GUIDEBOOK

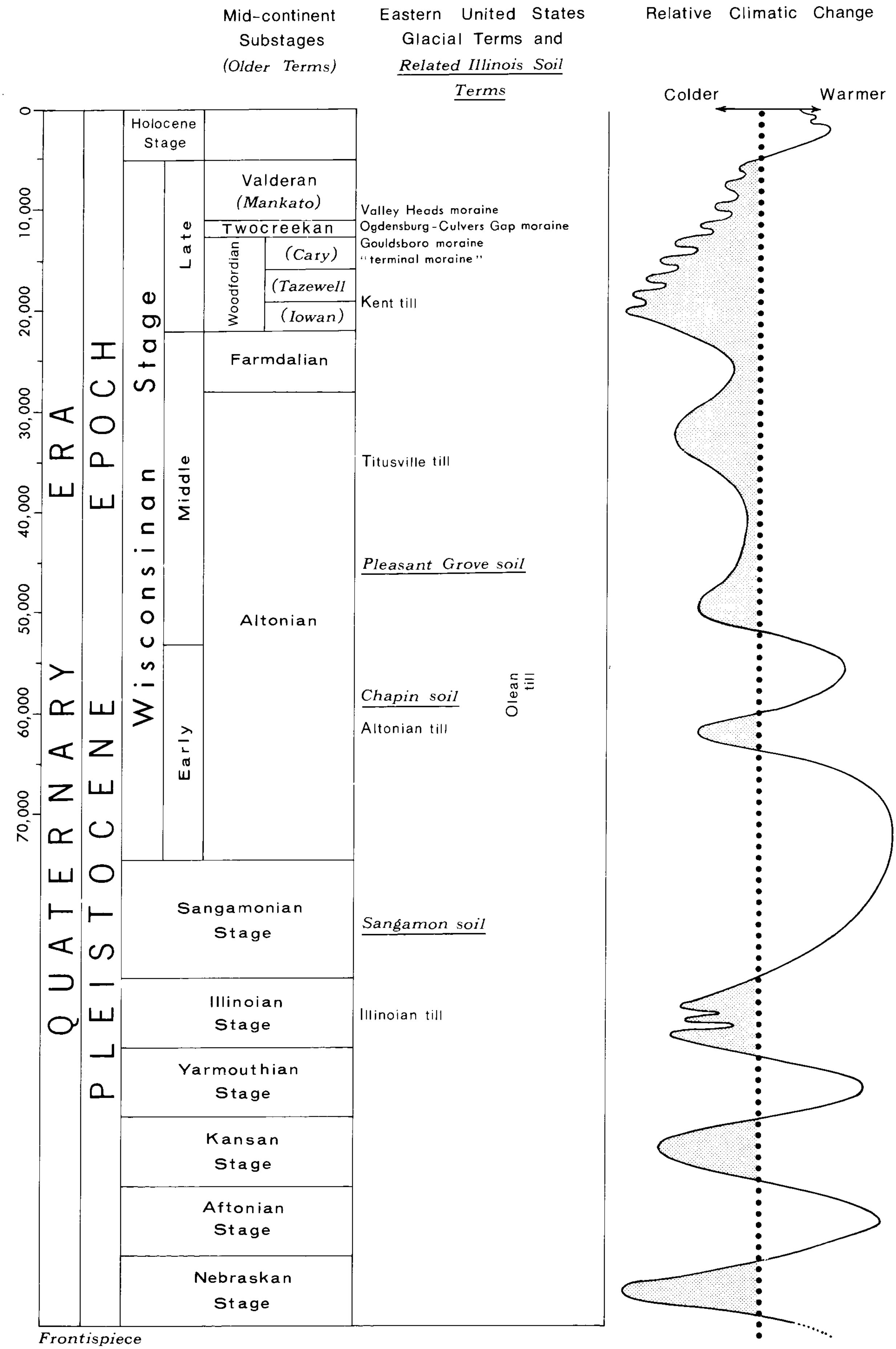
40th. Annual Field Conference Of Pennsylvania Geologists

The Late Wisconsinan Drift Border in Northeastern Pennsylvania

October 3 and 4, 1975

Bartonsville, Pa.

Host: Pa. Geological Survey



Frontispiece

Guidebook for the

40th ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

THE LATE WISCONSINAN DRIFT BORDER

IN

NORTHEASTERN PENNSYLVANIA

Leaders: W. D. Sevon, Pennsylvania Geological Survey
G. H. Crowl, Ohio Wesleyan University
T. M. Berg, Pennsylvania Geological Survey

October 3 and 4, 1975

Host: Pennsylvania Geological Survey

Headquarters Motel: Holiday Inn, Bartonsville, Pa.

Cover: A tired Woodfordian glacier creeps into Brodheadsville. Pocono Plateau Escarpment and Camelback Mountain in the background. Design: T. M. Berg. Art work: A. E. VanOlden.

Frontispiece: Diagram of Pleistocene stratigraphic nomenclature and climatic fluctuation.

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To the Memory

of

PAUL MacCLINTOCK 1891-1970

Professor of Geography, Princeton University 1928-1959

Paul was a long-time contributor to the study of Pleistocene Geology, an ardent Friend of the Pleistocene, and one who revelled in field work, posing questions to himself and his companions. If an answer destroyed a favorite theory he did not mourn - he had another possibility at hand. He was a man of delightful humor.

He did some of his last field work in this area in 1969 with George Crowl and Bill Sevon, and it seems appropriate to remember him now.

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

THE LATE WISCONSINAN DRIFT BORDER IN NORTHEASTERN PENNSYLVANIA

by W. D. Sevon[1], G. H. Crowl[2] and T. M. Berg[1]

INTRODUCTION

Much of the northern part of Pennsylvania has been subjected to the influence of at least three continental glaciations (Fig. 1). General knowledge of drift materials, relative ages, probable directions of ice movement and associated pro-ice periglacial deposits has been collected since the 1870's. Only within the last 15 years, however, with the advent of mapping at a scale of 1:24,000 has any detailed information been obtained about glaciation in northeastern Pennsylvania.

The present necessity for detailed information about glacial deposits and peripheral effects of the several glaciations is obvious in an area which is projected to have between 25 and 100 percent population growth in the next 15 years and which is 50 to 75 percent covered by glacial drift. Foundation conditions, septic systems, sources of good quality building materials, land use planning, road construction, slope stability, and effects on ground water supplies are the major areas of involvement and concern with glacial drift.

The purpose of this Field Conference is to demonstrate within and adjacent to the Late Wisconsinan drift border in northeastern Pennsylvania:

1. The character and variability of the Late Wisconsinan drift materials;

2. The similarities and differences between the Late Wisconsinan (Woodfordian) drift and pre-Late Wisconsinan-post Sangamonian (Altonian) drift;

3. The character of the Illinoian glacial drift;

4. The character of deposits of periglacial origin; and

5. The reasoning used in differentiating and dating these various deposits.

About 70 percent of this guidebook is textual discussion, general and detailed description, and treatment of issues that are sometimes controversial among specialists in Pleistocene geology. The remaining 30 percent is devoted to road log and Stop descriptions. To fully appreciate the outcrops and materials exposed at the various Conference Stops, and the terrain along the field trip route, we recommend that you familiarize yourself as fully as possible with the text, and refer back to specific

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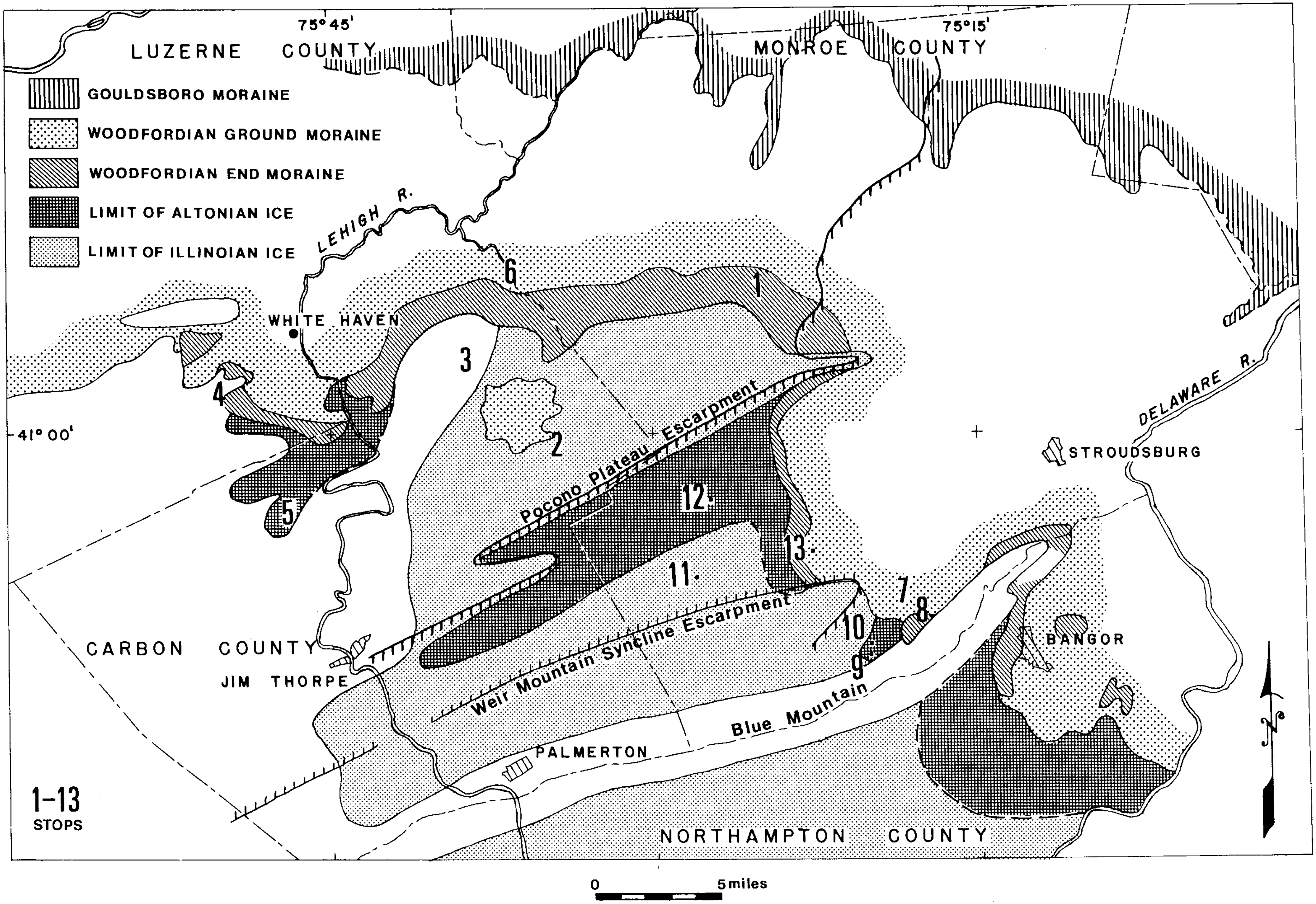


Figure I. Maximum known limits of Illinoian, Altonian and Woodfordian glaciations in northeastern Pennsylvania.

aspects through the table of contents during the trip. It is our intention, in presenting an extensive text, to provide as full a background as possible for those not fully-versed in glacial geology. If geologists are to take their responsibilities seriously in planning the future of our total environment, then they must be aware of the great variety and complexity that attend surficial deposits.

ACKNOWLEDGEMENTS

Many people have contributed to the accumulation of information and development of ideas about glaciation in northeastern Pennsylvania. Some will be mentioned in following sections, but several deserve special mention. G. Gordon Connally, State University of New York at Buffalo, has contributed significantly to the development of drift age relationships, and concepts of glaciation and deglaciation. Edward J. Ciolkosz, Pennsylvania State University, has been instrumental in developing our understanding of the soils formed on drifts of different ages. Jack B. Epstein, U. S. Geological Survey, was the first to begin the unravelling of the details of the area and to accumulate quantitative information. Donald H. Cadwell, Lafayette College, has contributed to our knowledge of the extent of Altonian glaciation south of Blue Mountain. Finally, we would like to acknowledge all the Friends of the Pleistocene who generously gave comment and criticism regarding the deposits and our ideas at the 38th Annual Reunion of the Friends in May, 1975.

PREVIOUS WORK AND HISTORICAL DEVELOPMENT

The study of glacial geology in Pennsylvania apparently got its start in 1851 when M. Edouard Desor, who had studied Alpine glaciers in Switzerland with Agassiz, ". . . volunteered his services for the study of the surface geology." (Lesley, 1876, p. 125). We do not, however, have any real evidence that Desor had an early influence on the study of Pennsylvania surficial geology except in the development of J. P. Lesley's concepts of glaciation. Indeed, H. D. Rogers held to the theory of the great deluge (Lesley, 1876, p. 86) and he made only the briefest mention of surficial deposits in his final report on the "Geology of Pennsylvania" (1858, v. 1, p. 36-39).

Nothing is known of activities in the study of glacial geology in Pennsylvania for the next 25 years, except that Desor and Lesley examined sites beyond the presently known maximum drift border where they thought glacial striae occurred (Lewis, 1884, p. xli). Berg and Sevon have attempted to relocate these sites and feel that we were not successful on Locust Mountain near Ashland and that the supposed striae on Peters Mountain north of Harrisburg are really slickensides.

By the mid 1870's, concepts about glaciation in Pennsylvania, New Jersey, and New York were apparently well developed and the several reports of that era are adequately reviewed by Leverett (1934, p. 2-6). The principle work of that time was that of Professor H. Carvill Lewis and the Rev. Mr. G. Frederick Wright (Lewis, 1884), who traced the southern boundary of the Late Wisconsinan ice sheet across Pennsylvania. They termed the boundary the "terminal moraine", a name which is still in common useage. This was a monumental piece of work for Pennsylvania because it defined on a map, for the first time, the limits of the last major continental glaciation. The excellence of the work as a whole may have been due in part to a general lack of forest cover resulting from extensive logging which allowed ready tracing of the moraine. The work of Lewis and Wright is particularly significant, in that it has served as the principal point of departure for subsequent work in Pennsylvania's glacial geology.

The first works of significance north of the "terminal moraine" in northeastern Pennsylvania are those of I. C. White (1881, 1882) who gives the first descriptions of some of the drift in Wayne, Susquehanna, Pike and Monroe Counties. The 1882 report also includes an ice flow map constructed by Lesley from striae data.

Between 1882 and 1920 Branner and Williams (Cramer, 1961, p. 39, 256-57) contributed information about glaciation in parts of northeastern Pennsylvania, particularly Williams who treated some of the deposits south of the "terminal moraine", which he referred to as Kansan in age. However, the significant work about drift outside the "terminal moraine" is that of Leverett in 1934. Leverett examined a large area south of the "terminal moraine" and prepared the first map showing the distribution of pre-Late Wisconsinan drift in Pennsylvania. He recognized mainly Illinoian drift and some pre-Illinoian drift. He modified the border mapped by Lewis (1884) and laid the foundation for future work on pre-Late Wisconsinan deposits in Pennsylvania.

Detailed mapping (scale of 1:24,000) of the bedrock and surficial deposits in northeastern Pennsylvania started in 1961. Since that time, new information and new ideas have enlarged the scope of our understanding of glaciation and deglaciation in northeastern Pennsylvania.

The first mapping of the surficial deposits in the area was that of Epstein (1969) who recognized deglaciation sequences later refined by Connally (Connally and Epstein, 1973). Epstein and others (1974) have produced the most comprehensive treatment of the Illinoian drift in this region and Epstein presents some evidence within the report for possible pre-Illinoian drift. Connally, in about 1972 (unpublished), was the first to recognize in the Saylorsburg area the existence of glacial deposits intermediate in age between Illinoian and Late Wisconsinan. Similarly positioned deposits, now tentatively called Altonian in age, were later verified elsewhere by Sevon (1973 & 1974) and Crowl (unpublished). The remainder of the work in the area has been almost exclusively mapping of the drift and includes: Berg, 1975; Berg and others, in prep.; Bucek, 1971; Crowl, 1971; Epstein, in prep.; Epstein and Connally, in prep.; Epstein and Sevon, in prep.; Schultz 1973, 1974; Sevon, 1975 a,b,c; and Sevon and Berg, in prep.

Additional detailed work is being done by Crowl who is remapping the "terminal moraine" from New Jersey westward to New York (Crowl, 1972; 1975).

REGIONAL SETTING

BEDROCK GEOLOGY

The physical character (lithology) of the rocks in an area undergoing and adjacent to glaciation has a pronounced effect on the glacial and periglacial processes as well as on the physical character of the resultant deposits. The various effects are related basically to the erodibility and color of the rocks. The erodibility is a function of (1) induration, (2) orientation, closeness of spacing, and degree of tightness of parting planes (joints and bedding planes), (3) hardness of constituent particles and (4) structural attitude. Erodibility of bedrock will control the quantity of material eroded by the ice, and will affect the character of glacial drift. The pre-glacial and much of the post-glacial geomorphology of the glaciated area are additionally affected by rock erodibility.

Rock color will affect the color of the resultant glacial drift, at least prior to the formation of pervasive and deep solums. The actual mechanics of glacial erosion, transportation, deposition, and subsequent weathering are not the subject of this guidebook; excellent treatments of these subjects may be found in Birkeland (1974), Boulton (1972, 1974), Flint (1971, p. 86-226) and Goldthwait (1971).

The sedimentary rocks in northeastern Pennsylvania include a diverse suite of formations and members ranging in age from Ordovician to Pennsylvanian. However, glaciation has little regard for stratigraphy and the numerous rock units can be grouped into three basic and significant categories: (1) LIGHT GRAY sandstones and conglomerates, (2) RED shales, siltstones, sandstones and conglomerates and (3) DARK GRAY to BLACK shales, siltstones, limestones and dolomites. The general lithologic characteristics of these categories and the stratigraphic units included in each is presented in Table 1, and their areal distribution is shown in Figure 2.

The erodibility of these rocks is variable, but corresponds fairly well with the tripartite color categorization. The only major exception is the uppermost member (Duncannon) of the Catskill Formation, which is placed in Category 2 because of its red color rather than Category 1 which has similar low erodibility. Category 1 is the most resistant to erosion and Category 3 the least resistant. The relative induration of the coarser clastics varies both laterally and vertically; the finer clastics tend to remain texturally constant and display a more homogeneous induration. Most bedrock cementation has been effected by silica solution with associated clay diagenesis; in general, resultant induration decreases with increasing grain size although some coarse-grained sandstones and conglomerates are quartzitic. All of the rocks have well developed parting planes which include bedding, joints, and cleavage. Joints with orientations centering around N10E-S10W and N20W-S20E, and cleavage orientations centering around N70E-S70W generally have steep dips and are common throughout the area. The concentration of these fractures is variable, but generally increases as grain size decreases. Beds tend to be thinner in the finer grained rocks.

Table 1. Lithologic characteristics and categories of bedrock units in northeastern Pennsylvania.

PENNSYLVANIAN

Pottsville Formation. CATEGORY 1. Light gray to white, quartzitic sandstones and conglomerates and some coal, 244 m (800 ft).

MISSISSIPPIAN

Mauch Chunk Formation. CATEGORY 2. Red siltstones and sandstones with some shales, 670 m (2,200 ft).

Pocono Formation. CATEGORY 1. Light gray, quartzitic sandstones and conglomerates, 423 m (1,387 ft).

DEVONIAN

Catskill Formation (in descending order).

One Member. CATEGORY 2. Cycles of red siltstones, sandstones and conglomerates, 295 m (968 ft).

Three Members. CATEGORY 1. Light gray, well indurated sandstones, with some conglomerates and minor red siltstones and shales, 832 m (2,729 ft).

Four Members. CATEGORY 2. Cycles of red shales, siltstones and sandstones in upper half; mixed red and non-red shales, siltstones and sandstones in lower half, 1,268 m (4,161 ft).

SILURIAN AND DEVONIAN

Marine. CATEGORY 3. Sixteen units ascending from Poxono Island Formation through the Trimmers Rock Formation. Upper 1,158 m (3,800 ft) dark gray shales and siltstones. Remainder variety of limestone and dolomite with some sandstone, 1,707 m (5,600 ft).

SILURIAN

Bloomsburg Red Beds. CATEGORY 2. Red shale, siltstone and sandstone, 457 m (1,500 ft).

Shawangunk Conglomerate. CATEGORY 1. Light gray, quartzitic sandstones and conglomerates, 457 m (1,500 ft).

ORDOVICIAN

Martinsburg Formation. CATEGORY 3. Dark gray claystone slate with interbedded siltstones and sandstones, 2,743 m (9,000 ft).

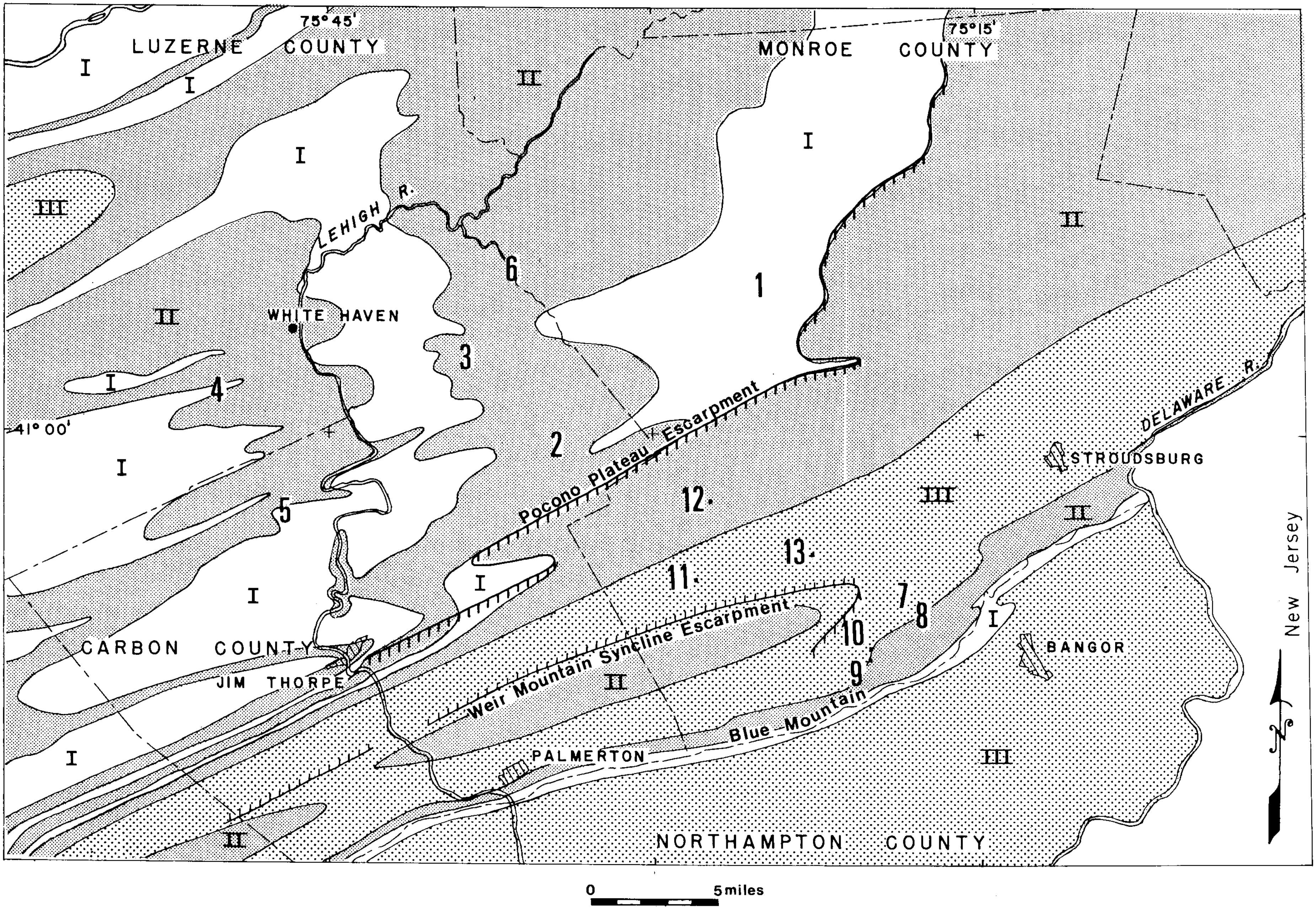


Figure 2. Simplified bedrock map of part of northeastern Pennsylvania. Roman numerals designate rock categories defined in Table I. Arabic numerals are Conference Stops.

Rocks in the western and southeastern part of the area have moderate to steep (45-90°) bedding dips resulting from folding. However, most of the northeastern quarter of the area is monoclinal and has been less intensely folded, with low (5-10°) bedding attitudes and north dips, except for rarely exposed steeper (25-45°) south dips associated with second and third order conjugate kink folds.

GEOMORPHOLOGY

The glaciated part of northeastern Pennsylvania embraces three physiographic areas: the Appalachian Mountain Section of the Valley and Ridge Province, and the Glaciated Low Plateaus Section and Pocono Plateau Section of the Appalachian Plateaus Province. A generalized discussion of the geomorphology of these areas follows.

Appalachian Mountain Section

The Appalachian Mountain Section comprises numerous linear ridges held up by resistant sandstones and conglomerates and adjacent parallel valleys underlain by more erodible siltstones and shales. The rocks in these ridges and valleys have moderate to steep north and south bedding dips and a general N65E strike. Drainage is well developed and, except for the Lehigh River, has a rectangular pattern controlled by regional bedding attitude. Erosion of these folded strata of different resistance has resulted in varied topographic form and striking relief. Blue Mountain, which forms the southern boundary of the section, is one of the most scenic topographic features in the area and rises generally over 305 m (1000 ft) above adjacent topography. Other local and linear topographic elements frequently range from 30 to 90 m (100 to 300 ft) in relief. Slopes are generally moderate to steep. The section is locally bounded on the north by the Pocono Plateau Escarpment (from the Lehigh River eastward to Camelback Mountain). The Wyoming-Lackawanna Basin (north of the Pocono Plateau Section) is also part of this section.

Most of the topography and drainage in this section is pre-glacial in origin and has been only moderately affected by glaciation. Modification has been in the form of valley oversteepening and overdeepening, and deposition of surficial deposits. Pleistocene gravels in tributaries of the Lehigh River (Epstein and others, 1974, p. 215-217), fill in local areas of the Lehigh itself (Epstein and others, 1974, Fig. 129, p. 231), and regional lack of evidence for severe bedrock downcutting since the Illinoian glaciation suggest that stream base level in northeastern Pennsylvania in pre-Illinoian (and probably pre-Pleistocene) time was comparable to the present level. Similar conclusions for western Pennsylvania were reached many years ago by Wright (1894, p. 168-170). The linearity and relief of topography in this section has had some control on glaciation.

All of the stops on the second day of the Conference and Stops 4 and 5 of the first day will be within this section.

Pocono Plateau Section

The Pocono Plateau Section is a broad area of low relief generally attaining elevations of 550 to 670 m (1800 to 2200 ft). The section is approximately bounded on the west by the Lehigh River, on the south and east by the Pocono Plateau Escarpment which displays local relief of 120 to 180 m (400 to 600 ft), and on the north by the Wyoming-Lackawanna Basin (Appalachian Mountain Section). Relief within the section itself is low and seldom exceeds 30 m (100 ft). Steep bedding attitudes in the western part of the section change eastwardly within a very few kilometers to gentle dips. Stated simply, the moderate to high relief and topographic linearity of the Appalachian Mountain Section is replaced by a low-relief surface lacking obvious structural control. Slopes are generally low. Although almost all of this section has been glaciated, and the abundant glacial deposits now obscure the nature of pre-glacial topography, it was probably characterized by low ridges of sandstone and conglomerate, yielding some structurally-controlled drainage and some dendritic drainage.

The pre-glacial topography of this section probably had little effect on glaciation of the area, but the elevation of the plateau and the rock materials present there were important factors in the glacial and periglacial history as will be discussed later.

Stops 1, 2, 3 and 6 of the first day of the Conference will be within this section.

Glaciated Low Plateaus Section

The Glaciated Low Plateaus Section is an area of dissected to undulating topography developed on numerous alternations of moderately well-indurated sandstones and readily erodible shales and siltstones. This section occurs east of the Pocono Plateau Section and north of the Appalachian Mountain Section throughout the remainder of northeastern Pennsylvania. Most of the original topography has been extensively modified by glacial erosion and deposition, but we assume that pre-glacial topography was comparable to that which exists today in the parts of the section having well-integrated drainage. Northwest of Stroudsburg slopes are moderate to steep, local relief is generally up to 90 m (300 ft) and a dendritic drainage system is well developed. Northeast of Stroudsburg (most of Pike County) slopes are low to moderate, local relief is generally less than 30 m (100 ft) and drainage is poorly developed. Glacial erosion has created ledges of resistant sandstone throughout the section. Monoclinal bedding with low dips persist throughout this area where north dips dominate.

No field trip stops are scheduled within this section, but it is an important physiographic entity in the region of this Field Conference.

GLACIAL GEOLOGY

INTRODUCTION

Northeastern Pennsylvania has been glaciated at least three times in the last 150,000 years and possibly one or more times at earlier dates. Each of the three known glaciations has modified the glaciated landscape by erosion and deposition. Each glaciation also had an effect on the landscape peripheral to the area actually covered by ice. These landscape modifications, glacial deposits and peripheral effects are the principal subjects of this Conference guidebook.

The following facts and assumptions are basic to our discussion of glaciation in northeastern Pennsylvania:

1. The successive glaciations were the result of continental ice sheets moving across Pennsylvania generally from north to south. No local mountain glaciation has been proved in Pennsylvania.

2. The climate peripheral to the margin of any continental ice sheet would have been affected considerably by the presence of such great quantities of ice.

3. The separation of northeastern Pennsylvania's glacial deposits into different age categories is based on various physical criteria and geographic arrangement in contiguous areas, and not on observation of superposed materials. In particular, degree of weathering and differential subaerial erosion, two of several criteria originally set forth by Salisbury (1893, p. 71-77) to distinguish glacial epochs, have been most utilized. To date, there is no vertical stratigraphy in the glacial deposits of northeastern Pennsylvania. Coates and Kirkland (1974, p. 103) have suggested that the absence of vertical stratigraphy in the glaciated Appalachian Plateau is most probably the result of ". . . removal of earlier deposits by erosion processes during interglacials." They also suggest, ". . . that early Wisconsinan ice may not have entirely covered the Plateau thus adding an even greater length of time for erosion." The existence of considerable quantities of drift thought to be Illinoian and Altonian in age beyond the limits of Woodfordian glaciation in Pennsylvania makes these propositions untenable. We believe that each successive ice sheet removed most if not all of any pre-existing drift. Coates and Kirkland (1974, p. 103) also suggested this possibility, but did not credit it with much validity.

STRATIGRAPHIC NOMENCLATURE

Stratigraphic classification is the arbitrary but systematic arrangment, zonation, or partitioning of the sequence of rock strata of the earth's crust into units with reference to any or all of the many different characters, properties, or attributes which the strata may possess (Hedberg, 1958, p. 1881-1882). In order to systematize and standardize the classification process, a comprehensive "Code of Stratigraphic Nomenclature" (Am. Com. Strat. Nomen., 1970) was developed which includes four basic categories of stratigraphic units: (1) rock-stratigraphic, (2) soil-stratigraphic, (3) biostratigraphic and (4) time-stratigraphic. In addition, the Illinois Geological Survey (Willman and Frye, 1970, p. 39) recognizes, for use with Pleistocene deposits, a morphostratigraphic unit. The code is precise with regard to the recognition and definition of stratigraphic units. Because we believe that the surficial deposits of northeastern Pennsylvania display no vertical sequence and are not adequately defined with a high level of physical precision, we do not follow the code. Our reasoning follows.

We recognize, in northeastern Pennsylvania, various unconsolidated surficial deposits which we interpret to be the products of glaciation. We believe that we can recognize deposits related to three different glaciations, each separated by a significant period of time. We have only recently recognized subdivisions of any particular glaciation. We do recognize facies extremes in temporally equivalent materials. We also believe that we have reasonable evidence for making some standard age assignments to the materials.

We believe that (1) no type section can represent the diversity of temporally equivalent deposits, (2) a type section in surficial deposits is too impermanent to be of real value and, (3) establishment of a type locality implies more knowledge of a unit than we possess. Therefore, we have not established type localities, and have limited our use of geographic names. When knowledge of surficial deposits in northeastern Pennsylvania indicates a need for greater precision in stratigraphic nomenclature, we recommend that it be applied. Until then, we recommend use of a broad and generalized nomenclature. At present our basic categorization is time-stratigraphic (Illinoian, Altonian, Woodfordian) supplemented by a mixture of morphostratigraphic (end moraine, ground moraine) and genetic (till, ice-contact stratified) terms. The time-stratigraphic framework currently in general use in North America is presented in the Frontispiece along with the position of some of the terms used in the remainder of this text.

PRE-ILLINOIAN DEPOSITS

To date, we have no positive evidence of pre-Illinoian glaciation in northeastern Pennsylvania. However, the evidence throughout the remainder of Eastern and Central United States that both Nebraskan and Kansan glaciations were multiple, and as extensive or more extensive than subsequent glaciations (White and others, 1969, p. 11-15; Reed and others, 1965; Goldthwait and others, 1965) strongly suggests that similar glaciations should have occurred in northeastern Pennsylvania.

Williams (1898; 1902; 1917; 1920) discussed the drift beyond the "terminal moraine" of Lewis (1884) and referred to it as Kansan. Examination of his work makes it clear, as has been pointed out by Leverett, (1934, p. 24) that Williams did not consider these deposits to be significantly older than those of the "terminal moraine". Most, if not all, of the materials he discussed have subsequently been assigned an Illinoian age by Leverett (1934). Williams (1917) does describe numerous deposits and localities which may warrant reexamination.

Leverett (1934, p. 81) suggested that pre-Illinoian drift occurs, ". . . in the valleys of western tributaries of the Lehigh from Broad Mountains southward. . ." particularly ". . . in the vicinity of Lansford, Coaldale and Tamaqua." We have not seen these deposits, but suggest that strip mining in that area has been so intensive as to make interpretation of remnant surficial deposits very difficult. Leverett makes scattered references throughout his report to thin and patchy materials or isolated erratics which may be pre-Illinoian, but these have not been reexamined in recent times in the light of accumulated knowledge.

Epstein (Epstein and others, 1974, p. 207-208) has suggested that a till underlying stratified drift south of Lehigh Water Gap may be either pre-Illinoian, or an early Illinoian till, but its real age is unknown.

G. Gordon Connally, State University of New York at Buffalo (pers. comm.) has suggested that a high chroma red pre-Illinoian till is present south of Blue Mountain in the Stockerton area. We have examined this till and believe it to be Illinoian rather than pre-Illinoian because of its general similarity to other tills of presumed Illinoian age.

To date, no indisputable pre-Illinoian drift is known in northeastern Pennsylvania. Lacking a vertical stratigraphy, we do not find this surprising. Any pre-Illinoian drift which might have been deposited in areas beyond the boundaries of known glaciations would have been subjected to a long period of erosion in a region (Valley and Ridge Province) characterized by steep slopes and mature drainage. There is small probability that any unconsolidated deposit will survive both several hundred thousand years of "normal" erosion and shorter periods of accelerated erosion under climatic regimes peripheral to subsequent glaciations. Probable evidence for such drift would now be limited to occurrence of erratics found by chance or by detailed mapping.

The term Jerseyan occurs in the work of Leverett (1934) and occasionally appears in more recent literature. The name was originally applied in New Jersey by Chamberlin and Salisbury (1906) to materials of glacial origin thought to be older than Illinoian. The name has not found common usage, but is available for use if an acceptable correlation can be made.

ILLINOIAN DEPOSITS

Introduction

When Lewis and Wright (Lewis, 1884) did their work on the "terminal moraine", they were theoretically defining the maximum extent of glaciation in Pennsylvania. They recognized that deposits of glacial origin occurred beyond the limits of the "terminal moraine" (Lewis, 1884, p. 97), but they attributed their origin to the action of glacial meltwater. Salisbury was the first to properly recognize the significance of drift material beyond the "terminal moraine" in Pennsylvania and New Jersey. He cited specific Pennsylvania deposits south of Bethlehem (Salisbury, 1892, p. 179) and near Sunbury (p. 180). Leverett (1934, p. 2-6) adequately reviews other early references to the extra-morainic drifts and discusses the inadequacy of Williams' usage of "Kansan". Leverett (1898) originally applied the name "Illinois" to deposits in the state of Illinois (first mentioned in literature by Chamberlin, 1896) and he was the first to apply the same name to glacial deposits south of the "terminal moraine" in Pennsylvania (1934, p. 13). He also prepared a map to show where Illinoian deposits could be found in Pennsylvania. Shepps and others (1959) were the first to map Illinoian deposits in any detail (scale of 1:125,000) in Pennsylvania and Epstein and others (1974) are the first to have mapped Illinoian deposits in detail (scale of 1:24,000) in northeastern Pennsylvania.

Age and Correlation

Although Leverett (1934, p. 13) was the first to apply the name Illinoian to glacial deposits in Pennsylvania, he gave no real reason for applying the name Illinoian nor has any unquestionable evidence been given as yet for such a correlation. Leverett had previously (1902, p. 221-222) assigned these deposits a Kansan or pre-Kansan age and had indicated (p. 225) that the Illinoian could be taken by direct tracing from Illinois only as far as Holmes County, Ohio. More recent work (Goldthwait and others, 1967) indicates that although the Illinoian is covered by Wisconsinan drift in the area immediately west of Holmes County, Ohio, Illinoian drift reappears almost 50 miles to the east in Stark County, Ohio, and can be traced into Pennsylvania. Shepps (1955, p. 47-52) has argued for an Illinoian age assignment to deposits in northwestern Pennsylvania because of soil profiles, now truncated, thought to have developed on these deposits during the Sangamonian Interglacial.

We have used the following reasoning with respect to the age of presumed Illinoian deposits in northeastern Pennsylvania:

1. A body of uniquely characterized tills and associated stratified drifts occur beyond the southern limits of two Wisconsinan drift borders, and therefore represents a prior and more extensive glaciation.

2. These tills have a thick soil profile unlike any other known in Pennsylvania.

3. This apparently older drift has been subjected to considerable erosion, colluviation and weathering since its subsequent deglaciation, but this degradation has not been sufficient to completely eliminate the drift or destroy the deep soil profile.

4. The paleosol color is unlike any other color developed on glacial materials in Pennsylvania, and is remarkably similar to Sangamon soil profile color developed on well-drained Illinoian deposits in Illinois as defined by Leverett (1898, p. 177) and more recently elaborated on by Frye and others, 1965 (p. 52) and Willman and Frye, 1970 (p. 85).

5. The soil profile is also typified by high clay content, another characteristic of the Sangamon soil in Illinois.

An Illinoian age seems reasonable for these deposits, although we are open to discussion regarding this assignment. The position of the Illinoian in the current North American time-stratigraphic framework is shown in the Frontispiece.

Areal Distribution and Thickness

The maximum known limit of Illinoian glaciation north of Blue Mountain is shown in Figure 1. This limit is based on identification of Illinoian drift and the occurrence of isolated erratics. The erratics could represent remnants of a pre-Illinoian glaciation, but they have been considered Illinoian because of their close proximity to Illinoian deposits. Normally, the erratics are quartzitic sandstone or conglomerate and their degree of weathering is minimal, providing no relationship to the age of glaciation that transported the erratics.

Figure 3 shows the areal distribution of Illinoian deposits in parts of nine 7 1/2-minute quadrangles in northeastern Pennsylvania. Comparison

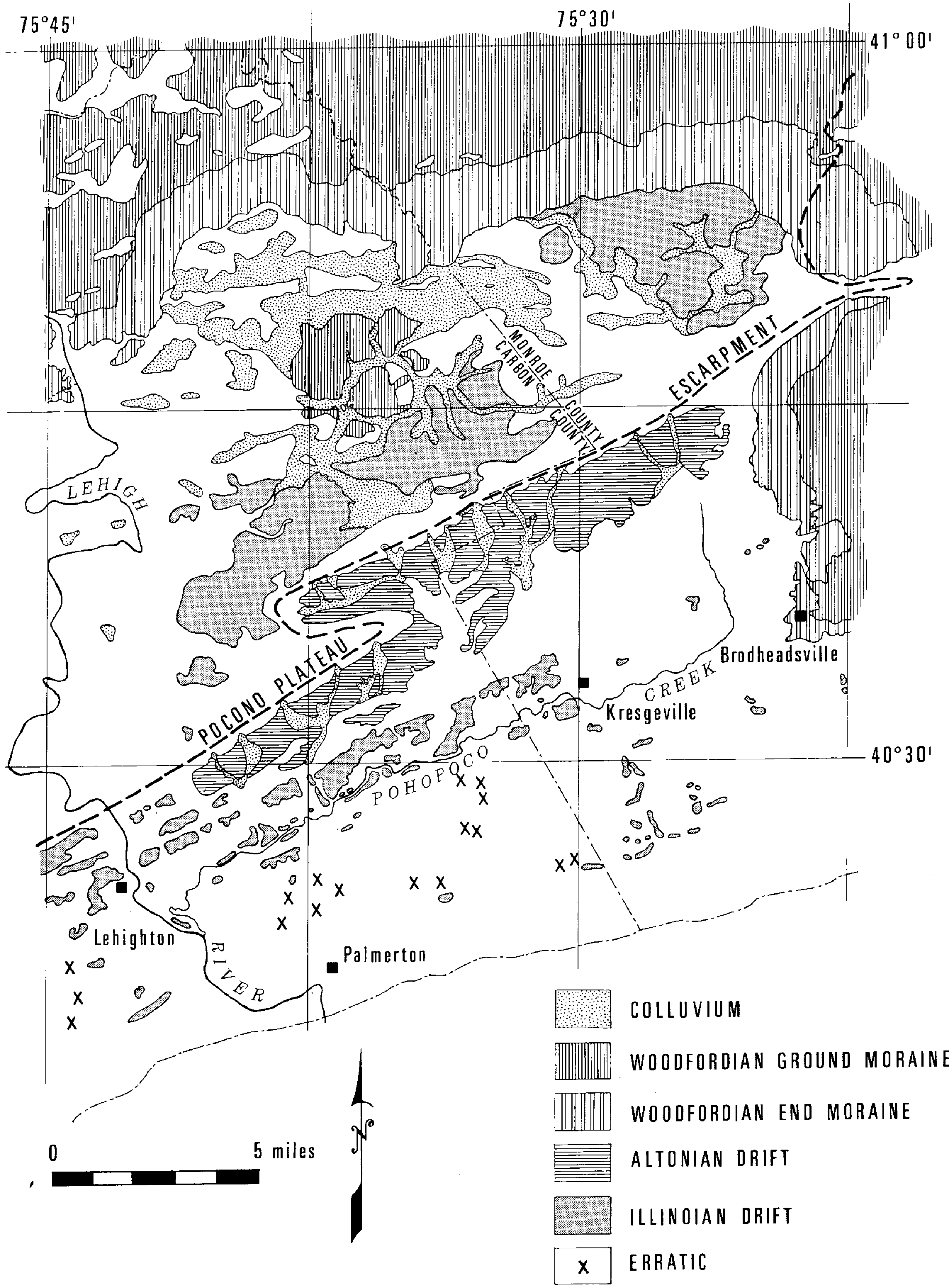


Figure 3. Distribution of Illinoian, Altonian and Woodfordian drift and colluvium north of Blue Mountain in part of north-eastern Pennsylvania.

of Figures 1 and 3 gives some suggestion as to the amount of Illinoian drift which has been eroded since Illinoian deglaciation. We do not imply that the area was once completely covered by drift, but probably at least half of the area had some drift cover. Post-deglaciation erosion has presumably been greater in the Appalachian Mountain Section than in the Pocono Plateau Section, but even on the Plateau a moderate amount of erosion has occurred.

Illinoian till is generally thin and frequently so thin that only scattered erratics and a trace of yellowish red color in freshly plowed fields indicates its former presence. Maximum known thicknesses occur in the area of Long Pond and the Pocono International Raceway on the Pocono Plateau where borings have recorded 3 to 36 m (10 to 117 ft) of what we judge to be Illinoian till. Thinner, isolated masses of till occur on the interfluves adjacent to Pohopoco Creek and Mahoning Creek. Scattered, isolated patches of till (e.g., Mileage 21.1, Day 2) and erratics (e.g., Mileage 19.8, Day 2) occur in the Weir Mountain Syncline. Thicknesses south of the plateau escarpment probably seldom exceed 3 m (10 ft).

Stratified Illinoian drift occurs mainly as terrace deposits along the Pohopoco Creek Valley, and rarely along the Lehigh River (Epstein and others, 1974, p. 213-215; Sevon, 1975 a). The thickness of these deposits occasionally exceeds 3 m (10 ft) and one deposit over 24 m (80 ft) thick occurs east of Lehighton (Epstein and others, 1974, p. 215).

Lithologies

No completely unweathered Illinoian drift has been found in northeastern Pennsylvania. Unweathered Illinoian till has been observed by the writers in northcentral Pennsylvania (new U. S. Route 220 near Montoursville, Lycoming County); moderately weathered Illinoian till south of Williamsport was described by Denny and Lyford (1963, p. 30-34).

Till. Illinoian till in this Conference area is generally a cohesive, unsorted mixture of clay, silt, sand, pebbles and boulders. The colors are generally high in chroma, ranging from red to reddish yellow to yellowish red on the 2.5YR, 5YR and 7.5YR HUE pages of the Munsell Soil Color Charts. Typical colors will be seen at Stop 2 (Day 1) and Stop 11 (Day 2). These red colors are due to iron oxide minerals. Gardner (1966, p. 34) reports between 2 and 5 percent by weight of Fe_2O_3 from 8 Illinoian till samples collected in the Brodheadsville-Pohopoco Mountain area.

Weathering of pebbles and cobbles within the till varies with degree of original induration of the rock and varies from completely rotten to virtually unweathered. Some pebbles and cobbles, particularly shales and siltstones, are rubified (coated with iron oxide) with a distinctive red (2.5YR4/8) (dry) to (10R4/8) (damp) color. This iron oxide coloration sometimes penetrates less well-cemented sandstones. Boulders 0.3 to 0.9 m (1 to 3 ft) in diameter are common and some up to 1.8 m (6 ft) in diameter are known. Striated clasts are extremely rare, due to extensive weathering.

The texture and composition of the till vary from place to place and depend in great measure, on the underlying bedrock. Little detailed work has been done on the coarse fraction composition of Illinoian till in northeastern Pennsylvania, but Samples 2a, d and 11a, b in Table 2 give an idea of the variation. No igneous or metamorphic clasts have been found in Illinoian till in northeastern Pennsylvania. Some rotten limestone clasts have been observed in the Brodheadsville area. A more thorough discussion of the effect of bedrock on general till composition is given in the section on the Woodfordian in this Guidebook. Epstein and others (1974, p. 243-244) indicate that Illinoian drift in northeastern Pennsylvania contains little or no chlorite, but abundant kaolinite and vermiculite; we have analyzed no samples to further substantiate this.

Summaries of some available textural data are presented in Table 2 and Table 3 (locations of samples in this table shown in Figure 4). These analyses suggest a larger clay fraction for Illinoian till than in the Altonian or Woodfordian tills.

In areas where erosion and colluviation have been minimal (e.g. Stop 2, Day 1), the till is more clayey near the surface than at depth (below 1.8 m (6 ft). This reflects the concentration of clay in the B horizon of the Sangamon soil profile. The clay difference is shown in the textural data for Samples 1 and 2 in Table 3. Except for a few places on the Pocono Plateau (e.g., Stop 2, Day 1) this Sangamon B horizon is generally no longer present. In areas where erosion has been extensive and the solum (A and B horizons) removed, the underlying bedrock will determine the proportion of clay to other constituents. In areas where the till has been colluviated, the upper several feet may be very similar to undisturbed Illinoian till, particularly in color and weathering of clasts, but it may be enriched in the upper few feet by locally unroofed bedrock which has been moved downslope by gravity and mixed with the till. Modern soil development frequently occurs in the upper 0.3 to 0.6 m (1 to 2 ft) of the Illinoian till and changes the Illinoian yellow and red colors to light browns. Illinoian till and the Sangamon soil are mapped as the Allenwood soil in Pennsylvania soils reports (Ciolkosz and others, 1971, p. 20-21, 33-34).

Stratified Drift. The few reddish-yellow to yellowish-red Illinoian outwash deposits in northeastern Pennsylvania are moderately to poorly sorted mixtures of sand and gravel with rounded to well-rounded pebbles and cobbles of varying lithologies (e.g., Stop 11, Day 2). Most pebbles are deeply weathered and some are completely rotted. Stratification is moderately good and layers of red to yellowish clay occur rarely. Vertical and lateral variation is generally unknown because of poor exposure.

Geomorphology

Because of the extensive erosion and colluviation which have modified Illinoian drift since the Sangamonian Interglacial, no original constructional topography remains. The till occurs either as thin remnants on upland portions of interfluves in the Appalachian Mountain Section (e.g., see Epstein and others, 1974, Plate 2) or on broad uplands of the Pocono Plateau. Stratified drift occurs as narrow linear terrace remnants along

Table 2. Compositional analyses (counts of 4.76 to 9.52 mm pebbles) and textural data for some Illinoian, Altonian and Woodfordian till and outwash samples from northeastern Pennsylvania. Sample numbers correspond to field trip **Stop** numbers. See **Stop** descriptions for locations of samples. Numerical values are percentages.

Sample No.	sandstone VC-C nr	sandstone M nr	sandstone F-VF nr	sandstone F-VF r	slst-sh nr	slst-sh r	qtz	chert ls	chert wht	chert blk	Gravel	Sand	Silt	Clay	Type Deposit*
1		3	87	9	1						15	51	24	10	Qwt
2a		3	43	31	3	14	6				0	31	51	18	Qit
2b											0	38	36	26	Qit
2c											0	33	43	34	Qit
2d		4	86		10						7	34	33	26	Qit
2e		2	82	7	2	7					11	58	31	10	Qwt
4			71		2	5	22				16	31	46	7	Qwt
5a	14	10		59	2	13	2				34	37	22	7	Qat
5b	3	2	16	55		23	1				12	23	34	31	Qat
6a			93		7						38	27	25	10	Qwt
6b			64	17	2	17					17	42	27	14	Qwt
8a		5	53		24		1	6	3	8	26	40	24	10	Qwt
8b			46	12	8	34					14	33	38	15	Qwt
8c	6	6	63	17	2		6				9	50	24	17	Qwt
8d			51	12	15	22					19	34	33	14	Qwt
9	12		58	5	6	2	3		14		17	31	36	16	Qat
10			4		96						1	27	31	41	Qc
11a			22		78						44	28	17	11	Qit
11b			23		77						22	34	28	16	Qit
11c	1	1	39		59						41	52	5	2	Qio
11d		3	28		69						17	63	12	8	Qio
11e											0	36	56	8	Qio
12a	3	3	44	30	4	12	4				13	43	24	20	Qat
12b			64	8	26	2					23	42	29	6	Qat
12c		2	22	31	2	43					20	34	34	12	Qat
12d			11	44	3	42					22	36	31	11	Qat

*Qwt - Woodfordian till; Oat - Altonian till; Qit - Illinoian till; Qio - Illinoian outwash; Qc - colluvium.

Table 3. Textural data for some Illinoian, Altonian and Woodfordian till samples from northeastern Pennsylvania (see Figure 4 for locations). Textural data from sieve and hydrometer analyses. See text for discussion.

Sample Number	Age	Gravel	Percentage Sand	Silt	Clay
1	Illinoian	38.6	31.1	18.3	12.0
2	"	27.8	35.4	14.5	22.3
3	"	12.9	45.2	20.5	21.4
4	"	28.0	34.3	18.8	18.9
5	"	24.7	31.1	24.6	19.6
6	"	6.4	39.4	10.9	43.3
7	"	17.4	40.3	16.4	25.9
8	"	5.5	47.8	20.4	26.3
9	"	10.5	45.6	31.5	12.4
10	"	7.4	38.0	36.5	18.1
11	"	20.0	30.0	27.0	23.0
Average	Illinoian	18.1	38.0	21.8	22.1
12	Altonian	11.1	35.5	40.6	12.8
13	"	8.7	43.2	33.0	15.1
14	"	38.4	22.4	28.0	11.2
15	"	28.9	40.1	25.0	6.0
Average	Altonian	21.8	35.3	31.6	11.3

Sample Number	Age	Gravel	Percentage Sand	Silt	Clay
16	Woodfordian	17.2	48.4	13.7	20.7
17	"	34.4	32.4	25.4	7.8
18	"	21.5	35.2	23.0	20.3
19	"	49.1	28.5	11.5	10.9
20	"	54.2	30.4	8.2	7.2
21	"	16.0	30.0	29.0	25.0
22	"	20.6	43.9	15.2	20.3
23	"	34.0	50.0	8.0	8.0
24	"	25.0	28.0	26.0	21.0
25	"	16.0	35.0	24.0	25.0
26	"	30.0	23.0	31.0	16.0
27	"	42.0	26.0	17.0	15.0
28	"	24.0	29.0	24.0	23.0
29	"	19.3	38.5	19.9	22.3
30	"	22.3	50.7	6.3	20.7
31	"	38.7	31.1	18.6	11.6
32	"	14.3	41.9	19.6	24.2
33	"	31.6	39.3	14.2	14.9
34	"	55.9	24.3	9.7	10.1
35	"	52.7	23.0	12.4	11.9
36	"	35.6	31.3	17.0	16.1
37	"	49.8	24.0	12.3	13.9
38	"	33.1	33.7	14.5	18.7
39	"	26.8	44.4	13.3	15.5
Average	Woodfordian	31.8	34.3	17.2	16.7

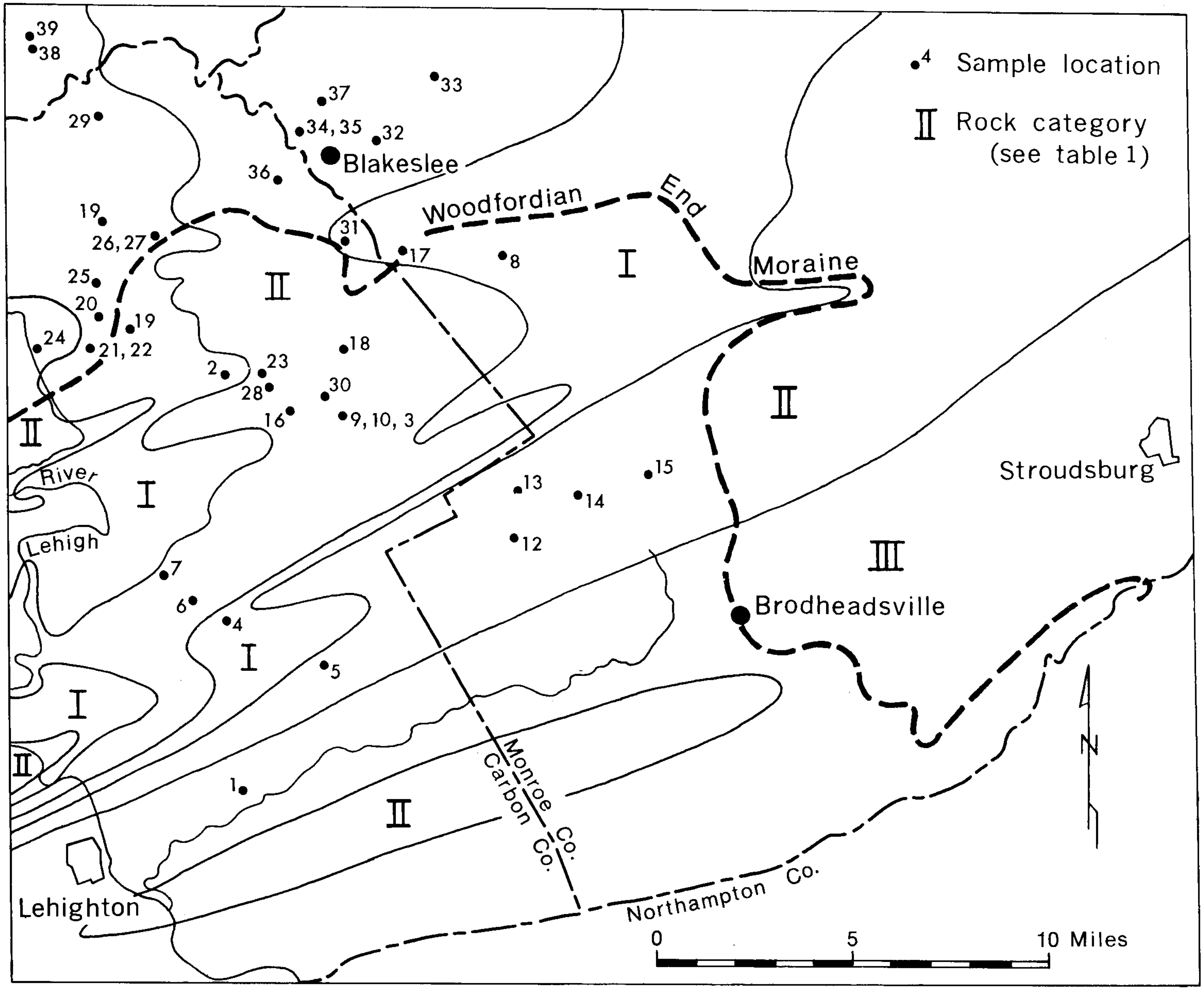


Figure 4. Location of Illinoian, Altonian and Woodfordian till samples in northeastern Pennsylvania. See Table 3 for textural data for samples and Table I for bedrock categories.

Pohopoco Creek, Aquashicola Creek, Mahoning Creek and the Lehigh River. The upper surface of an Illinoian terrace is generally no longer flat, having been rounded or dissected by erosion. Along the Lehigh River, only small remnant deposits are perched precariously on steep slopes. In some cases (e.g., Stop 11, Day 2) Illinoian stratified drift and till has been covered by a blanket of bedrock colluvium, and is buried beneath what falsely appears to be a low to moderate slope developed on bedrock.

Contacts

Exposures of undisturbed basal contacts of Illinoian drift are extremely rare in northeastern Pennsylvania, but we will see a basal contact with Mahantango shale at Stop 11, Day 2. We assume that basal contacts are usually with bedrock since we have no evidence of pre-Illinoian drift in the Conference area. We have observed no surfaces striated by Illinoian ice. Our observations of Illinoian drift suggest that it is overlain only by colluvium with either a sharp contact or a zone of mixing between the deposits. Nowhere have we seen Wisconsinan drift overlying Illinoian drift.

Exposures

Natural exposures of Illinoian drift are rare in the area. The best exposures occur in temporary excavations such as house foundations or borrow pits (e.g., Stop 2, Day 1; Stop 11, Day 2). Available exposures are generally limited to shallow roadcuts or ditches. Extensive hand angering and trenching are required for accurate mapping.

Mineral Resources

Clay-rich Illinoian till from a site along Pa. Route 443 just west of Lehighton and at Stop 2 (Day 1) on this trip, has been utilized to seal the bottoms of small ponds to prevent leakage. This low-permeability till was also utilized as the impervious core for the Beltsville earth-fill dam. The till at Stop 2 (Day 1) is mixed with broken Catskill sand-stone extracted from the same quarry, and used as base-course for roads in Towamensing Trails Development. The till was used as random fill in constructing the embankments for Pocono International Raceway (Mileage 20.8, Day 1).

Illinoian stratified drift has not been utilized to any extent in northeastern Pennsylvania because of the highly weathered character of the gravel, and the relatively small size of most deposits.

Engineering and Environmental Characteristics

The Illinoian drift in northeastern Pennsylvania has no known ground water potential. There are potential problems for onsite disposal of sewage effluent because of low permeability, but there is potential for sewage lagoons and sanitary landfill sites for the same reason. Illinoian drift displays limited cut-slope stability because it is un-consolidated, and sticky and slippery when wet. It has a color which is sometimes undesirable particularly when introduced into groundwater supplies.

Illinoian History

Because we have observed no Illinoian-age glacial striations and have done no fabric analyses of Illinoian lodgement till, we have no positive evidence of the direction of ice-flow in northeastern Pennsylvania during the Illinoian. We suspect that ice movement may have had a more northeast-southwest orientation than Woodfordian ice-movement, and that the linear topography of Blue Mountain, and the Weir Mountain Syncline and Pocono Plateau Escarpments may have controlled the main flow of ice as is suggested in Figure 5. Nothing is known about the source of the lobe, but the configuration of the glacial margin in this area, the large amount of Illinoian drift south of Blue Mountain and the large amount of glacial erosion accomplished in Pohopoco Creek Valley suggests that a lobe of Illinoian ice may have moved into northeastern Pennsylvania from east of the Catskill Mountains of New York. Although suspected, there is no evidence to confirm convergence of this lobe with another which moved west of the Catskill Mountains and into northeastern and northcentral Pennsylvania. We are lacking evidence to indicate whether or not Blue Mountain was always free of ice as it appears in this area or whether it was topped farther northeast as it was later during the Late Wisconsinan.

Glacial erosion by Illinoian ice is demonstrably excessive only in the Pohopoco Creek Valley. Between Brodheadsville and Kresgeville the valley has been excavated to a depth of 46 to 61 m (150 to 200 ft) and later filled with drift, mainly Woodfordian outwash, according to our interpretation of water well data. The south side of the valley, the Weir Mountain Syncline Escarpment, has been oversteepened in some places and subsequently covered with hillslope colluvium (Plate 1, A). This excessive glacial erosion supports the idea that the main ice movement in this conference area was controlled by the Weir Mountain and Pocono Plateau Escarpments. Thin, patchy deposits and lack of evidence of excessive glacial erosion immediately south of Pohopoco Creek Valley (within the Weir Mountain Syncline) suggests that ice overrode the escarpment, but was thin, caused minimal erosion and deposited little material.

There is no distinctive Illinoian end moraine in northeastern Pennsylvania. The nature and distribution of drift and erratics suggests that the ice reached its point of maximum advance as a thin ice sheet and immediately began ablation without significant deposition at the front margin. During the final phases of advance the Lehigh River was probably dammed in the vicinity of Jim Thorpe and a lake of unknown dimensions was created in that drainage basin as well as in Mahoning Creek Valley west of Lehighton.

During Illinoian deglaciation the Lehigh River valley was apparently filled with at least 15 m (50 ft) of outwash (Sevon, 1975a) and much outwash was deposited on Illinoian till in the Pohopoco Creek valley as the ice margin wasted farther and farther to the east. Nothing is known about Illinoian glaciation or deglaciation in areas where the Wisconsinan glaciers advanced.

One major drainage network change seems to have been effected in the area as a result of the Illinoian glaciation. This modification is illustrated by a sequence of diagrams in Figure 6. This drainage network was subsequently altered by Wisconsinan glaciation. Further, and

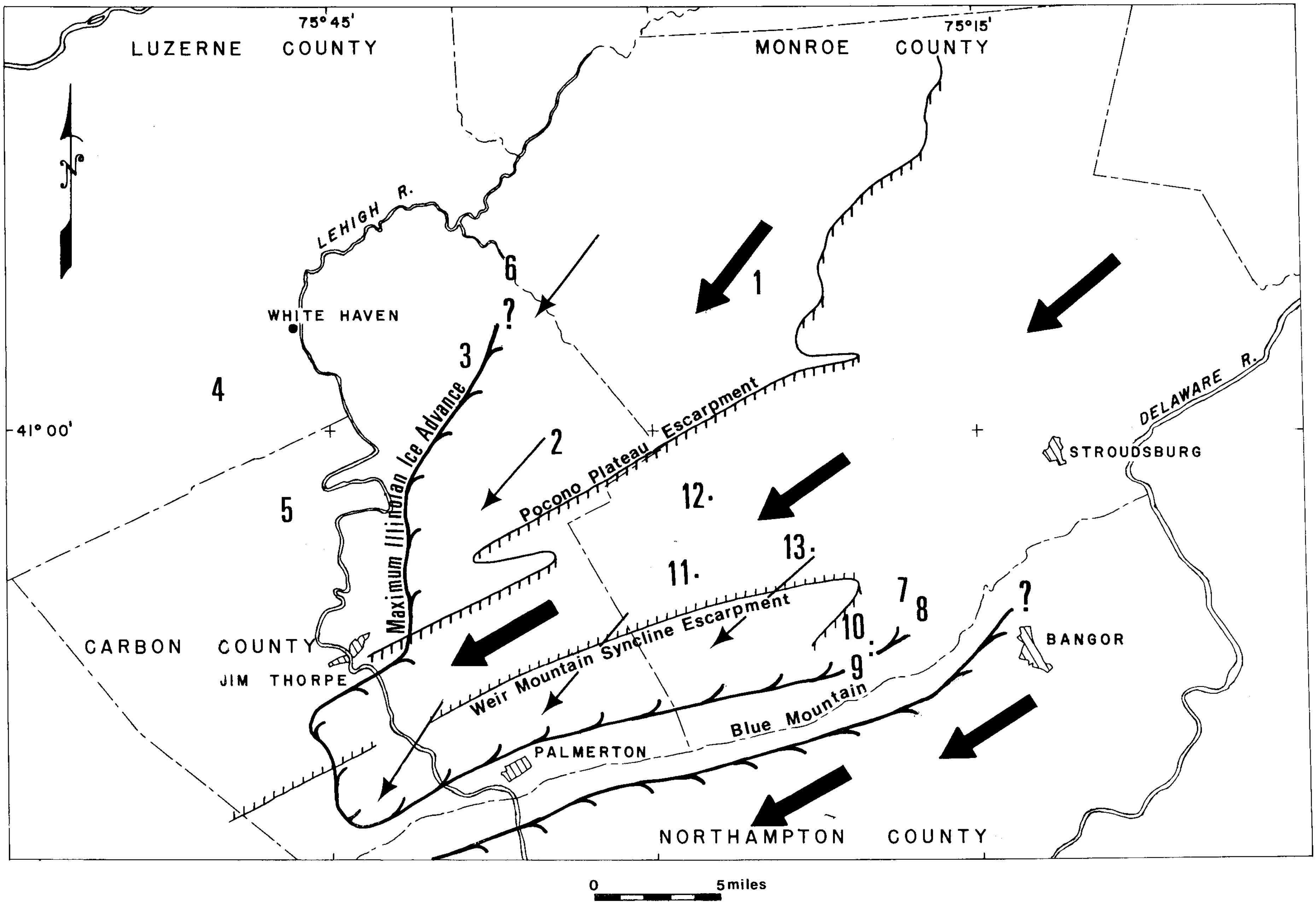


Figure 5. Hypothetical ice flow in northeastern Pennsylvania during Illinoian glaciation.

somewhat different speculations regarding this drainage are presented by Gardner (1966, p. 72-74).

Following deglaciation the Illinoian drift underwent deep weathering under climatic conditions of greater warmth and rainfall than today. The climatic conditions of the Sangamonian Interglacial Stage (Flint, 1971, p. 551-553) were well reviewed by Ruhe in 1970 and 1974. The weathering during this pluvial period was more intense than that affecting the glaciated parts of North America today, and resulted in very deep oxidation, with concentration of abundant iron oxide and downward movement and concentration of clay. The Sangamonian soil profile which characterizes Illinoian drift is the product of this intense weathering.

Extensive erosion and colluviation of Illinoian drift occurred during the Wisconsinan glaciations, resulting in the removal of much drift, the covering of some drift and the mixing of some drift with bedrock-derived debris.

ALTONIAN (PRE-FARMDALIAN WISCONSINAN)

Introduction

In his discussion of glacial deposits outside the "terminal moraine", Leverett (1934) did not recognize any drift intermediate in age between Illinoian and Wisconsinan. Higbee (year unknown) indicates an early Wisconsinan age for the "terminal moraine" drift in almost all of eastern Pennsylvania and places all drift beyond the "terminal moraine" in the Illinoian or "Jersian" [sic]. Denny and Lyford (1963, Plate 3, p. 20-21) assigned all of the Wisconsinan "terminal moraine" drift a post-Sangamonian and pre-Farmdalian age. No other workers prior to this decade have recognized a post-Sangamonian-pre-Late Wisconsinan drift.

G. Gordon Connally, S.U.N.Y. Buffalo, in about 1972 (unpublished), was the first to recognize in the Saylorsburg area the existence of glacial deposits intermediate in temporal and geographic position between Illinoian and Late Wisconsinan drifts. Similarly positioned deposits have been documented by Sevon (1973 and 1974).

Drift of apparently similar temporal position has recently been recognized south of Blue Mountain in the Easton area by Donald Cadwell, Lafayette College (1975, pers. comm.). Crowl (unpublished) has recognized similar deposits west of the Lehigh River (e.g., Stop 5, Day 1). Drift of Early Wisconsinan age is well known in western Pennsylvania (White and others, 1969).

Age and Correlation

Connally (unpublished) originally assigned no formal time terminology to this intermediate-age drift in northeastern Pennsylvania, but recognized mainly that the material did not have the weathering character of either the Late Wisconsinan or Illinoian drift in the area. No means of absolute dating for this drift have been found as yet, and the following facts are used to argue for an age intermediate between Sangamonian and Late Wisconsinan.

1. The drift does not possess a Sangamonian weathering profile typical of the Illinoian drift of the Conference area, either in depth of oxidation or concentration of iron oxide, but is weathered to a greater depth than Late Wisconsinan drift in the area and possesses a thicker soil profile than Late Wisconsinan drift in similar topographic settings.

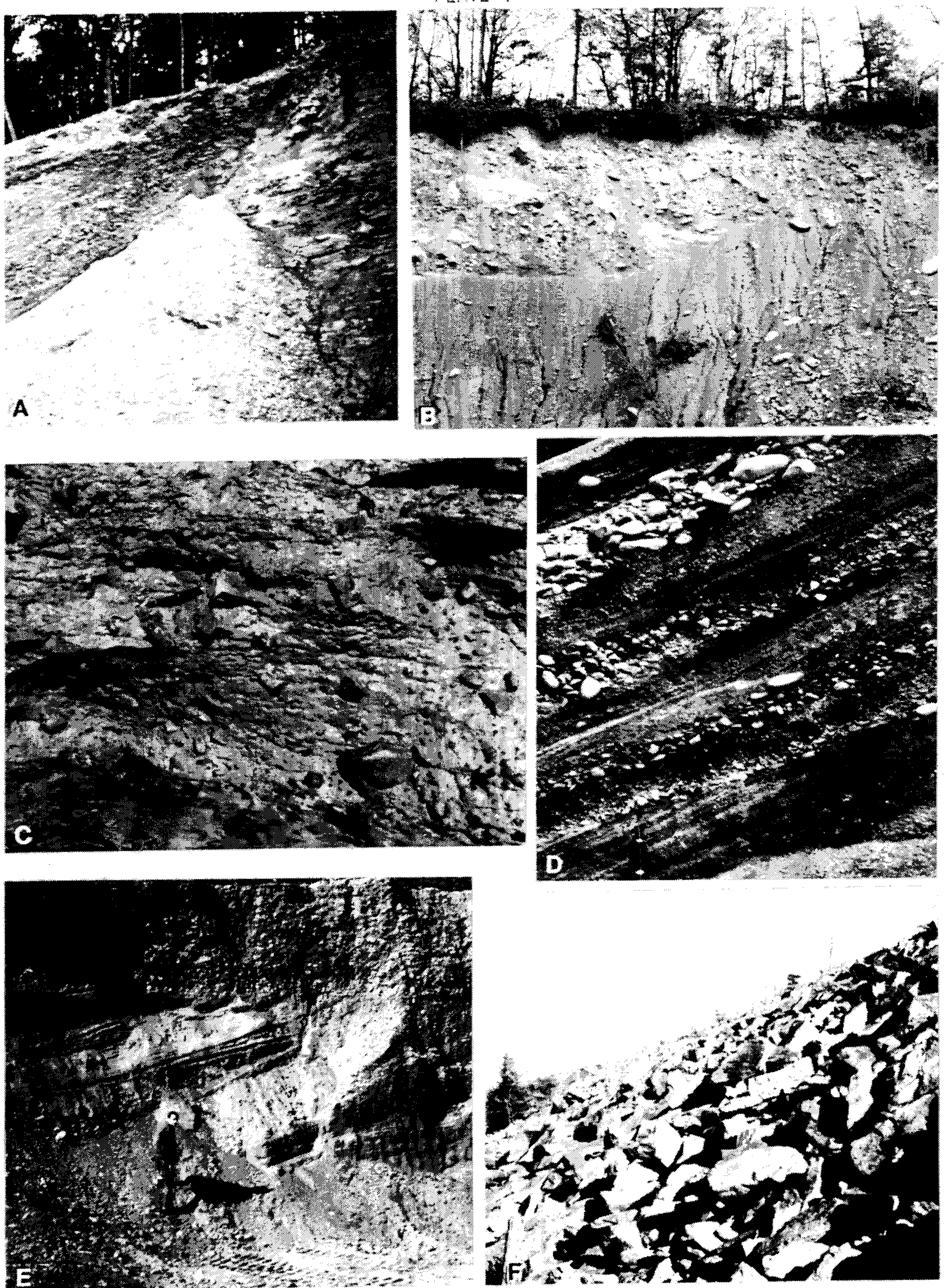
2. The drift has not been as extensively eroded as Illinoian drift of the area, but has been sufficiently eroded and colluviated that almost all original constructional topography has been destroyed. Some till has been covered by colluviated bedrock. Late Wisconsinan drift still preserves its original constructional topography and has been only locally colluviated on steep slopes.

3. The areal position of the drift indicates deposition by an ice advance of less magnitude than that of the Illinoian, but locally of greater magnitude than that of the Late Wisconsinan.

Since direct correlation of the intermediate age deposits in northeastern Pennsylvania is not yet possible, the age of these deposits must be inferred by comparing the above facts with other regions. Diagrammatic stratigraphic summaries of drift deposited by the Ontario-Erie Lobe in northwestern Pennsylvania and Ohio have been presented by Goldthwait and others (1965, p. 94, Fig. 6) and Dreimanis and Goldthwait (1973, p. 81, Fig. 3). Although there is some divergence in these summaries as to the maximum southern extent and timing of a Mid-Wisconsinan glaciation about 40,000 years ago, these summaries both indicate substantial Early and Mid-Wisconsinan glaciations. Muller (1964; 1965, p. 105) presents evidence for the probable existence of a pre-Farmdalian Wisconsinan glaciation in the Salamanca, New York, area. No information is available regarding the presence or absence of pre-Farmdalian Wisconsinan glacial deposits in New Jersey. The weathering and surface character of the Titusville Till in northwestern Pennsylvania (White and others, 1969, p. 27-30) is very similar to that of the intermediate-age drift in northeastern Pennsylvania and suggests a possible correlation. The Titusville Till is considered Early Wisconsinan (Altonian) in age by White and others (1969, p. 9, 30-31),

Plate 1. A. Oversteepened Pohopoco Creek valley wall. South side of Pohopoco Creek valley oversteepened by Illinoian glaciation and subsequently covered by hillslope colluvium. Photo looking northeast at site of south abutment for Beltsville dam. Bedrock is Trimmers Rock Formation. B. Exposure of Altonian ice-contact stratified drift overlain by Altonian till with well-developed soil profile. Exposure in Drumbor Sand and Gravel Pit near Weatherly, Pennsylvania (Stop 5, Day 1). C. Woodfordian lodgement till exposed in Buck Hill Creek, northwest of Mountainhome, Monroe County. D. Bedding and sorting variation in Woodfordian ice-contact stratified drift in kame near Blakeslee, Monroe County. E. Foreset and topset beds in Woodfordian kame delta deposit. Exposure at Lehigh Valley Sand and Gravel Company borrow pit, Brodheadsville, Monroe County (Stop 13, Day 2). T. M. Berg provides scale. F. Talus developed from Palmerton Sandstone.

PLATE 1



but as Mid-Wisconsinan in age by Goldthwait and others (1965, p. 94, Fig. 6) and Dreimanis and Goldthwait (1973, p. 81, Fig. 3). Remember that there is demonstrable superimposed drift stratigraphy in northwestern Pennsylvania and Ohio.

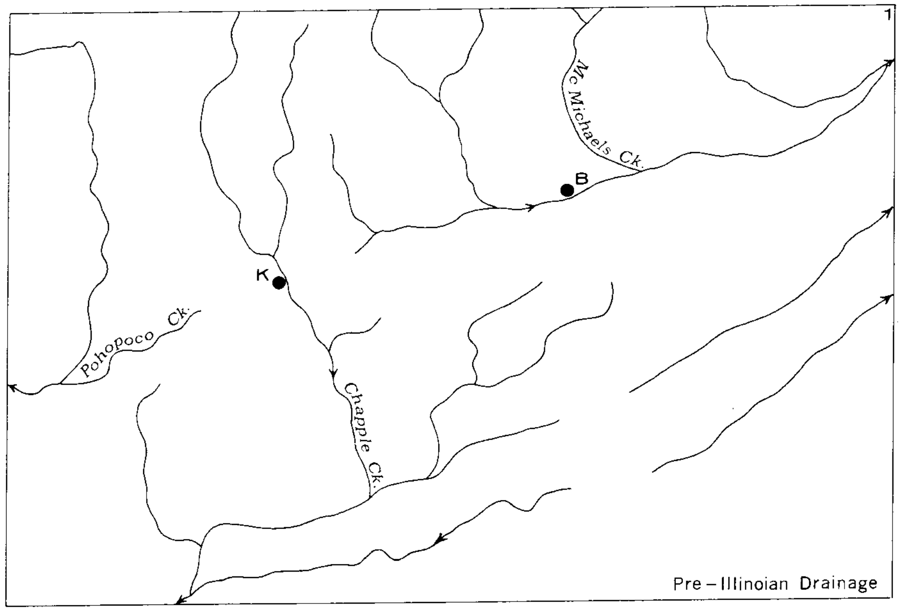
The available facts indicate: that a drift of intermediate age between Sangamonian and Late Wisconsinan exists in northeastern Pennsylvania; that this drift may correspond with either Early or Mid-Wisconsinan glaciations; and that positive correlation is currently lacking. Therefore, we are assigning this drift, tentatively, to the Altonian Substage until such time as its exact stratigraphic position becomes clearly known. We feel that the degree of soil development on this drift is probably sufficient to indicate an Early Wisconsinan age and is possibly equivalent in time to the Chapin Soil of Illinois (Willman and Frye, 1970, p. 86-87). However, the possibility of a Mid-Wisconsinan age, possibly equivalent in time to the Pleasant Grove Soil of Illinois (Willman and Frye, 1970, p. 87), cannot be excluded at present. This assignment does not imply any rock-stratigraphic correlation with the type Altonian in Illinois (Frye and Willman, 1960, p. 5-6). Our assignment is in the time-stratigraphic sense clearly stated by Willman and Frye (1970, p. 121). They placed the base of the Altonian Substage on the A-zone of the Sangamon Soil and the top of the substage at the top of deposits with radiocarbon dates of about 28,000 B.P. We believe that deposits here called Altonian adhere to those criteria.

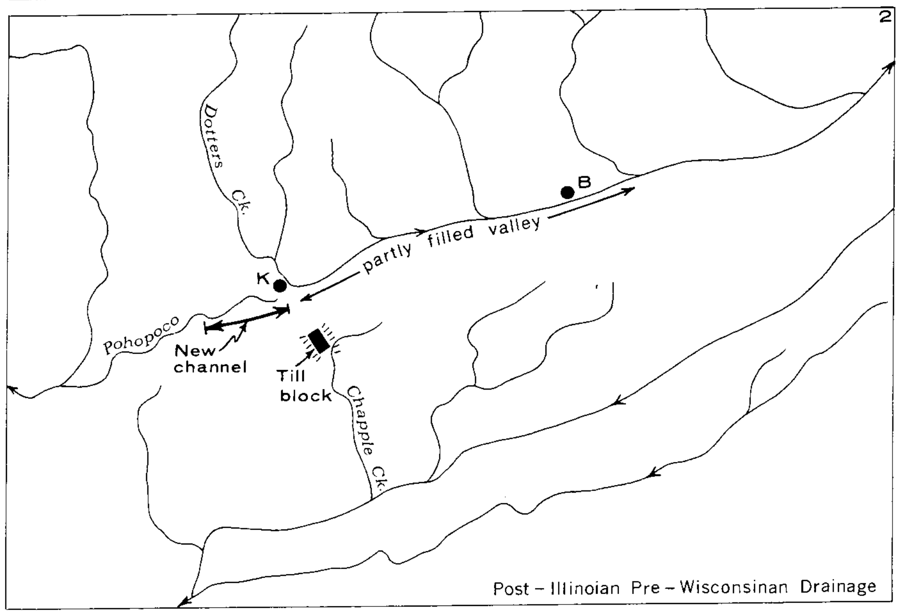
Areal Distribution and Thickness

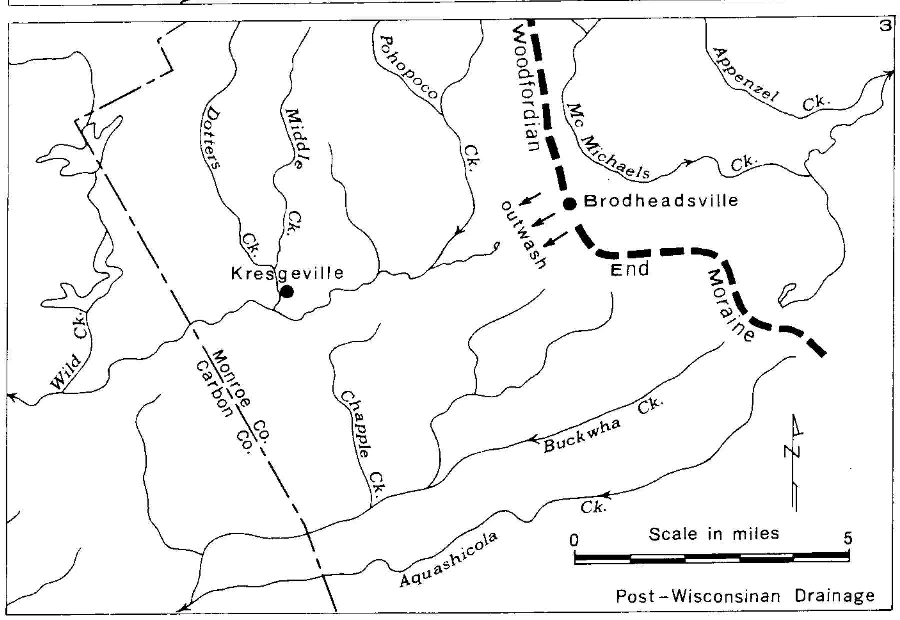
The maximum known limit of Altonian glaciation north of Blue Mountain is shown in Figure 1. This limit is based on identification of Altonian drift.

Figure 3 shows the areal distribution of the actual deposits in parts of nine 7 1/2-minute quadrangles in northeastern Pennsylvania. Compare Figures 1 and 3 to see the amount of Altonian drift which has probably been eroded or covered with colluvium since Altonian deglaciation.

Figure 6. Drainage network changes resulting from glaciation in part of southwestern Monroe County, Pennsylvania. 1. During pre-Illinoian drainage ancestral Dotters Creek flowed through the present Chapple Creek Valley while most of the area between Brodheadsville (B) and Kresgeville (K) drained eastward. 2. During Illinoian glaciation and deglaciation the relatively soft shales underlying the future Pohopoco Creek Valley were eroded considerably and the valley was partly filled with drift. Chapple Creek Valley was blocked with drift and Dotters Creek drainage was diverted to the east. 3. No modification is hypothesized during Early Wisconsinan glaciation, but Late Wisconsinan glaciation had considerable effect. The Woodfordian end moraine created an effective drainage divide in the area and the outwash from the melting ice filled Pohopoco Creek Valley from Brodheadsville to Kresgeville creating a base for stream flow diversion to Pohopoco Creek.


1
Mc Michaels Ck.
B
K
Pohopoco Ck.
Chapple Ck.
Pre – Illinoian Drainage


2
Dotters Ck.
B
partly filled valley
K
Pohopoco
New channel
Till block
Chapple Ck.
Post – Illinoian Pre – Wisconsinan Drainage


3
Pohopoco Ck.
Woodfordian
Appenzel Ck.
Mc Michaels Ck.
Dotters Ck.
Middle Ck.
Brodheadsville
outwash
End Moraine
Kresgeville
Wild Ck.
Monroe Co.
Carbon Co.
Chapple Ck.
Buckwha Ck.
Ck.
Aquashicola
0 Scale in miles 5
Post – Wisconsinan Drainage

Altonian till is moderately thick to thin. Maximum known thicknesses of up to 30 m (100 ft) occur in the area of Walcksville and probably represent deposits accumulated between the margin of Altonian ice and a topographic barrier. Records from a few water wells in the area and from exploratory drilling for the Pennsylvania Turnpike Northeast Extension indicate average thicknesses of 1.5 to 6 m (5 to 20 ft) and local thickness in excess of 18 m (60 ft). As indicated on Figure 3, Altonian till is more or less continuous and thickest along the base of the Pocono Plateau Escarpment; it becomes less continuous and thinner farther south and away from the escarpment. The distribution of Altonian till in the Saylorsburg area (Stop 9, Day 2) is not known, but is thought to be very limited. Moderately extensive deposits occur in the Weatherly area (Stop 5, Day 1), but they have not been mapped as yet and their thickness is unknown.

Stratified drift of Altonian age has been identified only in the Weatherly area (Stop 5, Day 1) where ice-contact sands and gravels over 12 m (40 ft) thick are overlain by Altonian till. Some of the terrace sand and gravel deposits along the north side of Pohopoco Creek, particularly those along Wild Creek, may be Altonian rather than Illinoian, but this has not been proven.

Little is known about the distribution and thickness of probable Altonian deposits south of Blue Mountain in the Easton area.

Lithologies

Till. Unweathered Altonian till is a moderately cohesive to cohesive mixture of clay, silt, sand, pebbles, cobbles and boulders 0.3 to 0.9 m (1 to 3 ft) in diameter. Matrix tends to be sandy and silty (see Table 2, Samples 5a, b; 9; 12a, b, c, d, and Table 3, Samples 15-18). Colors are generally reddish brown (2.5YR4/4 to 5YR5/3) and reflect the color of underlying bedrock (Category 2 rocks, Table 1). Material coarser than 8 cm (3 in.) in diameter is moderate to abundant and is dominated by angular to subrounded cobbles of gray sandstone or red siltstone derived from the Catskill Formation. Pebbles and cobbles in unweathered Altonian till are quite fresh and finer-grained lithologies are often striated. Similar pebbles and cobbles in the soil zone are weathered and may have weathering rinds up to 1 cm (0.4 in.) thick.

The texture and composition of the till varies with the underlying parent bedrock, but shows broad homogeniety in the Conference area because of bedrock uniformity. Pebble counts in Table 2 give an idea of the variation. Greater variation in composition would be anticipated in areas of more diverse underlying bedrock. No igneous or metamorphic clasts have yet been found in Altonian till in northeastern Pennsylvania.

A complete soil profile developed on Altonian till is rarely preserved because of erosion and colluviation during the Late Wisconsinan, but an excellent example is preserved near Weatherly (Stop 5, Day 1) (Plate 1, B). The profile comprises a thin A horizon which probably reflects recent development and a well developed and brightly-colored reddish brown B horizon about 1.5 m (5 ft) thick. Another soil profile exposed north of Effort (Stop 12, Day 2) suggests a similar thickness and development of B horizon. This B horizon thickness is an important characteristic of Altonian deposits. In many places only 0.3 to 0.9 m (1 to 3 ft) of the original B horizon remain and most of the till is fresh. Limited exposure in northeastern Pennsylvania and good exposure in northcentral Pennsylvania (north of Williamsport) suggests that weathering prisms (intensely leached light gray sub-vertical fractures) developed in Altonian till may extend to depths of over 3 m (10 ft) below the surface. Recent soil development is not always apparent and easily differentiable from Altonian soil development in shallow exposures because of the lack of obvious color contrasts such as are present in the Illinoian drift.

Stratified Drift. Altonian stratified drift is known only at the kame complex near Weatherly (Stop 5, Day 1). The sediments are dominantly sand and some gravel. The material is generally fresh and, although some weathering of the cobbles and boulders has occurred, most of the coarser material is fresh. More information regarding this deposit is given with the Stop description (Stop 5, Day 1).

Geomorphology

Erosion and colluviation have destroyed or modified most of the original constructional topography associated with Altonian drift, but two areas appear to retain subdued constructional topography. Open fields immediately east of the road intersection at Jonas, about 7.5 km (4.5 mi.) north of Kresgeville (approximately 40°58'06"N/75°30'42"W), have very low relief (1.5 to 3 m) (5 to 10 ft) hummocky topography which may have been associated with local end moraine development. A low ridge of till which may be a remnant lateral moraine along the Pocono Plateau Escarpment occurs on the north side of a road in Wild Creek Valley west of Penn Forest Reservoir (approximately 40°56'30"N/75°43'00"N). In most of northeastern Pennsylvania some erosion has occurred and Altonian drift has either been removed or topographically modified to rounded slopes. Periglacial colluviation was extensive during the Late Wisconsinan glaciation, and in some areas Altonian till has been covered with local bedrock colluvium (south of Pocono Plateau Escarpment) or covered with a mixture of Altonian till and bedrock colluvium.

Contacts

We have observed no basal contacts of Altonian drift in northeastern Pennsylvania. We assume any such contacts would be with bedrock rather than Illinoian drift. No surfaces striated by Altonian ice have been observed. Observed Altonian drift suggests that it is overlain only by colluvium (bedrock colluvium or colluviated Altonian drift) with either a sharp contact or a thin zone of mixing between the deposits.

Exposures

Natural exposures of Altonian drift are rare in this Conference area, but artificial exposures in ditches and roadcuts are common. Borrow pit exposures (e.g., Stop 5, Day 1) are rare. Available exposures generally show only part of the thick B horizon, not unweathered till.

Mineral Resources

Altonian till has not been utilized for any purpose other than random fill and is somewhat limited for that purpose because of stoniness. The stratified drift near Weatherly (Stop 5, Day 1) is currently being excavated for sand and an abandoned pit nearby once produced gravel. The quality of this material is good, but known reserves are limited and no large sand or gravel production is anticipated from stratified Altonian drift in northeastern Pennsylvania.

Engineering and Environmental Characteristics

The Altonian drift in northeastern Pennsylvania has no known ground water potential. It has limited potential for onsite disposal of sewage effluent because of low to moderate permeability, and has limited potential for sewage lagoons and sanitary landfill sites because of variable permeability. These deposits have limited cut-slope stability because of their unconsolidated nature, and are easily excavated with light equipment.

Altonian History

As is the case with the Illinoian glaciation, we have no positive evidence of the direction of ice-flow in northeastern Pennsylvania during the Altonian. Again, we suspect a strong influence on ice flow by Blue Mountain and the Pocono Plateau Escarpment, and suggest that an ice lobe entering northeastern Pennsylvania from east of the Catskill Mountains of New York was confined to the lower elevations south of the Pocono Plateau Escarpment and Blue Mountain (Figure 7). The lack of Altonian drift on the Pocono Plateau east of the Lehigh River and south of the Woodfordian end moraine suggests that the ice in that area was less extensive than ice during the Late Wisconsinan.

The lobe of ice which reached to Weatherly deposited a large amount of ice-contact stratified drift and till in that area, possibly as a complex end moraine in which the original constructional topography has subsequently been subdued. No other end moraine is known for the Altonian glaciation nor is any Altonian outwash proved. Nothing is known about Altonian deglaciation except that no stratified drift deposits can be positively assigned to that deglaciation. Ice-contact stratified drift is recognized only near Weatherly (Stop 5, Day 1).

Nothing is known about erosion by the Altonian ice sheet. Since no occurrences of Altonian drift overlying Illinoian drift have been found, we can only assume that the Altonian ice probably eroded most if not all of the Illinoian drift encountered. We have not been able to differentiate any periglacial features beyond the limits of Altonian drift from those which may be attributable to Late Wisconsinan climatic conditions. We do entertain a hypothesis of multiple colluviation at Stop 10 (Day 2).

If the assumption is made that what we designate as Altonian drift in northeastern Pennsylvania is Early Wisconsinan -- then, since deglaciation, that drift has been subjected to: (1) a warm to hot climate during which its excellent soil profile developed; (2) unknown effects during subsequent Altonian ice advances; (3) cool and moist conditions

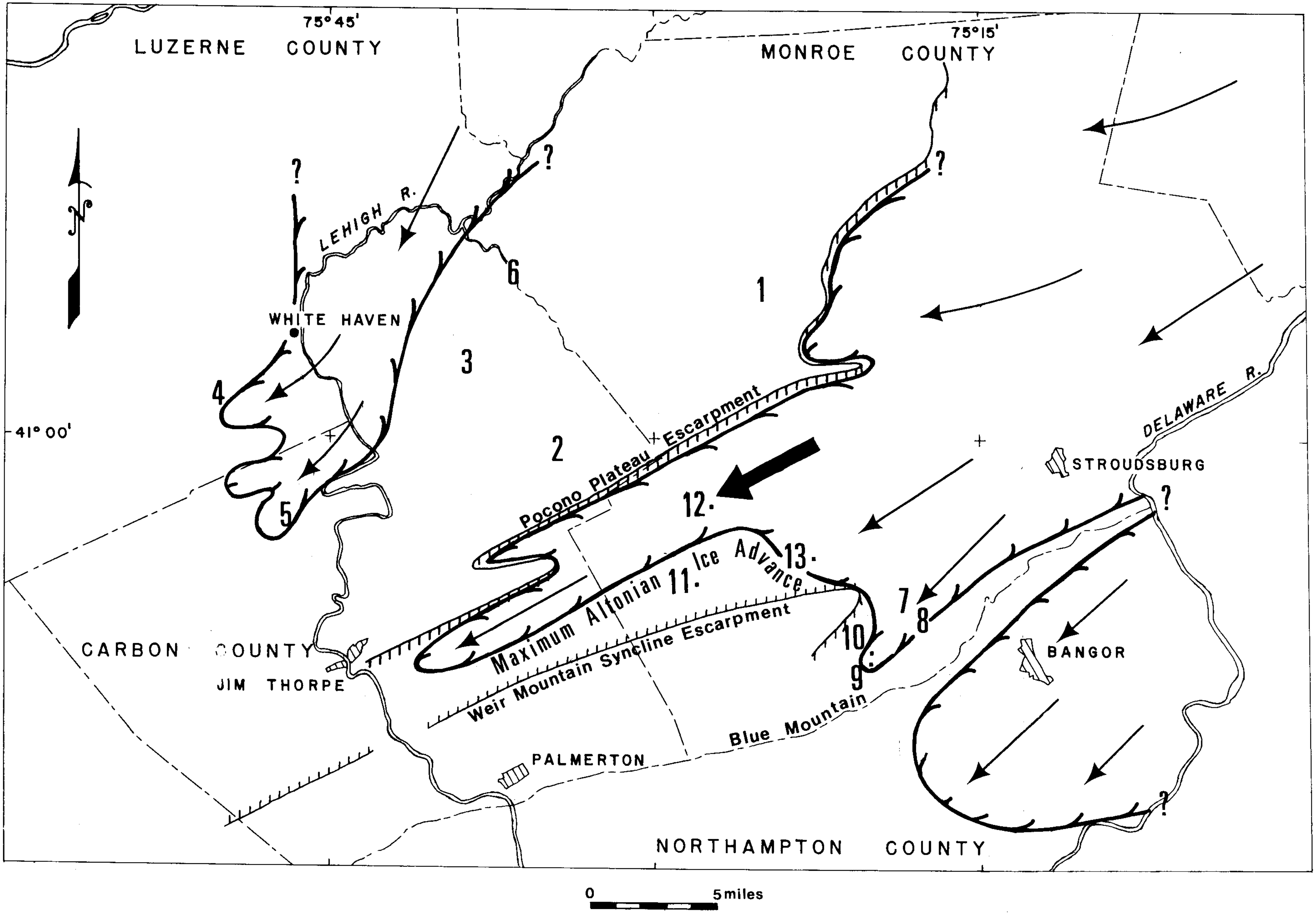


Figure 7. Hypothetical ice flow in northeastern Pennsylvania during Altonian glaciation.

during the Farmdalian Substage; (4) colluviation during the periglacial conditions associated with Late Wisconsinan glaciation; and (5) superimposition of a recent soil profile on its paleosol.

WOODFORDIAN (LATE WISCONSINAN) DEPOSITS

Introduction

The classic work tracing the limits of the last glaciation in Pennsylvania is that of Lewis and Wright (Lewis, 1884). Current remapping of the border (Crowl, 1972) indicates only minor changes in the "terminal moraine" as a physical border, but considerable conceptual revision of this border as a genuine terminal moraine (Crowl, 1975). Deposits of this glacial substage have been moderately well studied in western Pennsylvania (Shepps and others, 1959; White and others, 1969; Schooler, 1974) and have received considerable attention in northeastern Pennsylvania since 1961 as a result of detailed geologic mapping by the Pennsylvania Geological Survey and the U.S. Geological Survey. Woodfordian drift is the most widespread, thickest, least weathered, least eroded and most diverse surficial material in Pennsylvania. As such, it possesses considerable economic significance both as a mineral resource and material of environmental and engineering concern.

Age and Correlation

Introduction. The problem of the age and correlation of the "terminal moraine" and its associated drift in northeastern Pennsylvania is complex and not totally resolved. The discussion presented here is lengthy, but it is included for completeness. The essence of the problem centers about two points: (1) numerous workers have interpreted the "terminal moraine" of Lewis and Wright (Lewis, 1884) not to be the same age throughout Pennsylvania (older in eastern Pennsylvania); and (2) until recently, no radiometric criteria have been available to date the "terminal moraine" in eastern Pennsylvania.

We believe that the "terminal moraine" and associated drift are Woodfordian (Late Wisconsinan) in age because of: (1) the existence of five radiocarbon dates of less than 14,000 YBP, and (2) the fresh character of the drift which is reflected both in the lack of erosion of original constructional topography and shallowness of pedological development. We suggest that deglaciation started not earlier than 15,000 years ago. No correlation with named tills or moraines is made.

Discussion. The original work of Lewis and Wright (Lewis, 1884) wherein they traced the "terminal moraine" across Pennsylvania was carried out before any subdivisions of the Wisconsinan Stage had been named; at the same time, concepts regarding the reality of multiple glaciations were beginning to solidify (White, 1973). Perhaps most important is the fact that they considered the "terminal moraine" to represent the southernmost deposits of one ice advance: the last glaciation. Chamberlin (1883, p. 341) did not trace the "terminal moraine" across Pennsylvania, but accepted the work of Lewis and Wright. He did, however, place the "terminal moraine" in eastern Pennsylvania and the drift in Pennsylvania to the north of it in an older "first" glacial epoch (Chamberlin, 1883, p. 347-348). He was thus the first to suggest that the "terminal moraine" was not the same age in eastern and western Pennsylvania.

Following the assignment of specific names to various glacial epochs in the Mississippi basin area (Chamberlin, 1894; 1895) numerous workers began to use the names in other regions. Salisbury (1902, p. 186) correlated the "terminal moraine" of Lewis (1884) in New Jersey with the "Wisconsin formation" [sic] of the Mississippi basin while Leverett (1902) made a similar correlation for western Pennsylvania. However, Williams (1898, p. 84) may have been the first to use the term Wisconsin for the "terminal moraine" in Pennsylvania. No other correlation or naming of the youngest glacial deposits occurred during the next 40 years, although the names Wisconsin, Illinoian and Kansan were used (e.g., Ashley, 1927; Leverett, 1928; 1934).

The next stage of correlation and age determination of the "terminal moraine" drift was started by MacClintock and Apfel in 1944. They examined the various deposits associated with the pronounced re-entrant of the "terminal moraine" in the area of Salamanca, New York, and recognized two drift sheets at the Wisconsinan border, an older Olean and a younger Binghamton. They (1944, Fig. 1, p. 1145) correlated the Binghamton with the "terminal moraine" in western Pennsylvania and the Olean with the "terminal moraine" of eastern Pennsylvania. There was some question as to whether the Olean was Iowan or Tazewell (both part of the Woodfordian; see the Frontispiece) in age, but Olean was definitely considered older than Binghamton. They also indicated tentative corrrelation of the Olean with the Ronkonkoma Moraine on Long Island, New York. In 1954, MacClintock reaffirmed the assignment of the "terminal moraine" in eastern Pennsylvania to the Olean drift of Tazewell age through a study of leaching of gravels. He also (1954, p. 373-376) named the "terminal moraine" south of Blue Mountain in Northampton County the Bangor moraine and indicated that near the Delaware River at Belvidere, New Jersey, the Bangor moraine is overridden by the Portland moraine of Binghamton drift and Mankato age equivalence.

Shepps and others (1959) presented a landmark in Pennsylvania glacial geology with their treatment of all the glacial drift in northwestern Pennsylvania. They assigned the name Kent moraine to the "terminal moraine" of Lewis and Wright and placed the moraine and all younger deposits in the Cary Substage. They made no mention of the terms Olean or Binghamton nor did they make any suggested correlation with New York State, using instead a stratigraphy brought into Pennsylvania from Ohio.

Denny and Lyford (1963, p. 21) suggested that the "terminal moraine" and associated drift were the Olean of MacClintock and Apfel (1944), but that the drift was possibly pre-Farmdalian and post-Sangamonian (see Frontispiece) in age. They could also (1963, p. 23-24) find no compelling reason to recognize any Binghamton drift and denied its continuity through the Elmira area - thus casting doubt on the validity of the unit. Their conclusion was supported by the work of Moss and Ritter (1962). Denny and Lyford also did a reconnaissance mapping of the "terminal moraine" from New York to Blue Mountain in Monroe County (1963, Plate 3) and felt that it was the same moraine throughout.

Muller (1965, p. 104-109) reevaluated the various drifts in the Salamanca re-entrant area and indicated that: (1) material in the area called Illinoian by MacClintock and Apfel (1944) is probably Early Wisconsinan in age, (2) the Olean Substage is unchanged in status, and (3) the lack of continuity of the Binghamton is recognized and its name is replaced by Kent Till, Kent Moraine and Kent Glaciation.

White and others (1969) introduced the terms Altonian and Woodfordian (originally defined in 1960 by Frye and Willman for use with specific deposits in Illinois) to northwestern Pennsylvania and reference has already been made to possible Altonian correlation with northeastern Pennsylvania. They re-assigned the Kent Till to the Woodfordian.

Crowl (1971, p. 35-36) presented a summary of our understanding of the age of the "terminal moraine" and related drift. He indicated the discrepancy of a pre-Farmdalian and post-Sangamonian age at the Salamanca end of the "terminal moraine" and a Woodfordian age at the Long Island end (Muller, 1965) of the same moraine. He also presented several radiocarbon dates which supported a Woodfordian age for the "terminal moraine" drift in Monroe County, Pennsylvania. Since then, remapping of the "terminal moraine" (Crowl, 1972) northwest for over 161 km (100 miles) from Belvidere, New Jersey, has not revealed any age difference in the "terminal moraine". The possibility for locating such an age difference is now restricted to the area between Williamsport, Pennsylvania, and Salamanca, New York -- the area remaining to be remapped.

We presently have 4 radiocarbon dates from northeastern Pennsylvania and 1 radiocarbon date from northcentral Pennsylvania all associated with the "terminal moraine" or the drift north of the moraine. The dates are (see Figure 8 for locations):

OWU 430 13,235±1620 YBP	Echo Lake (4.5 miles northeast of Marshalls Creek above Delaware Water Gap to north of U.S. Route 209). Silty clay gyttja at base of organic section, overlying clay.
OWU 415 12,520±825 YBP	Leaps Bog (1 mile northeast of Marshalls Creek immediately south of U.S. Route 209). Decomposed woody peat at contact with underlying clay.
W-2893 11,430±300 YBP	Pocono Creek. (near base of kettle hole bog along Pocono Creek about 2.5 miles west of Stroudsburg). In A3 zone 2 m above herb zone.
SI 1341 12,760±135 YBP	Brodheadsville. (0.5 miles southwest of Brodheadsville in pipeline trench). Fragmental material in lake clay overlain by silts and gravel of Woodfordian outwash.
SI 1559 12,750±100 YBP	Sausser Bog. (Lycoming Valley, north of Williamsport). Clay gyttja at bottom of bog in "terminal moraine".

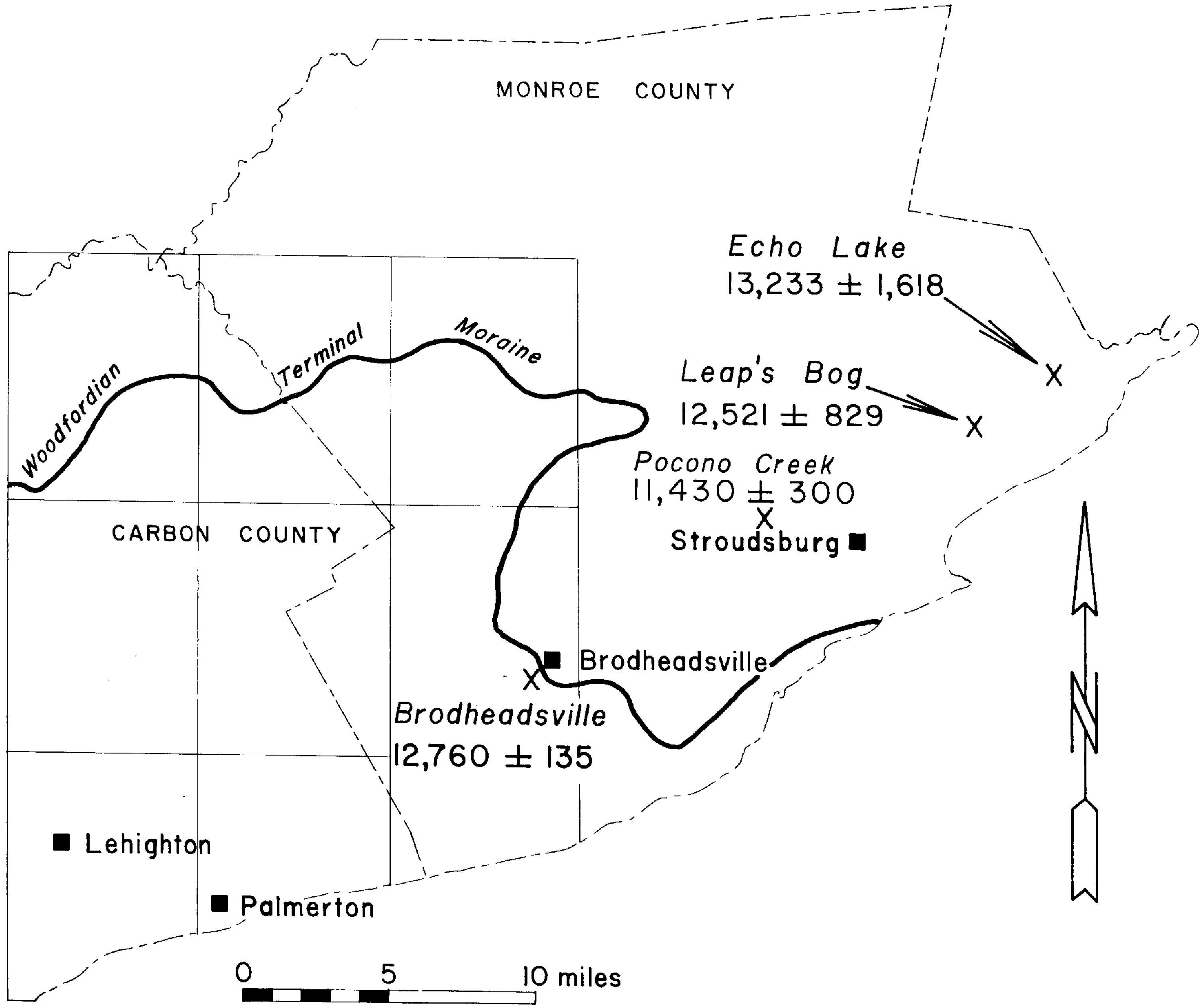


Figure 8. Location of radiocarbon dates in northeastern Pennsylvania.

None of these dates indicates the time of emplacement of the "terminal moraine"; they all refer to stages of deglaciation and indicate a minimum date. However, there is a disquieting consistency in these dates, particularly when compared with dates for the Valley Heads recession in the Finger Lakes Region of New York, which average 12,000 YBP (Muller, 1965, p. 108). Similar dates are also presented by Denny (1974, Fig. 14, p. 21; 43-44) for the St. Lawrence area. Either deglaciation of eastern North America occurred very rapidly and vegetation was reestablished very rapidly as has been suggested by Bryson and others (1970) and Connally and Sirkin (1971, p. 1002) or there is meaning in the dates which we do not fully understand, as yet.

It is a moot question how long an ice block persists in a kettle hole before organic sedimentation begins (Florin and Wright, 1969; Mickelson, 1968). The organic material at Brodheadsville (dated 12,760 $\pm$ 135 YBP) occurred in lake clay overlain by outwash silts and gravels and thus marks the melting of the ice front there.

Leslie Sirkin, Adelphi University (1975, pers. comm.), indicates that the pollen stratigraphy from a core taken at Pocono Creek corresponds closely with that of Flower Hill Bog on Long Island (Sirkin, 1967), Saddle Bog in northwestern New Jersey (Sirkin and Minard, 1972) and sample BR 12 in the Delaware Valley north of Trenton (Sirkin and others, 1970). The close correspondence of the pollen stratigraphy and the radiocarbon date of the A_3 zone to the other mentioned bogs favors a hypothesis of deglaciation starting about 15,000 years ago (see Sirkin, 1967, Table 5, p. 262-263, for correlation of pollen zones and years before present). Some questions may be raised by the fact that the Pocono Creek pollen stratigraphy has apparent correlation with New Hampton Bog No. 1 in the Wallkill Valley of New York state (Connally and Sirkin, 1970, p. 3300-3304), but a younger radiocarbon date for the same approximate stratigraphic position (Pocono Creek: 11,430 $\pm$ 300 YBP for A_3 zone; New Hampton Bog No. 1: 12,850 $\pm$ 250 YBP for between A_1-A_2 and A_3 zones). This single core with completed pollen analysis (Pocono Creek) may not account for the other similar dates in northeastern Pennsylvania, but it does suggest that the dates are probably not irrational.

Connally and Sirkin (1970, p. 3304) suggest that their initial Wallkill Valley advance to the Ogdensburg-Culvers Gap moraine is early Woodfordian. Since this moraine is about 64 km (40 mi.) northeast of the "terminal moraine", some question is raised as to what age assignment Connally and Sirkin would give to the "terminal moraine". The question is further confused when a Woodfordian age is applied to the "terminal moraine" by Connally and Epstein (1973) and a pre-Woodfordian age for the same moraine is suggested by Connally and Sirkin (1973, p. 63).

Areal Distribution and Thickness

The maximum known limit of Woodfordian glaciation in northeastern Pennsylvania is shown in Figure 1. This limit is based primarily on recent mapping in the area (see: Previous Work and Historical Development), and that till which occurs south of the "terminal moraine" is distinguished by criteria discussed later.

Figure 3 shows the areal distribution of the Woodfordian "terminal moraine" (in reality an end moraine, but called the "terminal moraine" for purpose of identification and historical use), but does not delimit the distribution of Woodfordian ground moraine in the several quadrangles covered. Where present, the end moraine covers 100 percent of the surface with thickness ranging from 1 to 52 m (4 to 170 ft) and averaging between 15 and 27 m (50 and 90 ft). Ground moraine frequently covers 50 to 75 percent of the surface in any area, ranges in thickness from 1.5 to 32 m (5 to 110 ft) and averages about 15 m (50 ft) thick on the Pocono Plateau and about 8 m (25 ft) thick in the Appalachian Mountain and Glaciated Low Plateaus Sections.

Areal extent of Woodfordian ground moraine is greater on the Pocono Plateau than elsewhere in northeastern Pennsylvania and natural bedrock exposures are not common. To the east, in eastern Monroe and Pike Counties, drift commonly covers 50 percent or less of the surface; bedrock ledges are common.

Stratified drift and ice-contact stratified drift are abundant throughout the area, both in the end moraine and along stream valleys in the ground moraine area. Thicknesses of the ice-contact sand and gravel deposits are apparently comparable to those of the end moraine and ground moraine although less is known about thickness of ice-contact stratified drift within the end moraine itself. Thickness of stratified drift in stream valleys is not well known, but well records near Tannersville, Monroe County, along Pocono Creek, indicate a maximum of 74 m (241 ft) of sand and gravel fill in that valley (Berg and others, in prep.). Exploration for the proposed Tocks Island dam on the Delaware River revealed over 46 m (150 ft) of mixed gravel, sand, silt and clay filling that valley (Crowl, 1971, p. 9, 38). Louis Kirkaldi, Soil Conservation Service, Harrisburg, Pennsylvania (1974, pers. comm.) indicates that foundation exploration for numerous small watershed dams in the glaciated part of eastern Pennsylvania commonly encounters much thicker stratified drift in narrow valley bottoms than is anticipated. He indicates that thicknesses of 31 m (100 ft) or more are not uncommon.

Lithologies

Till, ice-contact stratified drift and stratified drift occur within the Woodfordian end moraine as well as in front of and behind the end moraine. However, each drift type will be separately discussed, and anomalies resulting from position with respect to the end moraine will be noted.

Till. Till is the most variable constituent of Woodfordian drift. The till varies from a hard, cohesive, reddish brown (5YR5/3 to 2.5YR4/4), non-calcareous, nonsorted mixture of clay, silt, sand, pebbles, cobbles, and boulders (Plate 1, C) to a similarly-textured material which is calcareous and bluish gray to yellowish brown in color. Almost all of the till throughout the area is stony and sandy, and generally low in clay (Tables 2 and 3) and limestone.

Composition of the constituent materials and color reflect very closely underlying bedrock. Epstein (1969, p. 57-59) did pebble counts for numerous till samples in the Stroudsburg area which showed that as ice crossed a bedrock lithologic boundary, the quantity of that lithology in the resultant till rose rapidly to several tens of percent, and its persistence as a till component in down ice-flow direction depended on its resistence to erosion and disintegration. This principle is obvious throughout this Conference area although insufficient sampling and pebble counts have been done to quantify the apparent bedrock-till relationship. Variability in composition is shown in the analyses presented in Table 2. The larger, relatively uncommon till components, boulders 1.8 m (6 ft) or more in long dimension, are generally either very close to the original source or are very resistant to disintegration (e.g., quartzitic conglomerates of the Catskill Formation). Smaller boulders, averaging 0.3 to 0.6 m (1 to 3 ft) in diameter, usually are rounded to some extent, are mainly gray sandstones and are relatively common. Gravel-sized debris is commonly subangular to rounded and generally, even the more angular materials have some rounding on the corners. Almost all of the detrital components are unweathered and thin weathering rinds occur only in materials lying on or within 0.3 to 0.6 m (1 to 3 ft) of the surface. Rarely a cobble has a weathering rind sufficiently thick and intense to attest to reworking from older drift and incorporation into the Woodfordian drift. Many of the finer-grained clasts are striated. The coarser-grained sand sizes (1 to 2 mm) are dominated by rock fragments. The amount of rock fragments decreases with decreasing sand size, and material less than 0.5 mm in diameter is primarily quartz. Igneous and metamorphic rocks do occur, but they are not common. A garnetiferous gneiss derived from the Adirondack Mountains of New York State is the most abundant metamorphic erratic.

Both lodgement till and ablation till are commonly seen in exposures. Lodgement till is generally somewhat cohesive and commonly has a platy disintegration structure which is subparallel to the ground surface. Ablation till is usually more friable and lacks any platy disintegration structure. Although frequently easily distinguishable in fresh exposures, ablation and lodgement till are not readily mappable.

Soils formed on Woodfordian till generally do not show significant pedological development, are sometimes poorly defined and usually characterized by the presence of a fragipan (hard, brittle layer slowly or very slowly permeable to water). The solum is generally 1.5 m (5 ft) thick or less and has a color inherited from the till. Lackawanna and Morris soils are common in the till overlying rocks of Categories 1 and 2 (Table 1) while Bath and Mardin soils are common in till overlying rocks of Category 3. Ciolkosz and others (1971 p. 36-42) present descriptions of the soils from sites north of Stroudsburg. Each of the soils at these sites has a fragipan between 0.6 and 1.5 m (2 and 5 ft) below the surface. Additional soils information is available from Ciolkosz and others (1971, Appendix), Cunningham and others (1972), Taylor (1969) and U. S. Dept. of Agriculture (1970).

Stratified Drift. Stratified drift comprises horizontally to subhorizontally bedded deposits of gravel, sand, silt and clay. These deposits are known almost exclusively from exposure along present streams and usually only pebbles, cobbles, and some sand and boulders occur. These materials are generally rounded to well-rounded in the coarser sizes

(> 5 cm (2 in.)), and subangular to well-rounded in the finer gravel sizes. Interbedded layers of sand and gravel have both sharp and gradational contacts. Occasional beds of silt and clay also occur, but are generally only a few centimeters thick. The sand and gravel beds range from a few centimeters to several meters thick and vary from deposit to deposit. Size sorting of material within individual beds is variable, but the degree of sorting generally increases with decreasing grain size. Thus the sands tend to be moderately well to well sorted while the coarser gravels are less well sorted and dominantly have sand matrix.

Materials of slightly different nature are described from the Delaware River Valley by Crowl (1971, p. 16). Surface materials of the terraces comprise fine-grained sands and silts, either structureless or with only faint bedding. These materials overlie sands and coarse, bedded gravels with occasional thin lenses of silt and clay.

Composition of stratified drift is variable depending on amount of local bedrock influence, but is generally composed of resistant sandstone fragments. Shales and siltstones do occur as minor components. Sand composition varies with size in the same manner as it does in till, wherein the fine fraction is dominantly quartz.

Ice-Contact Stratified Drift. Ice-contact stratified drift is common throughout northeastern Pennsylvania and has been studied in greater detail than any of the other deposits because of its greater economic potential. These deposits consist of interbedded layers of sand and gravel frequently displaying extremes of variability in bed thickness, size-sorting, nature and angle of bedding, and composition.

Thickness of individual beds ranges from about a centimeter to several meters. In deposits formed in very close proximity to glacial ice (kames), beds are generally thin and size-sorting may be extreme between adjacent beds (e.g., a sand layer adjacent to a layer of cobbles and boulders). Size-sorting within any bed is variable and ranges from very good to very poor. In some cases beds are unsorted with sizes ranging from clay to boulders. These layers are generally flowtills. As distance from the ice source increases such as in a kame delta (Stop 13, Day 2), bed thicknesses generally increase, size-sorting is better, there is more uniformity within the deposit and beds of a particular size range frequently are a few meters thick.

Forset bedding in the near-ice deposits is usually at a steep angle (Plate 1, D). Within a single deposit, direction of bedding dip frequently changes by as much as 90 degrees. Contacts between beds of different size-composition are generally sharp. Small collapse faults commonly occur in sand beds and sometimes in gravel beds. Bedding in kame deltas is more uniform, including steep forset beds and horizontal topset beds (Plate 1, E). Contacts between beds of different texture vary from sharp to gradational. Ripple bedding is common, and flame structures and convolute bedding sometimes occur.

Composition of Woodfordian ice-contact stratified drift is variable from deposit to deposit, but corresponds closely to underlying bedrock. Table 4 presents compositional data derived from pebble count analyses

Table 4. Pebble count compositional analyses and results of various physical tests for selected gravel deposits in Monroe County. See Figure 9 for locations of samples Approximately 100 pebbles per count of size fraction 1.3 to 1.9 cm (1/2 to 3/4 in.).

Sample No.	cgl nr	sandstone VC-C nr	sandstone VC-C r	sandstone M nr	sandstone M r	sandstone F-VF nr	sandstone F-VF r	slst nr	slst r	claystshale nr	claystshale r	calc brec nr	calc brec r	ls	calc slst	qtzite	Freeze-Thaw*1 % Loss	Los Angeles Abrasion*2 % Loss	Bulk SpG	Percent Absorption*3	Type Deposit
1		1		14		66	5	11	3								3.5		2.69	1.05	Kame
2	3	7		9		32	9	8	30				1			1	9.9	14.8	2.71	0.66	Kame
3		10	1	20	1	40	8	11	9								2.5		2.69	0.95	Outwash
4		7		22		61	3	2	2			1					3.5	15.0	2.69	0.94	Kame
5	1	6		9		57	3	13	8			2					4.4	22.9	2.68	1.22	Kame
6		4		13		51	4	8	11								5.0	25.7	2.68	1.62	Outwash
7	1	2		8		41		34	11			3					5.2	15.4	2.71	1.03	Esker
8	1	2		6		34	4	5	39	4	1	4					2.4	18.3	2.71	1.30	Kame
9				8		30	6	18	38								5.4		2.70	1.72	Kame
10		1		3	1	37	1	36	14			5	2				6.2	14.6	2.71	0.90	Kame
11				1		5	1	8	5	6				58	17	4	15.6	22.8	2.69	2.48	Kame
12						4		53		30				7	6		38.7		2.65	2.47	Delta
13	2	2		8		27	4	26	14	8	7					1	2.7	14.8	2.69	1.56	Delta
14						10		53		35							10.4		2.66	2.94	Kame

1. Freeze-thaw: c. 2500 gm of 1.9 to 3.8 cm **(3/4 to 1-1/2 in.)** material weighed, run through 150 cycles of freeze in air and thaw in alcohol and water solution. Sample oven dried, sieved on 1.9 cm (3/4 in.) screen and reweighed.
2. Los Angeles Abrasion: c. 3000 gm of 0.9 to 1.9 cm (3/8 to 1/2 in.) material weighed, rotated for 15 minutes (500 rotations) in steel drum with 6 standard steel balls, washed, dried, sieved on 0.9 cm (3/8 in.) screen and reweighed. Not standard PennDOT test.
3. Percent Absorption: c. 500 gm of each fraction from 4.76 mm to 3.8 cm (0.18 to 1.5 in.) weighed, soaked 20 to 24 hours in water, surface dried and reweighed.

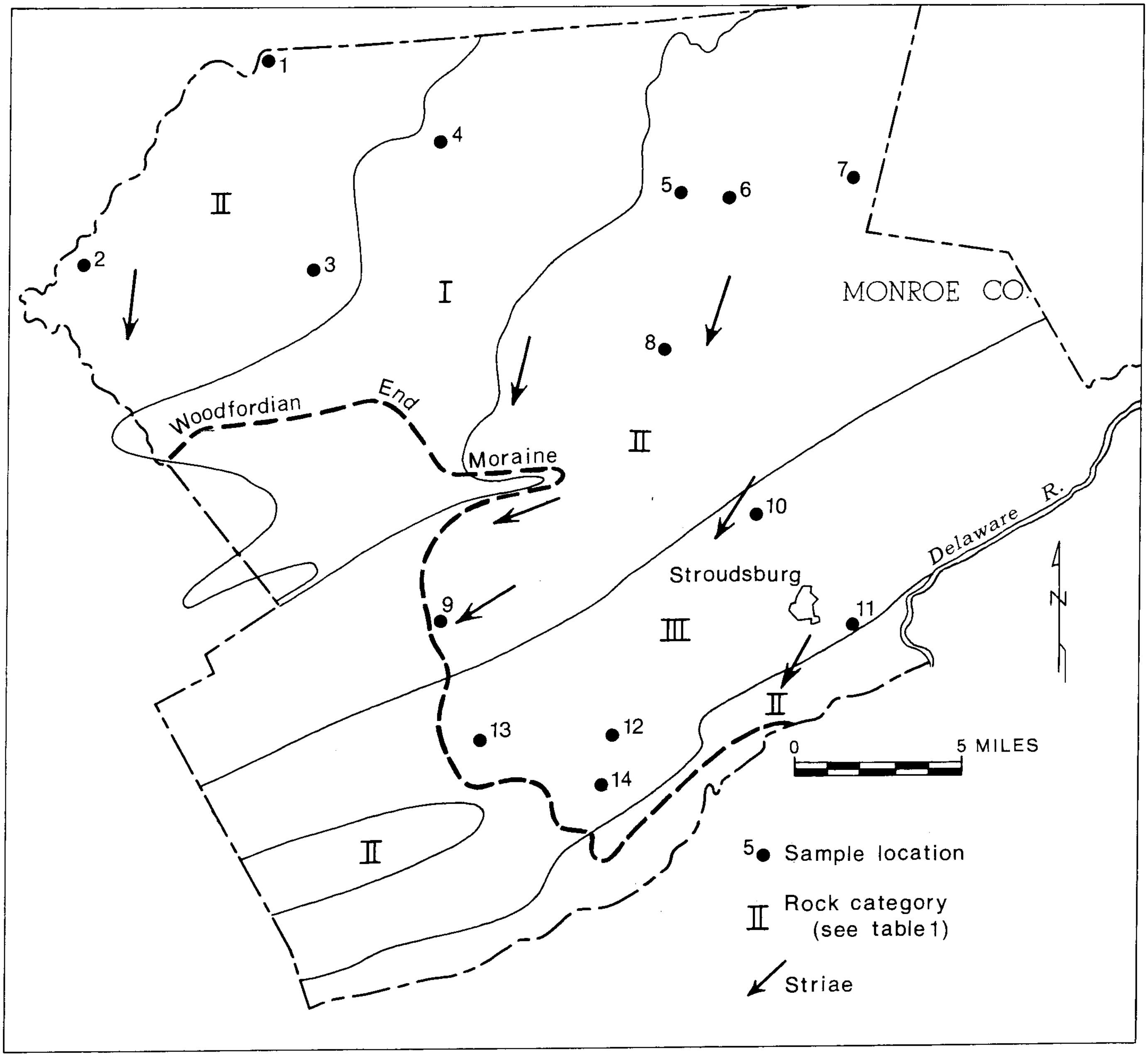


Figure 9. Location of 14 Woodfordian stratified and ice-contact stratified drift samples in Monroe County, Pennsylvania. Data from samples in Table 4.

of the 1.2 to 1.9 cm (1/2 to 3/4 in.) size fraction of 14 gravel samples collected in Monroe County (Figure 9 shows locations of samples). Composition varies not only with relation to bedrock, but also with grain size, in that the finer sizes have increased quantities of less resistant components such as red and gray siltstone or shale. The 1.2 to 1.9 cm (1/2 to 3/4 in.) fraction usually gives the best representation of overall composition. Again, sand composition is similar to that of till, and shows rock fragment dominance in the 1 to 2 mm interval, changing to quartz dominance below 0.5 mm.

Although the samples in Table 4 may appear similar in composition, they do reflect the underlying bedrock. Samples 1, 2 and 3 reflect the red character of Category 2 rocks (Table 1), particularly sample 2 which has had the longest transport distance over Category 2 rocks. Sample 1, transported the least, is high in gray sandstones. Sample 4 is high in gray sandstones as would be expected over Category 1 bedrock. Samples 5 through 9 generally reflect an increase in red siltstone from north to south which corresponds to known changes in the underlying bedrock. Sample 10 retains some red material but shows a sharp increase in gray siltstone characterized by Category 3 bedrock. Sample 11 occurs at the southern limit of the limestone outcrop belt and reflects that in its composition. Samples 12 and 14 are typical for Category 3 bedrock where limestone outcrop is minor. Sample 13 is from a kame delta deposit formed on Category 3 rocks but apparently had some of its material transported ice-marginally or sub-glacially from Category 2 rocks to the north. In general then, the composition of Woodfordian ice-contact stratified drift gravels can be predicted from knowledge of local bedrock and vice-versa. The bedding and composition of ice-contact kame terraces along the Delaware River Valley are discussed in detail by Crowl (1971, Table 2, p. 11; p. 19-26). These deposits comprise crudely bedded, sub-horizontal layers of sand and cobbles 0.3 to 0.6 m (1 to 2 ft) thick. The material is generally deficient in less resistant shales and siltstone, and has a down-terrace decrease in grain size.

Soils developed on Woodfordian stratified drift and ice-contact stratified drift include numerous series. Some of the series have fragipans, some do not. Pedological development is comparable to that of the tills.

Geomorphology

Woodfordian drift retains its original constructional topography almost everywhere with little or no modification since time of deglaciation. Erosion of the drift has been minor in most places, possibly because of the heavy vegetative cover, and geomorphic form, if present, is easily discerned, particularly on aerial photographs.

End Moraine. West of the Lehigh River ground moraine forms much of the Woodfordian border, particularly in rolling country of moderate relief. Patches of end moraine -- or local end moraines -- occur mostly on mountain slopes which formed a barrier to ice movement. However, between the Lehigh River and Camelback Mountain, on the Pocono Plateau the Woodfordian "terminal moraine" is the most striking glacial geomorphic feature in northeastern Pennsylvania (right hand, cover). In this area, the end moraine is a clearly-defined belt averaging about a mile in width, comprising an almost trackless maze of hummocky topography. Local relief varies from 3 to 31 m (10 to 100 ft). Undrained depressions, frequently with swamps or peat bogs, are common and no integrated drainage system exists (Plate 2, A). The hills are generally rounded with low to moderate slopes although steep slopes infrequently occur. The zone is generally heavily vegetated, difficult to traverse and undeveloped except for housing (e.g., area of Stop 1, Day 1). On the Pocono Plateau, the front margin of the end moraine is well defined by a nearly continuous ridge having steep slopes and a narrow crest. The boundary with ground moraine behind the "terminal moraine" is marked by a pronounced change in topographic expression and sometimes a small stream. Meltwater channels not occupied by streams are not common, but some do occur as dry boulder-floored valleys 15 to 31 (50 to 100 ft) wide and 3 to 9 m (10 to 30 ft) deep parallel to the end moraine frontal margin (e.g., mileage 38.8, Day 1).

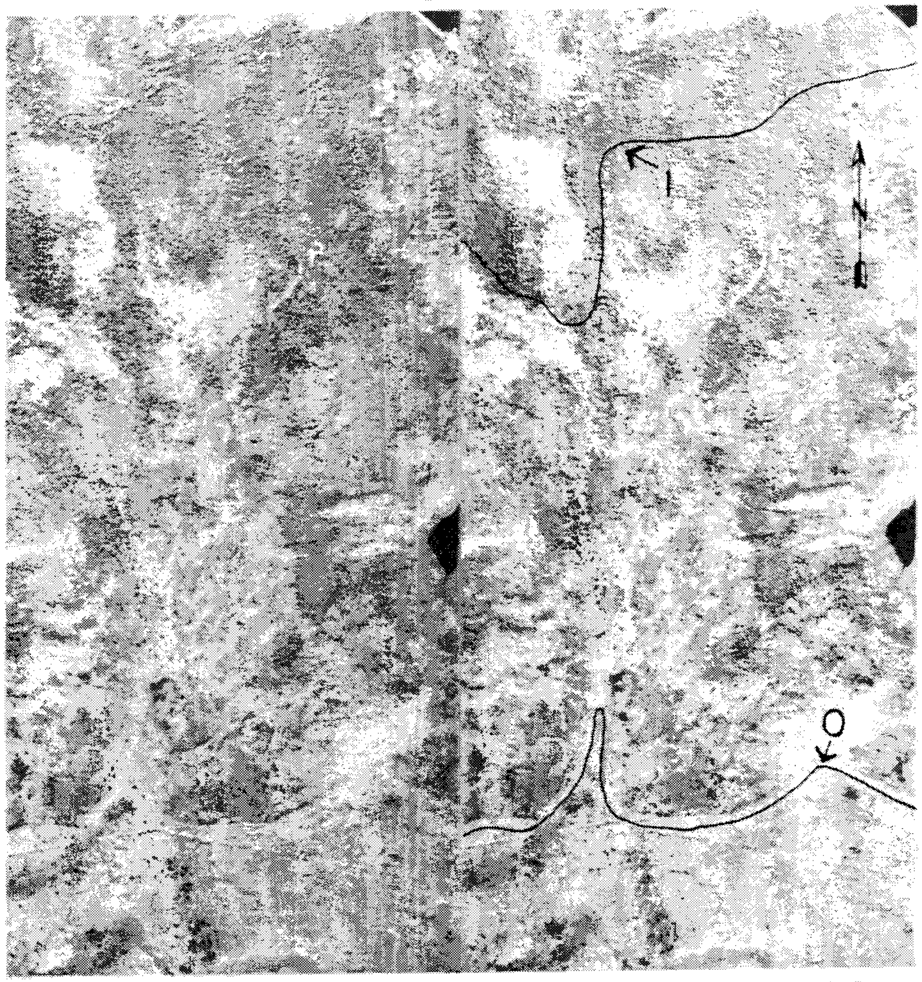
A second end moraine, the Gouldsboro moraine (Figure 1) (Sevon, 1975c) occurs several miles north of the "terminal moraine". The Gouldsboro moraine is similar to the "terminal moraine" in composition and geomorphology, but is not nearly as large. It is also discontinuous.

Ground Moraine. The topographic expression of ground moraine on the Pocono Plateau is subtle and almost featureless. The surface is relatively smooth and undulating; principal topographic interruptions are stream valleys or occasional bedrock ridges protruding through the ground moraine. Local relief is generally low (1.5 to 7.6 m (5 to 25 ft)) except where dissected by larger streams. Boulders occur occasionally on the surface, except within 3.2 km (2 mi.) of the Gouldsboro end moraine (Figure 1) where they are abundant and sometimes completely cover the surface.

To the east and southeast, in the Glaciated Low Plateaus Section and Appalachian Mountain Section, topography is much more dominated by bedrock. Ledges are very common and many rounded hills are bedrock-cored as are most slopes along stream valleys. Ground moraine forms relatively smooth, low to moderately sloping surfaces between the bedrock ledges and generally no marked topographic distinction occurs at the boundary between ground moraine and bedrock. Most bedrock ledges have low north dips, are oriented northeast-southwest, have a steep south face with boulder-rubble at the base, and are free of ground moraine on north facing slopes for a few to several tens of meters. Many of these rock surfaces are littered with broken, frost-riven rock, but some preserve excellent glacial striae. In general, the ground moraine in these two physiographic sections tends to fill and smooth low areas and is not a ubiquitous mantle.

Stratified drift. Stratified Woodfordian drift is confined to stream valley bottoms and almost invariably features a flat surface with a well-defined slope change at the valley sides. The gradient of the surface varies from valley to valley, but is generally low. In almost all of the stratified-drift-filled valleys in the Conference area, the stratified drift is currently being reworked and dissected by the modern stream and most of the surfaces represent the modern flood plain. Crowl (1971, p. 15-19) distinguished a higher outwash terrace from the modern floodplain along the Delaware River, but noted that even that terrace had been flooded 4 times since 1841.

PLATE 2



A. Stereogram of Woodfordian end moraine south of village of Pocono Lake (Pocono Pines quadrangle). Scale is approximately 1:25,680. Note irregular, very hummocky terrain with numerous undrained depressions; also note probable ice-push ridges just west of small lake near center of stereogram. Outer border of moraine drawn and marked "O"; inner border designated "I".

B. Surface covered with boulder colluvium 0.3 km (0.2 mi) south of Christian Corner (Palmerton Quadrangle, Carbon County).

An extensive outwash plain developed westward from the Woodfordian "terminal moraine" at Brodheadsville (Lunch Stop, Day 2). At the proximal margin it merges with the end moraine, but a clearly defined boundary is determined from relict anastomosing, braided stream patterns detectable on aerial photographs (Berg, 1975) and from ridge and swale topography leading away from the end moraine. Kettle holes also occur in the proximal outwash plain, and are visible along U.S. Route 209 west of the high school at Brodheadsville. The slope and surface irregularity of the plain decrease westward and the surface is flat and smooth at the distal end, 5 miles to the west at Kresgeville. The distal part of the outwash plain is characterized by a relict meandering stream pattern.

Ice-contact stratified drift. A variety of topographic forms occur associated with ice-contact stratified drift. Crowl (1971, p. 19-26) has previously described the sloping, ridged and swaled, discontinuous kame terraces along the Delaware River. Kame terraces are rarely seen elsewhere in the area and have been tentatively recognized only along Tobyhanna Creek northwest of Blakeslee (Sevon, 1975b) and south of Mount Pocono (Berg and others, in prep.). A few low, elongate narrow, sinuous esker ridges less than 1 km (0.6 mi.) long are known, but they are not abundant and are generally associated with kames. Most of the ice-contact stratified drift comprises either low, smooth rounded hills with low to moderate slopes or hummocky topography with moderate slopes, small knobs and undrained depressions. Many of these kames occur along the sides of or in the bottoms of relatively wide stream valleys. A few kames are plastered against bedrock valley walls and have only subtle topographic distinction from bedrock.

Contacts

Exposures of the basal contact of Woodfordian drift are common in northeastern Pennsylvania. All those we have seen have shown the drift in direct contact with bedrock. No exposures have revealed Woodfordian drift in contact with older drift. Woodfordian till or stratified materials where present, generally form the present surface and are not covered by anything other than local boulder fields or recent alluvium.

Exposures

Natural exposures of Woodfordian till are common along many streams in northeastern Pennsylvania, and small artificial exposures are relatively abundant in roadcuts (Stop 1, Day 1), ditches and temporary house-foundation excavations. Exposures of ice-contact stratified drift are moderately common in numerous large and small borrow pits. (Stops 7 and 13, Day 2), but are not common naturally. Stratified drift is rarely exposed except at the surface where material is being reworked by the modern stream or in temporary excavations, (e.g., pipeline across outwash, plain west of Brodheadsville).

Mineral Resources

Till. Woodfordian till has no mineral resource value except as random fill. It has some limitations for random fill because of stoniness. The fertility of soils developed on till has long been recognized and was commented on by Branner (1887a, p. 14-15). He also pointed out (p. 14½) that in some cases when the till, ". . . is made up almost entirely of bowlders, the land becomes very difficult and sometimes impossible of cultivation."

Stratified drift. Woodfordian stratified drift has large potential as a source of sand and gravel, but there has been no development of this resource. Exploitation of this material has probably been deterred because of the necessity to excavate, the problems of encountering ground water, and the present easy availability of ice-contact stratified drift. The quality of stratified drift would generally be good, particularly where source material has been derived from Category 1 and 2 rocks (Table 1). Size of material varies, but in general is moderately uniform within individual beds.

Ice-contact stratified drift. Woodfordian ice-contact stratified drift is the main source of sand and gravel in northeastern Pennsylvania. Numerous large and small borrow pits have been opened in these deposits and several large operations are in production today (1975). Most large operations involve crushing and washing to produce various types of aggregate, and data regarding one specific operation near Brodheadsville is given in the description for Stop 13 (Day 2). As previously indicated, composition of ice-contact stratified drift is controlled closely by underlying bedrock, and gravel quality varies considerably. Table 4 presents data for 14 samples collected in Monroe County and analyzed for composition and quality. The compositional variations were previously discussed.

The freeze-thaw tests indicate that Woodfordian material derived mainly from Category 3 rocks (Table 1) is more susceptible to break-up than material derived from other rock categories. This is reflected in the values for percent absorption, and is a result of the close spacing of parting planes in siltstone and shale clasts, a feature clearly observable in borrow pits of this type gravel (e.g., Stop 7, Day 2). Although the percent loss by Los Angeles abrasion test does not appear particularly consistent (Table 4), examination of the abraded materials indicates that: (1) red siltstones, claystones and shales disintegrate most rapidly by splitting and abrasion, (2) coarse- and very coarse-grained sandstones abrade with moderate rapidity, and (3) limestones break up rapidly.

Thus, at least in northeastern Pennsylvania, gravel quality in Woodfordian ice-contact stratified drift deposits can be evaluated tentatively from knowledge of the underlying bedrock and with relative accuracy by compositional analysis (pebble count) of the 1.3 to 1.9 cm (1/2 to 3/4 in.) size fraction.

The quantity of ice-contact stratified drift of good quality in northeastern Pennsylvania is not known, but must be estimated in terms of thousands of millions of cubic yards (see Crowl, 1971, p. 37, for estimates in the Delaware River valley). Most ice-contact stratified drift deposits comprise an adequate mix of sand and gravel for practical quarrying. Some deposits (e.g., deposit being quarried by Pike County Sand and Gravel Company near Blooming Grove) are extremely variable, both laterally and vertically, and are difficult to quarry because of this. Other deposits (e.g., Stop 13, Day 2) are fairly uniform, but have local or widespread beds, such as clay, which cause quarrying, crushing or washing problems.

Peat. As a result of erosion and deposition during Woodfordian glaciation and deglaciation, the topography, with its many closed depressions, and the subsequent climatic environment have been suitable for the development of innumerable peat bogs in northeastern Pennsylvania. Some of these are being quarried for peat, but the actual amount of production is small by comparison to the reserves. These deposits range from less than a meter to a few tens of meters in thickness and consist of decomposed sedges, reeds, rushes, mosses, shrubs and trees. Interested persons are referred to Cameron (1970) and Edgerton (1969) for more information on these deposits in northeastern Pennsylvania.

Engineering and Environmental Characteristics

Woodfordian till is variable in texture, and thus in permeability. Some of the till, particularly that derived from Category 3 rocks (Table 1) or from the more shaly parts of Category 2 rocks, has relatively low permeability and is generally unsuitable for septic disposal systems but reasonably suited for solid waste disposal. Some of the till is very sandy and has moderately rapid permeability. Many areas underlain by Woodfordian till have closed depressions with poor drainage and ground water perched at or very near the surface. Some of these depressions contain peat which has no foundation support strength. Woodfordian till has no known potential for the production of ground water. Almost invariably, water well drilling records indicate penetration to bedrock aquifers.

Woodfordian till is susceptible to slope failure when the natural slope has been modified or placed under unusual conditions of loading or moisture. The most common slope failure in till occurs in north facing roadcuts. The till in these cuts does not get direct sunlight most of the year and is never really dry. When excess water is added to this till, it slumps. South facing slopes dry rapidly and are not as subject to slope failure. Since most Woodfordian till in northeastern Pennsylvania tends to be sandy rather than clayey, all slopes in the till, both natural and artificial, should be treated with suspect when works of man are involved.

All of the Woodfordian drift materials are easily excavated except for the occasional to abundant large boulders encountered. The stratified and ice-contact stratified drift are rapidly permeable. They are generally unsuitable for anything requiring slow to moderate percolation (e.g., solid waste disposal, sewage lagoons) but are quite suitable where rapid percolation is desired (e.g., cemeteries). Thick stratified drift deposits in some stream valleys may have some ground water potential, but there is currently no sizeable production from this material. Natural slope stability of ice-contact stratified drift deposits is moderate, but cutslopes in these materials are quite susceptible to failure and slumping. There is potential for buried organic zones in Woodfordian stratified materials; these constitute "compressible soils" which may fail under heavy loading and cause collapse of large structures.

Woodfordian History

Introduction. Although no detailed or comprehensive hypotheses have been advanced for glaciation in northeastern Pennsylvania, the concept of multiple lobes in the area apparently goes back nearly 100 years to I. C. White (1881, p. 26) who suggested: "The glacier seems to have split against the butress of the Catskill mountains; one arm descending the Hudson valley to overflow New Jersey; the other arm slanting off S. 20° to 30° W., and flowing down the valleys of the Upper Delaware and Susquehanna rivers. . ." J. P. Lesley (Prefatory Letter in White, 1882, p. xviii) suggested that the glacial ice moved in different directions at different depths, with the basal flow being strongly controlled by local topography (and generally deflected southwest) while upper flow (or flow on low relief topography) was nearly due south. For the same report he also prepared a glacial map covering all of Pike and Monroe Counties and some adjacent areas which illustrated the general trend of ice flow based on striae data. This map does not suggest multiple lobes, but rather a large sinuous ice mass.

Chamberlin (1883, Plate XXXIII) indicates glacial movements coming down the Hudson Valley, splitting at the northern end of the Shawangunk Mountains with one lobe flowing into New Jersey and another into Pennsylvania. He also indicates flow deflected westward by the Catskill Mountains from the Mohawk Valley toward Pennsylvania.

The classic work of Lewis and Wright (Lewis, 1884) is almost entirely descriptive and does not discuss the glaciation process. However, in the Letter of Transmittal for that work, Lesley discusses (p. xix-xx) the idea "that the ice sheet as a whole was made up of a series of ice streams, each of great breadth and volume, like currents of water flowing side by side in a great river." Lesley suggested:

> . . . that one stream of the ice sheet descended the Hudson river valley as far as New York harbor, and that another stream (north of the Highlands) flowed more southwestward from Newburgh to the Delaware at Belvidere, and projected its lobe into Northampton county.
>
> A third stream followed the Wallkill valley, between the Catskill mountains and the Kittatinny mountain, from Rondout to Stroudsburg and beyond.
>
> A fourth stream coming from the Mohawk valley across Wayne county followed the water basin of the upper Lehigh, the Wapwallopen valley, and the Lackawanna valley as far as Berwick.
>
> Another stream descended the water basin of the Loyalsock nearly to Williamsport.

The remainder of Lesley's Letter of Transmittal is equally as perceptive. It is indeed unfortunate that Lesley did not devote more time to glacial geology in Pennsylvania. Perhaps the state of knowledge of glacial geology in the eastern United States would be much more advanced than it is.

The next attempt at reconstructing the glacial history of Pennsylvania was that of Williams (1917). He delineated 8 lobes in Pennsylvania and traced their source back to northern New York State. Williams did not recognize any significant difference in age between the drift we now call Illinoian and Woodfordian. Consequently, his scheme was the product of different glaciations resulting from the interplay of 8 lobes which waxed and waned at different times.

Denny and Lyford (1963, p. 19-20) suggested only the most generalized of models in which the ice sheet moved southwestward across eastern Pennsylvania in supposed accordance with the trend of the "terminal moraine" and the striae. However, Plate 3 of their report shows that some striae and parts of the "terminal moraine" configuration do not support a hypothesis of total southwestward ice movement in eastern Pennsylvania.

Connally and Sirkin (1970, p. 3298-3299) indicate definite evidence of glaciation by distinct lobes immediately east of Pennsylvania in the Wallkill Valley of New Jersey and New York, but do not discuss glaciation in Pennsylvania.

Coates and Kirkland (1974, p. 103-113) present an ice model in which ice entered northern New York and was split into a western Erie-Ontario lobe and an eastern Champlain-Hudson Valley lobe by the Adirondack Mountains. Eventually these lobes coalesced, the Adirondack Mountains were overwhelmed and became a center of outflow. They argue that the configuration of the "terminal moraine" corresponds favorably to an arc of constant radius having the Adirondacks as its center (ibid, Figure 4, p. 107). They give no indication of any influence on the ice flow pattern by the Catskill Mountains.

Implicit in the argument that the Adirondacks became a center of outflow is the idea that even after the mountains were overwhelmed something remained which substantially influenced meteorological conditions resulting in concentrated precipitation in the Adirondack Mountain area. We are aware of no evidence from existing ice sheets of continental proportions to suggest that mountain ranges, once overwhelmed by ice, have any influence on meteorological conditions. Because of this and because data in Pennsylvania do not support the hypothesis, we reject the concept of the Adirondack Mountains being a center of outflow which affected Pennsylvania.

We adhere instead to a concept of a Woodfordian ice sheet separated into two parts by the Adirondack Mountains, with reinforcing separation by the Catskill Mountains. Even at the stage when these two mountains were overwhelmed and the two ice masses coalesced, their movements were strongly affected and divided by the mountainous barriers.

Glaciation. At the local level in Pennsylvania, several specifics must be accounted for by any model of glaciation. These specifics are illustrated in Figure 10.

1. In northwestern Pike and Monroe Counties there are abundant striae indicating a S10°W movement while striae in the southeastern parts of the counties indicate a S30-40°W movement. In some places, these striae overlap.

2. Cobbles and boulders of white, quartzitic sandstone and conglomerate derived from the Shawangunk Formation which outcrops to the east of the area in New Jersey and New York occur northwest of the outcrop in areas where striae suggest ice movement toward the outcrop not away from it. The distribution of these boulders was first noted by White (1882, p. 42-43)

and recently confirmed by Berg and Sevon.

3. The configuration of the "terminal moraine" is locally irregular but regionally systematic and conformable to striae patterns.

The following sequence of Woodfordian glaciation in northeastern Pennsylvania is suggested and illustrated by Figure 11:

1. Initial movement of the Woodfordian glaciers into and towards Pennsylvania was by two ice masses separated by the Catskill Mountains. Figure 11A illustrates three hypothetical advancing positions for the Ontario (western, with subscript 'O') and Hudson (eastern, with subscript 'H') lobes. Note that ice movement in the northwestern part of the area was more southwesterly than that to the east (see Figure 10 for striae directions). This suggests that original southwesterly flow may have been strongly influenced by the Catskill Mountains and diverted to a more southerly orientation in Pennsylvania.

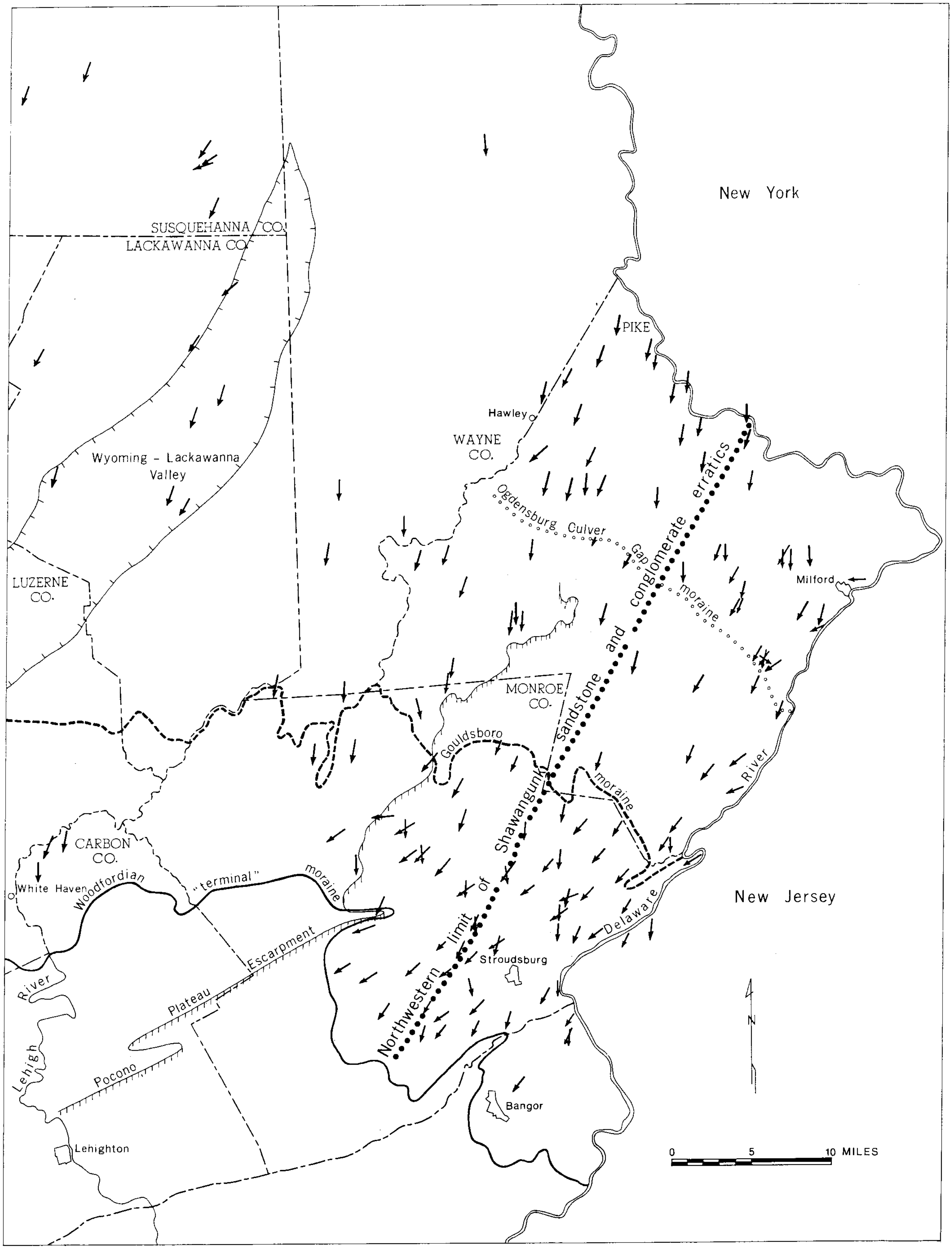
2. As glaciation proceeded, the Ontario lobe moved southward more rapidly than the Hudson lobe moved southwestward (Figure 11B). When the two lobes met we suggest that the Hudson lobe overrode the Ontario lobe. In such an overriding situation the south-oriented striae would be developed by the Ontario lobe, while quartzitic Shawangunk rocks would be distributed northwestward by the Hudson lobe. Positive proof of this hypothesis is currently lacking, but lodgement till in areas of south-oriented striae should lack Shawangunk erratics; the Shawangunk materials should be present only in ablation till.

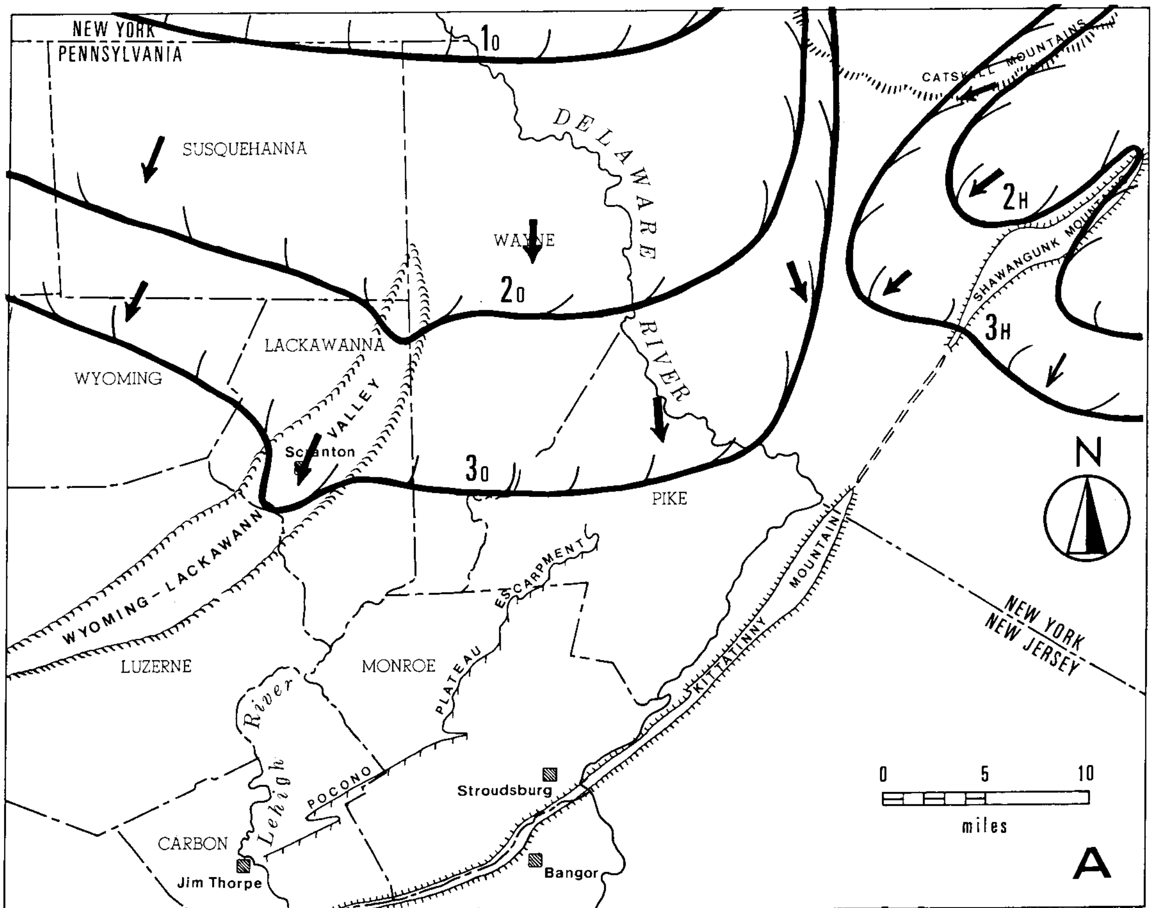
Note that while ice movement in Pennsylvania east of the Wyoming-Lackawanna Valley was nearly due south, the Valley apparently had an effect on ice movement, and movement became more southwesterly from the north to south ends of the Valley.

3. Figure 11C shows the ice lobes at their maximum positions. At this point it is suggested that the Ontario lobe has already lost some vigor, and some of its marginal ice may have become incorporated into the Hudson lobe and changed flow direction. This is illustrated by the apparent retreat of the overridden part of the Ontario lobe from position 5 in Figure 11B to position 6 in Figure 11C. West of the Conference area the "terminal moraine" has a northwest-southeast orientation corresponding to the more southwestwardly ice flow indicated west of the Wyoming-Lackawanna Valley in Figures 10 and 11C.

The isolated area of Woodfordian ground moraine located south of the "terminal moraine" in the Hickory Run and Blakeslee 7 1/2-minute quadrangles

Figure 10. Map of glacial striae in northeastern Pennsylvania. Most data in Carbon, Monroe and Pike Counties from field notes and mapping of Sevon and Berg. Other data from: Alvord and Drake (1971); Branner (1887b); Bucek (1971); Epstein (1969; 1975, pers. comm.); and White (1881; 1882; 1883). Also shown is the northwestern limit of Shawangunk erratics occurring in Woodfordian drift.


New York
SUSQUEHANNA CO.
LACKAWANNA CO.
PIKE
Hawley
WAYNE CO.
Wyoming - Lackawanna Valley
LUZERNE CO.
Ogdensburg Culver Gap moraine
Milford
Northwestern limit of Shawangunk sandstone and conglomerate erratics
MONROE CO.
Gouldsboro
moraine
River
CARBON CO.
White Haven
Woodfordian "terminal" moraine
New Jersey
Delaware
Stroudsburg
Pocono Plateau Escarpment
Lehigh River
N
Bangor
Lehighton
0 5 10 MILES



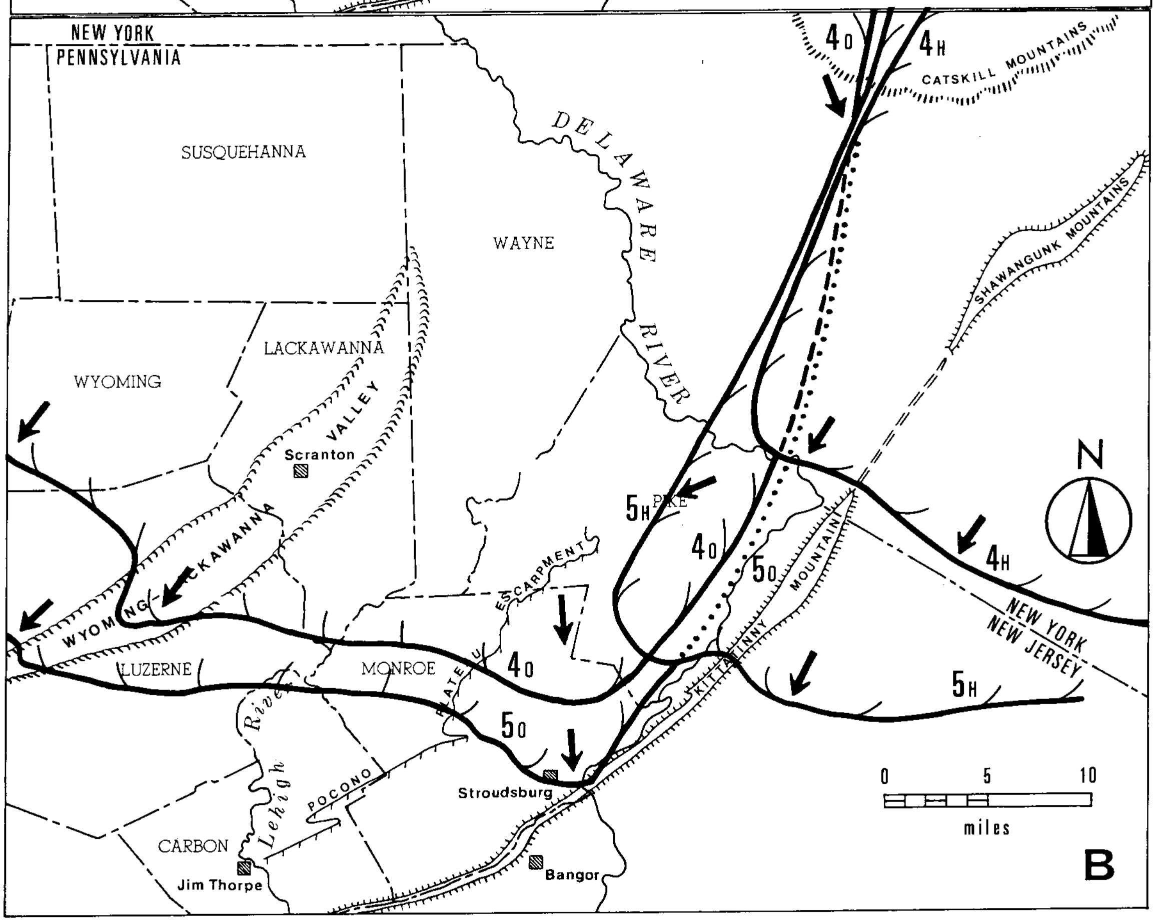
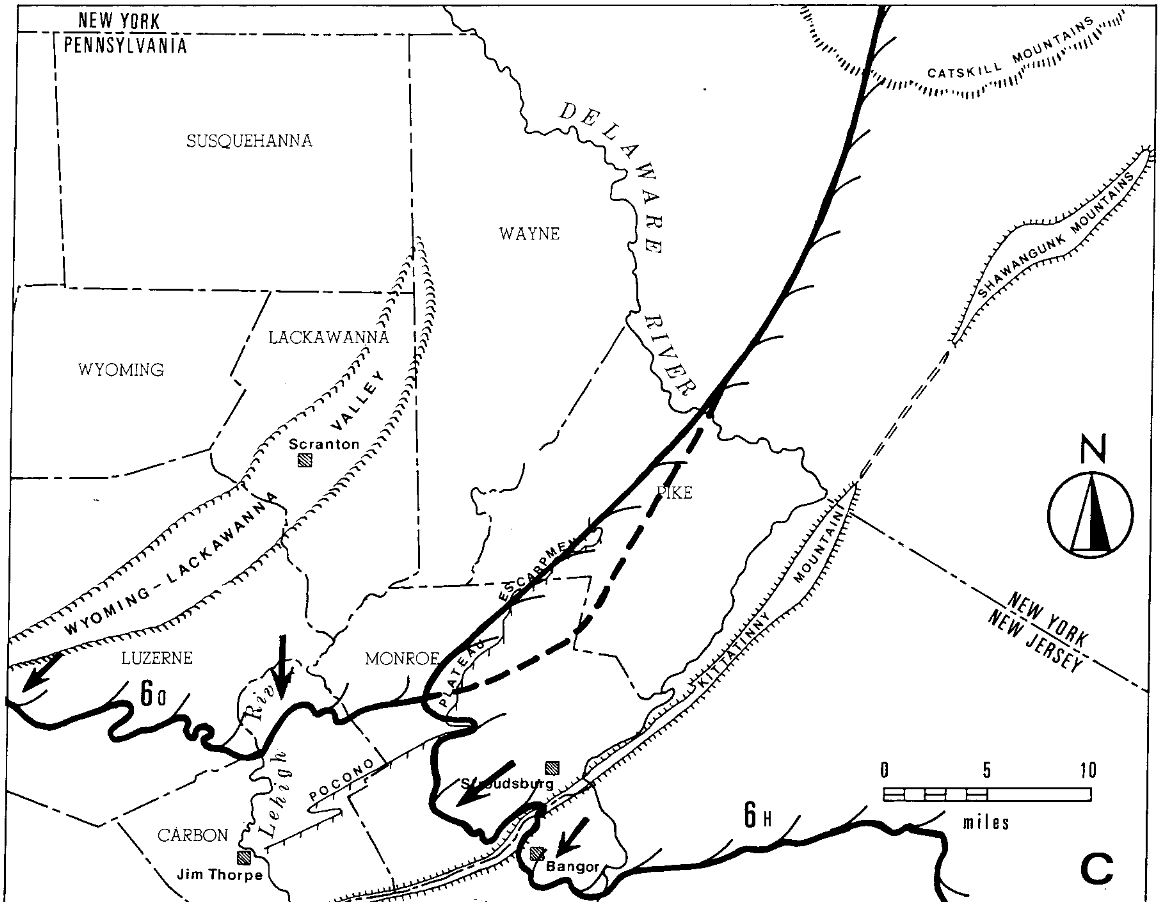
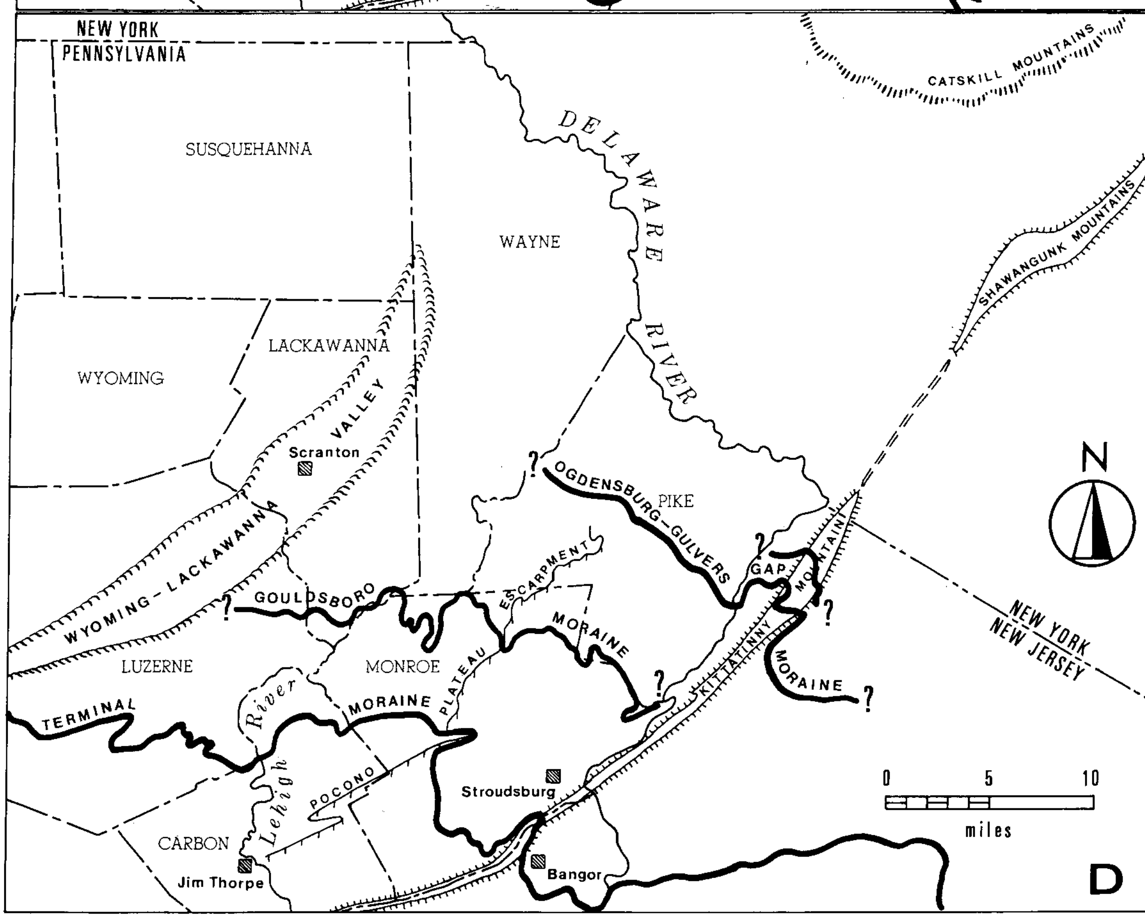


Figure II, A, B, C. Hypothetical ice flow in northeastern Pennsylvania during Woodfordian glaciation.





D. Positions of various Woodfordian moraines in northeastern Pennsylvania. See text for explanation.

(Fig. 1 and 3) must have been formed at this time. We hypothesize that the ice surged through the gap east of Lake Mountain, reached a maximum position and probably became disconnected from the main ice sheet. We suggest that the area covered by that ice was deglaciated prior to the wasting of the ice which built the "terminal moraine".

Figure 11D shows the positions of the Woodfordian "terminal moraine" and two other known moraines, the Gouldsboro moraine and the Ogdensburg-Culvers Gap moraine. We do not know positively whether the latter two are recessional or readvance moraines, but believe that they are recessional moraines formed during the wasting of the lobes which formed the "terminal moraine". Connally and Sirkin (1970, p. 3299) suggest that the Ogdensburg-Culvers Gap moraine is the result of a readvance. Since striae, occurrences of erratics (such as the Shawangunk rocks) and moraine configurations are the result of the last movements of ice in a given area, moraines developed by ice readvance might possibly destroy patterns of regional uniformity of ice sheet movement. As this is not the case in northeastern Pennsylvania, even the moraine configurations are sub-parallel, we conclude that all the moraines were formed after the initial Woodfordian ice advance, at different stages of wasting, perhaps with minor oscillations.

The Gouldsboro moraine has not been traced beyond its indicated limits even in reconnaisance, but presumably has some continuity farther to the west. Sevon (1972; 1975c) has shown that abundant boulder fields, boulder colluvium, and stone stripes and polygons developed on, and are derived from Woodfordian till in a narrow zone parallel to the Gouldsboro moraine on the Pocono Plateau. These periglacial phenomena suggest (1) that the area south of the ice was deglaciated prior to emplacement of the moraine and (2) that the periglacial climate adjacent to the ice was restricted to a narrow zone and occurred only at the higher elevations of the Pocono Plateau.

The presence of the Ogdensburg-Culvers Gap Moraine in Pennsylvania has only recently (1975) been identified by Sevon while mapping in Pike County, and it has not been traced northwestward beyond Lake Wallenpaupack. However, Sevon believes that it probably correlates with another end moraine south of Tunkhannock in Wyoming County.

Neither the Gouldsboro Moraine or the Ogdensburg-Culvers Gap Moraine are continuous features and both are composed mainly of ice-contact stratified drift with minor amounts of till. Numerous small deposits of outwash occur in valleys adjacent to the moraines.

We do not know whether or not the Ontario and Hudson lobes achieve their maximum positions simultaneously and wasted uniformly, but the apparent uniformity and continuity of the various end moraines, and the lack of any moraine marking a boundary between the lobes suggest that they functioned comtemporaneously once maximum position was reached.

Two things are accomplished by an ice sheet during glaciation: erosion and deposition. Each of these will modify the pre-glacial landscape to some degree, sometimes markedly, sometimes in a most subtle manner.

The amount of erosion accomplished by the Woodfordian ice sheet is problematic. White (1882, p. 44-48) believed that glacial erosion was variable. He believed that the hard sandstones were abraded slightly while the softer rocks were deeply scoured. His opinion as to the actual amount of erosion is not clearly stated, probably because of the influence of J. P. Lesley. Lesley (Letter of Transmittal, in White, 1881, p. vii) states that he (Lesley) has removed White's opinions from the text and left only the facts. He indicates that White exhibited, ". . . views of the erosive ability of moving ice such as those entertained by the ultra glacialists [sic]." Lewis (1884, p. 70) suggested a maximum of 21 m (70 ft) of erosion near the ice margin, but Epstein (1969, p. 40) says the evidence for Lewis' estimate comes from rocks not glaciated by Woodfordian ice. Coates and Kirkland (1974, p. 114) believe that the amount of erosion (both by glacial ice and subaerial erosion) was substantial, and may have amounted to over 61 m (200 ft) during all of the Quaternary. We suspect that the truth lies somewhere in between. Obviously, the appreciable quantities of till, ice-contact stratified drift, and stratified drift were derived from eroded bedrock and pre-Woodfordian drift. We know that most drift is essentially locally derived. Therefore, we tentatively conclude that in areas of thick drift, up-ice erosion has been substantial, while in areas of thin drift or no drift, up-ice erosion has been minimal. The thickness of fill in some valleys indicates excessive scour, and the prominent south-facing rock ledges in much of northeastern Pennsylvania indicate considerable plucking of the down-glacier ledge free-face. In contrast, the north-dipping bedrock ledge surfaces are commonly striated, but give no indication as to the amount of material which has been eroded from their surfaces.

Glacial erosion (and deposition) was sufficient in some areas to streamline the topography into drumlinoid shapes (Bucek, 1971), to scour and emphasize joint systems and fracture traces (Sevon, 1975c), to produce innumerable rock ledges, and to erode some valleys considerably below base level. However, no real estimates of the actual amount of downwasting by glacial erosion can be currently made for northeastern Pennsylvania. Any estimate is complicated by the fact that at least two earlier glaciations "had a go" at Pennsylvania, and their effect is very obscure.

During the forward movement of glacial ice, sediment is sometimes plastered on the underlying rock as lodgement till. This till is compacted by the ice, has definite fabric which indicates direction of ice flow, possesses platy structure and sometimes appears to be bedded (Plate 1, C). Lodgement till is common in northeastern Pennsylvania, but rarely well exposed, and no estimates can be made about the relative proportions of lodgement and ablation till.

Geologists have long speculated on the thickness of the ice which once covered Pennsylvania. Lewis (1884, p. 13-14) calculated that the ice in the area of Stroudsburg was about 610 m (2,000 ft) thick, and thicker farther to the northeast. He also calculated (p. 115) a maximum thickness of 122 m (400 ft) for the terminal edge of the ice. Epstein (1969, p. 7) concluded only that the ice was more than 396 m (1,300 ft) thick south of Stroudsburg. We do not disagree with these interpretations.

Geologists have also attempted to calculate the gradient of the ice sheet as it approached its terminous. Denny and Lyford (1963, p. 12-14) calculated varying gradients ranging between 18 and 95 m per km (100 and 500 ft per mi.) in the Williamsport area. Crowl has calculated gradients ranging from 13 to 76 m per km (71 to 415 ft per mi.) in the area between Delaware River and Trout Run north of Williamsport; the average is 30 m per km (196 ft per mi.). Where Allegheny Ridge is nearly parallel to direction of ice flow the gradient is 42 m per km (229 ft per mi.). We have calculated a gradient for the Woodfordian "terminal moraine" of 19 m per km (100 ft per mi.) along the south side of Camelback Mountain west of Stroudsburg.

Deglaciation. Epstein (1969, p. 44-51; Epstein and Epstein, 1967, p. 34-36; 1969, p. 170-172; Connally and Epstein, 1973) has developed a sequence of deglaciation in the Saylorsburg-Stroudsburg area which involves a large ice marginal glacial lake (Lake Sciota), several temporary ice-positions, formation of numerous delta deposits, and ultimate drainage of the lake through Delaware Water Gap. During the development of this Woodfordian deglaciation sequence, we suggest that the ice on the Pocono Plateau oscillated within a zone about 1.6 km (1 mi.) wide and developed the extensively ribbed and hummocky end moraine seen today (see A, Plate 2 and topography in area of Stop 1, Day 1).

Crowl (1971, p. 7-8, 18, 21) has described the deglaciation of the Delaware River Valley between Shawnee on Delaware and Matamoras. He depicts a nearly stagnant ice mass occupying the main part of the valley with gradual down-wasting of the surface, and back-wasting of the ice margin. During melting large quantities of sand and gravel were deposited between the ice and valley wall in kame terraces sloping downstream. As the valley was freed from ice, outwash gravels covered the valley floor.

Probably every major valley in northeastern Pennsylvania has a complex deglaciation story recorded by the sediments associated with each valley. Every valley history presumably fits into the larger picture of deglaciation for the region. Approaches to deciphering these histories are illustrated by the work of Epstein (1969), Koteff (1974) and Cadwell (1972, 1974, 1975). As yet, the detailed mapping and interpretation required for such historical reconstruction is lacking for most of northeastern Pennsylvania. In general, we know that as the ice down-wasted and back-wasted numerous ice-contact stratified drift deposits were formed, ablation till was deposited and some stratified drift in the form of outwash was deposited by meltwater.

PERIGLACIAL GEOLOGY

INTRODUCTION

During Woodfordian glaciation, extreme periglacial climatic conditions existed near the ice sheet. The extent of this extreme climatic zone is difficult to quantify, but apparently was not generally widespread. There is evidence (boulder fields, stones stripes and stone polygons) which suggests that the zone was wider at higher elevations (Sevon, 1972; 1975c). The climatic intensity is best shown by the development of boulder colluvium and boulder fields. These decrease rapidly south from the Gouldsboro end moraine and suggest a periglacial zone only 3 to 4 km (2 mi.) wide on the Pocono Plateau and almost no periglacial zone at elevations 150 m (500 ft) lower. Boulder fields and boulder colluvium become gradually less common with increasing distance from the "terminal moraine" in the Hickory Run and Christmans quadrangles and suggest an intense periglacial zone 8 to 10 km (5 to 6 mi.) wide at Pocono Plateau elevations. No real evaluation can be made for lower elevations.

Little conclusive evidence beyond a few convolutions in some hillslope colluvium exists to prove the development of permafrost during Woodfordian glaciation. Possibly most of the periglacial deposits and features of the area could have been formed more readily in a permafrost environment, but the lack of necessity for the environment leaves the question open.

AGE

The age of any of the various periglacial deposits or features can be determined only by position relative to glacial deposits of known age. Thus those lying beyond the limits of known maximum glaciation could be associated with any or all of the three glaciations. Numerous deposits (e.g., some valley fill colluvium, shale-chip rubble, talus) occur within the limits of Illinoian glaciation and are thus associated with Wisconsinan glaciation. Most of the boulder colluvium and boulder fields occur in areas glaciated during the Illinoian and Altonian and are thus associated only with the Woodfordian Substage. Some deposits (e.g., shale-chip rubble, in the Delaware River Valley, boulder field colluvium in the Tobyhanna area) occur in areas glaciated during the Woodfordian and thus represent Woodfordian deglaciation or post-Woodfordian deposits.

AREAL DISTRIBUTION AND THICKNESS

Mass-movement debris is widespread in northeastern Pennsylvania beyond the limits of the Woodfordian glaciation. Figure 3 gives some indication of the amount of this material; in reality, there is much more because many of the deposits have not been mapped or are not shown on Figure 3 (see Berg, 1975, Plate 2, for an example of detailed mapping of mass-movement debris).

Thickness of mass-movement debris is generally unknown, but limited information indicates a range from a few centimeters to over 20 meters (65 ft) for hillslope colluvium (Epstein and others, 1974, p. 222-227) and an average of less than 5 meters (16 ft) for most hillslope and valley-fill colluvium deposits. Nothing is known about the thickness of boulder fields. Boulder colluvium frequently has no appreciable thickness beyond variable boulder sizes. Sometimes boulder colluvium deposits are a few meters thick on the lower parts of slopes.

Patterned ground, frost-stirred ground and frost cracks are known at a few places in the area. Most of these features are seen only in artificial vertical exposures. Some features, such as stone polygons and ice-wedge casts, have been masked by subsequent mass-movement debris.

DEPOSITS AND GEOMORPHOLOGY

Mass-Movement Debris

The variety of mass-movement deposits in northeastern Pennsylvania vary in clast size, sorting, slope position and surface gradient. In all cases, their nature is ultimately controlled by parent rock.

Talus. Talus (Scree) is an accumulation of coarse angular rock fragments covering a steep slope below a free face of rock (Plate 1, F). The slope generally is 25 to 35°, but slopes of 42° are known. The constituent clasts are derived from the free face, show little or no evidence of abrasion or rounding, are coarsely sorted with the larger rocks at the slope base and the smaller rocks near the slope top, have random orientation, and are loosely packed and sometimes unstable. Clast size is dependent upon the bedding thickness and joint spacing of the parent rock, and ranges from blocks several meters across to fragments a few centimeters in dimension. There is no interstitial material near the upper surface of unvegetated talus, and finer-grained matrix material occurs only at depths of a meter or more. However, the interstices of many talus deposits are filled with fine-grained debris and organic material, and the surface is now vegetated. Although individual rocks may be unstable, these talus deposits currently seem to be at equilibrium.

Hillslope Colluvium. Hillslope colluvium is an accumulation of angular rock fragments generally occurring at the lower part of a hill slope. The upper edge of this type of periglacial deposit starts in the middle or lower part of a hill slope and extends to the valley bottom. There is usually a change in slope gradient at the ends of the deposit, but the change at the upper end is frequently subtle. The gradient of the colluvium deposit varies, but it seldom exceeds 35° and is frequently less than 20°. There is seldom any rock exposed above the colluvium.

Material comprising hillslope colluvium is largely derived from local bedrock, but occasionally glacial materials are incorporated, and rarely the colluvium is interbedded with fluvial sands and gravels at the lower end of the deposit (Crowl, 1971, p. 13-14). The material is usually less than 15 cm (6 in.) in dimension although larger fragments, particularly reworked glacial clasts do occur. Bedding is moderately well-developed and parallels the surface of the deposit. The clasts are angular and frequently size-sorted from bed to bed. Interstitial matrix is generally absent, but most clasts have a thin clay coating. Thin clay layers occur at some intervals. Clast size is dependent on the disintegration characteristics of the parent rock. Much hillslope colluvium is derived from highly-cleaved and thinly-bedded Mahantango shale which breaks up into thin chips and plates or pencil-like fragments generally 1 to 2 cm by 2 to 5 cm by up to 15 cm. This material has been mapped as shale chip rubble by Epstein and others (1974, p. 217-220) and as shale-chip colluvium by Berg (1975) along Pohopoco Creek Valley; it has been described as shale chip sharpstone by Crowl (1971, p. 12-14) along the Delaware River Valley. An excellent example of this material occurs at Stop 11 (Day 2). Coarser clasts occur in hillslope colluvium developed from Trimmers Rock siltstones and shales (Plate 1, A; Plate 3, F).

Hillslope colluvium is always vegetated and in the field its slopes are frequently difficult to discern from bedrock. Hillslope colluvium is related to talus but differs generally in: (1) position on slope, (2) presence of bedding, (3) size of clasts, and (4) vegetative cover. Colluvium of this type is mapped with relative ease utilizing aerial photogeologic techniques. The deposits display lighter soil tone in comparison with surrounding bedrock, and often have lobate margins at the valley bottom margins of the colluvium.

Valley-fill Colluvium. Valley-fill colluvium comprises a variety of gravity-transported and/or sheetwash materials which have filled the bottom of a V-shaped bedrock valley to create a flat-surface valley bottom. These valleys or dells frequently have no streams or very small intermittent streams. The two described examples of valley-fill colluvium that follow are common in northeastern Pennsylvania.

Numerous small tributary valleys of Pohopoco Creek have a flat-surfaced valley-fill comprising reworked Illinoian till and local bedrock. This material is a chaotic mixture of clay, silt, sand, pebbles and boulders and strongly resembles Illinoian till except for the occasional suggestion of crude bedding. Boulders are common on the surface. These deposits are up to a few tens of meters in width and of unknown thickness. The surface is usually heavily vegetated. The valley sometimes has an underfit stream.

The second example of valley-fill colluvium is several small tributary valleys of Mahoning Creek west of Lehighton which have flat surfaces, and either very small streams or none at all. These valleys have been partly filled by debris derived both from the underlying Mahantango shale, and from the Trimmers Rock Formation in which the valleys head. Nothing is known about the depth or character of fill in these valleys.

Boulder Colluvium. Boulder colluvium is a thin, surface-cover deposit comprising abundant boulders set in a soil matrix (Plate 2, B). The boulders range up to a meter or more in diameter, may or may not have any point contacts with adjacent boulders, and are not fitted, abraded, or polished. These periglacial deposits occur on slopes of all gradients, but are generally found on moderate slopes. Surfaces are vegetaged mainly by trees, with only a light undergrowth. The surface is relatively flat with microrelief of less than 0.5 m (1.5 ft). These deposits are abundant within 3 to 4 km (2 mi.) of the Woodfordian "terminal moraine" (Sevon, 1975b) and almost every slope in Hickory Run State Park (e.g., mileage 34.8 to 42.9, Day 1) is covered with boulder colluvium.

Boulder Fields. The following description of boulder fields is taken from Sevon (1969, p. 221-225):

> Boulder fields in northeastern Pennsylvania are mainly flat surfaced, moderate to low gradient boulder accumulations near the heads of small drainage basins or on mountain slopes. No completely barren boulder fields are known and some completely forested boulder fields occur... Gradient, surface morphology and lithology are variables common to all boulder fields. These variables can be used to describe boulder fields with almost any degree of

precision and practicality desired...

By definition a boulder field has a gentle slope. The Hickory Run Field... [Stop 3, Day 1]... has a gradient of 1°, the Bowmanstown boulder field (Sevon, 1967) has a gradient of 4 1/2-5°; and other fields in the area... have similar gradients. In all cases the boulder field surface gradient appears to be a reflection of the underlying bedrock surface gradient, although direct proof of this is not available...

Although most boulder fields appear to be flat surfaced... [Conference Plate 3, A]... they are really areas of complex microrelief. The surface irregularity variations in different parts of a boulder field are often subtle.

The following geomorphic forms can be differentiated on several of the barren boulder fields in Carbon County: stone rings... [Conference Plate 3, B]... with a central mound of small boulders surrounded by larger boulders; low mounds lacking well developed boulder segregation; elongate mounds... which lack boulder segregation but have definite linearity; channels generally oriented parallel to the length of the boulder field; pits of somewhat circular form...lobe fronts which show boulder orientation into lobate form; stone rings with small boulder concentrations in a depression surrounded by larger boulders... and boulder imbrication... [Conference Figure 12]... shows the surface morphology of part of the Hickory Run boulder field as mapped by Mr. Alan Adler during the course of his thesis research. These patterned features argue for periglacial conditions during and after the formation of the boulder field.

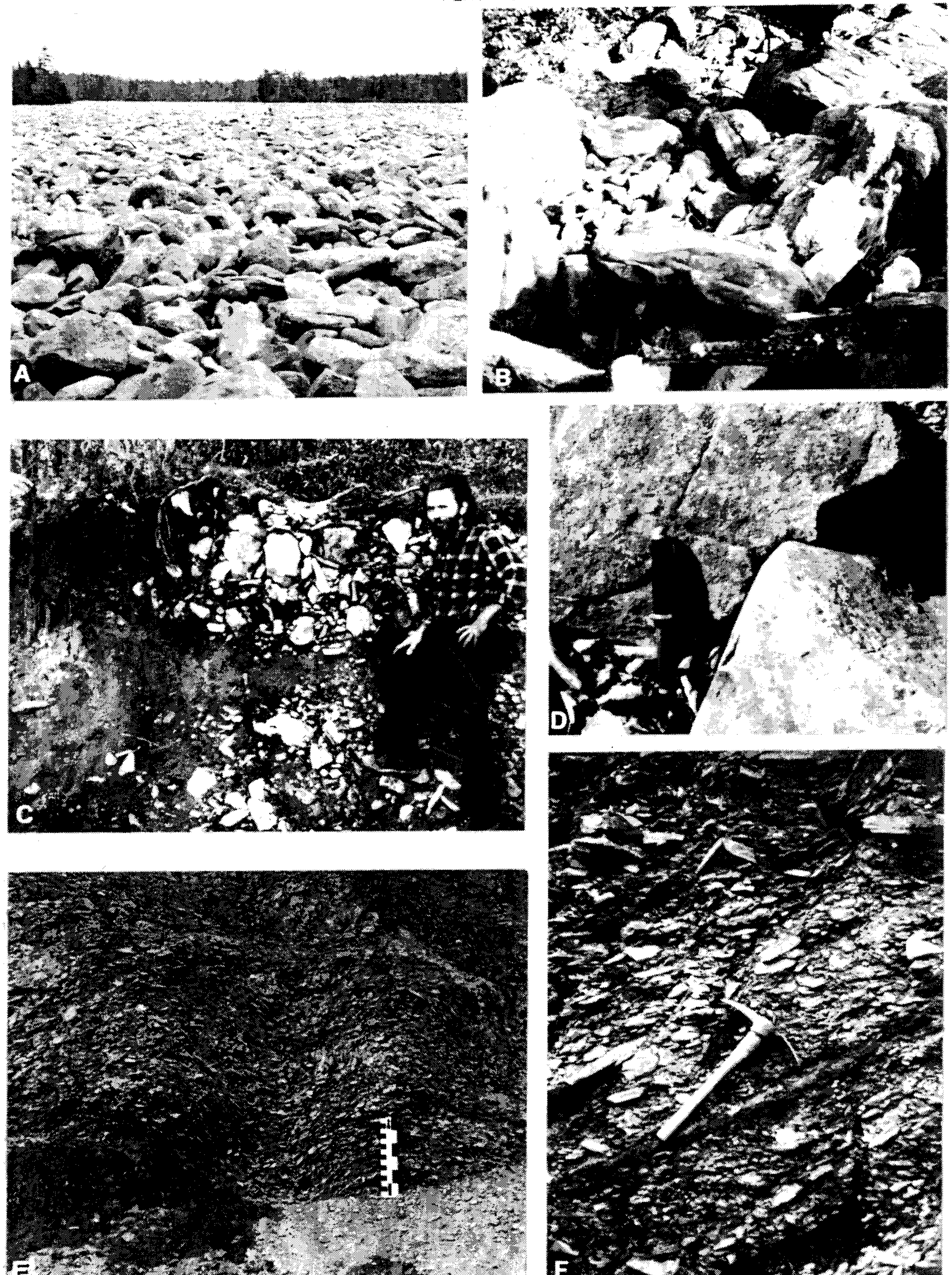
In the upper end of most boulder fields in Carbon County, rock streams can be traced from the boulder field proper to a specific outcrop area. Only rarely is it possible to detect stone stripes joining the larger rock streams...

The composition of any boulder field comprises two elements; lithology and texture, both a function of available bedrock even though initial texture is modified during transport.

Most of the boulder fields in Carbon County are composed of rocks derived from Catskill or Pocono rocks. Boulders in the Hickory Run boulder field are derived from the uppermost member of the Catskill Formation... and comprise hard, reddish sandstones

Plate 3. A. Surface of Hickory Run boulder Field, Carbon County. View is to east (upfield) from near parking lot entrance. Barren expense to end of field about 2000 feet. B. Stone ring developed in boulder field northeast of Christmans, Carbon County. Boot in upper right is scale. C. Stone strip developed in Woodfordian till about 4 km (2.5 mi.) north of Mount Pocono in temporary exposure in Pocono Farms Development. G. Gordon Connally provides scale. D. Fitted surface between two adjacent boulders on boulder field east of Tobyhanna, Monroe County. E. Convolutions developed in shale-chip rubble derived from Mahantango shale. Exposure in small burrow pit on north side of Pohopoco Creek east of Lehighton. Scale is 6 inches long. F. Bedded talus (grezes littees) on south side of Pohopoco Creek Valley at Beltsville Dam. See Plate 1, A for picture of outcrop.

PLATE 3



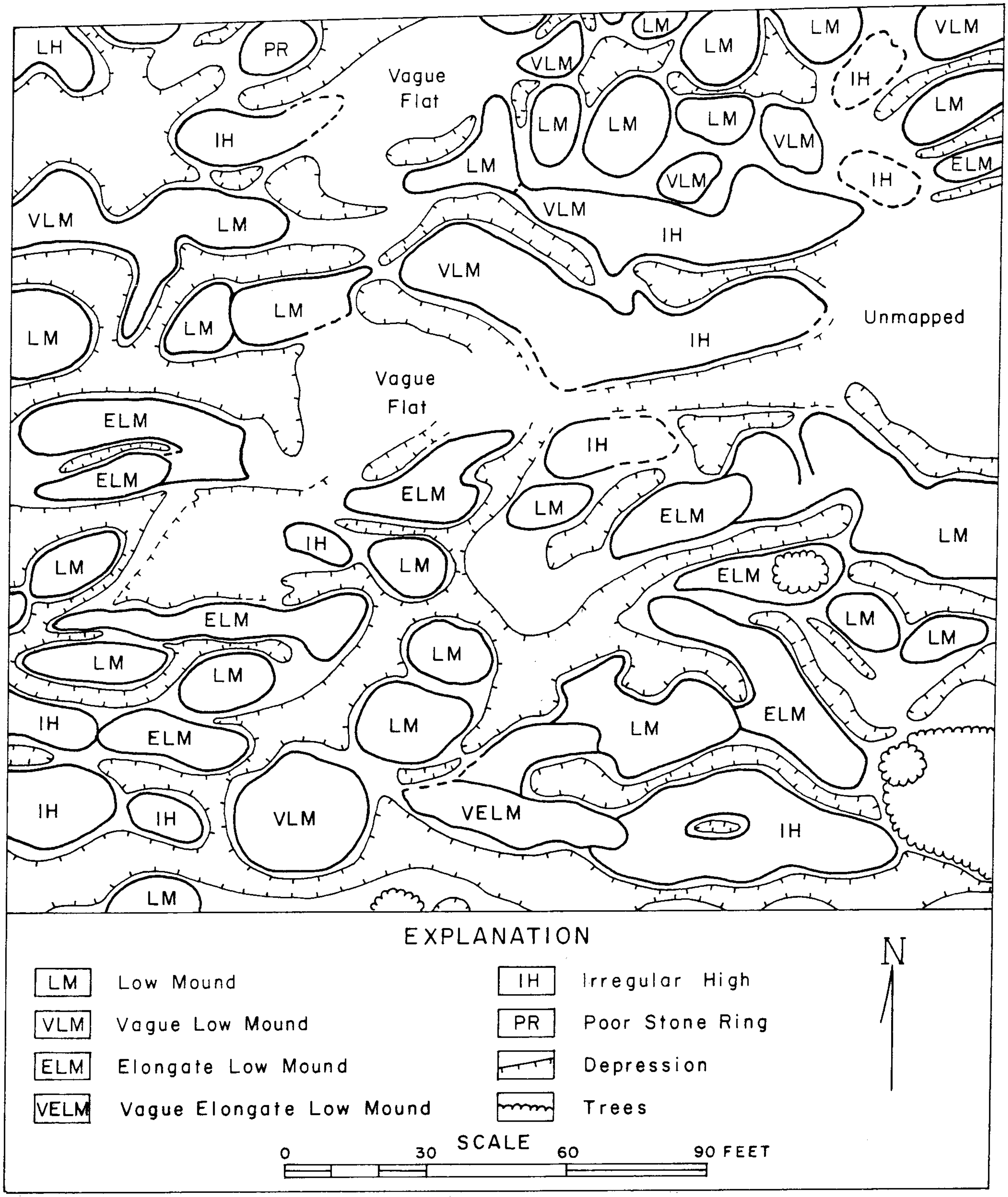


Figure 12. Map of the surface morphology of part of the Hickory Run Boulder Field (Stop 3, Day 1). Mapping by Mr. Alan Adler, Pa. Dept. of Transportation.

and conglomerates.

Texture varies from one boulder field to another, but is similar to the general texture of the Hickory Run field. At Hickory Run the boulder size ranges from 4-inch diameter cobbles to 30-foot long angular blocks (found mainly in the upper part of the field). Typical boulder sizes anywhere on the field are 1 to 5-feet in diameter. Generally, cobbles and smaller boulders are confined to high centers of microrelief features and larger boulders occupy lower parts of microrelief features. Although all shapes of boulders are present, equant, tabular and elongated shapes are most common. Boulders decrease in size and increase in roundness both with depth and down field.

Interstitial matrix material such as sand, silt and clay is conspicuously absent in the upper part of all barren boulder fields examined, but present at depths greater than 6 or 8 feet. Although interstitial matrix is generally thought to occur in the forested areas beyond the margins of barren boulder fields (Smith, 1953, p. 640; Sevon, 1967, p. 92), the writer finds that many Carbon County boulder fields (including Hickory Run) do not possess interstitial matrix in the forested marginal areas. Rather, the upper surface comprises a 1 to 2-foot thick humic layer which is underlain by empty interstices.

By using composition and surface morphology, Mr. Alan Adler mapped several distinct flows on the Hickory Run boulder field and a generalized part of his map is shown in figure... [Conference Figure 13]... Some of these flow units can be traced up gradient to source outcrops.

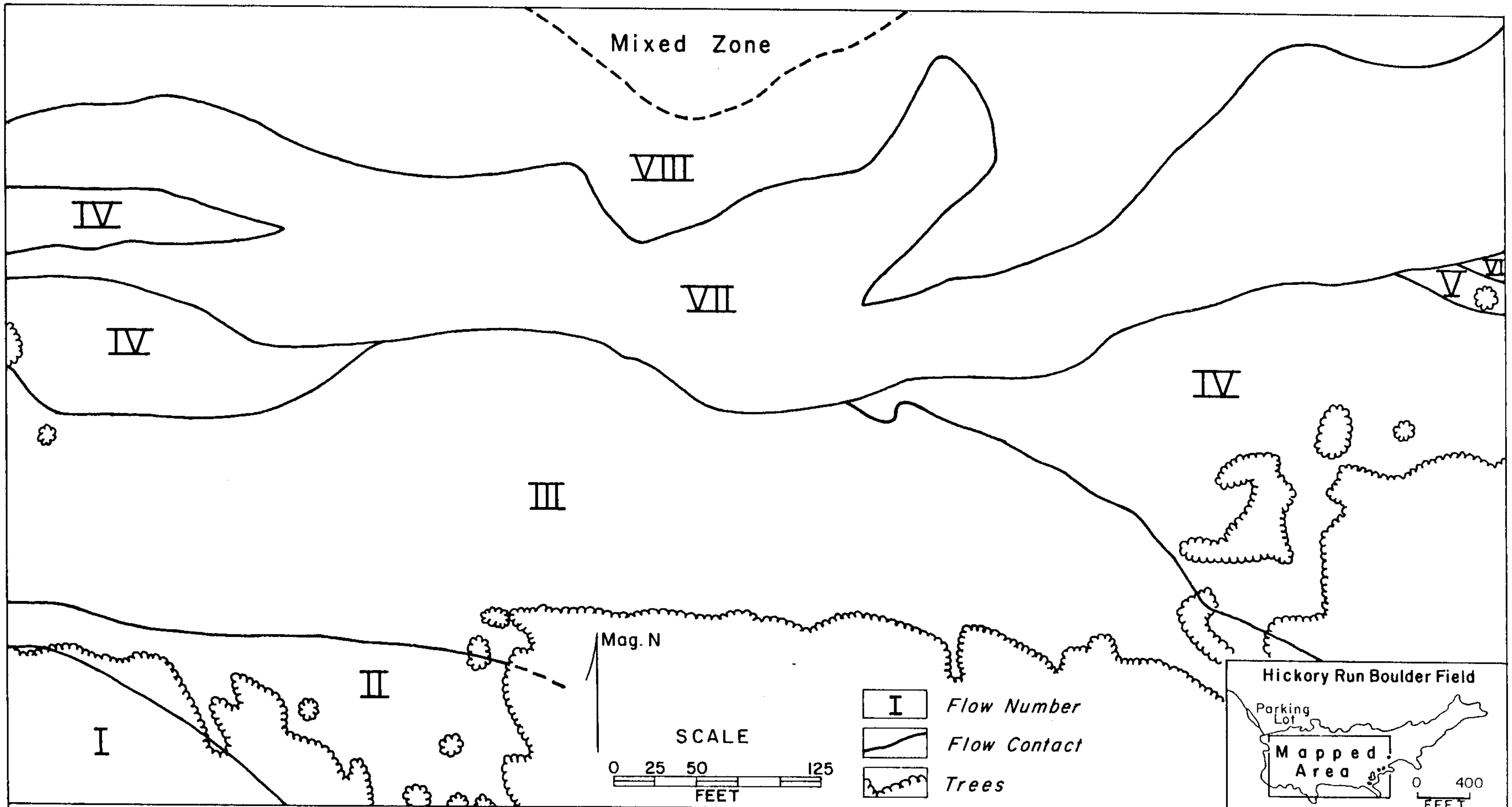
In addition to the above description we now recognize that boulders in some boulder fields, particularly the Hickory Run Boulder Field have been abraded sufficiently to create highly polished surfaces on individual boulders and fitted surfaces between adjacent boulders. The exposed upper surfaces of boulders are generally rough as a result of granular disintegration while protected underside surfaces are usually smooth. A brief fabric study performed in 1974 (Figure 14) indicates a definite preferred orientation of elongate and tabular rocks.

Numerous boulder fields have been mapped in the Hickory Run State Park area (Sevon, 1975b) and others are described by Epstein and others (1974, p. 220-222).

Patterned Ground

Patterned ground features are probably much more common in Pennsylvania than is realized, but thick vegetative cover in most areas makes their location and recognition difficult.

Stone Polygons. Stone polygons are concentrations of rocks or coarse soil material formed into polygonal patterns on level or nearly level surfaces with finer-grained material in the polygon centers. These features may be a few centimeters to several meters in diameter. The concentrations of coarse materials may be a few centimeters to over a meter in width and depth.



DESCRIPTIONS OF FLOWS

I: 100% Ss., 5-6' max. average boulder
II: 30% Cgl.+ Cgl.Ss., rounded purplish boulders
III: < 30% Cgl.+ Cgl.Ss., small red + gray Ss. boulders
IV: 50% ± Cgl. + Cgl. Ss., poor surface morphology
V: 5% ± Cgl., **small rounded boulders**, good morphology
VI: 30-60% Cgl., large rounded boulders
VII: 0-20% vcg. Ss., small rounded tabular boulders
VIII: 60-90% vcg. Ss., some Cgl.

Figure 13. Map of distinct lithologic flows of part of the Hickory Run Boulder Field (Stop 3, Day 1). Mapping by Mr. Alan Adler, Pa. Dept. of Transportation. A tentative sequence of flow is: V (oldest), VI, IV, II, III, VII and I or VIII (youngest).

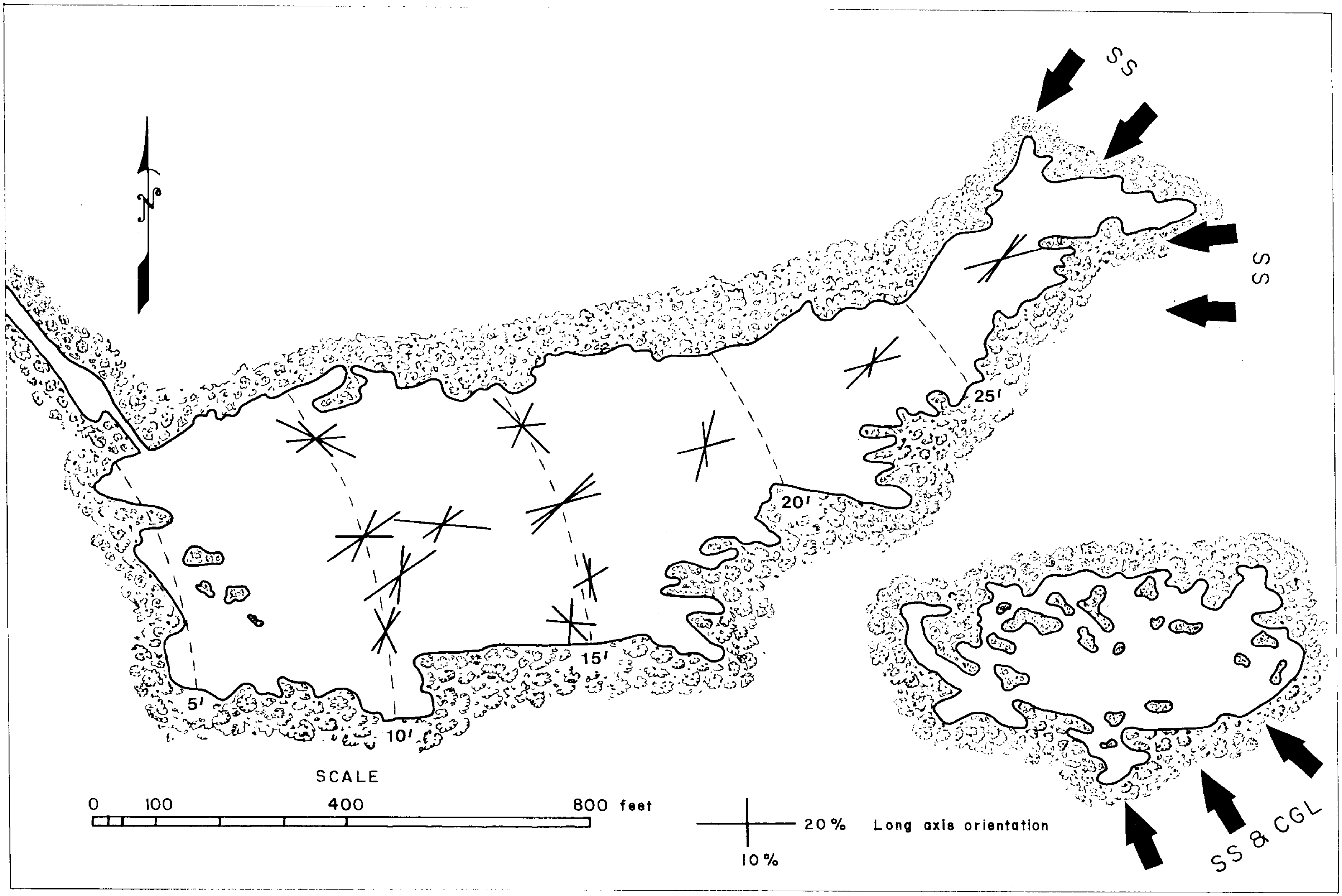


Figure 14. Fabric analysis of the Hickory Run Boulder Field. Data collected from boulders with an axis ratio of 2:1 by students of Geology 397, Lehigh University, fall 1974, H.T.U., 1953, Fig. 1, Plate 1, 1939 air photo.

One occurrence of stone polygons occurs north of Mount Pocono near the Gouldsboro moraine (Sevon, 1975c). Here concentrations of gray sandstones about a half meter in width and thickness occur as polygons with diameters of about 3 m (10 ft). These polygons are developed in Woodfordian till and are obscured by a surface coating of boulder colluvium. They were temporarily exposed in 1971.

Stone Stripes. Stone stripes are elongate concentrations of rocks on hill slopes. The concentrations are commonly 1 to 2 m (4 to 7 ft) in width and depth, relatively free of fine-grained matrix material, composed of chaotically oriented angular rocks and may extend upslope to a rock free face. The stripes are frequently obscurred on the surface by boulder colluvium and generally detected only in chance excavations. Stone stripes occur on the upper and lower slopes of Blue Mountain, on various slopes south of the Woodfordian "terminal moraine" and on slopes underlain by Woodfordian till near the Gouldsboro moraine (Plate 3, C).

Stone stripes have also been identified by Edmunds and Berg (1971, p. 61) in the southern Penfield area in Clearfield County, central Pennsylvania, about 113 km (70 mi.) beyond the glacial border.

Frost-Stirred Ground

Frost-stirred ground in northeastern Pennsylvania occurs as disrupted and distorted rock particles in colluvial deposits. The upper surfaces of some hillslope colluvium developed from Mahantango shale has been cryoturbated into whorl-like structures up to 0.6 m (2 ft) in diameter (Stop 11, Day 2) (Plate 3, E). Similar whorl and plume-like structures that are developed in mixed platy dolomitic shale and clayey-silt colluvium occur elsewhere (e.g., Stop 10, Day 2). All of these features occur on slopes with low to moderate gradient. Similar features are probably common throughout the area, but defy detection except in manmade exposures.

Ice Wedge Casts

Ice wedge casts are vertical wedge-shaped (or irregularly shaped) sediment-filled casts in space formerly occupied by ice. They may be a few centimeters to a few meters in depth but are generally less than a meter in width. The casts may be isolated, but also may be multiple, occurring in polygonal arrangement. Well-developed ice wedge polygons have recently been recognized near the Woodfordian glacial boundary in central New Jersey (Walters, 1975), but none have been recognized as yet, in a similar position in eastern Pennsylvania. E. Coilkosz, Pennsylvania State University (1974, pers. comm.) indicates that ice wedge casts do occur in various places in Pennsylvania either near the glacial border or at high elevations, but their detection is almost exclusively by chance.

MINERAL RESOURCES

Talus, valley-fill colluvium, and boulder colluvium have not been developed as a resource, and have little potential as such. Some talus (e.g., Plate 1, F) has potential as a source for crushed rock and rip-rap where limited quantities are desired without a necessity for quarry operations involving blasting or undercutting large slopes covered with such material. Shale-chip colluvium has been utilized for many years as a source of fill and low-use road top-course (Epstein and others, 1974, p. 365; Crowl, 1971, p. 37). This material compacts well because of its small grain size and moderately good sorting, disintegrating slowly to create a relatively firm surface and not resulting in a muddy mass when wet. Boulder fields have potential as scenic attractions (Stop 3, Day 1) and also as "different" sites for second home development. The inherent natural beauty and aesthetic value of such natural features may merit equal importance with mineral resources in overall environmental planning. Stone stripes, stone polygons and involutions have no known economic potential, but ice-wedge casts have agricultural significance (Walters, 1975, p. 120) in that they may retain moisture longer than adjacent materials, thus stimulating greater growth of deeply rooted plants. None of the periglacial deposits have any significant potential as a source of ground water although rare seasonal springs develop in some boulder-colluvium choked gulleys on the slopes of Blue Mountain.

ENGINEERING AND ENVIRONMENTAL CHARACTERISTICS

Mass Movement Debris

Talus. Most talus slopes in Pennsylvania are in states of static equilibrium if their slopes have not been disturbed by undercutting. Individual rocks on slope surfaces may be unstable, but the deposit as a whole is stable. However, as soon as any talus slope is disturbed by removal of some material, equilibrium is upset and movement of the talus may be initiated. Assuming a normal occurrence in which the toe or mid slope of a talus is cut for a roadway, the following movements may (and probably will) occur (Figure 15):

1. Rock will fall at low velocity piece by piece or in a small mass from the excavated face or the top of the face (Figure 15A).

2. Individual rocks may fall at high velocity from disturbed positions high on the slope (Figure 15B). Such rocks are likely to bounce.

3. Sequential and progressively larger slumps are likely to develop upslope from the disturbed zone (Figure 15C).

All of these features can be demonstrated in equilibrium-disturbed talus in the Lewistown Narrows along the Juniata River (Juniata County). The same principles of talus stability apply to this Conference area.

Hillslope Colluvium. Hillslope colluvium, as a result of its unconsolidated nature, slope position, and relatively high porosity and permeability relative to underlying bedrock, is susceptible to water saturation and slump failure. Such slumps are generally not large, but create small slip surface scars and bulges on hillsides. During periods of unusually high rainfall (e.g., Agnes, 1972), such deposits become very mobile and yield serious hazards.

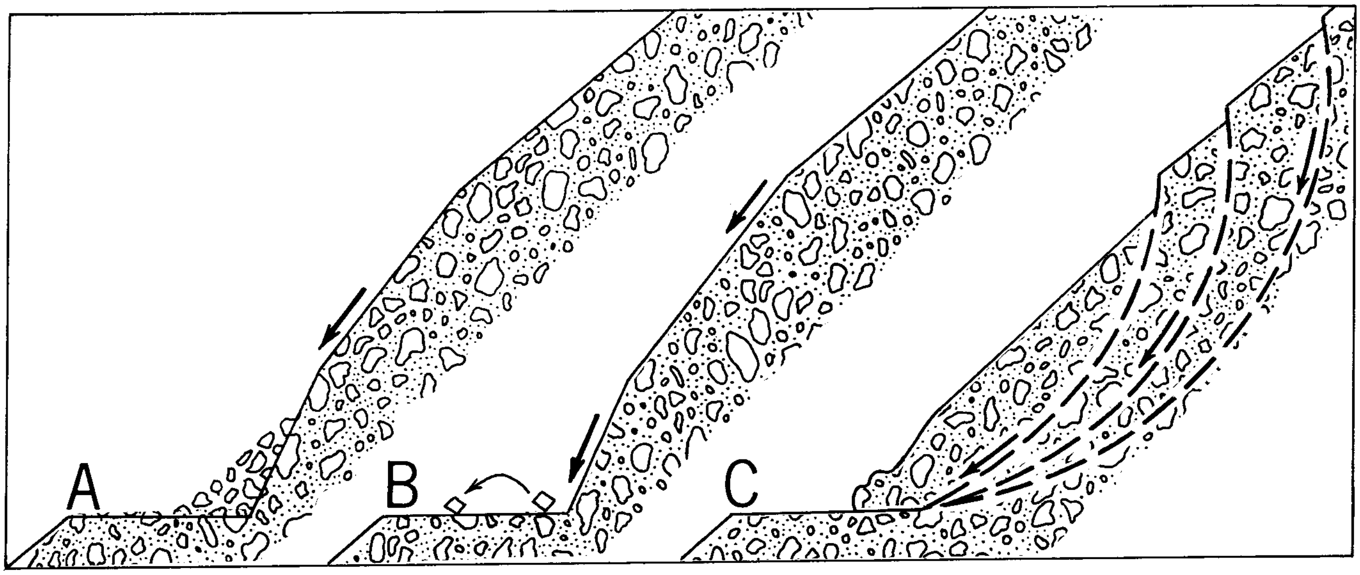


Figure 15. Sequential development of slope failure in disturbed talus slope. A. Low velocity rockfall from cut face. B. High velocity rockfall from high on slope. C. Development of sequential and progressively larger slumps.

Valley-fill Colluvium. Valley-fill colluvium generally does not give rise to significant problems. Foundation support strength is low for large structures and some surfaces are too stony for agricultural development.

Boulder Colluvium. Boulder colluvium-covered slopes are too stony for agriculture or grazing, but have been utilized infrequently for housing developments. On low to moderate slopes, no particular geologic hazards exist. On steep slopes, slumps are always a potential, particularly if the slope is undercut and equilibrium disturbed.

Boulder Fields. Boulder fields present no environmental or serious engineering problems, except for some difficulty in excavation, and potential flooding in some low-gradient boulder fields developed on Woodfordian till. The disruption of boulder fields is an aesthetic concern in total environmental planning.

Patterned and Frost-stirred Ground

Stone Stripes. Stone stripes are susceptible to low velocity rock fall from exposed faces (similar to talus, Figure 15A) in natural or artificial cuts. They are natural channels for water flow. They may cause unexpected excavation problems if not anticipated in construction planning.

Miscellaneous. Stone polygons, involutions and ice-wedge casts have no engineering or environmental characteristics other than those previously mentioned under MINERAL RESOURCES.

ORIGIN

Although some of the geologic processes which caused the periglacial deposits and features being discussed here, may be seasonally active in northeastern Pennsylvania today, they are not obvious, and it seems that these deposits and features are generally relicts of former conditions. Since similar deposits and features have known association with cold climatic environments, we assume that these deposits and features were formed during the time when Pennsylvania was being glaciated. The zone of extreme periglacial climate was probably not wide, and most intense only at elevations over 365 to 457 m (1200 to 1500 ft).

The most important process of rock weathering in the extreme periglacial zone is freeze-thaw action during which water freezes with about a 10 percent increase in volume and a high expansion coefficient, nearly equal to that of steel. Water crystallization also alters the ionic equilibrium in soils and alters the strength of clays. The critical factor in a periglacial environment is not the temperature extreme, but the number of freeze-thaw cycles: the greater the number, the greater the activities of congelifraction (frost splitting), congeliturbation (frost heaving) and congelifluction (material movement) (Embleton and King, 1968, p. 447-453; Tricart, 1968, p. 829-833).

Suitable moisture and temperature conditions necessary for periglacial activity function best when numerous rock parting planes and fine-grained unconsolidated sediments (soil) are present. The Mahantango shale is very suitable for disintegration by congelifraction because of ubiquitous and closely spaced bedding and cleavage planes (Stop 11, Day 2), and is an extreme example of a condition shared to varying degrees by all rocks in northeastern Pennsylvania. Sands, silts and clays are moderately abundant in most of the soil series developed on rock materials present in this Conference area, and contributed to ease of congelifluction. Certain basic elements are the same for the origin of periglacial deposits, but the exact mode of origin of each deposit and feature is unique.

Mass-Movement Debris

Most of the rock materials of mass-movement debris ultimately owe their origin to congelifraction from a free face of rock, although the mechanisms of debris transport vary. The size of resultant debris is determined by the spacing of partings in the parent rock. For example, the closer spacing of partings in the Mahantango shale produces smaller debris fragments than the Palmerton sandstone (Plate 1, F).

Talus. Talus is the most obvious product of periglaciation seen in Pennsylvania today. That these deposits are the result of pre-Holocene climatic extremes is indicated by the present negligible addition of fresh rock, as evidenced by tree and lichen growth. Congelifraction during any, or all of the periods of glaciation produced large quantities of rock debris which fell, bounced, rolled, and slid downslope mainly as individual pieces. As talus slopes develop, individual clasts are size-sorted with large at the bottom of the slope and fine at the top through a process of increased frictional resistance with increased size (Kirby and Statham, 1975, p. 353). Although there is definite downslope size-sorting in talus, the random nature of downslope movement, and coming to rest does not give rise to vertical sorting or bedding. Occasionally some disturbance, perhaps a large falling block, will upset the slope equilibrium and small areas will "run" and create a depression in an otherwise flat surface. The material which "ran" may spread out uniformly farther down the slope or build a small lobe. Disturbed equilibrium of talus may also result in small slumps which cause small surface depressions upslope from lobe-like surface bulges.

Hillslope Colluvium. Two forms of hillslope colluvium resemble talus in all respects except for the presence of well-defined beds. Such deposits are sometimes called grèzes litées. Shale-chip colluvium (Stop 11, Day 2) is one form of grèzes litées, and the colluvium shown in Plate 1, A and Plate 3, F is another. The physical processes producing these deposits is the same as for talus, but the exact mechanism of movement is not clearly known. Sliding on a snow-covered or frozen surface may be involved. Platy debris in these deposits are frequently imbricated with upslope dips and crude, to very good size-sorting is common. Convolutions (Stop 11, Day 2) at the top of some low gradient shale-chip colluvium deposits suggest that at least part of the deposit's history involved water saturation and congeliturbation. Gravity-driven sliding, slope wash and frost action are all involved, and the latter two are probably the principal mechanisms.

Valley-fill Colluvium. The exact mechanism of transport of valley-fill colluvium is not known, but, because of the low gradients present on the valley floors, water was probably involved in either a liquid or a liquid/solid/fluctuating state. Solifluction is definitely a possibility, but has not been proven with evidence of congelifluction in valley-fill colluvium. The presence of boulders up to a meter in diameter in some basically fine-grained deposits argues for a mudflow-type mechanism.

Boulder Colluvium. Boulder colluvium is somewhat comparable to talus in that the rock is congelifracted. However, debris production was limited, slope gradients were generally much less steep than on talus slopes, and the large debris was mixed with fine-grained soil material. Thereafter, downslope movement was probably accomplished by mudflow or solifluction mechanisms.

Boulder Fields. The following discussion of the origin of boulder fields is from Sevon (1969, p. 225-227):

> There seems to be little question today that boulder fields were formed by mass movement of rock material. The flow map of Adler [Conference Figure 13], the structural necessity for movement in the Bowmanstown boulder field (Sevon, 1967, p. 91-92) and the lobate forms of the Blue Rocks field (Potter and Moss, 1968, p. 260) all indicate flow.
>
> There are three primary criteria necessary for the formation of boulder fields: (1) source rock, (2) mechanism of boulder production, and (3) mechanism of movement...
>
> A suitable boulder field source rock must possess

three qualities: resistant lithology, planes of separation and sufficient outcrop. Any well-indurated rock capable of withstanding rapid disintegration into small particles (sand size or smaller) is suitably resistant as a boulder source. Catskill and Pocono sandstones and conglomerates in northeastern Pennsylvania meet these qualifications.

Bedding planes, joints and cleavage are the planes of separation essential for rock disintegration. Bedding planes are well developed in most of the Catskill and Pocono rocks of Carbon County and there is a widely spaced joint system oriented approximately normal to bedding and striking N20°W. A ...closely spaced fracture cleavage system is oriented approximately normal to bedding and strikes N65°E. These planes readily allow disintegration of Catskill and Pocono rocks into boulders.

Without adequate outcrop a boulder field cannot develop. Scarps with horizontal rock or rock dipping away from the boulder field are the most suitable outcrops and most boulder fields in Carbon County are derived from such outcrops. Exposures of dip slope rock may also be boulder sources, but the quality of boulders derived from them tends to be small...

Mechanical disintegration of rocks by frost action (freeze and thaw) is probably the only method capable of mass production of large quantities of boulders required to form a boulder field. Since there is no evidence that any rapid (in terms of volume produced) mechanical disintegration is occurring in Carbon County today, the more extreme climatic conditions associated with Wisconsin glaciation in Carbon County ...are thought to be responsible for rock disintegration...

The exact mechanism of movement for a low gradient boulder field such as Hickory Run (1°) is problematical. Smith (1953) indicated a periglacial mass movement. Mr. Alan Adler has interpreted some lobes in the eastern end of the Hickory Run field as possible flowage lobes in which freeze and thaw plus some basal sliding would move masses of boulders, matrix and ice. These lobes occur on steeper gradients than the main field and have a raised central part with imbrication across the front of the lobe. At the western end of the field Adler has detected some possible solifluction lobes. These have a steep frontal end with a concentration of large, partially imbricated boulders and a depressed area with smaller boulders behind the front.

The possibility of rock glacier flow such as described by Wahrhaftig and Cos (1959) is improbable because rock glaciers are not known to produce the degree of rock rounding and polishing found on the Hickory Run Boulder Field. Also, boulder fields in northeastern Pennsylvania do not possess the sets of parallel rounded ridges and V-shaped furrows typical of rock glaciers. Caine (1968, p. 110-111) suggests that blockfields in Tasmania originally possessed abundant fine-grained matrix and moved in response to ice segregation and frost-heaving. Potter and

Moss (1968, p. 261) suggested the importance of creep, which cannot be discounted for some of the steeper gradient boulder fields, but this seems unlikely for the low gradient of the Hickory Run Boulder Field. Cold climate, water/ice, soil matrix/no soil matrix, freeze/thaw cycles, and gravity seem to be involved, but the exact mechanism of movement is not yet known. Vertical congeliturbation did occur following downfield movement as evinced by stone rings. Sevon indicates (1969, p. 227):

> Characteristic of all barren boulder fields is the absence of interstitial matrix in the upper 6-8 feet of the deposit. Some writers (Smith, 1953; Andersson, 1906) feel that interstitial matrix must be present to aid in movement of the boulders and that this matrix is flushed out either during or after deglaciation of the area. Potter and Moss (1968, p. 261) have suggested the possibility of very little original matrix in the Blue Rocks boulder field. In an earlier section ...it was suggested that boulder production by frost action would produce very little fine-grained material.

The occasional occurrence of fitted adjacent boulder surfaces, the obvious increase in downfield rounding and the presence of high polish on unweathered boulders suggests that moderate amounts of fine-grained material were produced during movement. Presumably this material has either settled below the surface and is the matrix found at depth or it was eroded away. Smith (1953, p. 640) suggested that the fine material was flushed out by normal erosion. Smith later called the process "piping" (Smith, 1968). Caine (1968, p. 112-115) suggests that matrix in Tasmanian blockfields was removed during the last stages of movement and immediately thereafter, but is not being removed now. We believe that the original matrix was produced by grinding during movement, that it is presently at depth in the barren boulder fields and has not been flushed or piped away. Additionally, we believe that soil material is gradually being added to the margins of the fields and that vegetation is slowly encroaching onto the fields. This is suggested by the development of vegetative mats at the margins of the fields and in "islands" on the fields which support substantial plant growth, but overlie matrix-free interstices (determined by probing).

Patterned Ground

Stone Stripes and Stone Polygons. Stone stripes and stone polygons form as a result of some form of freeze and thaw action which concentrates the coarse debris in polygons or stripes. The process of formation probably involves repeated freezing and thawing of soil which moves coarse debris towards freezing zones, either upward toward the ground surface or laterally toward the edges of soil fractures. The exact nature is still speculative and probably polygenetic. Polygons form on horizontal or near horizontal surfaces and frequently grade into stripes where an increase in surface gradient occurs.

Frost-stirred Ground

Convolutions. Convolutions occurring in northeastern Pennsylvania

(Stops 10 and 11, Day 2) are produced by the general process of congeliturbation (cryoturbation). Although these convolutions may be the result of disturbance by frost heave (caused by frost crystal growth normal to cooling surface and vertical thawing), the sharp base of these convolutions suggests that they were formed by a solifluction process. During congeliturbation surface thawing of water-saturated material occurs, and slow downslope flowage occurs. The material below the thaw zone remains frozen and unaffected by flowage. If these convolutions were produced by this freeze-thaw solifluction process, they may indicate that a zone of permafrost existed in close proximity to the Woodfordian ice sheet.

Ice Wedge Casts

Ice wedges are formed by cyclic freeze-thaw action on relatively horizontal surfaces in zones of permafrost. Initially, contraction of frozen soil opens a crack (frost crack). During a subsequent thaw, the crack is filled with water which later freezes and expands. Subsequent contraction reopens a crack in the ice itself and the process repeats. When the area is no longer within a permafrost zone, the ice wedge melts and the opening is eventually filled with sediment, generally of a texture contrasting to the enclosing soil.

EPILOGUE

In his wisdom and foresight, J. P. Lesley (in Lewis, 1884, p. vii-viii) stated:

> It is hardly needful to remark that two trained observers could hardly carry on so extensive a line of investigation and confine themselves rigidly to a bald description of facts. Some method of accounting for observed facts is imperiously demanded and involutarily adopted by every intelligent mind. Traces of theories--if nothing more than traces--will, of course, be found in this report, and will justly claim respectful consideration; but the sanction of the Board for this special survey was obtained on the plea of a keenly felt necessity that the quota of facts respecting the American terminal moraine expected from the geological survey of Pennsylvania should no longer be withheld; and in the progress of the survey the time for obtaining and publishing these facts had come. They are now presented for the use of the citizens of the State, and of American geologists. The theories of the observers are of secondary importance; for when the text, the maps, and the illustrations of this report have been distributed, new observers will undertake to verify, correct, limit, and explain its statements for themselves. And this educational function of our reports is of the highest value.

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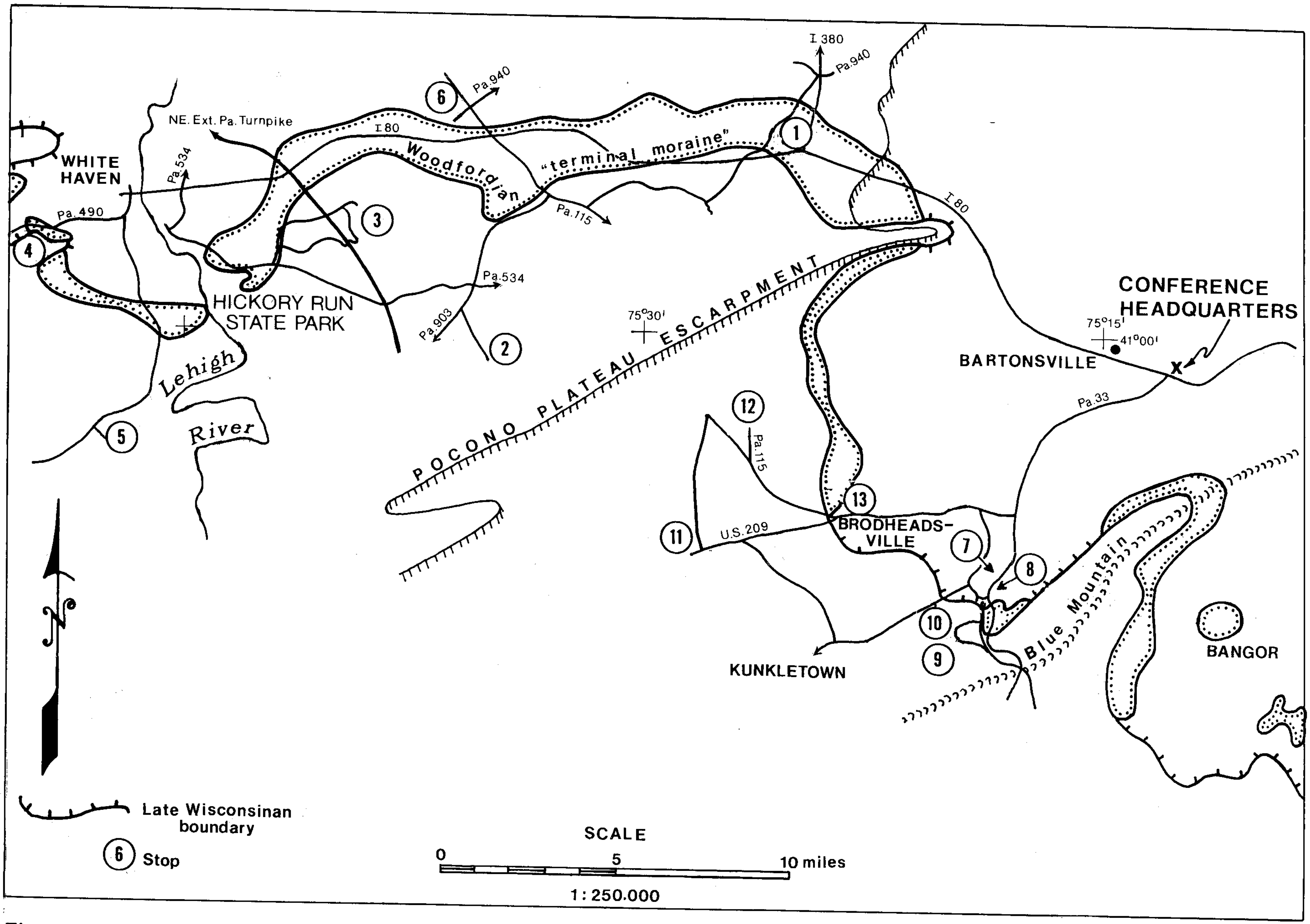

Figure 16. Route map for field trip.

ROAD LOG

Day 1

Friday, 3 October 1975

[See Figure 16 for route and stop locations]

Cum. Mil.	Inc. Mil.	
0.0	0.0	LEAVE parking lot of Bartonsville Holiday Inn. TURN LEFT onto Pa. Route 611 N.
0.1	0.1	TURN LEFT onto I80 W. Bear right to I80 W (do not go straight ahead on Pa. Route 33).
0.4	0.3	Join I80 W.
0.8	0.4	Outcrops of Upper Devonian Trimmers Rock Formation on both sides.
1.4	0.6	Outcrops of gray sandstones and red beds marking base of Catskill Formation on both sides. This formation will be under us most of the morning.
2.1	0.7	Outcrops of Catskill red shale and siltstone and gray sandstone on both sides.
3.7	1.6	View to left of Camelback Mountain, a projection of the Pocono Plateau. Woodfordian "terminal moraine" wraps around its flanks.
4.7	1.0	Climb the Pocono Plateau Escarpment.
7.3	2.6	Travel in Woodfordian "terminal moraine."
8.5	1.2	Outcrop of Woodfordian till on right.
9.4	0.9	BEAR RIGHT on I380 W.
10.0	0.6	Outcrop of Woodfordian till on right.
11.0	1.0	Borrow pit in sand and gravel on right has variety of igneous and metamorphic erratics including a garnetiferous gneiss from Adirondack Mountains. Crystalline erratics are generally rare in this region; this pit has anomalous concentration.
11.9	0.9	BEAR RIGHT onto Exit 1 to Pa. Route 940.
12.1	0.2	STOP. TURN LEFT onto Pa. Route 940 W.
12.3	0.2	TURN LEFT on road (LR 45040) to Emerald Lakes and Long Pond. Crossing Woodfordian ground moraine.
13.2	0.9	Cross road. CONTINUE AHEAD. Ascend proximal slope of Woodfordian "terminal moraine." Small road cuts show till.
14.1	0.9	TURN LEFT into Emerald Lakes entrance. These are private grounds and we enter by special permission.

STOP 1. Woodfordian till.

Woodfordian till exposed here is typical of that comprising the "terminal moraine" in this area. The till is brown, sandy, very stony, dominated by gray sandstone pebbles and cobbles and has thin soil development. Textural and compositional data for a sample of this till are presented in Table 2 (Sample 1). Note the extremely bleached white color of the gray sandstones at the surface and the fresh color of similar sandstones within the till. Note also the abundance of striated rocks. Soil profile at one place at crest of exposure:

A	0-30.5 cm (0-12 in.)	- light gray (5YR6/1-7/1), very sandy, loose, uncompacted, lacks clay, no peds, sharp base with 1/2 in. thick layer of dark reddish brown (5YR3/4) clayey loam.
B_1?	30.5-40 cm (12-16 in.)	- strong brown (7.5YR5/6), sandy, some clay, no peds, slightly compact, sharp base.
B_2?	40-52.5 cm (16-21 in.)	- brown (7.5YR5/4), sandy, some clay more compact than above, no peds, gradational base.
C ?	52.5 cm + (21 in. +)	- brown (7.5YR5/4), compact, very sandy and stony, some platy structure.

No fragipan is detected in this described site, but the soil is variable in the road cut, and at places, a fragipan is present and soil development is thicker.

The "terminal moraine" in this area varies from sandy till to ice-contact stratified drift and no clayey tills have been observed. Thickness in this area ranges between 3 and 52 m (10 and 170 ft) and averages 30 m (97 ft). End moraine topography is very well developed and typical of the "terminal moraine" between the Lehigh River (west) and Camelback Mountain (east). Glacial striae north of this area indicate ice movement about S10W. See Plate 2, A for a stereogram of topography about 1.5 km (1 mi.) west of here. Roadcuts are plentiful within the development, but the till is basically the same along Long Pond Road.

RETURN TO Emerald Lakes entrance. TURN LEFT (south) on Long Pond Road.

14.9	0.8	Emerald Lakes in kettle holes.
15.2	0.3	Cross distal (south) margin of "terminal moraine", followed by extensive flat surface underlain by Illinoian till.
16.4	1.2	Cross over I80.
18.0	1.6	TURN RIGHT at Y intersection.
20.6	2.6	Borrow pit on left shows Catskill Formation sandstones.
20.8	0.2	Pocono International Raceway on left. Racetrack embankments are made of Illinoian till.
22.1	1.3	STOP. TURN RIGHT onto Pa. Route 115 N.
23.6	1.5	TURN LEFT onto paved road (T636) beside large borrow pit soon after crossing Tunkhannock Creek and opposite small snack bar on right. PAUSE.

Woodfordian till and ice-contact stratified drift are exposed in a borrow pit in the south margin of the Woodfordian "terminal moraine". This is a complex of ice-contact stratified sand and flowtill. The till is generally reddish brown (5YR4/3-5/3), clayey to sandy, stony, compact, unweathered and shows some platy structure. Up to 4 flowtills in sharp contact with interbedded sands have been observed here. Pebbles, cobbles and boulders are mostly gray sandstone; red siltstone and shale occur mainly in the sizes 2.5 to 5 cm (1 to 2 in.). Some bedded sands have thrust faults overthrust to the south in a direction presumably away from the ice. The upper part of this pit is mainly flowtill. We have seen only a thin soil development. See Sample 2e (Table 2) for textural and compositional data of till collected here.

CONTINUE STRAIGHT AHEAD.

24.2	0.6	Approach sharp curve to left.
24.5	0.3	STOP. TURN RIGHT on Pa. Route 903 S.
25.5	1.0	Lake Harmony entrance on right. CONTINUE STRAIGHT AHEAD.
25.9	0.4	Blocks of Duncannon Member of Catskill Formation on left. Between here and next cross road much of surface underlain by Woodfordian till which lies south of the "terminal moraine".
27.7	1.8	Cross road. Junction Pa. Routes 903 and 534. CONTINUE STRAIGHT AHEAD
28.4	0.7	Entrance to Towamensing Trails on left. CONTINUE STRAIGHT AHEAD.
28.6	0.2	TURN LEFT onto gravel road (T516) at cross road.
28.9	0.3	Woodfordian kame on left shows sand and flowtill. This is part of a small area of Woodfordian drift which lies south of the "terminal moraine".
29.9	1.0	PULL OFF ALONG ROADSIDE. Walk into borrow pit on left.

STOP 2. Illinoian till.

Very clayey, yellowish brown material exposed in the vertical face is interpreted as the clay-enriched B horizon of a soil profile developed on Illinoian till during the Sangamonian Interglacial Stage. Darker material exposed locally at the top of the exposure may represent a superimposed modern soil profile. Weathered till apparently lacking clay enrichment occurs in lower levels of this pit. Samples 2a, b, c (Table 2) and Samples 9 and 10 (Table 3) present some textural and compositional data from samples collected at this exposure while Sample 2d is from similar till collected near mileage 16 (Day 1).

Brief description at one place (now quarried):

0-27.9 cm (0-11 in.)	- yellowish brown (10YR5/6), contains black organics, loose and friable, silty to sandy, no peds, gradational in lower 3 in., dries to form vertical plates.
27.9-57.5 cm (11-23 in.)	- yellowish brown (10YR5/6-5/8), more clayey than above, small tendency to break into blocky peds, forms vertical plates when dry, contains few pebbles and cobbles, gradational in lower 3 in., laterally numerous cobbles occur at base of this zone.
57.5-225 cm+ (23-90 in.+)	- till, yellowish red (5YR5/8), clayey, sandy, scattered small pebbles and occasional boulders, suggestion of subhorizontal platiness.

The vertical face showed some lateral variation in 1974 with thin layers of sand surrounded by till.

This site occurs in a very broad flat part of the Pocono Plateau and has not been subjected to much, if any, cryoplanation or colluviation. The locally detectable layer of cobbles may be related to Wisconsinan periglacial activity of some sort. There is no clear evidence that the site has been overridden by either Altonian or Woodfordian ice.

The critical questions at this site are: (1) what makes this diamicton a till? (2) if it is a till (and we say it is) is it different from that seen at STOP 1 and, (3) assuming a till of different age than Woodfordian, what age and why?

RETURN TO Pa. Route 903 via same route.

31.2	1.3	TURN RIGHT onto Pa. Route 903 N.
32.1	0.9	TURN LEFT onto Pa. Route 534 W.
33.7	1.6	Village of Albrightsville sits on Woodfordian drift which lies south of the "terminal moraine".
34.5	0.8	Hickory Run State Park boundary.
34.8	0.3	Woodfordian till exposed on left.
36.6	1.8	Crossing extensive boulder colluvium surfaces.
37.0	0.4	Road on right to Stony Point Forest Fire Tower. CONTINUE STRAIGHT AHEAD. Frost-riven sandstone of Duncannon Member of Catskill Formation occurs at base of fire tower. Similar outcrops were source of material at Hickory Run Boulder Field.
38.8	1.8	TURN RIGHT at entrance to Hickory Run State Park day use area. Road here is on Woodfordian "terminal moraine". Frontal drainage channel is immediately to right.
39.2	0.4	BEAR LEFT at road fork towards Boulder Field. Still travelling on "terminal moraine".
40.4	1.2	Kettle hole at outer edge of "terminal moraine" on left. Travel over flat surface of well-vegetated boulder field traceable up slope to sandstone outcrop of the Pocono Formation (Mississippian).
40.5	0.1	Hickory Run Lake on right.
40.6	0.1	Borrow pit on left (now grassed over) originally exposed Woodfordian ice-contact stratified drift formed when ice dammed Hickory Run and formed temporary lake somewhat larger than present Hickory Run Lake.
41.4	0.8	Pass under Northeast Extension Pennsylvania Turnpike. Now travelling south of "terminal moraine." Note boulder colluvium surfaces on both sides of road and stumps of former hemlock trees.
42.0	0.6	Road to right. CONTINUE STRAIGHT AHEAD.
42.9	0.9	STOP in parking area.

STOP 3. Hickory Run Boulder Field.

Hickory Run Boulder Field is probably the finest example in the eastern United States of a deposit resulting from periglacial activity. The field was first described by H.T.U. Smith in 1953 and was made a Registered Natural Landmark in 1967. The boulder field is only one of many in Pennsylvania, and is not the largest even in the conference area. However, it does possess the lowest known gradient, 1 degree, of such fields in Pennsylvania and preserves many features such as: (1) stone rings, (Plate 3, B), (2) lithology streams (Figure 13), (3) fitted and polished surfaces (Plate 3, D), (4) intricate surface morphology (Figure 12), (5) definite fabric (Figure 14), (6) imbrication, and (7) downfield boulder rounding and size reduction. Most of our text description regarding boulder fields is about the Hickory Run Boulder Field and the reader is referred to that section for detailed information. The boulder field lies within 2 km (a mile) of the Woodfordian "terminal moraine" and is presumably a periglacial by-product of that glaciation, although help from Altonian glaciation cannot be discounted. We are moderately confident that the area was glaciated during the Illinoian, and that the boulder field post-dates that ice advance. The mechanism of origin is open for discussion based on your observations, as is the question about whether vegetation is encroaching upon or retreating from the boulder field. Of special interest also are numerous small (2-3 cm diameter) circular structures which occur on the surface of many sandstone boulders.

As a starting place to study the field, proceed straight out from the parking lot path to the first vegetation "island". All of the features of the field can be located in that area.

LEAVE parking area.

43.8	0.9	TURN LEFT onto Exit Road. Do not continue straight ahead - entrance road is One Way to Boulder Field beyond Hickory Run Lake.
44.1	0.3	Cross Hickory Run and lower end of Hickory Run Boulder Field which here is almost completely vegetated.
45.4	1.3	Pass under Northeast Extension Pennsylvania Turnpike. Soil here is developed on Pocono Formation.
46.2	0.8	Hillside shoulder on right underlain by gray sandstone of Spechty Kopf Formation (Devonian-Mississippian).
46.9	0.7	BEAR RIGHT at road junction through picnic area. LUNCH STOP.
47.7	0.8	BEAR LEFT at road fork.
48.1	0.4	TURN RIGHT onto Pa. Route 534 W.
48.7	0.6	Hickory Run State Park Headquarters on left.
48.9	0.2	Cross Hickory Run. Pocono-Mauch Chunk Formations (Mississippian) transition zone exposed on right.
49.5	0.6	Travelling again across Woodfordian "terminal moraine".
50.5	1.0	Woodfordian till exposed in road cuts on left.
50.8	0.3	Mauch Chunk Formation crops out on left.
51.2	0.4	Cross Black Creek. Ahead on right is Woodfordian kame.

52.0	0.8	Village of Lehigh Tannery. Tanning mill formerly located here was main reason for cutting local hemlock forest during the 19th century.
52.2	0.2	GO SLOW! TURN SHARP RIGHT around curve and stay on Pa. Route 534 at road fork.
53.0	0.8	LaChateau golf course on left constructed on Woodfordian ground moraine. Note large erratic.
53.6	0.6	Peat bog on right was source of soil conditioner for golf course on left.
54.0	0.4	Cross I80.
54.1	0.1	TURN LEFT (west) onto I80 W.
55.2	1.1	Outcrops of Mauch Chunk Formation on both sides. This bedrock provides the reddish brown color of Woodfordian till in this area and is the only formation we travel on until after we pass this point going to Stop 6.
55.3	0.1	Cross Lehigh River.
55.5	0.2	BEAR RIGHT onto Exit 40 at White Haven.
55.7	0.2	TURN LEFT onto Pa. Route 940 W.
56.0	0.3	Outcrops of Mauch Chunk Formation on both sides.
56.3	0.3	BEAR RIGHT on Pa. 940 W at road fork.
58.2	1.9	Outcrop of Mauch Chunk Formation on right.
58.4	0.2	TURN LEFT into entrance of Hickory Hills Estates. Proceed to end of road.
58.9	0.5	TURN RIGHT at T intersection.
59.4	0.5	First ridge of "terminal moraine" on north slope of mountain.
59.5	0.1	STOP ALONG ROAD SIDE. Cutbank on left.

STOP 4. Woodfordian till.

Roadcuts in this development expose stony, reddish brown (2.5YR4/4 to 5YR4/4) till, characteristic of the Woodfordian in this area, and derived in large part from underlying red sandstones and shales of the Mauch Chunk Formation.

Till texture here is variable. A sample at 1.2 m. (4 ft) showed 49 percent sand, 33 percent silt, and 18 percent clay. A sample at 2.4 m (8 ft) showed 36 percent sand, 32 percent silt, and 32 percent clay. See Sample 4 in Table 2 for analysis of texture and composition. The anomalous lack of reflection of the underlying bedrock (Mauch Chunk Formation) may result from the lack of material coarser than 4.76 mm in the collected sample.

The end moraine was developed here in a situation where ice flow was impeded by the steep mountain slope to the south. The end moraine topography includes ridges that trend obliquely up the slope at about S28W. Some very small, and kettle ponds lie in some of the undrained depressions between the ridges. A similar end moraine area is northwest of here in the valley traversed by Interstate 80 between Green Mountain and Mount Yeager west of White Haven. A much weaker end moraine lies at the foot of Buck Mountain 2.4 km (1.5 mi) south, and continues east to the Lehigh River. These are counterparts of the end moraine in Hickory Run State Park and Emerald Lakes (Stop 1). Locally, a narrow belt of ground moraine lies south of the end moraine.

No drift has been found on the tops of Green Mountain and Mt. Yeager north of this point. However, elevations of the drift border on this slope, and estimates of ice surface gradients based on slopes of end moraines on nearby mountain slopes suggest that these mountains were over-ridden by Woodfordian ice.

The interpretation of end moraine here and glaciation of the mountains to the north is distinctly different from that by Leverett (1934). Basing his interpretation on the red color of the drift (which is unlike the true Illinoian "red"), he regarded as Illinoian in age all materials southwest of a line from Mount Yeager to the bend of the Lehigh River south of White Haven. He probably did not see these local end moraines.

We have given an interpretation to this material, but we again raise the questions: what are the criteria for determining (1) the origin of the diamicton and (2) the age of the diamicton?

TURN RIGHT, downhill. Note end moraine ridges.

59.6	0.1	TURN RIGHT and return to entrance road. Note that end moraine ridges dies out at base of mountain.
60.3	0.7	TURN LEFT onto entrance road.
60.8	0.5	TURN RIGHT onto Pa. Route 940 E. Retrace route travelling over Woodfordian ground moraine.
62.6	1.8	TURN RIGHT at road fork onto LR 40118. Pennsylvania Power and Light (PP&L) Center ahead on left.
62.8	0.2	Woodfordian kames on both sides of road. These are part of a belt of scattered kame areas in the ground moraine north of Buck Mountain which lies ahead of us on the right.
63.8	1.0	Cross road. CONTINUE STRAIGHT AHEAD.
64.8	1.0	North edge of Woodfordian "terminal moraine". Moraine has weak topographic expression in area to west and here lies on bedrock hills north of Sandy Run.
65.1	0.3	Outcrop on left in Mauch Chunk Formation.
65.4	0.3	Cross Sandy Run in midst of "terminal moraine".
66.2	0.8	South edge of "terminal moraine".
66.5	0.3	Carbon County line (Road number changes to LR A-1012).
66.7	0.2	Woodfordian pro-moraine till beyond "terminal moraine" was temporarily exposed in basement excavations on both sides. Notes that there is no real end moraine at Woodfordian border in this area. Till changes laterally to colluvium on bedrock. This type of border is common west of here where there was no topographic barrier to ice movement.
67.0	0.3	Bedrock and colluvium were temporarily exposed in house excavation on right.
68.2	0.7	Cross road. CONTINUE STRAIGHT AHEAD.

68.7	0.5	PAUSE along right side of road. Observe residual soil and angular sandstone fragments in fields.
70.8	2.1	Pond on left. WATCH FOR TURN.
71.0	0.2	TURN LEFT onto hidden dirt road, an old railroad grade which was used to take coal to the Lehigh River gorge where it went down by inclined plane to be loaded on canal barges and railroad.
71.6	0.6	STOP. Park in cleared area to right. Walk downhill into sand borrow pit.

STOP 5. Altonian drift.

This pit exposes sand, some gravel, and flowtill at the top, in part of an end moraine complex east of Weatherly and between Round Head and Penn Haven mountains. The flowtill is at the surface principally on the north and south sides of the pit, but similar till, either lodgement or ablation, is present elsewhere in the area. The till has the following soil profile:

A_1	1.25 cm (0.5 in.)	- organic material on and in mineral material.
A_2	5.1 cm (2 in.)	- silty sand, pinkish gray (5YR6/2).
B	1.5 m (5 ft)	- clayey, silt sand, red to reddish brown (2.5YR4/6-4/4).
C		- fresh till and sand.

Sample 5a in Table 2 indicates the texture and composition of the till at this site and sample 5b is from a similar till near mileage 68 (Day 1).

Leverett assigned an Illinoian age to these deposits and related tills to the west. We do not believe this, and have assigned an Altonian age to them. The sands resemble many Woodfordian sand deposits, but the till has a thicker weathering profile. There seems to be no comparison between the weathering of this till and those seen at STOP 1 and STOP 2, therefore, the Altonian age assignment.

This deposit lies 3 miles south of the Woodfordian border. Colluvium and Altonian till are widespread between here and that border. No Illinoian till has been discovered. Thus the question to be asked here is: "lacking vertical stratigraphy, what criteria may be used to establish the age of surficial deposits?"

RETURN via dirt road to paved road.

72.2	0.6	STOP. TURN RIGHT onto LR A-1012 and return to I80.
76.6	4.4	Low relief Woodfordian end moraine topography on left.
80.4	3.8	STOP. TURN RIGHT onto Pa. Route 940 E.
81.0	0.6	BEAR RIGHT onto I80 E.
81.3	0.3	Cross over Lehigh River.
82.5	1.2	Pass under Pa. Route 534.

82.6	0.1	Outcrops on both sides in Mauch Chunk Formation.
84.4	1.8	Cross over Northeast Extension Pennsylvania Turnpike and enter Woodfordian "terminal moraine". We travel across end moraine topography most of way to edge of the Pocono Plateau while on I80.
90.2	5.8	Woodfordian ice-contact stratified drift exposed on right.
90.5	0.3	BEAR RIGHT on exit ramp to Pa. Route 115.
90.9	0.4	BEAR LEFT at road fork. STOP. TURN LEFT onto Pa. Route 115 N.
91.6	0.7	Cross Tobyhanna Creek flowing parallel to northern margin of "terminal moraine".
92.5	0.9	[STOP at] Blakeslee stoplight [if red]. CONTINUE STRAIGHT AHEAD.
93.2	0.7	BEAR LEFT onto side road.
93.3	0.1	STOP along road side. Walk back on dirt road at left to borrow pit.

STOP 6. Woodfordian till

This borrow pit is developed in red siltstone-shale of the Duncannon Member of the Catskill Formation. Bedding has a low dip to the north. A small outcrop in the main roadway has several aestivation tubes (burrows of Upper Devonian lungfish). The quarry floor shows a common facies variation of red siltstone-shale grading laterally into greenish-gray siltstone-shale. The variation is one of color only with no textural change.

The bedrock is overlain by a few meters of Woodfordian till which shows considerable variation within the quarry. The entrainment of the underlying bedrock and gradual transition from broken bedrock to till is particularly well-shown in one face. A description of this face is:

A	0-17.5 cm (0-7 in.)	- dark brown (7.5YR3/2), organic zone, friable, pebbly, gradational base.
B_1	17.5-22.5 cm (7-9 in.)	- reddish brown (5YR4/4) to yellowish red (5YR4/6), friable, some clay, gradational base.
B_2	22.5-50 cm (9-20 in.)	- reddish brown (5YR5/4), clayey, clay coatings, small granular peds, stony, gradational base.
C	50-125 cm (20-50 in.)	- reddish brown (2.5YR4/4), clayey, stony, no peds, no obvious clay coatings, gradational base.
D	125 cm+ (50 in.+)	- dominantly angular fragments of red siltstone with some clayey matrix. Transitional from till above to bedrock below.

Another face yields the following description:

A	0-17.5 cm	- brown (7.5YR4/2-5/2), friable, organic zone, moderately sharp base.
B	17.5-30 cm	- brown (7.5YR5/4), platy peds up to 1/2 cm. long, clayey, gradational base.

C	30-132.5 cm (12-53 in.)	- light yellowish brown (10YR6/4) till with some small lenses of weak red (2.5YR5/2) till, light gray (10YR7/1) subvertical weathering prisms up to 1/2 cm thick with strong brown (7.5YR5/8) margins, moderately sharp to mixed base.
D	132.5 cm+ (53 in.+)	- till, reddish brown (2.5YR4/4), stony, no peds or clay coatings.

Other variations are common in the quarry, but the main influence of local bedrock change is in color. Samples 6a and 6b in Table 2 indicates the textural and compositional contrasts for these two sites.

The critical point at this stop is the variation in till in a very local situation. Contrasts in till are greater when bedrock differences are greater (compare tills at Stops 1, 4, 6 and 8). These variations in lithologic character of till over such short distances raises some questions about the value of named type sections for surficial deposits in northeastern Pennsylvania.

RETURN TO MAIN HIGHWAY. BEAR RIGHT (South) onto Pa. Route 115 S.

94.0	0.7	[STOP at] Blakeslee stoplight [if red]. CONTINUE STRAIGHT AHEAD.
94.7	0.7	Cross Tobyhanna Creek.
95.3	0.6	BEAR RIGHT onto entrance ramp for I80 E.
95.6	0.3	Pass under Pa. Route 115.
96.4	0.8	Pipeline right-of-way to right shows good end moraine topography.
99.9	3.5	Cross south margin of "terminal moraine." I80 is to south and parallel to moraine for some distance.
100.8	0.9	Small boulder field in woods to right.
103.0	2.2	Sign on right for Jct. 380 in 2 miles. Just beyond, re-enter "terminal moraine."
103.9	0.9	Borrow pit on right.
105.0	1.1	STRAIGHT AHEAD on I80 E. I380 goes left. Start long descent of Pocono Plateau Escarpment. Still crossing "terminal moraine." View of Camelback Mountain ahead to right. "Terminal moraine" wraps around mountain on lower slope (see guidebook cover diagram for glacier model in this area).
107.0	2.0	Rest area exit ramp on right.
107.7	0.7	Woodfordian till exposed in valley to right.
107.9	0.2	Catskill Formation exposed on right.
111.6	3.7	Base of Plateau Escarpment. Numerous road cuts ahead show Catskill Formation and some local bedrock folding.
114.5	2.9	BEAR RIGHT on Exit 46 to Bartonsville.
114.7	0.2	BEAR RIGHT onto Pa. Route 33.
115.0	0.3	STOP. TURN RIGHT onto Pa. Route 611 S.
115.1	0.1	TURN RIGHT into Bartonsville Holiday Inn parking lot.

END OF DAY 1.

ROAD LOG

Day 2

Saturday, 4 October 1975

[See Figure 16 for route and stop locations]

Cum. Mil.	Inc. Mil.	
0.0	0.0	LEAVE parking lot of Bartonsville Holiday Inn. TURN LEFT onto Pa. Route 611 N.
0.1	0.1	TURN LEFT onto Pa. Route 33 (stay left, do not bear right onto I80 W.
0.4	0.3	BEAR LEFT on U. S. Route 209 - Pa. Route 33.
0.9	0.5	Outcrop of Middle Devonian Mahantango Formation on right.
2.5	2.0	Outcrops of Middle Devonian Mahantango Formation on both sides.
2.8	0.3	View ahead of former Lake Sciota lake bottom; Godfrey Ridge ("Oriskany" sandstone) to left in foreground; Kittatinny Mountain (Shawangunk Formation) on skyline.
3.3	0.5	Crossing Lake Sciota lake plain.
4.6	1.3	View ahead to right of Sciota esker which fed large kame delta built into Lake Sciota when ice margin was just northeast of delta (Epstein and Epstein, 1967, p. 34-40; 1969, p. 170-173).
4.8	0.2	Eureka Stone Quarry on left extracts calcareous, argillaceous siltstone of the Schoharie Formation for road metal.
5.6	0.8	EXIT RIGHT on U. S. Route 209 S.
5.9	0.3	Lake clays in field to right.
6.0	0.1	Lake clays in field to left.
6.1	0.1	Outcrop of Middle Devonian Marcellus Formation on left.
6.4	0.3	EXIT RIGHT to Sciota.
6.6	0.2	STOP. TURN LEFT onto LR A-2734.
7.3	0.7	Hamilton Elementary School on right. Surface we ride on and equivalent level ahead to left is presumed Harrisburg peneplain level. Skyline is Kittatinny Mountain, presumed Schooley peneplain level.
7.8	0.5	TURN LEFT onto Blue Mountain Golf Course Road (T 393).
7.9	0.1	PULL OFF ON RIGHT. Walk down dirt road into quarry.

STOP 7. Woodfordian ice-contact stratified drift.

This borrow pit is operated by the Edinger Construction Company and we enter by special permission.

The material in this deposit is typical of that in this area where the ice had traversed several miles of Category 3 rocks (Table 1). The deposit is representative of ice-contact stratified drift deposits although it lacks the diversity of bedding orientations and steepness of bedding dip frequently present in this type of deposit. This deposit is situated within the Woodfordian "terminal moraine", and G. G. Connally (pers. com., 1975) places the deposit in Sequence 2 of the deglaciation series for the area (Connally and Epstein, 1973). Composition and physical test data for gravel from this deposit are presented in Table 4 (Sample 14).

Composition of the gravel is the main point of interest here. Note the abundance of dark gray siltstones and shales, presence of limestone and the relative lack of gray sandstones and red rocks of any kind. A few white Shawangunk sandstones occur. Note the breakup of the shales (Mahantango Formation), the local limonite cementation, and rare white gypsum encrustations in the northeast dipping forsets over the horizontal sand of the west face. These gypsum encrustations are derived from a complex reaction, involving oxidation of pyritic Mahantango shales to produce iron-bearing sulfuric-acid leachate which reacts with the carbonates, to yield a solution from which gypsum is precipitated (Evenson and others, 1975). This gypsum encrustation is best seen at a kame-delta deposit near Sciota (Epstein and Epstein, 1967, p. 34-40; 1969, 170-173).

As can be seen by the disintegration character of this gravel and the physical test data in Table 4 (Sample 14) this is not a high-quality gravel. It is not suitable for aggregate, but similar gravel in a kame delta deposit at Sciota (Epstein and Epstein, 1967, p. 34-40; 1969, 170-173) is being crushed into sand for use on icy roads during the winter.

The texture of this deposit is typical except for the lack of large boulders usually found in ice-contact stratified drift. Most of the gravel is relatively free of sand matrix. One local area on the west face shows a fining-upward gravel with uniform sand matrix which probably infiltrated after the gravel was deposited.

This deposit is a good example of the influence that underlying bedrock has on the composition of ice-contact stratified drift and on the quality of a potential economic resource. Compare this material with that to be seen later at Stop 13.

RETURN To LR A2734 via Blue Mountain Golf Course Rd.

8.0	0.1	TURN LEFT onto LR A-2734.
8.2	0.2	Village of Saylorsburg sign on right. Well-developed end moraine topography (Woodfordian) on left.
9.0	0.8	View to left behind Lily Pond Lodge of Saylors Lake, a kettle lake within the Woodfordian "terminal moraine".
9.3	0.3	STOP. TURN LEFT onto LR 930.
9.5	0.2	Saylorsburg Post Office on left.
9.8	0.3	Lake House Hotel on left. Crest of Cherry Ridge. LR 930 ends, join LR 165, (CONTINUE STRAIGHT AHEAD).
10.5	0.7	TURN LEFT onto Kemmertown Road (LR 45007).
10.6	0.1	PULL OFF ON RIGHT just after underpass. Walk up dirt road to left.

STOP 8. Woodfordian till.

The till exposed here occurs within the Woodfordian "terminal moraine" and is considered typical for this area. Ice movement was approximately S30-40W in this area (Figure 10) and the glacier had traveled over Category 3 rocks (Table 1) for many miles before this till was deposited. The till composition indicated for Sample 8a in Table 2 reflects that history.

The till is a variety of gray sandstones, siltstones, shales, limestones, a few red sandstones and siltstones and black chert. Striated cobbles are common. The fresh unweathered till is calcareous, but the carbonate has been leached to a depth of several feet. Soil development is weak and a brief profile description is:

A	0-7.6 cm (0-3 in.)	- brown (10YR4/3), loose, friable, root zone, sharp base.
B_{21}	7.6-32.5 cm (3-13 in.)	- between brownish yellow (10YR6/6) and yellowish brown (10YR5/6), clayey, small blocky peds.
B_{22}	32.5-37.5 cm (13-15 in.)	- similar to B_{21} but gradational into underlying material.
B_3	37.5-120 cm (15-48 in.)	- brown (10YR4/3), sandy, few clay coatings in some spaces and channels become less abundant below 36 in., abundant pebbles and cobbles.
C	120 cm+ (48 in.+)	- till, lacks clay coatings.

A fragipan is not apparent in this profile.

A comparison of this till and those seen at Stops 1, 4, and 6 illustrates the problem of till facies and nomenclature in northeastern Pennsylvania (see also the compositional data for samples 8b, c, d in Table 2; these samples are from Woodfordian till north of Brodheadsville). The character of the till is controlled by underlying bedrock which results in considerable compositional variation in material which can be correlated by physical tracing of a nearly continuous end moraine. Although two lobes of ice are hypothesized for deposition of the tills, approximate synchroneity of deposition is assumed lacking evidence to the contrary. Our approach at present is to use time-stratigraphic terminology. Following that approach, we refer to all three sites as Woodfordian till. An alternate approach is that followed by the Illinois Geological Survey (Willman and Frye, 1970) in which this till (Stop 8) might be the Saylorsburg Till Member of the Stroudsburg Formation and a part of the Saylorsburg drift deposited by the Delaware Valley lobe. The till at Stop 1 might be the Emerald Lakes Till Member of the Stroudsburg Formation and as part of the Fern Ridge drift deposited by the Wayne Lobe. The till at Stop 4 might be the Hickory Hills Till member of the Stroudsburg Formation and a part of the Fern Ridge drift deposited by the Wayne Lobe.

The merits and demerits of various nomenclature approaches for surficial units is a source of considerable debate.

RETURN to LR 165 via Kemmertown Road.

10.7	0.1	STOP. TURN LEFT onto LR 165. Driving between here and next town, note view of Chestnut Ridge to right and talus of Palmerton Sandstone (Middle Devonian).

11.7	1.0	TURN RIGHT towards Palmerton on LR 45006.
12.0	0.3	View ahead of Chestnut Ridge and Palmerton Sandstone derived talus (similar to Plate 1, F).
12.2	0.2	Cross bridge.
12.5	0.3	Cross bridge.
12.6	0.1	TURN RIGHT at cross roads onto T387.
12.8	0.2	PULL OFF ON RIGHT. Bank on left.

STOP 9. Diamicton.

Here we examine the diamicton exposed in the road cutbank and determine its genesis. Do not be deceived by the large clasts in the ditch since they have probably been introduced as road base course.

A general profile description is:

A	0-10 cm (0-4 in.)	- black (10YR2.5/1), friable, organic rich.
B_1	10-12.5 cm (4-5 in.)	- dark brown (10YR3/3), clayey, partly friable.
B_2	12.5-87.5+ cm (5-35 in.+)	- between brownish yellow (10YR6/6) and yellow brown (10YR5/6), clayey, blocky to platy peds, loose in upper part becoming more compact with depth, becomes yellow brown (10YR5/6-5/8) at depth but still with clay coatings.

The diamicton contains a variety of lithologies in clasts, but most obvious are the angular white chert fragments (Sample 9, Table 2). Large clasts piled locally on top of the cut bank are apparently sandstones of the Ridgeley and Palmerton Formations. Nothing in this diamicton is obviously foreign, and it could have been derived upslope. Is this hillslope colluvium? G. G. Connally (pers. com., 1975) suggests that this is Altonian till. We know that there is Altonian till in the area, but what criteria can be used to determine that this diamicton is a till?

Foreign lithologies and striated cobbles are common criteria. Are they present here? The area probably was glaciated during the Illinoian; could hillslope colluvium include erratics from an older glaciation? Why is there abundant white chert, but apparently no black chert such as that seen at Stop 8? Is the soil development diagnostic of age or genesis? How does one determine that a given diamicton is a till? The answer frequently is "with difficulty".

CONTINUE STRAIGHT AHEAD.

13.2	0.4	PULL OFF ON RIGHT. Bank on left.

STOP 10. Colluvium

The road cutbank here shows good clayey regolith developed from calcareous and dolomitic, laminated, fissile to nonfissile shale of the Poxono Island Formation. Composition and texture of this material is shown by Sample 10 in Table 2. Some of the broken shale has been convoluted by cryoturbation and the upper part has a few cobbles of Palmerton sandstone.

A brief profile description from near the center of the cut is:

A	0-20 cm (0-8 in.)	- brown (10YR4/3-5/3), friable, silty and clayey loam, some platy pebbles, gradational base.
B	20-57.5 cm (8-23 in.)	- brown (7.5YR4/4-5/4), more compact than A zone, no well-developed peds but tendency toward break out into small angular pieces, more clayey and sandy than A, some clay coatings, sharply gradational base.
B	57.5-85 cm (23-34 in.)	- dark brown (7.5YR4/4), sandy, silty, clayey, more compact than above, no peds, small platy granules, gradational and inter-tongued base.
C	85-155 cm (34-62 in.)	- reddish yellow (7.5YR6/6-6/8 to 7/6-7/8 approx.), very clayey, some color mottling, numerous small (less than 1/2 in. long) platy shale clasts frequently completely rotten.
R	155-210 cm (62-84 in.)	- grayish yellow green (5GY7/2) to light olive gray (5Y6/2) dolomitic shale, very platy breakup, base locally has 1 in. thick zone of reddish brown limonite and secondary quartz at base.
R_2	210 cm + (84 in.+)	- shale, very rotted with some parts nearly all clay, clay various shades of yellow brown and shale greenish gray, presumably grades down into fresh shale.

The broken shale has been cryoturbated into convolutions in at least two places and a flame-like structure at one place. Color and slight textural variations at the north end of the cut suggest the possibility of two phases of downslope mass movement. The Palmerton Sandstone clasts indicate the considerable distance downslope that materials may move. These features support the concept of periglacial activity in the area and, if two phases exist, they could be related to the Altonian and Woodfordian glaciations. There is also similarity between the fine-grained material here and the matrix of material at Stop 9. Do the textural similarity and the features shown here have any bearing on the genesis of the diamicton at Stop 9?

To the southeast on the skyline is Wind Gap, a well known and often-discussed geomorphic feature of the Appalachian Mountains (e.g., Wright, 1896; Ver Steeg, 1930; Ashley, 1935; Mackin, 1941; Thompson, 1949). Long considered to be the remnants of former stream valleys, Epstein (1966) has demonstrated that all of the major gaps in this area are located in zones of structural weakness where erosion was more effective in downcutting. He also indicates good structural reasons for the capture of one stream by another rather than vice-versa. Thus he favors the development of wind and water gaps at specific places as the result of efficient drainage evolution.

CONTINUE STRAIGHT AHEAD.

14.1	0.9	Reenter Woodfordian "terminal moraine".
14.3	0.2	TURN LEFT onto LR 165.
14.4	0.1	Lake House Hotel on right.
14.7	0.3	Saylorsburg post office on right.
14.8	0.1	Road to right leads to former East Lawn Research Center.

CONTINUE STRAIGHT AHEAD.

14.9	0.1	TURN LEFT towards Kunkletown on LR 45004, still driving on Woodfordian "terminal moraine".
16.0	1.1	Leave "terminal moraine" complex.
16.4	0.3	Shale-chip colluvium deposit in cutbank on right along side road.
16.7	0.3	Outcrop of Mahantango Formation behind house on right.
17.0	0.3	Deer Run Hotel on right. Mahantango Formation outcrops behind.
17.7	0.7	Shale-chip colluvium borrow pit on hill slope. Outcrop along road of Marcellus shale disintegrating into pencil-like fragments.
18.7	1.0	Small rib of rock in creek to left is a fossil zone in the Mahantango Formation.
19.3	0.6	Complex of barns on left at Rossland.
19.4	0.1	TURN RIGHT onto LR 45005. Bedrock up slope is Mahantango Formation. Trimmers Rock Formation and basal Catskill Formation form crest of hill. Will now proceed across Weir Mountain syncline.
19.8	0.4	Flat-surfaced valley to left filled with colluvium. Rare erratics between here and next cross roads suggest area has been glaciated. By what glacier? No known deposits.
20.6	0.8	Cross road. Continue straight ahead.
21.1	0.5	Just beyond hill crest, Illinoian till can be excavated from ditch on left and flat slope to right probably underlain by Illinoian till.
21.4	0.3	Small pond and houses on right. Illinoian till underlies surface between here and cross road ahead. Continue straight ahead.
22.0	0.6	BEAR LEFT at road fork onto Doney Road (T424).
22.2	0.2	Polk Township line sign on right. Note very stony fields and cut banks ahead on left.
22.5	0.3	STOP. BEAR RIGHT onto LR 45003. View ahead across Woodfordian outwash plain to Pocono Plateau Escarpment on skyline.
22.9	0.4	Now crossing Woodfordian outwash plain.
23.1	0.2	Village of Gilbert sign on right.
23.2	0.1	TURN RIGHT at cross roads onto West End Fairgrounds Road (LR 45053).
23.5	0.3	TURN RIGHT into West End Fairgrounds. LUNCH STOP. LEAVE Fairgrounds. TURN LEFT onto West End Fairgrounds Road.
23.8	0.3	STOP. CONTINUE STRAIGHT AHEAD at cross road.
24.4	0.6	STOP. TURN LEFT towards Lehighton on U.S. Route 209 S.
25.5	1.1	TURN RIGHT towards Merwinsburg and Sun Valley on Burger Hollow Road (LR 45044).
26.0	0.5	Cross intersection and TURN LEFT into borrow pit (about 53 m (175 ft) past intersection).

STOP 11. Illinoian till, glaciofluvial deposits, and Wisconsinan periglacial features.

This stop is on the property of Mr. Raymond Burger, who has very kindly provided access for this Conference. Permission to enter this property should be obtained from Mr. Burger. A variety of glacial and periglacial features are available for your inspection at this stop, but a preliminary regional orientation is necessary, and a few historical notes are worthy of mention.

The earliest residents of the Pohopoco Creek Valley (following trend of Lehighton Anticline) probably were the Lenni Lenape, or Delaware Indians. Local farmers have found some Indian artifacts and arrowheads; plowing the gravelly soils has occasionally unearthed apparent charcoal of bonfire sites. The early settlers had occasional conflicts with the Indians, possibly Iroquois or Shawnee, but Moravian missionaries were successful in establishing a mission station from 1760 to 1763 called "Wechquetank" about 1 1/2 miles southeast of this stop, near Gilbert. In 1756, the Province of Pennsylvania built Fort Norris on the south side of Pohopoco Creek Valley, and this was one of the frontier defenses during the French and Indian War. Built under the direction of James Hamilton and Benjamin Franklin, Fort Norris served to guard the settlers north of Blue Mountain. The Kresges, known for their successful commercial enterprise, were among the prominent settlers in this vicinity. In the 1870's, a small brick factory was operated on the property of Mr. Burger. The source of material for brickmaking was the fine, bluish lacustrine clay deposited in an arm of the outwash plain during the Woodfordian.

Looking south across Pohopoco Creek Valley, the very flat topography characterizes a "distal outwash plain", and contrasts markedly with the more rolling and undulatory topography of the "proximal outwash plain" near the "terminal moraine" at Brodheadsville (3 1/2 miles east of this stop). The distal outwash plain comprises clay and silt (lacustrine or pond deposits) with some sand and sporadic gravel. At the southern edge of the valley, the escarpment formed by the Trimmers Rock Formation on the northern flank of Weir Mountain Syncline (overlying the Mahantango Formation), is cut by fairly regularly-spaced, subdued ravines or dells. The interfluves are flattened and the ravine bottoms are gently concave--reflecting cryoplanation and colluvial filling under Wisconsinan periglacial conditions. Bedrock underlying the surficial deposits at this stop is the Middle Devonian Mahantango Formation. Here, the Mahantango is characterized by sparsely fossiliferous, cleavage-dominated silty clay shale. The shale is deeply weathered, and variously bleached to pale olive hues or rubified by striking vermillion clay films on fracture or cleavage surfaces. Mahantango shale is normally very dark gray to grayish black.

There are four important exposures at this stop that should pass your scrutiny. Their locations are shown in Fig. 17, as stations "A", "B", "C", and "D". A discussion of each station follows:

Site "A": Here, about 2.3 m of Illinoian stratified drift has been preserved under a cryoturbated blanket of Wisconsinan shale-chip colluvium. The close proximity of the stratified materials to Illinoian till (at Site

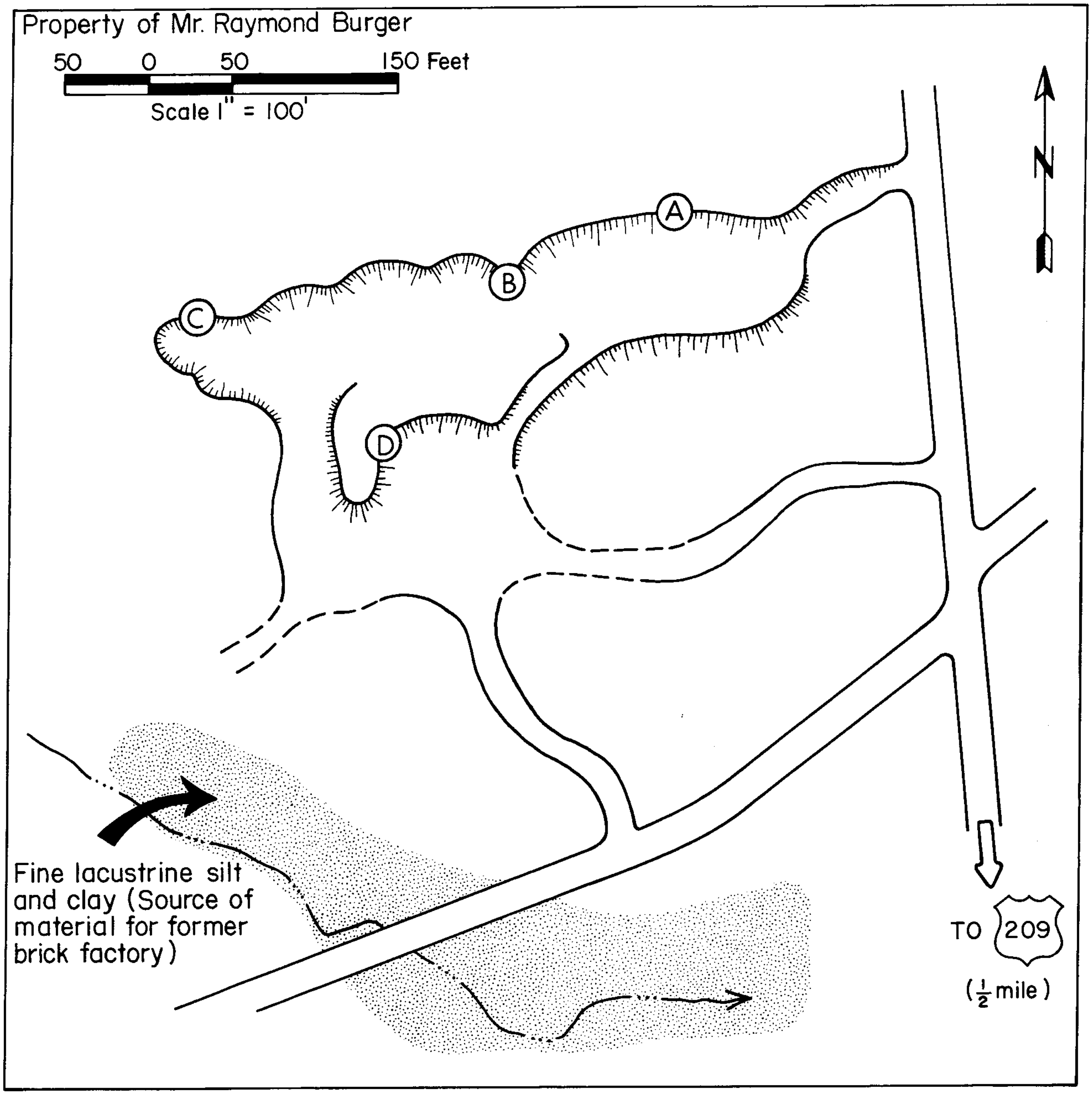

Figure 17. Location map for Stop 11 (Day 2).

"B") suggests a probable ice-contact origin, although an outwash origin might be interpreted. Bed thickness varies from a few cm to a little over 1/2 m. The range in size of materials varies from bed to bed and the gross geometry of the exposure as it appeared in 1972 is shown in Fig. 18. The gravel bed at sample site 11C (Fig. 18) contains cobbles up to 13 cm in diameter. The textural characteristics of the gravel and two sand and silt beds underlying the gravel bed are summarized in Table 2 (Samples 11c, d, e) (Location of channel samples are shown in Fig. 18). In the sandy beds, clay and silt laminations and layers may be observed along with scattered pebble bands. Colors of these Illinoian sediments vary between yellowish

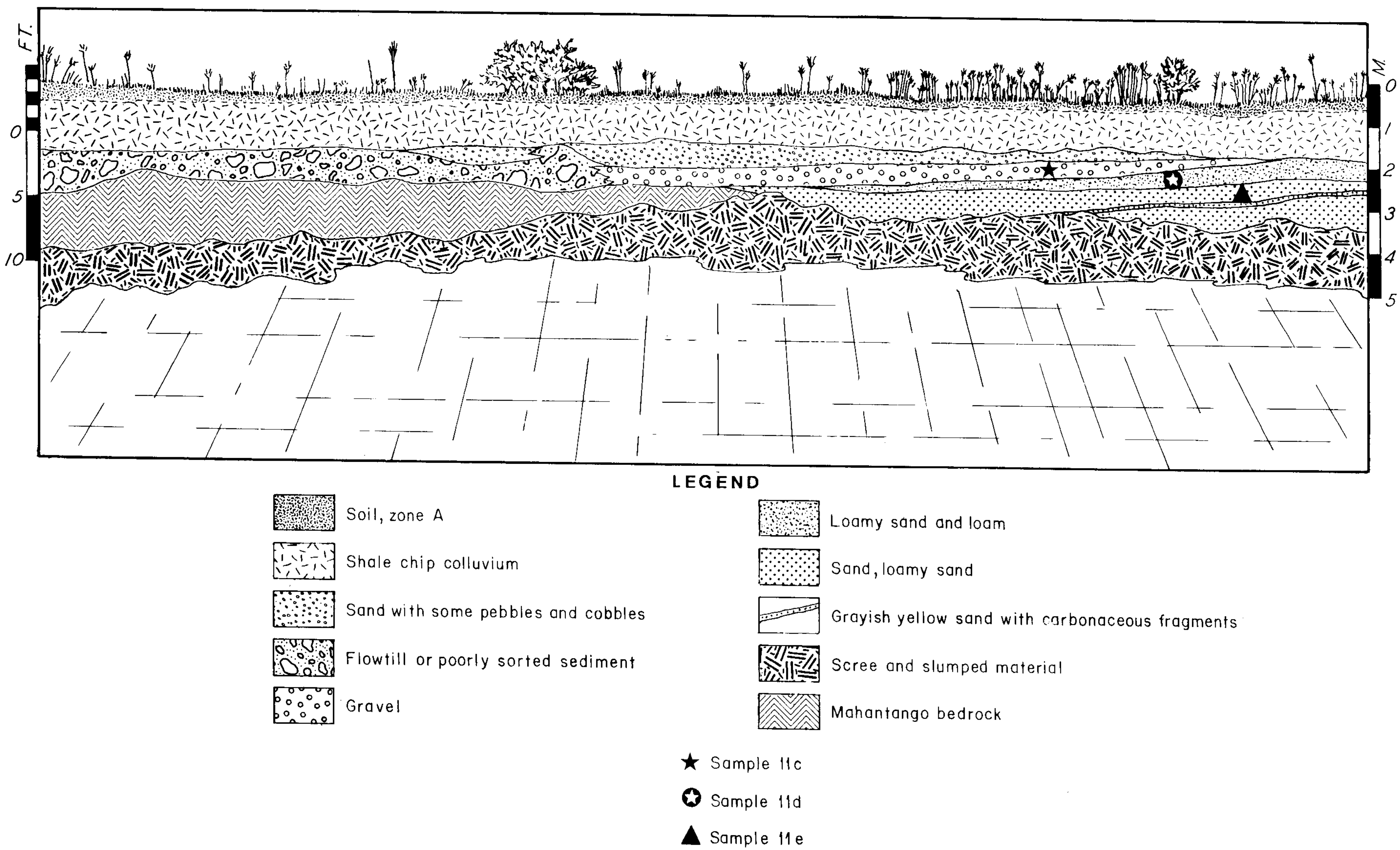

Figure 18. Diagram of outcrop at Stop 11 (Day 2), Site A, as it appeared in 1972.

red (5YR4/6 and 5YR5/8), and red (2.5YR4/8), with streaks of strong brown (7.5YR5/8). All the colors in these sediments display high chromas with medium values. The sand beds have asymmetrical current ripple structures with ripple heights up to 1.3 cm, and ripple lengths varying from 5.0 to 6.4 cm. The asymmetry pattern indicates meltwater flow from east to west. One thin, grayish yellow sand contains carbonaceous fragments, and might yield a palynoflora worthy of study.

Site "B": At this site, a wedge of Illinoian till is preserved between bedrock (Mahantango Shale) and platy to chippy colluvium. This is an unusual outcrop, because we rarely see Illinoian till resting directly on bedrock. The silt shale is cleavaged-dominated, and deeply weathered to a pale olive (5Y6/3) with many fracture surfaces displaying rubification films. The till matrix is red to dark red (2.5YR4/8 to 2.5YR3/6). The clasts ranging up to small boulders are rounded, and some show spheroidal weathering. The more porous clasts have well-developed weathering rinds. Pebbles and cobbles are generally siltstones or sandstones derived from the Mahantango, Trimmers Rock, and Catskill Formations. Mapping in the Brodheadsville Quadrangle has revealed some limestone clasts in Illinoian till, but none have been observed at this site. This till is very compact and dense. Manganese films are laced throughout. The till is apparently chaotic and heterogeneous, with no discernable fabric. Textural characteristics for this Illinoian till are summarized in Table 2 (Samples 11a and 11b). Colluviation or cryoturbation may have disturbed this deposit to some degree, but reworking is not extensive. The blanket of shale-chip colluvium overlying the till grades upward from coarse plates to fine chips. This stratified colluvium is common beyond the "terminal moraine" and reflects a history of intense frost riving and unroofing of bedrock source material upslope. The colluvium is better exposed at Sites "C" and "D".

Site "C": An excellent exposure of Mahantango-derived shale chip colluvium is available at this site, and should be studied in comparison with that exposed at Site "D". Here, the silt shale fragments are crudely stratified, and display a coarsening-upward arrangement through the 1.8 to 2.4 m (6 to 8 ft) of colluvium. This vertical arrangement is fairly typical in the Brodheadsville Quadrangle. The lower chippy colluvium is fairly uniform and well sorted, and has an average fragment size of about 0.5 cm, with no fragments larger than 2.0 cm. About 11 percent of the material passes a #200 U.S. Standard sieve (0.075 mm). The shale chips are subrounded to subangular, and are usually subhorizontal within the deposit; the colluvium is loosely coherent and generally well-drained. When damp, the material is moderate yellowish brown (10YR5/4); when dry, it is grayish orange (10YR7/3). This shale chip material has a bulk specific gravity value of 2.61 and an absorption value of 4.22 percent (tests run on washed and graded samples). Tests run on this chippy colluvium by the Pennsylvania Department of Transportation (R. Howe, pers. comm.), indicate that it is suitable for shale embankments that can be compacted with normal heavy equipment, in loose 8-inch layers, conforming to their specifications. Results of a Modified Washington Degradation test yielded a Degradation Factor of 13.3. Moisture-density relationships under standard compaction tests show that a maximum density of 122 lb/ft^3 can be reached with an optimum moisture content of 13 percent. This shale chip colluvium is an excellent source of fill material in this region and is easily mappable, using aerial photogeologic methods. Similar material has been used extensively in the Delaware

Valley region from Bushkill to Matamoras, and is often referred to as "chipstone" or "sharpstone". The finer, chippy colluvium is overlain by coarser, platy colluvium displaying well-developed cryoturbation whorls and frost-riving effects. The coarse colluvium is poorly sorted, and includes flat, angular fragments rarely in subhorizontal orientation. The coarsening-upward arrangement of chippy to platy colluvium presumably represents the unroofing of frost-riven bedrock upslope, with the finer, more chippy material representing shale that was subjected to earlier, and more intense periglacial conditions.

Site "D": At this point, another stratification phenomenon occurs that is not unusual in shale chip colluvium deposits beyond the "terminal moraine". Here, an almost vivid reddish orange or vermillion colluvium is overlain by more typical yellowish brown colluvium; the color break is quite sharp. On close inspection, the "vermillion" colluvium is texturally similar to the overlying yellowish material, but it displays light brown (5YR5/6) to moderate reddish brown (10R4/6) colors, especially a rubification films. It is fairly coherent, having a clayey matrix and some dark, manganese films, but may be disaggregated by hand. This "vermillion" colluvium bears chips of Mahantango shale ranging up to 2.5 cm (1 in.), and averaging 0.6 to 1.3 cm (1/4 to 1/2 in.) in diameter. The chips are flat and hackly, normally subangular, and are crudely stratified with chips in subhorizontal position. About 3.7 m (12 ft) of "vermillion" colluvium are exposed here with the upper surface marked by a thin (0.6 m or 2 ft) zone bearing some reworked Illinoian till clasts (cobbles, pebbles). The strongly colored shale chip colluvium is overlain by 1.2 m (4 ft) of "normal" colluvium which is moderate yellowish brown (10YR5/4) to medium yellowish brown (10YR6/4), and is not rubified. The "normal", nonred colluvium fragments appear to be less angular and more rounded than the "vermillion" colluvial shale chips. There are some pods or lenses of larger, platy shale fragments included in the non-red colluvium as at Site "C". What we believe to be recorded here in vertical section, is a sequence of unroofing by cryoplanation of materials upslope under Wisconsinan periglacial conditions. The earliest deposit includes shale chip material rubified and vividly colored by prior Sangamonian weathering of Mahantango bedrock. During frost riving and colluvial downslope movement, some Illinoian drift was mixed in with the shale chip material. Final stripping of Sangamonian-colored material was completed, and fresh, non-rubified Mahantango shale was subjected to the ravages of the Wisconsinan periglacial environment. The last periglacial event in this record was the cryoturbation of platy, yellowish brown colluvium. Some may argue that the vividly colored colluvium is actually a pre-Wisconsinan shale chip deposit, bearing a non-reworked Sangamonian soil profile, but we suggest that this is unlikely because other exposures of colluvium in this area contain interbedded pods of rubified and non-rubified materials, attesting to a complex but synchronous unroofing of intensely weathered Illinoian till and bedrock from slopes during the Wisconsinan.

RETURN to Burger Hollow Road, TURN LEFT (North).

26.7	0.7	Outcrop on left of Trimmers Rock Formation with overlying colluvium.
27.7	1.0	Outcrop on left of Catskill Formation sandstones.
28.4	0.7	Cross road. CONTINUE STRAIGHT AHEAD.

29.5 1.1 STOP. TURN RIGHT towards Effort on Merwinsburg Road (LR 45066).
29.9 0.4 Cross bridge.
30.0 0.1 PULL OFF ON LEFT. Walk up drive to outcrop by house.

STOP 12. Altonian till.

The exposure here shows till considered typical of the Altonian in the area south of the Pocono Plateau Escarpment. The site is over 4 km (2.5 mi.) west of the Woodfordian "terminal moraine". Similar till to the north immediately south of the Pocono Plateau Escarpment is covered with boulders moved downslope onto the till by mass movement during the periglacial conditions of the Woodfordian. The upper surface of the site has a slope of about 7° and some colluviation of the upper part of this till is probable. However, the soil profile is moderately thick and well developed and thought to be similar to that seen at Stop 5. Upper part of the profile probably a recent development and colors given are from relatively dry material.

A	0-27.5 cm (0-11 in.)	- brown-dark brown (7.5YR4/4), friable, little clay, stony, no peds, gradational irregular lower boundary.
B_{21}	27.5-55 cm (11-22 in.)	- reddish brown (5YR4/4), somewhat friable, some clay as clay coatings, stony, lower boundary appears delineated by stone accumulation, no peds, gradational lower boundary.
B_{22}	55-125 cm (22-46 in.)	- yellowish red (5YR4/8), clayey, stony, most clay between 85 and 100 cm (34 and 40 in.), sharply gradational lower boundary.
B_{23}	125-200 cm+ (46-80 in.+)	- reddish brown (between 2.5YR and 5YR about 4/4), compact, sandy, clay coatings, gray sandstone cobbles and rotted red shale and siltstone.
C	(dug from borrow pit floor)	- dark red (2.5YR3/6-4/6) clayey, sandy, stony, platy structure.

The till contains abundant gray sandstone pebbles and boulders. Those in the surface zone have weathering rinds 1 cm or more thick and many thin pebbles are rotted throughout. There is abundant red shale and siltstone in the sizes smaller than 2.5 cm (1 in.). The rare conglomerate pebbles are erratics from the Packerton Member of the Catskill Formation, the rock which crops out on the front edge of the Pocono Plateau Escarpment. The underlying bedrock (Long Run Member of the Catskill Formation) is a Category 2 rock (Table 1) and is similar to the Mauch Chunk Formation which underlies the Altonian till at Stop 5. The texture and composition of the till here is presented as Sample 12 a in Table 2 and data for similar tills in the immediate area as Samples 12b, c, d.

This is your final opportunity on this Conference to consider the reality of an Altonian age for this till. Compare it with the Woodfordian tills seen at Stops 1, 4, 6, and 7, the Illinoian tills at Stop 2 and 11 and the Altonian till at Stop 5. Does the hypothesis seem reasonable?

CONTINUE STRAIGHT AHEAD.

31.4 1.4 STOP. BEAR RIGHT towards Effort on Pa. Route 115 S.

31.7	0.3	Outcrop on left of Trimmers Rock Formation.
32.1	0.4	Effort Diner on right.
34.4	2.3	STOP. TURN LEFT onto U.S. Route 209 N. Now in Brodheadsville and on "terminal moraine".
35.4	1.0	TURN LEFT onto Silver Valley Road (T 432). Road is partly hidden by house and trees, but is located immediately before Meadowbrook Diner on right.
35.7	0.3	TURN LEFT into Lehigh Valley Sand and Gravel Company quarry.

STOP 13. Woodfordian Kame delta in "terminal moraine" complex.

This last stop of the Fortieth Annual Field Conference of Pennsylvania Geologists is on the property of Mr. Evo Taviani and Sons (Lehigh Valley Sand and Gravel Co., Inc.) who have kindly provided access. Permission to enter this quarry must be obtained from the Tavianis. A word of caution: the quarry faces may be unstable and susceptible to collapse; loose cobbles may fall at any time. Hard hats are recommended and routine caution is advised. During a normal working day, heavy equipment is in use and may not only be hazardous to you, but your presence may interfere with quarry operations.

The upper surface (225.6m or 740 ft elevation) of this kame delta stands about 14 to 15 m (45 to 50 ft) above the McMichael Creek floodplain. There is a sharp topographic break between the delta complex and the McMichael Creek outwash-alluvium deposits on the northeast. To the southeast, there is a more subtle topographic relationship between the delta deposits and what has been mapped as "ground moraine", which may in fact contain some stratified drift. The kame delta is bounded on the west and northwest by two large kettle lakes (Lake Mineola) within the Woodfordian end moraine complex.

This quarry was opened in the fall of 1968. The property being developed as an aggregate resource initially included 45 acres; to date, somewhat more than 15 acres have been utilized. The average working face is about 7.6 m (25 ft) high; clam bucket tests have shown that there are at least another 7.6 m (25 ft) of useable material below the present quarry floor. A maximum total of 21 m (70 ft) may be present in this deposit. It is estimated that the total area covered by this kame delta is 0.67 sq. km (0.26 sq. mi.) or 166.4 acres.

Features of geologic importance at this quarry include topset gravel beds, foreset sand and pebble beds, bottomset sand, silt, and clay beds, and kettle-fill deposits. The topset gravel beds, ranging up to 4.7 m (15 ft) thick, are crudely stratified and contain thin lenses or stringers of sand. Cobbles are generally 10 to 15 cm (4 to 6 in.) in diameter, but may be up to 46 cm (18 in.) in diameter, or boulder-sized. The cobbles are contained within a matrix of very coarse-grained sand and granules with some pebbles. The flat cobbles and pebbles are frequently imbricated, indicating a meltwater flow direction varying between S30°E and S30°W. Some cobble beds show no imbrication. This material was sampled in 1974 and subjected to several tests shown in Table 4 (Sample 13). Freeze-thaw testing showed a 2.7 percent loss, and visual examination indicated that this loss was principally due to disintegration of gray siltstones of Mahantango-Marcellus origin. A Los Angeles abrasion test run on the 3/8 in. to 3/4 in. material yielded a 14.8 percent loss; the flat, reddish shale fragments showed the greatest abrasion loss, while the other lithologies were equally abraded. The washed and graded sample showed a bulk specific gravity of 2.69 and a 1.56 percent absorption value. The dominant lithologies in these gravel beds are sandstones and quartzitic siltstones of the Catskill, Trimmers Rock, and Mahantango Formations; some minor and unusual lithologies include garnet-bearing granitic gneiss, metaquartzite, and vein quartz. A complete pebble count is given in Table 4 (Sample 13). Some of the pebbles and cobbles are coated with manganese films and goethite. Some sandstone cobbles rarely show deep weathering rinds, and may be reworked from Illinoian deposits.

The foreset sand and pebble beds display a diversity of primary sedimentary structures. Thickness of foreset beds is variable, but an average of 4.6 to 6.1 m (15 to 20 ft) is normal. Foreset dips range from 20° to 30°, generally closer to 30°. Foreset bearings range from south-southwest to southeast, indicating a meltwater flow originating from the north and northwest, near the inner margin of the "terminal moraine". The approximate altitude of the foreset-topset interface here is about 228.6 m (730 ft) in elevation, about 15 m (50 ft) above the level of deltas deposited in glacial Lake Sciota (Epstein & Epstein, 1967, p. 40) to the east, where a similar interface altitude is 207 m (680 ft). Clearly, these deposits are the result of deposition in an ice-dammed and moraine-dammed body of water that stood higher than Lake Sciota, and presumably predate the Lake Sciota sediments. Generally the damp sand is dark grayish brown (10YR4/2), but occasional clay and fine silt layers are reddish brown (5YR4/3) (when damp). Some of the clay layers are thin and discontinuous, and become laced throughout the sand as the bottomset beds are approached. The clayey zones near the bottoms of the foreset beds are frequently involved in very tight folds or convolutions, and sometimes display multiple, minute faults, presumably due to collapse during ice melting. Some of these clayey zones are pebbly, and may actually be flowtill pods incorporated in bottomset beds.

The bottomset beds are poorly exposed and are frequently covered during quarry operation. The clayey zones, probably of lacustrine origin, present difficulties to the quarry operation. The clays are sticky and coherent, are difficult to handle in the quarry, and do not totally disaggregate in the washing operation, occasionally coming out as clay balls.

Kettle-fill deposits are well-exposed at various places within this quarry, very near the upper surface of the topset gravel beds. The best deposit is on the northern side of the quarry and is illustrated in Figure 19. Here, very clayey gravel which is poorly stratified has filled a depression left by melting of a buried ice block, presumably within or below the foreset beds. Collapse faulting on the eastern margin is clearly visible. Elongate cobbles have been realigned parallel to the collapse fault surfaces; foreset sand and pebble beds have been offset. The kettle-fill sediments are light yellowish brown (10YR6/4). These clayey deposits also present some difficulties in the washing operation.

The Lehigh Sand and Gravel Company produces Type A sand and #1B, #2, and #3A gravel. About 75 percent of this coarse and fine aggregate is sent crushed and washed to the Ready-Mix Plants at Catasaugua and Bethlehem for use in the preparation of concrete and mortar mixes. The Lehigh Valley Company processes about 900 tons per day for 20 days each month, eight months out of each year. It is impossible to operate the washing operation after

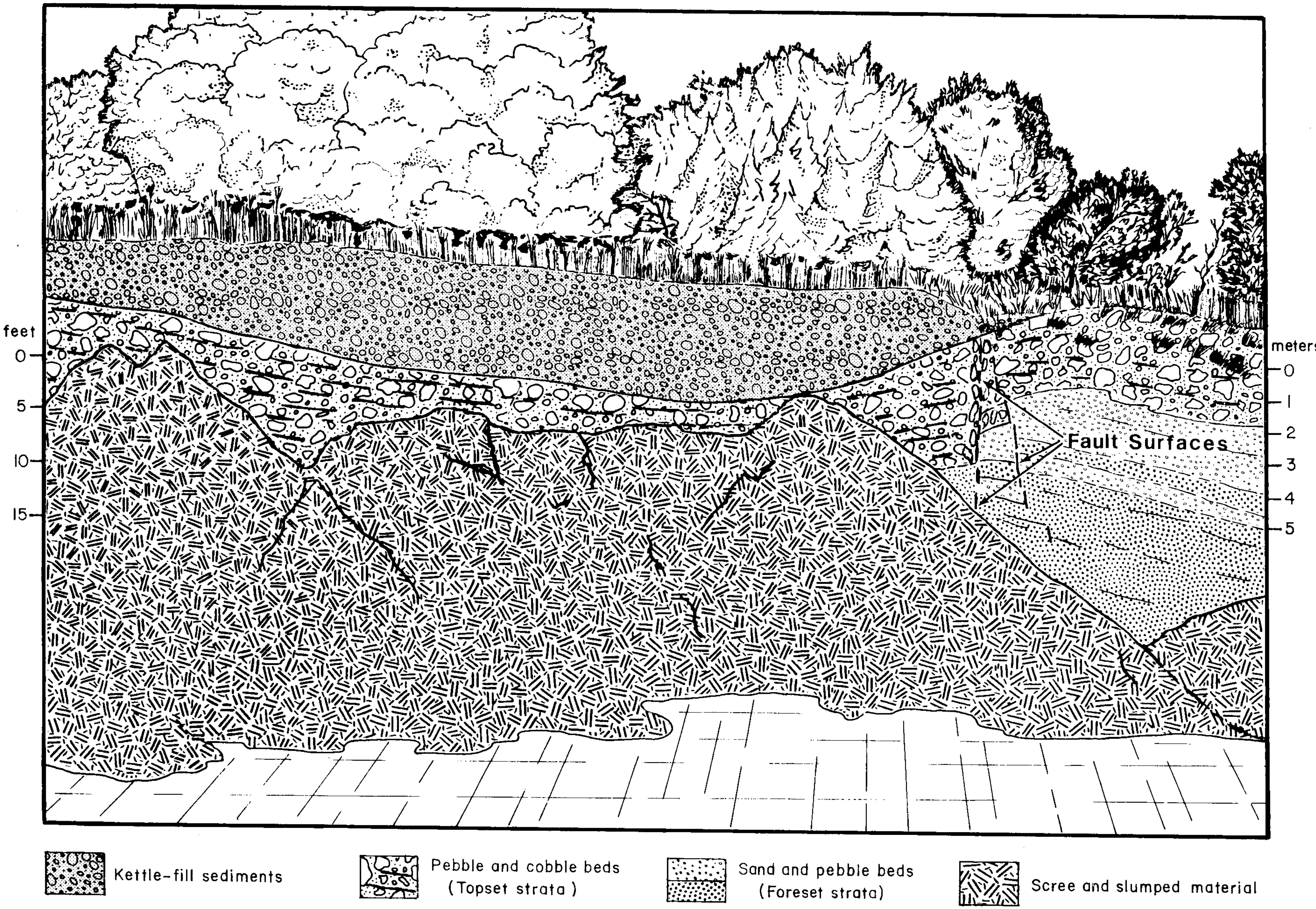

Figure 19. Diagram of kettle fill in kame delta deposits at Stop 13 (Day 2).

the mid-November freeze, but their stockpiles of processed material generally last until the mid-March thaw. Some local users purchase "pipe sand" directly "from the bank" which is principally utilized in laying out septic systems and drain fields. About 10 percent of the washed material passes as extra-fines which are allowed to settle in ponds and are later trucked back to the quarry for storage. Much of the extra-fine material is sold for baseball field surfaces and some secondary road surfacing.

RETURN to U.S. Route 209 N.

36.0	0.3	STOP. TURN LEFT onto U.S. Route 209 N.
36.6	0.6	Village of McIlhaney sign on right.
37.1	0.5	BEAR LEFT at road fork. Mario's on left.
40.1	1.0	LEFT LANE for U.S. Route 209 N - Pa. Route 33 to Stroudsburg.
41.1	1.0	Outcrops of Schoharie Formation on both sides.
41.3	0.2	Eureka Stone Quarry on right.
41.6	0.3	View of Sciota esker back to left.
42.1	0.5	LEFT LANE to I80W via Pa. Route 33. Crossing Lake Sciota lake plain.
42.8	0.7	BEAR LEFT towards Bartonsville on Pa. Route 33.
46.1	3.3	STOP. TURN RIGHT onto Pa. Route 611 S.
46.2	0.1	TURN RIGHT into Bartonsville Holiday Inn parking lot.

END OF FIELD TRIP.

BON VOYAGE.