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GLACIAL BORDER DEPOSITS OF LATE WISCONSINAN AGE IN NORTHEASTERN PENNSYLVANIA

by G. H. Crowl
Ohio Wesleyan University

W. D. Sevon
Pennsylvania Geological Survey

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PREFACE

This report and accompanying maps describe the nature and delineate the position of the late Wisconsinan glacial border in a 185-mile, northwest-southeast zone from northwest of Shinglehouse, Pennsylvania, to the Delaware River near Belvidere, New Jersey. Attention is devoted to the trace of the former ice border, as well as to associated economic deposits and environmental characteristics of deposits on both sides of the border.

This report provides new information on the most recent glacial history of Pennsylvania and also provides basic geologic and resource data for those charged with protecting our environment and planning proper land utilization.

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GLACIAL BORDER DEPOSITS OF LATE WISCONSINAN AGE IN NORTHEASTERN PENNSYLVANIA

by

G. H. Crowl[1] and W. D. Sevon

ABSTRACT

This report describes the trace and characteristics of the Olean glacial border of Woodfordian (late Wisconsinan) age from northwest of Shinglehouse, Pennsylvania (near the state border southeast of Olean, New York), for 185 miles (300 km) southeast to the Delaware River near Belvidere, New Jersey. The border is marked by large and small lobes and indentations that follow the bedrock topography. East of the Lehigh River, drift is nearly continuous and the border is marked by extensive areas of distinct and indistinct end moraine. West of the Lehigh River, drift is less abundant and end moraine is associated mainly with topographic barriers.

Measurements of striae indicate that ice flowed mainly from the north and north-northeast, but was deflected in some areas by local topography. Calculations of ice-surface gradients indicate a "best" gradient of 225 feet/mile (43 m/km).

Olean deposits comprise till, whose varying facies depend upon the underlying bedrock, and sands and gravels in various kames and kame terraces. Grain-size analyses of 70 till samples indicate that Olean tills cannot be differentiated from older tills by grain-size analysis. Pebble-lithology analyses show a close correspondence of pebbles to underlying bedrock.

Periglacial activity in areas marginal to ice positions produced a variety of collateral slope deposits, which include shale-chip rubble, boulder colluvium, and boulder fields. Smaller deposits such as stone stripes also occur.

Radiocarbon dates of organic materials from bog and lake bottoms indicate that deglaciation in eastern Pennsylvania started about 15,000 years ago.

Some of the sand and gravel, peat, and clay deposits associated with the Woodfordian glaciation in Pennsylvania have significant economic potential.

Deposits on either side of the glacial border defined in this report require different environmental considerations.

[1] Department of Geology and Geography, Ohio Wesleyan University, Delaware, OH 43015.

Details of the deposits along the border are given for small topographic regions such as the Oswayo Creek basin, North Mountain sector, Pocono Plateau, Delaware Valley, and others.

INTRODUCTION

The investigation reported here, the remapping of the border deposits of the last glacial advance across northern Pennsylvania, was undertaken to solve the problem that differing ages had been assigned to the east and west portions of the border at the junctions with the adjacent states of New Jersey and New York.

This report describes about 185 miles (300 km) of the Woodfordian drift border of late Wisconsinan age from northwest of Shinglehouse, Pennsylvania (near the state border southeast of Olean, New York), to the Delaware River near Belvidere, New Jersey (Figure 1).

The accompanying map (Plate 1) shows the course of the border and its various types of deposits in greater detail than has previously been available. Areas of older drifts south of the Woodfordian border and east of the Lehigh River are generalized from recently published maps. West of the Le-

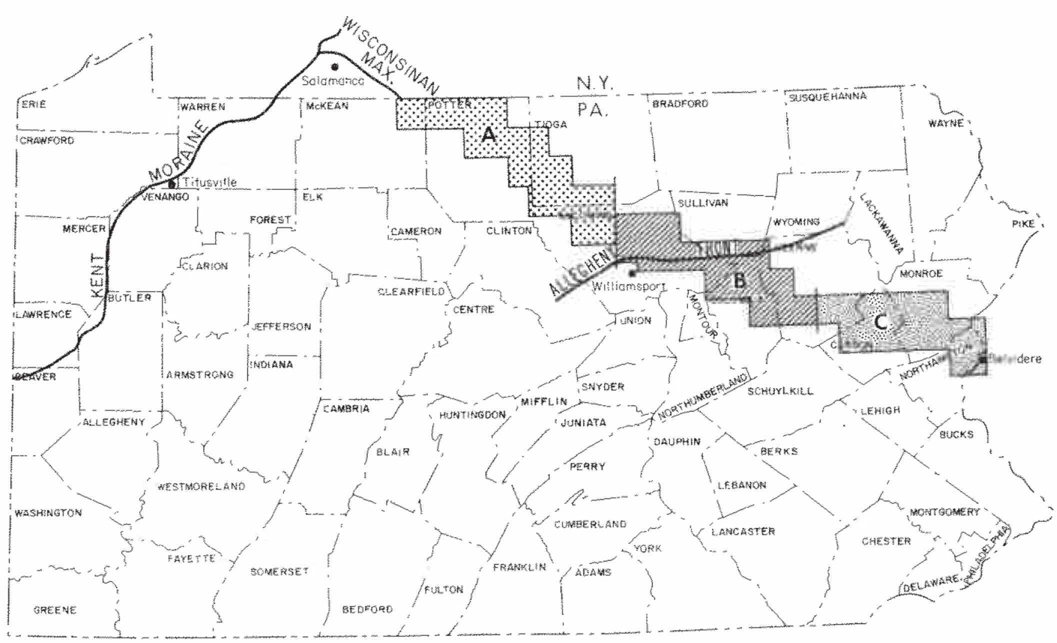

Figure 1. Index map showing areas included on Plate 1, the approximate position of the late Wisconsinan Kent moraine in western Pennsylvania, and the approximate position of the Wisconsinan glacial maximum in New York between the Kent moraine and the Pennsylvania State line.

high River, known locations of older drifts are indicated, but areal distribution is not shown on the map. Colluvium is present on both sides of the border, but it has not been mapped. It is much more extensive south of the Woodfordian border.

The glacial-border area was mapped at 1:24,000 scale and the accompanying map, Plate 1, at 1:100,000 scale, was compiled from these maps. Most of the map of the portion east of the Lehigh River was compiled from published quadrangle maps or open-file information. These sources are acknowledged in the text and on the index on Plate 1. West of the Lehigh River, Crowl mapped the border in a belt 2 to 5 miles (3 to 8 km) wide. The field maps for this latter area are on open file at the Bureau of Topographic and Geologic Survey, Harrisburg, Pennsylvania.

This report provides the following previously unavailable information on the glacial-border zone: (1) the distribution of till as ground moraine and end moraine, and of gravel deposits; (2) brief descriptions of the various materials; (3) locations of various glacial features; (4) the continuity of the border across north-central and northeastern Pennsylvania; and (5) new radiocarbon age determinations and consequent correlations which demonstrate the contemporaneity of the border deposits throughout the mapped area, and their Woodfordian age.

HISTORICAL PERSPECTIVE

H. Carvill Lewis and G. Frederick Wright (Lewis, 1884) first traced the boundary between glaciated and unglaciated regions, their "Terminal Moraine," across northern Pennsylvania (Figure 2) from Belvidere, New Jersey, on the Delaware River to Salamanca, New York, and thence southwestward across northwestern Pennsylvania. They regarded the border as being of the same age throughout its length. Their work filled a major gap in border mapping from Long Island and New Jersey (Cook, 1877, 1878, 1880) to Ohio (Wright, 1883, 1884), where detailed descriptions were already available. Their tracing of the "Terminal Moraine" provided a useful boundary across Pennsylvania. It was a remarkably fine achievement and has been the basis for all subsequent glacial work in the state. Chamberlin (1883) used it in his description of the glacial border across the eastern United States. The work attracted the attention of European geologists and resulted in a visit to Pennsylvania by Wahnschaffe (1892). However, Lewis and Wright were handicapped by inadequate base maps, causing a consequent lack of detail. Furthermore, Lewis (1884) stressed the "terminal moraine" character of the border—a low, hilly zone of till marking the southern margin of the drift. This is generally true east of the Lehigh River, but to the west a well-defined terminal moraine is rare, and the boundary lies between ground moraine and colluvium or bedrock residuum and has

Figure 2. The late Wisconsinan glacial boundary in Pennsylvania and New York and sites of radiocarbon dates to the nearest 0.1 thousand years (13.2 = 13,200 years ago). The New York boundary is drawn after Muller (1977) and the northwestern Pennsylvania boundary is drawn after White and others (1969). The boundary throughout is approximately that mapped by Lewis and Wright (Lewis, 1884).

little or no topographic expression. At first, Lewis and Wright did not clearly recognize the "fringe" of older glacial deposits in eastern Pennsylvania as they did later in the western part of the state (Lewis, 1884; Wright, 1893), and they sometimes included older drifts within their glacial border. By 1901, Alden (Fuller and Alden, 1903) had compiled a map of the glacial deposits of Pennsylvania and New York showing the Wisconsinan border.

Leverett (1934) recognized two older drifts beyond the Wisconsinan border, and termed them Illinoian and pre-Illinoian ("Jerseyan," that is, Kansan). He included drift here recognized as Altonian with his Illinoian drift. He made some minor revisions in the Wisconsinan border, but his map, at a scale of 1:1,000,000, is suitable for only very general use. His text descriptions of the border are vague in most cases; he noted the border in certain places, particularly in valleys, but did not trace it over the intervening hills. He gives a useful review of earlier literature as background for his discussion of older drifts in Pennsylvania.

Shepps and others (1959) remapped the glacial border in northwestern Pennsylvania and distinguished three drifts: Wisconsinan, and early and late Illinoian. Later, White and Totten (1965) demonstrated that this "late Illinoian" was really late Altonian in age, that is, middle Wisconsinan. Thus, the sequence in northwestern Pennsylvania, as now recognized, is Woodfordian, Altonian, and Illinoian (White and others, 1969). The recently recognized stratigraphy in northeastern Pennsylvania is comparable to that in northwestern Pennsylvania, as discussed below.

MacClintock and Apfel (1944) mapped the Salamanca reentrant in southwestern New York; it joins the east and west parts of the glacial border in Pennsylvania (Figure 2). They distinguished an Illinoian and two Wisconsinan drifts; the younger Wisconsinan drift was designated the Binghamton, and the older, the Olean. The Binghamton drift on the west side of the reentrant is now correlated with the Kent till in northwestern Pennsylvania and Ohio (Muller, 1965) and is early Woodfordian in age. The Olean drift on the east side of the reentrant marks the latest Wisconsinan drift border and was tentatively assigned to a Tazewell (early Wisconsinan) age (MacClintock and Apfel, 1944).

MacClintock and Apfel (1944) distinguished the western, Kent ("Binghamton") drift from the eastern, Olean drift by the higher content of "bright" pebbles (limestone and crystalline) in the Kent drift in addition to the usual shale, siltstone, and sandstone pebbles. They admitted that the distinction was not always clear-cut, but ascribed "bright" pebbles in Olean till to reworking of older drifts. Moss and Ritter (1962) pointed out that the "Binghamton" drift occurs in through-valleys where concentrated ice flow carried the "bright" pebbles farther south. The Binghamton drift is intermediate in composition between the Valley Heads drift to the north and the Olean on the neighboring hills, and does not represent a separate ice advance. Consequently, the name Binghamton has been abandoned. La Fleur (1979) describes interfingering of Kent- and Olean-type tills in the Snake Run section near West Valley, New York, 2 miles (3 km) within the Kent border at the apex of the Salamanca reentrant. Thus, the lithologic distinction between Kent and Olean tills is not clear-cut.

Denny (1956) traced the Olean drift border into north-central Pennsylvania and assigned to it an Iowan (earliest Woodfordian) age. Denny and Lyford (1963) reconnoitered the Wisconsinan glacial border in the Williamsport region to the east. They assigned an "early Wisconsin" (Altonian) age to the drift border. Muller (1965) and others agreed with this age assignment. Denny and Lyford's regional map east of the Williamsport area is redrawn from older sources, and they carry the same Altonian(?) border into central and eastern Pennsylvania. This conflicts with the authors' interpretation of a Woodfordian age for the latest drift border in northeastern Pennsylvania.

Muller (1977a) has recently compiled a map of the Pleistocene geology of southwestern New York. His Altonian age of the Olean boundary is based on the overlap in the Salamanca reentrant cited by MacClintock and Apfel (1944). The authors discussed the problem with Muller in the field in 1976 and 1978, but did not resolve the problem. Degree of soil development and radiocarbon information (see below) support the authors' conclusion that the border is Woodfordian in age.

Epstein (1969) began the modern study of Woodfordian deposits in northeastern Pennsylvania, and Connally (unpublished) was the first to recognize deposits intermediate in age between Woodfordian and Illinoian. These deposits are now referred to the Altonian. Crowl (1971) established the Woodfordian age of the drift in the Delaware Valley. The authors do not accept Connally and Sirkin's (1973) interpretation that the "Terminal Moraine" at Belvidere, New Jersey, is older than the Woodfordian boundary. Crowl and others (1975) and Sevon and others (1975) present summaries of the glacial geology of the area between the Delaware and Lehigh Rivers. Marchand (1978) presents information on old drifts in the Lewisburg area.

STRATIGRAPHY

Early investigations of glacial deposits in the United States provided evidence for more than one glaciation, and a concept of four major glaciations separated by long interglacial epochs was gradually developed. The Wisconsinan was the last major glaciation. Almost concurrently it was discovered that the Wisconsinan Stage could be subdivided into substages (White, 1973), and subsequent work indicated that older glaciations were also multiple.

The authors have found no exposures of superposed tills of different ages, although Connally (personal communication, 1975) reports a local stratigraphic succession in the Bangor district. The authors' age differentiation of tills, young to old, is based on a north-to-south geographic distribution within the state. The boundary between young and old drifts is the most continuous drift border within the state. North of this border, drift is extensive. South of the border, older drifts have been eroded from large areas and generally occur as remnants.

The Wisconsinan drift in southern New York has generally been termed the Olean drift, extending MacClintock and Apfel's (1944) term for drift on the east side of the Salamanca reentrant to the whole region. MacClintock and Apfel did not define type localities for either the Binghamton (Kent) or Olean drifts. The term Olean has not generally been applied to the drift in Pennsylvania; it is used in this report for all young drift in Pennsylvania southeast of Salamanca, New York. Olean drift is considered to be of Woodfordian age.

The terms Warrensville and Muncy (Wells and Bucek, in press) are used here for all Altonian and Illinoian drifts, respectively, in Pennsylvania east of the Salamanca reentrant. After more detailed work has been done in the region, all of these drifts should be subdivided into local drifts based upon distinctive lithologies, and should be given local names.

The authors follow the time-stratigraphic terminology of Willman and Frye (1970) for the Lake Michigan lobe (Figure 3), because stratigraphic evidence to subdivide the Altonian into early and middle Wisconsinan, as has been done in the Erie lobe (Dreimanis and Goldthwait, 1973), is lacking here. The authors suspect that the Warrensville Till is middle Wisconsinan in age, and base this suspicion on the general similarity of soil development on this till to that on the Titusville Till of northwestern Pennsylvania, which is assigned a middle Wisconsinan age (White and others, 1969; Dreimanis and Goldthwait, 1973). Marchand (1978) raises some questions about the correctness of the Altonian and Illinoian age designations, but that is not the subject of this paper, and the age assignments currently in use are accepted.

METHODS OF INVESTIGATION

Most of the mapping was accomplished by road traverses to examine numerous roadcuts; these were supplemented by other traverses off the roads in critical areas. All of this was enhanced by the use of aerial photographs at 1:20,000 scale.

Identification of material in plowed fields and along roads is relatively straightforward. Forested areas are more difficult to decipher, but some end moraines, usually identified first from morphology seen on aerial photographs and later confirmed on the ground, give good control. Where the border lies on mountain slopes it is impossible to locate the original depositional border accurately because some drift has been removed by colluviation. The boundary is drawn on slopes from till exposures on the hills and in the valleys. Some hills barren of drift within the drift border are regarded as nunataks; others, on the basis of calculated ice-surface gradients, are interpreted as having been covered with ice.

Materials are here described on the basis of composition, fabric, and color, and are then classified as tills, gravel, colluvium, or bedrock residuum. The criterion of form then completes the classification of glacial deposits—end moraine, ground moraine, and the various types of glaciofluvial deposits.

Grain-size analyses of the sand, silt, and clay portions of the tills were carried out to define more precisely their character. Tests of magnetic susceptibilities of the matrix were the basis for a further attempt at correlation of the tills. The results of these studies are discussed later.

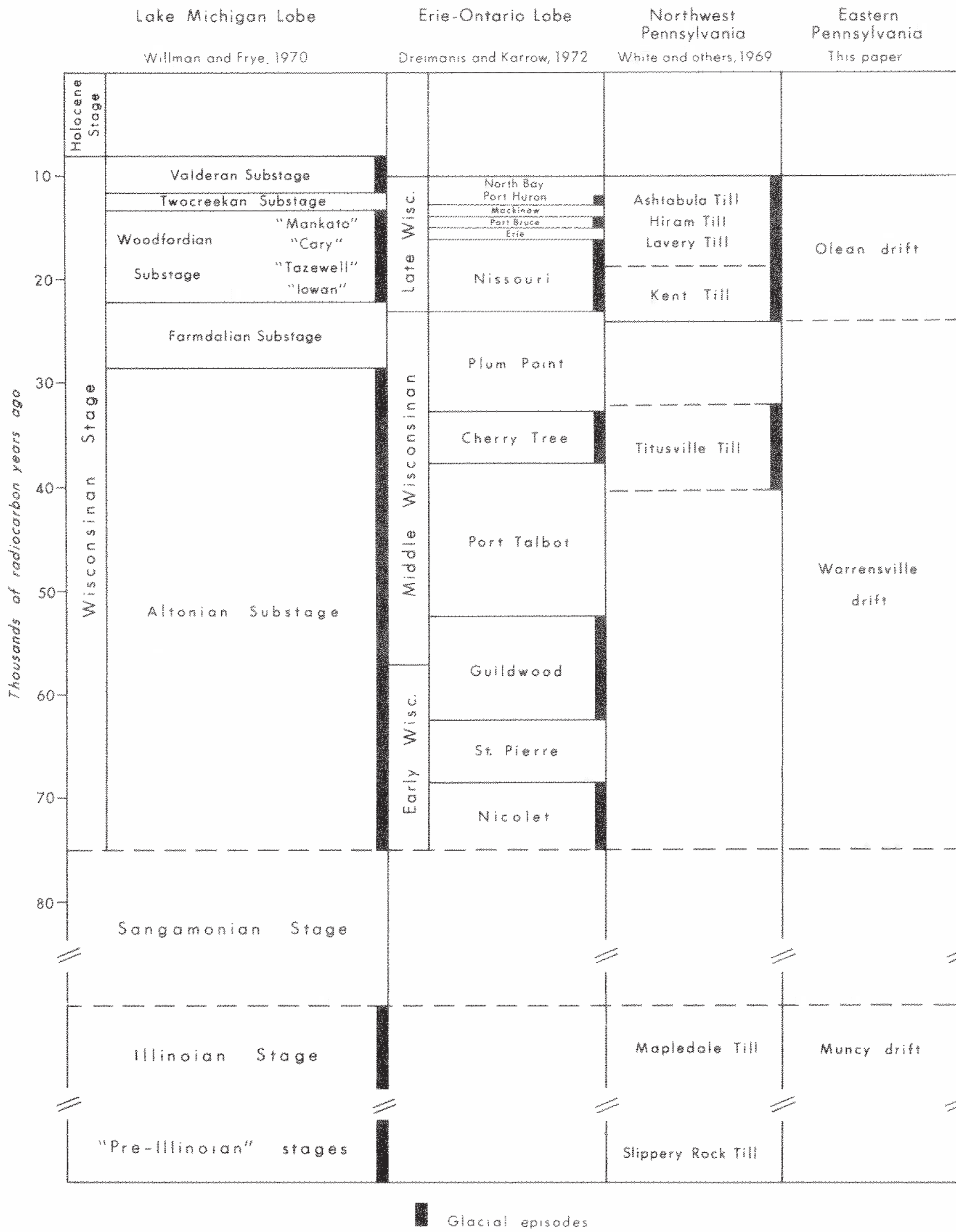

Figure 3. The relationship of Quaternary lithostratigraphic and time-stratigraphic terminology used in Pennsylvania to that used elsewhere.

ACKNOWLEDGEMENTS

The map of the area west of the Lehigh River is based principally on field work by Crowl from 1971 to 1977. In the early years it was partially supported by NSF COSIP Grant GY673 to Ohio Wesleyan University, Delaware, Ohio. Thomas Zeiner, Judson Ahern, Ronald Staufer, and Diane Nicholson assisted in the field and laboratory. The Bodines and Montoursville North quadrangles were mapped by Bucek (1975) and Wells and Bucek (in press); the Ellisburg, Sweden Valley, and Brookland quadrangles were mapped by Denny (1956); and the Berwick quadrangle was mapped by Inners (1978).

The map of the area east of the Lehigh River is compiled from quadrangle maps by Sevon (1975a, 1975b), Berg (1975), Berg and others (1977), Epstein (1969), Epstein and Connally (in preparation), and border mapping by Crowl to supplement unpublished mapping by Connally.

The authors are indebted to Edward Ciolkosz and Clifford Kohler for many fruitful discussions of soils problems. E. H. Muller, R. K. Fahnestock, and E. B. Evenson participated in a field trip along the New York border. R. Stuckenrath and J. G. Ogden kindly provided radiocarbon dating of basal organic sediments from bogs and lakes close to the border.

THE STYLE OF THE GLACIAL BORDER

The late Wisconsinan glacial boundary trends N60W from Belvidere, New Jersey, on the Delaware River, to the vicinity of Salamanca, New York, where its direction changes so that it trends southwestward into Pennsylvania and Ohio (Figure 2; Plate 1). Large- and small-scale lobes and indentations along its course are due to the influence of the bedrock topography. Major lobes occur in the Delaware Valley, in the Stroudsburg lowland northwest of Kittatinny Mountain, and in the Muncy Creek lowland at Picture Rocks. The principal reentrants are at Camelback Mountain northwest of Stroudsburg and at North Mountain and Huckleberry Mountain on the margin of the Appalachian Plateau northwest of Benton. The border trends almost west from Camelback Mountain to the Susquehanna River in the only notable departure from the northwest trend. Apparently the position of the Pocono Plateau between Camelback Mountain and the Susquehanna River, where altitudes are above 2,000 feet (608 m), and local high altitudes at the margin of the Plateau account for the east-west trend of this portion of the border.

Glacial striae indicate that the ice advanced southwest from the Hudson-Champlain lobe in northeastern Pennsylvania and south from the Ontario lobe in north-central Pennsylvania.

Drift is thick and nearly continuous in the east and there is an extensive end moraine at the border; west of the Lehigh River, end moraine is local and sporadic, drift in general is thin, and areas of colluvium and residual soils within the border become steadily more extensive toward the west. This varying thickness of drift apparently reflects more intensive glacial activity in the Hudson-Champlain lobe than in the Ontario lobe to the west. The movement of the latter was impeded by high altitudes on the Appalachian Plateau in southwestern New York. Nunataks are absent as far west as Red Rock Mountain at the edge of the Appalachian Plateau north of Benton. Some mountains, such as Mount Yeager, west of White Haven, are judged to have been covered by ice; but from Red Rock Mountain west, several mountains appear to have been surrounded, but not covered, by ice. These judgments are based on nearby firmly established heights of glacial-border materials, and calculated gradients of the ice surface (see page 14). No geomorphic features, such as end moraines on mountain flanks or deep residual soils on summits, remain to confirm this conclusion. Presumably they have been removed by intense frost action.

The glacial border is marked by segments of end moraine and ground moraine on the uplands and by kames in the valleys that cross the border. The authors have distinguished *distinct end moraine* from *indistinct end moraine* on the basis of local relief. Where local relief is on the order of 10 feet (3 m) or more and distinct knobs and swales are readily apparent on the ground and on aerial photographs (Figure 4), the term *distinct end moraine* is used. Where local relief is less than 10 feet (3 m) and not so readily apparent, yet the area contains recognizable knobs and swales (Figure 5) that distinguish it morphologically from neighboring ground moraine, the term *indistinct end moraine* is used. The authors avoid any implication that the indistinct end moraine has been reduced from a formerly more rugged condition. Areas of hummocky ground moraine occur behind the border, are topographically similar to indistinct end moraine, and some are mapped as indistinct end moraine on Plate 1.

Both distinct and indistinct end moraine mark much of the Olean border between the Delaware and Lehigh Rivers; ground moraine is subordinate. A 1- to 2-mile-wide (1.6- to 3.2-km-wide) distinct end moraine lies between Camelback Mountain and the Lehigh River, and is fronted by ground moraine south of Lake Harmony (Plate 1C), where ice flowed through the mountain gap (Blakeslee quadrangle). Either this ground moraine was deposited just prior to building of the end moraine or the gap so hindered ice flow that no end moraine was built at the drift margin. Indistinct end moraine lies between Camelback Mountain and Brodheadsville, and ground moraine forms much of the border east of Bangor.

West of the Lehigh River, ground moraine predominates at the border. Presumably thin ice melted quickly at the margin and the ice front retreated rapidly. Ground moraine marks much of the border east of Fishing Creek from the Appalachian Plateau south to Huntington Mountain. The till thins to a feather edge and is in contact with older tills and residual soils. There is no topographic break between till of the ground moraine and the older materials (Figure 6). Generally the older tills and residual soils are colluviated.

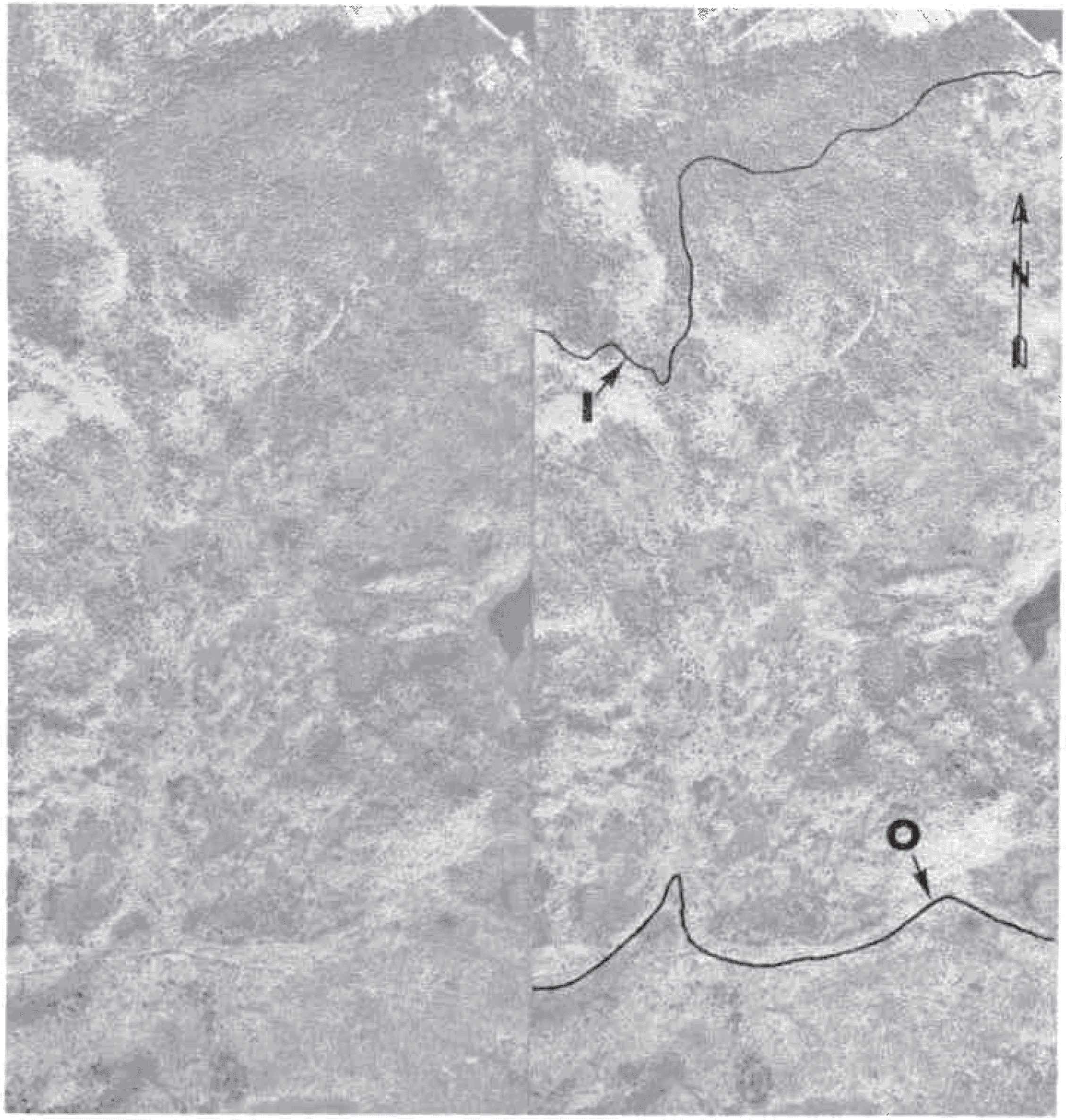

Figure 4. Olean distinct end moraine south of the village of Pocono Lake (see Plate 1C, Pocono Pines quadrangle; the approximate center of the stereogram is at 41°05′00″N/-75°28′00″W). Aerial photographs were taken for the U. S. Geological Survey in April 1963, from 13,500 feet (4,115 m) above mean ground; the scale is approximately 1:25,680. Note the irregular, very hummocky terrain and the numerous undrained depressions; also note the probable ice-push ridges just west of the small lake (Halfmoon Lake) near the right margin of the stereogram. The outer border of the moraine is marked "0"; the inner border is marked "I."

Figure 5. Hummocks and swales in Olean indistinct end moraine on the north side of a road about 0.6 mile (1 km) south-southeast of Franklin Church (Plate 1B, Sonestown quadrangle, 41°16′52″N/76°32′14″W). North Mountain is in background on the right.

End moraine occurs on some north-facing mountain slopes where ice flow was blocked (Figure 7). It also occurs on some south-facing lee slopes (Figure 7) where ice flowed over or around the mountain in sufficient volume to form an end moraine. Distinct end moraine lies on the Allegheny Front at North Mountain and Central Mountain (Plate 1B); indistinct end moraine lies on the north face of Nescopeck Mountain (Plate 1B) and Green Mountain (Plate 1C) west of White Haven.

North of the Woodfordian border, ground moraine lies on gentle slopes, and colluvium, composed of till or bedrock fragments, is present on moderately steep slopes. Till has been removed from the upper parts of steep slopes in the plateau and has accumulated at the base of the slopes. Broad hilltops and gentle slopes retain their till cover.

West of Lycoming Creek, till is even more restricted in distribution, and is generally abundant only in valley bottoms and on adjacent gentle side slopes. Its former presence on hilltops can readily be inferred from the presence of glacially rounded sedimentary erratics and a few crystalline erratics. This restricted distribution of till is ascribed to intense colluviation and removal of thin till from hilltops and hillslopes in an area where altitudes are generally higher than those to the east, and where a colder climate prevailed

Figure 6. The Olean drift border marked by a change from yellow-brown till in the ground moraine in the foreground to red bedrock residuum in the background. The border is not topographically evident; it is marked on the photograph by the dashed line. The view is to the southeast from the south side of a road 0.3 mile (0.5 km) southwest of Asbury (Plate 1B, Mifflinville quadrangle, 41°07′27″N/76°20′30″W). North Mountain forms the skyline on the right.

during deglaciation. Results of intense frost action are more apparent here than in the east. The glacial border is based upon the altitude and position of outcrops of till or occurrences of erratics. The influence of the topography on the ice margin in the plateau is readily apparent.

Kames or kame moraines and associated outwash deposits are usually present where the border crosses the larger stream valleys from the Delaware River to Lycoming Creek. Many small streams also have kames at the border. The only exception in the east is the Lehigh River gorge below White Haven. Here, apparently because of the constriction of the valley, most glacial deposits have been removed by erosion, although some kames are present on the adjacent uplands.

From Loyalsock Creek west to Shinglehouse on Oswayo Creek near the New York border, only small kames occur in valleys draining the glaciated area. Kames east of Galeton and lake deposits west of the town appear to be related to a proglacial lake in the valleys of Pine Creek and its West Branch, which drain toward the glacial border. The paucity of glaciofluvial deposits is probably related to thin ice.

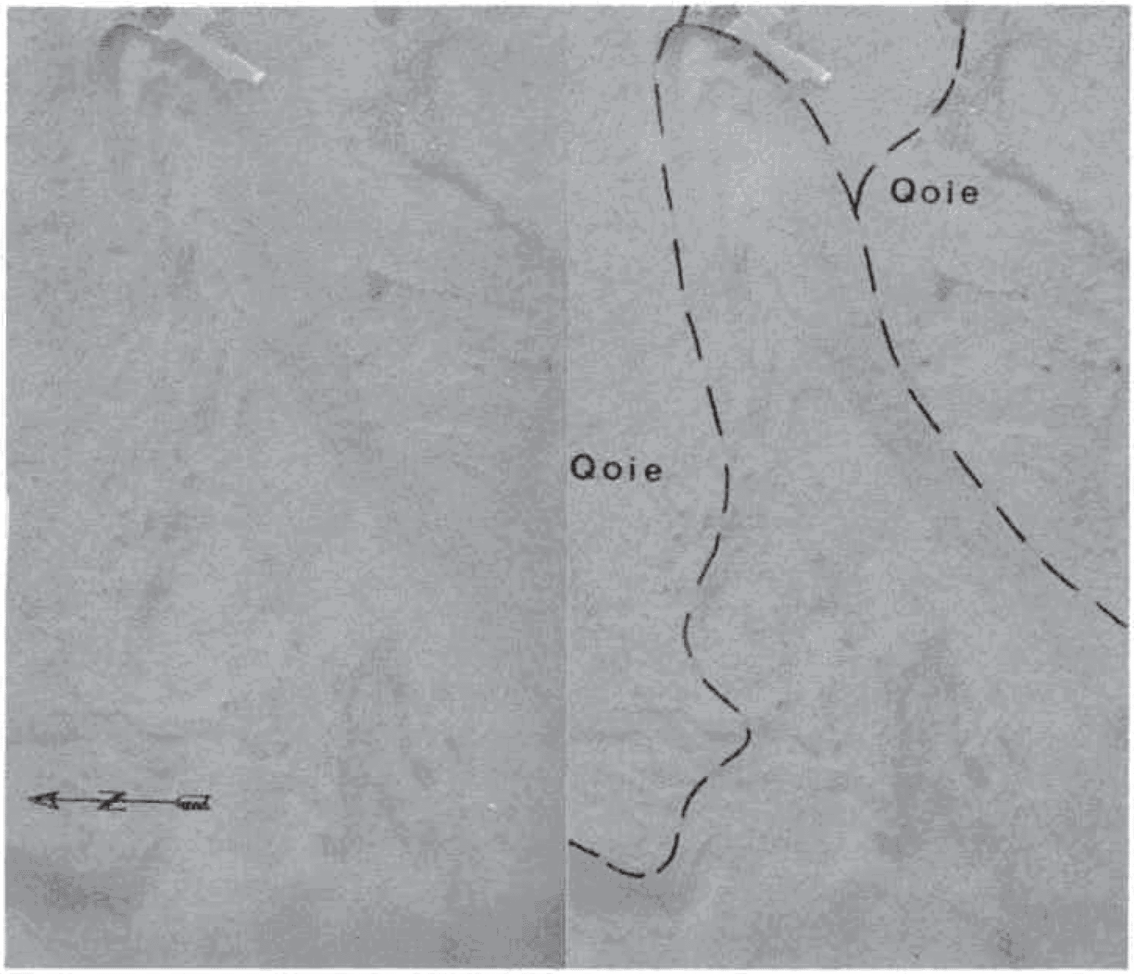

Figure 7. Olean indistinct end moraine southwest of White Haven (Plate 1C, White Haven quadrangle; the approximate center of the stereogram is at 41°02′00″N/75°49′06″W). Aerial photographs were taken for the U. S. Department of Agriculture in May 1959; the scale is approximately 1:19,200. Boundaries of indistinct end moraine (Qoie) are indicated by the dashed lines. Note the moraine ribs parallel to the ice-movement direction in the lower left corner.

THE GRADIENT OF THE ICE SURFACE

Calculations of the gradient of the marginal surface of the continental glacier in eastern North America are rare. In northeastern Pennsylvania, both the edge of ground moraine and stretches of end moraine along mountain fronts nearly parallel to the direction of ice flow provide an opportunity to estimate the gradient of the margin of the ice sheet.

Ice-slope measurements, as indicated by the contact of Olean drift with colluvium on mountain slopes, are necessarily approximate, for errors occur in plotting contacts and in deriving distances and elevations from these plotted contacts. Some of the points have necessarily been chosen arbitrarily. For these reasons measurements are given to the nearest 5 feet per mile (0.9 m/km); they are probably accurate to 25 feet per mile (5 m/km). They may be compared with those of Denny and Lyford (1963) in the Appalachian Plateau and those of Mathews (1972) in the Canadian Cordillera.

The data are summarized in Table 1, which shows the gradients, their locations, and their north- or south-facing aspects. They are tabulated in geographical order from southeast to northwest. The gradient is almost never so high as 300 feet per mile (57 m/km), cited by Denny and Lyford (1963) as a general figure, and seldom as high as 225 feet per mile (43 m/km) on the south-facing side of Allegheny Ridge (Picture Rocks quadrangle). The latter is probably the best measure of ice-margin gradient, for ice flow, as indicated by nearby striae, was approximately parallel to the plateau front.

STRIAE

Numerous striae are recorded in northeastern Pennsylvania in the area of detailed mapping. The smaller number of striae recorded in north-central Pennsylvania reflects less extensive field work and fewer suitable bedrock exposures. However, only striae in the border zone are shown on Plate 1.

Most of the striae range from N-S to S20W; a few have more westerly orientations and probably reflect the influence of local topography. Ice, then, moved south from the Lake Ontario basin and slightly southwest from the Catskill Mountains over northern Pennsylvania, and was diverted by major topographic features (Denny and Lyford, 1963, Plate 3; Sevon and others, 1975, p. 51).

In the Muncy Creek lowland, two striae reflect the influence of local topography in the development of a border lobe. Here, because of the wide break in the Allegheny Front, the ice poured through the gap and spread as a lobe in the lowland to the south. The western striation is nearly parallel to the Allegheny Front, and thus the moraine on that part of the escarpment, as has been noted, may provide the best estimate of the gradient of the ice surface at its margin. On the eastern side, the striation reflects the lobation just southwest of Huckleberry Mountain.

DEPOSITS

TILLS

The Olean till sheet of northeastern Pennsylvania is generally thin, on the order of 10 feet (3 m) or less, but may range to 170 feet (52 m). Locally derived pebbles, more-or-less rounded by glacial abrasion (Figure 8), are

Table 1. *Calculated Gradients of Ice-Marginal Surfaces in Eastern Pennsylvania*

(Kittatinny and Camelback Mountains are located on Plate 1C. All other locations are on Plate 1B.)

Location	Aspect	End moraine	Ground moraine	Gradient ft/mi	Gradient m/km
Kittatinny Mountain	S	X		80	15
Kittatinny Mountain	N		X	165	31
Camelback Mountain	S	X		110	21
Nescopeck Mountain	S	X		80	15
Nescopeck Mountain	N	X	X	80	15
Lee Mountain	S		X	405	77
Lee Mountain	N		X	70	13
Huntington Mountain	S		X	200	38
Huntington Mountain	N		X	195	37
Central Mountain	S	X		405	77
Huckleberry Mtn.-North Mtn.	S	X		90	17
Huckleberry Mtn.-North Mtn.	S		X	120	23
Allegheny Ridge	S	X	X	225	43
Rock Ridge	N		X	70	13
Jacoby-Blessing Mtn.	N		X	100	19

Range of distances measured	0.4–5.6 mi	0.7–9 km
Range of gradients	70–405 ft/mi	13–76 m/km
Median gradient of all slopes	110 ft/mi	21 m/km
Mean gradient of all slopes	165 ft/mi	31 m/km
Mean gradient of north-facing slopes	117 ft/mi	22 m/km
Mean gradient of south-facing slopes	190 ft/mi	36 m/km
"Best" gradient	225 ft/mi	43 m/km

Figure 8. Suite of mixed rounded and angular pebbles typical of till. The scale is 1 foot (30 cm) long. The site is a plowed field on the east side of a road 0.8 mile (1.3 km) north of Pond Creek (Plate 1C, White Haven quadrangle, 41°03′21″N/-75°50′52″W).

abundant in most till, but crystalline erratics are generally absent. Some striated pebbles are present. The authors recognize lateral differences in tills on the basis of color, matrix composition, and pebbles; all of these are dependent upon, and closely related to, the underlying bedrock. Detailed sampling followed by analyses of size and composition over the area of Olean Till may establish the widespread distribution of mappable till facies.

The till sheet may be subdivided into four general facies: (1) a red-brown clay or clay-sand till on, or close to, red beds of the Catskill or Mauch Chunk Formations, (2) a yellow-brown sandy-silt till on drab siltstones and shales such as the Trimmers Rock, Mahantango, and Marcellus Formations, (3) a yellow-brown sand till on gray sandstones of the Pocono Formation and younger rocks in the Pocono Plateau, and (4) a red till on red beds of the Catskill Formation in Potter County, which is similar to (1), but which has a small number of crystalline erratics. These erratics are absent from other tills in northern Pennsylvania. The fine-grained fraction—fine sand, silt, and clay—gives the colors to the tills, and the colors are enhanced by the pebble content of the tills. These results are clearly indicated in Table 2 and are corroborated by similar investigations in northeastern Pennsylvania (Epstein, 1969; Sevon and others, 1975). The yellow-brown tills have a reddish hue where they are in close proximity to red bedrock.

Seventy samples of Olean and older tills were collected in the border zone between White Haven and Benton. Size analyses were performed on the sand, silt, and clay matrix of the till by a modified Bouyoucos (1928) method. Pebbles in the 2- to 10-mm range were examined under a binocular microscope and lithology percentages were estimated as shown in Table 2.

Olean Till on red beds of the Catskill and Mauch Chunk Formations is reddish brown, usually 5YR4/4[1], and ranges from 2.5YR4/4 to 5YR3/3. Figure 9a shows sand-silt-clay ratios for tills on these red beds. The red color and the close grouping of the two sets of samples indicate a high degree of uniformity of tills derived from these formations. Table 2 shows that red fragments from the Catskill and Mauch Chunk Formations predominate in these tills.

Olean Till on the gray Mahantango and Marcellus Formations is generally yellowish brown (10YR5/6), but ranges to reddish brown (5YR4/4) in some cases, apparently from incorporation of nearby red-bed material. This till, as shown in Figure 9b, is more silty and clayey than those on the Catskill and Mauch Chunk Formations. Estimates of pebble lithologies in the till (Table 2) indicate derivation of the till from the underlying bedrock. Figure 9c shows that tills on these different bedrock formations are somewhat different in grain size, but they differ more obviously in color.

Grain-size analyses of Olean, Warrensville (Altonian), and Muncy (Illinoian) tills overlying the Catskill Formation northwest of Berwick in the Mifflinville quadrangle failed to show any differences in grain size of tills of different ages. Differentiation is not obvious in Figure 9d, which shows till composition only. The use of outcrop location and weathering-profile information permits the differentiation shown in Figure 9e. Comparison of Olean Till on gray Devonian shales, Figure 9b, with Altonian tills on Catskill rocks, Figure 9f, shows a corresponding lack of age distinction based on grain size of the matrix.

Grain-size analysis of the till matrix was performed on 39 samples of Olean and older tills collected on the Pocono Plateau east of White Haven. The data are presented elsewhere (Sevon and others, 1975). These data also

[1] Color designations are from Munsell Color Company (1971).

indicate that the various tills cannot be differentiated by grain-size analysis of the till matrix because of the wide range of values.

An attempt to distinguish ages of tills on the basis of their magnetic susceptibilities (Vonder Haar and Johnson, 1973), an indirect measure of the amount of iron-rich minerals in till, was not successful. Susceptibilities of tills range so widely that no valid conclusions could be drawn.

The most satisfactory criteria for distinguishing different ages of tills in northeastern Pennsylvania are differences in soil-profile development and the extent of colluviation. Olean tills are often stony; the A and B soil zones are thin, ranging up to 2 feet (0.6 m) in thickness, and generally have about the same reddish-brown (5YR4/4) or yellowish-brown (10YR5/6) colors as the unweathered till. Warrensville Till has a solum about 5 feet (1.5 m) thick. Its colors range from pinkish gray (5YR6/2) to light reddish brown (2.5YR6/4), a higher chroma than in the B horizon of Olean tills. Warrensville tills are often colluviated, and the flat stones are parallel to the slope, a characteristic not generally associated with Olean Till on low slopes. Muncy tills are characteristically red (2.5YR4/6) streaked with yellow. They have relatively few pebbles and abundant clay, apparently because of greater weathering. Siltstone and shale pebbles are often heavily coated with red clay or iron oxide (rubified), and many sandstone pebbles are weathered red throughout. The tills are strongly colluviated, even on low slopes.

GRAVELS

As noted earlier (p. 13), kames or kame terraces occur most often at the Olean border in south-draining valleys. With the exception of the kame moraine on the Susquehanna River (p. 56), all of the kame gravels are composed of local bedrock fragments. The pebbles and cobbles are generally rounded to subrounded (Figure 10). Sorting is usually poor, but there are local segregations of sand and gravel. Only in the gravel pits along the Susquehanna River at Nescopeck, and in a borrow pit along Interstate Route 380 north of Camelback Mountain, are crystalline erratics at all noticeable.

DRIFT SOUTH OF THE OLEAN BORDER

Colluvium mantles most of the slopes south of the Olean drift border, and remnants of the older drift sheets are present in many places. Many of these older drift remnants have been mixed with bedrock colluvium by downslope movement, thus increasing the difficulty of identifying the drift.

Close to the Olean border, and east of the Lehigh River where quadrangle mapping is extensive, outcrops of older drifts are generalized on Plate 1 from published information. West of the Lehigh River and south of the Olean border, no attempt was made to map either deposits of Warrensville and Muncy drifts or the extent of the colluvium. The location of drift

Table 2. *Till Pebble (2–10 mm Size Range) Analyses of Olean Tills in Northeastern Pennsylvania Between White Haven and Benton*

Probable bedrock source	Pebble lithologies	1	2	3	5	10	11	12	14	13	25	26	18	23	58	59	60	61	4**
Ppv	Ss, gy, mg, fg	5*	5																20
Ppv	Ss, gy, mg			3	20	35	40	35	5			3							
Ppv	Qtz, wt							10			2	2							
Ppv	Ss, gy, cg										3								
Mmc	Ss, rd, vfg to fg, mic, shy	95	85			30	40	20	40										80
Mmc	Ss and slst, rd, fg			90	60														
Mp	Ss, yllw-gy, vfg, mic		10																
Mp	Ss and slst, yllw-gy			7															
Mp	Slst and sh, yllw-gy				20		20												
Mp	Ss, gy, bwn, fg to mg					35													
Dck	Ss, gy, fg to mg									10									
Dck	Ss, rd, gy, fg									70									
Dck	Ss, rd, vfg to fg										60	40			5				
Dck	Slst, rd									20		40							
Dck	Ss, gy, gy-gn, cm, vfg to fg														65				
Dm	Slst, gy, cm								20					90	30		30		
Dm	Slst, cm												20						
Dm	Slst, gy, cm, ol-yllw															18			

Probable bedrock source: Indeterminate	Ss, gy, fg to mg	Probably Devonian, Dm, Dck							20	35			15	60	5					
	Slst, gy								15			5								
	Ss, gy-rd, fg											30								
	Ss, rd, fg to mg													5	5		5			
	Ss, cm													15						
	Ss, gy, cm, ol-gy, vfg to fg																77		85	
	Ss, gy, yllw, vfg to fg																	70		
	Slst, gy, cm, ol-yllw																		15	
Color			5 YR 3/3	5 YR 4/6	5 YR 3/3	5 YR 4/4	5 YR 5/4	5 YR 4/4	5 YR 4/6	5 YR 4/4	5 YR 4/4	5 YR 4/4	5 YR 4/4	5 YR 5/3	10 YR 5/6	7.5 YR 5/4	10 YR 5/6	10 YR 6/6	10 YR 5/6	5 YR 6/4
Underlying bedrock			Mmc	Mmc	Mmc	Mmc	Mmc	Mmc	Mmc	Dm	Dck	Dck	Dck	Dm	Dm	Dm	Dm	Dm	Dm	Dm

*Percent **Altonian till

Abbreviations: Probable bedrock source: Ppv, Pottsville Formation; Mmc, Mauch Chunk Formation; Mp, Pocono Formation; Dck, Catskill Formation; Dm, Marcellus, Mahantango, and Trimmers Rock Formations. Pebble lithologies: bwn—brown; cg—coarse grained; cm—cream; fd—feldspathic; fg—fine grained; gn—green; gy—gray; mg—medium grained; mic—micaceous; ol—olive; qtz—quartz; rd—red; sh—shale; shy— shaly; slst—siltstone; ss—sandstone; vfg—very fine grained; wt—white; yllw—yellow.

Dashed lines indicate approximate divisions into types of tills dependent upon lithology of underlying bedrock.

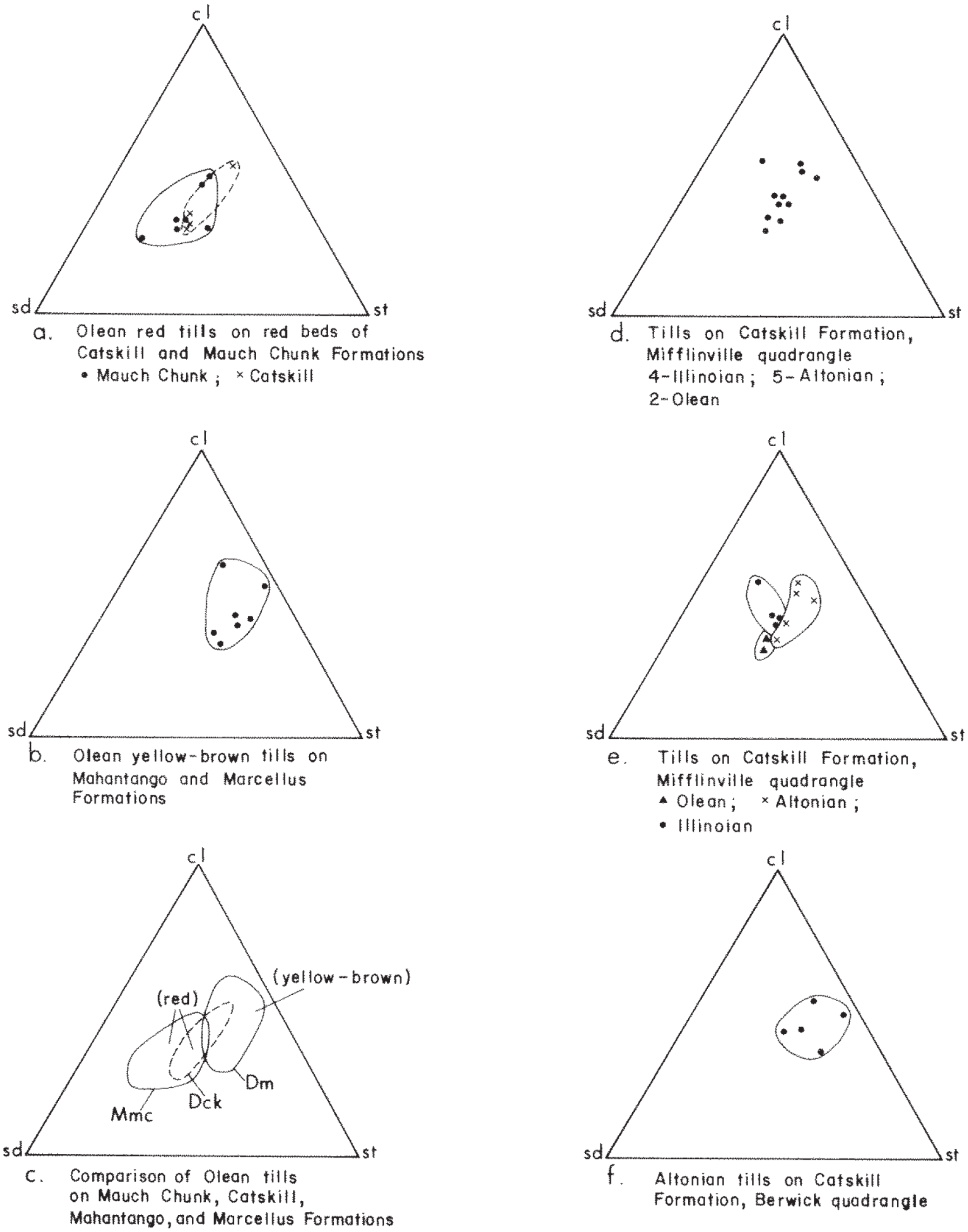

Figure 9. Grain-size analyses of tills in northeastern Pennsylvania between White Haven and Benton. sd—sand; st—silt; cl—clay.

materials has been plotted on the map wherever observed, but the extent of the materials is unknown. Mapping of the older drifts remains to be done in most of the area east of the Salamanca reentrant and west of the Lehigh River, for Leverett's map (1934) is now inadequate. Marchand (1978) has greatly expanded the known area of pre-Wisconsinan drifts in the Susquehanna River basin south of Williamsport.

Figure 10. Sand and gravel in variably sorted beds typical of kame and kame-terrace deposits. The scale is divided into feet (30-cm intervals). The site is in a quarry of A. Barletta and Sons, Honeyhole Sand and Gravel Company, on the south bank of the Susquehanna River, 2 miles (3.2 km) east of Nescopeck (Plate 1B, Berwick quadrangle, 41°03′40″N/76°10′42″W).

The following comments summarize what is now known about the scattered outcrops of older drifts west of the Lehigh River.

The southeastern part of Blessing Mountain north of Williamsport and the adjacent part of Jacoby Mountain, east of Wallis Run, have a remnant cover of Warrensville Till. Warrensville drift is widespread in the hilly area south of Allegheny Ridge, north of Montoursville, and west of the Olean border near Huntersville. Muncy drift occurs east of Williamsport along the

Susquehanna River and Muncy Creek (Bucek, 1975; Wells and Bucek, in press). Olean and Muncy terraces flank Loyalsock and Muncy Creeks south of the border.

Outcrops of Muncy and Warrensville drifts are widely scattered in front of the border from Muncy Creek east to the Lehigh River. There may be a till older than the Muncy Till in the hilly region southwest of Lairdsville, where one exposure (41°13′22″N/76°35′55″W) shows a deeply weathered gray till completely unlike other exposures of Muncy Till in the district. In the vicinity of Drums and St. Johns (Sybertsville quadrangle), large erratic boulders are scattered widely over a 2- to 3-square-mile (3- to 5-km^2) area in front of the Olean border. No drift was found, and these erratics are presumably the only remnants of an older drift.

North and east of Weatherly, Warrensville drift occurs discontinuously over several square miles (Sevon and others, 1975). Unweathered kame sands are beneath the Warrensville Till at the Drumbor gravel pit 1.5 miles (2.4 km) east of Weatherly. Unweathered Muncy till and sands were exposed in 1975 in deep highway excavations east of Montoursville (Bucek, 1975; Wells and Bucek, in press).

SLOPE DEPOSITS

Most of northern Pennsylvania is hilly or mountainous, and downslope movement of surficial debris has been widespread in the past, presumably during late glacial episodes when freeze-thaw activity was more intense. Current mass movements seem to be related either to catastrophic events such as Hurricane Agnes in 1972, which caused numerous landslips and mud flows, or to local disturbances such as roadcuts in the toes of slopes. Within the area of Olean drift, slope movement is important only on steep slopes. Older drifts are more strongly colluviated, even on gentle slopes.

The colluvial mantle is most easily recognized in outcrop by the alignment of flat bedrock fragments nearly parallel to the slope (Figure 11), and some exposures show crude stratification. The amount of coarse fragmental material in the colluvium is a function of its availability in the bedrock. Well-jointed siltstones and thin-bedded well-jointed sandstones provide the most abundant and easily recognized colluvium.

In many cases it is difficult to distinguish colluviated residual soils from colluviated old tills. In plowed fields, an abundance of angular fragments (Figure 12) and the absence of partially rounded stones or erratics is evidence for colluvium rather than till. In roadcuts, fabric is the best criterion—an irregular arrangement of stones indicates till; an arrangement parallel to the slope indicates colluvium.

An abundance of colluvium, termed shale-chip rubble, has formed from the thin-bedded and well-cleaved Mahantango shale because it is highly susceptible to frost action (Figure 13). Characteristically, the fragments are 1/2

Figure 11. Flat fragments of siltstone and sandstone aligned parallel to the slope in colluvial deposits 1.7 miles (2.7 km) south of Salladasburg along a small road on the east side of Larrys Creek (41°15′11″N/77°13′30″W). The pick is 17 inches (43 cm) long.

x 1 x 1 inch (1 x 2.5 x 2.5 cm) in size, and may range to 6 inches (15 cm) in the largest dimension. Shale-chip rubble is rarely interbedded with glaciofluvial gravels, as at the base of shale cliffs in the Delaware Valley (Crowl, 1971). This colluvium is easily susceptible to frost churning, so that whorls and plumes are often visible in artificial cuts in debris older than Woodfordian.

Boulder colluvium (Figure 14) is a thin surface deposit of boulders set in a soil matrix. The boulders are principally of sandstone or conglomerate, range up to a few feet (1 meter) in diameter, and may or may not have point contact with adjacent boulders. The deposits occur mainly on moderate slopes. Boulder colluvium is abundant on most slopes within 2 miles (3 to 4 km) beyond the Olean border in areas underlain by sandstone.

Many boulder-colluvium deposits are transitional downslope into boulder fields, which are flat surfaced, unvegetated boulder accumulations at moderate to low gradients, lacking matrix except at depths of several feet. Hickory Run Boulder Field (Figure 15) in Hickory Run State Park (Plate 1C) displays many typical features such as distinct surface morphology, fabric, polished boulders, fitted surfaces, stone rings, and lithology

Figure 12. Angular fragments typical of bedrock residuum derived from shales of the Mahantango Formation. The scale is 1 foot (30 cm) long. The site is a plowed field on the north side of a road 1 mile (1.6 km) southwest of Brodheadsville (Plate 1C, Brodheadsville quadrangle, 40°54′39″N/75°24′26″W).

streams. This field has been described in detail elsewhere (Smith, 1953; Sevon, 1969; Sevon and others, 1975).

Colluvium is more abundant at the base of hillslopes than on the almost bare upper slopes because it has moved downslope by surface wash, creep, and periglacial frost action. This is particularly true at the higher elevations of the Appalachian Plateau or at lower elevations close to the Olean boundary. Sometimes small valleys are floored with a pebbly mixture of alluvium and colluvium derived from bedrock and old till. These valley floors are nearly flat (Figure 16), and drainage is either subsurface or by small ephemeral streams. The depth of fill is unknown, but is probably less than 35 feet (10 m).

Earthflows are fairly common in the hills southeast of Lairdsville (Plate 1B). Here Muncy till and residual soils on Devonian shales apparently moved downslope during the Wisconsinan episodes of rigorous climate, for there is no indication of present-day movement.

Direct evidence of periglacial frost action is sparse. In addition to frost

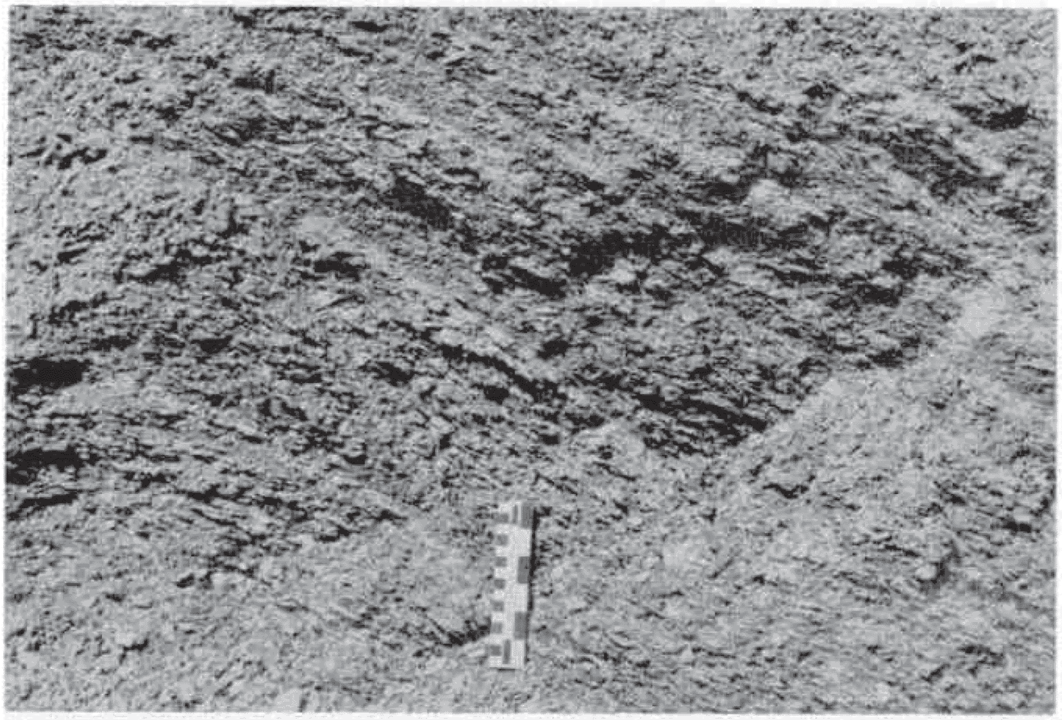

Figure 13. Shale-chip rubble (colluvium) composed of fragments derived from shales of the Mahantango Formation. The site is in a borrow pit on the west side of U. S. Route 209, 3 miles (4.8 km) southwest of Dingmans Falls in the Delaware River valley (Lake Maskenozha quadrangle, 41°10'54"N/-74°53'35"W). Note the alignment of flat fragments parallel to bedding. Bedding parallels the slope of the surface of the deposit. The scale is 6 inches (15 cm) long.

whorls in Mahantango debris described above, rare stone polygons and stone stripes occur (Figure 17). Connally (Crowl and others, 1975) has found frost wedges in Muncy till and residual soil at the border of Olean Till in the Bangor quadrangle. These various features have been identified at a number of places at high altitudes far beyond the glacial border in Pennsylvania (Edmunds and Berg, 1971, p. 61), and they occur to the southwest in Virginia and West Virginia (Clark, 1968; Ciolkosz and others, 1971; Clark and Ciolkosz, unpublished data). These features are probably more common than realized, but are seldom seen because their discovery is dependent upon chance exposures, generally in temporary excavations.

THE WOODFORDIAN AGE OF THE BORDER

As noted earlier, the age of the border deposits is in dispute. On the east side of the Salamanca reentrant in New York, the Olean drift is regarded as

Figure 14. A slope covered with boulder colluvium composed of angular plates and blocks of sandstone derived from outcrops upslope. Boulder colluvium overlies till deposited near the Olean drift border. Colluvium was developed after deglaciation while climatic conditions were severe. The site is on the north side of a road 1.9 miles (3 km) northwest of Emmons in an unnamed tributary to Painter Run (Plate 1B, Elk Grove quadrangle, 41°19′43″N/76°27′43″W).

Altonian (middle Wisconsinan) in age (Muller, 1977a). Where the border crosses the Delaware River near Belvidere, New Jersey, it is regarded as Woodfordian (late Wisconsinan) in age. The Altonian age assignment implies deglaciation prior to 28,000 y a (years ago) (Figure 3); the Woodfordian age assignment implies deglaciation about 15,000 y a. The border changes character from the Delaware Valley to Salamanca, New York, gradually losing its morainal attributes, and becoming less distinct toward the west. The authors found no place where a young drift border departs from the Olean boundary and trends more directly north into New York.

Figure 15. Hickory Run Boulder Field, a registered natural landmark, in Hickory Run State Park (Plate 1C, Hickory Run quadrangle, 41°03′00″N/75°38′40″W). The surface is relatively flat, having relief generally less than 2 feet (0.6 m), and slopes about 1 degree toward the viewer. The view is toward the east up the field. The most distant trees to the left of center are about 2,000 feet (610 m) from the viewer.

Therefore, the Olean border is regarded as being of the same age throughout. As already noted, end moraines and thin weathering profiles on the Olean drift support the interpretation that it is of Woodfordian age. These soil profiles are less well developed than those on older Warrensville and Muncy drifts south of the Olean border.

RADIOCARBON AGES

The above interpretation of a Woodfordian age for the Olean drift is enhanced by 12 radiocarbon dates from the lowest and oldest organic-rich sediments in glaciofluvial deposits and in kettles in end moraine and ground

Figure 16. A small colluviated dry valley on the south side of a road 2.4 miles (3.8 km) west-southwest of Brookland (Plate 1A, Brookland quadrangle, 41°49′02″N/77°50′32″W). Fill in the broad, flat part of the valley resulted mainly from movement of material off the side slopes. The valley is 1 mile (1.6 km) from the Olean drift border and thus is in an area where the periglacial climate would have been severe during the Woodfordian ice maximum. All material in the treeless area probably is colluvium.

moraine near the border. These all give minimum dates for time of deglaciation within the border zone. Three samples from bogs formed by periglacial frost action in southeastern Pennsylvania furnish additional information. Their locations, and others (all identified to the nearest 0.1 thousand years), are plotted in Figure 2 and the data are tabulated in Table 3.

Four of the dates in the lowland northeast of Brodheadsville range from 12,520 y a to 13,330 y a and average 13,000 y a. These dated samples are from basal organic sediments in shallow kettles in the open country north of Kittatinny Mountain, and the surfaces of these lakes and bogs are only a few meters below the general land surface. The fifth dated sample, at Wigwam Run (11.4 on Figure 2), is in a much deeper kettle, 48 feet (15 m) from the rim to the bog surface, and the relatively young date there may be ascribed to late melting of an unusually thick body of ice in the deep kettle.

Figure 17. A cross section of a stone stripe on the north side of Pa. Route 93 on the south slope of Nescopeck Mountain about 0.6 mile (1 km) northwest of the interchange with Interstate Route 80 (Plate 1B, Sybertsville quadrangle, 41°01′52″N/-76°05′22″W). The scale is divided into feet (30-cm intervals).

Saddle Bog (12.3) at 1,361 feet (415 m) on Kittatinny Mountain, New Jersey, is about 853 feet (260 m) above the sites in the adjacent lowland, yet organic sediment began to accumulate in the mountaintop bog slightly later than in the lowland bogs to the southwest, perhaps because of severity of climate and/or poor nutrient status of the water.

Northwest along the border, at Sausser Bog (12.7), the date of basal organic sediments is in the same time range as those to the southeast. The ages of samples from Rose Lake (14.2) and Corry (14.0), on either side of the Salamanca reentrant, are somewhat older.

All of these dates, except that for the sample from Brodheadsville (discussed below), record the beginning of organic sedimentation at their sites, and thus give a minimum date for deglaciation of the border. Estimates of the time interval between melting of the ice in a kettle and the beginning of organic sedimentation vary widely. Studies indicate that the interval may range from a few hundred years (Dreimanis, personal communication, 1978), to about 2,000 years (Mickelson, 1968; Florin and Wright, 1969), to about 4,000 years (Spear and Miller, 1976), and to about 6,000 years (Sirkin, 1977; Sirkin and Minard, 1972). This last figure is based on calculated rates of sedimentation by Davis (1969) and Davis and Deevey

Table 3. *Radiocarbon Dates from Organic Material Associated with the Olean Boundary and Other Relevant Locations*

(Locations are shown on Figure 2 and dates there are given to the nearest 0.1 thousand years.)

Map number (Figure 2) and laboratory sample number	Name, location, and description	Years ago
12.3 (W-2562)	Saddle Bog, 41°14′08″N/74°42′10″W. Kittatinny Mountain, New Jersey, Branchville quadrangle. In a spruce zone having 2 m of clay beneath, containing tundra herb pollen (Sirkin and Minard, 1972).	12,300 ± 300
13.2 (OWU-430)	Echo Lake, 41°04′09″N/75°03′42″W. 5.4 km southwest of Bushkill, Pennsylvania, Bushkill quadrangle. Silty clay gyttja at the base of an organic section overlying lake clay.	13,235 ± 1,620
12.5 a (OWU-415)	Leaps Bog, 41°02′50″N/75°06′42″W. A small pond at Oak Grove 10.6 km southwest of Bushkill, Pennsylvania, Bushkill quadrangle. Decomposed woody peat (detrital gyttja) at a basal clay contact. The sample was small, and the date may not be entirely reliable, but it fits with others.	12,520 ± 825
12.9 (W-3374)	Franklin Hill Bog, 41°01′00″N/-75°09′00″W. 2.5 km northeast of East Stroudsburg, Pennsylvania, East Stroudsburg quadrangle. Base of gel mud (Vic Carbone, personal communication, 1977).	12,900 ± 300
13.3 (WIS-781)	Cranberry Bog, 41°02′30″N/75°16′00″W. 3.5 km east of Tannersville, Pennsylvania, Mount Pocono quadrangle. Silty gyttja at 1,240–1,245 cm. Over 115 cm of silt and sandy silt that contains tundra pollen (H. E. Wright, personal communication, 1975).	13,330 ± 120
11.4 (W-2893)	Wigwam Run (WC#1 Delaware Valley), 40°59′03″N/75°15′15″W. 5 km west of Stroudsburg, Pennsylvania, Saylorsburg quadrangle. Peat, base of organic-rich sediments at 515–525 cm in A3 (spruce park tundra) zone 1 m above a herb zone (L. E. Sirkin, personal communication, 1975; Connally and others, 1979).	11,430 ± 300

Table 3. *(Continued)*

Map number (Figure 2) and laboratory sample number	Name, location, and description	Years ago
12.8 (SI-1341)	Brodheadsville, 40°54′54″N/-75°24′25″W. Pipeline excavation, 1.1 km southwest of Brodheadsville, Pennsylvania, Brodheadsville quadrangle. Fragmental organic material in lake clay overlain by silts and meltwater-washed shale-chip gravel in the front of the end moraine (Berg, 1975).	12,760 ± 135
12.7 (SI-1559)	Sausser Bog, 41°23′09″N/76°50′54″W. In Loyalsock Creek Valley 3 km west of Barbours, Pennsylvania, Barbours quadrangle. Clay gyttja at the bottom of a bog in kame moraine.	12,750 ± 100
14.2 (SI-3098)	Rose Lake, 41°53′50″N/77°55′15″W. 1.4 km west of Andrews Settlement, Pennsylvania, Ellisburg quadrangle. Green clayey gyttja, 1,273–1,298 cm, at the base of the core. Pine, spruce, and birch pollen, and a fragment of spruce.	14,170 ± 240
12.6 (WIS-727)	Belmont Bog, 42°15′N/77°55′W. 6.1 km east of Belmont, in Phillips Creek Valley, New York, West Almond quadrangle. Base of the spruce maximum in gyttja and clayey gyttja above 2.2 m of clay (Spear and Miller, 1976).	12,565 ± 115
14.0 (W-365)	Corry Pond, 41°55′30″N/79°40′00″W. 1 km west of Corry, Pennsylvania, Corry quadrangle. Bottom of a 1-m layer of marl below 3 m of peat. Abundant fossils. Clay and gravel beneath (Droste and others, 1959).	14,000 ± 350
13.6 (Y-478) (Y-479)	The Marsh, 40°07′30″N/75°45′28″W. 2 km southeast of Marsh, Pennsylvania, Elverson quadrangle. Full glacial herb zone, taiga-tundra (Martin, 1958).	13,540 ± 270 13,630 ± 230
12.5 b (WIS-780)	Longswamp, 40°29′N/75°40′W. Just north of Longsdale, Pennsylvania, Manatawny quadrangle. In a small pond, at the base of the spruce zone and the top of the tundra zone at 1 m; there is a 1.8-m tundra zone in clay beneath dated mud (H. E. Wright, personal communication, 1977).	12,540 ± 120

Table 3. *(Continued)*

Map number (Figure 2) and laboratory sample number	Name, location, and description	Years ago
15.2 (WIS-903)	Criders Pond, 39°58′N/75°40′W. About 3 km east of Scotland, Pennsylvania, Scotland quadrangle. Base of the principal spruce zone (H. E. Wright, personal communication, 1977).	15,210 ± 150
15.3 (I-5713)	South Dansville, 42°29′44″N/77°38′39″W. 2.9 km north-northeast of South Dansville, New York, Arkport quadrangle. At base of 40 cm of sphagnum peat overlain by 220 cm of clay and marly clay (Rynders, 1971).	15,300 ± 190

(1964). Sirkin (1977) and Connally and others (1979), using a basal organic sediment date of 11,430 y a and 2.15 m (7 ft) of inorganic sediment below the dated horizon, estimated an age of 17,430 y a for the beginning of inorganic sedimentation at the Wigwam Run site (11.4). The estimate is based on a sediment accumulation rate of 0.036 cm/yr (0.014 in./yr) (Davis and Deevey, 1964). Sirkin and Minard (1972), using the same figure, estimated a maximum age of 18,000 y a for disappearance of ice at Saddle Bog on Kittatinny Mountain. Using another sedimentation rate (0.08 cm/yr, or 0.032 in./yr) developed by Davis (1969), they estimated that ice could have disappeared from Saddle Bog as late as 15,000 y a.

The above sedimentation rates are derived from Rogers Lake, Connecticut, a lake having two basins, each about 1,640 feet (500 m) in diameter and about 115 feet (35 m) deep. The lake lies in open, rolling country comparable to that north of Kittatinny Mountain. Because the area of each Rogers Lake basin is about 25 times the areas of Wigwam Run and Saddle Bog kettles, sedimentation rates in Rogers Lake can hardly be comparable to those in these small depressions. Thus the age estimates of 17,000 and 18,000 y a for ice disappearance based on data from these small kettles is questionable.

The age at Brodheadsville (12.8) is from gymnosperm wood fragments, probably spruce (G. W. Burns, personal communication, 1972), in lake clays overlain by silts and shale-chip gravel immediately in front of the end moraine. Berg (1975, Plate 2, cross section) shows this shale-chip gravel as colluvium. However, reexamination of the original field notes indicates clearly that the material is meltwater-washed shale-chip gravel and that a mistake was made in editing the drawing. The anastomosing drainage pattern on the outwash plain is shown in Figure 18. The stratigraphy indi-

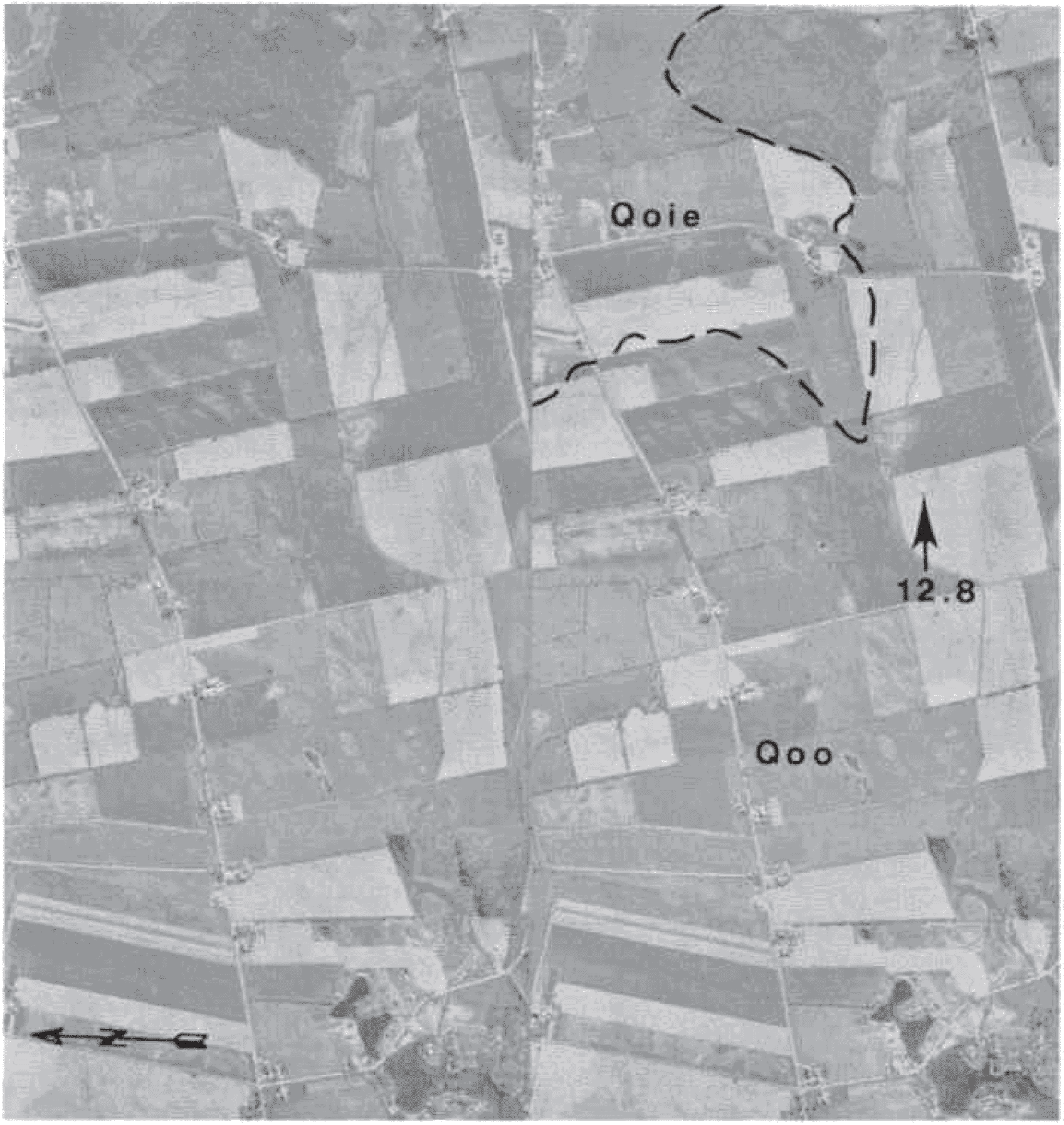

Figure 18. Olean indistinct end moraine and outwash plain at Brodheadsville (Plate 1C, Brodheadsville quadrangle; the approximate center of the stereogram is at 40°55′02″N/-75°24′30″W). The boundary between indistinct end moraine (Qoie) and the outwash plain (Qoo) is marked by the dashed line. The arrow indicates the site of a radiocarbon date of 12.8 thousand y a. The anastomosing drainage pattern on the outwash plain is well shown in the dark field immediately west of the end-moraine boundary.

cates deposition of abundant meltwater sediments just in front of the end moraine while spruce trees became established in the region. The spruce fragments in proglacial-lake sediments have nearly the same age as autochthonous organic sediments in kettle holes within the border. This close age relationship indicates that organic sedimentation probably began very shortly after disappearance of ice from kettles and that deposition of basal clay is more rapid than has been supposed by some authors (Sirkin, 1977; Sirkin and Minard, 1972).

Neglecting the clearly young age of organic sediment at Wigwam Run (11.4) in a very deep kettle hole, all the dates along the border range from 12,520 y a to 14,170 y a and have a time span of 1,650 years. This time span seems reasonable for nine dates along a 185-mile (300-km) length of the border, for the melting rate and volume of ice along the glacier front need not be uniform over its entire length. The scatter of ages of organic sediments in lowland sites, whose altitudes range from 492 feet (150 m) to 2,132 feet (650 m), indicates the possibility of stagnation and downmelting along the border as well as retreat of an active ice margin.

The dates in the Stroudsburg lowland, and those to the northwest, are younger than two dates from basal organic materials from bogs in New Jersey south of Kittatinny Mountain. One, 14,720 ± 260 y a (I-4162), is located at Glovers Pond, and the other, 19,340 y a (Gx-4279), on Jenny Jump Mountain (D. H. Cadwell, personal communication, 1979). The annual temperature at Stroudsburg is now about 1 °C cooler than in the Allentown-Bethlehem area south of Kittatinny Mountain (U. S. Department of Commerce, 1964). A comparable difference in climate during the late Wisconsinan may have led to earlier melting south of the mountain barrier.

The ages of two bog-bottom organic samples in New York (Figure 2), from sites 18 miles (30 km) and more within the border, warrant comment. The date at Belmont (12.6) was obtained from basal organic material above 2.7 m (8.9 ft) of clay in a kettle in a kame terrace in the Olean drift. Spear and Miller (1976), using a calculated sedimentation rate of 0.062 cm/yr (0.02 in./yr) determined from the lower part of the core, estimated that sedimentation began about 16,400 y a. They recognized the discrepancy between the age assigned to the Olean drift and the age of the core, but did not deal with the problem that Olean drift may be Woodfordian, and not Altonian, in age.

Although the South Dansville, New York, site (15.3), which has a date of 15,300 ± 190 y a, is possibly the most serious evidence against a 15,000 y a age for the Wisconsinan border in Pennsylvania, it is not compelling. The site lies within the Arkport moraine a few miles south of the Valley Heads moraine. A stratigraphic section, adapted from Rynders (1971), follows:

0–68 inches (0–170 cm)	Clay, loam, in part marly.
68–88 inches (170–220 cm)	Gray clay mixed with sedge peat (above) and sphagnum peat (below).
88–104 inches (220–260 cm)	Sphagnum peat.
100–104 inches (250–260 cm)	^{14}C date 15,300 ± 190 y a (I-5713).
104–124 inches (260–310 cm)	Blue-gray clay, marly, peaty in upper part.

The occurrence of dated peat between marly layers raises the possibility that the peat is contaminated by carbon derived from old carbonates rather than mainly from atmospheric CO_2, and thus gives a "too old" date. Ogden (1966) subtracted 980 years from radiocarbon dates at Silver Lake, Ohio, to arrive at true dates from a marly environment, and demonstrated "marl effects" of 1,200 years (J. G. Ogden, personal communication, 1979).

The ages of three samples from southeastern Pennsylvania, well beyond the glacial border, supply additional information. At Longswamp (12.5b), near Allentown, peat overlies 1.7 m (5.6 ft) of inorganic sediment on limestone of the Conococheague Group. The spruce zone is dated 12,540 ± 120 y a (H. E. Wright, personal communication, 1977). The Marsh (13.6) lies on Precambrian gneiss and quartzite, and the herb zone, representing taiga-tundra, is dated 13,540 ± 270 y a, and has an older, less reliable date (13,630 y a) below it (Martin, 1958). At Criders Pond (15.2) on the west flank of South Mountain, peat lies on 1 m (3.3 ft) of inorganic sediment containing spruce and tundra pollen. The principal spruce zone in the peat is dated 15,210 ± 150 y a (H. E. Wright, personal communication, 1977). The time span for these three dates beyond the border is 2,670 years, and the 1,650-year span of dates along the border is within that time. Bricker and Moss (1958) ascribe the origin of The Marsh to blockage by mass wasting and alluviation. Inspection of aerial photographs shows sinkholes in the vicinity of Longswamp and also clearly indicates abundant mass wasting on the flank of South Mountain at Criders Pond. The most logical time for abundant mass wasting in this region, and the consequent plugging of sinkholes and formation of other surface depressions, is during the height of the last glaciation. Presumably this mass wasting ceased as the climate warmed and forest vegetation became established. Because there were no ice blocks in those depressions, organic accumulation began as soon as mass movement ceased and the ground became stable.

In Ohio, three late Wisconsinan tills, and at least twelve end moraines deposited between 18,000 and 14,000 y a, indicate a complex Woodfordian history (Goldthwait and others, 1965). The Kent (Navarre) drift is overlain successively by the Lavery and Hiram drifts. At Fairlawn, northwest of Akron, Ohio, wood from a depression at the margin of the Hiram ice (G. W. White, personal communication, 1977) is dated 12,695 ± 600 y a (M 1971) (Teeter, 1970). Near Lodi, Ohio, at the Quillin site, basal organic material on Navarre (Kent) sand is dated 14,500 ± 150 y a (ISGS–402). According to Totten (1976; personal communication, 1978), the ice block did not melt until after the Hiram till was deposited over the sand. However, Hiram ice may have reoccupied this Navarre kettle as did the Lavery ice at Corry.

At Corry (14.0), on the west side of the Salamanca reentrant, an age of 14,300 ± 350 y a was obtained from organic sediments in a kettle in thin Lavery till on Kent till where Lavery ice reoccupied a kettle in Kent drift

(White and others, 1969; White, personal communication, 1977). The age corresponds closely to the age at Rose Lake (14.2), a kettle lake on the east side of the reentrant, and may indicate contemporaneous melting on both sides of the reentrant. The Ohio dates are minimum dates for widespread melting there, and they span the dates on either side of the Salamanca reentrant.

In the northeastern United States, Wisconsinan ice retreated from the Maine coast about 13,500 y a (Borns and Calkin, 1977) and was present on Martha's Vineyard probably 13,000 to 14,000 y a (Kaye, 1964). This latter estimate is based on two dates: (1) 15,300 y a in clays probably overlain by till (Kaye, 1964), and (2) 12,700 y a in postglacial peat (Ogden, 1963). These dates imply a glacial retreat prior to 15,300 y a and a readvance prior to 12,700 y a. The localities are part of the Nantucket, Martha's Vineyard, and Ronkonkoma, Long Island, moraine line (Flint, 1971). Sirkin (Sirkin, 1971; Sirkin and others, 1970), on the basis of a date of 16,700 y a in an extraglacial bog close to the Delaware River, New Jersey, inferred that the Ronkonkoma and Harbor Hill moraines were emplaced prior to 17,000 y a, but did not comment on the retreat of ice from the moraine. Newman (1977) reported till in the Elmhurst moraine, north of the Harbor Hill moraine, overlying peat dated 13,470 y a. This may indicate a last advance of ice just prior to the main retreat.

Preponderant evidence indicates that the Olean border in northern Pennsylvania is Woodfordian in age as indicated by the drifts, the soils, and the radiocarbon dates.

The marginal ice began to downmelt and retreat about 15,000 y a during the Erie Interstade (Figure 3). The proposed date of melting is much younger than the date of 17,000 to 18,000 y a (Sirkin, 1977; Sirkin and Minard, 1972) that is usually given. The proposed date of deglaciation does not accord well with some dates in the Ontario basin (Calkin and Miller, 1977; Muller, 1977b) nor with dates of Valley Heads deglaciation about 14,000 y a; for example, Valley Heads outwash on the Chemung River at the New York-Pennsylvania line is dated 13,320 ± 200 y a (Coates and others, 1971). Bog- and lake-bottom organic-sediment dates along the Woodfordian border range from 12,520 to 14,170 y a and are minimum ages for deglaciation. They lie within the time span of dates from sites affected by frost action in southeastern Pennsylvania. Stagnant ice probably survived as late as 12,760 y a and supplied outwash materials at Brodheadsville. The dates within and beyond the border favor a short time span between melting of ice and the beginning of organic sedimentation.

These dates for ice retreat accord well with those from Long Island and New England on the east and with those from northwestern Pennsylvania and Ohio.

ECONOMIC GEOLOGY

INTRODUCTION

This report has economic significance in two specific areas. First, the map (Plate 1) delineates glacial deposits associated with the border, some of which have economic importance. These deposits are briefly discussed below. Second, the border shown on the map defines regions where exploration for glacially associated economic deposits should occur. With the exception of outwash, economic deposits associated with Woodfordian glaciation—sand and gravel, peat, clay, and till for random fill—occur only north of (behind) the glacial border. The various products are discussed in order of their current economic importance.

SAND AND GRAVEL

Sand and gravel is the most important economic material deposited by the Woodfordian glaciation. In 1978, 19,000,000 short tons of sand and gravel valued at $54,000,000 was produced in Pennsylvania in 42 counties (U. S. Department of Interior, 1979). It is not known how much sand and gravel is produced from Woodfordian glacial deposits in northern Pennsylvania, but the presence of several large quarrying operations suggests a significant amount. Any attempt to utilize deposits discussed in this report should be preceded by a careful evaluation of the quality and quantity of the specific deposit. Such information is not provided here, but may be critical to a successful quarrying operation.

Sand and gravel deposits occur in three locations: (1) south of the glacial border, (2) associated with the border, and (3) north of the border. *Deposits south of the glacial border* comprise outwash sands and gravels restricted to the bottoms of numerous valleys through which meltwater drained from the glacier. Such deposits occur in the valleys of Lycoming Creek, Loyalsock Creek, Mill Creek, Little Muncy Creek, Fishing Creek, and the Susquehanna River (Plate 1B), and Pohopoco Creek and the Delaware River (Plate 1C).

The thickness, size distribution, and quality of materials within these deposits have not been investigated for this report. Most of the deposits probably exceed 13 feet (4 m) in thickness. Coarse gravel dominates near the glacial border and the average clast size decreases away from the border. Quality is dependent on soundness of constituent clasts, and dominant components will basically reflect the bedrock within 5 miles (8 km) north-northeast of the border in that area. The clasts are generally well rounded. Large clast size necessitates crushing.

Deposits associated with the border are either outwash or ice-contact sands and gravels. The outwash deposits are identical in character with those described above and include deposits in the valleys of Oswayo Creek and Pine Creek (Plate 1A), the Susquehanna River (Plate 1B), and the Delaware River (Plate 1C).

The ice-contact deposits comprise kame and kame-terrace deposits (Figure 19) at numerous places along the border (Plate 1). The kame-terrace deposits occur mainly along the sides of valleys. Ice-contact deposits also occur as part of end moraine on the Pocono Plateau shown in Plate 1C, but have not been differentiated there (Sevon, 1975b).

These deposits are generally extremely variable in grain size, persistence of individual beds, and bed attitudes. The dominant clasts generally reflect the bedrock of the local area and are variably rounded. Some deposits might be utilized by sizing alone, but crushing and sizing are required for most deposits. These deposits are variable in volume, and reserves should be carefully investigated before a mining operation is started.

Deposits north of the border comprise both outwash and ice-contact sands and gravels. These deposits are essentially the same as those described above. Outwash deposits occur in the valleys of the Genesee River and Pine Creek (Plate 1A); Lycoming Creek, Loyalsock Creek, and Muncy Creek (Plate 1B); and Pocono Creek (Plate 1C). Ice-contact deposits north of the border have not been mapped for this report, but occur mainly in the valley-bottom and valley-side positions previously described.

PEAT

Peat occurs in numerous poorly drained to undrained depressions in the glaciated area north of (behind) the border in northeastern Pennsylvania, particularly in Luzerne, Lackawanna, Monroe, and Pike Counties. The only known peat bog of moderate size occurring within the area mapped for this report is shown and described in Figure 20. In 1978 Pennsylvania produced 15,000 short tons of peat valued at $350,000 (U. S. Department of Interior, 1979). Most of the production was in northeastern Pennsylvania. The nature and occurrence of these peat deposits are well described by Edgerton (1969) and Cameron (1970), and the interested reader is referred to those publications for more information.

CLAY

Clay deposits of unknown size and value occur in several valleys once dammed by Woodfordian ice. These clays are plastic and relatively impermeable. Little is known about their composition, physical properties, and potential use. Small clay deposits are known to occur in Pine Creek val-

Figure 19. The working face of a quarry opened into a large kame-terrace deposit along the south bank of the Susquehanna River 2 miles (3.2 km) east of Nescopeck (Plate 1B, Berwick quadrangle, 41°03′40″N/76°10′42″W). The quarry is operated by A. Barletta and Sons, Honeyhole Sand and Gravel Company.

ley at Galeton (exposed on the north side of U. S. Route 6 just west of the center of town)(Plate 1A); larger deposits occur in the Cowanesque River valley in Tioga County and adjacent southernmost New York, and beneath Shohola Lake in Pike County. Other small clay deposits probably occur elsewhere north of the border.

Figure 20. A small peat bog that was once drained and mined for peat. Wood fragments on the surface result from deforestation. The bog occurs at the end of a small road about 0.6 mile (1 km) north of the Pocono International Raceway (Plate 1C, Blakeslee quadrangle, 41°04′14″N/75°30′47″W).

RANDOM FILL

Glacial till is used extensively throughout the area north of the border as fill material because of its availability, ease of extraction, generally good compaction characteristics, and stability following compaction. Most of the till has a sufficient clay content to assure good compactibility, but till in areas underlain mainly by sandstone (for example, Pocono Plateau, Plate 1C) is relatively clay deficient and is somewhat less compactible. Large boulders are sometimes a nuisance during extraction.

ENVIRONMENTAL GEOLOGY

This report provides an accurate delineation of the boundary of the area that was covered by Woodfordian ice. This boundary is environmentally important partially because some differences exist in the character of weathered bedrock on either side of the boundary, but mainly because of the various surficial materials resulting from the last glaciation.

South of the glacial border, bedrock is generally more deeply weathered than it is north of the border, but depth to sound rock is variable. Residual material on flat uplands is a few feet thick. Residual material on the upper, steeper parts of slopes may be very thin because of the movement of material from the upper to lower slopes to form colluvium (see previous section). These colluvial deposits may be many feet thick at the base of a hill. Such deposits are susceptible to slump if the toe of the deposit is removed. Good examples of these deposits occur in the Salladasburg and Cogan Station quadrangles (Faill and others, 1977).

Rock outcrops south of the border are frequently severely broken along various parting planes, such as bedding planes and joints, and sound rock may not occur near the surface. Extensive breakup and downslope transport of some of these rocks during the severe climatic conditions associated with the Woodfordian glaciation produced the large talus, boulder-colluvium, and boulder-field deposits previously described. Some rock that is fresh at the surface in areas north of the border is very deeply weathered south of the border; for example, the Lower and Middle Devonian limestones in Monroe County (Epstein and Epstein, 1967, p. 57-60). Sandstones weathered to saprolite occur locally near Brodheadsville (Berg, 1975) and White Haven (41°01′48″/75°50′30″).

North of the glacial border, bedrock is relatively sound where exposed at the surface, but a thin veneer of broken fragments may cover the surface and small accumulations of fragments may occur below ledges. Rock beneath various glacial deposits is generally fresh and sound where exposed by excavation.

Unconsolidated deposits of glacial origin are abundant north of the border. All of these deposits are susceptible to slump if the toe of a deposit is removed (Figure 21). Excavation of these materials may be accomplished with light equipment, but care must be exercised if steep slopes are created. Slope failure is very possible in sand and gravel deposits. Foundation support strength is usually adequate for small structures except on moderate to steep slopes.

In some areas north of the border, such as Pike County, surface drainage is poorly developed and many undrained or poorly drained areas exist. Some of these areas contain peat deposits, but many are only swampy and thus create a variety of wetland problems that must be considered in any development plan and generally require drainage and excavation to solid material. Internal drainage is dependent upon the material and varies considerably in the glacial deposits. Sands and gravels drain rapidly. Drainage in tills is slow, but varies considerably depending on the sand-silt-clay ratio. The rate of internal drainage determines the suitability of material for septic-system waste disposal.

Figure 21. A zone of continuing slope failure resulting from cutting the toe of the slope in till. The most recent failure (adjacent to the automobile) was derived from the upper part of the slope and flowed onto the road before it was cleared. The roadcut is on the north side of Bear Creek about 2 miles (3.2 km) east of Barbours (Plate 1B, Barbours quadrangle, 41°22′57″N/-76°46′00″W).

GROUNDWATER

The potential groundwater supply from deposits associated with Woodfordian glaciation is variable. Significant groundwater potential exists in the sand and gravel outwash deposits filling many valleys such as Oswayo Creek and Pine Creek (Plate 1A); Lycoming Creek, Loyalsock Creek, Muncy Creek, Little Muncy Creek, and Fishing Creek (Plate 1B); and Pocono Creek, Pohopoco Creek, Cherry Creek, and the Delaware River (Plate 1C). The thickness of fill in these valleys is variable, but is significant in some, such as the thickness of 241 feet (74 m) in Pocono Creek near Tannersville (Berg and others, 1977, p. 42), and 150 feet (46 m) in the Delaware

River at Tocks Island (Crowl, 1971, p. 17). Most, if not all, of these valley fills are saturated with water and the groundwater table is near the surface.

Carswell and Lloyd (1979) report for Monroe County that, assuming a storage capacity of 15 percent and an average saturated thickness of 65 feet (20 m), the river-valley deposits store some 70 billion gallons of water. They say (p. 11) that "Specific-capacity data indicate that one of every four wells located, drilled, and developed for high yield will probably produce 400 gpm [25 l/s] or more, with 25 feet [8 m] of drawdown after 24 hours of pumping." Such a well would be considered successful for municipal purposes. Similar water production may be anticipated in other valley-fill deposits.

The permeability and the thickness of till deposits are generally too small to make these deposits a source for even low-quantity domestic wells, and groundwater supplies must be derived from bedrock. Wells drilled through till into bedrock require casing through the total thickness of till.

Upland and valley-side ice-contact stratified-drift deposits have good permeability, but their position above the water table and their generally small thickness prevent them from being potential water resources. Wells drilled into bedrock require casing through these deposits.

AREAL DESCRIPTIONS

The following sections contain detailed descriptions of the Olean border from the New York-Pennsylvania State line southeast to the Delaware River. The named subdivisions are based upon drainage basins and mountain fronts within the Appalachian Plateaus province and on local geomorphic boundaries in the Valley and Ridge province to the southeast.

The Olean border crosses two geomorphic provinces in northern Pennsylvania (Figure 1). The Appalachian Plateau is an upland underlain by nearly horizontal rocks. Streams have carved narrow valleys into the upland, leaving broad surfaces of gentle relief at high altitudes. The Allegheny Front, which bears various local names, such as Allegheny Ridge and Huckleberry Mountain, is a steep escarpment that forms the boundary between the Plateau and the Valley and Ridge province to the south.

The Valley and Ridge province is characterized by linear ridges and valleys developed on folded rocks. The ridges are underlain by steeply inclined hard rocks, and the valleys have been incised into similarly inclined soft rocks.

In general terms, ice flow extended down valleys and was impeded by hills to form an irregular border.

The following areal descriptions can be best understood by reference to Plate 1.

OSWAYO CREEK BASIN

(Bullis Mills, Shinglehouse, Oswayo, Ellisburg, Ulysses, and Sweden Valley quadrangles, Plate 1A)

The Olean glacial border enters Pennsylvania from New York in the valley of Oswayo Creek, a principal tributary of the Allegheny River south of Olean, New York. It extends southeast towards Cobb Hill in the southwest corner of the Ulysses quadrangle. Cobb Hill is the divide between Allegheny (Mississippi), Genesee (St. Lawrence), and Pine Creek (Susquehanna) drainages.

Exposures of only slightly weathered till, sand, and gravel demonstrate the presence of Woodfordian ice on the south side of Oswayo Creek between the New York border and Shinglehouse. There are no deposits of drift farther east on the south side of Oswayo Creek. Till crops out in Bell

Figure 22. An outcrop of till in a ditch along the road on the north side of Elevenmile Creek about 2 miles (3.2 km) northeast of Millport (Plate 1A, Oswayo quadrangle, 41°56′28″N/-78°05′04″W). The scale is divided into feet (30-cm intervals).

Figure 23. The view looking west down Oswayo Creek valley about 2 miles (3.2 km) east of Oswayo (Plate 1A, Ellisburg quadrangle, 41°55′22″N/77°59′08″W). The floor of the valley is underlain by outwash. The Olean border occurs on the valley wall to the left (south) and is marked by till deposits about one third of the way up the slope.

Run valley for about a mile south of Oswayo Creek, and thus ice would have lain on the north-facing slope of Oswayo valley. Clays in Bell Run valley beyond the southernmost exposures of till indicate the temporary existence of a proglacial lake in this valley.

Similar till in tributary valleys on the north side of Oswayo Creek east to Millport (Figure 22), till and pebbles on the upland to the north, and till and end moraine in the valley of Elevenmile Creek indicate that ice extended onto the south slope of Elevenmile Creek valley. Across the hilltop to the east, the boundary was drawn down Grover Hollow to Oswayo because no till was found west of this line. The tributary valleys west of Oswayo are strongly colluviated and have alluvial fans at their mouths.

East of Oswayo, the border in Ellisburg and Brookland quadrangles is modified from Denny (1956). The border is placed on the north-facing slope of Oswayo valley (Figure 23), rising to the areas of ground moraine and end moraine on Cobb Hill. Most of these areas of end moraine lie behind the mapped border, and their deposition apparently was controlled more by topography than by the ice edge. One of the kames in end moraine on Cobb Hill shows a young soil profile (E. J. Ciolkosz, personal communication, 1977), which the authors believe to be indicative of Woodfordian age. A core from Rose Lake, in end moraine northwest of Cobb Hill, gives a basal date of 14,170 y a, and confirms the Woodfordian age. From Cobb Hill the border trends sharply south to the headwaters of the Allegheny River near Raymond. There is no outwash in the Allegheny River headwaters.

UPPER PINE CREEK BASIN

(Brookland, West Pike, Sabinsville, Galeton, and Marshlands quadrangles, Plate 1A)

The border extends across the Allegheny Valley west of the preglacial col at Raymond, crosses the hill to the east, and follows the south slopes of an unnamed tributary east into the valley of Pine Creek; it extends down the valley almost 2 miles south of Brookland and then crosses the ridge south of Jones Run to leave a reentrant in the border between Pine Creek and Genesee Forks to the east. Denny (1956), on the basis of an erratic pebble found within this reentrant, places the boundary farther south. Considering the height of the hill to the north (1,500 feet, or 457 m) and usual ice gradients, it seems unlikely that ice overtopped the ridge. The ice may have crested the hill, and meltwater carried the pebble downstream, or it may be a remnant of an earlier glaciation.

Ice flowed down the valley of Genesee Forks. It also occupied the two small valleys to the southeast, leaving the south ends of the intervening ridges as nunataks. Ice tongues flowed about a mile (1.6 km) northwest and southeast in Pine Creek valley from the Genesee Forks. Lakes within the ice border are indicated by clay deposits on either side of West Pike along U. S. Route 6. No evidence has been found in this part of Pine Creek valley for the presence of lakes beyond the limits of this ice tongue, although they probably were present.

A marked reentrant in the glacial boundary lies north of Galeton where ice flow was impeded by a north-facing escarpment, leaving the high plateau segment covered with residuum. The position of the boundary on the north side of the plateau is indicated by an end moraine in a small valley and, 2 miles (3 km) to the east, by till in the vicinity of a swamp (now an artificial lake) at the foot of the escarpment. The border descends into Phoenix Run valley, and its position is indicated by the highest elevation of glacial cobbles in Dodge Run, a tributary to Phoenix Run.

Ice entered the valley of Pine Creek east of Galeton and advanced west and south into the valleys that center upon the town. The position of the ice border is well indicated by exposures of till in the vicinity of the town, particularly at 1,600 feet (488 m) on the steep hillslope to the south. Lake clays in Pine Creek valley, within and beyond the ice border, indicate the presence of a proglacial lake west of Galeton. Similar lakes occupied the valleys of West Branch and South Branch, and Denny (1956) noted overflow channels at The Notch (altitude 1,970 feet, or 600 m), 7 miles (11 km) southwest of Galeton, and at the head of Acid Factory Hollow (altitude 2,010 feet, or 613 m) 2 miles (3 km) southeast. Both of these altitudes are above that of the mapped ice border, so lake waters must have overlapped the edge of the ice, or the lakes developed after considerable retreat.

As noted earlier, till in the headwater areas of Pine Creek basin (Brookland and Ellisburg quadrangles) is unlike tills to the southeast, for it contains moderate numbers of crystalline erratics (Denny, 1956). The authors suggest that these are relics of Warrensville drift incorporated into the Olean drift, for they are not found elsewhere in the Olean Till.

A unique exposure of till, interpreted as Warrensville Till, lies in a sag in the divide about a mile (1.6 km) southeast of Gold (Brookland quadrangle). This till appears more weathered, contains more clay than nearby Olean Till, and contains rare crystalline pebbles. It also resembles other Warrensville Till beyond the Olean border. Its relatively sheltered position in a sag in the upland may be the reason for its preservation. It is not overlain by Olean Till, but outcrops of Olean are nearby.

MIDDLE PINE CREEK BASIN

(Marshlands, Tiadaghton, Lee Firetower, and Cedar Run quadrangles, Plate 1A)

The course of the border west of Pine Creek gorge, in this dissected plateau area, is highly irregular. Its position is based upon the presence of drift in the valleys and on the slopes, and upon the absence of drift on the uplands to the west. Till lies in the valleys tributary to Elk Run (Marshlands) and in the short tributaries to Pine Creek (Tiadaghton). Altitude control is provided by till near Galeton at 1,600 feet (488 m), the area of end moraine near Lick Run Hill, and small end moraines in cols south of Lick Run Hill. Till exposures indicate that ice tongues extended down Slide Island Draft to the vicinity of Leetonia and only part of the way down Fahnestock Run. In this latter area abundant colluvium mantles the slopes beyond the border (Figure 24).

Southeast of Fahnestock Run, the border is drawn along the west wall of Pine Creek gorge south and west to the last exposures of Olean drift near Cedar Run Village. The plateau east of the gorge is widely covered with drift, but, on the west, the plateau is mantled with residual soils and colluvium, and no deposits of Woodfordian age can be identified.

Gravels are exposed in the valley of Cedar Run well above stream level, and till is exposed at one place near stream level. Denny and Lyford (1963) mapped these deposits as part of the last drift sheet in the area. The authors disagree with this interpretation and regard them as older drift, that is, Warrensville. The till, on a steep slope, is red brown and has not developed

Figure 24. A slope covered with boulder colluvium on the east side of Fahnestock Run about 0.6 mile (1 km) north of its junction with Cedar Run (Plate 1A, Cedar Run quadrangle, 41°35′08″N/77°28′04″W). Boulder colluvium is made up mainly of plates of gray sandstone, including some large blocks. The view is looking up a slope of about 28 degrees.

a distinctive soil profile because of erosion and slope movement, so its age is indeterminate. Most of the gravel deposits are 30 feet (10 m) or more above stream level and isolated from the stream by downcutting subsequent to deposition. The plateau surface between Cedar Run and Pine Creek is unglaciated, and the authors could find no evidence of an ice tongue down Mine Hole Run nor all the way down Fahnestock Run (Denny and Lyford, 1963, Plate 1). Colluvium in the lower part of Fahnestock Run valley (Figure 24) and in all of Mine Hole Run valley is thicker and more extensive than in areas of Woodfordian glaciation. Thus the drift in Cedar Run valley must be older than Woodfordian. It is presumably Altonian in age, for it is unlike the Muncy drift in the area.

Denny (1956) has located two glacial spillways in this area whose presence seems doubtful. They are: (1) at altitude 1,908 feet (581 m) between Thompson Hollow and Left Branch Four Mile Run, and (2) at 1,670 feet (509 m) between Slide Island Draft and a tributary to Ice Break Run. At 1,908 feet (581 m), end moraine lies on the east side, just below the level of the spillway; at 1,670 feet (509 m), end moraine is in the col. Glacial drainage through these cols would surely have removed the morainal deposits.

TEXAS MOUNTAIN-LAUREL MOUNTAIN SECTOR

(Cedar Run, Morris, English Center, White Pine, Nauvoo, and Liberty quadrangles, Plate 1A)

This sector comprises the drainage basin of the Trout Run tributary to Pine Creek, the broad divide area between Trout Run and Texas Creek to the east, and Blockhouse Creek basin.

From Pine Creek at Cedar Run the Olean border is traced east and then south around the headwaters of Trout Run and east along the escarpment marked by Texas Mountain. Texas Mountain was overridden by ice, but the escarpment to the west, nearer the ice margin, was an effective barrier to ice flow. The position of the border is well defined by exposures of till, colluvium on the slopes, and bedrock residuum on the plateau.

Ice flowed down Texas Creek to its junction with Blockhouse Creek. Exposures of Warrensville Till to the southwest, down Little Pine Creek valley and in a pit (open in 1977) at the base of the hill just west of the junction of Texas and Blockhouse Creeks, establish the position of the border.

The altitude of the border rises eastward up Blockhouse Creek valley and its position is delineated by the altitudes of the till exposed in Flicks Run and Steam Valley Run valleys. A long, narrow lobe of ice occupied the valley of Steam Valley Run. Colluvium lies on the upper slopes of Flicks Run valley, and Warrensville Till lies on the divide at the head of the valley of Steam Valley Run.

North and east of the valley of Steam Valley Run, the border rises onto Laurel Mountain. Its course is marked by exposures of till in the valley of Steam Valley Run and on the crest of Laurel Mountain, where exposures of till, colluvium, and residual soils closely delimit the border.

A nunatak lies on the north side of Blockhouse Creek opposite Flicks Run, where bedrock and residual soils are exposed on the ridge top. The position of the nunatak boundary is based upon the border gradient on neighboring slopes.

LYCOMING CREEK BASIN

(Trout Run and Cogan Station quadrangles, Plate 1A)

The Lycoming Creek basin is a deeply dissected portion of the plateau that has valley slopes so steep that most surficial material has been removed. Drift is found at the base of the valley slopes and on low plateau spurs west of Grays Run, a tributary to Lycoming Creek.

The south portion of Laurel Mountain is clear of drift, but till is present to the southeast in valley heads and on spurs at decreasing altitudes. Thus the boundary is drawn around the edge of the plateau. Drift is present in Hagerman Run valley but not on Narrow Mountain to the west, so the border is drawn on the east slope of Narrow Mountain. The top of Sugarcamp Mountain to the east is free of drift; it was a nunatak, as was the south spur of Bodine Mountain east of Grays Run.

The boundary on the west side of Lycoming Creek descends in altitude steadily to the kame moraine blocking the tributary valley north of Quiggleville (Cogan Station quadrangle), in the direct line of flow of the ice. Presumably a small lobe of ice extended down Lycoming Creek valley just north of the terminus.

Residual soils and colluvium on the east side of Lycoming Creek near the terminus indicate that ice was confined to the creek valley. The boundary is drawn northeast along the mountain front east of the stream to Shoemaker Run at Fields Station, where Olean Till is present in the valley head and in the basin to the east.

BLESSING MOUNTAIN-ALLEGHENY RIDGE SECTOR

(Bodines, Barbours, Hillsgrove, Montoursville North, Huntersville, Picture Rocks, and Sonestown quadrangles, Plate 1B)

The Olean glacial border extends into the Bodines quadrangle from Fields Station in Lycoming Creek valley via Shoemaker Run, and exposures of till and colluvium closely delimit the border. Rose Valley Lake is an artificial lake on the site of a postglacial swamp, and lies in an ice-block depression marking the ice border. The western margin of the lake buries the Olean drift border. Drift exposures here indicate that ice extended south, just into the Montoursville North quadrangle. A wide, flat-floored col on the east side of Mill Creek Mountain extends south into a tributary of Mill Creek and is interpreted as a former meltwater spillway. There is no similar feature on the headwaters of Mill Creek where drainage leaves Rose Valley Lake on the west side of Mill Creek Mountain, so apparently the former ice block diverted glacial drainage through the col to the south. It is also possible that subglacial drainage flowed east to Wallis Run valley and Loyalsock Creek.

The Olean boundary lies on the north slope of Blessing Mountain-Allegheny Ridge from Rose Valley Lake east to Crystal Lake (Picture Rocks quadrangle). Drift south and east of Rose Valley Lake along the base of the mountain, and local end moraines at Jacoby Mountain (Bodines quadrangle), near Smiths Knob and Hill 1825 (Huntersville quadrangle), and at

Crystal Lake (Picture Rocks quadrangle), give the major control for drawing the boundary. Additional control is provided by an outwash fan fed by meltwater in Jacoby Hollow, a tributary to Wallis Run; by kames in Loyalsock Creek valley near Butternut Grove (Montoursville North quadrangle); and by a kame on Hessler Branch of Bear Creek (Picture Rocks quadrangle). On these bases, and using an ice-surface gradient of 225 ft/mi (43 m/km), the glacial boundary has been drawn along the north-facing mountain slopes. More accurate locations are very difficult to give because of forest cover and colluviation on these slopes.

Extensive outwash terraces occur south of the Olean kame moraine in Loyalsock Creek valley. Numerous kames are present in the valley north of the boundary (Figure 25). A kettle hole in the kame at the sharp bend in Loyalsock Creek west of Barbours is the site of a peat bog that yielded a date, on basal organic material, of 12,750 y a (Table 3).

Figure 25. Sand and gravel in a kame on the south side of Pa. Route 87 in Loyalsock Creek valley about 2.5 miles (4 km) west of Barbours (Plate 1B, Barbours quadrangle, 41°23′12″N/-76°50′48″W). The scale is divided into feet (30-cm intervals).

Bear Creek has built a large postglacial alluvial fan in Loyalsock Creek valley at Barbours, containing material eroded from the Olean drift.

MUNCY CREEK LOWLAND

(Picture Rocks, Sonestown, and Lairdsville quadrangles, Plate 1B)

The nearly linear Appalachian Front is broken between Crystal Lake and North Mountain by Muncy Creek and its tributaries. The Olean ice extended in a broad lobe from this reentrant in the plateau front about 5 miles (8 km) farther south than on Allegheny Ridge on the west and North Mountain on the east.

Alternating segments of end moraine and ground moraine mark the border on the south face of Allegheny Ridge. As noted earlier (p. 15), this drift edge probably gives the best estimate of the slope of the ice front, 225 ft/mi (43 m/km).

Ground moraine marks the border from the base of Allegheny Ridge across the low hills to the base of Huckleberry Mountain at Lungerville. Kames mark the margin in the valleys of Muncy Creek, Gregs Run, and Beaver Run. Scattered areas of indistinct end moraine or hummocky ground moraine occur within the lobe border, usually in topographic depressions.

The ground-moraine border trends northwest up the slope of Huckleberry Mountain at Lungerville. The till-colluvium boundary is indefinite on the steep slope. A distinct end moraine lies within the ground-moraine border on the slope of the mountain. Its altitude increases steadily toward the northwest, parallel to the drift border. This clearly indicates flow of ice around the end of North Mountain toward the southeast.

Two dry valleys occur within this area: one, southeast of Hessler Branch (Picture Rocks quadrangle) in the border reentrant around Allegheny Ridge, is the site of a spillway where meltwaters cut down the col to drain south down the front of the plateau to Laurel Run. A dry valley south of Tivoli north of Picture Rocks is part of the preglacial valley of Big Run. Presumably glacial drainage waters in Big Run valley flowed east across a col, cutting a gorge into Muncy Creek while a long-lasting ice block occupied the lowest part of the original valley.

NORTH MOUNTAIN SECTOR

(Sonestown, Elk Grove, and Red Rock quadrangles, Plate 1B)

The North Mountain sector comprises the area of North, Huckleberry, and Red Rock Mountains. This high part of the Appalachian Plateau formed a barrier to the last ice advance so that the ice swept over the plateau front east of Red Rock Mountain and around North Mountain on the west to leave the southernmost part of the plateau free of ice and an area of colluvium and Warrensville drift in the lowland between Lungerville and Fishing Creek.

A very small end moraine in the valley of Hemlock Run, tributary to West Branch Fishing Creek, gives good control for the border, and the border is drawn around the west end of the plateau on the basis of a few additional exposures of till.

Numerous outcrops of till east of Hemlock Run demonstrate glaciation on the north part of the plateau in this area. Ground moraine on the plateau surface can be traced by use of aerial photography south to Painter Run and to the mid-portion of ridges to the east. The southern portions of these ridges, Huckleberry Mountain, and most of North Mountain appear to be unglaciated. Outcrops of colluvium and bedrock and lack of till on the plateau of North Mountain confirm this interpretation.

The crests of Central Mountain and Red Rock Mountain are likewise clear of young drift, although older drift may be present. A small end moraine lies on the north side of the col between the two mountains, and an extensive and distinct end moraine lies on their south slopes.

Within the plateau, and on its margins, drift has been removed from the steep upper slopes of the valleys, but colluviated drift is abundant on the lower slopes. Thin colluvium mantles the upper slopes. Alluvial fans lie at the mouths of steep tributaries to East Branch Fishing Creek.

FISHING CREEK LOWLAND

(Elk Grove, Red Rock, Benton, Stillwater, Shickshinny, and Mifflinville quadrangles, Plate 1B)

The Fishing Creek lowland comprises the drainage basin of Fishing Creek between the Allegheny Front and Huntington Mountain to the south, the northernmost mountain ridge of the Valley and Ridge province in the district.

The Olean border crosses the Fishing Creek lowland between the Allegheny Front and Huntington Mountain on the south. The border is delineated almost entirely by ground moraine, and the "feather edge" of Olean Till is usually in contact with colluvium or residuum (Figure 6). Near Benton, the Olean Till is in contact with Muncy Till. A kame moraine marks the boundary on Fishing Creek north of Benton, as described by Lewis (1884). Olean Till lies on the upland at the top of the steep valley wall east of Benton, but has been removed from the slope by colluviation. Hummocky ground moraine lies in valleys in the upland to the east. The border crosses the gentle valley slopes south of Benton.

Another kame moraine marks the boundary in Huntington Creek valley. This kame moraine is fronted to the southwest, downstream, by an outwash terrace. The kame complex extends upstream in Huntington Creek and Pine Creek valleys for more than a mile above their junction.

The ground-moraine border trends up Huntington Mountain eastward, crosses it just beyond the limits of Stillwater quadrangle, and extends down the steep slope into Little Shickshinny Creek valley. Several kames occur in the valley to the east behind the drift border. The position of the ground-moraine border loops back, trends up Lee Mountain on a gentle gradient, and crosses the mountain in the Berwick quadrangle.

SUSQUEHANNA RIVER LOWLAND

(Berwick and Sybertsville quadrangles, Plate 1B)

The Susquehanna River lowland extends from Lee Mountain south across the river to Nescopeck Mountain. It may be conveniently divided into two parts: low hills close to the mountain ridges north and south of the river, and a nearly flat outwash terrace bordering the river.

A large area of indistinct end moraine lies on the south flank of Lee Mountain. South of this, towards the river, some of the bedrock hills are also covered with indistinct end moraine, others with thin ground moraine.

A large kame moraine lies on the south bank of the Susquehanna River (Figure 26), and was recognized by Lewis and Wright (Lewis, 1884) as marking the edge of young glacial deposits. Indistinct end moraine continues southeast across the low hills to the base of Nescopeck Mountain and trends eastward with a low gradient along the mountain.

The outwash terraces along the Susquehanna River (Figure 26) are well displayed east and west of Nescopeck and Berwick, but they have not been studied for this report. Bedrock is exposed at low water in the channel of the river.

NESCOPECK MOUNTAIN-LEHIGH RIVER SECTOR

(Freeland, White Haven, and Weatherly quadrangles, Plate 1C)

Near the crest of Nescopeck Mountain, the border is ground moraine; on the south flank is an extensive area of distinct end moraine.

At its margin east of St. Johns (Plate 1B), part of the indistinct end moraine has a gravelly composition and approximates a kame moraine in composition as well as in topographic expression. Kames are abundant upstream in Nescopeck Creek valley, and the downstream portion of the valley is floored with outwash.

From St. Johns eastward, the Olean border extends across the north slope of Green Mountain on a low gradient into the gap between Green Mountain and Mt. Yeager, the route followed by Interstate Route 80. The border

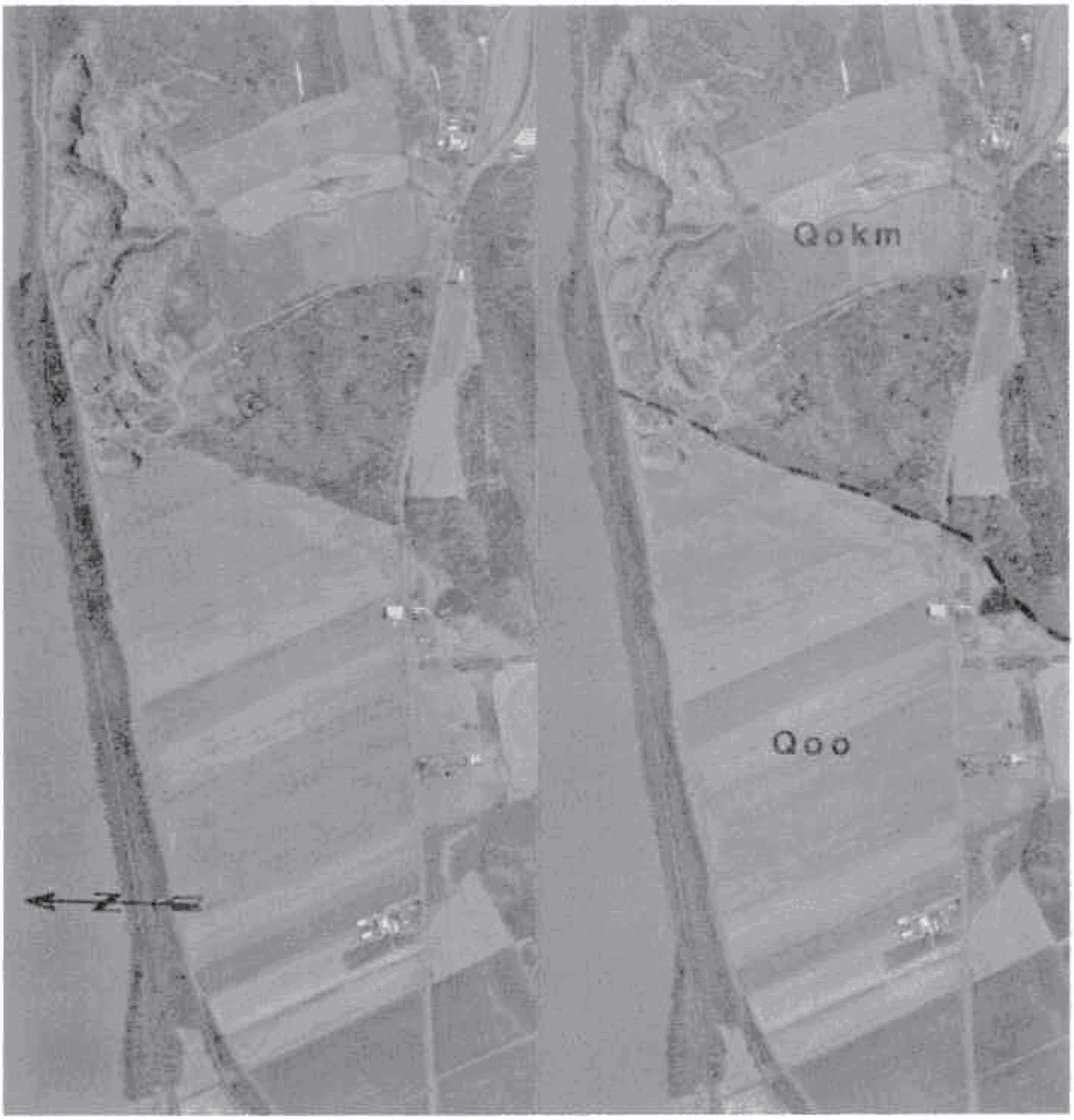

Figure 26. An Olean kame moraine and outwash terrace on the south bank of the Susquehanna River east of Nescopeck (Plate 1B, Berwick quadrangle; the approximate center of the stereogram is at 41°03′27″N/76°11′06″W). Aerial photographs were taken for the U. S. Geological Survey in April 1969; the scale is approximately 1:16,800. The quarry is that of A. Barletta and Sons, Honeyhole Sand and Gravel Company. The boundary between the kame moraine (Qokm) and the outwash (Qoo) is marked by the dashed line.

trends south to Buck Mountain in the Lehigh River valley and crosses the river at Hickory Run. Patches of distinct end moraine occur in the mountain-front reentrants, and indistinct end moraine and ground moraine

(Figure 27) form the border in areas of low relief eastward to the Lehigh River.

The crest of Mt. Yeager and the low eastern end of Green Mountain are bare of drift, but are surrounded by drift on their lower slopes. However, northward projection of the average ice-surface gradient from the glacial limits on Green Mountain suggests that the last ice advance overrode the mountain crests. Absence of drift on the mountaintops may be readily explained by either of two mechanisms: 1) the mountain ridges were high above the drift-laden basal zone of the ice, and were overridden by relatively clean ice, or 2) whatever drift was deposited there has been removed by subsequent colluviation.

Kames lie on either side of the Lehigh River at Tannery. These are the counterparts of kame moraines in other, wider stream valleys and are presumably remnants of larger deposits eroded from this constricted part of the valley.

Figure 27. The surface of ground moraine, characterized by slightly hummocky topography. The distinction between ground moraine and hummocky ground moraine in this area is somewhat subjective. The view is to the west from the road immediately north of the Luzerne-Carbon County line about 4 miles (6 km) south of White Haven (Plate 1C, Weatherly quadrangle, 40°59′55″N/75°45′39″W).

POCONO PLATEAU SECTOR

(Hickory Run, Blakeslee, Pocono Pines, and Mount Pocono quadrangles, Plate 1C)

The Olean border in the Pocono Plateau sector consists of an unbroken belt of distinct end moraine which extends eastward from the Lehigh River for over 20 miles (32 km) across the relatively flat Pocono Plateau upland to the eastern end of Camelback Mountain (Mount Pocono quadrangle). The end moraine has abundant small hills and undrained depressions (Figure 4), averages over a mile (1.6 km) in width, and usually has an abrupt slope bounding the south margin. It is best developed in the Pocono Pines quadrangle. End moraine terminates along the north side of Camelback Mountain, where ground moraine extends around the end of the mountain and down the escarpment. A few erratics and small deposits of washed till along the state park road at the top of Camelback Mountain indicate that Woodfordian ice flowed over the mountain crest.

A large area of thin Olean ground moraine occurs beyond the end-moraine border in the southwestern part of the Blakeslee quadrangle, as already noted (p. 10).

Glaciofluvial deposits are minimal in this sector except for ice-contact sand and gravel within the end moraine, and are not distinguished on the map.

Beyond the Olean border are extensive areas of boulder colluvium (Figure 28), boulder fields (Figure 15), and Muncy Till (Sevon, 1975b; Berg and others, 1977).

BRODHEADSVILLE LOWLAND SECTOR

(Pocono Pines, Mount Pocono, Brodheadsville, Saylorsburg, and Stroudsburg quadrangles, Plate 1C)

The Brodheadsville lowland extends across a variety of folded rocks between the Pocono Plateau escarpment on the north and Kittatinny Mountain on the south. The Olean border has a distinctly lobate form within this lowland.

The border is marked by ground moraine along the lower slopes of the nose of Camelback Mountain. About 2 miles (3 km) west of the eastern end of Camelback Mountain a narrow belt of indistinct end moraine extends southwestward along the slope of the mountain; it then takes on a southward trend. This belt of indistinct end moraine is continuous to Brodheadsville and has a moderately well defined front margin developed on the crests of low hills immediately west of McMichael Creek.

Figure 28. The surface of boulder colluvium developed on a low to moderate slope on the north side of Pa. Route 534 in Hickory Run State Park about 0.8 mile (1.3 km) northwest of the Pennsylvania Turnpike Northeast Extension overpass (Plate 1C, Hickory Run quadrangle, 41°00′54″N/75°39′01″W). Scale is divided into feet (30-cm intervals).

The Olean border in Pohopoco Creek valley at Brodheadsville is a mixed kame and till moraine of low relief made up of irregular masses of gravels and till, and grades almost imperceptibly into the valley train to the southwest (Figure 18). The moraine forms the divide between Pohopoco Creek drainage to the southwest and McMichael Creek to the east. This outwash plain is the site of a radiocarbon date, 12,760 y a, discussed on p. 34.

A ground-moraine border occurs eastward from Pohopoco Creek valley at Brodheadsville and trends south to a large kame-moraine complex which marks the end moraine at Saylorsburg north of Cherry Ridge. Distinct and indistinct end moraines lie between Cherry Ridge and Kittatinny Mountain to the south, and ground moraine marks the border on the north slope of the mountain.

DELAWARE VALLEY

(Stroudsburg, Bangor, and Belvidere quadrangles, Plate 1C)

Two areas of distinct end moraine occur on the south slope of Kittatinny Mountain. The western area of end moraine marks the border; it extends downslope to the vicinity of Bangor and changes to a kame moraine southwest of the city along Waltz and Greenwalk Creeks. From Martins Creek eastward over the hills, the border is principally ground moraine, but includes an area of end moraine to the north. An unusual concentration of boulders (Figure 29) 1.5 miles (2.4 km) southeast of Bangor may represent

Figure 29. A fence-line accumulation of boulders collected from adjacent fields. The large number of boulders is not common in ground moraine in this area, and their presence in a restricted area is thought to indicate an ice-border position that did not develop end-moraine topography. The site is on the north side of a road about 1.5 miles (2.4 km) east of Bangor (Plate 1C, Bangor quadrangle 40°51′27″N/-75°10′48″W).

Figure 30. The view looking north across the surface of an outwash terrace along the Delaware River. The site is on the north side of a road 1.3 miles (2.1 km) west of Foul Rift, New Jersey, near Belvidere (Plate 1C, Belvidere quadrangle, 40°48′20″N/75°07′20″W).

an end moraine, and may correlate with the eastern end moraine on Kittatinny Mountain.

The valley floor of the Delaware River (Figure 30) is essentially a valley train 70 to 100 feet (20 to 30 m) above the river surface. Southwest of Belvidere, at Foul Rift, the surface of the outwash is broken by a kame complex which marks the former position of the ice front. Similar kames are found on the New Jersey shore.

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GLOSSARY

Clast. An individual grain or fragment of a soil, till, or sediment.

Col. A pronounced saddle-like divide between two valleys, or a marked saddle-like depression in the crest of a mountain ridge.

Colluvium. A loose, incoherent mass of soil material or rock fragments deposited by mass wasting or sheet erosion, usually at the base of a steep slope or cliff.

Drift. All rock material transported and deposited by a glacier or by running water derived from a glacier.

End moraine. Glacial debris left stranded at the front of a glacier as melting proceeds.

Erratic. A rock fragment, different from underlying bedrock, carried and deposited by a glacier.

Glaciofluvial. Deposits formed by meltwater streams from glaciers. See *kame, kame moraine,* and *kame terrace.*

Ground moraine. A thin layer of till deposited over a land surface from a melting glacier.

Ice-contact stratified drift. Stratified drift deposited in contact with melting ice by meltwater.

Interstade. A warm substage of a glacial stage marked by a temporary retreat of ice.

Kame. Poorly sorted sand and gravel deposited by a meltwater stream from a glacier, and now forming a hillock or low, steep-sided ridge.

Kame moraine. A group of kames formed along the front of a stagnant glacier.

Kame terrace. A more-or-less flat-topped bench at the base of a hill formed of sand and gravel deposited by a meltwater stream in the hollow between the valley slope and an ice tongue in the valley.

Kettle. A bowl-shaped depression in drift, often containing a lake or swamp, formed by the late melting of a large detached block of glacier ice.

Nunatak. An isolated hill of bedrock that projects above the surrounding glacier surface.

Outwash. Sand and gravel washed out of a glacier by meltwater streams and deposited in front of the ice. See *valley train.*

Periglacial. Extreme and variable cold climatic conditions at the margin of a continental glacier which promote frost action and accelerated mass-wasting processes.

Saprolite. A soft, thoroughly decomposed rock formed by in situ chemical weathering.

Solum. The upper layers of the soil resulting from weathering processes.

Stone stripe. A linear concentration of coarse stones flanked by fine material and oriented downslope.

Striae. Fine scratches or furrows on a rock surface made when glacier ice dragged another rock fragment across that surface.

Taiga-tundra. The subarctic transitional zone between the coniferous forest (taiga) and the treeless, swampy, herbivorous zone (tundra) to the north.

Terminal moraine. An end moraine that marks the farthest advance of a glacier.

Till. Unsorted, unstratified drift, ranging from clay to boulders in size, deposited directly by melting ice.

Valley train. Outwash deposited by meltwater streams beyond the ice front and confined to a single valley. See *outwash*.