 1150 to 1200 feet (No. 6a), depth — ½ to 1½ feet.	12.8	86.3	0.1	0.9	25.7
North east slope at 1150 to 1200 feet (No. 6b), depth — 1½ to 2 feet. .	5.1	94.3	0.2	0.3	14.4
North East Slope at 1050 feet (No. 7a), depth — 3 to 4 feet.	65.8	19.9	2.8	11.4	15.6
North east slope at 1050 feet (No. 7b), depth — ½ to 1½ feet.	33.2	56.9	2.7	7.2	18.7
North east slope at 1050 feet (No. 8), in gulch.	1.6 (b)	97.7 (a)	. .	0.8 (c)	30.5
Cove (No. 3), depth — 3 feet.	58.6	30.4	3.4	7.7	24.7

depth of 3 to 4 feet, and is represented by sample No. 7a. The till rests directly on bed rock and yet, as is shown in Table 3, is composed predominantly of sandstone pebbles. However, the warp (cf. sample No. 7b from the upper

PLATE VI. VIEW LOOKING SOUTHWEST ON THE NORTHERN SLOPE OF MT. MISERY.

The man is seated just to the right of pit No. 8. A few boulders can be seen on the surface. (*Photograph by author*).

part of the same pit and also Nos. 5, 6a and 6b) is considered to have been derived, during the Periglacial Interval, from the till by frost-heaving and solifluction with a considerable admixture of fragments of crystalline rock from the neighboring ledges. The reasons for the above conclusions are as follows.

By comparing the two samples from Pit No. 7 it was noted that the warp (No. 7b) contains 56.9 per cent pebbles of crystalline rock, whereas the underlying till (No.

7a) contains only 19.9 per cent. The topographic location of this pit is shown by Fig. 6. If we assume that the original glacial drift was predominantly a sandstone till, as a score or more of pits elsewhere tend to indicate (See Table No. 2), whence came the boulders of crystalline rock in the warp? Their shape and surface form pre-

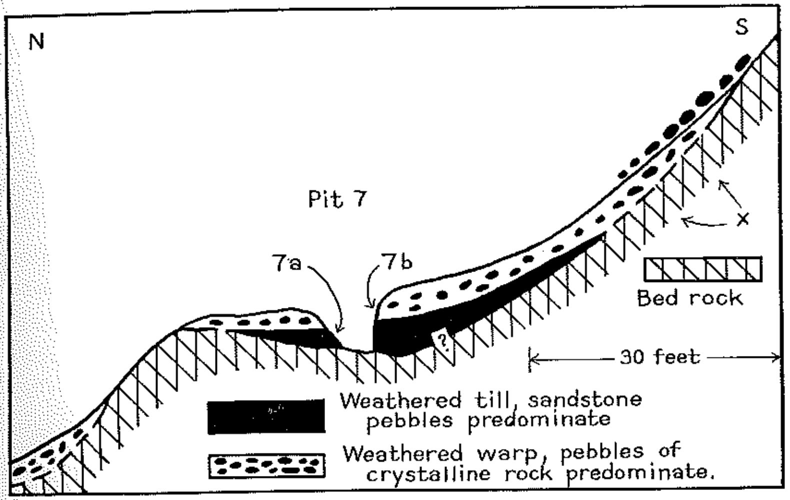


FIG. 6. CROSS-SECTION, SKETCHED FROM FIELD NOTES, THROUGH KNOLL AT AN ALTITUDE OF ABOUT 1050 FEET ON NORTHERN SLOPE OF MT. MISERY.

clude the possibility of their derivation from the underlying till. Since the lower till (No. 7a) is hard and compact, and the characteristic till texture is preserved, these crystalline boulders could not have been broken from the ledge directly below (i.e., passed upward through the till). The only other possible source is the ledge farther up the slope ("x" in Fig. 6). They have reached their present position by sliding down slope and mixing with frost-heaved till. This movement took place after the underlying till was laid down. No movement is in progress at the present time.

The weathered till and warp differ in the character of the pebbles found in them. The following criteria were worked out to distinguish pebbles of the till from those of the warp.

A greater variety of rock types is found in the till than in the warp. All types of foreign stones are present, the net result being that a till sample is relatively low in crystalline rock. Also the pebbles of crystalline rock, or those derived by the glacier from the bed rock, vary more among themselves in color and in texture (having many different lithologic types) than do pebbles of crystalline rock in the warp. A sample of pebbles of crystalline rock from the till will include fragments of pegmatite, fine-grained granite, gneiss, and several varieties of schist. A sample of the warp will have pegmatite or gneiss almost to the exclusion of any other type.

Although the form of stones from the till is highly variable, some of the sandstones are "flat-iron" shaped. When compared with pebbles from the warp, most glacially transported stones are nearly equidimensional. The ratio of maximum and minimum diameters of a pebble from till is nearer one to one than a similar ratio for a rock fragment from warp. The edges of stones from till tend to be rounded off and there are no small projections (See Plate VII). Glacial transportation removes whatever sharp edges and points the pebble had when freed from the parent ledge. This is true of local crystalline rocks as well as of foreign stones.

Many stones in the warp have angular edges and points (See Plate VIII). Slightly concave surfaces are common, which form appears dependent on the distribution and character of joints in the country rock. At exposures of weathered bed rock, where quarried for road metal or in recently blasted road cuts, there are heaps of fragments with such curved joint planes, and otherwise identical in form with pebbles from warp. It is probable that some of the concavo-convex fragments have been removed from the bed rock by exfoliation. Differences in form between

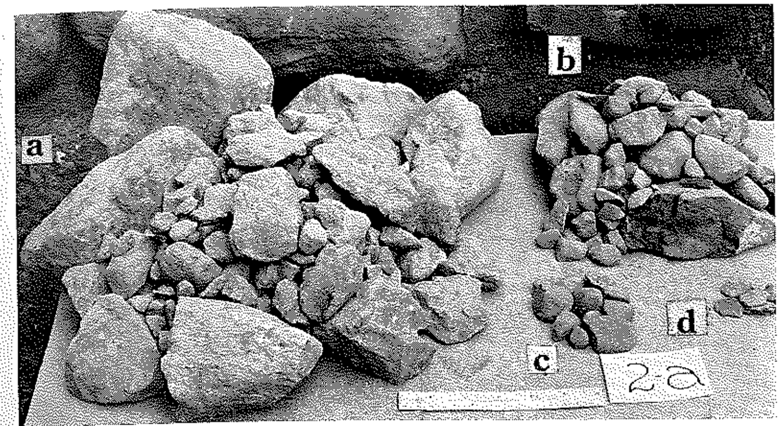


PLATE VII. SAMPLE FROM WEATHERED TILL WHICH IS EXPOSED IN THE "NEW STORM KING HIGHWAY" CUT (No. 2a).

Letters refer to Table No. 2. (*Photograph by H. M. Raup*).

PLATE VIII. SAMPLE FROM WEATHERED WARP IN GULCH AT AN ALTITUDE OF 1050 FEET ON NORTHERN SLOPE OF MT. MISERY (No. 8).

Letters refer to Table No. 3. (*Photograph by H. M. Raup*).

stones from warp and from till are brought out clearly by a comparison of Plates VII and VIII.

Pebbles from the till which are of the finer-grained rocks show a soled and striated surface. Some fragments of slate, only one-half to one inch long, are striated and polished. No striated pebbles of crystalline rock were observed, although some present rather smooth surfaces. Foreign stones show more modification by ice action than do local pebbles. This may be due not only to the coarser grain of the latter, but also to the greater distance over which the former have been transported. The surfaces of pebbles from unweathered till are clean and bright. The slates are a deep blue-gray. The feldspar crystals in the crystalline rocks are clear and untarnished.

The surface of many pebbles from the warp is rough and more or less weathered. The more schistose specimens break up easily. The feldspar crystals of the coarser-grained types are dull, and have weathered out leaving the quartz grains as projecting points. In Pit No. 18 near the junction of the Chatfield and Ledge trails,

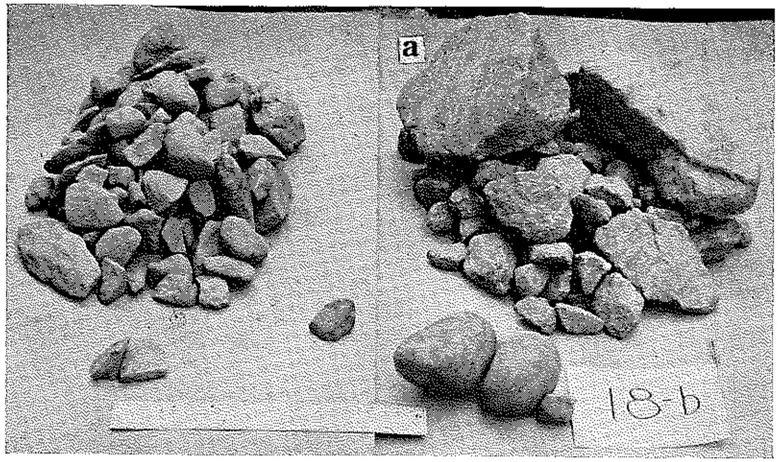


PLATE IX. SAMPLE (No. 18b) FROM WEATHERED WARP EXPOSED IN PIT No. 18 ON THE UPLAND SURFACE.

Fragment of glaciated ledge marked with "a". (*Photograph by H. M. Raup*).

several boulders of crystalline rock were found which are fragments of the underlying glaciated ledge. One surface of the stone is polished and striated, whereas the others are rough and have sharp edges (See Plate IX). Although clear distinctions between the stones of unweathered and considerably weathered tills are easily made, the real problem is to distinguish stones derived from a weathered till from those derived from a weathered warp. The surfaces of both types are stained and rough.

The warp on the northern slope of Mt. Misery contains a mixture of stones derived from the till and from the bed rock. There are all gradations of this surficial material from a mass of sand and clay to a layer of boulders. Pit No. 8 yielded a sample (Plate VIII) of warp which contained 30.5 per cent of stones per cubic foot. The slope here is steeper than at any of the other localities (See Plate VI). Pit No. 5, at the summit of Mt. Misery (on an almost horizontal surface) yielded only 7.0 per cent of stones. The percentage of stones in the warp is roughly proportional to the slope of the surface. The fine material in the warp is derived from the matrix of the till, and from the break up of some of the less resistant pebbles, by intense frost action during the Periglacial Interval.

New Storm King Highway

During the construction of the new Storm King highway several deep cuts were made just outside the southeast border of the Forest. Plate X shows very clearly that the location of small patches of weathered warp is related to structures in the bed rock. The gneissic banding of the country rock dips to the northeast (to right in photograph). A well-defined joint set is steeply inclined toward the southwest. Small patches of weathered warp lie in pockets determined by the intersection of these two structures. Locally the mat of litter and tree roots rests

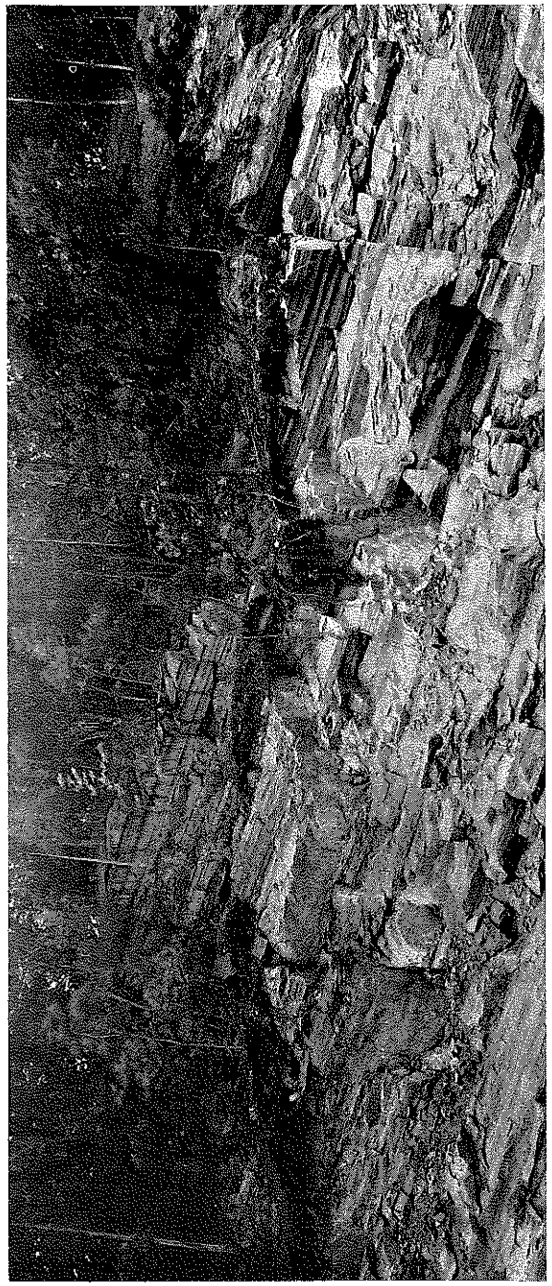


PLATE X. ROAD CUT ON NEW STORM KING HIGHWAY JUST NORTHEAST OF CASCADE BROOK.

Thin patches of weathered warp rest in pockets in the bed rock surface. (*Photograph by H. H. Tryon*).

directly on the ledge, and roots can be seen penetrating many feet into the joint cracks.

In the cut bank of the new highway at a point just southeast of the Old Continental Road and a few hundred yards southwest of Cascade brook, a mass of talus blocks and weathered warp rests on a thin layer of sandy till which has been only slightly weathered. This ex-

PLATE XI. ROAD CUT ON NEW STORM KING HIGHWAY JUST SOUTHWEST OF CASCADE BROOK.

Talus overlies weathered warp which rests on slightly weathered, sandy till (light colored). Surveyer's rod is 5 feet long. (*Photograph by H. H. Tryon*).

posure is shown in Plate XI. The bed rock is smooth and unweathered, although blasting has broken up the ledge and opened joint cracks. In the photograph the ledge appears to lie from 10 to 15 feet below the surface, but this distance is considerably exaggerated because of the steep slope (28 to 30 degrees). Bed rock is found at the surface about 100 feet up slope.

A sample (No. 2b) from the 2 to 6 foot layer of slightly weathered, sandy till which lies in a small pocket on the sloping bed rock surface contains 19.4 per cent of stones per cubic foot. The percentage of pebbles of crystalline rock is 92.5. These pebbles from the till are small, not over 3 to 4 inches in diameter; and the few sandstone pebbles are also small and not striated. These stones lie in a gray-colored matrix of rather clean, fine sand.

A somewhat weathered bouldery warp, 3 to 5 feet thick, overlies the sandy till. There is much fine material in this yellowish-brown horizon, yet it contains 36.3 per cent of stones per cubic foot. The frost-heaved zone passes upward into talus blocks which rest on the slope. In the warp pebbles of crystalline rock predominate (No. 2a) but reach only 81.5 per cent by volume, somewhat less than the number in the sandy till (No. 2b). The sample came from the base of the warp, in which stones with glacial form predominate (See Plate VII) and resemble those from the lower zone (No. 2b). Some of the larger sandstone pebbles are striated. The sample from the upper zone (No. 2a) and that from the upper portion of a Glycerine Hollow pit (No. 15b) show a higher percentage of sandstone pebbles than the underlying till. Perhaps this is an original variation in the till.

The surface above the new Storm King highway section is capped by blocks of crystalline rock most of which are from 5 to 10 feet in diameter (See Plate XI). Many smaller stones lie between these large boulders and farther up the slope. The blocks are arranged according to size, with the largest at the base of the slope, to form

a talus. Tall straight trees, with a basal diameter of 1½ feet, grow on top of this talus, and there are no traces of disturbance of these trees during growth either by movement of their roots or in the form of scars on their uphill side caused by sliding boulders. No evidence is found in the vegetation for any recent movement on the slide, although it is probable that on such a steep slope as this one, a few small boulders occasionally roll down. In order to account for the size distribution of the boulders we must postulate a former period during which the large ones rolled or slid down the slope. The underlying warp is a frost-heaved and solifluction layer formed at the same time; that is, during the Periglacial Interval.

Upland Surface

The Highland section of the Forest is a rolling upland where outcrops of crystalline rock are separated by bodies of till which partly fill small depressions in the bed rock surface. Swamps are abundant. The thin patches of till are much weathered, of a gray-brown color, and are overlain by about 3 feet of weathered warp. Large erratics of sandstone and of crystalline rock are common.

Chatfield Trail

Two pits were dug on the upland to the south of Tamarack Pond at a point located on the north side of the Chatfield trail near its junction with the Ledge trail (altitude 1391 feet). The area is characterized by rock outcrops and patches of weathered warp and till. Pit No. 17 lies on the northeast slope, at an altitude of 1390 feet, or about 10 feet below the top of the ridge, where Pit No. 18 is located.

Pit No. 17 encountered a glaciated ledge 2 feet below the surface. Striae on it ran about 28 to 29 degrees west of north. A loose-textured, yellowish-brown warp overlies the ledge at this point. This weathered warp is a nearly-pure clay, contains little or no sand, and only 1.5 per cent of stones per cubic foot. At the surface a thin layer of leaf litter overlies one-half an inch of humus and 1 to 2 inches of brown forest soil. The few pebbles from this sample are 67.4 per cent crystalline rock and 29.1 per cent sandstone by volume. The pebbles of crystalline rock are angular, rough surfaced and are more or less elongated although one or two are more rounded. The few slates and sandstones are small and unstriated.

Pit No. 18 on the top of the ridge, at an altitude of 1400 feet, reached bed rock in 3 feet. The leaf litter, humus and brown forest soil are similar to Pit No. 17. A yellowish-brown, weathered warp of sandy clay overlies a compact sandy till. The warp contains a considerable number of pebbles (15.5 per cent by volume). The grayish-brown till is weathered, and shows patches and films of brown clay, apparently of secondary origin. The pebbles of the warp (No. 18b) when analyzed consist of crystalline rock, 62.0 per cent; sandstone, 32.1 per cent; slate 0.3 per cent. A large pebble of crystalline rock has one flat surface which is striated and polished, whereas its other surfaces are rough and the edges sharp (See "a" in Plate IX). It is a fragment of the glaciated surface of the bed rock. Sandstone pebbles include both angular and rounded forms. No striae were observed.

A sample of the lower till (No. 18a) contains 8.1 per cent of stones, including 18.9 per cent crystalline rock, 69.2 per cent sandstone and 8.5 per cent slate. A tendency towards an equidimensional shape is characteristic of pebbles of crystalline rock. Slate pebbles are striated and soled, as are many of the sandstone pebbles.

The surface material at these two localities (upper 2 feet) is a frost-heaved and weathered layer which rests either on bed rock or on a grayish-brown weathered till (No. 18a). The warp is a mixture of material derived

from the till and of fragments of crystalline rock derived from the ledge, as is shown by the fragment of striated bed rock in Sample No. 18b. The upper horizon contains abundant angular pebbles of crystalline rock, and a smaller percentage of sandstone and slate pebbles than does the underlying till. The stones from the latter are more equidimensional, and more highly polished. At locality No. 18 the ground is approximately level and there are a few small boulders on the surface. The movement of stones by frost action in the Periglacial Interval must have been predominantly in a vertical direction. Perhaps the entire section in Pit No. 18 has been frost heaved and then the lower foot re-cemented. However, such a mixing of the entire section should result in a more uniform rock composition for both horizons.

Bog Meadow Pond

A pit 3 to 3½ feet deep was dug in the bottom of a small swale near the north end of Bog Meadow Pond (No. 23; just west of trail intersection, at an altitude of 1267 feet). A pavement of boulders from 1 to 2 feet in diameter covers the surface (See Fig. 7). Crystalline rock types predominate, but a few large sandstone boulders are present. Sample No. 23a, from bottom of pit, is a hard, compact, yellow-brown till, containing numerous small boulders. About 12 to 15 inches above bed rock this horizon passes upward into a zone of mottled clay (yellow, gray and brown colored), one foot thick, which contains almost no stones (No. 23b). The upper foot at this locality is a layer of stones (crystalline rock and sandstone), some of which are breaking up into many angular slabs (No. 23c). Masses of peat lie in the spaces between the stones to a depth of 6 inches below the surface. Water stands in this swale for a considerable period during the spring. The results of the mechanical analysis are shown in Table No. 4.

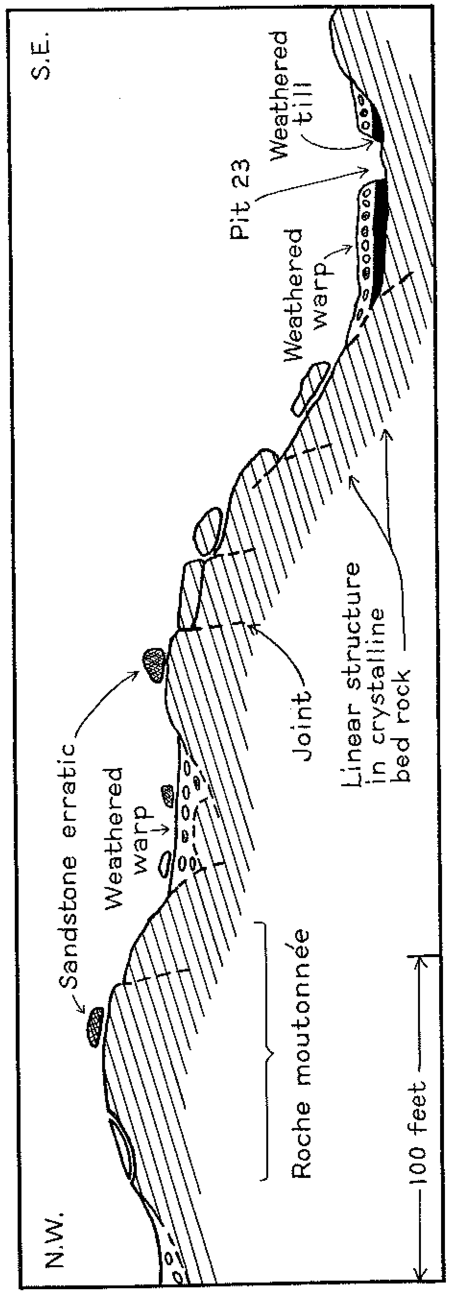


FIG. 7. CROSS-SECTION, SKETCHED FROM FIELD NOTES, THROUGH A PORTION OF UPLAND TO NORTHWEST OF BOG MEADOW POND.

TABLE No. 4

MECHANICAL ANALYSIS OF SAMPLES FROM PIT No. 23

	Percentage by volume				
	Sandstone	*Crystalline Rock*	*Slate*	*Miscel.*	*Total Stones*
Lower (No. 23a)....	64.6	19.1	10.4	5.9	7.8
Middle (No. 23b)...	60.9	10.5	6.2	22.5	2.3
Upper (No. 23c)....	64.5	32.8	0.8	1.9	44.9

Most of the stones from the lower horizon have a glacial form, many sandstones are striated and soled, as are the few slate pebbles. A few angular fragments are present. In the upper horizon many sandstones are rough surfaced, but show glacial forms. Small and large, broken fragments of sandstone and of crystalline rock are numerous. Some large pebbles of crystalline rock show characteristic glacial forms.

The lower zone (No. 23a) is interpreted as a somewhat weathered till, which contains a high proportion of sandstone fragments, overlain by a more severely weathered and frost-heaved layer derived from it. The absence of pebbles in the middle zone may be due to frost action which has raised them to the surface, where they are at present concentrated. Perhaps because it is concealed by vegetation, the boulder pavement does not show any polygonal arrangement. Such a boulder-free horizon as the middle zone (No. 23b) was encountered nowhere else in the Forest. It is thought that the undrained condition of this locality caused, and perhaps still causes, frost action to be more intense here than elsewhere. The break up, in place, of large sandstone boulders into angular fragments suggests modern frost action.

Isaac Odell Place

A pit (No. 14), 7½ feet deep, was dug in the southwest corner of the Forest near the Isaac Odell place. Here a small mass of till lies on the rocky, northeast slope of Mt. Rascal. The pit exposed a hard, compact till consisting of dirty-brown colored clay with a small admixture of sand and pebbles. Samples were gathered from depths of 7½ (No. 14a), 4½ (No. 14b), and 1½ feet (No. 14c) below the surface. The results of the mechanical analysis are shown in Table No. 5.

TABLE No. 5

MECHANICAL ANALYSIS OF SAMPLES FROM PIT NO. 14

	Percentage by volume				
	Sandstone	*Crystalline Rock*	*Slate*	*Miscel.*	*Total Stones*
Lower (No. 14a)...	77.9	8.5	11.1	2.5	2.7
Middle (No. 14b)...	72.2	8.6	12.8	6.3	6.4
Upper (No. 14c)....	78.2	12.2	6.7	2.9	6.1

The till contains very few pebbles, and of those present, sandstones are most abundant. The lower 3 feet is cut by nearly vertical seams of light gray clay, which appear to be secondarily derived by weathering from above. Completely unweathered till is not encountered. This exposure suggests a depth of weathering comparable to the Black Rock brook section.

Conclusions

The three above-mentioned localities on the upland surface are typical of its general features. Pit No. 23 is located on the floor of a small undrained swale. Here the three zones contain 60.9 to 64.6 per cent of sandstone pebbles, in contrast to the pits near the Chatfield trail (Nos. 17 and 18) where the surficial layer contains a greater percentage of pebbles of crystalline rock than the underlying till. This fact indicates that at the Bog Meadow Pond locality (No. 23) periglacial processes were able only to remove and rework whatever original

till covering there was, but were not able to break up the bed rock to any great extent. On the other hand, at the Chatfield trail locality some break up of the glaciated bed rock surface has taken place.

At the Isaac Odell place the absence of boulders at or near the surface, in spite of the presence of the steep, rock-covered slope of Mt. Rascal only about 50 feet to the west, indicates that only a small number of boulders of crystalline rock were removed from the side of Mt. Rascal by frost action in the Periglacial Interval.

If there has been any considerable removal of material

PLATE XII. ROUNDED LEDGE OF CRYSTALLINE ROCK (ROCHE MOUTONNÉE) WHICH HAS BEEN BROKEN INTO BLOCKS.

Photograph shows a portion of the cliff at northern end of Bog Meadow pond just east of Bog Meadow road. (*Photograph by H. M. Raup*).

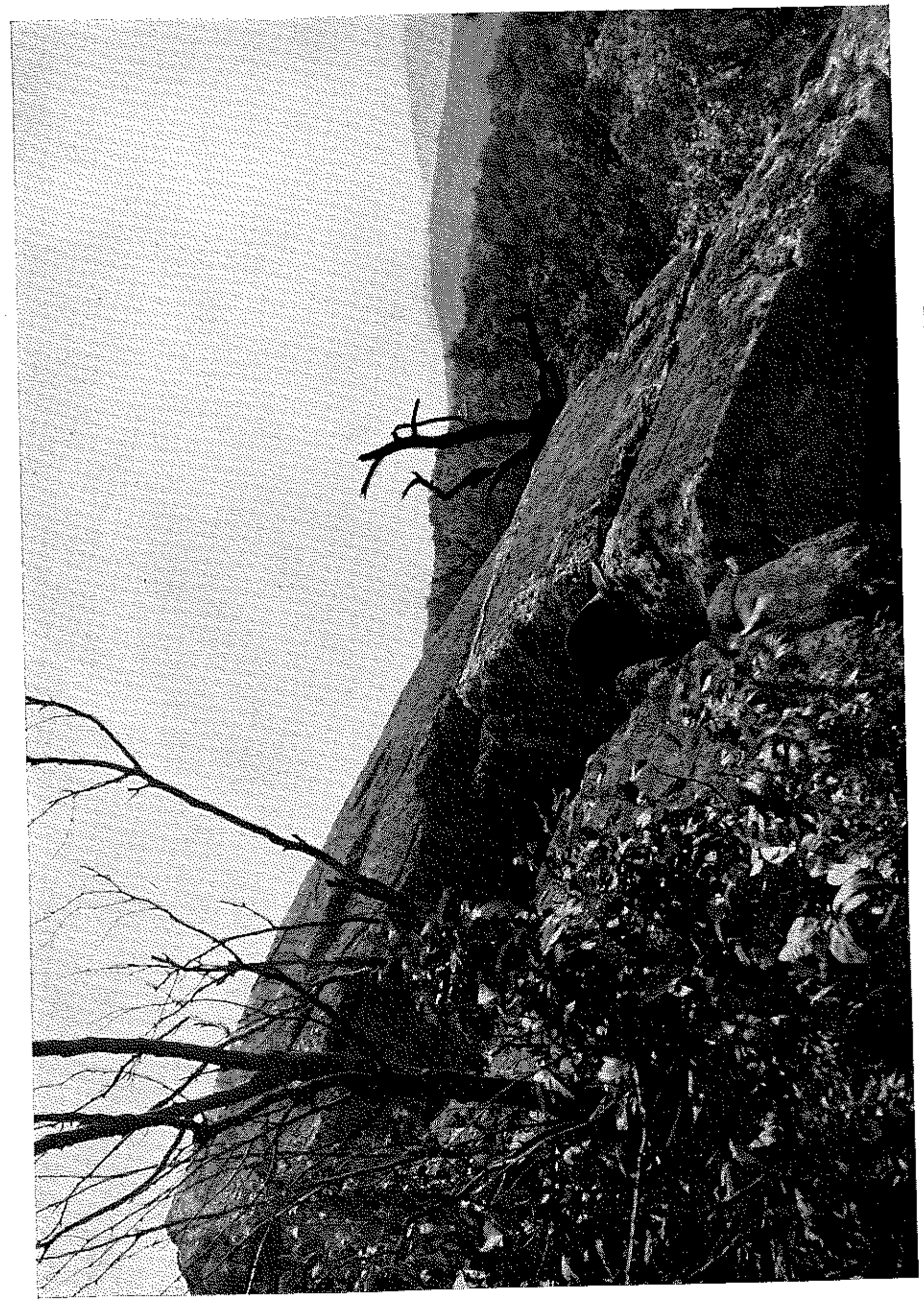


PLATE XIII. EXPOSED LEDGE ON THE SUMMIT OF BLACK ROCK.

from the upland in post-glacial time, alluvial fans should be found today in the valley bottoms. No such depositional forms are observed. It is, therefore, concluded there has been no appreciable removal of material from the upland since the Periglacial Interval.

The surface features of the ledges have been described (p. 6). Their rounded form and rough surface are shown in Fig. 7. Locally they have been broken into blocks (See Plates XII and XIII). Large erratic boulders of sandstone rest on the ledge at many places. The ledges are roches moutonnées, the surfaces of which have been lowered a few inches at the most by post-glacial weathering. The original glacial surface has been completely removed from all of the exposed ledges, although an unweathered glacial surface is laid bare in many road cuts.

Higher Summits

Black Rock

Black Rock, reaching an altitude of 1410 feet, is one of the highest points in the Forest. The actual summit, about 200 feet across, consists of outcrops of bed rock separated by small patches of mineral soil which support a growth of scrub oak and pitch pine, together with several grasses and other herbaceous or shrubby species (See Plate XIV). In one of these patches a pit was excavated which extended 2½ to 3 feet to the slanting surface of bed rock. About 3 inches of leaf litter and humus soil is underlain by 2 feet of loose, yellow-brown warp, rather fine-textured, which is somewhat weathered and contains many large, rounded boulders of sandstone. Between this horizon and the only slightly weathered bed rock, which is covered by a mat of roots, there is a 6 inch to 1 foot layer of compact and weathered till which is sandy in texture and yellowish-brown in color. The stones have a well-defined glacial form. The results of the mechanical analysis are shown in Table No. 6.

TABLE No. 6

Mechanical Analysis of Sample from Pit No. 10

	Percentage by volume				
	Sandstone	*Crystalline Rock*	*Slate*	*Miscel.*	*Total Stones*
Sample No. 10......	69.1	25.8	3.9	1.2	16.5

Ten feet east of this locality there is a small patch of grass between outcrops of bed rock. Here about 6 inches of humus soil and of grass roots forms a mat which contains numerous small fragments of crystalline rock plus a few small sandstone pebbles. These angular fragments of crystalline rock were broken from the bed rock, or possibly are the result of the break up of boulders of crystalline rock in a till now entirely removed. On Black Rock, therefore, there are small masses of weathered till, together with patches of weathered warp. Furthermore, the thickness and general character of the glacial deposits on the summit and on the slopes of Black Rock are similar, and differences in the types of vegetation cannot be attributed to variation in the lithological character of these deposits.

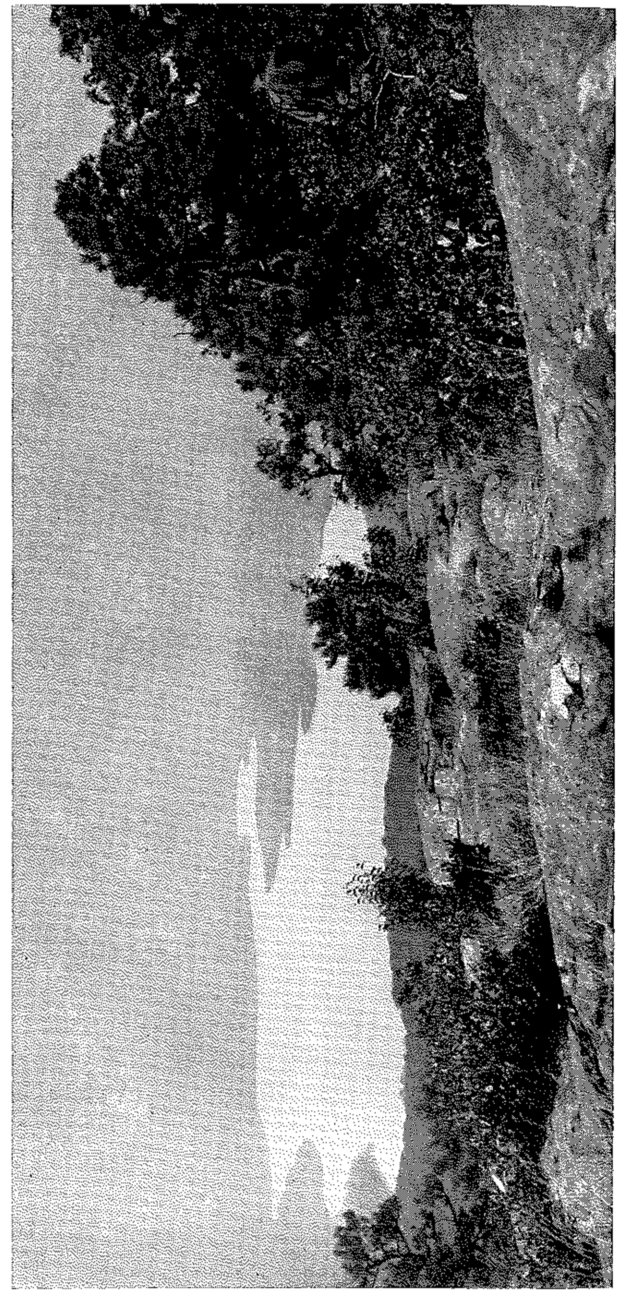


Plate XIV. VIEW NORTH FROM THE SUMMIT OF BLACK ROCK WITH THE HUDSON RIVER IN THE BACKGROUND.
Rock ledges are interspersed with grassy areas. Man is standing by pit No. 10. *(Photograph by H. M. Raup).*

THE FORMATION OF WARP DURING THE PERIGLACIAL INTERVAL

THE writer believes that the till found in the Forest was deposited by the continental ice sheet in Early or Middle Wisconsin time, when the continental glaciers advanced as far south as the terminal moraine in northern New Jersey (See Fig. 8), although such an age for the till and for the terminal moraine is only tentative at the present time. On the northern, eastern and southern flanks of the Catskill mountains Rich (1935) has mapped a "Late Wisconsin Terminal (?) moraine stage," the limits of which are shown diagrammatically in Fig. 8. The boundary between the "Late Wisconsin" and older deposits was not traced to the east of Ellenville. Reconnaissance by the writer indicates that Rich's "Late Wisconsin" ice did not extend as far south as the Hudson Highlands. It is not known whether this "Late Wisconsin" ice represents a major advance of the ice sheet, following a prolonged recession or is merely a minor oscillation during the general deglaciation of the region. In any case the Highlands were subjected to the vicissitudes of a periglacial climate during the withdrawal of the ice from the immediate vicinity of the Forest and probably also during Rich's "Late Wisconsin" advance into the Catskill Mountains only about 50 miles away. During this interval the surficial material in the Forest was disturbed and altered by frost action as has been pointed out above. Post-glacial weathering has affected this layer to some extent and extends downward into the undisturbed till. How much weathering of the till in the Forest area went on during the Periglacial Interval is uncertain. In any case the till in the Forest was slightly weathered before the withdrawal of

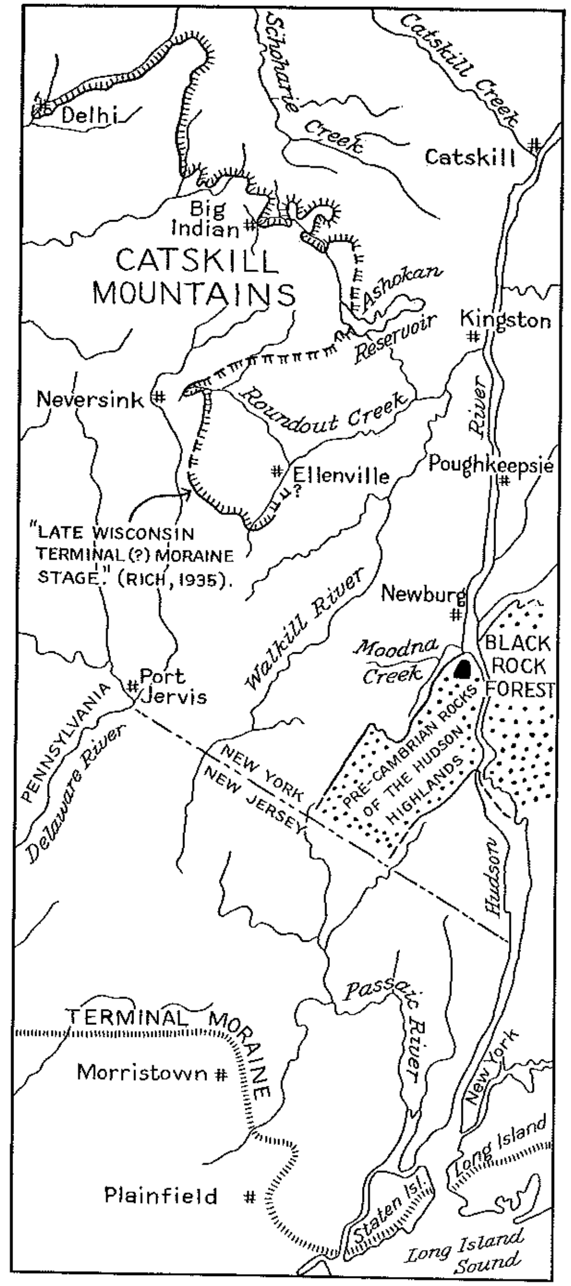


FIG. 8. MAP OF A PORTION OF SOUTHEASTERN NEW YORK AND ADJACENT AREAS TO SHOW THE TERMINAL MORAINE OF THE WISCONSIN ICE, AND RICH'S (1935) "LATE WISCONSIN TERMINAL (?) MORAINE STAGE" IN THE CATSKILL MOUNTAINS.

the "Late Wisconsin" ice from the Catskill Mountains.

The slopes are covered by two kinds of surficial material: (1) a solifluction layer or warp, the predominating type; and (2) talus (blockmeere of German writers), restricted to steeper slopes. The talus, which is most abundant on steep northwestern and southwestern slopes, was formed by ice wedges which, acting along joints, forced the rocks apart and caused large boulders to roll down the slope. This process is perhaps still active, to a limited extent, on bare-rock summits. The warp, on the other hand, was formed by the down-slope movement of material under severe frost action, which process is known as solifluction.

It is evident, therefore, that two types of down slope movement have taken place: (1) the movement of the surface layer more or less as a unit; and (2) the rolling and sliding of individual blocks down slope. Evidence for the latter type of movement is found in the size distribution of the boulders on steepest slopes, from largest at the base to smaller up slope.

There are three lines of evidence which indicate that the upper 2 to 4 feet of material (warp) on the slopes of the Highlands has been disturbed and has moved down hill: (1) the loose texture of the warp as compared with weathered till below; (2) the presence in the warp of angular blocks of crystalline rock, the size and number of which is roughly proportional to the angle of slope; and (3) angular blocks of crystalline rock resting on undisturbed till—blocks which must have come from ledges up slope, not from underlying till.

At the Black Rock brook section a loose mass of pebbles and boulders overlies weathered till. This somewhat weathered warp is taken as characteristic of the surface layer on top of the thick till. The evidence that this layer was formed by solifluction is not as clear as it is for the warp on the slope of Mt. Misery. Nevertheless, the evidence for solifluction and severe frost action during the Periglacial Interval includes: (1) the abundance of large boulders in the upper 3 to 4 feet of the Black Rock brook section; and (2) the smooth upper surface of the thick glacial deposits.

The thick till covers the floor of broad, U-shaped valleys (as is brought out in Fig. 3). The topographic map of the Palisades Interstate Park shows many such broad, U-shaped valleys. The Pleistocene glaciers must have widened some of these valleys considerably. On the northern slopes in the Forest area the contact between the thick till overlain by warp and the bed rock is very sharp, and gives rise to a marked break in slope (See Fig. 1 and Plate IV). The glacier must have originally deposited a thick mass of boulder clay in the present U-shaped valley of Canterbury brook. The surface of this deposit should have had many topographic irregularities as in other morainal areas. The contact between this irregular surface and the mountain slope must have been highly irregular. Patches of till must have lain on the rocky slope beyond the limit of the main mass. Under the periglacial climate solifluction removed these surface irregularities and produced the present smooth surface. This removal would tend to straighten the line of contact between the thick glacial deposits and the mountain slope.

The age of the frost-heaving and solifluction which formed the warp is a problem. Evidence of recent sliding is lacking. The vegetation on the slopes does not appear to have been disturbed by any movement of the soil. The trees are large and straight. The boulders are covered with lichens and other small plants. There is a uniform surface layer of humus and brown forest soil over most of the steep slopes except where bed rock emerges. This is true even for such surfaces as that at Pit No. 8 on Mt. Misery which is in a mass of bouldery warp where almost no fine material is present. No involutions were observed in the brown soil or humus (Cf. conclusion of Scholz on p. 4). The slide rock found along the New Storm King highway lies on a very steep slope of nearly 30 degrees. Large trees grow on this slide, yet there is almost no evidence in the vegetation or the soil of any recent movement. It is reasonable to suppose that if present day frost action is causing this down-slope movement, the best evidences for it should be found on the steepest slopes, yet such data are absent. Many of the larger talus blocks are fractured and have broken up in place into several pieces.

There is an inadequate knowledge of the efficiency of present day frost action in the Highlands under the forest cover. The forest has never been entirely removed, except near one or two of the old farms (cf. Chatfield and Isaac Odell places). However, the surface material on all but the steepest slopes (such as west side of Mt. Misery and Eagle Cliff) appears to be stable. The "Old Continental road" built under General Washington's direction during the Revolution runs in a ravine cut about 4 feet below the surface. In places it has been necessary to move the roadway to the side because of deep gullying of the warp and underlying thick till by streams arising in the old track. Elsewhere there is no evidence of erosion under the forest cover except in the deep ravines, which send out almost no branches. Apparently the surface soil is rather stable except where man has destroyed the forest cover. This observation suggests that if vegetation did not come back into the area soon after periglacial action ceased, more dissection of the thick till would be apparent.

Perhaps the best evidence that the warp is relatively old and not in process of formation at present is the fact that post-glacial weathering has effected both the warp and the underlying till (See Fig. 9).

In the Forest the surfaces of most of the talus blocks are rough and the corners rounded. No fresh surfaces are to be seen. As von Lozinski (1933) points out, the original form of a frost-rifted block is sharply angular;

but under the influence of post-glacial weathering it will become rounded. At the base of steep talus slopes large boulders of crystalline rock are now breaking into small pieces. Post-glacial weathering thus tends to conceal the surface features due to solifluction, and makes their recognition more difficult. On the foregoing evidence it appears that the warp is old; and it is suggested that frost-heaving and solifluction took place during the Periglacial Interval.

There is also the problem of where did solifluction deposit the material that it removed from the surface of the bare rock and from the original hummocky surface of the thick till. The lowlands to the north of the Highlands are filled with a very considerable thickness of water-laid sediment, predominantly sand and gravel. Streams have dissected these deposits to depths of as much as 50 feet. Cutting in bed rock by small streams at the base of the Highlands amounts to 10-15 feet. It is probable that most of the solifluction material was either carried away in streams of melt water, which perhaps may have deposited the coarser portions in the lowland as sand and gravel; or that post-glacial dissection has removed almost all trace of the material from the base of the northern slopes.

The total volume of material thus removed is unknown, because we have no precise evidence as to the amount of material originally laid down by the ice. Because the glacial form of the rock knobs (roches moutonnées) in the Highland section is still preserved, periglacial processes were operative only long enough to remove almost all of the glacial covering from the Highlands, but on the other hand were not so long continued that frost action was able to destroy the typical rounded, roche moutonnée form.

In Alaska Eakin (1916) has described "altiplanation" terraces as a very common topographic feature; nevertheless, such forms are not readily apparent in the Forest, except that perhaps the sharp break in slope along the bank of Canterbury brook at an elevation of about 900 to 950 feet may be such a feature. It is interesting to note that Eakin (op. cit.) reports that in the Yukon-Koyukuk region, talus and solifluction slopes are developed on the coarse-grained, crystalline rocks, whereas the "altiplanation" terraces are limited to areas of metamorphic rocks of Mesozoic age.

The apparent complete absence of water-laid material (sand and gravel) in the Forest is remarkable, but can perhaps be explained by the hypothesis that solifluction has removed any glacio-fluvial sediment originally present, or has so mixed it with frost-heaved material that its original character has been obscured (See Smith's observations quoted on p. 9).

It is, therefore, concluded that during the Periglacial Interval solifluction removed almost all of a probably thin covering of till from the Highlands, and smoothed the surface of the thick till which laps up onto the Highlands. The warp or solifluction layer, now found at the surface throughout the Forest, is the relic of this movement; and is texturally and lithologically distinct from the till upon which it rests.

GEOLOGICAL SUMMARY

Outcrops of crystalline rock separated by small patches of weathered till overlain by 1 to 3 feet of weathered warp characterize the Highland section of the Forest. A thick mass of weathered till overlain by a similar layer of weathered warp laps up on the Highlands from the lowlands to the north. The till, when unweathered, is a blue-gray boulder clay containing a small amount of calcium carbonate. The carbonate has been leached out of the drift down to a depth of about 10 feet. A slight staining by iron oxide and presumable slight oxidation has descended to about 12 feet. In the upper 8 feet calcareous sandstones and the more schistose crystalline rocks are stained but otherwise not greatly altered. There has been some downward migration of fine material, but very little deposition of secondary calcium carbonate.

The relatively small amount of weathering of the glacial drift indicates that it is of Early or Middle Wisconsin age, although no exact correlation with the standard section in the Middle West is as yet possible. A brief reconnaissance of the area of Rich's (1935) "Late Wisconsin" deposits in the Catskill mountains suggests that the till in the Black Rock Forest is slightly more weathered than those deposits, and that surface irregularities such as are characteristic of areas of Late Wisconsin ground moraine are more pronounced on the surface of the "Late Wisconsin" deposits than they are on the surface of Rich's "Early (?) Wisconsin" drift or of the till in the Black Rock Forest. It is suggested that the till in the Forest area corresponds more closely in age to Rich's "Early (?) Wisconsin."

No indication was found in the weathering profile of the till for a recent change in climate such as Raup

(1937), on the basis of botanical and other lines of evidence, has postulated for southern New England and adjacent New York. Under the climatic regime of the present day, iron and aluminum are being carried down and deposited in the sub-soil. If a recent climatic change, such as Raup suggests, has taken place, it might appear probable that under this warmer and drier climate weathering processes would have deposited calcium in the subsoil; and traces of this deposit should now be found. However, its absence may be due to either of two possibilities: (1) that the climatic change which occurred was too slight to cause a change in the weathering process; or (2) that any calcium which was deposited under the previous climatic regime, has been entirely removed by weathering processes of the present day.

The surficial layer of warp was formed by intense frost action under the periglacial climate of Middle or Late Wisconsin time, that is during the deglaciation of the region and probably also when ice was still present in the vicinity of the Catskill mountains less than 50 miles away. The disturbed layer which is only 1 to 4 feet thick consists of material derived from the till and from the bed rock of the region. It is a mixture of angular fragments of crystalline rock, derived by frost-rifting from bed rock, and of glacially molded pebbles from the till. These glacially-molded pebbles are predominantly of stones foreign to the region, i.e., sandstone, slate, quartzite and so forth. The warp is in large part the result of a down-slope movement or solifluction, and has been somewhat weathered in Post-glacial time.

The steeper slopes are strewn in many places with talus boulders derived from bed rock. The weathered surface of these boulders and their partial covering by mineral soil and vegetation indicate that these slides are relic features produced in the Periglacial Interval.

It is probable that since the Periglacial Interval this area has been continuously under a forest or some equally

protective cover. There is no evidence of any movement of surface soil or of boulders at present, except on a few of the steepest slopes.

The glacial striae in the area indicate a general ice movement from the north-northwest. The readings vary from 6 to 37 degrees west of north (See Fig. 1). Striae in the lowlands to the northwest are reported as running toward the southwest. (See map compiled by Goldthwait in Antevs, 1922.) The percentages of pebbles of crystalline rock per cubic foot of till are shown on Table No. 2. In general the samples which run highest in foreign stones are located on the northwest side of the Forest, whereas those highest in pebbles of crystalline rock are located on the southeast side. Samples from the northern and western sides of Black Rock are much higher in native rocks than are those from the summit of Black Rock or from the lowland to the west. It is suggested that the steep slope of Black Rock caused the ice to drop its load of foreign stones and to quarry abundant fragments of crystalline rock, whereas the gentler gradient of the valley of Canterbury brook to the west enabled the ice to progress up the slope without much opposition and to deposit near Arthur's Pond a till consisting almost entirely of foreign stones. On the southeastern side of Mt. Misery two samples of till were gathered within a few hundred yards of each other. One ran 30 per cent of crystalline rock (No. 3), the other 97 per cent (No. 9c). The reason for this difference is not readily apparent, but it suggests either a considerable variation in the original drift sheet or the presence of two distinct lobes of the advancing continental glacier.

RELATIONSHIP BETWEEN TIMBER TYPES AND GLACIAL DEPOSITS

This study has shown that there is a close correlation between the areal extent of the thick till and the cove type of timber. The configuration of the timber types in the Black Rock Forest is essentially as follows.[5] Most of the slopes are clothed with a forest of red and chestnut oaks (*Quercus borealis* and *Q. montana,* respectively), associated with other trees in lesser abundance. In general the red oaks are more abundant on the lower slopes, and the chestnut oaks on the upper; but in very rocky places the chestnut oak is likely to predominate even at low levels, while the red oak may predominate at high levels if the slopes are gradual. The coves have a mixed forest in which sugar maple (*Acer saccharum*), white ash (*Fraxinus americana*), red oak (*Quercus borealis*), linden (*Tilia americana*), yellow birch (*Betula lutea*), tulip-tree (*Liriodendron tulipifera*), and red maple (*Acer rubrum*) are the commonest species. Beech (*Fagus grandifolia*), American elm (*Ulmus americana*), black birch (*Betula lenta*), white oak (*Q. alba*), shagbark hickory (*Carya ovata*), and a few other species of similar requirements are usually present in smaller numbers. Northward-facing ravines and lower north slopes usually have a high proportion of hemlock (*Tsuga candensis*), and in a few restricted localities the beech becomes a primary tree. The crowns of the hills are distinguished by two types of vegetation. The southwest sides usually have an open scrub of pitch pine (*Pinus rigida*) and scrub oak (*Q. ilicifolia*) interspersed with grassy areas. The northeast sides are usually covered with a rather scrubby forest of white oak and pignut hickory (*Carya glabra*). This as-

[5] Abstracted with slight change from Raup (1937).

sociation is extremely limited in extent, rarely descending below the crown of the hills, and then only on warm southern slopes.

The cove type of timber and associated thick till extend from an altitude of 450 to 1150 feet. The till thins out at its upper contact, and outcrops of bed rock in gulches nearby indicate that here the till is not over 10 feet in thickness. The break in the vegetation at the contact is very striking. The rocky slopes with their patchy covering of thin till and warp, support a growth of red and chestnut oaks. Associations on the hilltops, however, do not appear to be correlated with changes in the glacial deposits. The white oak—hickory and pitch pine—scrub oak types grow on soils derived from till or from warp which cannot be readily distinguished from those of the upper slopes which support red and chestnut oaks in abundance.

No evidence was found that the repeated cutting and burning of the forest since colonial times has caused an acceleration of geological processes, such as erosion.

The important contribution of this study to the problem of the origin of the forest soil is to point out the nature of the parent material upon which the soil-making processes are acting, the material which is referred to by foresters and soil workers as the "mineral soil" or the "C" horizon. The brown forest soil has been derived from a "C" horizon which is the result of two distinct processes operating at different times: (1) frost action in the Periglacial Interval which caused predominant mechanical weathering; and (2) the predominant chemical weathering of post-glacial time. These two agents have produced a set of features which are shown in Fig. 9, which is an ideal cross-section of the thicker glacial deposits of the Black Rock Forest. Abundant large sandstone boulders are to be found on the surface, together with a few boulders of crystalline rock. These rest on and in a slightly weathered warp which contains a con-

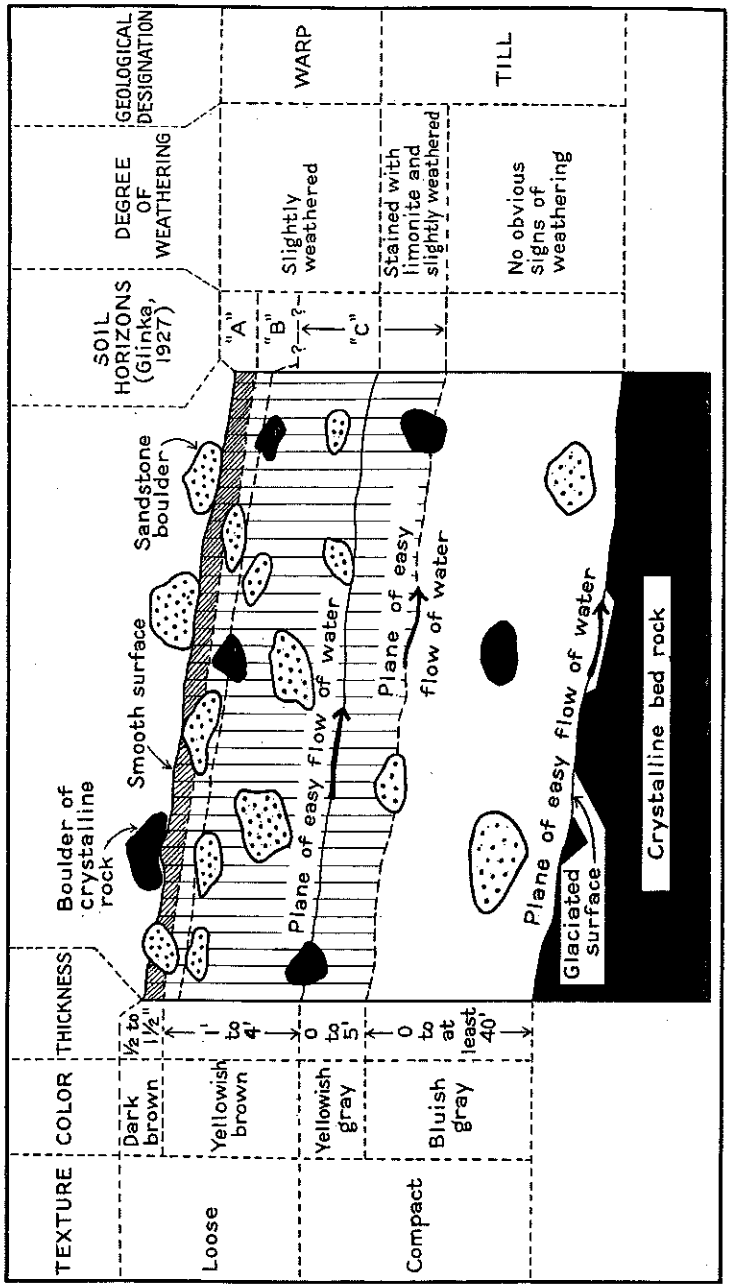


FIG. 9. IDEAL CROSS-SECTION THROUGH THE THICKER GLACIAL DEPOSITS FOUND IN THE BLACK ROCK FOREST.

siderable number of boulders. The warp overlies till of which the upper portion is slightly weathered, but the lower portion remains an unweathered boulder clay.

The "A" horizon includes in most places the brown forest soil, humus layer and so forth. Locally under hemlock stands, a slightly podsolized profile is found, with its characteristic grayish-white, leached band (Scholz, 1931). The "B" horizon or zone of illuviation is not obvious, but is no doubt present. The "C" horizon or parent material consists of (1) an upper portion composed of slightly weathered warp; and (2) a lower portion which is a yellowish-colored layer composed of stained and slightly weathered till. Periglacial frost-action is primarily responsible for the loose texture of the upper portion of the profile (warp); and later, post-glacial weathering has stained with limonite and slightly altered both the warp and the upper portion of the underlying compact till.

The arrows designate the loci of flow of underground waters: i.e. (1) on top of yellow and compact, weathered till; (2) on top of the unweathered bluish-gray till; and (3) on the glaciated surface of the bed rock. These three planes of easy flow of water are also the most likely places for vegetation to obtain its water. In a wet season water will flow along all three planes, but in drier seasons only along the lower or lowest one. It is probable that in a drought the water table lies somewhere beneath the surface of the crystalline bed rock. Obviously the plane of easy flow of water directly overlying the bed rock is the zone of most permanent flow because of the less permeable surface below, and the greater water-holding capacity of the overlying, compact till as compared with that of the loose warp. Thus areas where the till was disturbed by periglacial frost action to its base, will have a subsoil which dries out more rapidly than will an area, such as that of the thick glacial deposits where the warp is underlain by unweathered compact till. It is suggested, therefore, that the association of the cove timber with the thick till overlain by warp is related to the greater water-holding capacity of the latter as compared with the warp on the uplands.

Conclusions

This study has shown that the trees in the Forest grow upon weathered warp, and not directly upon weathered till. Observation indicates that such a relation holds good for the northern portion of the Hudson Highlands. A warp has been described by Bryan (1936) from southeastern Massachusetts; and it is probable that such a surface layer is much more widespread in southern New England than has formerly been supposed.

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TABLE No. 7

MECHANICAL ANALYSES OF SAMPLES OF GLACIAL DEPOSITS FROM THE BLACK ROCK FOREST

Number (for location see Fig. 1)	*Sandstone*		*Slate*		*Crystalline Rock*		*Quartzite*		*Miscellaneous*		*Total*		*Percentage of stones per cu. ft. (by vol.)*	*Depth below surface (ft.) (r)—on bed rock*	*Till or Warp*
	% by no.	*% by vol.*	*% by no.*	*% by vol.*	*% by no.*	*% by vol.*	*% by no.*	*% by vol.*	*% by no.*	*% by vol.*	*% by no.*	*% by vol.*			
1	72.5	91.0	15.2	4.2	8.5	2.2	3.1	2.7	0.7	0.1	100.0	100.1	23.3	4(r)	T
2a	23.5	17.8	2.5	0.1	71.3	81.5	2.5	0.6	...	...	100.0	99.8	36.3	6(r)	W
2b	8.3	7.5	...	...	91.4	92.5	...	...	0.1	0.1	100.0	100.1	19.4	10(r)	T
3	55.3	58.6	9.0	3.4	29.1	30.4	5.8	7.3	0.9	0.4	100.1	100.1	24.7	4	T
4a	59.8	60.7	28.2	26.8	4.0	3.6	6.1	6.5	1.8	2.4	99.9	100.0	13.7	12	T
4b	67.1	67.5	21.2	17.4	4.7	7.1	4.8	7.0	2.2	1.0	100.0	99.9	23.8	10	T
4c	74.4	83.9	15.1	7.9	6.6	1.1	4.1	3.2	1.1	4.0	100.1	100.0	37.4	5	T
5	20.2	12.2	2.4	0.5	75.3	86.4	2.0	1.1	...	...	99.9	100.2	7.0	3	W
6a	23.0	12.8	0.5	0.1	75.3	86.3	1.0	0.9	...	...	99.8	100.1	25.7	1	W
6b	10.2	5.1	0.4	0.2	88.0	94.3	0.8	0.2	0.2	0.1	99.6	99.9	14.4	2(r)	W
7a	70.0	65.8	6.4	2.8	18.4	19.9	4.6	11.3	0.2	0.1	99.6	99.8	15.6	4(r)	T

TABLE No. 7—*(Continued)*

Number (for location see Fig. 1)	Sandstone % by no.	Sandstone % by vol.	Slate % by no.	Slate % by vol.	Crystalline Rock % by no.	Crystalline Rock % by vol.	Quartzite % by no.	Quartzite % by vol.	Miscellaneous % by no.	Miscellaneous % by vol.	Total % by no.	Total % by vol.	Percentage of stones per cu. ft. (by vol.)	Depth below surface (ft.) (r)—on bed rock	Till or Warp
7b	45.0	33.2	6.5	2.7	45.1	56.9	3.2	7.2	...	...	99.8	100.0	18.7	1	W
8	5.0	1.6	...	...	94.2	97.7	0.6	0.8	...	...	99.8	100.1	30.5	1(r)	W
9a	4.7	6.6	...	...	94.2	92.9	0.5	0.4	...	...	99.4	99.9	4.0	1	W
9b	10.4	7.5	1.6	0.5	87.1	91.6	0.8	0.3	0.2	0.1	100.1	100.0	26.3	3½	T
9c	4.3	2.3	0.5	0.1	95.1	97.7	...	...	...	...	99.9	100.1	19.9	6	T
10	73.5	69.1	8.7	3.9	14.4	25.8	3.0	1.0	0.3	0.2	99.9	100.0	16.5	2(r)	T
11	43.2	28.8	7.4	5.2	47.7	56.2	1.2	0.8	0.4	8.9	99.9	99.9	12.6	2(r)	W
12	65.8	67.0	12.7	11.1	19.1	13.6	2.3	8.3	...	...	99.9	100.0	9.6	2(r)	W
13	49.8	27.6	3.3	2.3	45.2	68.3	1.7	1.7	...	...	100.0	99.9	14.3	1(r)	W
14a	77.2	77.9	7.8	11.1	12.1	8.5	2.8	2.5	...	...	99.9	100.0	2.7	7½	T
14b	69.9	72.2	10.9	12.8	11.4	8.6	6.7	5.3	1.0	1.0	99.9	99.9	6.4	4½	T

TABLE No. 7—*(Continued)*

14c	65.0	78.2	11.2	6.7	17.9	12.2	4.5	2.6	1.3	0.3	99.9	100.0	6.1	1	W
15a	53.4	39.2	...	...	44.6	58.4	2.0	2.3	...	...	100.0	99.9	6.1	5	T
15b	68.3	70.3	2.8	0.8	25.9	25.8	2.4	2.7	0.5	0.2	99.9	99.8	4.6	2	W
16	61.5	52.4	3.7	1.3	32.9	44.4	1.5	2.0	0.4	0.1	100.0	100.2	9.7	3	T
17	43.2	29.1	6.8	3.5	50.0	67.4	...	...	...	...	100.0	100.0	1.5	2(r)	W
18a	55.5	69.2	9.6	8.5	29.2	18.9	4.4	3.3	1.4	0.4	100.1	100.3	8.1	3(r)	T
18b	51.3	32.1	1.7	0.3	44.4	62.0	2.7	5.5	0.5	0.2	100.6	100.1	5.5	1	W
19	71.5	90.5	10.9	3.2	10.9	1.9	6.4	4.4	0.3	0.1	100.0	100.1	31.2	5(r)	T
20a	43.6	28.6	3.2	1.6	51.6	69.5	1.6	0.3	...	...	100.1	100.0	10.2	5½	T
20b	29.9	14.1	0.6	0.2	67.6	84.9	1.5	0.6	0.3	0.1	99.9	99.9	15.2	1	W
20c	52.6	49.6	8.9	1.8	34.0	46.2	3.7	2.3	0.8	0.1	100.0	100.0	16.2	3½	T
21	53.5	49.8	8.9	4.6	34.0	42.7	3.0	2.7	0.5	0.2	99.9	100.0	14.6	3(r)	W
22a	40.2	36.2	5.4	3.7	51.9	58.8	2.4	1.1	...	...	99.9	99.8	19.4	7	T
22b	65.2	74.9	8.9	5.2	22.9	17.9	3.0	2.1	...	...	100.0	100.1	22.8	1	W
23a	61.3	64.6	18.5	10.4	13.5	19.1	5.7	4.5	1.1	1.4	100.1	100.0	7.8	3(r)	T
23b	72.1	60.9	13.5	6.2	9.6	10.5	4.8	22.5	...	...	100.0	100.1	2.3	1½	W
23c	84.2	64.5	2.5	0.8	13.0	32.8	0.3	1.9	...	...	100.0	100.0	44.9	½	W

BLACK ROCK FOREST PAPERS

1. A Method for Determining the Nutrient Needs of Shade Trees with Special Reference to Phosphorus; by H. L. Mitchell, April, 1935. Price 25 cents.
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