Surficial Geology and Geomorphology of Potter County Pennsylvania

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By Charles S. Denny

ABSTRACT

Potter County is located in the Appalachian Plateaus of north-central Pennsylvania and contains the headwaters of the Genesee River, the Allegheny River, and the Susquehanna River. Drift of Wisconsin age covers the northeastern part of the county. This study includes a detailed survey of the surficial deposits of the Genesee quadrangle in north-central Potter County and a reconnaissance of the remainder of the county; a soil survey and a botanical survey were carried on concurrently.

The region is a deeply dissected plateau having extensive areas of steeply sloping land separated by narrow ridges and valleys; there is very little level land. Near the junction of the three watersheds the uplands rise to altitudes of more than 2,500 feet. The maximum relief in the Susquehanna drainage is more than 1,500 feet; in the Genesee and Allegheny drainage it is about 800 feet. Valley walls are steep (15° to 30°), and the uplands have gentle slopes (0.5° to 10°). The drainage pattern is trellised.

The climate is continental. Temperatures range from about −30° F. to more than 100° F. The average annual precipitation ranges approximately from 34 to 42 inches. Floods may occur at any season of the year. The large volumes of water from rain or melting snow carried by small streams come from springs. There is little precise data on frost in the ground, but it is probable that the ground seldom freezes in forested areas.

The soils of Potter County have relatively immature profiles with poorly developed horizons that commonly have many characteristics inherited from their parent materials. At the great soil group level, the zonal soils are divided into Podzol soils and Brown Podzolic soils. Many soils have a high silt content in the upper part of the profile, apparently derived (at least partly) from a mantle of eolian silt.

Most of Potter County is covered by second-growth forests consisting of 40- to 60-year-old hardwood stands. The present forests growing on slopes and summits are composed approximately of 25 species of trees. The northern hardwood region includes most of the county, with an oak-forest region near the borders, principally along its southern margin.

Potter County is underlain by sandstone, siltstone, shale, conglomerate, and minor amounts of coal and calcareous rock that range in age from Late Devonian to Pennsylvanian. These rocks form broad open folds that strike northeast.

South of the border of the Wisconsin drift, and possibly at two localities inside the drift border, are scattered remnants of ancient soils (here called paleosol), that were formed in pre-Wisconsin time—probably during the Sangamon interglacial stage. This paleosol ranges in texture from clay loam to silt loam, ranges in color from yellowish red to red, includes a few percent to more than 25 percent of rock fragments, and apparently contains a small percentage of gibbsite and varying amounts of kaolinite. Known thicknesses range from 1 to 33 feet. Paleosol was developed on diverse kinds of parent material, such as till, stratified drift, colluvium, and residuum, at altitudes ranging from a few hundred to 2,400 feet. The climatic conditions under which the paleosol formed are uncertain; however, these ancient soils may record an episode of subtropical climatic conditions during which lateritic soils were formed. Perhaps these soils are analogous to the Red-Yellow Podzolic soils of southeastern United States.

Except for one possible remnant, no pre-Wisconsin drift has been recognized in Potter County.

The Wisconsin glacial deposits of Potter County belong to either the Iowan or Tazewell substages and are dominantly till with minor amounts of glaciofluvial deposits. Erratics of igneous or metamorphic rock comprise less than 0.1 percent of the total number of rock fragments. The till is slightly weathered to depths ranging from 3 to about 12 feet.

The drift border is indefinite and has been drawn at the southern limit of erratics or well-rounded or striated pebbles and is only locally marked by a terminal moraine or by a distinct change in the surficial deposits. The drift border is relatively straight and crosses the Genesee quadrangle in a northwesterly direction with little regard for the major topographic features, thus suggesting that the Wisconsin ice sheet had a relatively straight and steep front.

Over most of the unglaciated part of Potter County, the bedrock is concealed beneath rubble that probably was formed during the Iowan or Tazewell substage, almost contemporaneously with the adjacent drift. In general, the rubble is thickest and most extensive within about 10 miles of the drift border, becoming thinner and less continuous farther away. The apparent parallelism between a belt of thick periglacial deposits and the drift border suggests that the deposits result from climatic factors in operation while the Wisconsin ice sheet was nearby. Ancient soil structures or patterned ground occur at, or near, the surface of both the periglacial deposits and the adjacent drift. These ancient soil structures are so similar to modern forms in arctic or alpine environments that they are considered to be the result of vigorous frost action. Many of the structures are believed to be a result of down-slope movement of debris by solifluction, facilitated by a frozen subsoil as much as 10 feet deep. Perennially frozen ground may have been present, but this is not a prerequisite. The periglacial deposits underlie long smooth slopes that extend from ridge crest to valley bottom. Flood plains are absent near the headwaters of many streams, the valley walls forming a V-shaped profile. While frost action was in progress, forests probably were restricted to flood plains, lower slopes, and scattered upland areas. Large parts of the upland were bare or partly covered by tundra vegetation; elsewhere, there were scattered trees but no dense forest.

Recent alluvium and alluvial fans include sand and sandy loams, 1 to 3 feet thick, that overlie gravel. The alluvium contains organic matter and lenses of finer materials. Thickness ranges from a few to more than 100 feet. Along the principal streams the alluvium probably overlies Pleistocene deposits. Most of the alluvial fans are composed of unstratified rubbly, pebbly, cobbly, or bouldery sandy loams to silty clay loams with local lenses of stratified sand and gravel. The alluvial fans mapped in the Genesee quadrangle probably include both Wisconsin stage and Recent deposits.

The summits of the Appalachian Plateaus in north-central Pennsylvania have long been recognized as the remnants or traces of one or more peneplains. To test this hypothesis, a restored contour map was prepared to show the configuration of a supposed peneplain on the assumption that the plateau tops are remnants of such an old erosion surface.

The restored contours delineate a surface that corresponds roughly to rock structure. In general, the uplands slope parallel to the dip of the bedrock. The major streams, such as the West Branch Susquehanna River, cross the ridges and valleys of the restored surface in such a way that it is difficult to suppose that the restored surface was ever graded to these streams. On the contrary, it is probable that the restored surface never existed and that the plateau tops are structurally controlled surfaces held up by sandstone and conglomerate beds in the Pottsville and Pocono formations. The plateau tops may have been lowered by erosion as much as 200 feet during the Pleistocene—in other words, after the major streams were incised. If this portion of the Appalachian Plateaus was ever reduced to a peneplain, such a hypothetical surface must have lain many hundreds of feet above the uplands of the present day. The only alternative that might involve peneplanation is the improbable hypothesis that the plateau tops are remnants of a slightly deformed peneplain and that the peneplain was folded along the axes of the Appalachian orogeny. This remote possibility is not supported by any known evidence.

The geomorphic analysis yields no new data on the origin of the cross-axial drainage. Regardless of whether the plateaus are peneplain remnants or are structurally controlled surfaces, the beginning of the major southeastward-flowing streams long antedates the existing landscape.

The geomorphic history of Potter County begins with an assumed long interval of erosion during the Mesozoic and early Cenozoic eras, for which no record remains in this area. The southeast master drainage was established by the latter part of the Tertiary period (perhaps at a much earlier date), probably as the result of the northwestward migration of the Atlantic-interior divide. In late Pliocene(?) time, areas adjacent to parts of the West Branch Susquehanna River—and probably elsewhere—had a moderate relief ranging from 300 to 700 feet. Some segments of the West Branch meandered across a broad valley that lay about 900 feet above the present streams. The landscape probably was covered by deep residual soils, perhaps by saprolite.

The early Pleistocene history of Potter County is essentially unknown. No deposits of the Kansan stage are known except for a possible trace of pre-Illinoian drift on the uplands in central Potter County (Ayers Hill quadrangle). Some deposits in central and eastern Pennsylvania may be of Kansan age. It is probable that the assumed Aftonian regolith was removed by mass movements and other processes during the Kansan stage, thus resulting in a lowering of the plateau tops by as much as 10 feet. By the close of the Yarmouth(?) interglacial stage the major streams were incised to essentially their present depths. The climates of the Yarmouth interglacial stage probably produced deep residual soils over the landscape, parts of which may still be preserved in the paleosol remnants of the present day.

No Illinoian drift is known in Potter County, but drift assigned to this stage occurs in areas to the northwest and to the southeast. Some valleys, such as Kettle Creek valley, were filled with sand and gravel alluvium to depths of as much as 150 feet above their present flood plains. It is assumed that the Yarmouth residual soils were removed by mass movements and other processes induced by a periglacial climate, thus lowering the plateau tops by as much as 10 feet.

During the Sangamon interglacial stage, deep (10-to-20 foot) residual soils or paleosol were developed in Potter County and probably throughout much of Pennsylvania, perhaps as a result of lateritic weathering in a subtropical climate. It is possible that the paleosol was largely removed by mass movements and by running water during late Sangamon time.

During either the Iowan or Tazewell substages of the Wisconsin (perhaps the Iowan), the ice sheet advanced into the northeastern part of Potter County. The drift is similar to the Olean drift (local usage). The paleosol was almost completely removed by mass movements and other processes induced by a periglacial climate, prior to drift deposition. This removal probably resulted in a lowering of the plateau tops by as much as 10 feet since Sangamon time. Nearly contemporaneously with drift deposition, the periglacial deposits were formed by frost heaving, solifluction, and fluvial transport in areas outside the drift border. Soil structures or patterned ground were developed on both the drift and the periglacial deposits. It is probable that the forests in the periglacial area were greatly restricted and that large areas on the uplands were essentially treeless.

Little is known about the history of Potter County in post-Olean time. Presumably, forests completely covered the county by the onset of the next substage, during which the Binghamton drift of MacClintock and Apfel was deposited. This drift also is found in southern New York State. The formation of the alluvium and alluvial fans probably began in the Tazewell substage and continued during the Recent epoch. Since these deposits were formed there has been very little dissection.

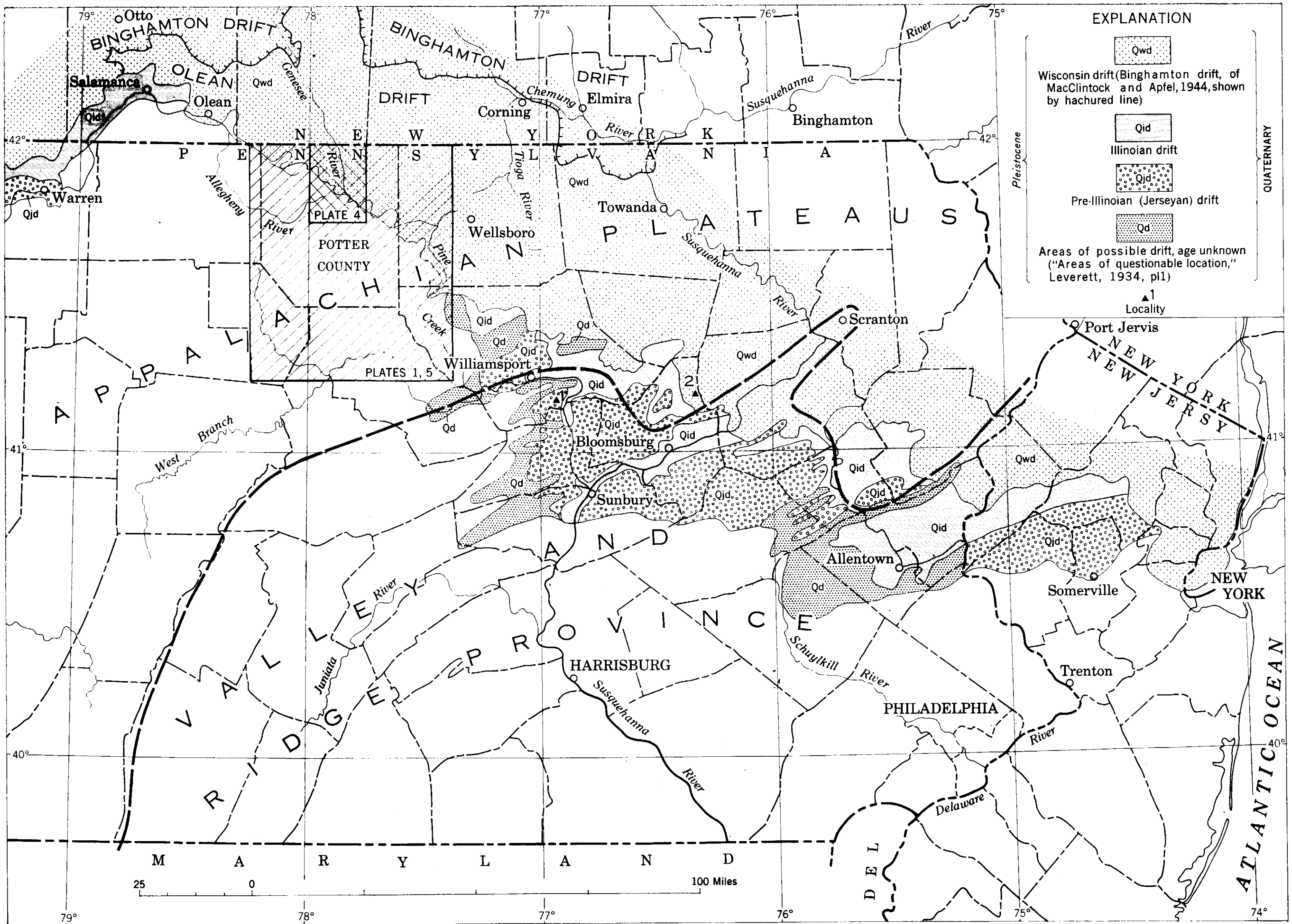
There is little, if any, difference between soils developed on periglacial deposits and soils developed on drift. The roots of fallen trees have disturbed the soil horizons, and it is unlikely that the existing soil profiles are more than 500 years old.

The forested landscape of Potter County has a distinctive microrelief ranging from a few inches to a few feet of mounds and pits produced by the roots of fallen trees. Most mounds and pits range from 10 to 20 feet in length and from 6 to 15 feet in width. On level land, many mounds are oriented with their long axes trending northward, and in some areas the orientation is random. On slopes, the mounds are oriented with their long axes at right angles to the maximum slope as a result of trees falling downslope. The toppling of trees increases the permeability of surficial deposits and mixes and destroys the soil horizons. The microrelief is a factor in forest development. The toppling of trees on slopes is a significant agent of slope erosion. The process loosens, breaks up, or overturns the upper 2 to 3 feet of the forest soil, and it tends to make the surficial layer more stony and to produce features resembling soil structures.

INTRODUCTION

LOCATION

The area under consideration is a portion of the Appalachian Plateaus in north-central Pennsylvania (fig. 1) and covers Potter and parts of adjacent counties,



Drift sheets in Pennsylvania from Leverett (1934), slightly modified in or near Potter County; in New Jersey from Salisbury (1902), and Flint and others (1945); in New York from MacClintock and Apfel (1944)

FIGURE 1.—Map showing location of Potter County and glacial deposits in parts of Pennsylvania, New Jersey, and southern New York.

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which contain the headwaters of the Genesee, Susquehanna, and Allegheny Rivers.

PURPOSE AND SCOPE OF STUDY

The study had four primary objectives: (1) the detailed mapping of the surficial deposits in the Genesee quadrangle in the north-central part of the county, (2) a reconnaissance survey of the surficial deposits in the remainder of Potter County, (3) an analysis of deposits and land forms in the area outside of the border of the Wisconsin drift and (4) the relations between surficial geology, soils, and the present vegetation.

Potter County lies in a reentrant in the border of the Wisconsin drift and rises to altitudes of more than 2,500 feet. The drift border crosses the northeastern part of the county; to the north and east lies the drift-covered area, and to the south and west lies the periglacial area. Thus, Potter County is favorably situated to test the hypothesis that some areas peripheral to the Wisconsin ice sheets, the so-called periglacial areas, were subjected to vigorous weathering, erosion, and deposition by processes related to the nearby glacial ice.

ACKNOWLEDGMENTS

This project was begun as a part of an informal collaboration between the Geological Survey and the Soil Survey of the Department of Agriculture. A soil survey of the county was in progress during the geological work.

It is a pleasure to acknowledge the interest of Charles E. Kellogg, chief of the Soil Survey, in the collaboration. Various members of the Soil Survey have helped the writer both in the office and in the field, especially J. K. Ableiter, E. D. Fowler, W. H. Lyford, C. C. Nikiforoff, A. C. Orvedal, O. C. Rogers, R. S. Simonson, and Guy D. Smith. J. G. Cady of the U. S. Department of Agriculture visited the area and collected soil samples for laboratory analysis. H. W. Higbee of Pennsylvania State University visited Potter County to aid in the investigation and showed the author some of his work in central Pennsylvania. It is a special pleasure to express appreciation to K. V. Goodman, soil scientist in charge of the Potter County soil survey, and his assistants, J. C. F. Tedrow, L. G. Yearick, and R. W. Stem, for their assistance throughout this investigation.

The late S. H. Cathcart, former director of the Pennsylvania Topographic and Geologic Survey, aided the project in various ways. In 1948, the writer was ably assisted by B. J. O'Neill, Jr.; in 1949, by B. J. O'Neill, Jr. and S. E. Watson; in 1950, by F. J. Wagner and D. M. Raup; and in 1951, by D. U. Wise. The writer benefited from discussions in the field and in the office with W. E. Benson, J. T. Hack, C. B. Hunt, L. C. Peltier, A. W. Postel, and G. W. Richmond of the Geological Survey, and with J. H. Moss of Franklin and Marshall College. Finally, it is a pleasure for the author to acknowledge his indebtedness to J. C. Goodlett and H. M. Raup of the Harvard Forest, Petersham, Massachusetts, for stimulating discussions both in the field and in the laboratory. Goodlett made a botanical survey of the county and has been kind enough to assemble a summary of his results for inclusion in this paper.

GENERAL PHYSICAL GEOGRAPHY

TOPOGRAPHY

Potter County is in the Appalachian Plateau province and includes parts of the Southern New York, Kanawha, and Allegheny Mountain sections (Fenneman, 1938). The drainage basins of the northward-flowing Genesee River, of the westward-flowing Allegheny River, and of the southeastward-flowing Susquehanna River meet in northern Potter County. Streams flow in steep-sided, narrow valleys that are incised to depths of several hundred feet below gently sloping upland surfaces. Near the junction of the three watersheds, the uplands rise to a maximum altitude of 2,560 to 2,580 feet. The greatest relief is in the Susquehanna drainage basin, which includes the southern part of the area shown in plate 1. The maximum relief in any one valley (about 1,650 feet) is along the West Branch, south of Hyner. In the Genesee and Allegheny drainage basins, however, the maximum relief in any one valley is about 800 feet, and the streams at a given distance from drainage divides are 200 to 400 feet higher than similar points along streams in the Susquehanna drainage (table p. 46). In Potter County, the gently sloping ridge tops and valley bottoms are elongate, narrow, and sinuous; their total surface area is small by comparison with that of the steeply sloping land.

The drainage pattern (pl. 1) is trellised. The principal streams—the Genesee River, the Allegheny River, the West Branch Susquehanna River, and Pine Creek—flow in general across, but have long segments parallel to, rock structure. The first-order tributaries, such as Kettle Creek, more or less parallel the structural axes (pl. 5), and most geologists would class them as subsequent. Tributaries of the second order, such as those that enter Kettle Creek from the north or from the south, flow across the rock structure. Most southeastward-flowing second-order tributaries are several times longer than those that flow northwestward.

CLIMATE

GENERAL FEATURES

The climate of Potter County is continental. Data for the following table are abstracted from U. S. Dept. Agriculture publications (1941; U. S. Weather Bur., 1935). The average January temperature ranges from about 22° to 24° F.; the minimum temperature recorded is about −31° F. The average July temperature ranges from about 66° to 70° F.; the maximum temperature recorded is about 104° F. The daily temperature range is fairly large, averaging about 20° in midwinter and 26° in midsummer. The growing season is fairly short, ranging from about 77 days in the northeastern part to about 150 days in the southeastern corner. At West Bingham, Genesee quadrangle, frosts have occurred during all months of the year. The average annual precipitation ranges from about 34 inches in western Tioga County to about 42 inches in southwestern Potter County. The greatest 24-hour precipitation at Emporium is 2.56 inches (35-year record) and at Wellsboro 7.45 inches (33-year record). The average warm-season precipitation (April to September, inclusive) ranges from about 20 to 22 inches. The average annual snowfall at Emporium is 46.4 inches (41-year average), and at Wellsboro 51.8 inches (40-year average). Fields are normally snow covered about three-quarters of the winter. The average depth of frost penetration is shown as 25 to 30 inches on a map published in the 1941 Yearbook of Agriculture (U. S. Dept. Agriculture, 1941, p. 747).

Climatic summary for Potter County and vicinity, Pennsylvania

[From U. S. Dept. Agriculture Yearbook, 1941]

Station	County	Temperature (° F)					Average dates of killing frosts				Average monthly precipitation (inches)													
		Length of record (years)	January average	July average	Maximum	Minimum	Length of record (years)	Last in spring	First in fall	Growing season (days)	Length of record (years)	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Bradford	McKean	14	24.2	68.8	100	−24	18	May 26	Sept. 23	120	21	3.82	2.60	3.22	3.60	3.63	4.47	3.83	3.41	4.08	3.41	3.48	2.96	42.07
W. Bingham	Potter	15	22.3	64.6	98	−31	14	June 17	Sept. 2	77	14	2.42	2.00	2.63	3.03	3.92	3.90	3.68	3.60	3.23	3.04	2.21	2.13	35.79
Emporium	Cameron	40	26.1	69.5	103	−31	40	May 20	Oct. 2	135	40	3.60	2.78	3.69	3.66	4.12	4.34	4.36	3.96	3.42	3.13	2.88	3.20	43.14
Renovo	Clinton										39	2.77	2.30	2.97	3.36	3.78	4.15	4.03	3.57	2.95	2.98	2.48	2.54	37.88
Ansonia	Tioga										30	2.12	1.76	2.27	3.25	3.55	3.77	3.20	3.65	3.14	2.87	2.25	1.90	33.73
Wellsboro	Tioga	40	24.2	69.0	104	−30	40	May 27	Sept. 22	118	40	2.27	1.94	2.65	2.92	3.17	3.68	3.13	3.44	2.92	2.76	2.22	2.10	33.20

FLOODS

Floods occur at all seasons (Grover, 1937a and b; Langbein and others, 1947; and Mangan, 1936, 1943). They frequently take place during March and April—the spring thaws. Other floods primarily result from excess local precipitation. Most valley walls are not gullied; water from rain or melting snow seeps in and joins the ground water. Hence, the nonwinter floods of small streams do not result from excess surface runoff concentrated in channels on slopes; instead, they result from ground water that emerges as springs near the valley bottom.

FROST IN THE GROUND

Data on present-day frost action (largely from Lassen and Munns [1]) are valuable but, unfortunately, available observations justify only a few broad generalizations. Some of the surficial deposits in Potter County are attributed to more intensive frost action than occurs today. One test of this hypothesis is to ascertain the effects of present-day frost in the ground.

The type of structure, depth of penetration, and duration of frost depend upon climatic, topographic, soil, and biotic factors.[1] Foresters have gathered some information on frost in the ground (Kittredge, 1948; Anderson, 1947; Post and Dreibelbis, 1942). Soil frost under bare ground or a sparse vegetative cover usually is of the "concrete" type—an extremely dense mass of many thin ice lenses that is more or less impervious to water. Under a forest, on the other hand, soil frost is described as a "honey comb" or a "stalactitic" type—loose, porous types of structure that do not restrict infiltration. Uncompacted soils with a thick surface layer of organic matter commonly have "honeycomb" or "stalactitic" types of frost. Frost penetrates deeper in open areas than in woodlands, deeper in compacted than in uncompacted soils, and deeper in grazed ,burned, or heavily logged forests than in undisturbed woodlands.

Data on soil frost in forest and adjacent open areas are available for the Arnot Forest, a small tract in the plateaus about 80 miles east-northeast of Potter County (Spaeth and Diebold, 1938). This forest lies about 14 miles southwest of Ithaca, N. Y., at altitudes of 1,170 to 1,970 feet. The bedrock consists of shale and fine-grained sandstone of the Chemung formation. The soils are similar to those found in Potter County. Soil temperatures were measured at depths of 1, 5, 12, and 30 inches. Snow drifted in bare areas, whereas the cover was deep and uniform in woodlands. A 7-inch cover of snow during 1935–36 was insufficient to prevent the soil of a bare field from freezing to depths

[1] Lassen, Leon, and Munns, E. N., 1947, Vegetation and frozen soils, U. S. Dept. Agriculture, Forest Service (mimeo.), presented at meeting of Am. Geophys. Union, April 1947, Washington, D. C.

of more than 30 inches in February, which was the coldest month of that year. During that winter the soil was never frozen under grass-covered fields, where the depth of snow ranged from 10 to 17 inches, nor in the forest, where snow depths ranged from 17 to 31 inches. Frost-heaving produced mounds or pimples in open fields, where the water table was close to the surface for long periods. No pronounced heaving occurred in any soils under a forest cover.

The Arnot Forest data suggest that much of the ground in the forested areas of Potter County remains unfrozen during many winters. When a long period of subfreezing temperature precedes the first snowfall, or during winters that are exceptionally free of snow, the ground probably freezes to depths of at least 1 foot. However, during such a winter it is unlikely that ground temperatures at a depth of 1 foot fluctuate across the freezing point many times during the winter season. The high permeability of surficial deposits on many slopes would tend to decrease frost heaving. Poorly drained soils are most likely to be frost heaved at present. Mounds or pimples occur where such soils are under grass, but not where they are under forest. The 25 to 30 inches given as the average depth of frost penetration in the 1941 Yearbook of Agriculture (U. S. Dept. of Agriculture, 1941, p. 747) is probably too large for the forested areas of Potter County. However, such values may be accurate for bare areas. The meager data on present-day ground frost suggest that frost can now effect only minor disturbance of soil under a forest.

SOILS

At the level of the great soil groups, the zonal soils of Potter County are divided into Podzol soils and Brown Podzolic soils (U. S. Dept. Agriculture, 1938, map of "Soil associations of the United States"). Both are light colored podzolized soils characteristic of timbered regions. Podzol soils have an organic mat and a very thin organic-mineral layer above a gray leached layer (all parts of the *A* horizon) which rest upon the dark-brown illuvial *B* horizon. Iron oxide and alumina, and sometimes organic matter, have been removed from the *A* and deposited in the *B* horizon (U. S. Dept. Agriculture, 1938, p. 1174). Brown Podzolic soils have a thin mat of partly decayed leaves over very thin dark-grayish-brown organo-mineral soil and a trace of pale-gray leached A_2 horizon over a brown or yellowish-brown *B* horizon that is heavier in texture than the surface soil (U. S. Dept. Agriculture, 1938, p. 1163). The poorly drained soils associated with the podzolized soils in Potter County are classified as Half Bogs and Low Humic Gley soils which develop under swamp-forest vegetation or in other poorly drained areas underlain by relatively impervious materials. The flood plains, young alluvial fans, steep slopes, and other areas of thin mantles over hard rock are occupied by soils lacking well-defined profile characteristics, which are classified as Alluvial soils and Lithosols.

The soils of Potter County have rather weakly developed profiles and are closely related in lithology and texture to the surficial deposits that underlie them. Most soils are acid throughout the profile and contain abundant fragments of rock.

BEDROCK GEOLOGY

SOURCES OF DATA

Potter County and adjacent areas are underlain by sandstone, siltstone, shale, conglomerate, and minor amounts of coal and calcareous rock that range in age from Late Devonian to Pennsylvanian. No attempt was made to map the bedrock during this study. The best bedrock map available is the Geologic Map of Pennsylvania (Stose and Ljungstedt, 1931). The following table lists and briefly describes the units shown on this map within Potter County and vicinity, together with a generalized section for the rocks exposed in the Leidy gas field (Ebright and Ingham, 1951) just south of the county. The geology of Potter County was described by Sherwood (1880) and by Cathcart (1934). The Gaines quadrangle was mapped by Fuller (1903a), and the Wellsville quadrangle, N. Y., north of the Genesee quadrangle, was mapped by Woodruff (1942). The geology

Generalized sections of formations described in various reports on the geology of Potter County and vicinity.

Age of formations	Geologic map of Pennsylvania [1]	Leidy gas field [2]
Pennsylvanian	Allegheny formation: sandstone, shale, limestone, clay, and coal.	Allegheny formation: sandstone shale, clay, and coal.
	Pottsville formation, conglomerate overlain by sandstone, shale, and coal; thickness 50 to 100 feet.	Pottsville formation: sandstone, shale, clay, and coal.
Mississippian	Mauch Chunk shale; thickness 10 to 100 feet.	Mauch Chunk series: shale and shaly limestone; maximum thickness 50 feet.
	Pocono formation including the Oswayo formation, conglomerate, sandstone, and shale; thickness 500 to 600 feet.	Pocono group; sandstone, locally conglomeratic, shale, siltstone, and locally thin lenses of calcareous breccia and sandy limestone; thickness about 570 feet.
		Oswayo formation: sandstone and shale, calcareous beds similar to those in Pocono group; thickness about 300 feet.
	Catskill and Cattaraugus formations: red shale, gray shale, and sandstone; thickness about 675 feet.	Catskill red beds: sandstone, siltstone, shale, and calcareous beds similar to those in Pocono group; thickness about 840 feet.
Devonian	Chemung formation, shale and sandstone; thickness 1,760 to 2,100 feet.	Chemung facies: sandstone, shale, and calcareous sandstone; exposed thickness about 200 feet.

[1] Stose and Ljungstedt, 1931; Lohman, 1939.
[2] Parts of the Hammersley Fork, Tamarack, Keating, and Renovo West quadrangles, Pennsylvania (Ebright and Ingham, 1951).

of the Bradford, Pa., quadrangle, 15 miles west of Potter County, has been described by Fettke (1938). The lithologic descriptions given in the following paragraphs are drawn from Cathcart (1934), Lohman (1939), and Ebright and Ingham (1951).

CHEMUNG FORMATION

The Chemung formation is composed of thin-bedded, green and gray shale, sandy shale, siltstone, and fine-grained sandstone, slightly calcareous in places. Locally, there are thin beds of impure limestone and limy shale, some of which are highly fossiliferous. Reddish layers occur in a few places. In the Leidy area, fossils suggest a late Chemung age, but possibly they may be early Catskill. The formation floors some of the major anticlinal valleys (pl. 5).

CATSKILL FORMATION

The Catskill formation (Catskill and Cattaraugus formations of the Geologic Map of Pennsylvania, Stose and Ljungstedt, 1931) is a succession of sandstone, siltstone, and shale, which are predominantly red. Associated with the red beds are minor amounts of green and gray shale, sandstone, siltstone, and conglomerate. The sandstones are dominantly fine to medium grained, micaceous, and thin bedded. A few thin, calcareous units are present, as noted by Ebright and Ingham (1951, p. 10) who state:

> Locally, thin, very calcareous, lenticular sandy layers, sometimes containing shale fragments, calcite crystals, and carbonaceous material are found (calcareous breccia).

The Catskill formation underlies areas near anticlinal axes (pl. 5)—either on lower valley walls or on upland surfaces, most of which are smaller and lower than upland surfaces underlain by the Pocono and Pottsville formations.

POCONO FORMATION

The Pocono formation (including Oswayo formation of the Geologic Map of Pennsylvania, Stose and Ljungstedt, 1931) consists of sandstone, siltstone, shale, and conglomerate. The sandstone is dominantly fine to medium grained, gray to brown, micaceous, and thin bedded or crossbedded. A few beds of red shale or siltstone are present. A few thin lenses of calcareous breccia and of sandy limestones are present, similar to those in the Catskill formation. The Pocono formation occurs in the synclines (pl. 5) and underlies gently sloping upland surfaces.

POTTSVILLE FORMATION

The Pottsville formation consists of white to brown quartz conglomerate, coarse-grained sandstone, clay, and coal beds. These rocks occur in synclines (pl. 5) and underlie gently sloping upland surfaces commonly bordered by prominent cliffs or steep slopes mantled by blocks, 10 to 30 feet in maximum diameter. Outcrops of bedrock are scarce. The Pottsville formation as shown on the state map (Stose and Ljungstedt, 1931) erroneously includes a conglomerate now believed to be of Pocono age (Cathcart, 1934, p. 6; Lohman, 1939, p. 90; Ebright and Ingham, 1951, p. 8–9).

ALLEGHENY FORMATION

The Allegheny formation includes sandstone, shale, clay, and several coal beds. On the state map (Stose and Ljungstedt, 1931) it is shown on uplands west of Keating Summit, east and south of Emporium, and north of the West Branch Susquehanna River between Keating and Hyner.

STRUCTURE

The rocks of Potter County form broad open folds that strike northeastward (pl. 5) and are essentially parallel to each other (Cathcart, 1934). The oldest rocks appear at the surface in anticlinal valleys, whereas younger rocks are preserved in synclinal ridges. Most of the folds plunge southwestward. The intensity of folding decreases from southeast to northwest. The folds are asymmetric, with slightly steepened southeast limbs. Average maximum dips are about 5°.

SURFICIAL GEOLOGY

TERMINOLOGY

In describing the surficial deposits of Potter County, some terms are employed that are used by soil scientists to describe certain features usually disregarded in geologic literature.

TEXTURE

The following table presents a classification of unconsolidated sedimentary materials according to particle size and shape. It conforms to accepted usage, except that the term "block" is applied to an angular, more or less equidimensional fragment of rock more than about 10 inches in diameter, and the term "rubble" refers to a deposit that contains a considerable proportion of angular, more or less equidimensional fragments of rock from about 1/10 to 10 inches in diameter. Many of the surficial deposits in Potter County contain numerous angular fragments of thin-bedded sandstone, and the following terms are used to describe such fragments. A "flagstone" is a relatively thin fragment of rock that ranges in maximum diameter from 6 to 15 inches (Soil Survey Staff, 1951, p. 216), and materials that contain numerous flagstones are described as being "flaggy". If the relatively thin fragments range in maximum diameter from about 1/10 to 6 inches, the material is described as "channery" (Soil Survey Staff, 1951, p. 215).

Classification of unconsolidated sedimentary materials according to particle size and shape

Fragments larger than 2 mm (0.079 in.) [1]

Diameter		Shape			
		Angular		Rounded	
mm	in.	Single particle	Type of deposit	Single particle	Type of deposit
		Block [2]	Block field, blocky till.	Boulder	Bouldery gravel, bouldery till.
256	10.08				
		Fragment	Rubble,[3] rubbly periglacial deposit.	Cobble	Cobbly gravel, cobbly till.
64	2.52				
		Fragment	Fine rubble, fine rubbly till.	Pebble	Gravel, gravelly till.
2	.079				

Fragments smaller than 2 mm (0.079) [4]

Diameter		Class
mm	in.	
2.0	0.079	
		Very coarse sand.
1.0	.0394	
		Coarse sand.
.5	.0197	
		Medium-grained sand.
.25	.0098	
		Fine sand.
.10	.0039	
		Very fine sand.
.05	.0020	
		Silt.
.002	.000079	
		Clay.

[1] Particle-size definitions of fragments larger than 2 mm according to National Research Council (1947).
[2] "Block" is an angular, more or less equidimensional fragment of rock equivalent in size to a boulder.
[3] "Rubble" is used for an accumulation of angular, more or less equidimensional fragments of rock from 2 to 256 mm in maximum diameter, equivalent to an accumulation of pebbles or cobbles or both. Such usage conforms to that of Pettijohn (1949, p. 12), Woodford (1925, p. 183), and Bryan (1923, p. 86–90) except that it places an upper size limit at 256 mm.
[4] Particle-size definitions of fragments less than 2 mm according to the U. S. Department of Agriculture (Soil Survey Staff, 1951). All mechanical analyses included in this paper were made by the U. S. Department of Agriculture and use these grain-size definitions.

"Block fields" are masses of boulders or blocks that cover an area ranging from a few tens to hundreds of feet in width and from hundreds to one or two thousand feet in length. The term is applied to areas where more than half of the ground surface is covered by large rock fragments. A block field is transitional into "miniature block fields" or into bouldery deposits or rubbles. Block fields occur on hilltops, on lower valley walls, and on the floors of small valleys, either near their headwaters or where the valley is crossed by a belt of massive sandstone or conglomerate. The few block fields that occur in Potter County, and other block fields that are found throughout the plateaus of north-central Pennsylvania, are relatively small in comparison with those found in central and eastern Pennsylvania where the blocks are derived from more massive rock (Smith and Smith, 1945, Peltier, 1949).

The basic soil-textural classes (fig. 2) are used in describing the surficial deposits of Potter County (Soil Survey Staff, 1951, p. 205–213). To many readers, the

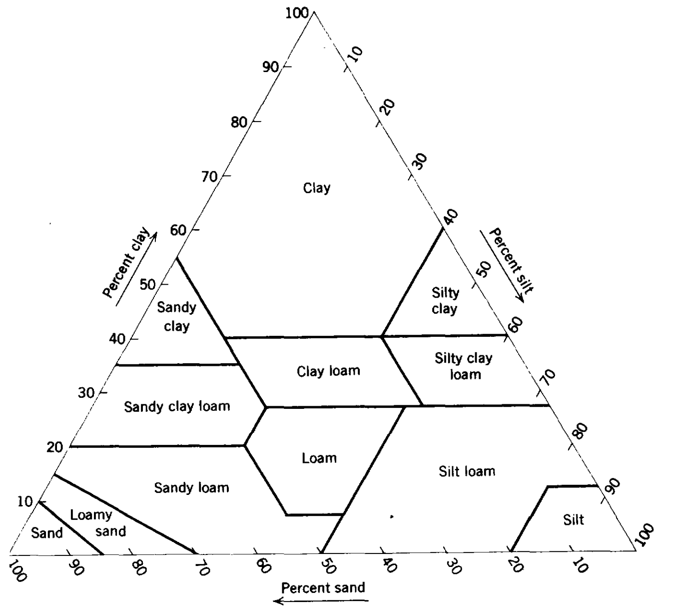


FIGURE 2.—Chart showing percentages of clay, silt, and sand in the basic soil-textural classes (Soil Survey Staff, 1951, fig. 38).

term "loam" implies a friable soil containing some organic matter (Trefethen, 1950, p. 58). However, loam defines a large area of sand-silt-clay mixtures that are characteristic of most unstratified surficial deposits (fig. 2), and therefore it is a useful descriptive term. The terms for soil-textural classes are used with certain reservations in the descriptions that follow. A few textural determinations are based on laboratory analyses, and some were made by soil surveyors. The majority, however, were made on the basis of the "feel" of the material. Such a procedure is not precise, but it is thought that the range in texture given in the description of any one horizon is sufficient to cover the probable error inherent in the method (Soil Survey Staff, 1951, p. 212; Shaw, 1928).

STRUCTURE

In describing surficial deposits and soils, the term "structure" is used. Nikiforoff (1941, p. 193) states:

> The term "soil structure" denotes an arrangement of the soil material into aggregates in which the primary particles of such a material are held together by ties stronger than the ties between the adjacent aggregates * * *. Structure characterizes a condition of the soil material intermediate between a loose or "single grain" condition, which represents a complete disruption of the ties between the primary particles of such a material, and a massive condition, representing a uniform cohesion of the primary particles throughout the soil.

Soil scientists employ a rather elaborate terminology to describe soil structure (Soil Survey Staff, 1951, p. 225–230). Four principal types are recognized, based on the shape of the aggregates ("peds"), and these four types are divided into classes on the basis of the average size of the aggregates. There is a further subdivision into grades, which are determined by the relative stability of the aggregates and by their ease of separation.

In this paper the following terms are used—the definitions are those of Nikiforoff (1941). "Platy structure" refers to materials composed of aggregates whose horizontal axes, extending parallel to the surface of the ground are longer than the vertical axes. "Prismatic structure" refers to materials composed of aggregates whose horizontal axes are shorter than the vertical. "Blocky structure" refers to materials composed of aggregates whose horizontal and vertical axes are more or less equal in length. The aggregates lie rather closely together and their swelling when wet may completely close the voids between them. "Granular structure" refers to materials composed of more or less rounded aggregates lying loosely together. There are relatively large and irregular voids between the adjacent lumps.

CONSISTENCE

Consistence "comprises the attributes of soil material that are expressed by the degree and kind of cohesion and adhesion or by the resistance to deformation or rupture" (Soil Survey Staff, 1951, p. 231). The terminology used in this paper for consistence of surficial deposits is a simplified version of that used by soil scientists (Soil Survey Staff, 1951, p. 232–234).

Terminology for consistence

I. Consistence when wet at, or slightly above, field capacity:
  A. Stickiness: The quality of adhesion to other objects. For field determination, press material between thumb and finger and observe its tendency to adhere.
    Nonsticky: After release of pressure, practically no material adheres to fingers.
    Sticky: After release of pressure, material adheres to fingers and tends to stretch and pull apart rather than pulling free from the fingers.
  B. Plasticity: The ability to change shape continuously under the influence of an applied stress and to retain the impressed shape after removal of the stress. For field determination, roll material between thumb and finger and observe whether or not a wire can be formed.
    Nonplastic: No wire can be formed.
    Plastic: Wire formed with moderate pressure.
II. Consistence when moist:
  Loose: Noncoherent.
  Friable: Material crushes with gentle to moderate pressure between the fingers and coheres when pressed together.
  Firm: Material crushes under moderate pressure between the fingers but resistance is distinctly noticeable.
  Very firm: Material barely crushable between the fingers.
II. Consistence when moist—Continued
  Compact: Denotes a combination of firm consistence and close packing or arrangement of particles.
III. Consistence when dry:
  Loose: Noncoherent.
  Soft: Material is very weakly coherent and fragile; breaks to powder under very slight pressure.
  Hard: Moderately resistant to pressure; can be broken in the hands only with difficulty.

DRAINAGE

Drainage of surficial deposits and soils refers, in a dynamic sense, "to * * * the rapidity and extent of the removal of water from the soil, in relation to additions, especially by surface runoff and by flow through the soil to underground spaces." As a condition of surficial deposits or soil, drainage refers to "* * * the frequency and duration of periods when the soil is free of saturation or partial saturation" (Soil Survey Staff, 1951, p. 165). Soil scientists define seven classes of soil drainage based on observations and inferences of surface runoff, permeability, and internal drainage. The classes are defined in the following table both in broad general terms and in terms of the morphological characteristics of podzolic soils (Soil Survey Staff, 1951, p. 165–172).

Soil-drainage classes

Soil-drainage class	Characteristics
Excessively drained	Water is removed from the soil very rapidly. Most excessively drained soils are very porous or occur on steep slopes, or both, and are free of mottlings[1] throughout the profile. In Potter County, most of the excessively drained soils are less than 3 feet thick to bedrock.
Somewhat excessively drained.	Water is removed from the soil rapidly. Most somewhat excessively drained soils are sandy, very porous, and free of mottling throughout the profile.
Well drained	Water is removed from the soil readily, but not rapidly. Most of the well-drained soils are intermediate in texture and are free of mottling to depths of several feet.
Moderately well drained.	Water is removed from the soil somewhat slowly, so that the profile is wet for a small but significant part of the time. Most of the moderately well drained soils have a slowly permeable layer at a depth of 2 to 3 feet, a relatively high water table, additions of water through seepage, or combinations thereof. Most of the moderately well drained soils are mottled at depths of 2 to 3 feet.
Imperfectly or somewhat poorly drained.	Water is removed from the soil slowly enough to keep it wet for significant periods, but not all the time. Most imperfectly or poorly drained soils have a slowly permeable layer at a depth of 1 to 2 feet, a high water table, additions through seepage, or combinations thereof. Most of the imperfectly, or somewhat poorly, drained soils are mottled at depths of 6 to 16 inches.

[1] Mottling means "marked with spots of color," and "is described by noting: (1) the color of the matrix and the color, or colors, of the principal mottles, and (2) the pattern of the mottling" (Soil Survey Staff, 1951, p. 191–193; see also Simonson, 1951).

Soil-drainage classes—Continued

Soil-drainage class	*Characteristics*
Poorly drained	Water is removed from the soil so slowly that it remains wet for a large part of the time. In poorly drained soils, the water table commonly is at, or near, the surface during a considerable part of the year and is due to a high water table, to a slowly permeable layer within the profile, to seepage, or to some combination thereof. Poorly drained soils are light gray in color from the surface downward, with or without mottlings.
Very poorly drained	Water is removed from the soil so slowly that the water table remains at, or near, the surface most of the time. Most of the very poorly drained soils occur in level, or depressed, sites, frequently ponded. Most of the very poorly drained soils have dark-gray or black surface layers and are light gray, with or without mottlings, in deeper parts of profile.

COLOR

The descriptions of color employ the numerical symbols of the Munsell system and were determined by using the color chart of the Soil Survey (Soil Survey Staff, 1951, p. 194–203) rather than the Rock Color Chart of the National Research Council (Goddard, and others, 1948). The former contains a wider variety of color chips that correspond to the colors encountered in surficial deposits than does the latter. Both charts use the numerical symbols of the Munsell system. The color names given in this paper are those used by the Soil Survey.

PRE-WISCONSIN PALEOSOL

GENERAL FEATURES

Throughout central and eastern Pennsylvania, south of the border of the Wisconsin drift, are scattered remnants of ancient soils that were formed in pre-Wisconsin time, probably during the Sangamon interglacial stage. No complete soil profile of any one of the ancient soils has been found. The existing remnants have profiles that have lost all of the *A* horizon and, in places, probably much of the *B* horizon. (For definitions of *A* and *B* horizons, see Soil Survey Staff, 1951, p. 174–183.) The remnants are the "roots" of ancient soils, which included many different soil series, but which may have been formed under similar climatic conditions. The term "paleosol" (Hunt and Sokoloff, 1950) is applied to these remnants of ancient soils formed in pre-Wisconsin time. The paleosol is a useful horizon marker both within and outside of the area covered by the Pleistocene ice sheets in northeastern Pennsylvania, and it can be used to locate, tentatively, the position of the Wisconsin–pre-Wisconsin boundary in the Quaternary system of the region.

Most of the paleosol remnants range in texture from clay loam to silt loam (fig. 3) and contain from a few percent to more than 25 percent of fragments of rock that range in size from pebbles to boulders or blocks several feet in diameter. Observed thicknesses of paleosol range from 1 to more than 30 feet. The matrix is considerably weathered, but most of the pieces of rock are firm and little weathered. Some pieces of medium-grained sandstone have yellowish-red, weathered rinds that range from 3 to 4 inches in thickness (the "rubified" pebbles of Peltier, 1949, p. 26–30). Fragments of calcareous rock are conspicuously absent, and many pieces of siltstone and shale are essentially fresh.

The matrix is very strongly acid. A preliminary study of its clay fraction by J. G. Cady of the U. S. Department of Agriculture (memorandum dated June

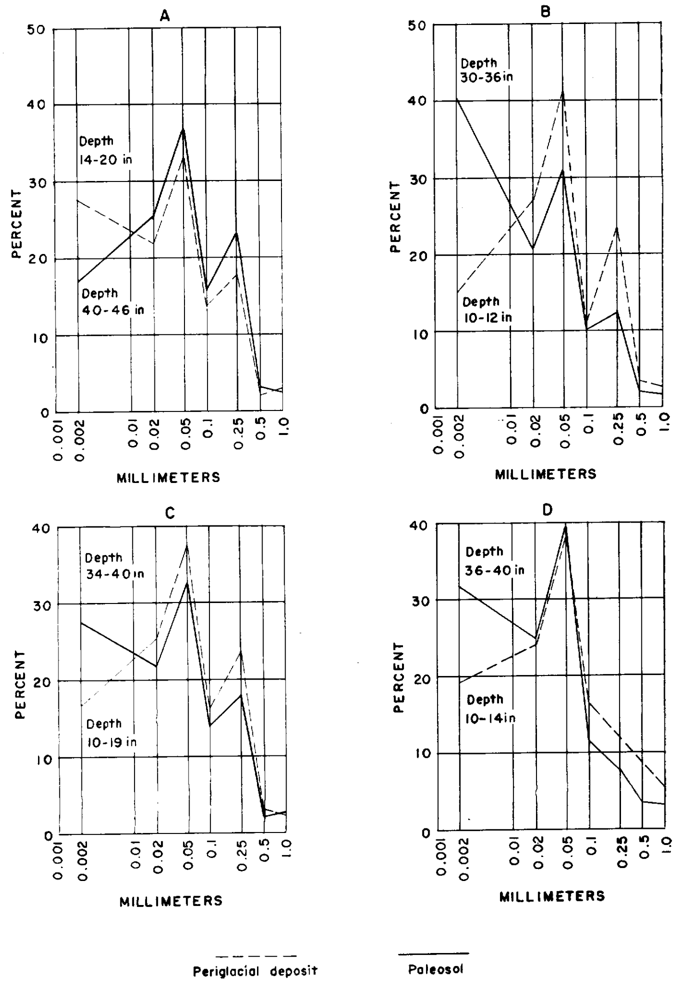


FIGURE 3.—Mechanical analyses of paleosol and overlying periglacial deposits, Potter County, Pa. Graph *A*: Uplands near Germania, Galeton quadrangle. Road cut about 200 feet south of junction (altitude 2,202 feet) of State Highway 144 and county road, about 1 mile west of Germania (loc. 16, pl. 1). Graph *B*: Uplands about 2½ miles north-northeast of Sweden, Genesee quadrangle (loc. 10, pl. 1). Graph *C*: Uplands about 1½ miles north northeast of Sweden, Genesee quadrangle. Rectangular area about 7⁄10 mile by one ⅛ mile (loc. 9, pl. 1). Graph *D*: Uplands west of Wharton, Wharton quadrangle. Road cut on west side of Ridge Road at head of Shanty Branch Hunts Run (loc. 19, pl. 1).

6, 1951) shows that it may contain as much as 4 percent of gibbsite and as much as 20 percent of kaolinite. The most conspicuous characteristics of the paleosol is its color which ranges from yellowish red to red (5 *YR* 4/6 to 2.5 *YR* 4/6). The red color is chiefly due to the clay fraction, which imparts the color to the whole matrix. There is some overlap in color between the paleosol and unweathered mantles derived from red beds in the Catskill formation. In most exposures however, the yellowish-red color of the paleosol and the purplish-red color of material derived from red beds can be differentiated. In general, the color of younger soils is within the 10 *YR* to 7.5 *YR* range (fig. 4).

The paleosol was developed from diverse kinds of parent material, such as calcareous till, gravel, and sand, residual mantles derived from sandstone, siltstone, shale, or any mixture of these various materials. Paleosol has been found outside the border of the Wisconsin drift throughout much of central and eastern Pennsylvania at altitudes that range from a few hundred feet to as much as 2,400 feet. Some remnants of the paleosol are on gently sloping uplands, others are on alluvial terraces, and still others are on rather steep valley walls.

In many places the paleosol is exposed on the ground surface, elsewhere it is overlain by younger deposits. In the Genesee quadrangle and elsewhere the paleosol is overlain by several feet of loose rubbly material that is believed to be a periglacial deposit of the Wisconsin stage. At two localities, just inside the border of the Wisconsin drift (Cobb Hill, Potter County, and in Columbia County), Wisconsin till rests on what is presumed to be paleosol.

POTTER COUNTY

The known remnants of paleosol in Potter County and vicinity are shown on plate 1 and most of them are listed in table 1. Some of the remnants are described on the following pages.

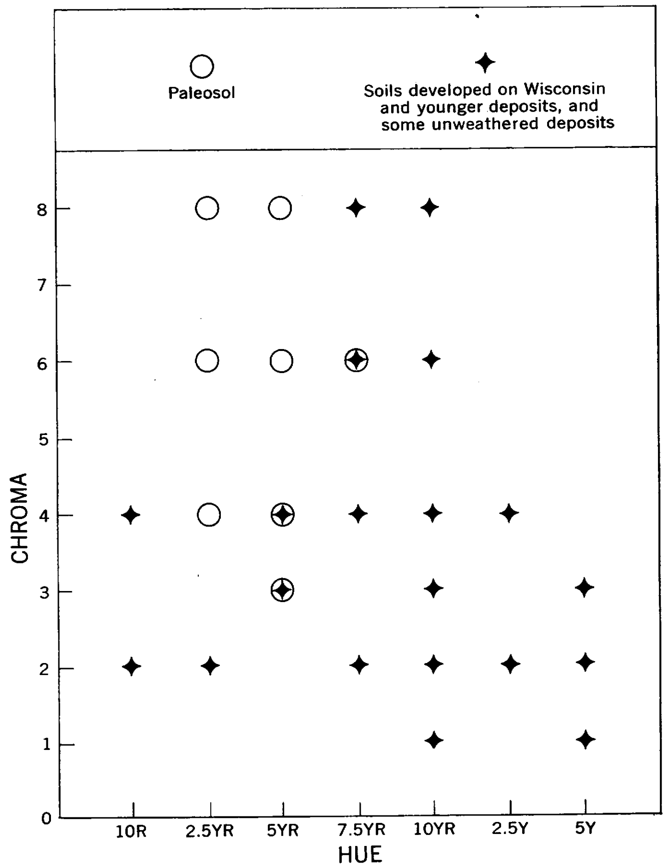


FIGURE 4.—Diagram showing hue and chroma of paleosol, of soils developed on Wisconsin and younger deposits, and of some unweathered deposits.

TABLE 1.—*Paleosol localities in Potter County and vicinity*

Locality no. on plate 1	Location [1]	Description
1	Uplands east of Hebron, Coudersport quadrangle. Gas line crossing Hebron-Greenman Hill School road, about 1/5 mile west of benchmark 2,342 feet. Altitude 2,240 feet.	Fragments of paleosol in material thrown up along excavation for gas line. Bedrock is sandstone and shale of the Catskill formation.
2	Uplands south of Hebron, Coudersport quadrangle. Road cut on divide between west branch of Dingman Run and Hogpen Hollow. Altitude 2,260 feet.	Paleosol, a gravelly clay loam, yellowish-red (5*YR*–4/6); overlain and mixed with periglacial deposit, a channery silt loam. Bedrock is sandstone and shale of Pottsville formation.
3	Cobb Hill, Genesee quadrangle	Possible remnant of paleosol, a sandy clay loam, reddish-yellow to strong-brown (7.5*YR*–6/6 to 5/6); overlain by at least 3 feet of Wisconsin till, silt loam to sandy clay loam, dark-reddish-gray (5*YR*–4/2), compact, contains well-rounded pebbles.
4	Uplands near Sweden Hill cemetery, which is 1¾ miles west of Sweden; Genesee quadrangle.	See text under Paleosol near Sweden Hill cemetery (p. 14).
5	Uplands at headwaters of Dry Run, Genesee quadrangle. Road cut about ½ mile south of Lyon Hill. Altitude 2,460 feet.	Paleosol, a sandy clay loam, yellowish-red. Bedrock is coarse-grained sandstone and fine-grained conglomerate of Pottsville formation.
8	Uplands northeast of Sweden, Genesee quadrangle. Road cuts along Sweden Valley-Brookland road, from 4/5 mile to 1 1/10 miles northeast of Sweden. Altitudes range from 2,300 to 2,320 feet.	Paleosol(?), channery clay loam, yellowish-red; developed on red shale and siltstone, Catskill formation.
9	Uplands about 1½ miles north-northeast of Sweden, Genesee quadrangle. Rectangular area about 7/10 mile long by 1/5 mile wide. Altitudes range from 2,360 to 2,520 feet.	Periglacial deposit, a gravelly loam to fine sandy loam, yellowish-brown, very strongly acid, thickness ranges from 1 to at least 5 feet; overlies paleosol, a gravelly clay loam, yellowish-red, very strongly acid, thickness at least 3 feet. Bedrock is red shale and gray sandstone, Catskill formation.
10	Uplands about 2½ miles north-northeast of Sweden, Genessee quadrangle.	See text under Paleosol northeast of Sweden (p. 13).
11	Uplands about 2 3/10 miles south of Gold, Genesee quadrangle. East bank of road, about 7/10 mile south-southwest of road corner, altitude 2,499 feet. Altitude of locality, 2,440 feet.	Periglacial deposit, a channery fine sandy loam, light-olive-brown (2.5*Y*–5/4), weak platy structure, thickness 20 inches; overlies paleosol, a channery clay loam, yellowish-red (5*YR*–4/6). Bedrock is sandstone and shale, Catskill formation.
12	Valley of Ninemile Run at mouth of Commissioner Run, Genesee quadrangle. Road cut on north side of U. S. Highway 6, east of Commissioner Run. Altitude 1,800 feet.	Periglacial deposit, a channery sandy loam, yellowish-brown, contains a 10-foot boulder of coarse-grained sandstone and fine-grained conglomerate, thickness ranges from 5 to 10 feet; overlies paleosol(?), a channery silt loam, yellowish-red to strong-brown, contains numerous fragments of yellowish-red (weathered) sandstone, thickness more than 1 foot. Bedrock is sandstone and shale, Catskill formation.
15	Uplands near Germania, Galeton quadrangle. Road cut at road corner 1 1/5 miles north-northwest of Germania or about 1/5 mile north of benchmark 2,061 feet. Altitude 2,080 feet.	Paleosol interlaid with periglacial deposit. Bedrock is red shale and sandstone, Catskill formation.
16	Uplands near Germania, Galeton quadrangle. Road cut about 200 feet south of junction (altitude 2,202 feet) of State Highway 144 and county road, about 1 mile west of Germania. Altitude 2,180 feet.	See plate 3, section E.
17	Terrace at mouth of Cowley Run, near Sizerville, Emporium quadrangle. Northwestern edge of terrace about 35 feet above flood plain to southeast of Cowley Run. Southeast side of county road about 1,600 feet east of mouth of Cowley Run. Altitude 1,220 feet.	Periglacial deposit, a channery silt loam, gray and brown, mottled, thickness about 6 feet; overlies paleosol, a gravelly clay loam, yellowish-red, mottled, contains well-rounded and disc-shaped pebbles of sandstone that crumble easily in the fingers. Bedrock is shale and sandstone, Catskill formation.
19	Uplands west of Wharton, Wharton quadrangle. Road cut on west side of Ridge Road at head of Shanty Branch Hunts Run, about 1,200 feet east of western border of quadrangle. Altitude 1,920 feet.	Periglacial deposit(?), a gravelly loam, yellowish-brown, thickness about 20 inches; overlies paleosol, a clay loam, yellowish-red. Bedrock is sandstone and shale of Pocono formation.
20	Southeast side of valley of Kettle Creek, Short Run quadrangle Southeast of Laurel Bottom. Altitude 1,160 to 1,300 feet.	Paleosol, gravelly sandy clay loam, yellowish-red to yellowish-brown; underlain by sand and gravel (see pl. 8).
24	Uplands near Tamarack, Tamarack quadrangle. Road cut on north side of road about 2/5 mile north-northeast of Tamarack. Altitude 1,730 feet.	Periglacial deposit(?), a silt loam, yellowish-brown (10*YR*–6/6), thickness about 18 inches; overlies paleosol, a gritty clay loam, red (2.5*YR*–4/8), black stain on surface of cracks, contains a few fragments of yellowish-brown and of yellowish-red (weathered) sandstone, thickness at least 1 foot. Bedrock is red beds of Catskill formation.

See footnote at end of table.

TABLE 1.—*Paleosol localities in Potter County and vicinity*—Continued

Locality no. on plate 1	Location[1]	Description
25	Valley of Kettle Creek, Tamarack quadrangle. Road cut on northwest side of State Highway 144, about 1,600 feet southwest of bridge over Kettle Creek near Laurel Hill cemetery and 1 mile southwest of Cross Fork. Altitude 1,080 feet.	See figure 9, section F.
26	Valley of Kettle Creek, Tamarack quadrangle. Road cuts on northwest side of State Highway 144 northwest of mouth of Bundle Hollow, 2½ miles east of Cross Fork. Altitude 1,160 feet.	Periglacial deposit, a gravelly sandy loam, thickness 2 to 5 feet, overlies paleosol, a gravelly sandy clay loam, yellowish-red, thickness at least 6 feet.
30	Valley of Kettle Creek, Keating quadrangle. Road cut about 70 feet above west bank of Kettle Creek located about ⅗ mile north of bridge. Altitude 890 feet.	Periglacial deposit, a channery silt loam, purplish-red, thickness about 2 feet; overlies paleosol, a gravelly clay loam, yellowish-red, thickness at least 2 feet. Paleosol contains a few, well-rounded pebbles. Bedrock is red beds of Catskill formation.
31	Valley of West Branch Susquehanna River, Renovo west quadrangle. Road cut on north side of U. S. Route 120 about 1,400 feet west of North Smith Run, 2⅒ miles southwest of Westport. Altitude at road 730 feet.	Periglacial deposit, a blocky colluvium, contains blocks as much as 6 feet in diameter; thickness ranges from 6 to 10 feet; overlies paleosol developed on blocky colluvium that ranges in thickness from 10 to 20 feet. The colluvium rests on bouldery gravel, thickness exposed ranges from 10 to 20 feet. Bedrock is sandstone and shale, Ponoco formation.
32	Valley of West Branch Susquehanna River, Renovo west quadrangle. Road cut on north side of U. S. Route 120 about 600 feet southwest of Shintown Run and 3/10 mile west of Shintown. Altitude at road 740 feet.	See plate 3, section G.
33	Valley of Pine Creek, Slate Run quadrangle. Road cut at cemetery about 70 feet above mouth of Slate Run.	Paleosol, a pebbly and cobbly gravel with a silt loam matrix, yellowish-red (5*YR*–5/6); some pebbles crumble in the fingers.

[1] Location of paleosol localities described with reference to minor geographic features that are not shown on plate 1 but appear on the topographic maps of the quadrangles Coudersport, Genesee, Ayers Hill, Galeton, Emporium, Wharton, Short Run, Oleona, Lee Fire Tower, Tamarack, Slate Run, Waterville, Keating, Renovo West issued by the U. S. Geological Survey. The map of the Genesee quadrangle is the base for plate 4 of the present report.

PALEOSOL NORTHEAST OF SWEDEN, GENESEE QUADRANGLE

In the periglacial area northeast of Sweden (loc. 10, pl. 1) several small remnants of paleosol lie on the divide between the Allegheny River and Pine Creek (pl. 4), not more than 2 miles southwest of the border of the Wisconsin drift.

One of the remnants is located along the road that runs from Sweden to Gold on the divide between Woodcock Creek and Reese Hollow, about 2 miles south-southeast of Raymond (fig. 5). The paleosol underlies an oval-shaped area whose surface form and microrelief is identical with that of the surrounding gentle slopes.

The paleosol is developed on unweathered mantle that is unsorted silty material containing numerous fragments of sandstone and siltstone. This mantle ranges from a few inches to at least 2 feet in thickness and overlies partially disintegrated bedrock.

The paleosol (fig. 6, and pl. 3, sec. *A*) ranges in texture from loam to clay (fig. 3), clay loam being the most common type. In most places the material contains rock fragments that make up from 10 to 20 percent of the total volume of paleosol. About half the fragments are yellowish red and many of them have a yellowish-brown rind about a quarter of an inch thick. The color of this paleosol is dominantly yellowish red (5*YR* 4/6).

The periglacial deposits range in texture from rubbly or channery fine sandy loam to silty clay (fig. 3), silt loam being the most common type. These deposits contain from 20 to 40 percent by volume of fragments of greenish-gray sandstone and siltstone, which are very slightly weathered throughout, or which have weathered rinds not more than a quarter of an inch thick. A very few fragments of yellowish-red sandstone are present also.

The color of the periglacial deposits is dominantly yellowish brown (10*YR* 5/6). The material is unsorted, generally loose to friable, and soft to hard when dry, depending on its content of fine-textured material.

J. G. Cady of the U. S. Department of Agriculture, made a preliminary study of clay minerals in samples of the paleosol and overlying periglacial deposits from the exposure shown in figure 6 (memorandum dated June 6, 1951). The periglacial deposits contain "* * * about 8 percent kaolinite, trace of gibbsite, and a large amount of illite or other micaceous mineral." The paleosol contained "* * * about 20 percent kaolinite, 3 to 4 percent gibbsite, and illite and chlorite or vermiculite (i. e. a mineral with 14A interplanar spacing) but not montmorillonite."

The paleosol forms a lens-shaped body that is overlain by a blanket of perioglacial deposits (fig. 7). The contact between the paleosol and periglacial deposits

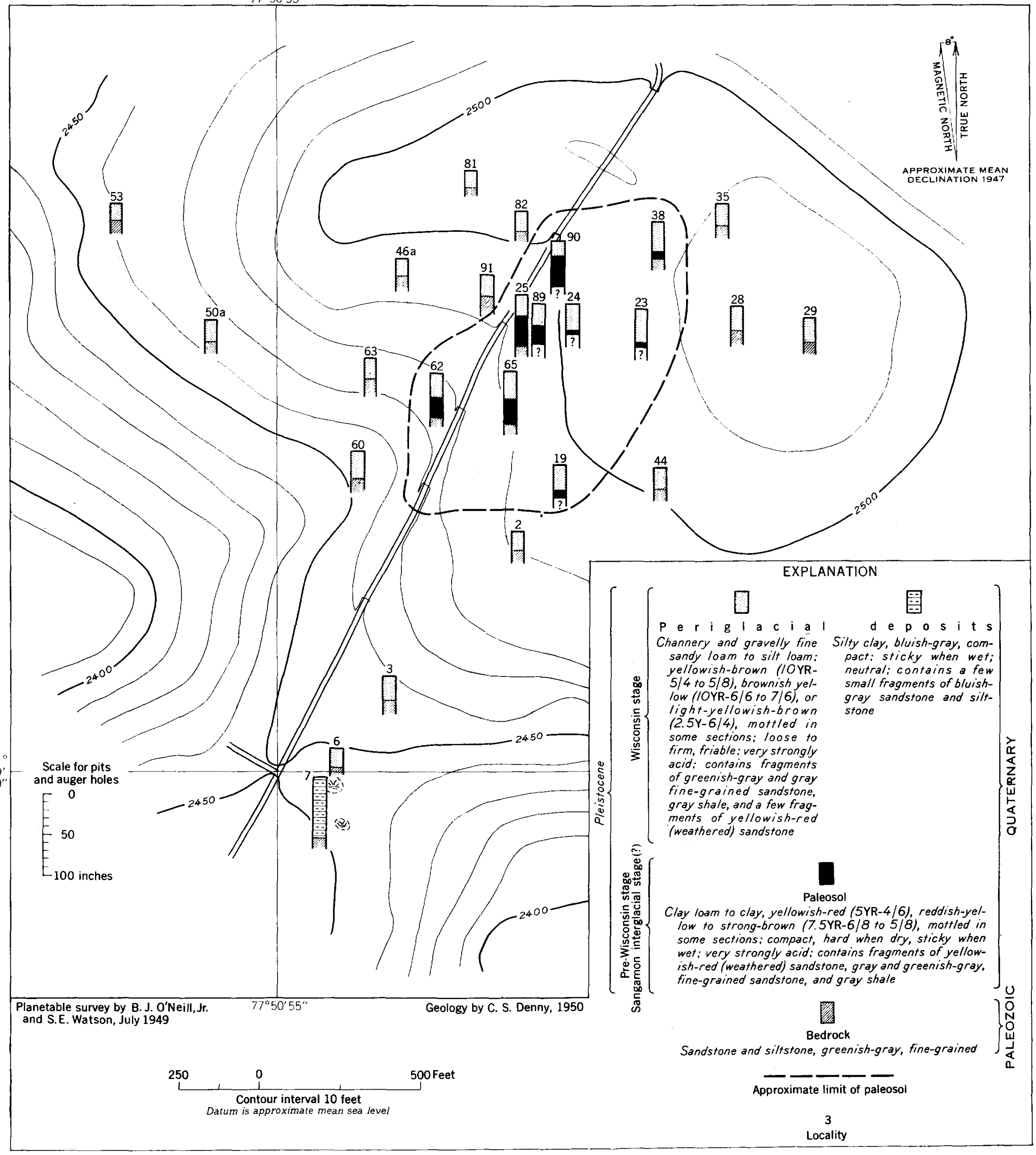


FIGURE 5.—Map showing distribution of and data recorded from pits and auger holes in and near area underlain by paleosol northeast of Sweden, Genesee quadrangle, Potter County, Pa. Area is located about 2 miles south-southeast of Raymond along road on divide between Woodcock Creek and Reese Hollow. In 1949, there were continuous exposures of paleosol and periglacial deposits along road.

is in some places sharp; elsewhere, the transition zone may be as much as 6 inches wide. Where the ground surface is essentially horizontal, the contact may have a microrelief of as much as 2 feet. On some gentle slopes (fig. 6), tongue-shaped masses of periglacial deposits project downward into the paleosol and incline slightly upslope ("plications", Bryan, 1946, fig. 4).

PALEOSOL NEAR SWEDEN HILL CEMETERY, GENESEE QUADRANGLE

Remnants of paleosol occur on the uplands about 2 miles west of Sweden (loc. 4, pl. 1) or about 4 miles southwest of the border of the Wisconsin drift (pls. 2 and 4). The scarce bedrock exposed is dominantly greenish-gray sandstone, with a few beds of purplish-red siltstone and gray shale (Catskill formation). The surficial deposits were nearly continuously exposed along the northward-trending road.

The paleosol here ranges in texture from sandy clay loam to sandy loam. In most places the paleosol contains not more than 5 percent by volume of rock fragments, most of which are less than 2 inches in diameter. Yellowish-red and greenish-gray sandstone predominate, but purplish-red siltstone is present also. The fragments of yellowish-red sandstone probably owe their color to pre-Wisconsin weathering of greenish-gray sandstone. A boulder of sandstone 1 foot in diameter has a yellowish-red surficial rind 2 inches thick, inside of which is a yellowish-brown zone 1 to 2 inches thick that surrounds a core of hard, and apparently unweathered, greenish-gray sandstone.

The pits and auger holes shown on plate 2 suggest that a lens-shaped remnant of paleosol extends from near locality 107 southwestward to the intermittent stream. This paleosol is developed on weathered, and probably residual, sandy and silty materials. It thickens upslope and apparently rests in a slight concavity on the bedrock slope.

At two other localities there are possible remnants of paleosol. Near the cemetery, at locality 19 (pl. 2), about 3½ feet of yellowish-red silt loam to sandy clay loam overlies at least 3 feet of brownish sandy loam (pl. 3, section *C*), which contains fragments of yellowish-red sandstone assumed to be colored by pre-Wisconsin weathering. This assumption suggests that the sandy loam is a Wisconsin periglacial deposit derived in part

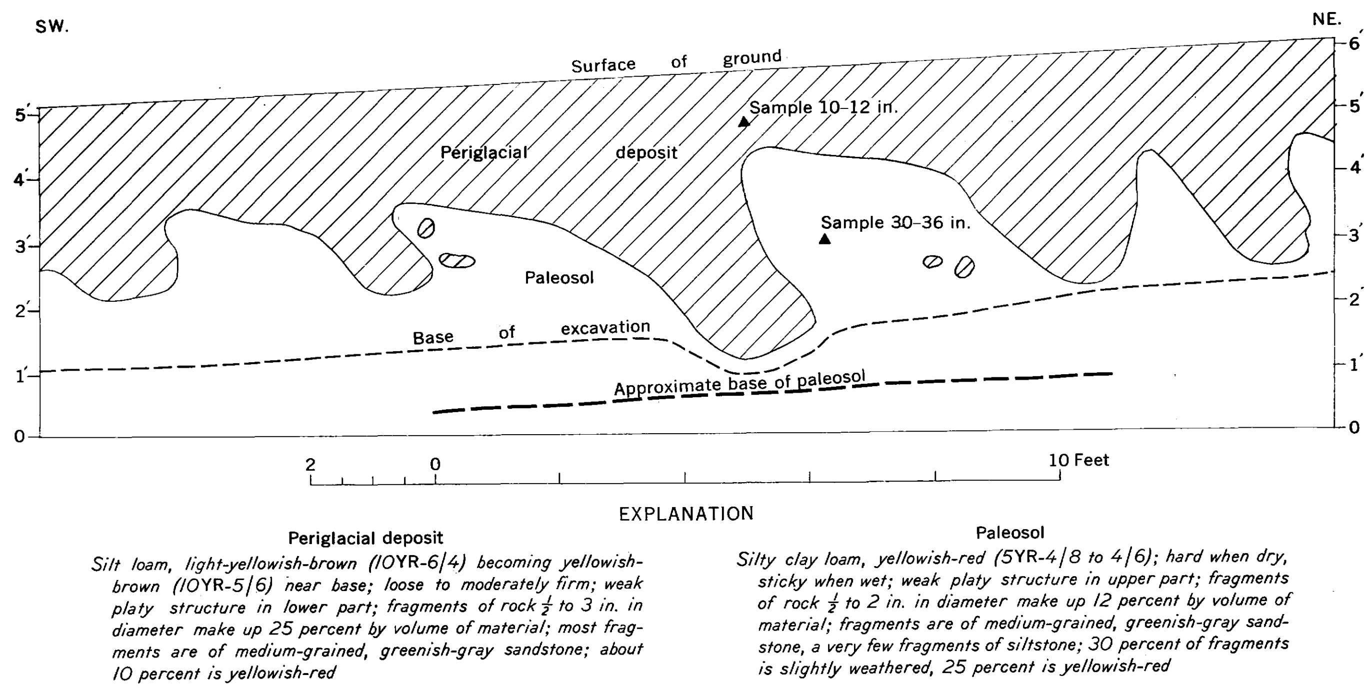


FIGURE 6.—Section through paleosol and overlying periglacial deposit. West bank of Sweden-Gold road, 2½ miles north-northeast of Sweden, Genesee quadrangle, Potter County, Pa. (loc. 25, fig. 5). Altitude 2,480 feet. Slope about 3° (5 percent) to southwest.

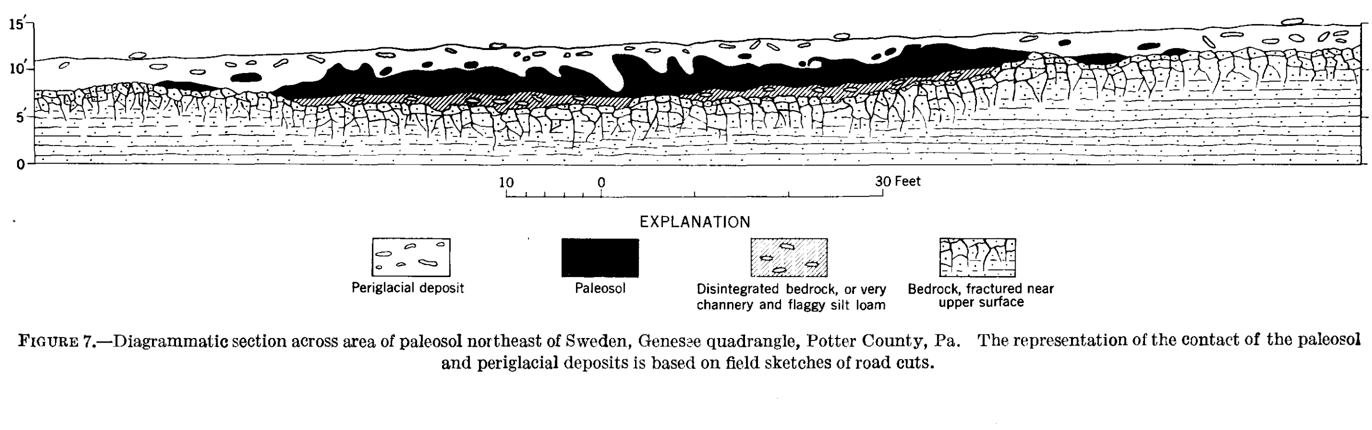


FIGURE 7.—Diagrammatic section across area of paleosol northeast of Sweden, Genesee quadrangle, Potter County, Pa. The representation of the contact of the paleosol and periglacial deposits is based on field sketches of road cuts.

from paleosol. Between these two horizons is a layer, about 6 inches thick, of reddish sandy loam (depth 3.5 to 3.9 feet), which apparently has been weathered very little, and which contains numerous fragments of purplish-red siltstone. The upper yellowish-red horizon probably was weathered in pre-Wisconsin time and then was transported, more or less en masse, in Wisconsin time to its present position. The data at locality 21, to the west, suggest also an interlayering of remnants of paleosol with less weathered material presumed to be a Wisconsin periglacial deposit. It is probable that many remnants of the paleosol have been transported from their places of formation.

Most of the materials that overlie the paleosol are believed to be of periglacial origin. They are unstratified and sandy, but range in texture from loamy sand to silt loam. The consistence is loose to moderately friable. These sandy materials contain fragments and blocks that range in maximum diameter from a fraction of an inch to more than 1 foot, and these fragments and blocks comprise, roughly, from 1 to 15 percent of the total volume of material. The most abundant rock type is yellowish-brown to greenish-gray sandstone, with subordinate yellowish-red sandstone (presumed to have been derived from the paleosol), purple siltstone, and gray shale. These materials range in thickness from 2 to at least 7 feet, with an average of about 3 feet. These sandy deposits apparently thicken from the ridge crests down toward the intermittent stream in the southwestern part of the area. The depth to bedrock in the well at locality 14 is reported to be 22 feet.

ORIGIN OF PALEOSOL

The paleosol was developed by weathering in pre-Wisconsin time, probably during the Sangamon interglacial stage; the overlying periglacial deposits were formed by weathering and mass movements, chiefly solifluction, during and immediately following the time of maximum extent of the Wisconsin ice sheet. The paleosol was developed on material that closely resembles the overlying periglacial deposits. Indeed, it is possible that the parent materials were periglacial deposits of the Illinoian stage. No erratics or other evidence have been found to indicate that the parent materials were drift. The paleosol contains a higher percentage of clay than the parent material and the overlying periglacial deposits (fig. 3). It also contains gibbsite, a mineral usually associated with lateritic weathering. The yellowish-red fragments of rock in the paleosol are assumed to owe their color to the episode of weathering that produced the gibbsite; in other words, the coloring is a result of weathering in pre-Wisconsin time before the overlying periglacial deposits were formed. Presumably, the paleosol originally covered the entire area and has now been almost entirely removed.

The overlying periglacial deposits probably result from downslope movement of a mixture of frost-broken bedrock and paleosol. The ancient soil is preserved under gentle slopes because transport of material downslope was relatively slow. Where the bedrock surface is steep, the ancient soil was removed completely. The periglacial deposits moved downslope and became relatively stabilized with the amelioration of the climate following deglaciation.

The periglacial deposits were derived largely from the bedrock rather than from the paleosol—at least the latter was not the principal source. The periglacial deposits are discussed in detail in a later section of this paper (p. 30).

An alternative explanation is that the paleosol is the *B* horizon of a soil whose *A* horizon is represented by the periglacial deposits. For example, in the area of paleosol northeast of Sweden the boulders in the *A* horizon (periglacial deposits) are residual boulders concentrated by removal of fines, and the complicated structures in the soil were produced by minor differential mass movements during a cold period. This hypothesis is unlikely because relatively unweathered fragments of rock are much more abundant in, and on, the periglacial deposits than in the underlying paleosol, and because (in places) 5 feet of periglacial deposits overlie paleosol. In some places, the surface of the periglacial deposits is littered with large fragments and blocks, whereas the underlying paleosol contains only small fragments of rock. The plications of the periglacial deposits with their upslope inclination suggests movement of the periglacial deposits down slopes of only 2° to 3° (3 to 5 percent). A certain amount of mixing of the materials took place near their plane of contact. The tongues of periglacial deposits that project downward (fig. 6) may be the casts of ice wedges. On ridge crests, the periglacial deposits are thin (fig. 5). Their weathering is similar in degree, depth, and general character to that of the adjacent early Wisconsin drift. If the periglacial deposits on ridge crests were derived from the paleosol by weathering in place, it is unlikely that the resulting material would appear to be so little weathered. Ancient boulder rings, boulder stripes, and miniature block fields are found on the surface of the periglacial deposits in parts of the area northeast of Sweden and near Sweden Hill Cemetery (p. 34). Evidently, the periglacial deposit that overlies the paleosol was chiefly derived from bedrock upslope. All known remnants of the paleosol in the Genesee quadrangle lie on gentle slopes; none are found on hilltops.

The surficial deposits in the area near Sweden Hill Cemetery apparently thicken toward the intermittent stream near the road corner (pl. 2); therefore the valley of the stream was probably deeper in pre-Wisconsin time than it is now. Transportation and deposition of periglacial deposits of the Wisconsin stage tended to fill the stream valley and to reduce the local relief slightly. These processes produced smooth ungullied slopes that are more gentle than the surface of the underlying bedrock.

LYCOMING COUNTY, PENNY HILL, MILTON QUADRANGLE

A deep section of paleosol that developed on gray moderately calcareous till is exposed in a road cut on Penny Hill, Milton quadrangle. The exposure (loc. 1, fig. 1) is on the west side of U. S. Highway 15, about 1¾ miles southwest of Montgomery in the top of a broad ridge that is underlain partly by till and partly by thin-bedded, gray sandstone and siltstone. The exposure is described in detail by Peltier (1949, p. 28, fig. 8), who states that the yellowish-red, weathered ("rubified") horizon passes horizontally from the till into the adjacent bedrock. This cut is the thickest section of paleosol known to the writer.

About 16 feet of red (2.5 *YR*-4/8 moist) reticulately mottled clay loam overlies about 10 feet of yellowish brown (8–9 *YR*-5/8) clay loam with prominent black coatings that rests on about 7 feet of extremely acid olive clay loam. The underlying material (from 33 feet to base of cut at 38 feet) is olive calcareous clay loam (till).

Pebbles of sandstone and siltstone occur throughout the profile and are only moderately weathered except in the upper 16 feet where some of the fragments crumble between the fingers. Washing of the fragments removes most of the red color, which apparently is chiefly in the clay fraction. The material is leached of free carbonates down to a depth of 33 feet. Pebbles, cobbles, and fragments of sandstone, siltstone, shale, conglomerate, and dark-gray, fine-grained limestone are found in the calcareous till. Many are striated.

For the following reasons, the paleosol is believed to have formed in place from the underlying calcareous drift: the transition in color downward; the high percentage of clay in the upper part of the paleosol, which is believed to result from weathering; the presence of striated pebbles and cobbles in the lower part of the paleosol; and the absence of limestone pebbles in the paleosol.

AGE OF PALEOSOL

The paleosol is believed to have been formed in pre-Wisconsin time for the following reasons. The paleosol is not found at the surface within the area of Wisconsin drift. Two exposures of Wisconsin drift resting on material that may be paleosol have been found—one in Potter County (loc. 3, pl. 1), and the other in Columbia County (loc. 2, fig. 1). The presence of paleosol on the deposits of a high terrace along the West Branch Susquehanna River (loc. 32, pl. 1), and its absence on low terraces, suggest that the low terraces are younger than the paleosol. Peltier's work (1949) indicates that the low terraces were formed during the Wisconsin stage and that the high terrace was formed during a pre-Wisconsin stage. In eastern Pennsylvania, as at Penny Hill, the paleosol is thicker than soils developed on Wisconsin and younger deposits. In addition, there seems to be more clay developed by weathering in the paleosol than is present in soils developed on Wisconsin and younger deposits (fig. 3).

In the Genesee quadrangle, the paleosol is overlain by periglacial deposits. The hypothesis is presented elsewhere (p. 30) that the periglacial deposits were formed during an early substage of the Wisconsin stage and, therefore, the underlying remnants of paleosol are of pre-Wisconsin date. The material exposed in the trench silo near Colesburg, Genesee quadrangle (fig. 22), is interpreted as periglacial colluvium of the Wisconsin stage. The lower reddish material was derived from paleosol, the upper, less-weathered colluvium is composed of material derived from beneath the paleosol, probably from disintegrated bedrock.

The paleosol is assigned tentatively to the Sangamon interglacial stage. The exposure at Penny Hill demonstrates that there was at least one stage of glaciation prior to development of the ancient soil. The reasons for assigning this episode of soil formation to the Sangamon stage, and the materials thus affected to the Illinoian stage, are as follows: The fragments of rock in the paleosol are slightly weathered as compared with those in deposits of pre-Illinoian date, such as gumbo tills of the Kansan stage (Kay and Apfel, 1929) or the pre-Illinoian or Jerseyan drift in New Jersey (MacClintock, 1940). In a region of considerable relief, such as central and eastern Pennsylvania, most deposits dating from pre-Illinoian time should have been moved by erosion. The widespread occurrence of paleosol suggests that it is not older than the Illinoian stage; however it is possible that several ages are represented, the residua of which are more or less haphazardly preserved.

ORIGIN AND CLIMATIC SIGNIFICANCE

The paleosol is believed to result from weathering during the Sangamon interglacial stage. Originally, the ancient soils probably made a relatively continuous blanket of varying thickness, which, since the Sangamon has been extensively eroded and completely removed from broad areas. Some of this removal may have taken place in late Sangamon time. The climatic conditions under which the paleosol was formed are unknown. The characteristic yellowish-red color probably was developed in only relatively well-drained material. Parent materials that were poorly drained throughout Sangamon time would not have been transformed into a soil with a yellowish-red color.

The paleosol resembles the Red-Yellow Podzolic soils of the southeastern states; soils that "* * * are found characteristically under humid, warm-temperate climates, but * * * extend into tropical climates as well" (Simonson, 1950, p. 316. See Simonson's paper for a definition of Red-Yellow Podzolic soils, past and present concepts of their genesis; and their relationship to other great soil groups). Cady's study of clay minerals in the paleosol (memorandum dated June 6, 1951) indicates that it contains a small percentage of gibbsite, a mineral found in some Red-Yellow Podzolic soils and usually associated with lateritic weathering (Alexander, Hendricks, and Faust, 1942). Nikiforoff (personal communication) suggests that if there was no ice in Greenland during the Sangamon (that is, a true interglacial period), the great soil groups would extend across the continent as broad bands trending more or less eastward rather than southeastward as they do today (Orvedal, 1949). During Sangamon time, a broad belt of red lateritic soils may have extended from Illinois eastward through Pennsylvania and New Jersey. Therefore, it is possible that yellowish-red paleosols over a wide area are the products of weathering and soil formation during the Sangamon stage. If the paleosol in Pennsylvania is Sangamon, where should the boundary be drawn between the area of paleosol remnants and the region of Red-Yellow Podzolic soils? This problem raises the question as to whether or not some Red-Yellow Podzolic soils are relics of a past climatic episode—a hypothesis once favored by soil scientists but, at present, largely abandoned (Simonson, 1950).

Possibly the paleosol formed under a climate similar to the present. Perhaps the absence of paleosol on Wisconsin drift merely indicates that there has been insufficient time since the drift was deposited to develop a soil with a heavy-textured, yellowish-red *B* horizon. If the Sangamon stage was several times longer than post-Sangamon time, it is possible that the paleosol might have been formed under a climate similar to the present, and it may not be indicative of more-tropical conditions (Guy D. Smith, personal communication).

PRE-WISCONSIN GLACIAL DEPOSITS

POTTER COUNTY

There has been no undoubtedly pre-Wisconsin drift recognized in Potter County. K. V. Goodman of the Soil Survey found numerous rounded pebbles on a gently sloping upland (pl. 1, and fig. 8) in the periglacial area about 10 miles southwest of the border of Wisconsin drift. Here, a cultivated field was covered with scattered pebbles and fragments of sandstone and conglomerate and one fragment of weathered chert was found. The pebbles are round to oval, and many are more or less weathered throughout to yellowish brown. A few of the pebbles and some of the fragments weather yellowish red and resemble those found in the paleosol. Near the lower northwest end of the area the pebbles and fragments appear more weathered, both in degree and proportion, than those near the upper end. Many pebbles were broken before they were deeply weathered. Some of the fragments are subangular and resemble fragments from till; one subangular fragment was striated. The area is underlain by 1 to 3 feet of yellowish-brown loam to silt loam. This, in turn, rests on reddish channery silt loam to clay loam that contains many fragments of red siltstone and shale, apparently derived from the Catskill formation. No paleosol was

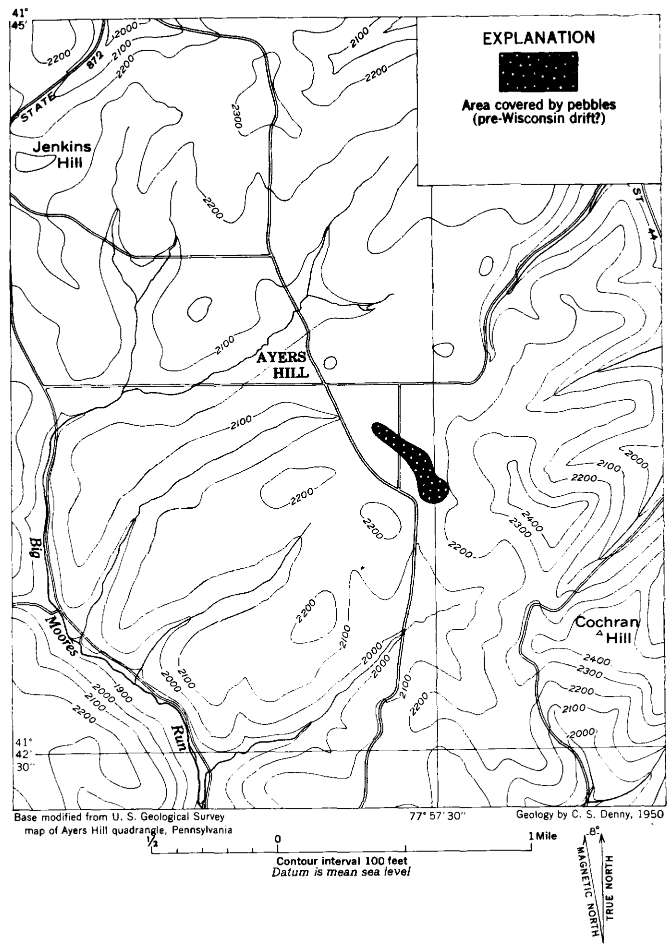


FIGURE 8.—Map of remnant of pre-Wisconsin drift (?) southeast of Ayers Hill, Ayers Hill quadrangle, Potter County, Pa. The locality is about 10 miles southwest of border of Wisconsin drift (pl. 1).

found under the pebble-covered area, but paleosol is exposed on the uplands about 1¼ miles to the north (loc. 13, pl. 1).

The data justify the following conclusions: The pebbles have been transported by running water, were broken after they were rounded, and, later, were weathered in pre-Wisconsin time. Their occurrence on a divide where no streams could have transported them in recent or late Pleistocene time indicates considerable antiquity. The pebbles antedate the paleosol, and none of the paleosol remnants in or near Potter County are developed from drift. The nearest remnant of pre-Wisconsin drift is near Williamsport (fig. 1). Either the pebbles are a remnant of an early Pleistocene, pre-Illinoian drift, or they are remnants of ancient stream deposits. The finding of one fragment of chert (an erratic?) and one striated pebble favor the drift hypothesis.

SALAMANCA REENTRANT

In the Salamanca reentrant in New York, northwest of Potter County (fig. 1), MacClintock and Apfel (1944) recognized one Illinoian and three Wisconsin drifts. The Illinoian drift apparently is not covered by yellowish-red paleosol which is so characteristic of the so-called Illinoian drift in the Susquehanna Valley. After seeing outwash gravel in the Susquehanna Valley that is "rubified" to depths of as much as 10 feet, it is difficult to escape the conclusion that the latter gravels have undergone an episode of weathering that has not affected the so-called Illinoian gravels of the reentrant. Perhaps some of the Illinoian drift of MacClintock and Apfel in the Salamanca reentrant is of early Wisconsin age.

PRE-WISCONSIN ALLUVIAL DEPOSITS IN KETTLE CREEK VALLEY

Alluvial and colluvial deposits are widely scattered throughout the area outside of the border of the Wisconsin drift. Most of the deposits belong to the Wisconsin stage, but some are the parent material for paleosol and apparently date from pre-Wisconsin time. The following is a brief description of the pre-Wisconsin alluvial deposits along the valley of Kettle Creek, which resemble those in other valleys in and near Potter County.

On either side of Kettle Creek valley (pl. 1) are alluvial fans and colluvial benches whose tops slope gently toward the creek. On the southeast side of the creek above Laurel Bottom, about 4½ miles southwest of Oleona (pl. 8) paleosol is developed on sand and gravel that extends from the floodplain to a height of about 150 feet above the creek. The data indicate that in pre-Wisconsin (pre-paleosol) time the valley was excavated to at least its present depth and then was filled with at least 150 feet of sand and gravel. In texture and lithology these deposits resemble those now being deposited by the creek, and they may record a period of valley filling of Illinoian age; the filling was caused by climatic change rather than by the presence of glacial ice in the headwaters. Other gravel deposits, which probably are of the same episode of valley filling, are found near Oleona, Cross Fork, and south of Leidy (locs. 25, 26, and 30, pl. 1). These pre-Wisconsin alluvial deposits were greatly modified during Wisconsin and later times (p. 38).

WISCONSIN GLACIAL DEPOSITS, GENESEE QUADRANGLE

The Wisconsin glacial deposits of Potter County belong to either the Iowan or Tazewell substages—probably to the Iowan. The deposits are dominantly till with small masses of glaciofluvial sediments. The till is an unsorted mixture of rock fragments in a matrix that ranges from sandy loam to silty clay. Most of the till is of local origin. The dominant rock type is sandstone; erratics of igneous rock or of metamorphic foliates comprise less than 0.5 percent of the total number of rock fragments. Thicknesses range from a few feet to about 50 feet. The drift is slightly weathered to depths that vary over wide limits. Till occurs as small areas of low knolls and depressions on uplands and in valleys, and as material underlying smooth gentle slopes on lower valley walls and valley bottoms (pl. 4). In the first instance, the till may be ground moraine; in the second instance, the till probably has been modified by mass wasting and other processes during deglaciation. Many of these smooth gentle slopes are mantled with boulders that locally have the configuration of boulder rings or boulder stripes.

Small and scattered deposits of stratified sand and gravel occur as kame terraces in the Genesee Valley near Genesee (pl. 4); near Shinglehouse, Coudersport quadrangle; in the Gaines quadrangle (Fuller, 1903a) along Pine Creek near Galeton; and in the Cowanesque Valley. Varved silt and clay, believed to antedate the last glaciation, are exposed at a few places in the Genesee Valley near West Bingham.

The drift border is indefinite; it has been drawn at the southern limit of erratics or well-rounded or striated pebbles and cobbles, and in a few places it is marked by a belt of terminal moraine or by a distinct change in the surficial deposits. There are almost no glaciofluvial deposits in valleys that drain away from the drift border. The drift border forms a relatively straight line that conforms in detail to the local topography but, in general, crosses the area in a northwesterly direction with little regard for the major topographic features. Study of the drift border leads to the assumption that the ice sheet had a relatively straight and steeply sloping front. Several glacial spillways (pl.1) near the drift border south and southeast of Galeton probably were cut by melt water ponded between the ice sheet and the hills to the southwest.

Inside the drift border, miscellaneous surficial deposits mantle slopes, uplands, and valley bottoms and are mapped as "thin mantles" (pl. 4,). Most of these deposits are less than 5 feet thick and include rubbles that resemble the periglacial deposits and drift. The mantles are of diverse age and origin—being part glacial, part periglacial, and part postglacial.

TILL

LITHOLOGY

The till ranges from sandy loam to silty clay and is unsorted except for a very few lenses of stratified material. Near Genesee, however, is a bouldery and pebbly till composed of reworked fluvial deposits. Unweathered or very slightly oxidized till derived from sandstone is grayish brown (10*YR*–5/2) to gray (5*Y*–5/1). The firmness, compaction, and plasticity of the till varies directly with the percentage of clay in the matrix. Heavy-textured, clay-rich till is hard when dry and is sticky and moderately plastic when wet. The upper 2 to 3 feet of most of the till is loose; it contains a higher percentage of rock fragments than the material below and resembles the thin mantles.

The till contains varying proportions of pebbles, cobbles, boulders, fragments, flagstones, and blocks. The percentage of rock fragments varies from 2 to more than 30 percent by volume. A medium-grained, thin-bedded, gray to greenish-gray or purplish-gray sandstone is the dominant rock type. Striated fragments are found in essentially unaltered till, but they form only a few percent of the total. Well-rounded pebbles are relatively abundant in till on the slopes of northward- and eastward-draining valleys, which drained toward the ice sheet as it advanced. These pebbles were derived from older gravel deposits. Erratics are found on the surface of most exposures of till, but very few erratics have been found in situ in the till, where they form less than 1 percent of the total.

A moderately well developed platy structure is seen in many exposures of clay-rich till. The long axes of the plates are about parallel to the ground surface. This type of platy structure is found in clay-rich tills in many regions and has been attributed to the orientation of mineral grains by the weight of the overlying ice. It has been described as a "cleavage" or as a "horizontal fissility" (Flint, 1947, p. 106.) However, such a structure is also present in the *A* or *B* horizons of many soils outside of glaciated areas.

The origin of such a platy structure in till is obscure. Perhaps it results from the formation of ice lenses, either at present or in the past. Platy structure seems most apparent in the upper part of thick tills and may be absent at depths of 10 to 20 feet. This relationship does not necessarily exclude till fabric as a factor in development of platy structure, but it suggests that other factors should be considered.

THICKNESS

Although the till is mapped only where it is assumed to be at least 5 feet thick, exposures are insufficient to demonstrate thickness everywhere—delineation of till on the map is based on consideration of local topography, soil drainage, and vegetation. Outcrops of bedrock are scarce compared with the area of thin mantles (pl. 4).

Deep exposures are scarce—none exceed 20 feet and few reach depths of 6 feet. The field relations along Raplee Hollow, west of Gold (pl. 4), suggest a thickness of at least 30 feet, perhaps as much as 50 feet. The stream in the hollow flows eastward to Gold through a bedrock gorge. The upper reaches of the hollow probably drained northeastward to Middle Branch before the drift dammed the lower end of the valley and forced the stream to cut the bedrock gorge. Data from wells (pl. 1; Lohman, 1939, pl. 2 and p. 180–187) show depths to bedrock at various localities but do not differentiate in detail the material encountered. A well on the valley wall north of Raymond (no. 387, pl. 1) went through 50 feet of surficial deposits; a well at Gold (no. 385, pl. 1) was sunk to a depth of about 70 feet in sand and gravel; wells on the uplands near Lewisville and North Bingham encountered surficial deposits to depths of about 40 feet (nos. 374, 380, 383, and 384, pl. 1).

WEATHERING

The till is slightly weathered and much of it is oxidized to depths of more than 10 feet. The weathered till is yellowish brown, and where it is rich in clay it is mottled. Most rock fragments are fresh or only very slightly discolored, a few are slightly weathered throughout, and a few crumble easily in the fingers. These fragments probably were weathered prior to being transported by ice. A rind about a quarter of an inch thick on most sandstone fragments is a yellowish-brown color in contrast to the greenish-gray interior. A few fragments of yellowish-red sandstone resemble fragments in paleosol. Thin seams or stains of brown limonitic material are present in some exposures. The pH of the matrix at depths of 1 to 4 feet averages about 5.0; at depths of 10 to 12 feet the values are generally 6.0 to 7.0, but values of 4.5 to 7.0 have been found at depths ranging from 4 to nearly 20 feet. No calcareous drift has been found.

The depth of weathering of till varies over wide limits. Variations in texture, lithology, and topographic position apparently cause wide variations in the weathering of the till at similar depths from different localities. Clay-rich till may be essentially unweathered with a pH of 7.0 at depths of only 3 to 4 feet; a loose-textured sandy till may be oxidized and apparently leached (pH=4.5) at depths of 12 feet. Probably much of the till in Potter County originally was very slightly calcareous. The absence of outcrops of calcareous drift therefore indicates leaching of calcium carbonate to depths of as much as 20 feet in some places.

TOPOGRAPHIC SETTING

DESCRIPTION

The till occupies two topographic settings: small areas of low knolls and depressions, both on uplands and in valleys, and larger areas on lower valley walls and valley bottoms where the till underlies smooth gentle slopes (figs. 9 and 10). Till in the second topographic position commonly has a high water table and is the parent material for poorly and very poorly drained soils. Most of the smooth surfaces on till slope at grades of less than 15 percent, generally between 5 and 10 percent. Commonly, a marked topographic break occurs between the gentle slope on till and the steep bedrock slope covered by thin mantles (fig. 9). The till surface rises toward the drainage divides, and near the divides the valleys that are underlain by till have essentially no flood plains and are almost undissected—for example, the area near North Bingham (pl. 4). In some areas the till is dissected by flat-bottomed and steep-sided channels that range from 2 to 3 feet in depth and from 10 to 30 feet in width. In many places the till is covered by patches of boulders that (in a few places) are arranged in polygonal patterns resembling boulder rings (fig. 11).

The higher water table in the till is reflected by the composition of the flora, which differs from that on the thin drift. Sedges are abundant, and blue beeches (*Carpinus caroliniana*) are found in some places. Many pastures on till have low turf-covered hummocks of mineral soil. Such hummocks probably are a result of present-day frost action, which is more effective under the turf cover than it was under the original forest cover.

ORIGIN

The till that underlies low knolls and depressions may be ground moraine that was laid down directly from glacial ice with an initial topographic expression more or less modified by later erosion (Flint, 1947, p. 126). Most of this morainal topography is subdued in comparison with that found in areas of Valley Heads drift (Fairchild, 1932) north of Potter County, a drift younger than that in Potter County. The till that underlies the long, smooth, and gentle slopes, on the other hand, is not typical ground moraine. These slopes are best explained as being the results of erosion, penecontemporaneous with drift deposition. The possibility cannot be ignored however that the topographic differences between the drift in Potter County (Olean drift of MacClintock and Apfel) and the younger Valley Heads drift of Fairchild are largely original, resulting from differences in regimen of the Olean and Valley Heads ice sheets.

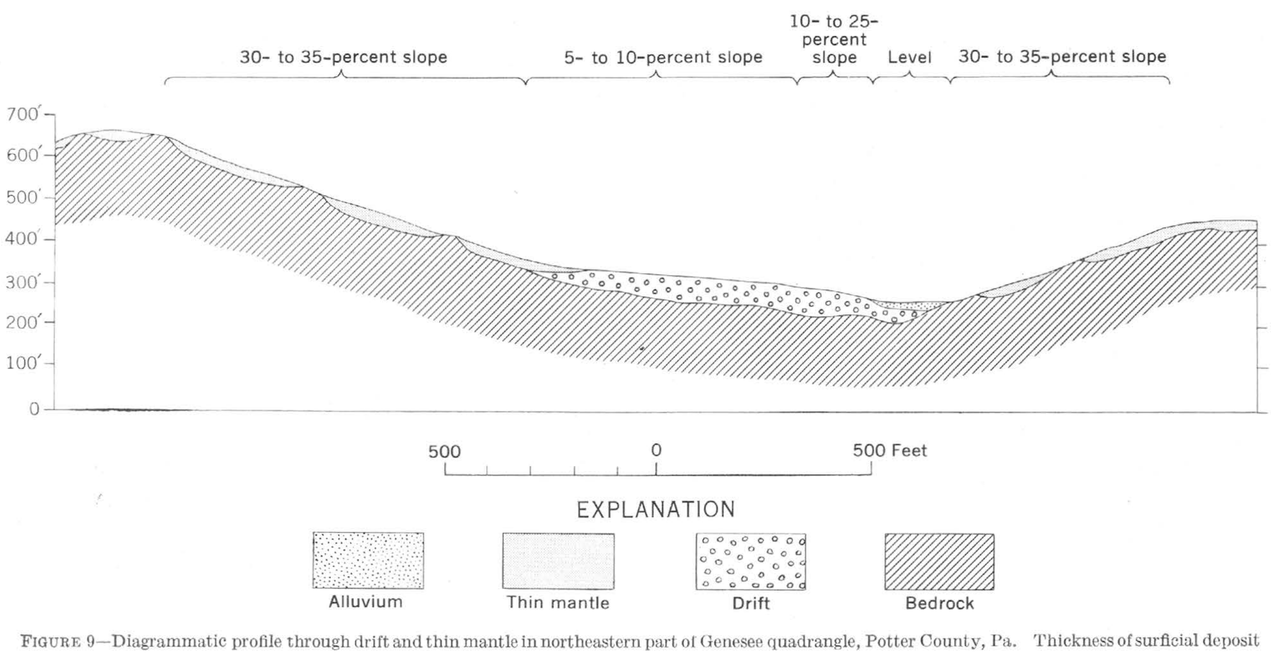


FIGURE 9—Diagrammatic profile through drift and thin mantle in northeastern part of Genesee quadrangle, Potter County, Pa. Thickness of surficial deposit exaggerated.

FIGURE 10.—Characteristic landscape developed on Olean drift, Potter County, Pa. Gently sloping bench underlain by till. Surface covered by low hummocks of turf. Flood plain in foreground. Locality near Bingham Center, Genesee quadrangle

FIGURE 11.—Ancient boulder rings formed during deglaciation, Potter County, Pa. Boulders of sandstone arranged in roughly circular patterns (as around camera case). Area, underlain by till, is located 9/10 mile northwest of North Bingham, Genesee quadrangle.

If the drift in Potter County was originally more extensive than at present—that is, if more of the till (both in valleys and on upland slopes) was typical ground moraine—then it is possible that the drift was modified by mass movements almost contemporaneously with deposition and that part of it was carried downward from the upland slopes into the major valleys, where it was redeposited in part as kame terraces. In places, essentially all of the till may have been cleaned off the bedrock in the areas mapped as thin mantles. In other words, the gentle slopes on till may have been determined partly by the transportation of material across them and partly by the configuration of the underlying bedrock. Initially, till should have been deposited with a more irregular contact on upland slopes than is found at present (Denny, 1938, p. 57). The present-day contact, with its characteristic break in slope, forms a smooth curve (pl. 4) that follows present-day drainage lines. The erosion of the drift probably was caused by processes related to frost action during the deglaciation of the early Wisconsin ice sheet.

Some of the pavements of boulders on the surface of the till resemble boulder rings formed by frost action. It is not known where the boulders came from, nor when they attained their present arrangement.

The volume of boulders present in any one place is several times greater than in an equal volume of the most bouldery drift. Not all pavements are related to the outcrop of massive sandstones. Pavements within a few hundred feet of divides cannot be attributed to stream action. It seems probable that some pavements represent a concentration of boulders derived from the reworking of a considerable mass of till. Perhaps the reworking was the result of a downslope movement of till from the surrounding slopes. The boulders are a lag deposit left on the gentler slopes—the finer material having reached the valley bottom where it was carried away by streams. Most boulder pavements are not more than two boulders deep. It is possible that frost action during the Wisconsin stage was effective enough to smooth the steeper slopes and to sort the boulders into incipient rings. The problem is more fully discussed under the heading "Wisconsin periglacial deposits" on page 30.

THIN MANTLES

DESCRIPTION

Most of the thin mantles within the glaciated area consist either of till (similar to that previously described) or of rubbles (similar to those in the periglacial deposits, see p. 30). The thin mantles are generally less than 5 feet thick, but they probably are thicker in places because few exposures attain depths of more than 5 feet. Rock outcrops (although here they are more abundant than in areas of till, see pl. 4) are scarce and generally restricted to steep slopes, creek beds, and road cuts. Areas of thin mantles have long smooth slopes and rounded divides. Such slopes are bedrock controlled. Most of the thin mantles are the parent materials of well-drained soils. The principal distinction between the thin mantles north of the drift border and those to the south is the presence of erratics on the surface north of the border and their absence to the south. Erratics are scattered over the ground surface even to the highest hills (pl. 4), thus indicating that all of the area north of the drift border was covered by glacial ice.

ORIGIN

Much of the material mapped as thin mantles inside the glaciated area is not till. It resembles the periglacial deposits outside and south of the border of the Wisconsin drift. This non-till-like material is loose and contains a high proportion of rock fragments. Upended fragments (fragments whose long axes are nearly vertical) are found in many exposures; and, in a few places, boulders and blocks on the surface are arranged in bands that resemble ancient boulder stripes. The thin mantles are polygenetic—the result of frost disturbance of till and bedrock during deglaciation and of later movements of the mantle by frost action, tree roots, and other Recent weathering processes.

The origin of the thin mantles north of the drift border can be explained in other ways. A voluminous literature dating back three quarters of a century deals with the so-called upper and lower till. The concept is forcibly presented by Flint (1947, p. 111–114, and figs. 27, 28), who stated that the basal or "lower" till is "dense and clay-rich," the superglacial or "upper" till includes "less clay and silt in proportion to sand, and the stones it contains are on the average larger and less worn than those in the lower member." The lower till is attributed "to deposition, by lodgement beneath the ice of the basal drift" and the upper till is "due to the gradual letting-down of the superglacial ablation moraine." This hypothesis is adequate to explain the field relations observable in many areas. However, proof that these processes actually took place is difficult to obtain. In the Genesee quadrangle, for example, the non-till-like material of the thin mantles has many characteristics in common with upper till. However, the occurrence of similar material (periglacial deposits) outside the glaciated area casts doubt on the applicability of the super-glacial till hypothesis to the non-till-like material mapped as thin mantles.

KAME TERRACES

DESCRIPTION

Only a few small and scattered kame terraces are found in the Genesee quadrangle (pl. 4). A few small deposits included in this mapping unit do not form terraces—for example, the deposits on top of Cobb Hill.

In general, the deposits form small terraces that rise from 10 to 200 feet above the surrounding terrain and are indented by a few kettles. Much of the material is a bouldery to pebbly gravel and coarse sand, together with lenses of silt and clay. In some places, sand is the dominant constitutent. The pebbles and cobbles range in shape from rounded to angular. Some of the material is a rubbly gravel. Many gravel beds are poorly sorted and contain considerable amounts of fine sand and silt as a matrix. The stratification is irregular, and crossbedding is common. Near Genesee, the gravel consists of 95 to 99 percent, by number, of sandstone pebbles. A greenish-gray, medium-grained, thin-bedded sandstone is the dominant rock type. Fresh gravel is dominantly gray. At depths of 5 to 10 feet the gravel changes from a gray to a yellowish-brown color. These gravels and sands rest on till.

ORIGIN

The irregular stratification and variable texture of the deposits that underlie the kame terraces and the presence of kettle holes and of isolated knolls are evidence that the material was laid down in association with wasting glacial ice. It is commonly assumed that most kame terraces are composed of debris which was derived from glacial ice (or from the till beneath the ice), and which was transported and deposited by glacial melt water. However, some of the outwash material may have been derived by mass movements from the adjacent slopes (Dines, Hollingsworth, Edwards, Buchan, and Welch, 1940). Perhaps the abundance of fine rubble in the gravel is evidence that part of it came from the adjacent slopes and was only slightly reworked by running water. However, it is equally possible that the fine rubble was derived directly from glacial ice with too little water sorting to produce any noticeable rounding of the fragments.

If mass movements did contribute significantly to the fine rubble, they probably were not active after the close of the kame-terrace deposition; otherwise, rubble should overlie the terraces where they abut against the steep valley walls. Such a mantle has not been found.

If the kame terraces were formed in association with wasting (presumably stagnant) ice, the question arises as to the width of the stagnant zone. There is no evidence bearing on this problem. The topographic position of the kames near Genesee appears to necessitate drainage northward and down the Genesee Valley during the interval of kame formation.

LAKE DEPOSITS IN THE GENESEE VALLEY

In the Genesee River valley near West Bingham are a few outcrops of varved silt and clay. The best exposure is described in the following section.

Till overlying lake beds exposed in east bank of Genesee River about 1,000 feet north of the road junction at West Bingham, Genesee quadrangle

	Depth below top of bank (feet)
Soil	0–1
Till(?), rounded and striated pebbles, cobbles, and boulders in a clay loam matrix; slumped	1–6
Varved silt and clay, couplets of silt or fine-grained sand and clay, 4 or 5 varves to 1 inch	6–21
Transition zone	21–23
Sand, fine- to medium-grained, well sorted; few clay layers. Extends downward to the river level	23–28

Other exposures show till resting on deformed varved silt and clay. The exposures suggest that varved sediments were deposited before the overlying till—presumably, in a lake in front of the advancing Wisconsin ice sheet.

Fairchild (1896, pl. 19, and p. 433 ff) described several glacial lakes in the Genesee Valley. Apparently, his inferences were based on topography and on the presence of cols at the headwaters of the Genesee River. Six such spillways are shown by Lohman (1939, pl. 2). The col at the head of Elevenmile Creek is striking, and a smaller one crosses the upland between the headwaters of Kenyon and Leadville Hollows (not shown on pl. 4). These cols probably were formed by overflow of melt water from the Genesee Valley, but there is no other evidence for any extensive lakes. The existing cols could have been cut by ice-marginal streams.

ERRATICS

About 99 percent, by number, of the pebbles, cobbles, and boulders in the drift of the Genesee quadrangle and vicinity are of rock types that occur within the glaciated part of the area (area *A*, pl. 1). The 1 percent of erratics include sedimentary rocks like those of southern New York and igneous and metamorphic rocks whose source lay in the pre-Cambrian rocks of Canada or the Adirondacks. These pre-Cambrian erratics were studied because they might include distinctive types whose source could be identified, thereby indicating the general direction of ice movement.

In Potter County, the erratics of igneous and metamorphic rock were collected more or less at random from road cuts, plowed fields, or stream gravels (pl. 4); only about 20 were found in place in the drift. No attempt was made to determine the actual percentage of pre-Cambrian erratics in the drift. Because so few were found in place, and because pebble counts from road cuts indicate fewer than 1 pre-Cambrian pebble in about 250, the percentage of pre-Cambrian erratics probably is no more than 0.01 percent. In many places it is much less.

SIZE AND SHAPE

The erratics of igneous and metamorphic rock range in size from pebbles one-half inch in diameter to boulders several feet in diameter—however, most of the erratics measure less than 4 inches in diameter. Most are well rounded, some are almost spherical. The largest erratic was found near Bingham Center, Genesee quadrangle, on the south side of the south fork of Turner Creek, about 3,000 feet east of the junction with the north fork, or about 300 feet southwest of the road corner on north side of the south fork. It is a boulder of very coarse grained porphyroblastic gneiss (group II, table 2) that measures about 6 by 4 by 3 feet.

A well-rounded boulder (about 4 feet in diameter) of similar lithology was found in the bank of the stream in Leadville Hollow, Genesee quadrangle. A third, and somewhat smaller, boulder of porphyroblastic gneiss was found at the drift border near the headwaters of the Allegheny River. Altogether, about a dozen boulders more than 1 foot in diameter were noted.

TABLE 2.—*Erratics of igneous and metamorphic rock in Wisconsin drift, Genesee quadrangle and vicinity, Potter County, Pa.*

[Lithologic description of hand specimens and possible source areas by A. W. Postel]

Group	Lithology	Number of specimens	Percentage of total number	Possible source areas
I	Medium-grained, pink granite gneisses, containing biotite, hornblende, or pyroxene, or combinations of those mafic minerals; includes some nonmafic types.	182	31	Typical of the youngest granite complex of the Adirondacks. The Lyon Mountain granite of Miller (1919, 1926), or the St. Regis granite of Buddington (1937, 1939), and Postel (1952).
II	Medium-grained, well-foliated, biotite syenitic and granitic gneisses; white when fresh, weathers to yellow brown; includes a few muscovite granite gneisses.	141	24	Unknown.
III	Dark-gray, aphanitic, gneissic rocks, some specimens contain hornblende crystals; suggestive of recrystallized mylonites.	46	8	Unknown.
IV	Dark, fine- to coarse-grained rocks, amphibolites, with more or less equal parts of plagioclase and hornblende; most are well foliated; finer-grained specimens are the darkest; in the coarse-grained specimens the plagioclase is easily discernible. This group may include metasedimentary and metaigneous rocks; in general, the two types cannot be megascopically differentiated.	39	7	This type of rock occurs in all of the pre-Cambrian gneisses of the Adirondacks.
V	White granitic gneisses, in part aplitic and in part gneissic; both aplitic and gneissic types occur with and without garnet.	35	6	Unknown.
VI	Quartz rocks, probably of vein origin	31	5	Unknown.
VII	Coarse-grained, bluish- to purplish-gray anorthosite and gabbroic anorthosite.	27	5	Typical of the anorthosite rocks of the Adirondacks (Buddington, 1939).
VIII	Fine- to medium-grained, gray, foliated rocks; includes biotite gneisses, purplish biotite and garnet gniesses, and quartzitic gneisses.	20	3	Typical of the Grenville series metasedimentary rocks of the Adirondacks.
IX	Coarse-grained, phacoidal, low-ferromagnesian granite gneiss.	15	3	Typical of the Hawkeye granite of Miller (1919, 1926), or the coarse facies of the Santa Clara complex of Buddington (1937), the Diana complex of Buddington (1937), and the Stark complex of Buddington (1948).
X	Medium-grained, white- and black-banded, biotite-hornblende granitic or syenitic gneisses; some of the bands are pink locally.	14	2	Unknown.
XI	Gray-green, medium-grained, foliated quartz syenite; 2 specimens almost fresh, 3 specimens weathered to a chalky-white outer surface and brown interior.	5	1	Typical of the quartz syenite of Miller (1926), or of the chilled border facies of the Santa Clara complex of Buddington (1937).
XII	Pegmatite	4	.5	Unknown.
XIII	Dark porphyritic metadiabase; ground mass is aphanitic, phenocrysts are plagioclase as large as 2 mm square.	2	.5	Typical of pre-Cambrian dike rocks that cut the pre-Cambrian gneisses of the Adirondacks; occurs as pebbles in basal conglomerate of the Potsdam sandstone.
XIV	Miscellaneous	19	4	Unknown.
Total		580	100	

LITHOLOGIC TYPES

The 580 specimens in the collection were classified into 14 lithologic groups by A. W. Postel (table 2). The dominant rock types are syenitic and granitic gneisses. This classification is similar to that of Peltier (1949, table 6) for pebbles from Olean drift in the Susquehanna Valley. A partial breakdown of Peltier's tabulation for Olean drift into Postel's groups is as follows: group I=55 percent; group II=10 percent; and group III=17 percent. This indicates that the pre-Cambrian erratics in the Olean drift of the Susquehanna Valley are similar in lithology to those from Potter County.

DISTRIBUTION

All of the lithologic groups seem uniformly distributed throughout the glaciated part of the Genesee quadrangle and vicinity (area *A*, pl. 1). Distribution by relative percentage of number of specimens in each group is shown graphically in figure 12. Graph *A* is for the entire collection, and graphs *B* through *I* represent the specimens collected within small areas of 2 to 7 square miles (loc. *B* through *I*, pl. 1). The graphs show that

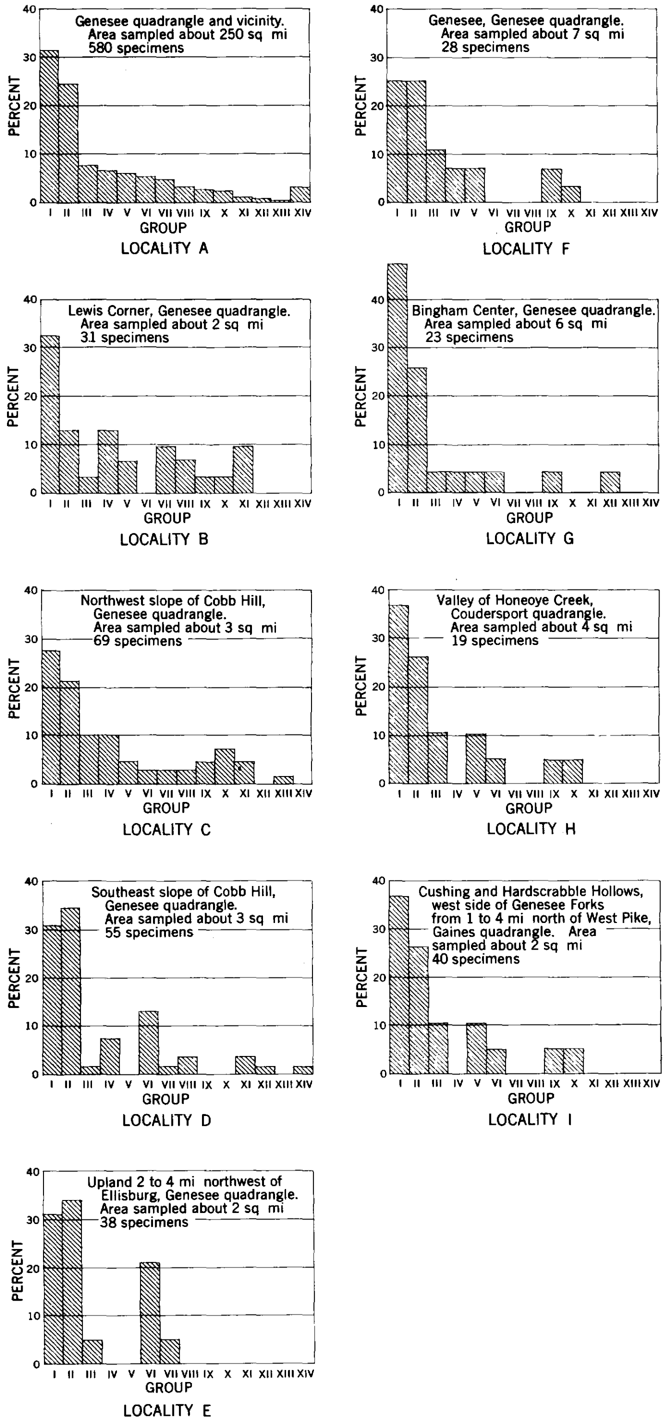


FIGURE 12.—Relative proportions of groups of erratics of igneous and metamorphic rock from Genesee quadrangle and vicinity, and from selected localities within that area. For definition of groups see table 2, and for location of areas sampled see plate 1.

no one group is restricted to any specific small area. Groups I and II respectively are larger than any other group in all examples except graph *B*. In general, groups I and II are at least twice as large as any one of the other groups.

There is no marked change in the relative proportions of the groups in collections from small areas along the drift border. Compare, for example, graph *H* (Coudersport quadrangle), graph *C* (Genesee quadrangle), and graph *I* (Gaines quadrangle). Also groups I and II respectively are larger than any one of the other groups, although the number of specimens from the small areas ranges from 19 to 69. Even the 19 specimens from an area along Honeoye Creek, graph *H*, are a sample that compares rather closely with the total collection, graph *A*. About 50 specimens from an area of Olean drift in this part of Pennsylvania probably constitute a representative sample.

Many more specimens were collected from some parts of the area than from others. In the Genesee quadrangle about 250 specimens came from an area along the drift border, covering a belt about 2 miles wide (an area of about 30 square miles). In contrast, about 60 specimens were picked up within an area of the same size in the northeast corner of the quadrangle, about 6 to 12 miles northeast of the drift border. Exposures and intensity of field work were roughly the same in both areas, therefore it is suggested that crystalline erratics are relatively more abundant near the drift border.

WEATHERING

None of the specimens are absolutely fresh—all have weathered rinds or at least have a surface coloration differing from the interior. Most specimens are slightly to strongly weathered throughout. Of group *I*, most of the pink gneissic granites are slightly tinted with brown and only about 10 specimens are essentially unweathered. Most specimens in group I have either yellowish-brown or nearly white (bleached) rinds, which range in thickness from one-eighth to one-half inch, and which surround a pink interior. Most of the gneisses of group II are stained yellowish brown throughout. About half of group II are strongly colored, many have light-yellowish-brown rinds, which range in thickness from one-quarter to one inch, and which surround paler cores. About 10 percent of the specimens in group II have gray to white centers. Most specimens can be broken easily with a hammer; a few can be broken by hand.

Many of the specimens in the other groups (III to XIV) have grayish or brownish exteriors and are weathered to depths ranging from paper-thin to one-quarter of an inch in thickness. The centers are fresher than the exteriors. Some specimens have rough surfaces with mineral grains protruding as much as a quarter of an inch. Such surfaces are characteristic of the dark-gray, aphanitic, gneissic rocks of group III, and of the gabbroic anorthosites of group VII.

Most of the specimens are surface finds, and there is no means of determining whether all the weathering of the specimens took place after deposition of the Olean drift of MacClintock and Apfel or whether some of the alteration is of pre-Olean date. No yellowish-red colors characteristic of rock fragments in the pre-Wisconsin paleosol were noted.

POSSIBLE SOURCE AREAS

Postel has indicated, in table 2, possible source rocks in the Adirondack province for some of the several groups. About 50 percent of the specimens in the collection are lithologically similar to rocks known to occur in the Adirondacks, and about half are unlike those known to crop out in that province.

MacClintock and Apfel (1944, p. 1153–1154) collected erratics of igneous and metamorphic rock from three exposures of Olean drift in the Salamanca reentrant, New York, from one exposure of Illinoian-drift, and from four exposures of Binghamton drift. The specimens were examined by A. F. Buddington who found that:

> * * * the vast majority of them are typical of the Grenville province and could have come from Quebec or the central Adirondacks. However, in the samples [of Olean drift from two localities] * * * were porphyries which occur in the Champlain Valley on the east side of the Adirondacks. In the [Olean] moraine west of Peth was an epidote amygduloid of the type which outcrops, likewise, in Champlain Valley. These relative unique rock types suggest ice movement from east of the Adirondacks at the Olean stage.

In west-central New York, near the Finger Lakes, Holmes (1952) studied the progressive changes in drift character by means of pebble counts within a single index grade size (¼ to ½ inch in diameter). The drift belongs chiefly to the Valley Heads substage (Fairchild, 1932) of the Wisconsin, although small areas of older Binghamton drift of MacClintock and Apfel are included near the southern margin of the area, and younger drift may be present near Lake Ontario. In a discussion of the "crystalline" rock group, Holmes (1952, p. 1005), says in part:

> This group consists chiefly of several gneissoid types, a few schists, and a few varieties of igneous rocks whose petrographic affinities are often difficult to determine megascopically within the index grade size * * *. Three significant observations may be made from their distribution: * * * (1) Most of the percentages are unusually low. About a third of the samples show less than 1 percent, and the highest is 8.3 percent. (2) Dispersion is virtually complete throughout the area notwithstanding the small amounts * * *. (3) Quite in contrast with the other groups [of sedimentary rocks], the areal distribution shows almost no consistent trend or pattern as related to the general southward movement of the Valley Heads ice * * *. [The] distribution gives no clear indication as to direction of transport, but it does show that their glacial history is more complicated than that indicated by the distribution patterns of the other groups.

CONCLUSIONS

The analysis of the crystalline erratics from the Genesee quadrangle and vicinity indicates that (1) the rock types are randomly distributed, and the various groups are completely dispersed; (2) most of the specimens are weathered, (3) half of them could have come from the Adirondacks but the remainder are not known to occur there, and (4) possibly the erratics are more abundant near the drift border than further to the northeast.

The essentially complete dispersal of the various groups here (table 2, and fig. 12) is like that in the Susquehanna Valley (Peltier, 1949, table 6) and in the Finger Lakes region (Holmes, 1952, fig. 8). A higher proportion of the erratics from Potter County are weathered throughout than would probably be found in a similar collection of local sedimentary rocks, but few erratics were found in place and therefore no direct comparison can be made. Some of the erratics probably required at least two glacial stages to be carried from their pre-Cambrian sources to Potter County. It is possible that they were weathered during an interglacial stage.

Although half of the crystalline rocks are of types found in the Adirondacks, this fact does not prove that all, or some, of them came from that province. On the other hand, if this fact is accepted—that these crystalline rocks came from the Adirondacks—it does not demonstrate that these specimens were quarried by the Olean ice sheet as it passed across the Adirondacks and carried at least 150 miles southwestward to Potter County. Buddington concluded that some erratics from Olean drift in the Salamanca reentrant, New York, came from areas on the east side of the Adirondacks ((MacClintock and Apfel, 1944, p. 1153–1154). However, this conclusion does not prove that the Olean ice sheet advanced from east of the Adirondacks. The quarrying and some of the movement of the erratics could have been caused by any older glaciers in pre-Wisconsin time.

WISCONSIN DRIFT BORDER

GENESEE QUADRANGLE

IDENTIFICATION

The drift border in the Genesee quadrangle (pl. 4) is an indefinite line that has been drawn at the southern or southwestern limit of erratics and well-rounded or striated pebbles and cobbles. The surficial map (pl. 4) shows the location of known crystalline erratics northeast of the drift border. The area along the drift border was studied in detail, and the border is generally definable within about a quarter of a mile, especially in plowed fields or pastures.

SCARCITY OF TERMINAL MORAINE OR GLACIOFLUVIAL DEPOSITS

Most of the drift border is not marked by terminal moraine or by glaciofluvial deposits but there are a few small areas with slightly irregular surfaces that suggest much-subdued terminal moraine. One such area is on the uplands southeast of Raymond at the head of Reese Hollow (shown as till on pl. 4). Here, the surface has a local relief ranging from 2 to 5 feet. The sags are floored with bulrushes and scattered sphagnum. The slopes of the adjacent knolls or ridges are very low; in many places they are not more than 5 percent. To the west, near the drift border due south of Raymond, a few knolls and ridges are nearly 10 feet high, and the slopes may be as much as 12 percent (also shown as till on pl. 4). Erratic and rounded pebbles are relatively abundant; here, the southern limit of the drift can be located within less than a quarter of a mile.

The low knolls of sand and gravel on Cobb Hill (included with the kame terraces on pl. 4) are only about half a mile east of the drift border and suggest a small area of terminal moraine. Much of the till to the south and southwest of Rose Lake forms low knolls and ridges and might also be considered as terminal moraine.

Generally, there is no terminal moraine near the drift border in the valleys of Oswayo Creek, Allegheny River, and Pine Creek. Along Oswayo Creek, the drift border cannot be located closer than about half a mile. Near the western edge of the map the border is drawn along the creek, but a small area north of the creek near Tyler Hollow apparently was not glaciated. Erratics are relatively abundant near the Allegheny River, and the drift border can be located within short distances; they are scarce in Pine Creek valley south of Brookland, and the drift border is drawn at the upper limit of the well-rounded pebbles scattered on the lower valley, expecially to the south of Buckseller and Jones Runs.

There are almost no glaciofluvial deposits in valleys that drain away from the drift border. This fact was commented on by Lewis (1884, p. 141, 143) who suggested, "* * * the main drainage of the edge of the ice was northward and therefore sub-glacial." In addition, there are no large or extensive glaciofluvial deposits for many miles north of the drift border.

TOPOGRAPHIC POSITION

The drift border crosses the Genesee quadrangle in a northwesterly direction and is relatively straight. The two marked irregularities are: in the valley west of Brookland where the drift border forms a westward-pointing tongue slightly more than a mile long, and on the uplands east of Pine Creek where the existing data suggest an easterly trend (however, exposures are scarce in this thickly wooded area).

The drift border varies in altitude from about 1,600 feet where it crosses Pine Creek to more than 2,500 feet on the uplands near the headwaters of the Allegheny River. Between the point where the border crosses State Highway 49 (about 1 mile southwest of Raymond), and the summit of Cobb Hill, the drift border varies about 1½ miles from its general northwesterly trend and rises about 400 feet in a distance of about 2 miles. Between a point on the upland at the head of Reese Hollow and the Allegheny River to the west, the drift border deviates about 1 mile from its general northwesterly trend and rises about 360 feet in a distance of about 2 miles. These values suggest that, in some places, the edge of the ice sheet at its maximum had a slope of more than 300 feet per mile.

ORIGIN

The straightness of the drift border implies that the ice sheet was relatively thick so that its front was not greatly affected by ridges and valleys and therefore remained relatively straight and steep. The glaciofluvial deposits on Cobb Hill (pl. 4) indicate that ice covered the hilltop, even though it is only about 1½ miles north of, and 350 feet above, the point where the drift border crosses the headwaters of the Allegheny River. Perhaps a relatively straight ice edge is characteristic of early Wisconsin drift borders as compared with those of later Wisconsin substages. The advance of the edge of the Wisconsin ice sheet across the Genesee quadrangle may have been stopped by change in glacier regimen rather than by the local topography (Lewis, 1884, p. 147 footnote), and the ice may have disappeared from this marginal area because its front melted back rather than because its upper surface was lowered by ablation (Flint, 1947, p. 158). The relative straightness of the drift border suggests that all of it was formed by one ice sheet at approximately the same time, rather than by separate tongues advancing down different valleys.

The fact that the drift border is indefinite implies that the ice was relatively clean—not carrying much debris. Either the ice edge remained only a short time at its maximum limits and then retreated, or the terminal zone stagnated. The scarcity of water-laid drift, both outside the drift border and for a considerable distance inside it, may have several possible explanations: (1) cold summers resulting in little melting, (2) ice at drift border for only a short time, (3) drainage northward under ice (Lewis, 1884, p. 141, 143), and (4) burial of outwash by Recent alluvium. The scarcity of outwash inside the drift border supports the first explanation, although the second may be true also. The scarcity of outwash suggests that when the ice stood at, or near, the drift border, the summers were relatively cool and the production of melt water was slight. If considerable volumes of melt water drained northward under the ice, one would expect to find evidence of it in the form of water-laid drift.

Some glaciofluvial deposits may be buried under Recent alluvium. There are essentially no terraces along any streams in the Genesee quadrangle outside of the glaciated area. Low terraces occur along Pine Creek near West Pike in the Gaines quadrangle (Fuller, 1903a), along Oswayo Creek near Shinglehouse, Coudersport quadrangle, and near Port Allegany on the Allegheny River, about 4½ miles west of Potter County. Near Coudersport, the alluvium is at least 180 feet thick; near Shinglehouse, it is at least 130 feet thick (pl. 1). It is possible that postglacial dissection has not yet reached the Genesee quadrangle, because it is situated on the drainage divide of the Allegheny, Genesee, and Susquehanna Rivers.

The fact that the drift is attenuated at its border might imply also that the glacial zone merged into the periglacial zone (Hack, written communication, October 31, 1952). In the periglacial zone next to the ice sheet, stagnant ice or névé may never have been thick enough to move as part of the ice sheet itself. The location of Potter County, which is in the higher parts of the plateaus, might have led to the development of such névé fields. This possibility is in accord with the explanation advanced by Higbee (1947, p. 91) for certain colluvial deposits in the folded Appalachians of southern Pennsylvania. Another factor that may have contributed to the apparent attenuation of the drift is the removal of drift from the uplands by solifluction during, and immediately following, deglaciation (see p. 30). The extensive areas inside the drift border mapped as thin mantles (pl. 4) suggest that considerable drift has been removed by mass movements. Such a removal would tend to give the appearance of an indefinite drift border.

COUDERSPORT QUADRANGLE

No detailed mapping was done in the Coudersport quadrangle. The drift border shown on plate 1 is based on reconnaissance by the writer and on data gathered by soil scientists. The border follows that of Leverett (1934, pl. 1) except in the area along Oswayo Creek between Millport and Shinglehouse, where the line is drawn along the creek. No drift was found southwest of Oswayo Creek. A belt of subdued moraine crosses the valley of Elevenmile Creek about 2 miles southwest of Crystal. Ridges, about 25 feet high, curve part way across the valley. This moraine closely resembles the Olean moraines in the Salamanca reentrant, New York, just to the northwest of the Coudersport quadrangle (MacClintock and Apfel, 1944).

The Olean drift border of MacClintock and Apfel (1944, pl. 1) enters the Coudersport quadrangle just west of Honeoye Creek, northeast of Shinglehouse, whereas on plate 1 the border of the Wisconsin drift is drawn along Oswayo Creek to cross into New York State near Ceres, Smethport quadrangle, about 5 miles northwest of Shinglehouse (pl. 1). K. V. Goodman of the Soil Survey found drift on the uplands north of Shinglehouse, and kame gravel (believed to be Olean) is found on the northeast side of Oswayo Creek about 2 miles southeast of Portville, Olean quadrangle (about 1½ miles north of the state line). The exposure is in a gravel pit at Carroll, Olean quadrangle. The data suggest that the morainic loops in the valleys east and southeast of Olean (MacClintock and Apfel, 1944, pl. 1) do not mark the maximum extent of the Olean ice sheet; instead, the data suggest that it extended a few miles farther to the southwest.

GAINES QUADRANGLE

The surficial geology of the Gaines quadrangle has been described by Alden and Fuller (Fuller, 1903a). The drift border, as shown on plate 1, enters the quadrangle from the west at a point about due east of Brookland. The location of the border suggests that a tongue of ice extended for about 3 miles down the valley of Genesee Forks to Pine Creek, leaving an unglaciated reentrant on the uplands to either side of Genesee Forks. This interpretation is based only on reconnaissance work, and differs from that of Alden, who placed the drift border along Pine Creek (Fuller, 1903a).

GALETON, MARSHLANDS, TIADAGHTON, AND CEDAR RUN QUADRANGLES

Widely scattered field observations and an inspection of topographic maps are the basis for the location of the drift border in the eastern part of the area shown on plate 1. The border is drawn across Pine Creek at a point about 1 mile east of Galeton, but it is possible that the Wisconsin ice advanced somewhat farther westward up the creek. The border passes south of Marshlands and thence eastward nearly to Pine Creek, which it follows southward to a point near Cedar Run.

GLACIAL SPILLWAYS

Several glacial spillways are shown on plate 1 near the drift border to the south and southeast of Galeton. These are narrow, steepsided troughs, as much as 150 deep, that cut across broad, rounded divides.

The glacial spillway (The Notch), altitude 1,970 feet, located west of Germania, Galeton quadrangle, probably was cut by the overflow from a lake in the upper Pine Creek drainage which was dammed by the Wisconsin ice east of Galeton, although water may also have flowed through The Notch in some pre-Wisconsin glacial stage. The Notch is a narrow gorge, about 1,000 feet long, that is cut about 150 feet into the adjacent rolling uplands. This spillway carried water into the headwaters of Little Kettle Creek. Tributaries that enter Little Kettle Creek within about the first mile of its course south of The Notch have steep gradients near their mouths and have gentler gradients upstream. These hanging-tributary valleys suggest a downcutting by Little Kettle Creek of as much as 20 to 40 feet.

A second notch, altitude about 2,010 feet, that probably is a glacial spillway, crosses the divide southeast of Galeton between South Branch Pine Creek and Elk Run, Marshlands quadrangle. It is not known whether the water flowed northwestward or southeastward through this spillway.

Another glacial spillway, altitude 1,908 feet, crosses the divide southeast of Marshlands and carried water from the Elk Run Valley eastward into the headwaters of the Left Branch Fourmile Run, which flows into Pine Creek Gorge.

A fourth glacial spillway, located on the uplands west of Tiadaghton, carried water from Pine Creek valley into the headwater of Cedar Run through a notch at an altitude of about 1,670 feet.

AGE AND CORRELATION OF DRIFT IN POTTER COUNTY

The drift of Potter County belongs to an early Wisconsin substage—either to the Iowan or the Tazewell substage of the Wisconsin glacial stage, probably to the Iowan. Morainal topography is scarce and "subdued". The depth of weathering is variable, and in the absence or scarcity of lime carbonate in unweathered drift, it is difficult to compare the drift in Potter County with that of better known areas of lime-bearing Wisconsin drift. The dissection of the drift and the development of alluvial fans suggest an early Wisconsin date. The absence of paleosol on the drift suggests that it is younger than the so-called Illinoian drift of the Susquehanna Valley.

The drift of Potter County is considered to be of the same age as that of the Olean drift in the Salamanca reentrant, New York, on the bases of continuity, similar lithology, degree of weathering, and topographic expression. MacClintock and Apfel (1944) believed that the Olean drift in the reentrant is of Tazewell age. Their younger drifts, the Binghamton (fig. 1) and the Valley Heads of Fairchild (not shown on fig. 1), were assigned to the Cary substage (see also MacClintock, 1954). On the basis of field work in 1953 and 1954, the writer believes that the Olean drift is older than all of the drift of Wisconsin age in New Jersey east of the Delaware River, in the Hudson Valley, and in New England (Denny, 1956), and that the Olean drift is the oldest drift of Wisconsin age in northeastern United States. Thus, it is logical to place the Olean drift in the early Wisconsin, perhaps in the Iowan substage. However, this tentative correlation is not based on precise data and its evaluation awaits further study of the drifts in the western parts of New York and Pennsylvania and doubtless also in the Central Lowlands.

WISCONSIN PERIGLACIAL DEPOSITS

GENERAL FIELD RELATIONS

Throughout most of the unglaciated portion of Potter County, a blanket of unconsolidated debris conceals the bedrock. This debris, exclusive of the paleosol and Recent alluvium, is dominantly a rubble—fragments of rock mixed with varying amounts of finer material. In general, the rubble is thickest and most extensive within about 10 miles of the drift border and is thinner and less continuous in areas farther away. This suggests that the rubbles were formed almost contemporaneously with the adjacent early Wisconsin drift. The rubbles therefore are periglacial deposits, implying thereby that they occur near the drift border and are the product of climatic factors that, although not existing at present, were in operation when the Wisconsin ice sheet was nearby (Denny, 1951). In some places on or near the surface of these deposits and the adjacent drift are ancient soil structures or patterned ground including boulder rings, boulder stripes, and block fields.

LITHOLOGY

The periglacial deposits are heterogeneous masses of very diverse sizes of material: locally, a silty clay essentially free of fragments; elsewhere, a deposit of boulders or blocks as much as 30 feet in diameter. The texture of the matrix and the kinds of rock fragments in the deposits depend primarily on the types of rock beneath and upslope. The coarse-grained white to gray sandstone and conglomerate (Pottsville or Pocono formations) give rise to sandy loams or loamy sands and to large and more or less equidimensional boulders or blocks. In most of Potter County these rocks occur at or near ridge tops, therefore most large blocks are found on upper slopes and reach the valley bottoms only where slopes are steep. The medium-grained gray sandstone and greenish-gray shale and siltstone (largely Pocono and Chemung formations) produce sandy loams, loams, and silt loams and fragments and flagstones ranging from 1 inch to 2 feet in diameter and from ½ to 2 inches in thickness. The reddish shale, siltstone, and fine-grained sandstone (red beds of Catskill formation) yield silt loams, clay loams, and silty clays retaining the colors of the parent rock. In a few places, shale is the parent rock for a periglacial deposit that is composed primarily of small chips from ½ to 2 inches in diameter.

INTERNAL STRUCTURE

Most periglacial deposits are unsorted and unstratified. Where they include many fragments of rock, the deposits contain many interconnecting voids (figs. 13, 14). As the rock fragments become larger and more abundant, the voids, which may be as much as 3 inches in diameter, also become larger and more abundant. On a volume basis, such periglacial rubbles may be about 40 percent rock fragments, 40 percent voids, and 20 percent matrix. A deposit of silty clay with less than about 5 percent by volume of rock fragments is very firm and closely resembles silty till. Megascopic voids are essentially absent and, when dry, the material is difficult to excavate with a shovel.

Many deposits, especially on lower slopes, contain abundant thin fragments or flagstones, locally with a preferred orientation. Their broad flat surfaces lie about parallel to the surface of the ground or are inclined or imbricated with lower dips downslope (fig. 15). Elsewhere, the slabs are orientated more or less at random unless they are part of a boulder stripe or boulder ring—in which case their broad flat surfaces may stand nearly vertical.

Some periglacial deposits show rude stratification owing to variations in the parent bedrock, the imbrication of fragments, or the presence of irregular lenses of material of differing texture. For example, on slopes underlain by interbedded gray sandstone and red shale, the periglacial deposits show a faint color banding with a yellowish-brown silt loam interlayered with a reddish silt loam. Such layering can be traced downslope from the outcrop of red beds for a few tens of feet. In places, especially on lower valley walls, the imbricated fragments form discontinuous layers that impart a rude stratification to the deposit. Such imbrication was well shown in the trench silo near Colesburg, Genesee quadrangle (fig. 22). Elsewhere, they contain layers of rock fragments of varying size, perhaps interlayered with irregular lenses of fine material; still other deposits are relatively free of rock fragments and show faint layering due to changes in texture; but in many places, especially on uplands, the deposits show no stratification whatsoever.

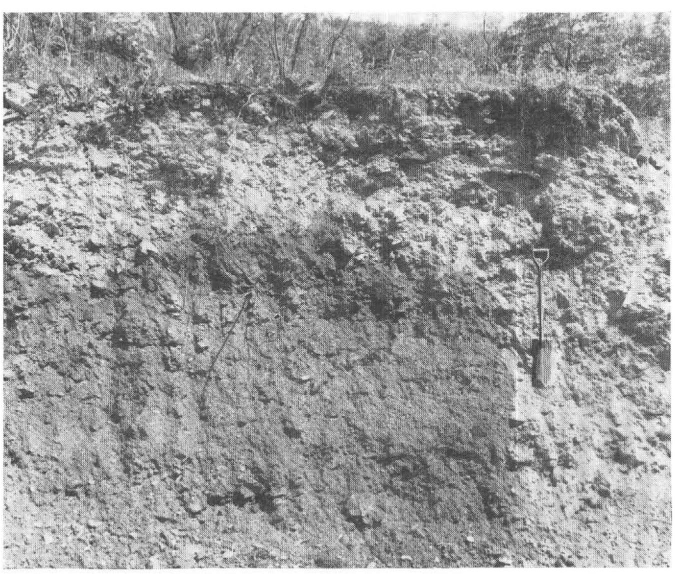


FIGURE 13.—Unsorted mixture of sandstone fragments in a silty matrix. Exposure, about 10 feet high, is in borrow pit on north side of Mill Creek (U. S. Highway 6) at western edge of Genesee quadrangle.

FIGURE 14.—Unsorted mixture of sandstone fragments in a silty matrix, overlies fractured sandstone bedrock. Exposure north of road corner at Lymansville, Genesee quadrangle.

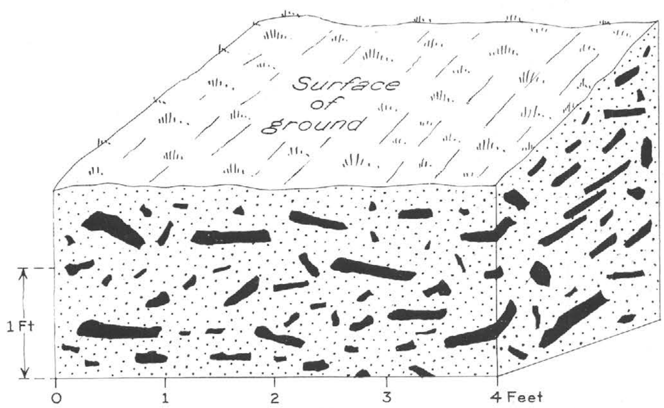


FIGURE 15.—Diagram showing preferred orientation of thin fragments or flagstones in periglacial deposits. The fragments lie with their broad flat surfaces about parallel to the ground surface or dipping less steeply than the slope.

THICKNESS AND AREAL EXTENT

The periglacial deposits range in thickness from 1 to at least 20 feet; perhaps the deposits are deeper along valley bottoms. In general, these deposits are 1 to 5 feet thick on ridge crests and upper slopes (thin mantles, pl. 4) and 6 to 10 feet thick on gentler slopes near the valley bottom (periglacial deposits, pl. 4). Within about 10 miles of the drift border, bedrock outcrops are scarce even on steep slopes and the deposits form an almost continuous blanket. In southwestern Potter County, 20 miles or more from the drift border, outcrops are relatively more abundant both on ridge tops and on slopes, and the periglacial deposits are apparently thinner and less extensive here than nearer the drift border.

SURFACE EXPRESSION

The periglacial deposits underlie long, smooth slopes that extend from ridge crest to valley bottom. Near the headwaters of many valleys within about 10 miles of the drift border, flood plains are absent, and the valley walls meet to form a V (Denny, 1951, fig. 7). Bedrock benches mantled by periglacial deposits are present in some places but are not conspicuous features of the landscape.

On lower slopes, the deposits underlie benches that slope toward the center of the valley. The lower end of a bench at the top of the steep riser may lie 5 to 30 feet above the adjacent flood plain. In places this steep bank is the result of dissection. In headwater areas, however, such banks may be in part original depositional features. Elsewhere the benches were dissected by streams that built alluvial fans, which, at their lower ends, now stand 10 to 20 feet above the flood plain of the main stream (fig. 21).

At the mouths of many small valleys are fan-shaped deposits that are covered with, and contain, boulders or blocks as much as 20 feet in diameter. The matrix of the deposit is an unsorted and unstratified mixture of all sizes of material from clay to fragments of rock. Such fan-shaped masses are interpreted as periglacial colluvium because of their content of unsorted materials.

Elsewhere, commonly at the mouths of larger tributary valleys, are typical alluvial fans composed of somewhat water-worn sand and gravel. On the map of the Genesee quadrangle (pl. 4) both these sorted and unsorted deposits are lumped together as alluvial fans of undetermined age, which probably includes some fans formed during the Wisconsin stage and others in the Recent epoch.

GROUND-WATER CONDITIONS

The widespread mantling of slopes and ridge tops by rubbly periglacial deposits greatly reduces surface runoff. Most precipitation sinks into the ground to emerge from springs far down the slope. An increase in coarseness in the rubbles creates a corresponding rise in porosity and permeability. The absence of surface runoff can be inferred from the absence of gullies on most slopes. However, slopes are gullied and cultivated fields or pastures show evidence of recent mass movements where the periglacial deposits are clay loam or silty clay and where the proportion or rock fragments is small. Such features are found in areas underlain by red beds (Catskill formation), for example, south of the Allegheny River near Colesburg, Genesee quadrangle.

STRATIGRAPHIC AND TOPOGRAPHIC POSITION IN RELATION TO GLACIAL DEPOSITS

In some places, Wisconsin drift is overlain by material that is believed to be a periglacial deposit. Soil structures or patterned ground occur on drift. Some of the material on the sides of Pine Creek valley south of Brookland, Genesee quadrangle, north of the drift border, is a rubble that contains a few erratics or stream-worn pebbles. Such rubbles are interpreted as periglacial deposits derived in part from drift, although no thick periglacial deposits have been found resting on drift. It is difficult, if not impossible, to demonstrate conclusively the origin of a layer of rubbly material that is only 1 to 3 feet thick. In postglacial time many processes have operated that could produce such a rubble. For example, the effects produced by the roots of fallen trees are adequate to account for such a layer (p. 59).

The topographic relations between land forms on periglacial deposits and those on drift were studied in the valley of Pine Creek upstream from Galeton (pl. 1) to Walton and along Ninemile Run to the west. Ninemile Run drains a broad region outside the drift border. Downstream from Walton near West Pike, Pine Creek crosses the end of the glaciated area at the mouth of Genesee Forks and reenters the periglacial area that extends to a point east of Galeton. The following table lists the elevations of glacial terraces, of periglacial terraces, and of the lower ends of periglacial fans above the flood plain of Ninemile Run and of this segment of Pine Creek.

Altitudes of glacial terrace, periglacial terraces, and fans above flood plain of Ninemile Run and Pine Creek

Location	Deposit		Altitude above flood plain
	Form	Origin	
North side of Ninemile Run, about ¼ mile west of mouth of Dry Run (pl. 4).	Terrace	Periglacial	20 ft above Ninemile Run.
North side of Ninemile Run, about 1 mile west of Walton (pl. 4).	Terrace	Periglacial	25 ft above Ninemile Run.
South of Ninemile Run, ½ mile west of Walton (pl. 4).	Alluvial fan	Periglacial	15 ft above Ninemile Run.
Mouth of unnamed stream south of Walton (pl. 4).	Alluvial fan	Periglacial	10 ft above Ninemile Run.
Mouth of Lossey Run (pl. 4)	Terrace	Periglacial?	25 ft above Pine Creek.
Between West Pike and Galeton (pl. 1).	Terrace	Glacial	40 ft above Pine Creek.

These scattered remnants of periglacial terraces and truncated alluvial fans do not fall into any specific hypothetical ancient grade line of these streams. However, all these remnants lie well below the hypothetical grade line of the supposed 40-foot outwash terrace southeast of West Pike. Therefore, these terrace remnants in the unglaciated area above West Pike were developed at least in part during the dissection of the outwash plain to the southeast. The climatic conditions that produced the periglacial deposits along Ninemile Run probably existed or persisted in this area during at least a part of the time when the ice sheet was disappearing. Therefore, some of the periglacial deposits date from the period of deglaciation of the Olean ice sheet.

ANCIENT SOIL STRUCTURES AND RELATED FEATURES

On or near the surface of the periglacial deposits and of the drift are concentrations of boulders—locally, they form irregularly shaped, bouldery areas; elsewhere, the boulders are arranged in circular or linear patterns. Such concentrations are characteristic surface features of arctic and alpine regions and are called "soil structures" (Sharp, 1942) or "patterned ground" (Washburn, 1950). The soil structures recognized in Potter County include block fields, boulder rings, boulder stripes, and terraces.

BLOCK FIELDS

In Potter County, the block fields are composed of blocks that are either angular, subangular, or slightly rounded. In this discussion of block fields, the term "block" is used irrespective of the shape of the rock fragment. Maximum diameters range from 2 to as much as 30 feet.

The large blocks are composed of coarse-grained sandstone or fine-grained conglomerate (Pottsville and Pocono formations), the smaller blocks are of medium-grained sandstone (Pocono, Catskill, or Chemung formations). The blocks rest on, or are partly imbedded in, a heterogeneous mass of sand, silt, clay, and small rock fragments. The surface of the matrix lies below the top of the adjacent blocks, generally at depths of 1 to 6 feet (or about at the base of the larger blocks). The base of most block fields is not exposed. Some block fields, composed of blocks 2 or 3 feet in diameter, rest on a bouldery periglacial deposit at depths of 3 to 6 feet.

The upper surface of most block fields is relatively smooth and merges with the surrounding slopes—that is, the block fields have no distinctive topographic expression. The surface may be nearly level or it may slope as much as 10°. The microrelief is low, from 1 to about 3 feet. Some blocks are arranged in roughly circular patterns that suggest boulder rings—either a ring of large blocks around smaller fragments, or a ring of smaller fragments surrounding a large block. The latter type is a large-scale example of "stone centered polygons" (Gregory, 1930).

Probably all block fields in Potter County were forest covered in precolonial times. However, block fields of large blocks with no interstitial fines to depths of 2 to 6 feet possibly were never forested. At present, most block fields are partly covered by second-growth forest or by turf and bushes.

In many places a superficial layer of small rock fragments (from 6 inches to about 2 feet in diameter) covers an area ranging from a few tens to a few hundreds of feet in diameter (figs. 17, 19). Such "miniature block fields" resemble block fields except for the smaller size of the fragments. Miniature block fields occur both within and outside of the glaciated area and in all topographic positions except on flood plains. The substratum may be either periglacial deposits or till. Most miniature block fields are in poorly drained soils on material with a high water table. Miniature block fields are transitional into bouldery till or periglacial rubbles and are probably surface concentrations of rock fragments derived from material below or upslope. In a few places, the fragments form boulder rings or boulder stripes. It is probable that all miniature block fields were forest covered in precolonial times.

BOULDER RINGS

In Potter County, typical boulder rings (fig. 11) occur in a few scattered localities, most of them inside the drift border. The borders of the rings are composed of fragments, flagstones, boulders, or blocks—mostly of sandstone. These fragments range from 6 inches to 3 feet in diameter and many are upended with their longer axes nearly vertical. Most are subangular with rough, pitted surfaces partly covered by lichens. The fragments have weathered rinds from a quarter to half an inch thick and are cracked and exfoliated with a weathered layer along the cracks. The borders of the rings range in width from 2 to 6 feet, in depth from 2 to 4 feet, and enclose roughly circular areas from 4 to 15 feet in diameter. The centers of the rings are chiefly silty material that contains a few fragments of rock and are covered by moss, turf, bushes, or trees. Some vegetation grows in pockets of mineral soil between the fragments that make the border.

Boulder rings occur on level land or on slopes as steep as 3°. An area covered by boulder rings has a microrelief that ranges from 1 to 3 feet; the centers of rings are the high points in most places. Boulder rings cover areas that range from 50 to 200 feet in diameter. Most of the rings rest on silty till that commonly has a high water table and is the parent material for poorly and very poorly drained soils.

The antiquity of the boulder rings is indicated by their partial covering by vegetation, by the weathered rinds and lichen cover of individual rock fragments, and by their breakdown in place into fragments, which suggests that present-day weathering is destroying the individual fragments rather than forming new rings.

The similarities between these rings and those now forming in subarctic or alpine environments suggest that the two have a common origin—that is, they are a result of a period of deep seasonal freeze and thaw. The depth of the boulder borders suggests that this assumed freeze and thaw was only moderately deep (about 10 feet). A further assumption is that the ground did not have to be perennially frozen.

BOULDER STRIPES

Boulder stripes are bands of rock fragments, which are separated by wider bands (relatively free of rock fragments) that trend down gentle slopes of about 2° to 5°. Boulder stripes are found in numerous, widely scattered localities, both within and outside of the glaciated area. The boulder stripes are composed of platy fragments of rock that are oriented with their flat surfaces nearly vertical and trending downslope. Most stripes are composed of fragments of sandstone. Large blocks or boulders form block fields but do not form boulder stripes. The reason for this limitation is not clear, but perhaps the ancient frost action was not sufficiently severe to sort the large fragments into stripes. It is probable that all boulder stripes were forest covered in precolonial times.

BOULDER STRIPES NEAR SWEDEN HILL CEMETERY

Boulder stripes are found on a southwest-facing slope about three-tenths of a mile southeast of Sweden Hill cemetery in the headwaters of Lyman Creek (pl. 4). The locality is near the top of the plateaus at altitudes that range from about 2,300 to 2,400 feet, about 4 miles southwest of the drift border. The boulder stripes are associated with miniature block fields and imperfectly formed boulder rings and cover an area of several acres that slopes between 2° to 4°. The microrelief is slight. The interstripe areas rise as much as 1 foot above the adjacent stripes. There are a very few low blowdown mounds (see p. 59 ff.).

The boulder stripes range from 4 to 15 feet in width (fig. 16) and from 50 to 200 feet in length. At least 75 percent of the surface area of a stripe is made up of rock fragments, the remainder is covered by organic matter. The stripes are essentially straight and trend downslope. The rock fragments are of gray, fine-grained sandstone and are essentially fresh to slightly stained throughout. Some fragments have weathered rinds a fraction of an inch thick. A very few of the fragments are yellowish red and resemble those in paleosol. Most rock fragments are angular slabs, flagstones, or blocks that range from 2 inches to about 2½ feet in diameter and from 1½ to 4 inches in thickness.

The sparse matrix is a loose, friable, yellowish-brown, fine sandy loam to silt loam. There are many connecting voids. A rough estimate of the volume ratio of fragments to voids to matrix is 2 to 2 to 1. The boulder stripes are at least 3 feet deep (fig. 16*B*). The rock fragments in the stripes have their broad flat surfaces nearly vertical and trending downslope. The fragments are tightly packed and difficult to remove. The arrangement of the fragments suggests that the stripes have been compressed horizontally.

The interstripe areas are 10 to 25 feet wide and have few rock fragments scattered over the surface (fig. 16). The underlying material is a yellowish-brown sandy loam to silt loam—a periglacial deposit with not more than 5 volume percent of small fragments of sandstone.

Without doubt, the area of boulder stripes was forested-covered in precolonial times. The present vegetation consists of stump sprouts of red maple with considerable quantities of sugar maple, beech, and a few black cherry, which are about 20 to 30 years old. The undergrowth is dominantly spinulose and New York fern with a few *lycopodium* (Goodlett, oral communication). The area apparently has never been plowed but is surrounded by fields, some abandoned, with stone walls and piles of boulders.

No outcrops of bedrock are known near the boulder stripes, but the area probably is underlain by interbedded sandstone and shale. On the upland just northwest of the cemetery is a small area of paleosol (pl. 2), but no traces of it were seen near the boulder stripes.

The area has a thin podzolic soil profile with a discontinuous gray A_2 horizon that is about 2 inches thick. The *B* horizon is a yellowish-brown, fine sandy loam that is transitional into the *C* horizon, which is a grayish-brown to gray sandy loam (fig. 16). In the boulder stripes, the *A* and *B* horizons are much thicker than in the interstripe areas. However, the reason for this greater thickness is uncertain. The ready permeability of the stripes, coupled with less material per unit volume to be altered by soil-forming processes, might cause soil horizons to be thicker. Possibly, as suggested by Richmond (personal communication), fine material has been removed by water running through stripes under the surface layer of organic matter. Perhaps this hypothesis is more applicable to steep slopes (20° or more), where soil horizons may have been trenched by runoff through permeable rubbles.

The boulder stripes near Sweden Hill cemetery are attributed to frost action during the Wisconsin stage.

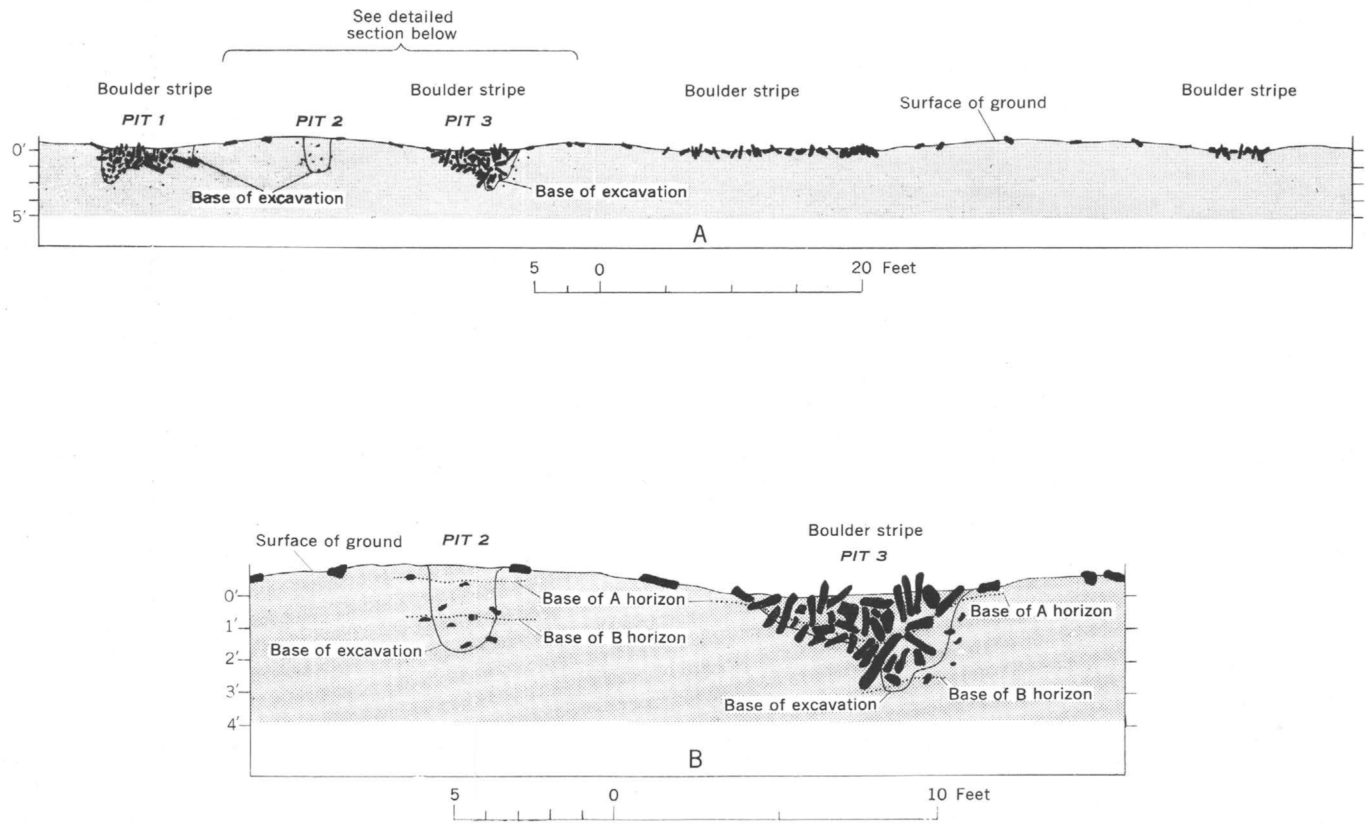


FIGURE 16.—Boulder stripes near Sweden Hill cemetery, Genesee quadrangle, Potter County, Pa. The area is a southwest-facing, 2° to 4° slope, altitude 2,300 to 2,400 feet, located about 4 miles southwest of border of Wisconsin drift or about three-tenths of a mile southeast of known paleosol locality no. 4 (pl. 1). *A*, Subsurface characteristics of stripes and interstripe areas are shown only where excavated; *B*, shows base of *A* and *B* horizons of soil profile exposed in pits in boulder stripe and interstripe areas.

Processes related to frost action concentrated rock fragments on the ground surface; these fragments were derived either from material below or upslope. The fragments may be a lag deposit, the finer constituents having been carried downslope by mass movements. In a few localities, these processes formed boulder stripes. Such localities have stony soils unfavorable for agriculture. Possibly many other slopes were originally covered with miniature stripes (for photographs, see Sharp, 1942; Troll, 1944) that, because of the small size of the rock fragments, were destroyed by plowing or by tree roots.

The boulder stripes are not forming now, and the presence of a podzolic soil profile suggests that the stripes have been stabilized for at least several hundred years. Their occurrence in a second-growth forest and their partial covering by turf and lichens also indicates relative stability. The gentle slope of the area, 2° to 4°, is believed insufficient to cause movement under the present climate. Even on much steeper slopes, 20° or more, one has to search over wide areas to find much evidence of present-day mass movements.

BURIED BOULDER STRIPES

In some periglacial rubble, the individual rock fragments are irregularly distributed below depths of 1 to 2 feet. Masses of fragments with almost no fines are separated by masses that contain few rock fragments and more fines. Within 1 or 2 feet of the ground surface, however, the rubble is a heterogeneous channery and flaggy deposit that includes the *A* and part of the *B* horizon of the soil profile. Such an exposure is interpreted as a cross section through buried boulder stripes, which originally extended to the surface but which have been destroyed by various processes.

A good example of buried boulder stripes is shown in figure 20. The area (fig. 17) is underlain by interbedded sandstone and shale and includes an abandoned field surrounded by second-growth forest. At the east end of this field is a knoll whose summit and southwestern slope is barren and covered by a miniature block field that is composed of platy fragments of sandstone from 1 to about 12 inches in diameter. The block field is probably a relict of the Wisconsin stage, which was reexposed when the land was cleared. Present-day

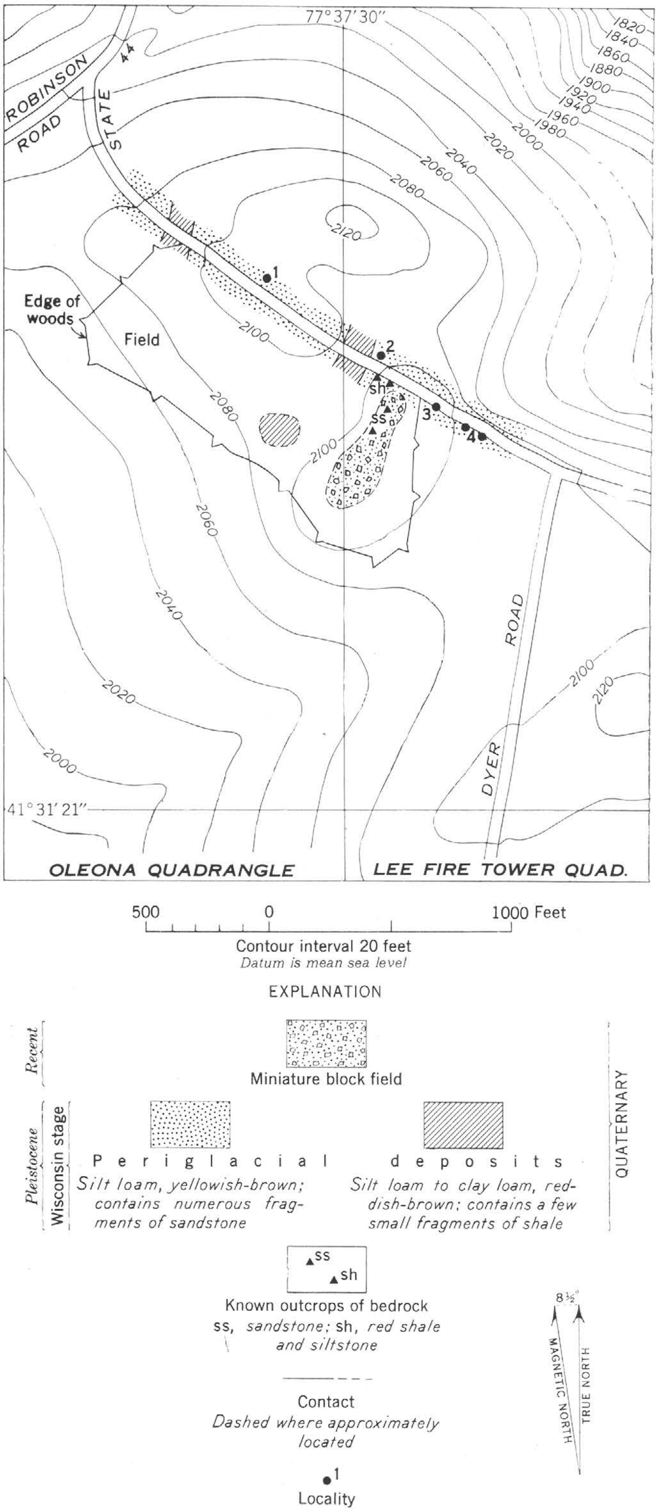


FIGURE 17.—Map of miniature block field. Location is on uplands along State Highway 44 east of Kettle Creek in the Oleona and Lee Fire Tower quadrangles, Potter County, Pa.

frost action, rain wash, and possibly wind erosion are preventing the vegetation from regaining a foothold. In Wisconsin time this block field was the source of fragments of sandstone, which were spread over the surrounding gentle slopes and which locally were concentrated into boulder stripes. (See figs. 17 to 19).

In parts of the road bank (loc. 1, fig. 17) north of the miniature block field, the rock fragments in the periglacial deposits are not regularly distributed; instead, they are concentrated into pockets here interpreted as parts of boulder stripes on a 1° to 2° slope (fig. 20).

FIGURE 18.—Bouldery alluvium, Potter County, Pa. Exposure in the west bank of the Genesee River at Genesee, Genesee quadrangle. The bank is about 7 feet high.

FIGURE 19.—Miniature block field, Potter County, Pa. Pavement of upended and flat-lying fragments of sandstone, believed to be a relict of Wisconsin stage reexposed when forest was cut off. Locality is on uplands east of Kettle Creek, along State Highway 44 about 1½ miles west of the Potter County line (see fig. 17).

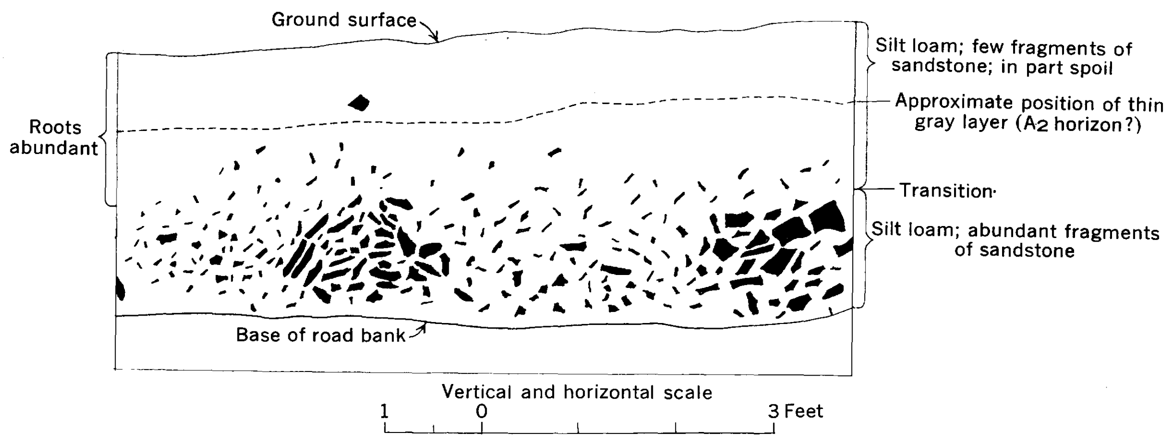


FIGURE 20.—Buried boulder stripes(?) exposed in road cut along State Highway 44 on uplands east of Kettle Creek about 1½ miles west of Potter County line, Oleona quadrangle and Lee Fire Tower quadrangle (loc. 1, fig. 17). Drawn from a photograph.

In the upper 1½ to 2 feet of the cut the rock fragments are almost uniformly distributed throughout, but at depths of 2 to 3 feet the larger rock fragments are concentrated in pockets with little fine material and with numerous large connecting voids. The intervening areas have more fines, fewer voids, and numerous fragments as much as 3 inches in diameter.

In other places (loc. 3, fig. 17), the periglacial deposits consist dominantly of sandstone fragments with very little silty matrix and with large interconnecting voids. Apparently, this is a wide boulder stripe that descends northeastward from the miniature block field down a slope of about 5° and is exposed in cross section in the road bank—the sandstone slabs apparently were derived from the block field. Beneath this stripe is silt loam with relatively few coarse fragments and abundant fines as compared with the material above.

Along the road just north of the miniature block field (loc. 2, fig. 17) about 3 feet of periglacial deposit containing numerous sandstone fragments overlies red siltstone and shale. Here, the periglacial deposit has moved northward down a 4° slope from the miniature block field and has buried the underlying red beds. Along the road east of the miniature block field (loc. 4, fig. 17) the periglacial deposits contain irregular masses of yellowish-red, silty material apparently derived from paleosol.

TERRACES

In Potter County, slopes on periglacial deposits are smooth. However, in one or two places there are terraces 3 or 4 feet high (with a steep front), 50 to 100 feet long, and 10 to 30 feet wide. These terraces occur on relatively gentle slopes near ridge crests and are not to be confused with bedrock benches or with sloping benches on periglacial deposits near the valley bottoms. Such terraces are found along State Highway 44 near the Cherry Springs Fire Tower, Cherry Springs quadrangle. Where the road bank intersects the terraces, they are demonstrably underlain by rubble—not by bedrock. These terraces resemble those found in arctic or alpine regions, which are attributed to mass movements induced by thawing of surficial deposits over frozen ground. Perhaps the terraces in Potter County had a similar origin.

DEPOSITS NEAR COLESBURG, GENESEE QUADRANGLE

North of the Allegheny River and about half a mile southwest of Colesburg is a small alluvial fan whose lower end has been slightly trimmed by the Allegheny River. This fan resulted from dissection of the adjacent thick periglacial deposits that are well exposed in a trench silo (figs. 21, 22). The periglacial deposit is dominantly loose and friable channery silt loam with fragments of rock whose flat surfaces dip into the hill (fig. 15). The lower part of the deposit in the northwestern half of the trench is a yellowish-red silt loam to loam with many yellowish-red fragments of sandstone, resembling those in paleosol, and some unweathered fragments of greenish-gray sandstone.

Most of the upper part of the deposit contains the same rock types as those below, but there are fewer yellowish-red fragments. All the deposit has a weakly developed platy structure. The upper 1 or 2 feet of the deposit contains few fragments of rock and is probably postcultivation.

The periglacial deposit is faintly stratified (Denny, 1951, fig. 5), partly owing to imbrication of fragments and partly owing to slight textural differences in the matrix. The contact between the yellowish-brown deposits above and the yellowish-red deposits below can be located within about 2 inches. The tongues of the lower type of deposit, projecting downslope into the upper type (fig. 22), were identified on the northbeast side of the trench (width about 6 feet), but they could not be found on the southwest side.

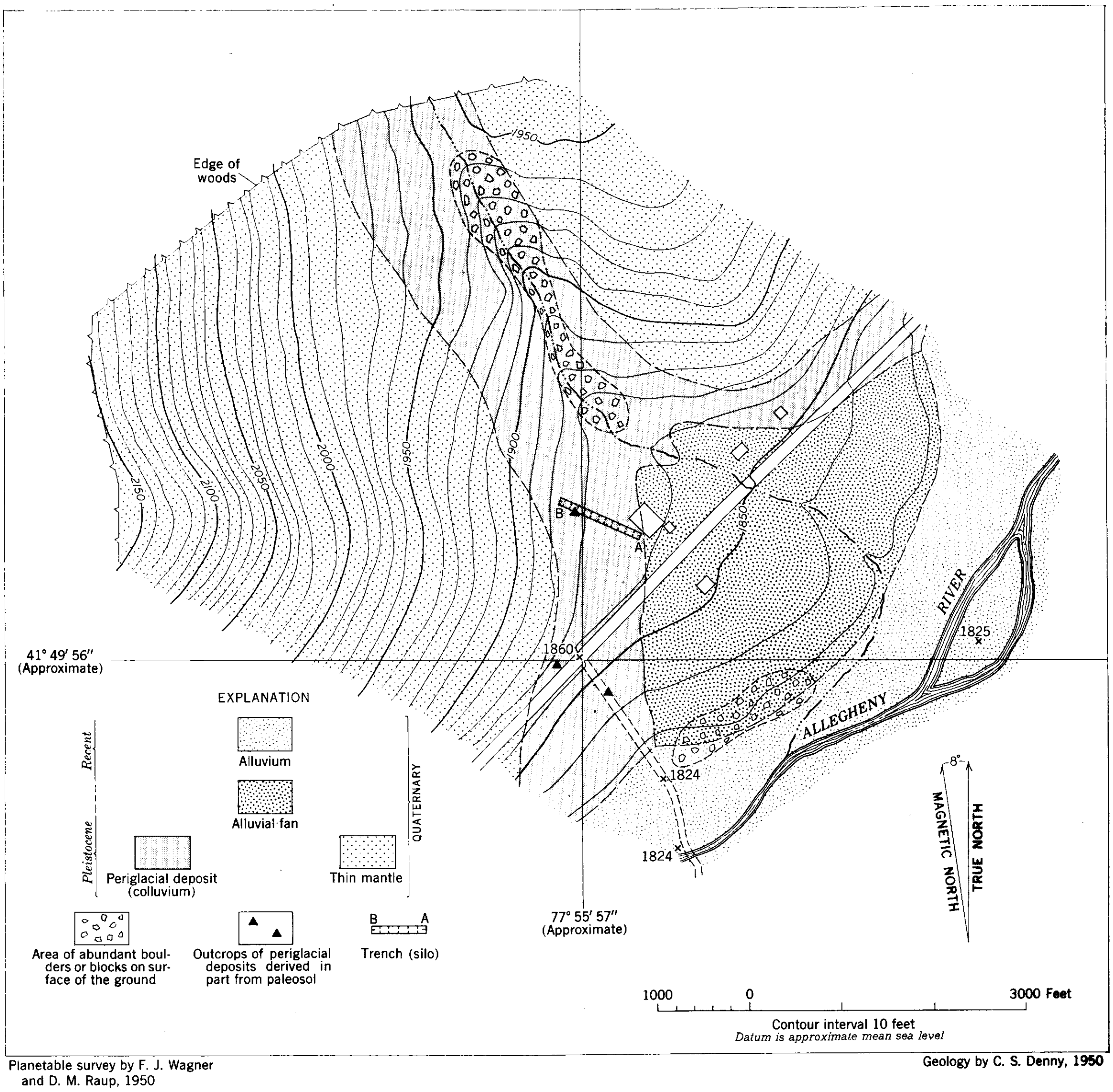


FIGURE 21.—Map of alluvial fan and periglacial deposit in area on north side of Allegheny River and about half a mile southwest of Colesburg, Genesee quadrangle, Potter County, Pa.

The history of these deposits is interpreted as follows: The paleosol, which covered the adjacent slopes and ridge crests in pre-Wisconsin time, was eroded in Wisconsin time (or perhaps in late Sangamon time) and carried downslope toward the Allegheny River. Much of it was completely removed, but some, mixed with less-weathered material, accumulated at a lower level as the yellowish-red periglacial deposit of the trench silo. Continued erosion of slopes buried this material with less-weathered colluvium derived from bedrock or from surficial deposits beneath the paleosol. Probably during the Wisconsin stage the boulders or blocks of sandstone along the intermittent streams were carried down steep slopes in the headwaters to the north of the area shown in figure 21.

In later Wisconsin or in Recent time, the thick periglacial deposits were dissected and the alluvial fan was built. Perhaps the boulders and blocks along the intermittent stream were further concentrated by removal of finer matrix material. The alluvial fan is now being dissected both by the intermittent stream and by the Allegheny River.

DEPOSITS IN KETTLE CREEK VALLEY, OLEONA AND SHORT RUN QUADRANGLES

Along Kettle Creek, south of Oleona (pl. 8), are thick periglacial deposits composed of unsorted channery and flaggy silt loam, which in places contain a few well-rounded pebbles. Also, there are gravel deposits that locally are the parent material for paleosol (p. 19) and apparently are remnants of a pre-Wisconsin valley

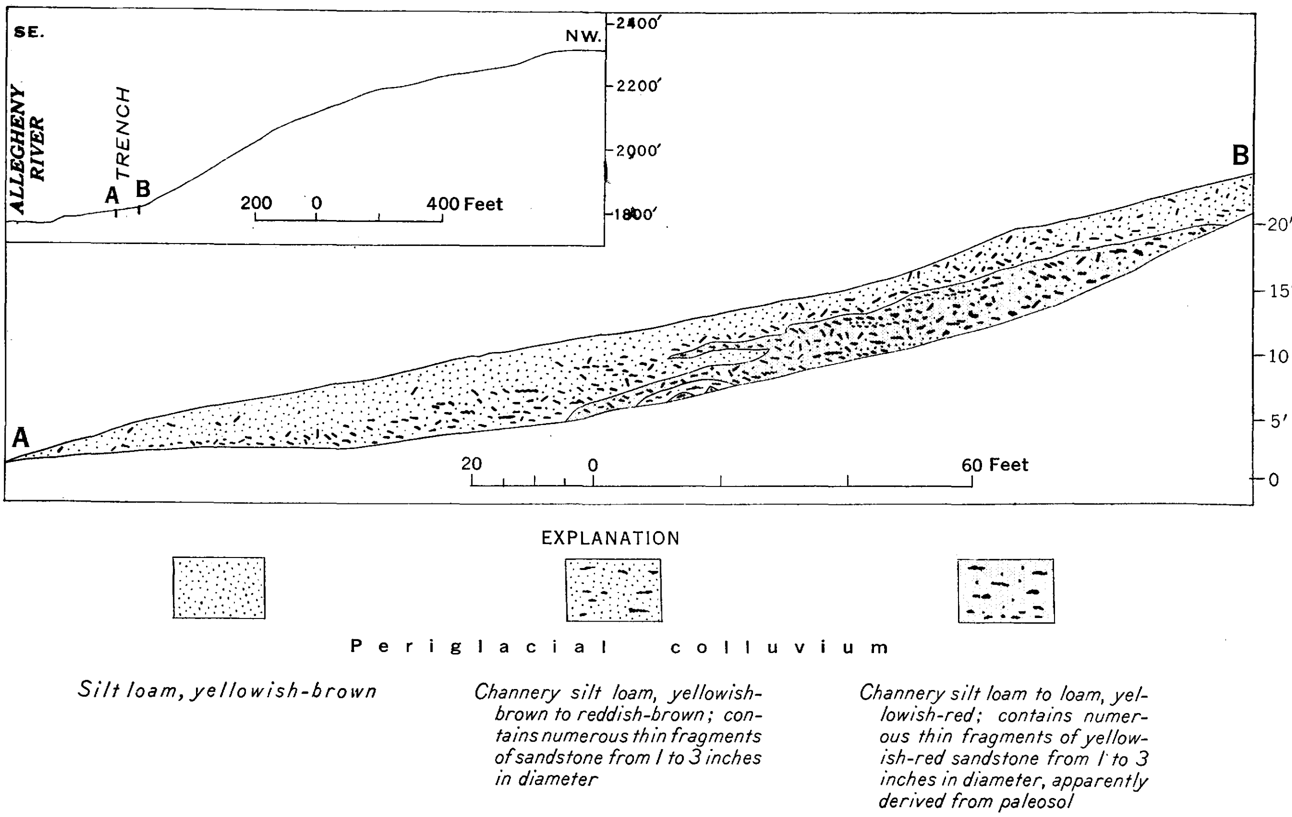


FIGURE 22.—Periglacial colluvium in part derived from paleosol, exposed in trench silo near Colesburg, Genesee quadrangle, Potter County, Pa. For location see figure 21.

fill (before the formation of the paleosol), at least 150 feet thick, that has been largely removed. The remnants of this fill are not preserved as terraces on the valley sides, but they form sloping benches. This suggests that the valley fill was dissected in late Sangamon time to form a terrace that was modified by periglacial mass movements during the Wisconsin stage to produce the gently sloping benches of the present day. The finding of stream-worn pebbles in the unsorted periglacial deposits suggests that these deposits were derived in part from gravel. Therefore, most of the 150 feet of downcutting by Kettle Creek took place either prior to, or concurrent with, the mass movements that formed the periglacial deposits. This assumption is contrary to the widespread belief (Peltier, 1949) that valleys in periglacial areas were alluviated during glacial substages and were dissected during interglacial or interstadial intervals. Perhaps this difficulty can be resolved by assuming that the 150-foot gravel fill was dissected by Kettle Creek in late Sangamon or very early Wisconsin time, which was prior to arrival of the ice sheet in northeastern Potter County. Or perhaps the flow of ponded water through The Notch (pl. 1) at the head of Little Kettle Creek (p. 29) cut down the channel in spite of the quantities of material supplied to it by mass movements on the valley sides.

EOLIAN(?) DEPOSITS

Much of Potter County both within and outside of the glaciated area is mantled by silty material of probable eolian origin. The surface layer of most soils is silty whether the underlying material is rubble, gravel, or till, or whether the local bedrock is sandstone, shale, or conglomerate. This silt mantle is 6 inches to 2 feet thick and is believed to have been formed in early Wisconsin time, contemporaneously with the periglacial deposits.

AGE AND ORIGIN

The periglacial deposits and associated soil structures of Potter County are believed to have been formed during, and shortly after, the deposition of the Olean drift of MacClintock and Apfel (early Wisconsin or Iowan time) by processes active in the periglacial area within a few tens of miles of the border of the Wisconsin drift. The periglacial deposits have been described in detail. The features that bear on their age and origin can be summarized as follows:

(1) The periglacial deposits are thickest and most extensive in an area within about 10 miles of the drift border and are thinner and less extensive in areas further removed from the drift border. This is the best evidence that the deposits are related in time to the

presence of an ice sheet at or near the border of the Wisconsin drift, and it eliminates the possibility that the periglacial deposits are the result of erosion and deposition under the present climate—in other words, during post-Mankato time. The relationship has been established by detailed mapping in the Genesee quadrangle and by reconnaissance work elsewhere in Potter County. It is also in accord with observations made in other parts of Pennsylvania south of the border of the Wisconsin drift. Without doubt, much of Leverett's "Areas of questionable location" (Leverett, 1934, pl. 1), and the materials attributed by Williams to his "Pennsylvania glaciation, first phase" (Williams, 1917), are periglacial deposits.

(2) The slopes appear to be essentially stable at the present time. Present-day erosion of slopes by runoff is very slight, and it is very difficult to find a block that has moved downslope in recent years. Most of the periglacial deposits are very permeable except in areas underlain by shale or siltstone. After heavy rains the spring-fed streams are full from bank to bank, but very little water can be seen flowing downslope on the ground surface. One of the most important agents of weathering and erosion of surficial deposits at the present time is disturbance by the roots of fallen trees, which produces a characteristic microrelief of mounds and pits (p. 59.). On slopes, such blowdowns result in downslope movement, but the rate is slow. On steep slopes, the existence of large blowdown mounds and pits that are judged to be several hundred years old attests to the relative stability of the surficial materials. The presence of a Podzolic soil profile on steep slopes also suggests the relative stability of the surficial deposits for at least the last few hundred years. Furthermore, the fact that the periglacial deposits on the uplands have moved down gentle slopes (1° to 5°) and have accumulated to thicknesses of several feet is difficult to reconcile with the essential stability of much-steeper slopes at the present time, unless it is assumed that the movement took place in the past under an environment that no longer exists.

(3) Both the periglacial deposits and the Wisconsin drift postdate the paleosol, which is presumed to be of Sangamon age. The paleosol is overlain by periglacial deposits and perhaps by Wisconsin till. Both the periglacial deposits and the Wisconsin drift contain fragments of paleosol.

(4) Soil structures occur on both drift and periglacial deposits and were formed almost contemporaneously with the underlying deposits. In the absence of buried soils, or weathering horizons between soil structures and the underlying deposits, this conclusion is justified. As a corollary, soil structures on periglacial deposits and on drift are assumed to have been formed at essentially the same time. The soil structures are the result of processes no longer in action. Their essential stability at present is indicated by their partial covering by vegetation, by the weathered rinds and lichen cover of the individual rock fragments, and by the breakdown of the individual fragments into smaller pieces, thus suggesting that present-day weathering is destroying the individual fragments rather than forming new soil structures. The morphological similarity between the ancient soil structures in Potter County and those now forming in arctic, subarctic, or alpine environments indicates that both are the results of the same processes. It is well established (Sharp, 1942) that modern soil structures are the result of a deep and repeated freeze and thaw of the ground in areas devoid of forests, and, in many places, these structures are associated with perennially frozen ground.

(5) The heterogenous character of most of the periglacial deposits indicates that most of them were deposited by mass movement. Some periglacial deposits are more or less stratified, thus suggesting that running water contributed in part to their deposition.

(6) The kind and depth of weathering and types of soil found on the periglacial deposits are similar, if not identical, to those on the adjacent Wisconsin drift, thus suggesting that the two deposits were formed at about the same time. However, as pointed out in a later section (p. 65), the fact that the upper 2 or 3 feet of the soil probably has been disturbed by the roots of fallen trees during all of late Wisconsin and Recent time would tend to make the soils on the Wisconsin drift similar to those on the periglacial deposits, at least in the *A* and in the upper part of the *B* horizons. Thus, similar soils on periglacial deposits and drift is not unequivocal evidence that the two deposits are contemporaneous.

On the basis of the features summarized in the preceding paragraphs, the periglacial deposits and associated soil structures of Potter County probably were formed during and shortly after the deposition of the Olean drift—that is, during early Wisconsin, perhaps Iowan, time by processes active in the periglacial area within a few tens of miles of the border of the Wisconsin drift.

One alternative explanation is that the periglacial deposits and soil structures are much younger than the adjacent Wisconsin drift—in other words, they are of Tazewell or Cary age or, to use the terminology of MacClintock and Apfel (1944), they are correlative of either the Binghamton or Valley Heads drifts (Fairchild, 1932). Peltier (1949) thus explained some of the surficial deposits on terraces along the Susquehanna River. The soil structures in Potter County just inside the border of the Olean drift would be attributed to the periglacial climate of the Binghamton substage, whose drift border lies 30 to 40 miles to the northeast (fig. 1). This alternative requires that the periglacial climate of Binghamton time extended across a belt that was at least 40 miles wide. However, in Potter County the periglacial deposits apparently are thickest and most continuous in a zone about 10 miles wide that parallels the Olean drift border. This fact indicates that in Potter County the periglacial deposits and the Olean drift of MacClintock and Apfel are essentially contemporaneous. Therefore, it is most likely that the periglacial deposits date from early Wisconsin, Iowan(?) time. However, it is possible that in Potter County some periglacial deposits, or the upper part of such deposits, are of Binghamton or Valley Heads age.

OTHER INFERENCES FROM PERIGLACIAL DEPOSITS

If it is true that the periglacial deposits were formed almost contemporaneously with the adjacent early Wisconsin drift, then a few speculations can be given concerning the environment of the periglacial area, its possible climate and vegetation, the presence or absence of permafrost, the processes involved in the formation of the periglacial deposits, and the removal of an assumed blanket of paleosol.

The processes that probably were active in the periglacial area include a relatively deep and repeated freeze and thaw, which is necessary to explain the formation of soil structures and the movement of unsorted, heterogeneous periglacial deposits down gentle slopes. Such movement probably was the result of solifluction—the movement of water-saturated, thawed ground over a frozen subsoil. The faint stratification in the periglacial deposits suggests transport in part by running water. However, some fans outside the border of the Wisconsin drift are underlain by till-like periglacial deposits that suggest transport by mass movements instead of by running water. This fact alone does not favor transportation by mass movement related to a deep and repeated freeze and thaw of the ground over other types of mass movement. Without doubt, periglacial deposits on steep slopes were moved by normal creep and by other mass movements that are unrelated to a frozen subsoil.

For the most part, terraces, lobes, or other microrelief features that are characteristic of modern landscapes in areas of perenially frozen ground are absent. Such microrelief features may never have been present here or, if originally present, they might have been removed by later weathering or erosion. Slopes in the periglacial area are underlain by debris, which formerly was in transit downslope, but which now is relatively stable. If this is true, either the periglacial deposits were carried away by the stream as fast as supplied, or, more probably, the valleys were aggraded. Dissection since aggradation took place has not reached these headwater areas.

A possible contributing factor for the movement of periglacial debris is snow. Conceivably, snow accumulated as large drifts on the sides of valleys in the periglacial area. The movement of periglacial deposits might then be attributed to frost action around these snow banks and to melt water. Such a process could explain the alluvial fans, but it cannot account for the soil structures.

The soil structures in Potter County are shallow, occur only in small areas, and are composed of small fragments of rock. In comparison with structures in arctic, subarctic, or alpine regions, they are small. This suggests that frost processes forming them during an early Wisconsin substage were either moderate or short-lived, or both. However, such a conclusion is not necessarily correct. Most of the local rocks are thin-bedded and break up into relatively small fragments. Therefore, even assuming optimum conditions, most soil structures would have been made of rock fragments not more than 1 foot in diameter. Most soil structures now visible will be found in areas where large fragments of rock were available. If large areas on the uplands were originally covered by soil structures, such structures are now buried beneath the forest floor, destroyed by the roots of fallen trees, or disturbed by plowing. Many very stony cultivated fields may have been covered originally by soil structures. Observations in central and eastern Pennsylvania, both within and outside of the Wisconsin drift border, suggest that ancient soil structures are most prominent in areas of massive rock.

An intensity of frost processes sufficient to produce soil structures and solifluction on low slopes could result from a moderate lowering of the average annual temperature of Potter County to a degree sufficient to cause a somewhat deeper seasonal freeze and thaw than at present; a reduction of forest cover also would greatly increase the effectiveness of frost action. If the daily freeze and thaw period in spring and fall could be lengthened, an increased disturbance and movement of surficial deposits by frost-related processes probably would result without a marked lowering of minimum winter temperatures. There is no evidence of permafrost in Potter County during the formation of the periglacial deposits; a depth of freezing of as much as 10 feet probably is sufficient for the formation of the deposits.

There are no known remains of the vegetation that grew during Olean time except for a layer of peat found by MacClintock and Apfel (1944) north of Salamanca, N. Y. Near Otto, Cattaraugus quadrangle (fig. 1), a layer of peat rests on till and gravel believed to belong to the Illinoian stage and is overlain by Olean outwash gravel. The peat contains pollen of fir, spruce, and pine (as determined by Paul B. Sears) and has a carbon-14 date of more than 35,000 years (Suess, 1954). These data suggest that a boreal forest grew in a valley in front of the advancing Olean ice sheet. The data neither affirm nor deny the presence of essentially treeless areas on the adjacent uplands.

While the northern part of Potter County was covered by the ice sheet, the southern part probably did not have a forest that was comparable to that which prevailed before about 1800. The soil structures, the movement of periglacial deposits down gentle slopes, and the eolian(?) deposits suggest that the uplands probably supported some sort of tundra vegetation. Forests were doubtless restricted to flood plains, to lower slopes, and to scattered areas on uplands. Numerous studies on modern soil structures establish beyond reasonable doubt that they do not occur in dense forests. Most present-day examples occur outside of forested regions, either on mountains above timber line or in high latitudes. The ancient soil structures in Potter County attest to an absence of forest vegetation, at least where the structures formed. In the subarctic, the mass movement of surficial deposits on gentle slopes occurs over perennially frozen ground in areas devoid of dense forests. By analogy, it is suggested that when such mass movements took place on the uplands in Potter County, these uplands were not covered by a dense forest.

The formation of some periglacial deposits after deposition of adjacent drift suggests that the forest did not return to the drift-covered area during deglaciation. A delay in the reforestation of the drift might have resulted from the instability of surficial material because of frost action. The fact that the periglacial deposits are thickest and most extensive within about 10 miles of the drift border suggests that forest vegetation was most restricted here. Farther from the drift border, forests may have been absent only from the areas of ancient soil structures or perhaps only from the highest ridge tops.

The paleosol remnants probably are part of a soil that originally covered most of the uplands. Perhaps it was almost completely removed by periglacial mass movements. However, during a late Sangamon or very early Wisconsin substage, the paleosol may have been removed by normal erosion, not by periglacial processes. Because the paleosol contains more clay and is relatively less permeable than the periglacial rubbles, the paleosol might be much more easily removed by erosion than the periglacial rubbles under a climate such as the present one. The paucity of exposures of paleosol overlain by Wisconsin drift, or of drift containing paleosol (except for a few fragments of yellowish-red sandstone), suggests that the paleosol was largely eroded away by the time the ice sheet invaded the area.

The stratigraphic relations exposed in the trench silo near Colesburg, Genesee quadrangle (fig. 22), suggest that debris derived from paleosol was deposited first, and that this deposition was followed by material from unweathered surficial deposits and bedrock, or both. But this does not date this movement, except that it postdates the paleosol.

RECENT DEPOSITS

ALLUVIAL FANS

In Potter County are numerous small alluvial fans, some definitely are modern, others may date from the Wisconsin stage. The only large alluvial fans are in the valleys of Oswayo Creek and Allegheny River in the Coudersport quadrangle. The fans are composed of rubbly, pebbly, cobbly, or bouldery sandy loams to silty clay loams. Much of the material is unstratified. Lenses of gravel and sand are found in some places. The larger fans along Oswayo Creek and Allegheny River have not been studied in detail, but as compared with other fans, they probably contain a higher proportion of sand and gravel.

In the Genesee quadrangle (pl. 4) the alluvial fans are small and much of the material is only faintly stratified. In the periglacial area it is difficult to separate alluvial fans of Recent date from those of the Wisconsin, which are composed of periglacial material. The distinction is based largely on topographic form. Masses of relatively unsorted materials in the shape of essentially undissected alluvial fans are shown as Recent, whereas similar materials forming gently sloping benches or alluvial cones on the lower valley walls are mapped as periglacial deposits. The lower ends of many of these benches and cones are elevated 10 to 20 feet above present flood plains; they have been dissected and are not being actively built.

The large alluvial fans commonly end in a steep bank, as much as 10 feet high, resulting from later dissection by the major stream. The surface gradient of the fan, if projected toward the major valley, intersects the present flood plain. The dissection, therefore, can be attributed entirely to lateral cutting by the major stream and does not necessarily indicate any lowering of the flood plain of the major valley after the fan was formed.

ALLUVIUM

Recent alluvium on flood plains consists of sand and sandy loam, 1 to 3 feet thick, that overlies pebbly, cobbly, bouldery, channery, or rubbly sandy loam to gravel (fig. 18). In places, the surface layer or the underlying material contain lenses of silt loam to clay loam and organic matter. The alluvium is well to faintly stratified and ranges in thickness from a few feet to more than 100 feet. The thicker masses of alluvium (pl. 1) probably include deposits of the Pleistocene epoch, which are buried beneath Recent sediments.

A few observations on the degree of rounding of rock fragments in alluvium along streams in the periglacial area suggest that about 2 miles from the headwaters many fragments of rock as much as 2 inches in diameter are well rounded and that fragments as much as 4 inches in diameter are subangular to slightly rounded.

For example, Buckseller Run, a small tributary of Pine Creek, Genesee quadrangle (pl. 4), has the following characteristics:

Length, approximate	miles	2⅗
Altitude:		
At headwaters	feet	2, 400
At mouth	do	1, 680
Depth of valley at mouth	do	700
Gradient, average	feet per mile	300
1st quarter	do	700
2nd quarter	do	360
3rd quarter	do	200
4th quarter	do	100

Bedrock—essentially flat-lying sandstone, siltstone, shale, and conglomerate (Pottsville and Pocono formations).

Near the headwaters of the run, rock fragments in the alluvium form angular slabs or flagstones. About 1 mile from the headwaters, fragments 1 or 2 inches in diameter are somewhat rounded, and the larger ones are angular. About 1¼ miles downstream from the headwaters, fragments 1 to 2 inches in diameter are well rounded, and those 2 to 4 inches are slightly rounded; larger fragments are angular.

Commissioner Run, a tributary of Ninemile Run, Genesee quadrangle (pl. 4), has the following characteristics:

Length, approximate	miles	2⅗
Altitude:		
At headwaters	feet	2, 460
At mouth	do	1, 790
Depth of valley at mouth	do	600
Gradient, average	feet per mile	280
1st quarter	do	400
2nd quarter	do	360
3rd quarter	do	230
4th quarter	do	115

Bedrock—essentially flat-lying. sandstone, siltstone, shale, and conglomerate (Pottsville and Pocono formations).

Near the headwaters of the run, rock fragments in the alluvium are angular. However, at the mouth of the run, the alluvium contains an abundance of somewhat-rounded to well-rounded fragments of sandstone, ranging from ½ to 2 inches in diameter; the larger fragments are angular and subangular.

GEOMORPHIC DEVELOPMENT OF THE APPALACHIAN PLATEAUS

Remnants or traces of one or more peneplains have long been recognized in the Appalachian Plateaus of north-central Pennsylvania. The influence of rock resistance and rock structure in the development and preservation of such erosion surfaces has been emphasized by many workers. Closely woven into all arguments that deal with these peneplains is the origin of the Appalachian drainage. The two problems have been inseparable since Davis first proposed his theory for the origin of Appalachian topography and drainage.

The voluminous literature dealing with the "Appalachian problem" is summarized by various authors (Bowman, 1911; Johnson, 1931; Bryan, Cleaves, and Smith, 1932–33; Fenneman, 1938; for Pennsylvania *see also* Ashley, 1930, 1933, 1935; for the plateaus of north central Pennsylvania *see* Fridley, 1929, and Cole, 1941). The Davis theory is given in Davis (1889, 1891). For a discussion of Pennsylvania drainage *see* Strahler (1945) and Thompson (1949). A slightly different approach is that of Béthune (1948).

The recent publication of a block of topographic maps, scale 1/24,000, covering southern Potter County and vicinity, furnishes an adequate topographic base with which to analyze and interpret the configuration of the plateaus in terms of the peneplain hypothesis. The analysis consisted of the preparation of a restored contour map (pl. 5) to show the configuration of a supposed peneplain on the assumption that the tops of the plateaus are remnants of an old-age erosion surface.

The restored contours delineate a surface that corresponds roughly to rock structure. In general, the uplands slope parallel to the bedrock and toward the synclinal axes. The major streams, such as the West Branch Susquehanna River, cross ridges and valleys of the restored surface in such a manner that it is difficult to suppose that the restored surface was ever graded to such streams. On the contrary, it is probable that the restored surface never existed and that the uplands are structurally controlled surfaces held up by sandstone and conglomerate beds in the Pottsville and Pocono formations. The plateau tops may have been lowered as much as 200 feet by erosion after the major streams were incised. If this portion of the Appalachian Plateau was ever reduced to a peneplain, such a hypothetical surface must have lain several hundred feet above the present-day uplands (Ashley, 1935, p. 1414).

DESCRIPTION OF UPLAND SURFACES

SIZE AND SHAPE

The tops of the Appalachian Plateaus are gently sloping surfaces of moderate local relief and are long and narrow with very irregular outlines (pl. 5). The most extensive one is on the divide between Pine Creek and the West Branch Susquehanna River along the boundary line between Lycoming and Clinton counties. In the Susquehanna drainage, except near the main Susquehanna-Allegheny divide, upland surfaces are more extensive near synclinal axes than along the axes of anticlines. Several groups of upland surfaces trend definitely northeastward. In the Allegheny and Genesee drainages, upland surfaces are smaller and less well defined.

SLOPES

The upland surfaces slope between ½° and 10°—the average is about 4°. Very few of the upland surfaces are level. Most uplands larger than 1 square mile in area have slopes of more than 1°. In detail, the upland surfaces are rounded in profile and slope generally outward toward their margins. The valley walls have steep slopes ranging from about 15° to 35°—the average is about 20°. In places, the valley walls slope more than 35°, especially where they are undercut by streams.

AGE

Precise stratigraphic or geomorphic evidence for the age of the upland surfaces is scant. These upland surfaces cut slightly folded rocks of Devonian to Pennsylvanian age and are unquestionably post-Paleozoic. On the upland surfaces and in the bottoms of the deep valleys are widely scattered remnants of paleosol that are unquestionably pre-Wisconsin, and probably date from the Sangamon interglacial stage. Therefore, the upland surfaces were close to their present altitude in Sangamon time. As outlined below (p. 48), the upland surfaces probably owe their present form largely to Pleistocene events having been reduced by erosive processes similar to those acting today or in the recent past—that is, the gradual lowering of the ridge tops by chemical and mechanical weathering and by mass movements, more or less independent of downcutting by streams.

RESTORED CONTOURS DRAWN ON UPLAND SURFACES

METHOD OF CONSTRUCTION

To test the peneplain hypothesis, a restored contour map (pl. 5) was prepared in which all areas now dissected were made level with the plateau tops. The upland surfaces were then outlined so that the altitude of all points within them are within the restored contour interval. This method excludes a small part of many upland surfaces that lie above the break in slope at the top of steep valley walls. To reduce such exclusions to a minimum, the boundaries are drawn in some places through points as much as 20 feet above or below the limits established by the restored contours. In other words, wherever a restored contour crosses an upland surface, it represents essentially the true altitude at that point except for the smoothing of the contours necessary to permit reduction from a scale of 1/24,000 to that used on plate 5. Finally, the major structural axes from available oil and gas maps (Ingham, 1951; Ebright and Ingham, 1951; Ebright, 1952; Bolger and Gouse, 1953) were added.

The map (p. 5) thus shows at a glance the data used in constructing the restored contours and the areas where no data are available. The method eliminates about 10 to 20 percent of the upland surfaces actually present. It also avoids the difficulty of defining the break in slope between upland surface and valley wall. In places, the location of the break in slope is easy to define. However, where upland surfaces are small and where total relief from valley bottom to plateau top is not great, the location of the break in slope is arbitrary and cannot be uniformly defined for the whole area.

FORM OF RESTORED SURFACE

The restored surface consists of long, northeast-trending broad ridges and wide valleys, perhaps better described as greatly elongated low arches and shallow troughs. In areas between upland surfaces, where no data are available to control the restored contours they were drawn as straight or gently curving lines. Though the restored contours are essentially fixed where they cross upland surfaces, they could be changed elsewhere, depending on the hypothesis favored for the origin of the upland surfaces. The restored surface ranges in altitude from 1,500 feet along the West Branch Susquehanna River near Keating to 2,500 feet on the Allegheny-Genesee-Susquehanna River divide. Broad areas on the tops of the arches or on the bottom of the troughs are essentially level, the former being areas where almost no upland surfaces are preserved. The ridges slope between about ½° to 10°; the average is 4°. Many of the troughs are slightly canoe-shaped with a closure of 100 to 200 feet.

The northeasterly trend of the restored ridges and valleys breaks down in the Coudersport quadrangle where the restored contours suggest a late mature valley draining northwestward along Oswayo Creek. Here, upland surfaces are scarce and small. Somewhat analagous relationships are suggested in the Genesee Valley. The straight northwesterly course of Oswayo Creek is strongly at variance with the other major streams.

RELATION TO LITHOLOGY AND STRUCTURE

The general distribution of the rocks is shown on the Geologic Map of Pennsylvania (Stose and Ljungstedt, 1931) and is described in the present report on page 6 and in table 2. In general, throughout Potter County and vicinity, upland surfaces are underlain by sandstone and conglomerate (Pottsville and Pocono formations) preserved in synclines. The Catskill and Chemung formations (dominantly shale and siltstone) crop out in anticlines where most of the land slopes steeply and where upland surfaces are small and widely scattered. However, in the Oswayo Creek drainage, Coudersport quadrangle, and near the major Allegheny-Genesee-Susquehanna River divide, this generalization does not apply—here, upland surfaces do not correlate so closely with lithology and structure.

The form of the restored surface is strongly indicative of the rock structure. In many places the average dip of the rocks coincides with the general surface slope as shown by restored contours (pl. 5). For example, the southwestward-plunging Jersey Mills syncline crosses the West Branch Susquehanna River near Glen Union. The restored contours outline the northeast end of a canoe-shaped valley, which plunges southwestward and whose trough corresponds rather closely with the synclinal axis. This restored valley has a closure of at least 100 feet; it probably has a closure of more than 200 feet in the Howard quadrangle (outside of the area of pl. 5). North of the West Branch Susquehanna River west of Renovo, a broad canoe-shaped valley (shown by the restored contours) coincides closely with the axis of the Clearfield-McIntyre syncline.

Along anticlinal axes, on the other hand, the restored contours suggest broad elongate ridges with flat or slightly depressed summits. Upland surfaces are generally lacking along anticlinal axes exposing the Catskill formation, but narrow ridges may rise above the plateau tops of the adjacent synclines. The restored contours reflect the Leidy dome along the axis of the Wellsboro anticline.

Extensive upland surfaces are found along axes of the Clearfield-McIntyre and Kettle Creek synclines. The restored surface closely follows the bedrock structure. The upland surfaces are especially extensive along the northwest limb of the Clearfield-McIntyre syncline where they slope southeastward at angles of 4° to 7° and where the structure contours indicate that the bedrock dips in the same direction at 5° to 6°. Toward the axis of the syncline the restored surface slopes southeastward at a gentler angle than the bedrock. The upland surface, therefore, does not strictly parallel the rock structure. In a topographic profile (fig. 23) the upland surface crosses about 350 feet of strata.

It thus appears that the upland surfaces are controlled by the rock structure; their altitude and surface form result from erosion more or less independent of downcutting by the major streams. The upland surfaces are not independent evidence of the existence of a peneplain in the past; however, they do not conflict with such an hypothesis.

DESCRIPTION OF DRAINAGE

Potter County contains the headwaters of the Allegheny, Genesee, and Susquehanna Rivers. The three drainage basins meet at a point near Gold, Genesee quadrangle, on the terminal moraine of the Wisconsin stage. About three quarters of the area (pl. 5) are in the Susquehanna drainage basin, which itself contains three main subdivisions—the drainage basins of Cowanesque River, Pine Creek, and West Branch Susquehanna River, which is the largest.

SUSQUEHANNA DRAINAGE BASIN

The West Branch Susquehanna River leaves the map area (pl. 5) through a gorge less than a mile wide between Glen Union and Hyner and crosses the southern limb of the Hyner anticline. The river lies from 1,000 to 1,500 feet below the adjacent upland surfaces, which slope toward the southeast at a rate of 100 to 300 feet per mile.

Between the mouth of Young Womans Creek and Keating, the West Branch flows more or less parallel to the structure of the rocks on the south limb of the Clearfield-McIntyre syncline. The restored contours of plate 5 show that the lowest parts of the upland surfaces in this section are not adjacent to the West Branch; instead, they are to the northwest along the synclinal axis. The West Branch has a meandering course deeply intrenched below the adjacent upland

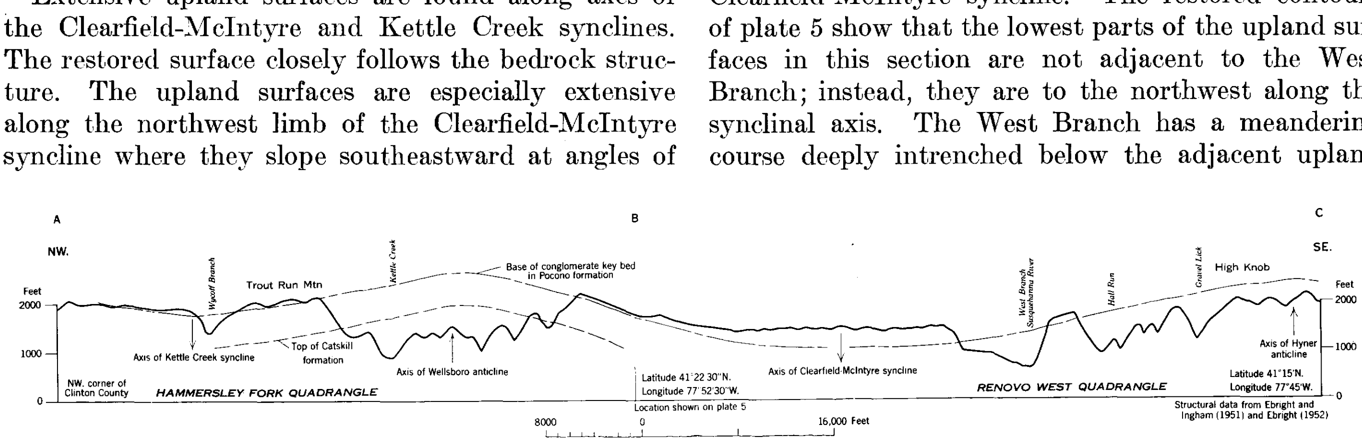


Figure 23.—Cross section across Renovo West and Hammersley Fork quadrangles to show relation of upland surfaces to rock structure. Structural data from Ebright and Ingham (1951) and Ebright (1952). For location, see plate 5.

surfaces. There are two abandoned meanders—one curves around Round Top Mountain, and the other encircles Little Round Top (Keating quadrangle). The summit of Round Top Mountain, altitude 1,400 feet, lies about 50 feet below the adjacent upland surfaces. Southwest of Keating (outside of the area shown on pl. 5) the West Branch continues its meandering course on the southeast limb of the Clearfield-McIntyre syncline for many miles upstream.

From its headwaters near Keating Summit to Driftwood, Sinnemahoning Creek follows a more or less southerly course across the structure. From Driftwood to Keating, the creek has a southeasterly course that trends generally around the southwestern end of the Leidy dome (pl. 5).

From Westport to Leidy, Kettle Creek flows across the structure in a manner that closely parallels that of many other nearby tributaries of the North Branch (pl. 5). From Leidy to Oleona, the creek trends southwestward and nearly parallel to the strike along the northwest limb of the Wellsboro anticline. There is an intrenched meander along Kettle Creek just south of Hammersley Fork where the creek bed is at an altitude of about 900 feet. From Leidy to Oleona, the southeast-flowing tributaries of Kettle Creek are 5 to 10 times longer than those entering it from the south. The divide southeast of the creek is close to the axis of the Wellsboro anticline and the divide to the northwest is roughly along the axis of the Marshlands anticline. The southeast-flowing tributaries run athwart the axis of the Kettle Creek syncline. In similar fashion, East Fork Sinnemahoning Creek has a southwest-trending strike course and its south-flowing tributaries are many times longer than those that flow northward.

From Ansonia to Blackwell, Pine Creek flows generally southward in a gorge (Pennsylvania's "Grand Canyon"). Near the axis of the Blossburg syncline, the adjacent upland surfaces slope toward the synclinal axis. The creek flows around the northeast end of the Kettle Creek syncline. From Blackwell to Slate Run, Pine Creek follows a southwesterly course along the northwest limb of the Slate Run anticline. The tributaries from the south are relatively short and head just north of the axis of the Clearfield-McIntyre syncline. The tributaries from the north are many times longer, head on the north limb of the Wellsboro anticline, and cross the axis of the Blossburg syncline through narrow gorges incised below upland surfaces that slope toward the synclinal axis. From a short distance below Slate Run to its junction with the West Branch Susquehanna River at Jersey Shore (outside area shown in pl. 5), Pine Creek trends almost directly southeastward across the structure.

GENESEE AND ALLEGHENY DRAINAGE BASINS

The headwaters of the Genesee River (pl. 5) are a network of streams that radiate outward from Genesee in a manner that has little accord with the rock structure. The main stream trends north-northwestward, and continues northward into New York State for about 30 miles.

The Allegheny River begins at the border of the Wisconsin drift and flows southwestward more or less along the southeast limb of the Coudersport syncline to a point about 4 miles below Coudersport. From there, it flows northwestward and westward across the structure to the western edge of the map (pl. 5). Oswayo Creek, the principal tributary of the Allegheny River in Potter County, takes a direct northwesterly course across the structure.

DRAINAGE DIVIDE

The divide between the Allegheny and Genesee drainage basins and the Susquehanna drainage basin is asymmetric. The headwater streams of the Susquehanna flow at lower altitudes and on steeper gradients than those of the Allegheny or Genesee systems (see following table). This asymmetry is well shown on the Genesee quadrangle (pl. 4).

Altitudes and stream gradients of selected points on both sides of the divide between the Allegheny drainage and the Susquehanna drainage

Location of divide	Distance from divide (miles)	Altitude (feet)			Average stream gradient in feet per mile for selected portions of streams					
		Allegheny-Genesee drainage	Susquehanna drainage	Difference	Allegheny-Genesee Rivers	Susquehanna River	Allegheny-Genesee Rivers	Susquehanna River	Allegheny-Genesee Rivers	Susquehanna River
					5–10 [1]		10–15 [1]		15–20 [1]	
Middle Branch Genesee River–Pine Creek, Genesee quadrangle	0	2,360	2,360	0						
	5	1,860	1,620	240						
	10	1,620	1,440	180	48	36	16	28	12	20
	15	1,540	1,300	240						
	20	1,480	1,200	280						
Mill Creek–Ninemile Run, Genesee quadrangle	0	2,420	2,420	0						
	5	1,740	1,640	100						
	10	1,620	1,440	180	24	40	16	28	10	20
	15	1,540	1,300	240						
	20	1,490	1,200	290						
Allegheny Portage Creek–Sinnemahoning PortageCreek, Keating Summit quadrangle	0	1,860	1,860	0						
	5	1,570	1,290	280						
	10	1,470	1,190	280	20	20	6	42	4	12
	15	1,440	980	460						
	20	1,420	920	500						

[1] Distance from divide, in miles.

ORIGIN OF UPLAND SURFACES

THE PENEPLAIN HYPOTHESIS

The hypothesis that upland surfaces are remnants of one or more peneplains was developed by Davis (1889) in his essay "Rivers and valleys of Pennsylvania." Though variously modified during the last 60 years, it remains widely accepted that the Appalachian Plateaus are remnants of one or more uplifted peneplains that bevel the structure of the rocks.

Under Davis' hypothesis, the configuration of the upland surfaces should accord with major drainage lines. Along the West Branch Susquehanna River, for example, the upland surfaces should reflect an ancient grade line of this river or of a possible ancestor. A glance at the restored contours of plate 5 shows that this is not the case. The surface, as restored, rises and falls along the valley, and the river cuts across the elongated ridges of the restored surface. Therefore the question arises as to whether the contours can be drawn consistently with the data to show conformity between the upland surfaces and the West Branch. The restored contours are essentially fixed on the upland surfaces of plate 5. These points must remain fixed, therefore any alternative reconstruction can differ from plate 5 only in areas outside the upland surfaces.

To test the peneplain hypothesis, the contours in an area along the West Branch Susquehanna River have been redrawn on the assumption that the upland surfaces were graded to an ancestral course of that river. This reconstruction, plate 6, is identical with plate 5, except that along the West Branch the contours are restored so as to show a through-flowing river. This reconstruction requires a narrow gorge between Hyner and Glen Union where the river crosses the southeast limb of the Hyner anticline. The restored level of the river is 500 to 700 feet below the upland surfaces. These upland surfaces slope southeastward at angles of 1° to 6° or more, far too steeply to be undeformed remnants of a peneplain. The only analogous erosion surfaces with comparable slopes are some pediments in the western United States. Except for the remote possibility that these upland surfaces are remnants of a peneplain that was slightly folded along the axes of Appalachian folds, these surfaces appear unrelated to any former base level of the West Branch.

Upstream from the mouth of Young Womans Creek to Keating, and for many miles to the southwest outside of the map area, the ancestral West Branch follows a broad valley that is evident on both of the two reconstructions (pls. 5 or 6). The two abandoned meanders near Keating also suggest an ancient mature, or broad-valley, stage for the West Branch. The restored contours suggest that this broad-valley stage occurred when the river flowed about 800 feet above its present level. The present meander of Kettle Creek, near Hammersley Fork, might represent the same broad-valley stage.

Northwest from Keating, the "peneplain reconstruction" (pl. 6) requires the ancestral Sinnemahoning Creek to flow through a narrow gorge incised 400 to 500 feet below the uplands on either side. Thus, the broad valley of the West Branch below Keating must, under the peneplain hypothesis, be younger than the adjacent ridges (along the Hyner and Wellsboro anticlines) that slope from 1° to at least 6°. Such ridges are hardly steep enough to be monadnocks, yet they are too steep to be parts of an old-age erosion surface. Likewise, it is difficult to consider them as pediments graded to the ancestral West Branch.

Another difficulty encountered by the peneplain hypothesis lies in the relation of upland surfaces northwest of Hammersley Fork along the Kettle Creek syncline to the upland surfaces northwest of the West Branch Susquehanna River on the northwest limb of the Clearfield-McIntyre syncline. On the peneplain reconstruction (pl. 6) the upland surfaces northwest of Hammersley Fork could represent an old-age valley that drained southwestward by way of the ancestral First Fork Sinnemahoning Creek to the ancestral Sinnemahoning Creek near Sinnemahoning, where the latter creek flowed in a canyon 300 to 400 feet deep. Downstream, the floor of this canyon is at the level of the broad valley between Keating and Renovo. Therefore, the peneplain hypothesis requires the upland surfaces northwest of Hammersley Fork to be older than the broad valley along the Clearfield-McIntyre syncline. Furthermore the upland surfaces that are northwest of Hammersley Fork and upland surfaces of the broad-valley stage both attain the same altitudes—2,000 to 2,200 feet. This implies that erosion at the older and higher stage produced a surface that sloped gently at 1° to 3°, whereas erosion at the later broad-valley stage produced steeper slopes of 1° to 6°. This seems very unlikely.

The only possible explanation under which the West Branch Susquehanna River served as the regional base level requires two stages of development involving areas too small to be called peneplains. Furthermore, it is noteworthy that the surfaces conform so closely to the structure of the rocks. It would indeed be surprising if they are cyclic surfaces controlled by a regional base level—a peneplain, by definition, is more or less independent of rock structure.

Therefore, the present-day upland surfaces in the Susquehanna drainage are not remnants of a peneplain unless they have been folded along the Appalachian structural axes. This unlikely possibility is not supported by any other evidence. This portion of the Appalachian Plateaus may have been reduced to a peneplain once or several times since the Permian, but the existing upland surfaces or plateau tops are not the remnants of such old-age erosion surfaces.

In the Genesee-Allegheny drainage the restored contours of plate 5 suggest that the upland surfaces are remnants of an old-age stage of the Genesee River and of Oswayo Creek, but not of the Allegheny River upstream from Roulette, Coudersport quadrangle. However, it would be entirely possible and consistent with the data to draw the restored contours outside of the existing upland surface in such a way as to show an old-age valley extending from Roulette to the headwaters. The delimitation of upland surfaces in the Coudersport and Genesee quadrangles is more difficult than in the 1/24,000 scale quadrangles to the south, partly because of difference in map scale and partly because the upland surfaces are in many places small and narrow. The reconstruction of any ancient hypothetical land surface is necessarily less accurate here than to the south.

HYPOTHESIS OF STRUCTURAL CONTROL

Another hypothesis holds that the upland surfaces are controlled by the rock structure, and that, for the most part, the surfaces are held up by sandstone and conglomerate beds in the Pottsville and Pocono formations, which are more resistant than the underlying red beds in the Catskill formation. The facts supporting this hypothesis are: (1) The upland surfaces (pl. 5) are more extensive in the synclines, where the Allegheny, Pottsville, and Pocono formations are exposed, and are less extensive in the anticlines, where the Catskill and Chemung formations are at the surface. (2) The general direction of slope of the existing remnants conforms closely to the general direction of dip of the underlying bedrock.

The slope of the upland surfaces is, of course, not strictly parallel to the dip of the bedrock. The upland surfaces north of the West Branch Susquehanna River, on the north flank of the Clearfield-McIntyre syncline, cut across about 350 feet of strata (fig. 23).

The upland remnants north of the West Branch Susquehanna River have a local relief (above the break in slope at the top of the steep valley walls) that ranges from 100 to 200 feet (not shown on the generalized map, pl. 5). As mentioned previously, these remnants may be the relic of a broad-valley stage of the West Branch at an altitude of about 1,500 feet (800 feet above the present river). This suggests that the upland surfaces have been lowered as much as 200 feet since the West Branch began to dissect its broad valley. The problem thus arises as to the current rate of erosion or the amount of Pleistocene lowering of upland surfaces. The only stratigraphic evidence bearing on this problem lies in the scattered remnants of paleosol on upland surfaces. Using this admittedly tenuous evidence, the amount of lowering of upland surfaces since Sangamon time—and, by analogy, for the whole of the Pleistocene—can be estimated.

Assuming that the paleosol dates from the Sangamon interglacial stage and assuming that the paleosol had an average depth of 5 feet, the present sparse remnants suggest that the paleosol was almost completely removed in post-Sangamon time. The relatively unweathered and widespread colluvial deposits that locally overlie paleosol suggest that post-Sangamon erosion also removed fresh material from beneath paleosol. Therefore much of the upland may have lost at least 10 feet of material since Sangamon time.

Assuming that this value is roughly correct, it is possible that upland surfaces were lowered as much as 50 feet throughout the Pleistocene epoch. However, it is possible that Tertiary weathering produced a much more deeply weathered mantle than resulted from Sangamon weathering, perhaps resembling the saprolite of the southeastern states (Becker, 1895, p. 289; King, 1949; Miser, 1950; Bridge, 1950). If this assumption is correct, it follows that the upland surfaces may have been considerably more susceptible to erosion during the earliest Pleistocene than at any later time and may have been lowered considerably more than 10 feet. Therefore, the upland surfaces may have been lowered as much as 75 feet—possibly 100 feet—since the Pliocene. These values approach those for the assumed lowering of the upland surfaces along the Clearfield-McIntyre syncline since the hypothetical broad-valley stage of the West Branch. Therefore, this broad-valley stage might be of Pliocene age, and the West Branch might have cut down about 800 feet since that time. The lowering of the uplands by solution or processes other than mass movements have not been considered. Without doubt, such processes have been proceeding at unknown rates since Permian time. They would increase the above estimates for Pleistocene degradation.

As previously noted, the restored contours in the Genesee-Allegheny drainage (pl. 5) have been drawn in a manner to suggest an old-age erosion surface rather than one due to structural control. Within the control supplied by the existing upland surfaces, however, the restored contours could have been drawn to show more emphatic bedrock control. Such control is least apparent in the northwest corner of the Coudersport quadrangle, which is underlain by the Chemung formation. Perhaps the absence here of resistant sandstones and conglomerates accounts for the apparent lack of structural control.

ORIGIN OF DRAINAGE

The foregoing analysis yields no significant information on the origin of the cross-axial drainage. Whether the upland surfaces are peneplain remnants or whether they are structurally controlled, it is evident that the major southeastward-flowing streams existed long before present upland surfaces. It seems probable that the cross-axial drainage of the Appalachian Plateaus is the result of headward migration of the ancestral Atlantic-interior divide (Thompson, 1949). The data on structural control of the Appalachian Plateaus support Thompson's hypothesis. These do not, however, include critical evidence of the detailed structure near water gaps, which Thompson has clearly shown to be a prerequisite to an understanding of their origin.

WEST BRANCH SUSQUEHANNA RIVER

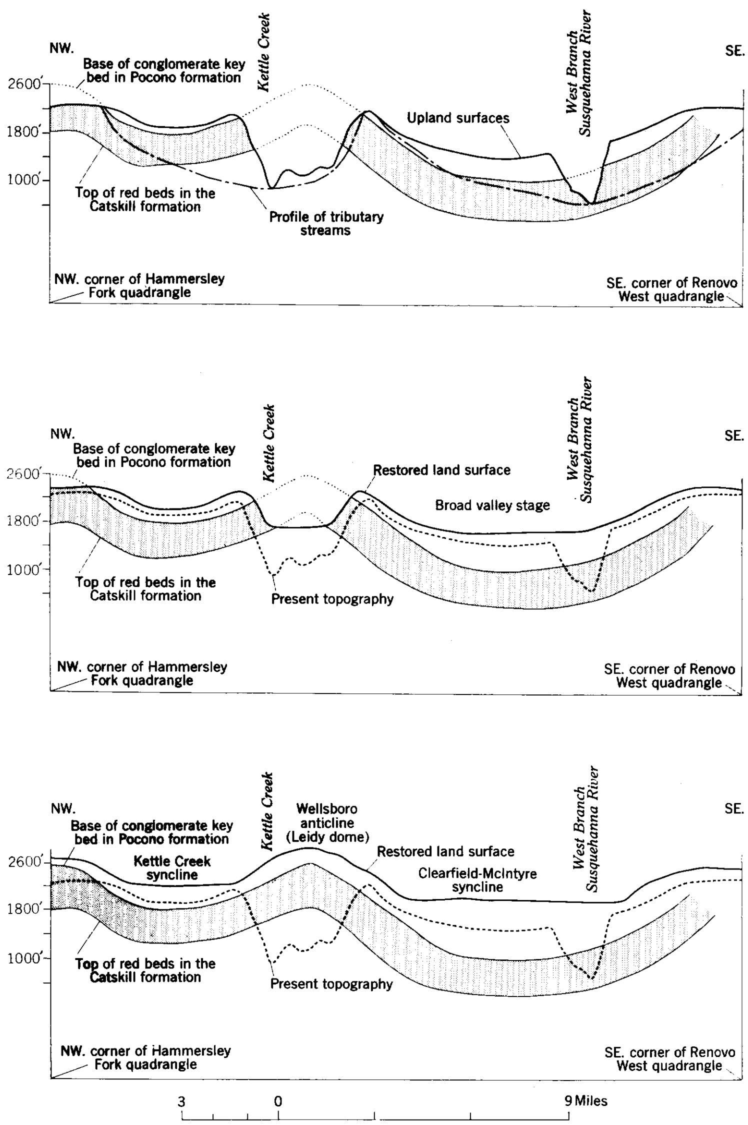
No attempt is made here to trace the drainage history back farther than the time when the ancestral West Branch was flowing across the Hyner anticline. It is easy to picture the development of the West Branch by headward cutting along the axis of the Clearfield-McIntyre syncline. Sinnemahoning Creek has a cross-axial course that lies near a sag in the axis of the Wellsboro anticline (that is, the saddle southwest of Leidy dome), which suggests structural control.

Many of the principal streams, such as the West Branch Susquehanna River above the mouth of Young Womans Creek, follow the south limbs of synclines. The northwestern tributaries of these subsequent streams are many times longer than those from the southeast. If these subsequent streams have developed by headward erosion, it is easy to picture the development of their meandering course during a broad-valley stage (suggested for the West Branch above Renovo). As a result, at the present time their courses may not be in perfect adjustment to synclinal axes. Perhaps the lack of adjustment is related to the asymmetry of folds, but the structural data are inadequate for solution of this possibility. The hypothesis of structural control does not explain why these streams should be confined to the south limb of the synclines nor does it explain why the southeastward-flowing tributaries should be so much longer than those flowing northwestward.

Other streams follow an anticlinal axis. The most notable example is Kettle Creek between Leidy and Oleona, where the creek lies just north of the Wellsboro anticline. Another example is East Fork Sinnemahoning Creek north of the Marshlands anticline. Because any stream north of an anticlinal axis is also on the south limb of the adjacent syncline, perhaps it is more meaningful to say that Kettle Creek appears to have originated by headward cutting in weak rocks brought up along the Wellsboro anticlinal axis.

A plausible origin of Kettle Creek is as follows: During a late Tertiary(?) stage several tributaries of the West Branch were cutting headward (northwestward) into the Wellsboro anticline between Keating and the mouth of Young Womans Creek: such as the ancestors of Sinnemahoning Creek, Kettle Creek south of Leidy, and Young Womans Creek. For some unexplained reason, perhaps distance from West Branch to the red beds in the Catskill formation or to Leidy dome, the ancestral Sinnemahoning and Kettle Creeks were the first to pierce the hard rock cap (Pocono and Oswayo formations) of the Wellsboro anticline. Perhaps the ancestral Sinnemahoning Creek cut across a low point in the axis of the Wellsboro anticline, whereas the ancestral Kettle Creek, once it encountered the weak red beds in the Catskill formation brought up along the Leidy dome, cut headward (northeastward) along the axis and beheaded the other southeastward-flowing tributaries of the West Branch to the east. The latter were still working in the more-resistant cap rocks above the red beds. Some of these tributaries have now extended into the red beds and are forcing the Kettle Creek-West Branch divide closer and closer to Kettle Creek.

This explanation of the course of Kettle Creek is illustrated by figure 24, in which section *C* represents a stage in the late Tertiary (?) period when Kettle Creek was not in existence. The Wellsboro anticline (Leidy dome) formed a ridge along the Atlantic-interior divide. Kettle Creek cut headward and breached the Wellsboro anticline. Once it reached the red beds in the Catskill formation it extended by headward erosion northeastward along the anticline. This subsequent course in the red beds may have been established by the close of Pliocene time. A meander developed near Hammersley Fork contemporaneously with the broad-valley stage of the West Branch (fig. 24, section *B*). Since the onset of the Pleistocene, both West Branch and Kettle Creek have cut down as much as 800 feet below the broad valley and the upland surfaces have been lowered at least 100 feet and perhaps as much as 200 feet (fig. 25, section *A*).



A. PRESENT DAY

Section shows the upland surfaces in relation to the present drainage and structure of the rocks. Note the asymmetry between the short northwest-flowing tributaries of Kettle Creek and the longer southeast-flowing tributaries of the West Branch Susquehanna River

B. LATE PLIOCENE OR EARLIEST PLEISTOCENE(?) BROAD VALLEY STAGE

The same section as section A as it might have appeared just prior to the earliest stage of the Pleistocene. The ancestral Kettle Creek is shown as already in existence on the assumption that the incised meander near Hammersley Fork was initiated at this stage. The Kettle Creek—West Branch divide is essentially symmetrical, suggesting that the present asymmetry is due in part to the incision of the West Branch along the southeast side of its broad valley

C. STAGE IN THE LATE TERTIARY(?) PERIOD

The same section as section A as it might have appeared in late Tertiary time. Kettle Creek is not in existence. The Wellsboro anticline forms a ridge on the restored land surface and is the location of the Atlantic-interior divide. The area along the Kettle Creek syncline drained southwestward toward the present position of Sinnemahoning Creek and thence northwestward toward the interior of the continent

Figure 24.—Cross sections to illustrate a possible explanation for the origin of Kettle Creek. Sections extend from the northwest corner of the Hammersley Fork quadrangle southeastward to the southeast corner of the Renovo West (7½ minute) quadrangle. Sections show base of conglomerate key bed in the Pocono formation and top of red beds in Catskill formation.

PINE CREEK

Pine Creek differs from the West Branch Susquehanna River in that its course is partly the result of glacial diversion. From Tiadaghton to the southern edge of the area (pl. 5), Pine Creek follows a course that is analagous to the West Branch. However, from its headwaters near Brookland, Pine Creek flows southeastward and eastward to Ansonia where it turns southward into the gorge. This gorge is the only break in a former divide that extended from the junction of the watersheds of the Allegheny, Genesee, and Susquehanna Rivers southward and southeastward to the gorge and thence southeastward outside of the map area nearly to Wellsboro, southward around the headwaters of the Tioga River, and northeastward to the Chemung River at Corning, N. Y. (fig. 1). Ancestral Pine Creek above Ansonia originally drained northeastward to join the Tioga River. The relation of Pine Creek Gorge to the old drainage divide is clearly shown on the Tiadaghton quadrangle. The present Pine Creek-Tioga River divide is a swamp (altitude 1,170 feet) on the floor of a broad valley and lies (just outside of pl. 5) about 8 miles northeast of Ansonia. Pine Creek near Ansonia flows at an altitude of about 1,140 feet.

The border of the Wisconsin drift crosses Pine Creek just east of Galeton and continues southeastward to recross Pine Creek near Cedar Run (pl. 1). Wisconsin drift is found in the gorge between Blackwell and Cedar Run, therefore the gorge antedates the Wisconsin stage. Paleosol is developed on a gravel terrace on the west side of the creek at Slate Run, thus, the diversion of Pine Creek below Ansonia probably dates from a pre-Illinoian glacial stage (Fuller, 1903a).

ALLEGHENY RIVER

Oswayo Creek flows northwestward into New York State to join the Allegheny River at a point near Olean where the river turns southwestward to join the Monongahela at Pittsburgh. This course has long been explained as due to diversion of an ancestral northwestward-flowing drainage by early Pleistocene glaciation (Chamberlin and Leverett, 1894; Leverett, 1902). Little can be said about the origin of this ancestral drainage. The restored contours of plate 5 indicate that the ancestral Oswayo Creek could have flowed on an old-age erosion surface, now represented by the adjacent upland surfaces. However, it is possible that the course of Oswayo Creek across the structure was initiated as drainage that was marginal to an early Pleistocene ice sheet.

ALLEGHENY-GENESEE-SUSQUEHANNA RIVER DIVIDE

The divide between the Allegheny, Genesee, and Susquehanna Rivers is asymmetric with stream gradients that are steeper toward the Susquehanna than toward the Allegheny and Genesee (see table p. 47). The divide is migrating northwestward. There are no good examples of stream piracy in that part of the divide shown on plate 5, although they have been described nearby (Thompson 1949, p. 51).

GEOMORPHIC HISTORY OF POTTER COUNTY

PRE-TERTIARY PERIODS

The Paleozoic bedrock of Potter County was gently folded during the Appalachian orogeny (see table below). Nothing is known of the geologic history during the Mesozoic, and no deposits of that era occur in this part of Pennsylvania.

Geomorphic history of Potter County, Pa.

Era	Period	Epoch	Stage	Substage	Sequence of events
		Recent			Deposition of alluvium. Development of microrelief resulting from fallen trees.
		- ? - - - ? -	- - - ? - - -	- - - ? - - -	
				Mankato(?).	Continued deposition of alluvium and formation of alluvial fans.
				Cary(?).	Deposition of Valley Heads drift of Fairchild in New York State. Continued deposition of alluvium and continued formation of alluvial fans.
				Tazewell(?).	Deposition of Binghamton drift of MacClintock and Apfel largely in New York State. Deposition of alluvium and formation of alluvial fans begun.
			Wisconsin.	Iowan(?).	Development of boulder rings, boulder stripes, and block fields. Deposition of Olean drift of MacClintock and Apfel in northeastern part of Potter County; and development of periglacial deposits by frost heaving, solifluction, and fluvial transport in area outside of border of Wisconsin drift. Formation of ice-dammed lakes in Pine Creek valley and cutting of spillways. Essentially complete removal of paleosol by mass movements and other processes induced by periglacial climate, perhaps resulting in lowering of upland surfaces by as much as 10 feet.
			Sangamon (interglacial).		Partial removal(?) of paleosol by mass movements and running water. Development of paleosol, deep (5 to 10 ft) residual soils, over entire area; perhaps as a result of lateritic weathering in a subtropical climate.
Cenozoic.	Quaternary.	Pleistocene.	Illinoian.		No evidence for glaciation in Potter County. Deposition of till and outwash in Salamanca reentrant, New York., and in areas southeast of Potter County. Assumed removal of weathered mantle by mass movements and other processes induced by periglacial climate, perhaps resulting in lowering of upland surfaces by as much as 10 feet. Valleys, such as Kettle Creek, filled with sand and gravel alluvium to depths of at least 150 feet above present flood plains.
			Yarmouth (interglacial).		Assumed development of residual soils, perhaps including some paleosol. Major valleys, such as Kettle Creek, cut to essentially their present depths by close of this stage.
			Kansan.		Deposition of possible pre-Illinoian drift near Ayers Hill, Ayers Hill quadrangle. Some drift in central and eastern Pennsylvania and in New Jersey may belong to this stage. Assumed removal of weathered mantle by mass movements and other processes induced by a periglacial climate, perhaps resulting in lowering of upland surfaces by as much as 10 feet.
			Aftonian (interglacial).		Assumed development of residual soils analogous to paleosol.
			Nebraskan.		No evidence for glaciation in Potter County. Assumed removal of postulated thick weathered mantle (saprolite) by mass movements and other processes, perhaps induced by periglacial climate, and possibly resulting in a lowering of upland surfaces by as much as 25 to 50 feet.
	- - - ? - - -	- - - ? - - -	- - - ? - - -	- - - ? - - -	
		Pliocene(?).			Broad-valley stage of West Branch Susquehanna River and Kettle Creek(?) at altitudes about 900 feet above present streams. Relief about 300 to 700 feet. Landscape assumed to have been covered with deep residual soils (saprolite).
	Tertiary.	- - - ? - - -	- - - ? - - -	- - - ? - - -	
		?			Development of southeast master drainage, perhaps as result of northwestward migration of Atlantic-interior divide.
Mesozoic.					? ? ? ?
Paleozoic.					Appalachian orogeny. Deposition of sediments.

TERTIARY PERIOD

All theories of Appalachian geomorphology assume that the major southeastward drainage of Potter County was established by the close of the Tertiary period. The Atlantic-interior divide is migrating very slowly to the northwest and was probably close to its present position by the end of the Tertiary. The evidence for structural control of upland surfaces favors the theory that the cross-axial drainage resulted from the northwestward migration of the Atlantic-interior divide.

The incised meanders of the West Branch Susquehanna River, both occupied and abandoned, suggest a broad-valley stage for the ancestral West Branch about 900 feet above the present river. This stage may be late Pliocene or early Pliestocene in age. Perhaps the present meander of Kettle Creek near Hammersley Fork was inherited from this stage. If so, Kettle Creek was in existence by the close of the broad-valley stage, and its course along the north limb of the Wellsboro anticline was established earlier. The breaching of the Wellsboro anticline by ancestral Kettle Creek below Leidy, and the beheading of other south-flowing tributaries on the north side of the West Branch Susquehanna River (both to the east and west of Kettle Creek), probably took place when the Atlantic-interior divide lay near the axis of the Wellsboro anticline. It is possible that the ancestral Sinnemahoning Creek cut headward around the southwest end of the anticline while the ancestral Kettle Creek was able to cut headward into the weak red beds in the Catskill formation on the southeast flank of the Leidy Dome. In any case, both the southeasterly course of the lower part of Sinnemahoning Creek and the subsequent course of Kettle Creek above Leidy probably antedate the close of the broad-valley stage. During this stage, the landscape was doubtless covered by deep residual soils developed under forest vegetation, which perhaps were analogous to the saprolite of southeastern United States.

EARLY PLEISTOCENE EPOCH

The early Pleistocene history of Potter County and vicinity is essentially unknown. The following account is based largely on inferences drawn from other areas. There is no evidence for Nebraskan or for any other very early Pleistocene glaciation. It is assumed that the postulated thick Tertiary residual soils (saprolite?) were largely eroded during the earliest glacial stage, thus lowering the upland surfaces by as much as 25 to 50 feet.

Nothing is known about the history of Potter County during the Aftonian or first interglacial stage. Perhaps residual soils developed, analogous to the paleosol.

The history of the Kansan stage is likewise a mystery. Perhaps the pebbles and cobbles on the upland near Ayers Hill, Ayers Hill quadrangle, are remnants of Kansan drift. Some of the pre-Wisconsin drift in central and eastern Pennsylvania and in New Jersey may belong to this stage. The diversion of Pine Creek from its original northeasterly course from Ansonia into Tioga River valley to its present southerly course through Pine Creek Gorge was probably the result of glacial diversion, and without a doubt it antedated the Illinoian stage. It is assumed that upland surfaces lost their postulated Aftonian regolith by mass movements and other processes induced by periglacial climate. This loss may have lowered upland surfaces by as much as 10 feet.

It is assumed that by the close of the Yarmouth interglacial stage the major streams of Potter County had incised themselves to their present depth. It is also assumed that the climates of the Yarmouth produced deep residual soils over the landscape, parts of which may still be preserved in the paleosol remnants of the present day.

ILLINOIAN STAGE

No drift of the Illinoian stage has been recognized in Potter County, but till and outwash deposits referred to this stage have been identified in the Salamanca reentrant in New York State. (MacClintock and Apfel, 1944), and in areas southeast of Potter County—the nearest deposits being those near Cogan House, Lycoming County (Leverett, 1934, p. 45–46). It is assumed that any weathered mantle inherited from the previous interglacial stage was removed by mass movements and other processes induced by a periglacial climate, perhaps resulting in the lowering of upland surfaces by as much as 10 feet. Valleys, such as Kettle Creek, were filled with sand and gravel alluvium to depths of as much as 150 feet above their present flood plains.

SANGAMON STAGE

During this interglacial stage, residual soils, 5 to 10 feet deep, were developed in Potter County and probably throughout much of Pennsylvania. These soils are now preserved as isolated remnants and are known collectively as paleosol. The climatic controls that produced the paleosol were effective over a broad area and over a vertical range in altitude of more than 2,000 feet. These facts suggest that at least some of the climates during Sangamon time were different from those of Wisconsin and later times. The paleosol contains a few percent of gibbsite, a mineral commonly regarded as suggesting lateritic weathering. The supposition is that the paleosol records a warm subtropical climate that caused lateritic weathering, but this supposition is by no means proven. Presumably, the area supported an essentially complete forest cover.

Perhaps the Sangamon landscape of Potter County was in its broader aspects, much like the present. However, perhaps the divides were more rounded and the gullies more numerous. Streams had small flood plains that extended to their headwaters, their valley walls being slightly steepened or undercut near the base. Perhaps the topography was like that of the lower plateaus in West Virginia west of the Allegheny Mountains, instead of like that of Potter County at present where headwater streams have little or no flood plains and where valley walls either meet to form a V or form slightly gentler slopes near their bases (Denny, 1951, fig. 7).

With the climatic changes that accompanied the transition from the interglacial stage to that of the earliest substage of the Wisconsin, the paleosol, being no longer in dynamic equilibrium with the environment, became subject to modification and removal. Perhaps the deep residual soils on steep slopes became unstable, with the result that mass movements and stream erosion removed much of it long before the Wisconsin ice sheet reached Potter County. The almost complete absence of paleosol beneath drift, and the absence of drift containing fragments or traces of paleosol, suggest that the old soils were nearly gone before the ice came.

WISCONSIN STAGE

IOWAN-TAZEWELL(?) SUBSTAGES

The drift in Potter County is assigned to either the Iowan or Tazewell substages, perhaps the Iowan. The drift is similar to the Olean drift of MacClintock and Apfel (1944), who favored assignment to the Tazewell substage. The climates that prevailed in Potter County during the advance of the Olean ice sheet may well have produced unstable slopes, thus leading to erosion and almost complete removal of the paleosol that remained after late Sangamon time. Actually, some of the periglacial deposits may have accumulated long before the ice sheet reached Potter County. The Olean ice sheet probably came from the northeast. Presumably, this southwestward advance produced lakes in northward- and eastward-draining valleys, such as those along the Cowanesque and Genesee Rivers. The lake deposits near North Bingham, Genesee quadrangle, may represent such a lake.

In the Genesee quadrangle, when the ice sheet reached its maximum extent it probably had a relatively straight front with a slope of about 300 feet per mile for the first 2 or 3 miles. Erratics are found at all levels inside the drift border and suggest that the ice sheet completely covered the area northeast of the drift border; no nunatacks were found. In the Gaines and Coudersport quadrangles, the ice edge was apparently more lobate, tongues of ice projected downvalley for several miles, perhaps because the local relief is greater in these latter areas than in the Genesee quadrangle. At, or near, the Olean maximum, ice-dammed lakes were formed in the Pine Creek valley near Galeton and overflowed through glacial spillways.

During deglaciation of the Olean ice sheet, small kame terraces were formed in the Genesee Valley and in a few of the larger valleys in the Coudersport and Gaines quadrangles. Melt water associated with wasting ice in the Genesee Valley cut glacial spillways across the surrounding divides—the most conspicuous spillway is at the head of Elevenmile Creek in the northwest corner of the Genesee quadrangle. Because of the absence of extensive lacustrine deposits in the Genesee drainage basin in Pennsylvania, it seems more probable that the spillways are the result of ice marginal drainage rather than of the successive outlets of large lakes.

In the periglacial area, during Olean time, it is probable that the forests were greatly restricted and that large areas on the uplands were essentially treeless. Here, processes related to frost action were much more active than under the existing forest canopy. Mass movements, such as solifluction, rain wash, and small streams, carried material down both gentle and steep slopes and deposited faintly stratified colluvial deposits on lower slopes. At the mouths of gulches, steeply sloping alluvial cones were built; at the mouths of tributary streams, alluvial fans were formed. Where massive rocks were available, small block fields formed on uplands and gentle slopes. There are no definite indications of perennial frozen ground, the existing landforms and soil structures can be explained by postulating a deep seasonal freeze and thaw in areas without a dense forest cover.

The movement of material downslope alluviated the valleys. In headwater areas, this alluviation produced narrow V-shaped valleys with essentially no flood plains or with gently sloping colluvial benches on the lower valley walls. No doubt the terrace form of some benches is the result of later dissection, but some may be initial depositional features. Thus, a landscape was developed with long smooth slopes that met along streams. Such landscapes have been little modified by later processes and are distinct from those found in some plateau areas farther removed from the border of Wisconsin drift (Denny, 1951, fig. 7).

These erosive and depositional processes in the periglacial area persisted for a time during deglaciation of the Olean ice sheet. The alluvial fans, benches, and terraces along Pine Creek and its tributaries in the Genesee and Gaines quadrangles seem to be graded to levels below the Olean outwash terrace near Galeton; this fact, and the presence of boulder rings and boulder stripes on drift, indicate that the periglacial climate persisted during the waning of the Olean ice sheet.

Most, if not all, of the periglacial deposits and soil structures of Potter County were probably developed during the Olean substage. By the time of advance of the Binghamton ice sheet (MacClintock and Apfel, 1944), the area was again forested and the landscape had essentially its present aspect except for later slight stream dissection and continued development of some of the larger alluvial fans. The greater thickness and extent of periglacial deposits within about 10 miles of the drift border, as well as their southward thinning, suggest that the belt of restricted forest vegetation was only 10 to 20 miles wide, except perhaps along the higher parts of the Appalachian Plateaus. The "intense periglacial zone" of the Olean substage of MacClintock and Apfel was probably only about 10 miles wide, therefore the "intense periglacial zone" of the less-extensive Binghamton substage of MacClintock and Apfel probably was not any wider. The Binghamton drift border lies 30 to 40 miles to the northeast. By this tenuous reasoning, the Binghamton "intense periglacial zone" probably did not extend as far south as Potter County.

There is no evidence in Potter County to record the extent of the northward retreat of Olean ice before the advancement of the Binghamton ice sheet.

CARY AND MANKATO SUBSTAGES

Nothing is known of the history of Potter County during later Wisconsin time. During all of post-Olean time, Potter County has probably been a forested region and has undergone only slight erosion, largely by running water. The rubble-mantled slopes of the present day have persisted essentially unmodified, perhaps since the close of the Iowan substage and almost certainly since the end of the Tazewell substage.

Some of the alluvial fans (now dissected) in the Genesee quadrangle may be younger than the periglacial deposits. And thus, if the periglacial deposits are Iowan, these dissected fans may date from the Tazewell or Cary substages, or from both.

RECENT EPOCH

No boundary can be drawn between Pleistocene and Recent epochs here. The alluvium is of Recent date and probably rests on Pleistocene deposits. Many streams are intrenched a few feet; perhaps this dissection is related to deforestation and farming during the last 150 years. Some alluvial fans may have been built in part in Recent times, but most of them are probably older. Their very slight dissection, largely explainable by lateral cutting by the main streams rather than by downcutting, suggests youth. However, the absence of terraces along the Allegheny River in Potter County, and their presence downstream, suggest that headward erosion has not reached here since the last stage of alluviation.

SPECIAL PROBLEMS

SOILS AND SURFICIAL GEOLOGY

The outstanding geologic aspects of Potter County soils are (1) their shallow depth, (2) their weak horizon development (many of whose characteristics are inherited from the parent material), and (3) their apparent youth. The roots of fallen trees have destroyed or disturbed the horizons of soil profiles. The data presented elsewhere (p. 59) indicate that most of the land surface of the county has been disturbed by this process during the last 300 to 500 years; consequently, the existing *A* and upper *B* horizons cannot be older than 500 years and are probably younger. These facts suggest that the soil profiles on periglacial deposits, on Olean drift, and doubtless on the younger drifts (Binghamton drift of MacClintock and Apfel and Valley Heads drift of Fairchild), owe their acquired characteristics to post-Pleistocene events. This suggestion casts doubt upon the use of soil profiles as a means of differentiating Wisconsin drifts in northeastern United States.

Other than the soils developed on paleosol, such as the Sweden and Germania series, all the Potter County soils are derived from parent materials that were formed in the Wisconsin stage or Recent epoch. If the bulk of such deposits belong to the Iowan (?) substage, it is reasonable that indications of later climatic events might be found in the soils. However, such relics are almost unknown. In a few places a thin Podzol soil appears to be developing in the *A* horizon of an older Gray-Brown Podzolic soil profile, suggesting past climatic changes. It is possible that the older profile formed in the postglacial climatic optimum, and that the Podzol profile formed under the influence of the present climate. However, stratigraphic evidence in support of such a theory is lacking.

Soil scientists recognize no significant differences between some of the soils developed on drift, on periglacial deposits, or on thin mantles. Therefore, some soil series are mapped across the border of the Wisconsin drift. The soil map will show the extent of paleosol in greater detail than is possible here.

In the glaciated area, soils whose parent material is a local till are classed separately from those of mixed-till origin, although both tills are composed of similar rock types. The mixed till contains relatively abundant well-rounded pebbles and erratics and is found in valleys or on lower slopes. The local till is composed of angular fragments of the local rock with very few erratics or rounded pebbles, and it occurs on upper slopes and ridge tops. Such a distinction is not made by most geologists. The local till doubtless is chiefly periglacial deposits derived from both till and bedrock—materials that were mapped as thin mantles in the Genesee quadrangle (pl. 4).

VEGETATION AND SURFICIAL GEOLOGY

By J. C. Goodlett

VEGETATION REGIONS AND FOREST TYPES

Forests cover most of the southern half of Potter County; the remainder is about one-half forest-covered and one-half cultivated land. Most of the trees are second-growth stands, 40 to 60 years old. A few scattered stands of old trees are relics of the pre-settlement woodlands. The forests growing on slopes and summits consist of about 25 species. For purposes of this discussion, Potter County is divided into two vegetation regions: a "northern hardwood" region that includes most of the county, and an "oak forest" region that occurs near the borders of the county, principally along its southern margin (fig. 25).

The actual forest stands in the vegetation regions are subdivided arbitrarily into forest types. Within the northern hardwood region, forest stands lacking species of oaks are referred to as the "beech" forest type for brevity in place of the forester's and ecologist's term "beech-birch-maple" forest type. The beech-forest type consists largely of beech, sugar maple, yellow birch, black cherry, and hemlock. Other stands within the northern hardwood region contain red oak, which characterizes the "red oak" forest type. Forests of the red-oak type contain as many as 15 species of trees. In addition to the trees listed above, white ash, basswood, black birch, and red maple are common. Forests in the "oak forest" region consist chiefly of white oak, red oak, chestnut oak, red maple, and beech. Stands that contain chestnut oak are called "chestnut-oak" type forest, and stands that lack chestnut oak but contain white oak are called "white-oak" type forest. Red oaks usually grow in both chestnut-oak and white-oak type forests. Red-oak type forests, or stands lacking both chestnut oak and white oak, are also present. The forest types in the oak-forest region are not shown in figure 25.

This classification of the vegetation is used to give the nonbotanical reader a general understanding of the forests of Potter County and their possible relationships to geology. In a botanical report the evidence for the division into vegetation regions and forest types is presented (Goodlett, 1954).

Within the northern hardwood region most of the high plateaus support forests of the beech type, which cover the landscape from ridge crest to valley bottom and which are most extensive on the broad divide between the Allegheny, Genesee, and Susquehanna watersheds (fig. 25). Red-oak type forests within the northern hardwood region occupy most of the valleys that extend outward from this broad divide. The oak-forest region covers the southern part of the county and a small area near Galeton, and it also is present in the Oswayo Creek drainage basin, where it is an eastward extension of the oak-forest region of the Allegheny River valley.

FOREST TYPES AND SURFICIAL GEOLOGY

NORTHERN HARDWOOD REGION

The character, structure, and distribution of bedrock and surficial deposits in the northern hardwood region of Potter County are shown in figure 26. The surficial deposits are divided into two classes: rubbles—deposits that contain an abundance of rock fragments; and nonrubbles—deposits that are dominantly silt loam or loamy sand. Across the top, the diagram shows the forest types that are associated, in most areas, with the geologic bodies that lie directly below.

Figure 26 is a broad generalization based upon detailed field work. It shows that the beech and red-oak forest types overlie both the Pocono and Catskill formations. The red-oak type grows on rubbles, whereas the beech type is found on nonrubbly surficial deposits. There are many exceptions to these generalizations; however, two relationships that have almost no known exceptions are: the occurrence of the beech type on ridge crests underlain by sandy materials derived from sandstone and conglomerate of the Pottsville formation, and the occurrence of the red-oak type on rubble. However, it also is true that all rubble does not support the red-oak forest type; rubble on some plateau tops supports forests of the beech type. Steep upper slopes covered with a thin mantle of rubble generally support the red-oak type. In general, the mantle of surficial materials is thicker toward the valley floor, and the forest may change to the beech type. Forests of the beech type are found also on gentle upper slopes near the heads of streams.

OAK-FOREST REGION

The character, structure, and distribution of bedrock and surficial deposits in the oak-forest region of Potter County are shown in figure 27. Here, the mantle of surficial deposits is, in general, thinner and more rubbly than in the northern-hardwood region. Sur-

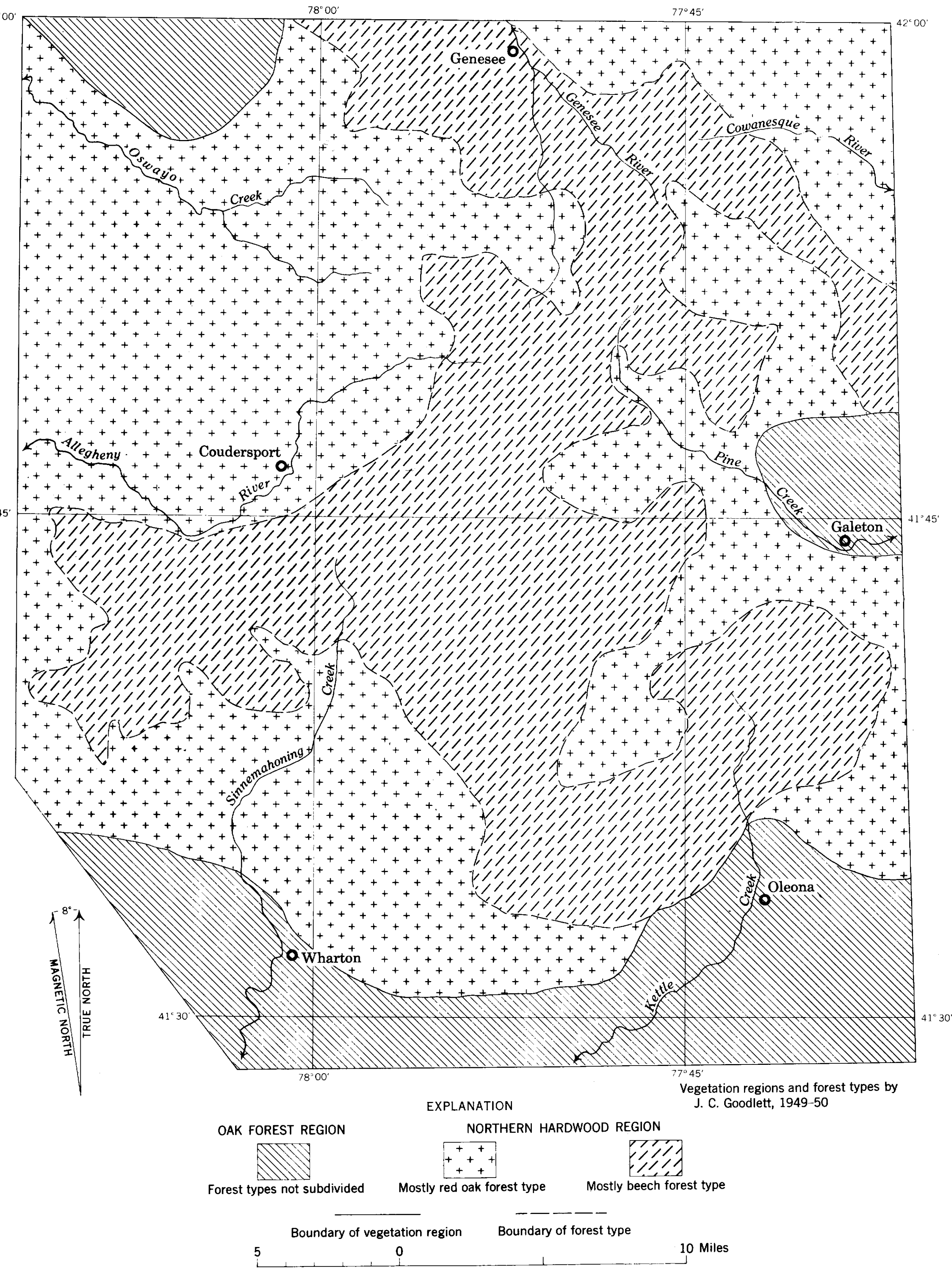


FIGURE 25.—Map of vegetation regions of Potter County.

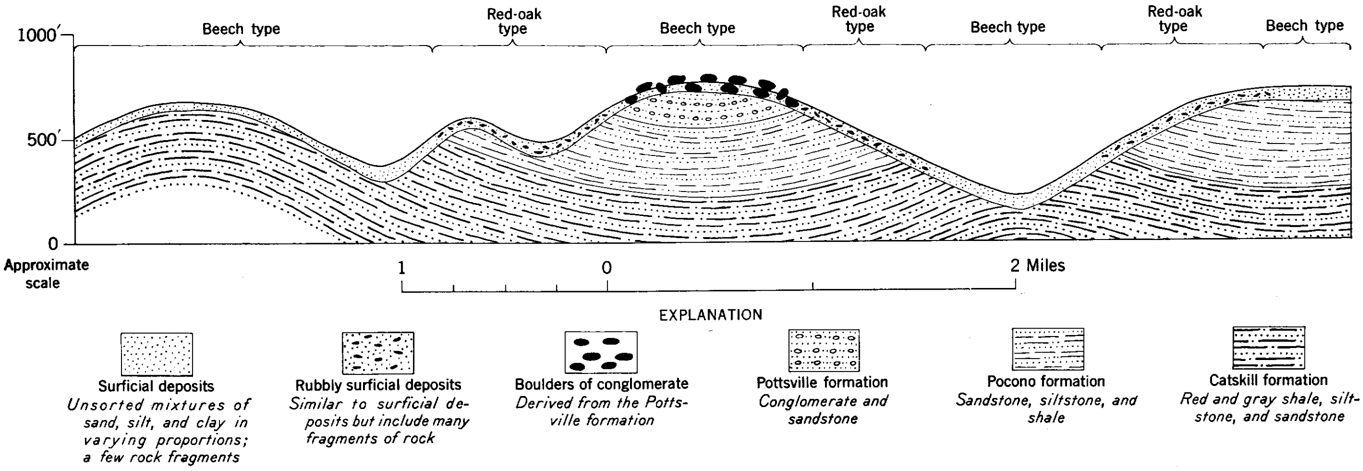


Figure 26.—Idealized profile showing forest types, surficial deposits, and bedrock geology in the northern hardwood region of Potter County. Datum assumed. Vertical exaggeration about 5 times. Alluvial deposits in valleys omitted. Thickness of surficial deposits greatly exaggerated.

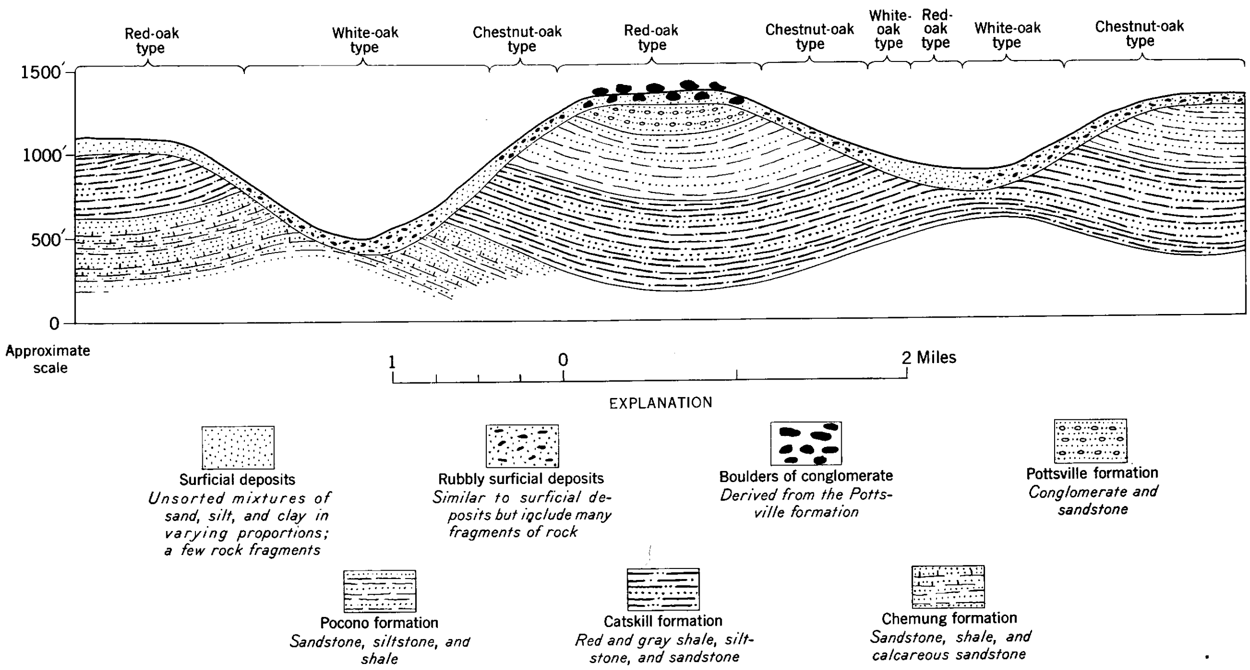


Figure 27.—Idealized profile showing forest types, surficial deposits, and bedrock geology in the oak-forest region of Potter County. Datum assumed. Vertical exaggeration about 5 times. Alluvial deposits in valleys omitted. Thickness of surficial deposits greatly exaggerated.

ficial materials on lower slopes are only 2 to 3 feet thick in many places, and outcrops of bedrock are more numerous. In general, in the oak-forest region the chestnut-oak forest type grows on very rubbly materials derived largely from the Pocono formation, whereas the red-oak forest type grows on the Pottsville formation and on the thicker and less-rubbly materials derived from the Catskill formation. In general, white-oak type grows on surficial materials that are thicker than those beneath the chestnut-oak type, but they are more rubbly than those beneath the red-oak type. There is a suggestion, therefore, of a coincidence between the sequence chestnut oak-white oak-red oak forest types and a change from thin rubbly surficial deposits to thick nonrubbly surficial deposits.

The relations between forest types and surficial deposits vary to some extent with topography. However, the chestnut-oak type forest grows on thin very rubby deposits without regard to topographic position. Some thin rubbles, on the other hand, support forests of the white-oak type. Many gentle slopes are mantled with somewhat thicker or less rubbly materials than is present on adjacent steep slopes. A change in slope, therefore, is often accompanied by a change in forest type. Nonrubbly deposits on steep slopes generally support forests of the white-oak type. Nonrubbly deposits on gentle slopes, particularly if derived from the Catskill formation, often support red-oak type forests. Forests of the red-oak type are uncommon on steep slopes.

POSSIBLE EXPLANATIONS OF GEOBOTANICAL RELATIONSHIPS

Within each of the two vegetation regions, the forest types are probably related to variations in the surficial deposits. The most significant variation is in the degree of stoniness of the materials, whether they are rubbly or nonrubbly. The most xerophytic forest types (the red-oak type in the northern hardwood region and the chestnut-oak type in the oak-forest region) grow, almost without exception, on rubbles. However, all rubbles do not support these forest types.

A working hypothesis to explain these changes in forest types assumes that they are related to the permeability of the surficial mantle. The thinner and more rubbly surficial deposits are very permeable and support the more xerophytic forest types. Such types may be related, therefore, to the presence of the permanent water table at a greater depth than it is present in the rubbly deposits. In rubbles, it is probable that a temporary high water table caused by heavy rains or melting snow will not exist for so long as a similar temporary water table in the less permeable nonrubbly surficial deposits.

Most changes in surficial materials occur with changes in altitude (figs. 26 and 27) because the bedrock lies essentially flat. The accompanying changes in vegetation might be due, therefore, to changes in altitude or slope. However, on a few ridge tops a change in surficial deposits without change in altitude shows the same change in forest type, thus indicating that the relationship is primarily between surficial deposit and forest type, rather than between slope, exposure, or altitude, and forest type. The occurrence of single forest type from the summit to the base of a hill that has uniform surficial materials further suggests such a relationship.

No direct connection apparently exists between the forest types and the Wisconsin drift. There is no observable difference in the forests on either side of the border of the Wisconsin drift, except for the change from the northern hardwood region to the oak-forest region near Galeton (fig. 25). The relative uniformity of the forests in the northern hardwood region, both within and outside the border of the Wisconsin drift, is probably the result of the uniformity of surficial materials both within and outside of the glaciated region.

MICRORELIEF RESULTING FROM FALLEN TREES

By C. S. Denny and J. C. Goodlett

INTRODUCTION

The forested landscape of Potter County has a distinctive microrelief—a mosaic of mounds and pits (figs. 28 and 29) produced by fallen trees (Shaler, 1892, p. 273–274; Lutz and Griswold, 1939; Lutz, 1940). The mounds are oval or circular in plan, 10 to 20 feet long and 6 to 15 feet wide, and have slopes that range from 5° to 40°. Their cross profiles may resemble an isosceles triangle, or a broad dome 10 to 15 feet across and only 6 inches high in the center. Young mounds held together by the roots of a tree that fell within the last year or two are long and narrow with esssentially vertical walls. However, year by year the binding roots decay and the mound is lowered and widened until all trace of roots disappear from the ground surface. Pits are crescentic, oval, or irregular in shape, and they range in depth from 6 inches to about 2 feet. On essentially level land many mounds are oriented with their long axes trending in a northerly direction—approximately at right angles to the prevailing westerly winds. In some areas, mounds have a random orientation. Mounds on slopes are oriented with their long axes at right angles to the direction of maximum slope, parallel to the contours. The mound-building trees fell down slope.

Most mounds and pits are larger (perhaps twice as large) than those produced by present-day tree fall. The second-growth trees of the present day grow at any point on the microrelief except at the bottom of the pits. This fact shows that most of the microrelief was produced by the toppling of relatively large trees in the original forests. The original forests in Potter County were cut from about 1810 to 1914 and were essentially similar to those of the present day (Goodlett, 1954), except that hemlock was more abundant and stands of white pine were widespread except perhaps in the beech forest type (fig. 25).

The mound-building material is loose and porous. Nearly level areas between mounds and pits have thin podzolic soil profiles, whereas most mounds and pits have essentially no soil profile. On the side of the mound that is nearest to the fallen tree trunk, thick masses of organic matter and material derived from a gray A_2 horizon may be present.

Mechanical disturbance by the roots of fallen trees increases the permeability of surficial deposits, mixes weathered and fresh materials, and destroys or greatly disturbs soil horizons. Much of the land surface of

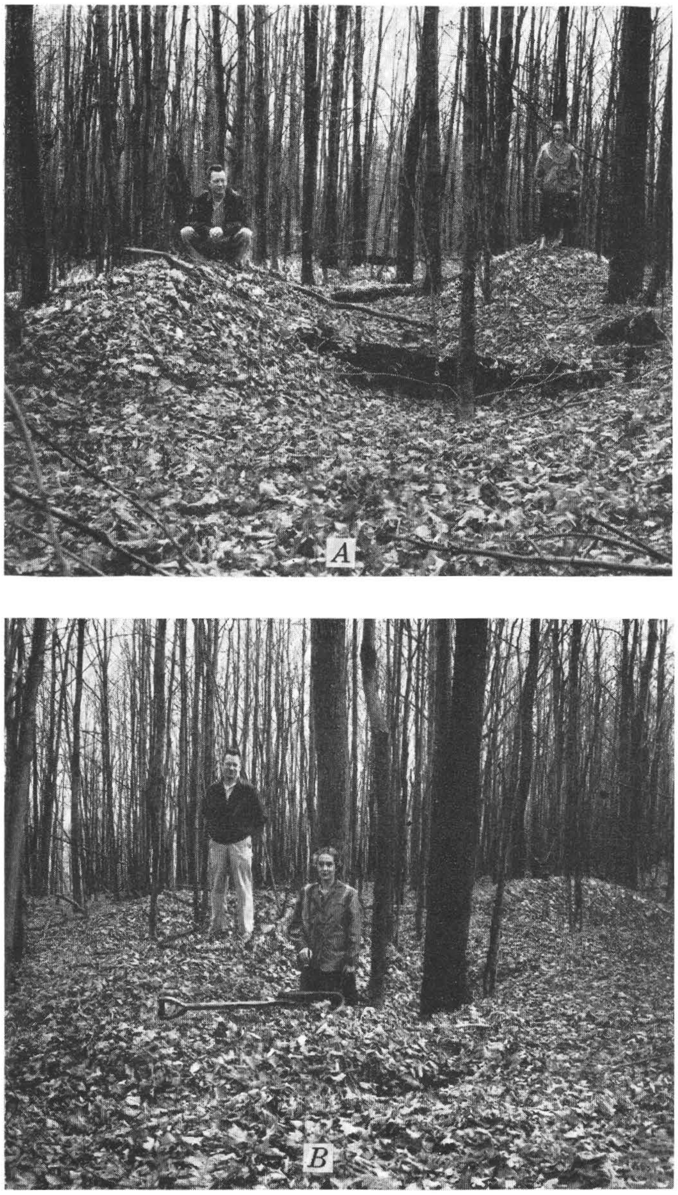


FIGURE 28.—Blowdown mounds on uplands along Ridge Road near head of Big Carlson Hollow, Wharton quadrangle, Potter County, Pa. (see pl. 7, map *A*). *A*, View looking northward. Man on mound 1; woman on mound 17. *B*, View looking southeastward. Woman standing in pit 4; man on mound 3.

the county has been disturbed by this process at one time or another during the last few hundred years and, doubtless, for thousands of years. Here and there, trees fell every year; in addition, storms have felled large stands of timber at various times throughout the years. Thus, in most parts of the county, the existing soil horizons, or those within 2 or 3 feet of the surface, are not more than a few hundred years old.

This process is a factor in the development of existing forests. The bare mound is a vastly different habitat for plant germination than is provided by the adjacent pit or surrounding forest floor. The development of microrelief produces local differences in depth to the water table—differences that may be significant in determining the relative abundance of species in a given area. The stands of giant white pine, found by early settlers, may have germinated on blowdown mounds formed by the toppling of an earlier stand of trees (Goodlett, 1954).

MICRORELIEF ON ESSENTIALLY LEVEL LAND ALONG RIDGE ROAD, WHARTON QUADRANGLE

A small area of the microrelief is located along Ridge Road near the head of Big Carlson Hollow, Wharton quadrangle, (loc. 18, pl. 1). The area is about 20 miles southwest of the border of the Wisconsin drift and includes a small tract of nearly level land on the ridge top (altitude about 2,200 feet) and a portion of

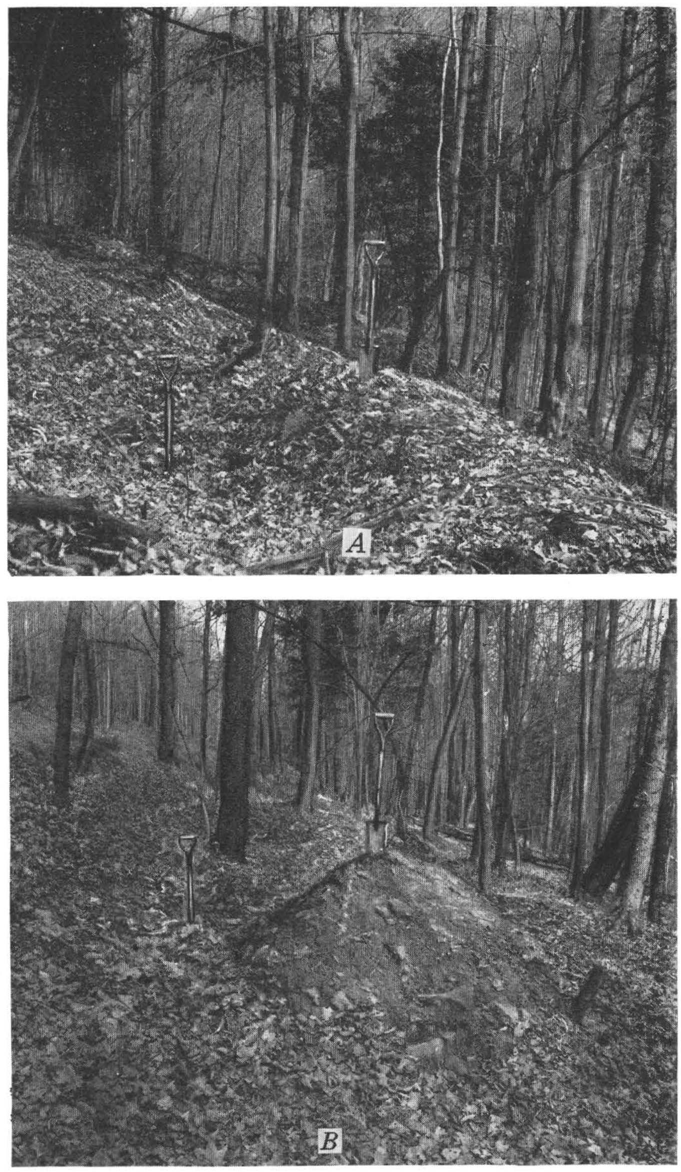


FIGURE 29.—Blowdown mounds on slope along Ridge Road at head of Jacob Hollow, Cherry Springs quadrangle, Potter County, Pa. *A*, Shovel at right on mound; shovel at left in pit. *B*, Shovel on bare mound at right; shovel at left in pit. Mound-building tree fell to right, downslope.

the adjacent steep slope. The local bedrock is thin-bedded gray sandstone. Mapping and trenching (pl. 7 and fig. 30) show that the mounds can be divided into several age classes on the basis of the approximate age of the associated living trees, the state of decay of the stump or trunk of the tree that formed the mound, the presence or absence of a soil profile on top of the mound or in the pit, and the shape and orientation of the mound.

YOUNGEST MOUNDS AND PITS

Mounds 1 and 17 (pl. 7, map *A*; fig. 28, *A*) probably are the youngest in the map area (table 3). There is no soil profile in the top of either mound. In the bottom of the pits, 2 to 3 inches of partially decayed leaves rest on a 1-inch layer of small fragments of sandstone. Below the material is a loose, yellowish-brown unmottled silt loam. There is, apparently, no soil profile in the material that underlies the pits.

TABLE 3.—*Data on mounds in map area along Ridge Road*

Mound no.	Location	Length (feet)	Width (feet)	Maximum relief from floor of pit to top of mound (feet)	Maximum slope of mound (degrees)	Orientation of long axis of mound	Volume or capacity (cubic feet)		Estimated age (as of 1950)
							Mound	Pit	
1	Ridge top	24	7	3½	40	N. 19° E.	1,150	280	60
17	do	23	7	3½	40	N. 20° E.	1,330	160	60
3	do	15	7	3	40	N. 1° E.	500	110	70–80
18	do	18	8	3	35	N. 2° E.	1,500	160	70–80
19	do	14	4	2	25	N. 60° W.	180	80	100+
Trenched mound	do	13	8	2½	40	N. 13° W.	680	130	Unknown
5	Slope	23	13	2½		N. 26° E.	3,100	380	60+
8	do	8	3	1		N. 10° E.	230	100	60+
22	do	15	5	1½		N. 1° E.	330	130	60+
28	do	12	5	1		N. 30° E.	260	100	60+

The stumps of hemlock trees that produced these two mounds are intact, although they are somewhat shattered or decayed. The stumps are slightly more than 20 inches in diameter, and the annual rings are still visible in the center. One log was salvaged after the trees fell. The saw line across the top of the stump is recognizable, and the remaining portion of the trunk is still present.

The age of the two mounds was estimated in 1950 at roughly 60 years. The trees that grow on sides of these mounds are 40 to 60 years old. Using the decay of hemlock logs as a criterion, the salvage operation took place within 5 years after the trees fell—probably between 1888 and 1895, which was the time that hemlock was cut from this ridge (Goodlett, 1954). A figure of 60 years is taken as a reasonable guess for the age of the youngest mounds and pits.

OLDER MOUNDS AND PITS

Another mound (no. 3, pl. 7) probably is slightly older than the youngest mounds (table 3). There is no soil profile under the top of the mound. Below the pavement in the pit, a slightly mottled, yellowish-brown, channery silt loam becomes grayer and less mottled at a depth of 1 foot, thus suggesting the incipient development of an imperfectly drained soil.

The age of this mound (3 on pl. 7) is estimated, as of 1950, to be 70 to 80 years. An ash tree, with a diameter at breast height of 19.4 inches, located at the south end of the mound, was estimated (by use of an increment borer) to be about 70 years old. On this basis, the minimum age of the mound is 70 years. There are no visible remains of the trunk of the fallen tree that produced the mound; however, fragments of beech or maple wood were found inside the mound. Logs of beech and maple will disappear from the forest floor more rapidly than hemlock; thus, absence of remains of the mound-producing beech or maple tree (3 on pl. 7) does not conflict in age correlation with the presence of remains of the hemlocks that produced mounds 1 and 17.

Still another small mound (19 on pl. 7), has its long axis oriented approximately N. 60° W., which is at variance with that of most other mounds, not only in the map area but elsewhere on the ridge (table 3). A beech tree with a diameter at breast height of 18 inches grows close to, and probably postdates, the mound. The tree probably is about 100 years old, and the minimum age of this mound, therefore, is 100 years. The orientation of the mound, and the location of the pit, suggest that the mound-building tree was toppled by northeasterly winds; however, it is possible that this mound is the result of a southwesterly wind—in other words, it is a "thrust mound", a type described by Lutz and Griswold (1939, p. 395), in which the pit forms on the leeward side of the mound.

INTERNAL STRUCTURE OF MOUNDS

A trench was dug through a mound (table 3) located about halfway between the area shown in map *A* and that shown in map *B*, plate 7. The ground east of the mound (at *A*, fig. 30) has a Podzolic soil profile. Near the west end of the trench, to the west of the pit, the gray A_2 horizon of the soil is discontinuous. Just east of the top of the mound, fragments of a gray A_2 horizon that apparently antedates the fall of the tree are broken,

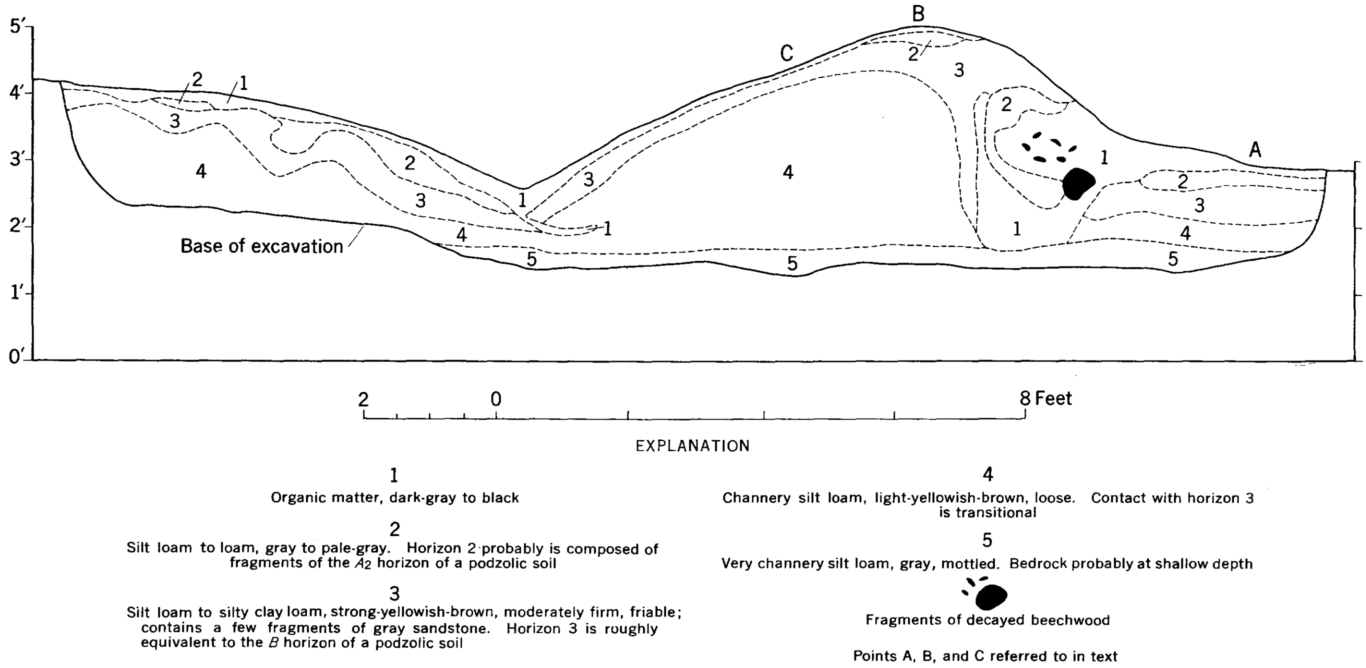


FIGURE 30.—Cross section through blowdown mound. Locality is on uplands along Ridge Road near head of Big Carlson Hollow, Wharton quadrangle, Potter County, Pa. (loc. 18, pl. 1). Mound is located on ridge top about halfway between area shown in map *A* and that shown in map *B*, plate 7.

overturned, and thickened into a jumbled mass (see photographs in Lutz and Griswold, 1939). On top of the mound, at *B*, there is a possible remnant of a thin Podzolic soil profile and, to the west of the slope of the mound, as at *C*, there is a suggestion of incipient profile development. The age of the mound is unknown.

MICRORELIEF BETWEEN MOUNDS AND PITS

Areas between distinct mounds and pits in the map area (map *A*, pl. 7) have a microrelief that ranges from about 6 inches to 2 feet—these areas are not depicted accurately by the 1-foot contour interval. This "intermound" microrelief is probably worn-down ancient mounds and partly filled pits, because their outlines are locally recognizable although the microrelief is not more than 1 foot. Numerous post holes and exposures in the banks of Ridge Road show that the gray A_2 soil horizon is discontinuous under the intermound areas. Extensive trenching might make it possible to outline the "roots" of ancient mounds and pits whose surface expression has been lost.

ASSOCIATED VEGETATION

The forest on the ridge top in, or near, the map area consists of sugar or red maple, black cherry, ash, beech, and small hemlock. Trees grow on the sides of mounds or pits and elsewhere on the intermound areas, but no trees grow on the bottom of the pits even where the microrelief is not more than 1 foot. Trees grow at the ends of many mounds but are not common on their summits. Young hemlocks occur on on top of old mounds in many places and apparently grow very slowly until they reach the forest canopy.

MICRORELIEF ON SLOPING LAND ALONG RIDGE ROAD, WHARTON QUADRANGLE

Mounds occur to the east of Ridge Road on a relatively smooth 22° (40 percent) slope with essentially no microrelief except for five mounds and pits (pl. 7, map B; table 3). The slope is underlain by permeable rubble. No bedrock crops out nearby.

Mound 5, one of the largest seen, is composed of fragments and blocks of medium-grained sandstone with a little yellowish-red sandy matrix. The mound is covered by a 1-inch layer of organic matter. Under the pit, 3 to 4 inches of organic matter overlies a very channery and flaggy, highly permeable, yellowish-brown silt loam. The minimum age of the mound was estimated in 1950 at 60 years. No trees grow on the mound, and the nearest trees probably are 40 to 60 years old.

The minimum age of mound 22 was estimated in 1950 at about 60 years. A black birch growing on top of the mound is estimated to be 40 to 60 years old. The state of decay of the hemlock stump on the downhill side of the mound is similar to those associated with mounds 1 and 17 on the ridge top, mounds whose minimum age is estimated at about 60 years. Mounds 8 and 28 also were estimated in 1950 to be at least 60 years old.

ORIENTATION OF MOUNDS

The longer axes of mounds 5 and 28 trend northward and slightly downslope. The longer axis of mound 8 is essentially parallel to the slope, and that of mound 22 runs slightly downslope in a southerly direction. These slight differences probably result from slightly different wind throws. The small gully at the north or the south end of a mound is probably an initial form produced by the fallen tree and is not a result of later erosion.

ASSOCIATED VEGETATION

The vegetation of the slope is not greatly different from that on the adjacent ridge top, except that beech is more abundant and a few red oaks are present, which may result from a slight change in soil moisture between the ridge top and the slope. Here, as on the ridge top, none of the trees grows on the bottom of the pits.

FORD HILL, GENESEE QUADRANGLE

Mounds associated with pine stumps were studied in a small area on the north slope of Ford Hill (pl. 4), just southwest of the corner where the road to the South Branch of Oswayo Creek branches off the road that runs northward from Ford Hill to Oswayo Creek. The altitude is about 2,300 feet; the ground slopes 2 to 5 percent and has a microrelief of about 1 foot. The surficial deposits have a silt loam texture. A thin Podzolic soil profile was noted in some post holes but not in others. The existing forest is a second-growth stand of mixed hardwoods ranging from 40 to 80 years old.

Most pine stumps stand on low circular mounds that are about 10 to 12 feet in diameter and 1 foot high. Most of the stumps are not associated with a pit, although some pits scattered throughout the area are as much as 1 foot deep. A few stumps stand on essentially level land; most are spaced 20 to 30 feet apart, and a few are only 10 to 15 feet apart. These pines apparently grew on old blowdown mounds that have largely disappeared through erosion, except where they were protected by tree roots.

AGE

In 1950, the minimum age of mounds beneath the pine stumps was estimated at 250 to 300 years. The pine stumps range from 30 to 40 inches in diameter and are deeply decayed. Ring counts of recently cut pine with comparable diameters found elsewhere in Potter County suggest that these stumps were 175 to 225 years old when they were cut. The trees probably were cut about 1860, certainly not later than 1885. Thus, in round figures, the mounds are at least 250 to 300 years old.

SIGNIFICANCE

Several tentative conclusions can be drawn from the mounds near Ford Hill. If the microrelief at the time of germination of the pine was roughly comparable to that along Ridge Road, it follows that over a period of 250 to 300 years erosion had reduced the microrelief to about 1 foot and has obliterated most of the pits. Most of the remaining mounds are held together by pine roots that spread out from the stump over the sides of the mound. The root mat is roughly circular in plan and will retain a roughly circular mound of earth (the rest of the original elongate mound having been eroded away).

Although in a few places in Potter County the forest floor is essentially a plane surface, in most areas the floor has a microrelief of at least 1 foot. This suggests that most of the forest floors in Potter County have been disturbed by the roots of fallen trees within the last 300 to 500 years; the latter figure is based on the assumption that the rate of erosion decreases as the microrelief decreases.

Perhaps some mounds topped by stumps are residual forms rather than the result of fallen trees, the gound surface having been lowered by erosion except where protected by roots. However, some pine stumps on mounds are associated with a pit or a closed depression. If such a mound were the result of the protection of surficial deposits by roots, while the adjacent material was eroded away, the adjacent pit should have been filled also.

AREA ALONG HUNGRY HOLLOW ROAD, OLEONA QUADRANGLE

A small remnant of presettlement forest is located along Hungry Hollow Road, Oleona quadrangle (loc. 21, pl. 1), on a ridge (altitude about 2,100 feet) at the head of Sawmill Run, just north of the boundary between Abbott and Stewardson townships. The area is underlain by a sandy loam that contains a few small fragments of sandstone. No bedrock crops out in the vicinity. In this forest on the ridge top the microrelief ranges from 1 to 3 feet; the mounds probably are not quite so large as those in the area along Ridge Road.

Here, some of the living trees are about 200 years old, and therefore it is possible to trace the history of the existing microrelief over a longer time than was possible in the area along Ridge Road. A few giant maples, estimated to be 150 to 200 years old, grow on low, circular mounds that resemble those found under pine stumps near Ford Hill; it is conceivable that they are ancient mounds that have been eroded away except where protected by roots. Because of their relation to the existing trees, the rest of the mounds probably belong to two age classes. These mounds resulted from the toppling of trees in the presettlement forest, where the trees were spaced at distances of 20 to 40 feet apart. Some mounds are only 10 feet apart and in places almost intersect, thus indicating that all of the disturbances could not have taken place at the same time. The random orientation of mounds also suggests that they are not the result of a single violent wind; instead, the indications are that the trees toppled one by one in diverse directions over a period of at least 100 years.

SIGNIFICANCE FOR GEOLOGY

ANCIENT AND MODERN FROST ACTION

The processes that create the microrelief may produce soil structures or rubbly materials that, as Lutz and Griswold point out (1939), resemble some of those found in arctic and subarctic regions. The erosion of a mound may remove much of the finer constituents (the silt and clay) and leave the larger rock fragments on the surface. If cycles of mound development and erosion have been in effect for thousands of years, the upper 1 or 2 feet of the mantle has been enriched in rock fragments. The periglacial deposits of Potter County may be, in part, the result of such activity. However, the areal distribution and thickness of the periglacial deposits in relation to the border of the Wisconsin drift make this hypothesis untenable.

Mounds interrupt the essentially plane surface of some miniature block fields. Many upland areas with very channery and flaggy surficial deposits originally may have been covered by miniature boulder stripes of early Wisconsin age. It is possible that such stripes are scarce today because the roots of fallen trees have destroyed them.

The roots of a fallen tree can bring fragments of rock to the surface from depths of 1 to 2 feet. This process must have operated for centuries over most of the northeastern states where the soils contain a high proportion of silt. In parts of the Susquehanna Valley, and elsewhere, these silt mantles have been interpreted as loess. These mantles locally contain many rock fragments, and the explanation has been advanced by Peltier (1949), and by others, that the fragments were mixed with the loess by frost heaving during a later interval of periglacial climatic conditions. For example, the loess may be referred to the Olean substage, and the introduction of the rock fragments may be referred to frost processes during a later substage of the Wisconsin. Such a hypothesis is reasonable, but one should not forget that it is possible that the rock fragments were brought up from below by the roots of fallen trees.

EROSION OF SLOPES

In Potter County most of the forested slopes, which are underlain dominantly by sandstone and conglomerate, probably are relatively stable at present and have been stable since the present forests became established. Furthermore, the toppling of trees is probably the most important factor in the downslope movement of the mantle on these slopes. Slopes underlain by considerable amounts of shale and siltstone are less stable.

Slopes underlain by sandstone, as example, along Ridge Road (pl. 7), are common in Potter County. Here, the surficial materials are permeable rubbles, and water from rain or melting snow flows through the mantle rather than on its surface.

In support of this assumed stability, the following facts are pertinent:

(1) The blowdown mounds are widespread on slopes of diverse angle, orientation, and rock type. Almost all of the mounds are at least 50 years old—many are much older. In 50 to 100 years, erosion has not erased the microrelief.

(2) There are no tilted trees and there is no accumulation of material or scars on the uphill side of tree trunks.

It is possible that the entire forest cover is creeping downslope more or less as a blanket. This is plausible, but if one considers the resistance by tree roots to the force exerted by strong winds, it seems unlikely that gravity could exert sufficient force to move a blanket of roots downslope. Unquestionably, some material is moved downslope grain-by-grain by running water, but the amount of material must be very small, even over a period of 100 years.

The toppling of trees breaks the root mat, lays bare the underlying surficial mantle, and piles it into mounds. The act of toppling moves the material downslope for distances of several feet. After decay of the binding roots and erosion of the fine material (by rain drops) slope wash, frost, and creep carry some material back into the pit, but most of it is carried farther downslope. If such slopes have been forest-covered for at least 10,000 years, the continued toppling of trees downslope must have caused downslope movement of the mantle at a rate faster than that produced by all other processes combined.

The rate of downslope movement of the mantle caused by the toppling of trees on the slope along Ridge Road has been calculated. The method involves: an estimate of the movement resulting from the development and destruction of the four mounds on the slope (pl. 7, map *B*), and an estimate of the frequency of the occurrence of similar mounds in the past. The figures are exceedingly rough, but they could be refined with additional data, such as by a study of growth rings in the wood buried in the mounds.

First, the volume of a mound is estimated on the approximation that it is half of a prolate spheroid.

The volume of a prolate spheroid equals $4/3\pi ab^2$ where

the major axis, a=length of mound

and

b, the minor axis=

$$\frac{\text{width of mound}+2(\text{height of mound})}{2}$$

Therefore,

the volume of a mound$=2/3\pi ab^2$.

The capacity of a pit was estimated in a similar manner. The total volume of material in the four mounds on the slope (table 3), excluding mound 24, is roughly 4,000 cubic feet. Inspection of the map and profile (pl. 7) suggests that after these mounds and pits are eroded, half of the volume (2,000 cubic feet of material) will have moved downslope an average distance of 3 feet, or half the average width of the mounds. Because the slope area, excluding mound 24, roughly covers 3,000 square feet, the 2,000 cubic feet of material is equivalent to a layer of mantle two thirds of a foot thick spread over the entire slope. Therefore, this hypothetical layer will have moved downslope a distance of 3 feet within the life of the existing mounds.

To visualize the possible magnitude of such movement over a period of thousands of years, we must assume that new mounds were formed every few hundred years. If the growth of a new stand of trees took 200 years, then 50 generations would have formed in 10,000 years and the possible total amount of movement during the last 10,000 years would be 50 times that deduced above (100,000 cubic feet moved a distance of 3 feet). This volume is equivalent to that of a layer of mantle two thirds of a foot thick that moved downslope 150 feet.

EROSION ON ESSENTIALLY LEVEL LAND

It is evident that a continuous struggle has existed between the forces that produce the microrelief and those that work towards its obliteration. The data from areas along Ridge Road and Hungry Hollow Road suggest that the microrelief persists on essentially level land for at least 100 to 200 years. The data from the Ford Hill area suggest, on the other hand, that the microrelief is largely obliterated within 250 to 300 years. Possibly the rate of erosion of mounds near Ford Hill was greatly increased following the clear cutting of the pines, which occurred from 1860 to 1885. Therefore these mounds may have been eroded more rapidly than those along Hungry Hollow Road, where the forest has never been clear cut.

A perplexing problem revolves around the fact that many mounds persist as distinct microrelief features for 100 to 200 years and are not greatly reduced by erosion. Many mounds are essentially bare (fig. 29, *B*) and their surfaces may have small pebbles perched on a pinnacle of finer material that may be nearly 1 inch high. Such pinnacles apparently result from erosion caused by the impact of raindrops on the bare surface. It is difficult to picture such a mound maintaining its height and its steep side slopes unless some process tends to perpetuate or retard its destruction. It is possible that present-day frost action is such a process. In winter, frost will form to a considerable depth in a bare mound composed of material with a channery silt loam texture. This frost will retard erosion by rain wash and, on melting, will tend to maintain or increase the originally high permeability. Although it is possible that a mound could be maintained by lateral pressure of ice in the pit, observations by foresters suggest that there is little or no frost in the ground under a pit because the pit is partly filled by leaves or snow, or both (p. 5).

SOILS ON DRIFT OF THE SEVERAL SUBSTAGES OF THE WISCONSIN STAGE

In parts of western United States, a detailed study of the deposits and land surfaces of the several Wisconsin substages demonstrates that these features have characteristic soil profiles that can be used in correlation. However, in northern Pennsylvania the disturbance of the upper 2 to 3 feet of the soil by the roots of fallen trees suggests that comparative studies of soil profiles on drifts of the several Wisconsin substages cannot be based on the morphological character of the soil horizons—at least not on those within 2 or 3 feet of the ground surface. Podzolic soil profiles may occur at many points within an area of the microrelief, but the foregoing analysis indicates that such profiles are not more than 300 to 500 years old.

SIGNIFICANCE FOR SOIL SCIENCE

Most of the land surface of the county has been disturbed by the toppling of trees at one time or another during the last 300 to 500 years. Most of the existing podzolic soil profiles probably are not more than 500 years old and doubtless are somewhat younger. The mantle has been undergoing chemical weathering and soil formation since the close of the periglacial interval, but the existing thickness and arrangement of an *A* horizon, and probably at least the upper part of a *B* horizon, have developed during the last 300 to 500 years.

The roots of fallen trees have destroyed or disturbed the horizons of the soil profile. Material from lower horizons or from the parent material is mixed with or laid upon the upper horizons of the profile. This process may actually increase the volume of weathered mantle produced in a given time.

The soils on the ridge tops appear to form a mosaic of small areas with podzolic soil profiles interspersed with small areas of imperfectly to poorly drained soil and with areas with no soil profile whatsoever. The latter areas are not strictly confined to distinct mounds and pits; they are also found in intermound areas. The data suggest that old pits are filled by material from the adjacent mound.

SIGNIFICANCE FOR PLANT ECOLOGY

The evolution of the microrelief has fundamental significance for any concept of forest succession. It is probably responsible for development of the stands of giant white pine that were present in Potter County at the time of settlement. The toppling of a tree produces a mound of bare mineral soil that is a vastly different habitat for the germination of a tree than the adjacent forest floor with its surface layer of organic matter, or the bottom of a pit where almost no trees have germinated. The evolution of the microrelief produces local minor changes in the depth to water tables, which, in turn, may affect the kind and abundance of trees. Goodlett (1954) has discussed the botanical implications of the evolution of the microrelief.

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