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THE HICKORY RUN BOULDER FIELD, CARBON COUNTY, PENNSYLVANIA*

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ABSTRACT. The Hickory Run boulder field is located in the Pocono Plateau region of northern Carbon County, northeastern Pennsylvania, along a valley flat near the headwaters of Hickory Run. It lies within an area mapped as Illinoian drift, just beyond the border of the Wisconsin drift. The boulder field is irregular in outline and roughly 400 by 1800 feet in extent. The surface of the field is a bare expanse of unsorted, loosely packed boulders up to 20 feet or more in length. Despite minor irregularities, the overall appearance of the field is one of striking flatness, and the surface gradient is close to 1°. The boulders are composed of quartzitic sandstone and conglomerate of local derivation. Many boulders show splitting, pitting, rounding, and discoloration by weathering in place. Scattered excavations show a complete absence of any finer interstitial material down to water level, at a depth of several feet. Bordering the boulder field are wooded slopes of moderate declivity, with scattered blocky patches and numerous blocks projecting through the forest floor.

The morphology and lithology of the boulder field, together with its present aspect of stagnation and decay, are best explained as resulting from periglacial climatic conditions during the near approach of the Wisconsin ice sheet, inferred to have effected a marked interruption of the stream erosion cycle, with frost action in a major role. The bouldery material is believed to have been supplied by intensified mechanical weathering, to have been carried downslope onto the valley flat by accelerated mass movement, and then to have been left immobile when deglaciation brought climatic amelioration. Subsequent resumption of the normal processes of weathering and erosion now observable has worked toward gradual breakdown of the boulders in place and gradual flushing of interstitial soil material.

INTRODUCTION

THE Hickory Run boulder field, the largest of its kind on record in the Appalachian region, is unusual both scenically and geologically. It is located in the Hickory Run State Park, in the Pocono Plateau region of northern Carbon County, northeastern Pennsylvania (fig. 1). The designation "boulder

* Publication authorized by the Director, U. S. Geological Survey.

field," used locally, is retained here as a purely descriptive term for an irregular expanse of contiguous blocks and boulders¹ with little or no soil. Such terms as "block field" and "felseneer" have been used also for this type of accumulation.

The purpose of the present paper is to place on record the pertinent facts about this unusual geomorphic feature, to compare it with similar features elsewhere, and to consider its origin and significance. The paper is based on a field examination made for the National Park Service, under the auspices of the U. S. Geological Survey, during 2½ days in June 1945 and an additional day in August 1948.

Acknowledgment is due to Mr. Daniel A. Brady and to Mr. John J. McGinley, officials in charge of the Hickory Run State Park in 1945 and in 1948, respectively, for courtesies extended. A copy of Leverett's unpublished field map of the glacial boundary (used in preparation of Leverett, 1934), together with other information, was provided by Dr. G. H. Ashley, of the Pennsylvania Geological Survey.

TOPOGRAPHIC AND GEOLOGIC SETTINGS

The boulder field lies in the valley flat of Hickory Run near its headwaters, between 1800 and 1900 feet in elevation. It is bordered by wooded slopes of moderate declivity, leading up to low, rounded ridges. Local relief is from 200 to 400 feet. The general topography of the area is shown in figure 2 and is represented more fully on the Stoddartsville, Pennsylvania, topographic sheet.

Bedrock in the vicinity of the boulder field is mapped as the Pocono formation, of Mississippian age (Stose and Ljungstedt, 1931). The bedrock is mostly covered by surficial rubble deposits, so that outcrops are comparatively few and small. The exposures observed by the writer are all on the north side of the valley, and are of hard, massive, reddish quartzitic sandstone. Dips are low and jointing is prominent.

Glacial geology of the area has been studied only in reconnaissance fashion. According to Leverett (1934, plate 1), the

¹ In this paper the term "boulder" is used, according to the Wentworth grade scale, as a general term for rock fragments having a diameter of more than 256 mm (approximately 10 in.), regardless of shape. The term "block" is used to designate those particular boulders of angular habit whose form directly reflects the joint and bedding planes by which they were outlined originally.

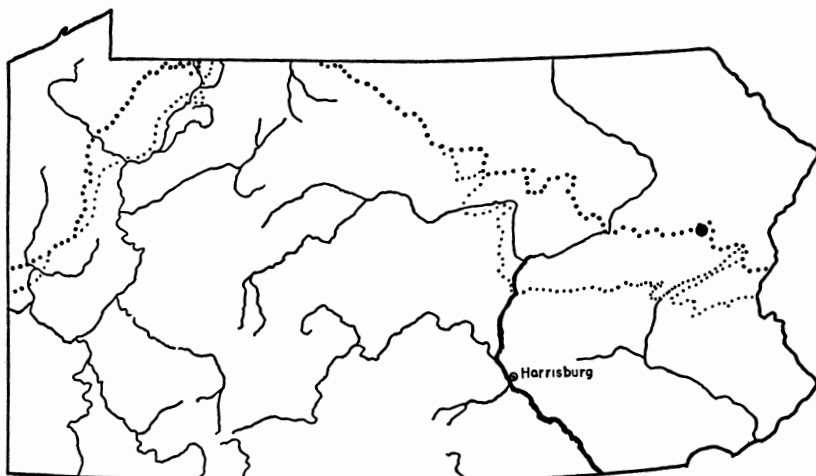


Fig. 1. Outline map of Pennsylvania, with location of the Hickory Run area marked by a larger black dot. The heavy dotted line marks the Wisconsin drift border, and the light dotted line the pre-Wisconsin drift border, according to Flint, et al., 1945.

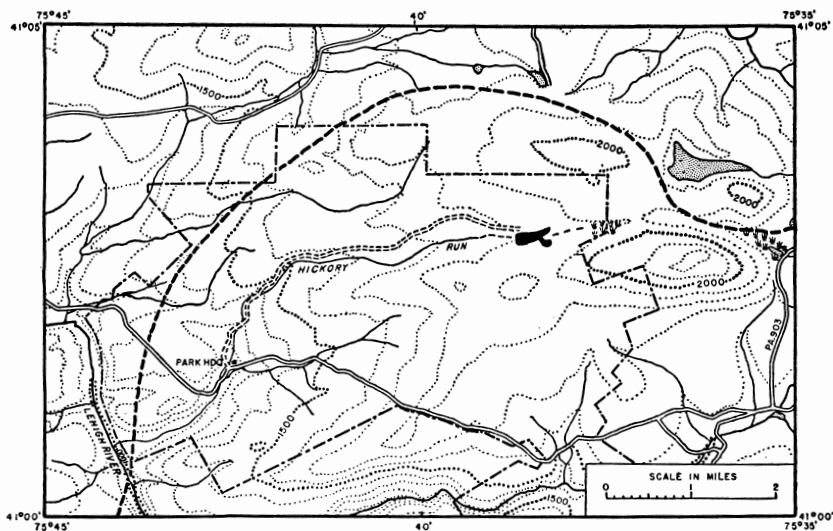


Fig. 2. Generalized contour map of the Hickory Run area. The boulder field is marked in black. The heavy dashed line represents the Wisconsin drift border, according to Leverett's field maps (made available by Dr. G. H. Ashley). Contours, shown by dotted lines, are on an interval of 100 feet, with sea level datum. The dot and dash line shows the boundary of the Hickory Run State Park. North is at the top. Drawn from the Stoddartsville, Penn., topographic map.

border of the Wisconsin drift lies between 1 and 2 miles north of the boulder field (fig. 2), and the Illinoian drift extends many miles to the south (fig. 1). Deposits conforming to Leverett's description of the Illinoian drift are exposed in several cuts along the main road through the Hickory Run State Park and along State Highway 903 to the south. The cobbles and boulders in these deposits are mostly less than 2 feet long and are predominantly of gray, greenish, and buff sandstone and orthoquartzite. No fragments of igneous or metamorphic rock were observed. The proportion of fine material is much larger than that of the cobbles and boulders.

DESCRIPTION OF THE BOULDER FIELD AND ITS ENVIRONS

The main section of the Hickory Run boulder field is a fish-shaped bouldery tract measuring roughly 400 by 1800 feet (*AB* on plate 1, fig. 1). Branching eastward from it is a subsidiary bouldery tract, the bare portion of which (*CD* on plate 1, fig. 1) is separated from the main boulder field by a zone of boulders that are partly covered by vegetation.

The general surface of the boulder field is a barren expanse of jumbled cobbles and boulders of widely varied size and shape (plate 1, fig. 2), so loosely packed that some of them shift in position when walked on. Irregular hollows and projecting boulders make for a very uneven surface, with a microrelief of about 4 feet. Despite the roughness in detail, however, the overall appearance of the boulder field is one of remarkable flatness, and the axial gradient, in fact, is close to 1°. The bareness of the boulder field is striking. Except for a few trees near the margins, vegetation is virtually absent, and no soil is to be seen on or between the boulders.

Numerous individual boulders show rough surfaces, and many are pitted by weathering, particularly on the upper surface (plate 3, fig. 2). Spalling and splitting along joint planes are common also. The color of the rock in the greater part of the boulder field is dull reddish, but mottling by dark-colored lichens is widespread. Some boulders when broken open are seen to be darker inside than on the surface, indicating discoloration by chemical weathering.

The boulder field is continuous from one side of the valley flat to the other. It has no surface drainage, at least in times

of ordinary runoff. Locally the sound of running water under the boulders is audible, and in three widely separated pits water level was seen to be from 4 to 6 feet below the average surface of the field. Along the southern margin of the boulder field the ground is swampy in places. The possibility that the surface of the boulder field might be flooded at times of heavy rainfall was suggested by the presence of debris draped around tree trunks in the area immediately downvalley from the boulder field.

In traversing the boulder field, it is found that the surface characteristics and ease of walking are distinctly different in different sections. Toward the northeast (toward *B* on plate 1, fig. 1), walking is particularly difficult. The surface is extremely uneven (plate 2, fig. 2), footing is insecure, and many blocks sway when stepped on. Large, upended blocks and slabs are particularly common. The average size of the blocks or boulders is somewhat larger than in the western section, angularity of outline is more pronounced, and tabular form is more common. The tumultuous appearance of the surface suggests arrested motion after forcible movement, somewhat in the fashion of an ice jam in a river.

In the semidetached eastern section of the boulder field (*CD* on plate 1, fig. 1), blocks are much larger than in any other section. Many are 15 to 20 feet long, and some reach a maximum of about 25 feet. Bedding planes in the various blocks show dips that are erratic both in amount and in direction. Surface irregularity is extreme (plate 2, fig. 1), with deep hollows and crevices between blocks, giving a microrelief of 6 to 8 feet. The observer must climb or jump rather than walk.

Lithologically also, the northeastern and eastern sections of the boulder field are different. In the eastern section (*CD* on plate 1, fig. 1) quartzitic conglomerate is the common rock. In the northeastern section (toward *B* on plate 1, fig. 1) quartzitic sandstone is predominant, and the prevailing color is darker; conglomerate is rare, and where found it is generally much finer grained than in the eastern section.

Toward the west, on the main section of the boulder field, surface roughness decreases and the proportion of smaller boulders increases. Near the western end (plate 3, fig. 1), the average size of the boulders is reduced to a few feet, and rounding is more noticeable. Walking is much easier here.

Subsurface characteristics of the boulder accumulation were observed at three well-separated places in pits excavated to water level, at depths of 4 to 6 feet. In two pits bottoms were seen to be sandy, and in the third bouldery. Above water level there is no interstitial material. The boulders are loosely packed and the proportion of open space is large. Boulders beneath the surface all show a conspicuous rusty-brown to black stain, and a few were incrustated completely with black mineral matter. In general, the boulders appeared to be of smaller average size below the surface than on the surface. Boulders below the surface also show less roughness than those on top.

The margins of the boulder field are irregular, with considerable interfingering of the bare area with the soil-covered area. At many places the transition is gradual. Locally near the east end of the boulder field, however, the break is sharp between the bare surface of the boulder field and the adjacent vegetation-covered flat. The flat, if projected outward, would cover all but the higher points of the larger boulders beyond. The bouldery area appears to be expanding by marginal sapping of the soil-covered zone, as suggested by several small bouldery patches from which stripping of the soil is working outward, probably through the action of subsurface waters.

Valley slopes bordering the boulder field are gradual at most places, although locally on the north side near the northeastern end the boulders pass up over slopes as steep as 23° . On the wooded slopes rising from the boulder field, numerous weather-beaten boulders project through the soil mantle, and small, open bouldery patches, superficially similar to the main boulder field, are widely though irregularly distributed. The general appearance is such as to suggest that, if the forest and the soil mantle were stripped off from the slopes, a bouldery surface similar to and continuous with that of the boulder field itself would be produced.

Upvalley from the boulder field, narrow, irregular, and discontinuous bouldery bands persist for several hundred feet. About half a mile east of the boulder field, at the head of the valley, there is a large, swampy flat bordered on the north side by rock ledges rising some 40 feet above the flat. These ledges are undergoing disintegration in place, and are mantled

by loose blocks. There is no indication of active creep toward the valley, and no appreciable talus at the base of the steeper ledges. That the rate of separation and removal of the blocks is slow compared with the present rate of weathering is suggested by a joint block that has been much rounded by weathering while the gap between it and the once contiguous facing block has not opened more than about a foot under gravitational movement. Further breakdown of the rounded, detached block, in place, is evidenced by a comparatively recent fracture separating a sizable segment of the block from its parent by about an inch.

Downvalley from the boulder field is a tree-covered bouldery area with moss on the ground surface. Flowing water can be seen in scattered openings between the boulders. A definite stream emerges about half a mile below the boulder field.

COMPARISON WITH OTHER AREAS

Talus and other types of bouldery accumulations are well known in mountainous areas of strong relief and steep slopes. Accumulations of similar material on low gradients in areas of moderate relief, however, are much less common. Of those that exist, probably only a small proportion have been described in geologic literature, as they easily escape notice in wooded terrane, and furthermore have been of little interest to many geologists. Comparisons are therefore limited to a relatively small number of described localities.

Ashley (1933, p. 89-91) has noted four bouldery areas in eastern Pennsylvania, popularly known as Devil's Race Courses, and Peltier (1949, p. 73-74) has given additional data on block fields in the same region. None of the occurrences described by these workers have the areal extent and low gradient of the Hickory Run boulder field.

Chadwick (1935) has reported a rock stream in New York, but he does not give sufficient detail to permit comparison.

In Maryland and adjoining parts of West Virginia, "rock streams" up to about 1800 feet in length and 100 feet in width are found (Smith and Smith, 1945). Although having the same surface appearance as the Hickory Run boulder field, they differ in being narrower and in having a steeper gradient and a smaller range in the size of the boulders.

In Wisconsin, in the Baraboo section of the Driftless Area, there are several boulder fields and rock streams (Smith, 1949*a*), but all are smaller and steeper than at Hickory Run.

In northern Sweden, boulder fields more or less similar to the Hickory Run occurrence have been described by Högbom (1926). Various boulder accumulations in upland areas of central Europe have been described by many writers, but few if any of those occurrences are comparable to the Hickory Run occurrence in size and low gradient.

Undoubtedly the closest parallel to the Hickory Run boulder field is found in the "stone rivers" of the Falkland Islands, in the South Atlantic. These features, made known by the classic descriptions of Charles Darwin (1846, p. 253-255), Sir Wyville Thomson (1877), and J. G. Andersson (1906, 1907), indeed may be regarded as the type example for this type of landform. The streamlike accumulations of blocks and boulders ramify through entire valley systems, and are bordered by bouldery, soil-mantled slopes rising to the hill crests, interrupted in places by bouldery tracts barren of soil. Differences between the Falkland Island and Hickory Run occurrences are mainly those of size and extent.

In short, the Hickory Run boulder field is unusual, if not unique, among comparable accumulations of blocks and boulders on record in the United States by reason of its large extent and low gradient. It probably is matched by few of the described boulder fields of Europe, but it is dwarfed by comparison with the stone rivers of the Falkland Islands.

ORIGIN

Four possible modes of origin may be considered for the boulder field: (1) glacial or glaciofluvial deposition; (2) accumulation as a residual weathering product; (3) accumulation as a lag deposit by more or less vertical settling of boulders during the erosional development of the valley; and (4) accumulation by mass movement from the valley sides. Working hypotheses based on each of the above processes are given critical examination below.

The occurrence of the boulder field within a glaciated area naturally suggests the possibility of accumulation by glacial processes. Direct deposition from glacial ice, however, must be excluded because of the following considerations: (1) The

PLATE 1

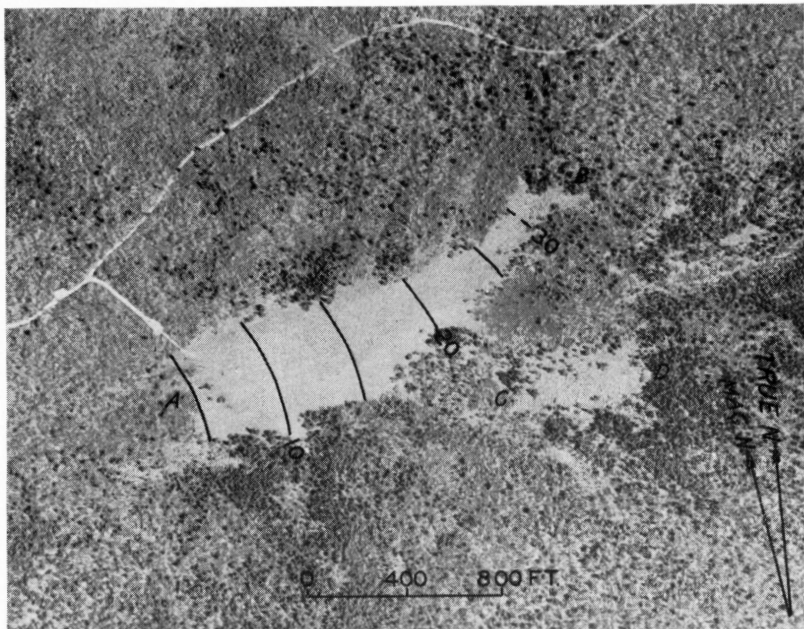


Fig. 1. Vertical air photo of the Hickory Run boulder field. Contours are on a 5-foot interval with assumed datum, and are based on a plane-table survey. U. S. Dept. Agriculture, PMA, photo no. AQT-74-127, dated 1939.



Fig. 2. View of the boulder field from a point near the upper or north-eastern end, looking southwest.

PLATE 2



Fig. 1. View of the large conglomerate blocks in the eastern part of the boulder field (*CD* on plate 1, fig. 1).



Fig. 2. Details of the surface of the boulder field toward its upper end, near the 25-foot contour of plate 1, figure 1, showing extreme irregularity, with upended blocks and slabs.

PLATE 3



Fig. 1. Surface appearance of the boulder field toward the western or lower end, near the 10-foot contour.

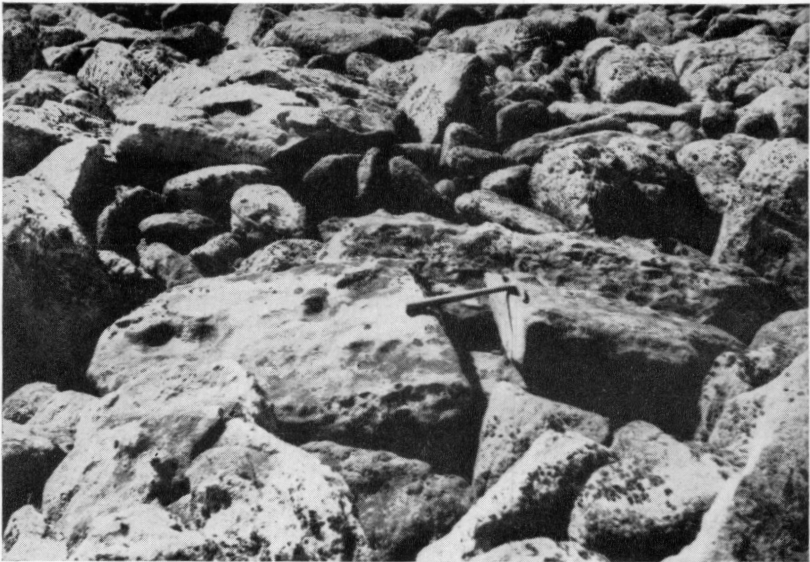


Fig. 2. Details of weathering features near the western end of the boulder field.

comparative flatness of the surface of the boulder field contrasts sharply with topographic irregularity of most morainic deposits. (2) Numerous blocks in the boulder field are as much as 10 times larger than any observed in local exposures of till. (3) The boulder field fails to show the lithologic variety found in the local till. (4) Abundance of conglomerate blocks on one side of the boulder field as compared with their virtual absence on the other side points to strictly local derivation, and is incongruent with glacial deposition. (5) Boulder accumulations superficially similar to the one at Hickory Run, though smaller in size and on steeper gradients, occur at distances of more than 100 miles outside of the glacial boundary. This same consideration, together with the size, composition, distribution, and total volume of the boulders, also rules out the possibility of glaciofluvial deposition under any past drainage conditions that could reasonably be inferred at this locality. The possibility that the boulder field is underlain by glacial or glaciofluvial deposits, however, is not excluded.

Accumulation of blocks or boulders as a residual product of mechanical weathering is generally accepted as characteristic of alpine areas where frost action is vigorous. A similar origin was postulated by Lozinski (1909, 1912) for certain ancient "felsenmeere" in upland areas of Europe, believed by him to date back to a time when periglacial or near-glacial climatic conditions prevailed. The efficacy of chemical weathering to produce similar results has been claimed by Penck (1924, p. 54-57). To appraise the possibility of residual accumulation for the Hickory Run boulder field, it is necessary to ascertain whether the structural features and topographic relations of the boulder field are best explained with or without movement of the component fragments.

The following structural characteristics of the boulder field are pertinent: (1) The sharp discordance in shape, size, and orientation of adjoining blocks and boulders, together with the large and irregular voids between them, indicates that something more than mere modification and loosening of rock by weathering along joints has taken place. (2) Except for the upper surfaces of the topmost blocks, the same degree of weathering or lack of weathering is found on boulders throughout the vertical range exposed. This condition is more readily explained by transportation from a source area where all material received

similar preparation by weathering than by accumulation in place. (3) The tendency toward segregation of the larger boulders at the top of the accumulation is the opposite of what would be expected as a result of residual weathering per se. (4) The upended position of numerous blocks and slabs (plate 2, fig. 2), together with discordances in dip and strike of other blocks, indicates some lateral movement.

The occurrence of the boulder field in a valley flat presents further difficulties to any hypothesis based on residual accumulation. In such an area, there is normally a mantle of alluvium, laid down concurrently with stream erosion, which tends to protect the bedrock floor of the valley from weathering. Only if the alluvial cover were stripped off and further stream action halted could the bedrock floor of the valley be exposed to boulder-forming processes of weathering. The occurrence in a valley flat, furthermore, would make it difficult to exclude the possibility of derivation from the bordering bouldery slopes by mass movement, a phenomenon well established for comparable areas (Büdel, 1937). It must be concluded that interpretation of the boulder field as a strictly residual weathering product is untenable. It is not impossible, however, that such an interpretation may apply to overgrown bouldery tracts on some parts of the adjoining valley sides or uplands.

The hypothesis of lag accumulation of more resistant rock by gradual downsettling during valley growth goes one step beyond the residual weathering hypothesis. Davison (1889) invoked this mechanism to account for the stone rivers of the Falkland Islands, writing as follows:

“. . . in the Falkland Islands, we have . . . bands of hard quartzite separated by seams of soft and crumbling sandstone. When streams began to flow over the primitive surface of the country, they bore away the loosened debris of the softer bands, but the resulting blocks of quartzite were too heavy to be moved by them and hard enough to resist atmospheric disintegration. The streams then flowed across and below the blocks, and continued to remove the softer bands beneath, working their way from side to side of the valleys. The quartzite blocks thus gradually sub-

sided vertically all over the valleys, most along the axis and in the lower regions.

“. . . the formation of the stone rivers has all along taken place concurrently with the excavation of the valleys.”

A modified and less extreme version of this hypothesis has been advocated recently by Joyce (1950), with particular reference to block accumulations on valley sides in the Falkland Islands. Assuming that the valleys were already in existence and were steep-sided, and that frost weathering was effective, he stated that:

“Where shales underlie the quartzite, there would be a progressive undercutting and the frost-parted blocks would in the course of time be detached from the scarps. The blocks would remain almost in the position where they fell, and thus would carpet the area over which the scarps retreated.”

Davison's hypothesis has gained no acceptance by other investigators. It assumes that water flowing on low gradients, under a block mantle necessarily offering high frictional resistance to flow, could have sufficient velocity to erode the bedrock floor of the valley more rapidly than the blocks are reduced by weathering. Merely to state the hypothesis in these terms suffices to label it as unacceptable—out of keeping with modern concepts of erosional dynamics, and unsupported by observation on present-day erosional processes.

A subhypothesis of lag accumulation along the sides of pre-existing valleys during the process of valley widening may be considered separately, first in general terms and then with reference to the Hickory Run locality. This hypothesis assumes the gradual and passive settling of blocks of the more resistant rocks as the less resistant rock beneath is removed by erosion. It is implied that any lateral component of block movement is subordinate to the vertical component. Unfortunately, no critical field studies on lag accumulation are available for guidance in evaluating the effectiveness of the process under particular conditions. Simple deductive analysis, however, suggests limitations and points to consequences that may be checked against field data. The essential part of the process of lag accumula-

tion is, of course, removal of the less resistant rock material beneath or between the more resistant layers, and it is unlikely that any agent except running water could be very effective in this capacity. The rate of removal thus should depend both on the degree of erodibility of the non-blockforming rock and on the velocity of flow, which, in turn, should vary directly with the steepness of the slope and with the amount of space between the settling blocks. Assuming favorable lithologic conditions, lag accumulation then would be expectable to a significant extent primarily in areas of relatively steep slope. Whether the process could be operative on moderate slopes is open to question, unless the blocks are spaced widely. If operative at all on moderate gradients with close spacing of blocks, it should be exceedingly slow, being limited by the rate at which weathering could produce material sufficiently fine for pickup by the slow-moving waters weaving between and beneath the blocks. Under such conditions, the blocks should be of progressively greater age from the sides toward the center of the valley and should exhibit a corresponding systematic increase in the degree of weathering. At the Hickory Run boulder field the slopes are too low and the spacing of the boulders is too close to be favorable for lag accumulation, and no significant differences in degree of weathering are observed in a cross-valley direction. The hypothesis of lag accumulation per se must therefore be discarded.

There remains to be considered the hypothesis of mass movement, in which the lateral component of movement greatly exceeds the vertical components, and the coarser and finer products of weathering move downslope together. In varied forms, this process has been advocated by many investigators, both for the stone rivers of the Falkland Islands and for boulder accumulations elsewhere. Sir Wyville Thomson (1877*a*, p. 245-249, *b*) early attributed the stone rivers of the Falkland Islands to the gradual creeping of blocks and soil from bedrock ledges on the valley sides, presumably proceeding now at the same rate as in the past. Geikie (1877, 1894, p. 722-723) accepted the general idea of mass movement, but he believed that it took place more rapidly during a shorter interval, at a time when climatic conditions were more severe and frost action more intense than at present. Andersson (1906, 1907) particularized further on the concept of mass movement. In the light of ob-

servations in present-day Arctic regions, he described the process of "solifluction," or "slow flowing from higher to lower ground of large masses of waste saturated with water." He regarded the stone rivers of the Falkland Islands as "fossil" products of that process, dating back to a time when a more frigid climate accompanied the glaciation of nearby regions. The bareness of the more conspicuous parts of the block accumulations he attributed to "a secondary washing away of the finer material that once filled the interspaces between the big blocks or carried parts of them on its surface."

Subsequent to Andersson's work, the term "solifluction" came into widespread though varied usage, its relation to areas of perennially frozen ground was noted, and the past action of the process, under periglacial climatic conditions, was hypothesized by Salamon (1917) and others (Smith, 1949*b*) to account for various block accumulations in Europe. The latter extension of the solifluction interpretation, however, was challenged by Penck (1924, p. 85-88), who doubted whether the process of solifluction was necessarily related to periglacial climatic conditions and questioned whether the supposed "fossil" solifluction features were truly comparable to features observed in Arctic regions. Perhaps a need for more critical study was indicated by Penck's objections. In any event, later workers, by finding casts of ancient ground-ice wedges, and related frost phenomena, did provide confirmatory evidence of the supposed former periglacial climatic regime, and Büdel (1937) demonstrated that block accumulations which had moved long distances on low gradients were immobile during post-glacial time.

Although Andersson's general hypothesis for block or boulder accumulation has been accepted, some details of the process have remained open to question. Joyce (1950) has pointed out specific mechanical difficulties with Andersson's original interpretation, noting the great resistance to movement offered by blocks jammed so closely together and the lack of sufficient soil material to have served as a transporting medium. Earlier studies by Eakin (1916, p. 76-82) and by Kessler (1925, p. 105-111) suggest that an answer, or partial answer, to such objections may be found in the net downslope movement effected by frost heaving alternating with gravitational settling of blocks. Although much remains to be learned about the details

of the mass movement process, it does seem clear that intense frost action, in one form or another, is a major factor in vigorous mass movement of coarse material.

From the foregoing discussion, it may be concluded that elimination of competing hypotheses, together with the precedent established in other areas for similar accumulations, leaves mass movement of blocks from the adjacent valley sides as the preferred hypothesis for the origin of the Hickory Run boulder field. It remains to particularize on the local application of this hypothesis, especially with reference to the probable time and conditions of origin.

At present there is no indication that mass movement is active. The growth of vegetation is undisturbed, and the individual boulders are gradually breaking down in place (plate 3, fig. 2), with chemical weathering apparently more active than mechanical weathering, the process by which the boulders must have been shaped originally. The mineral staining and coating on boulders beneath the surface, furthermore, are unmarred, indicating that deposition proceeded to completion and was left thereafter without disturbance by further movement of the boulders. The boulder field thus appears to be stable at present and to have remained so for a considerable interval of time.

Further evidence relating to the time and conditions of boulder accumulation is indirect. It is found in the comparative weathering of boulders in different parts of the accumulation and in the relation of the boulder field to the valley bottom. Boulders of the same lithology show essentially the same range in size and the same degree of weathering in the different parts of the boulder field and on the uncovered parts of the adjoining slopes; neither characteristic shows any systematic change in a cross-valley direction. It is therefore indicated that the boulders were all formed and moved to their present position in one limited interval of time, and much more rapidly than they could have been broken down into smaller fragments by continued weathering during transportation or for a long time after accumulation. In terms of present-day processes in the area, this represents a decidedly anomalous situation.

The extension of the boulder accumulation across the entire valley bottom indicates an interruption of the normal progress of stream erosion. Running water is powerless to move the large

boulders in its way, under any conceivable conditions of volume and gradient in this area, and must remain so until the boulders are gradually reduced to much smaller particles by weathering. Previous erosion of the bedrock valley could have taken place only in the absence of such a supply of coarse material. It is evident that the pre-existing balance between stream transportation and the supply of material from the bordering slopes must have been completely disrupted for a time.

The above data indicate that the accumulation of the boulders marks a limited interlude in the late geomorphic history of the area, a time characterized by conditions and processes notably different from those now prevalent. The one event in the local geologic history that could have produced such a change was the advent of glaciation and the associated climatic refrigeration. This would have placed frost action in the dominant role, both for weathering and for the transportation of weathering products, as nearly as can be judged from present-day analogues of the near-glacial environment. The development of the boulder field is thus best explained as a result of periglacial conditions accompanying one or more substages of the last glaciation, and terminated by deglaciation (cf. Denny, 1951). More specific evidence for dating is not yet available in the area studied, but a date has been established in European areas where comparable accumulations are found under a cover of undisturbed bog deposits with a complete postglacial pollen sequence (Büdel, 1937, p. 22).

From the evidence of the boulder field itself, little can be said about the nature of the periglacial climatic conditions except that the inferred frost action required more frigid conditions than now prevalent. It seems probable also that temperature was lowered sufficiently to cause the development of perennially frozen subsoil, or permafrost. This has been established for European areas in which comparable boulder accumulations occur (Poser, 1947), and, in the light of available information on the mechanics of the process, it would be more difficult otherwise to explain the mass movement of coarse material on low gradients. Specific confirmation, however, must await the finding of other more diagnostic phenomena in the area. Other aspects of the periglacial climate are discussed by Peltier (1949, p. 131-139).

The bareness of the boulder field is best explained as a secondary feature due to the gradual flushing of interstitial fine material by running water, as originally suggested by Andersson (1906). It seems unlikely that the boulders could have moved to their present position without an interstitial filling of soil material to retain moisture, reduce friction, and promote frost heaving. Although some flushing may have taken place *pari passu* with accumulation, it is believed that this process did the major part of its work after accumulation of the boulders was completed. In marginal parts of the boulder field, it appears still to be in progress. Gradual extension of flushing upvalley would account for the somewhat more weathered appearance of boulders toward the western end of the boulder field, on the basis of their having been uncovered and exposed to weathering for a longer time.

CONCLUSIONS

The Hickory Run boulder field is an anomalous feature in terms of present-day processes in its locale. It is best explained as a relict or "fossil" phenomenon, dating back to a time when glaciation of adjoining territory was attended by more frigid climatic conditions. It is believed to represent a special, local facies of a more extensive rubble deposit, formed by accelerated mechanical weathering and mass movement related to intensified frost action, probably with perennially frozen subsoil. These processes were actuated with the advent of Wisconsin glaciation, and for a time were so vigorous as to interrupt the normal progress of stream erosion, mantling the slopes and choking the stream valley with debris too coarse for running water to move. When deglaciation brought climatic amelioration, frost action lost its effectiveness, and "normal" processes of weathering and erosion by running water returned, working now toward the very gradual reduction and removal of the rubble inherited from the preceding episode. As a first step, interstitial soil material was flushed from the bouldery accumulation along the valley bottom, producing the barren aspect now so striking.

The large size and low gradient of the boulder field, which make it an unusual example of its kind, are interpreted as due to proximity to the glacial border, making for maximum intensity of the periglacial processes.

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