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Glacial geology of the Western Catskills

James Totten Kirkland
Binghamton University--SUNY

J. T. KIRKLAND

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James Totten Kirkland

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Donald R. Coates	Donald R. Coates (Advisor)	May 10, 1973 (Date)
Marie Morisawa	Marie Morisawa	May 10, 1973
Cuchlaine A. M. King	Cuchlaine A. M. King DRC	May 10, 1973
Paul Enos	Paul Enos	10 May 73

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ABSTRACT

Ice flow directions on the glaciated Appalachian Plateau in central New York were from the Adirondack Mountains. This is demonstrated by both striae directions and erratic provenance studies. No evidence for more than one Wisconsin glaciation as suggested by Rich (1935) could be found. Theories for local glaciation during the decline and after the retreat of the Laurentide Ice Sheet were also unsubstantiated.

The East and West Branches Delaware River had different styles of deglaciation. The West Branch is characterized by zones of stagnation. The length of a zone is controlled by relief of the valley and corresponds to that length of ice confined within the valley. Stagnation of a zone results from the difference in the ability of ice to flow within the confines of a valley as compared with ice on the uplands. Each zone contains a number of sequences consisting of a gradation from outwash to kame moraine to kame terrace. Within a given zone there is a vertical succession of kame terraces and a corresponding horizontal succession of kame moraines. Kame moraines occur at the junctions of tributaries to the West Branch and derived much of their sediments from them. Reconstructed ice profiles for the sequences demonstrate that the ice forming the sequences was stagnant at the time of sequence formation.

The East Branch appears to have been the site of more massive stagnation caused by topographic detachment of ice from the retreating ice sheet. Three different lakes were formed with progressive stagnation of ice up the East Branch. The most conspicuous features associated with the different lakes are kame deltas. The kame deltas formed at the junction of tributaries with the East Branch and their sediments reflect both an ice and an upland source. Three main units are recognized for kame deltas in the East Branch: (1) A lower sequence which prograded outward between the ice and the valley wall. (2) Overlying steeply dipping silt foreset beds from sediment originating in the uplands. (3) A ripple-drift section representing late stage sedimentation by meltwaters from the ice.

INTRODUCTION

Format

The contents of this dissertation are arranged in the following order: 1. An introduction which includes the general setting, geology and historical perspective. 2. Sections dealing with the movement and direct effects of active ice. 3. Sections relating to stagnant ice and resulting glaciofluvial features. The sections concerned with deglaciation are treated within distinct physiographic sections of the study area. The features within each area are then treated in chronological order of deglaciation.

This format of presentation was chosen due to the broad scope of the material covered. Not only can the study be broken down geographically but also in terms of glaciation and deglaciation. Because of this complexity, material is presented in chronological order and subdivided as to physiographic regions. By doing this each part of the study becomes a separate distinct unit yet retains a continuity in the overall study.

Purpose

The purpose of this study is to analyze glacial and deglaciation events in the western Catskill Mountains and to assess their relationships to events in adjoining regions. Reevaluation of the possible existence of local glaciation in the Catskill Mountains is an integral part of the analysis. The style of deglaciation in a region of

high relief is also studied.

The major part of the study is the New York region of the East and West Branch Delaware Rivers. This area forms the interface between the central part of the glaciated Appalachian Plateau and the higher Catskill Mountains, thus allowing both local and regional interpretations. Emphasis is also placed on topographic and geomorphic interpretations throughout the region.

Location

The study area is located in the western Catskill Mountains and encompasses parts of the Andes, Delhi, Deposit, Hobart, Livingston Manor, Long Eddy, Margaretville, Neversink, Ninevah, Starrucca, and Walton 15 minute U.S. Geological Survey 1:62,500 scale topographic maps (Fig. 1). The major part of the region is drained by the East and West Branch Delaware Rivers and their tributaries.

Physiography

The Catskill Mountains are part of the glaciated Appalachian Plateau Province and are considered mountains because of their relief and rugged character. Thornbury (1965) attributes the formation of a series of cuestas with scarps of varying magnitudes in the Catskill Mountains to differences in erosion resistance between the shales and sandstones. Summit elevations range from 2000-2300 ft in the Deposit area to 3000-3600 ft in the eastern part of the study area. Major valley elevations range upward from

about 900 ft giving local relief in excess of 1000 ft. Many hillslopes show a pronounced asymmetry with north slopes considerably steeper than south slopes (Coates 1966).

Structure

The Devonian conglomerates, sandstones, siltstones, and shales comprising the Catskill Mountains are nearly horizontal, having a very gentle dip to the southwest.

Rocks in the region are strongly fractured with major joint sets trending north-south and east-west (Parker 1942). The joints are essentially vertical and have little influence on the topography except for a few small streams which are locally joint controlled.

According to Fluhr (1953) the presence of faults is rare in the Catskill Mountains. He reports faults are normal type, with the northwestern side downdropped in relation to the southeastern side. Fluhr (1959) characterizes fault zones as having crushed and decayed materials, and reports that the presence of these faults is unpredictable even though some have "considerable displacement".

Previous Studies

Mather (1843) assigned the drift and abundant "scratches" on the rocks to the Drift division of the Quaternary System. He further attributed their existance to currents of water from the polar regions.

Chamberlin (1883) described the presence of "knobby drift hills" at or near Stamford, Hobart, Bloomville,

Walton, Fishs Eddy, Hancock and between Roxbury and Prattsville. He also described the steep-sided bedrock chasm at Grand Gorge and attributed it to the passage of powerful ice streams. He expressed doubt that the ice overrode the higher Catskills but was "broken up into valley currents and practically arrested in its progress. To these are referred the minor moraines scattered through the mountain valleys though some of them may be due to independent local glaciers of later date" (p. 373). He also mentions a "pear shaped" lobe between the Catskills and the Shawangunk Mountains.

Rich (1906) proposed local glaciation in the Catskill Mountains on the basis of large "U-shaped" amphitheaters and morainic loops. It appears Rich was strongly influenced by the early works of Hitchcock, Packard, Vose, Agassiz, Upham, and especially Tarr, all of whom at one time or another in New England proposed some type of local or valley glaciation. He was also familiar with Cushing's work on valley glaciers in the Adirondacks and was in personal communication with Tarr who strongly reinforced his interest in local or valley glaciation. It was in the paper, "Local Glaciation in the Catskill Mountains", that Rich (1906) first placed emphasis on drift color and striae as indicators of age and direction respectively. He continued to use these concepts throughout his work in the Catskills to support his theories on the age of the drift

and local glaciation.

Johnson (1917) agreed with some of Rich's evidence for local glaciation in the Catskills but expressed doubt as to the validity of others. Some features, he concluded, could have been the result of continental ice tongues moving up-valley. He cautioned against the mininterpretation of land slides as "morainic" and noted that "slopes were suffering to an extraordinary degree from creeping and slumping" (p. 549).

Rich (1915, 1917, 1935, 1941) continued to champion the concept of local glaciation although he recoginized the effects of a waning continental ice-sheet (1916, 1941). Rich was certainly not without his critics. In the discussion immediately following Rich's 1916 paper of local glaciation Dr. Frank B. Taylor suggested that ice tongues coming through cols could produce the same type of features that Rich had attributed to local ice. In addition Professor J. W. Goldthwait questioned the existence of local glaciers at elevations of 3000 ft because cirques in the White Mountains of New Hampshire are confined to the sides of summits which exceed or approach 5000 ft. Rich replied to a question by Professor Grabau that, "It is impossible to determine with certainty from the content of till whether moraines in the Catskills are to be ascribed to local glaciers or not" (p. 134). Rich (1915) showed full awareness of the importance which topography played in the glacial history of the

Catskills.

Chadwick (1928) demonstrated that glacial ice had overtopped the Catskills as evidenced by glacial striae on the summit of Slide Mountain. Although Rich (1935) recognized Chadwick's evidence, he maintained that during the most recent glaciation the higher peaks above 3900 ft projected above the ice as nunataks. He attributed striae found by Chadwick to an Early or pre-Wisconsin glacier.

Fairchild (1932) correctly suggested that morainal drift would be "scanty" in Sullivan County and recognized the difficulties in tracing marginal positions in the uplands and valleys of the Catskills. He did support Rich's contention of local glaciation stating; "And the citizens of Prattsville, Grand Gorge, and Gilboa should erect a monument at the Fly Brook moraine; and while the discoverer is yet living" (p. 658).

Rich (1915, 1935) two distinct drift sheets in the Catskills, the outer or younger he correlated tentatively with the Valley Heads moraine. He considered both to be Wisconsin in age. His criteria for distinguishing between the two drift sheets was drift color, appearance, and striae abundance.

MacClintock and Apfel (1944) working in the Salamanca region separated the drift sheet below the Valley Heads into Binghamton and older Olean drift sheets. They included the Catskills south of Oneonta within the Olean drift

area.

Flint (1953) suggested a correlation of Rich's younger drift with the Binghamton of MacClintock and Apfel (1944).

Denny (1956) revived the concept that Rich's younger drift was correlative with the Valley Heads moraine rather than the Binghamton.

Moss and Ritter (1962) considered the Binghamton drift to be a valley phase of the Olean and suggested the elimination of the Binghamton drift boundary of MacClintock and Apfel (1944) as representing a separate glacial event.

Coates (1963) considered the "Olean" and "Binghamton" to be facies of the same drift sheet. He further considered the Catskill drift to be a phase of the Olean. Unlike Rich, Coates noted only one drift sheet in the Catskills and could find no evidence for a Binghamton facies. He concluded that the Catskills reflect the work of only one major Wisconsin ice sheet.

Coates (1965) noted from well logs that north slopes for part of the glaciated Appalachian Plateau are twice as steep as the south slopes; the asymmetry is a function of thicker drift on the south producing "till shadow hills".

Connally (1967) working to the east attributed deposits to former glacial lobes in the Wallkill Valley and in the Minisink Valley on the west side of the Shawangunk Mountains. He suggested that the confluence of the two lobes was north of New Paltz. The lobe referred to by Connally is the

Minisink Valley is probably the same "pear shaped" lobe described by Chamberlin (1883).

Borings and well log records collected by Frimpter (1970) in Ulster County fail to give evidence for multiple till sections in the region occupied by the "pear shaped" lobe of Chamberlin (1883). This implies that the pear shaped lobe was not a separate advance or readvance but rather a phase of the deglaciation in the region.

Connally and Sirkin (1970) using pollen stratigraphy and radiocarbon dating suggest glacial ice was actively building moraines in the Wallkill Valley about 15,000 years B.P.

LaFleur (1969) working in the Schoharie Basin showed stratigraphic evidence for multiple glaciations and attributes these to minor readvances of the latest glaciation.

Connally and Sirkin (1971) place the ice margin north of the Hudson-Mohawk confluence between 15,000 and 13,200 yrs B.P. which would require the prior deglaciation of the Catskill Mountains.

Coates, et. al. (1971) confirm this conclusion with a 13,320 yr B.P. date on a mastodon pelvic bone from Valley Heads outwash gravels in the Susquehanna River Valley.

Cadwell (1972) has dated wood from the base of a kettle hole bog near Chenango Forks in the Susquehanna River Valley giving an age of 16,650±1800 yrs B.P. The kettle hole is located in a valley plug which he interprets to have been

formed as a retreatal ice margin of Woodfordian Age.

Study Methods

Field work was conducted during the summers of 1969, 1970, and 1971. Reconnaissance mapping was on a scale of 1:24,000. The Deposit, Walton, and Andes 15 min. U.S.G.S. topographic maps were mapped in considerably more detail than adjacent areas since they contain the regions of the East and West Branches Delaware River critical to this study. Data was continually evaluated during the study, with conclusions serving as a guide for further field work.

The acquisition of hundreds of New York City Board of Water Supply, (B.W.S.), boring records prior to field work in 1971 permitted the extension of the study to include the subsurface. These data also provided information about areas inundated by the Pepacton and Cannonsville Reservoirs.

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GLACIAL MOVEMENT AND EROSION

Erratics-Provenance and Transport Study

Erratics in the western Catskills comprise much less than 1% of the drift and are restricted almost entirely to the stratified deposits. Crowl (1971) reports only 2 "Canadian erratics" in the drift below Port Jervis in the Delaware River Valley. The erratics with the exception of a few limestones are entirely compatible with a southern Adirondack assemblage. Fig. 2 shows the probable source areas for four of the more distinctive erratics, three of which were identified and located by Dr. Yngvar Isachsen of the New York State Museum Service. The remainder of the erratics noted in the field are primarily gneisses. All of the erratics used in provenance determination were found in either kames or kame terraces. Those from valley trains were not used since they may have been fluvially transported many miles downstream from the ice terminus. On Fig. 2 the apex of each region is the location where the erratic or indicator stone was found while the rays extend northward to encompass the probable source area. The actual locations where the erratics or indicator stones were collected are 1, 2 at Oneonta, 3 at Delhi, and 4 at Corbett. This method of protraying indicator stones in relation to their source areas is used in preference to the line diagrams usually employed because it does not imply greater accuracy in source area location than actually exists. As can be seen

from Fig. 2 the probable source area is the southern Adirondack Mountains. A southwest direction of possible transport is indicated. This is in good agreement with striae directions even though striae tend to vary locally and parallel major valleys (Plate 2).

Although ice movements as indicated by striae might only reflect the last movement of the ice sheet which covered the Catskill Mountains, it appears that regional flow during the late Wisconsin maximum was south out of the Adirondack Mountains onto the Appalachian Plateau and that basal flow was strongly influenced by topography.

The lack of erratics in the East and West Branches Delaware River as contrasted with the abundance of erratics in the through valleys to the west as reported by Moss and Ritter (1962), may possibly be explained by one or more of the following hypotheses: 1. Most of the accumulation of ice may have been at the margins of the ice sheet rather than at its original source. In the Catskill region this may have been particularly true if the local relief of the Catskills acted as a local precipitation source. This would have reduced the number of erratics transported into the Catskills. 2. Most transport of debris was in the basal part of the ice sheet and thus erratics appear in greater abundance in those valleys which head close to the Adirondack Mountains due to a channeling of the basal ice down valley. 3. The Catskill Mountains form a topographic high.

If the lower part of the ice sheet contained the greater percentage of erratics they may have been diverted around the Catskills. 4. East to west channeling of the ice through the Mohawk Valley may have helped divert erratic-rich ice away from the Catskill Mountains to through valleys to the west. 5. Since erratics are more common in the stratified deposits than in the tills most till may have been locally incorporated at the base of the glacier and re-deposited. If it is assumed that in order for erratics to be transported any distance, they would have been transported by the glacier in a supraglacial position than the higher the position of the erratic, the longer the transport distance. In a rugged terrain such as the Catskills the glacier would have derived considerable amounts of local rock englacially thus diluting the already small erratic percentage. This method of incorporating debris englacially is suggested by Boulton (1972) to explain englacial and supraglacial material in temperate glaciers. It is likely that a large amount of the englacially transported material is eventually deposited in what Rich (1935) referred to as "thick drift". The greatest percentage of erratics would be concentrated near or at the surface of the ice. It is in this position that they would have been most subjected to meltwater action and subsequent deposition in stratified deposits. 6. The presence of local ice in the Catskills prior to the last continental ice sheet acted as a barrier to the continental

ice sheet. This prevented the inclusion of erratics until the continental ice could override the already ice covered Catskills and introduce erratics into the region.

Glacial Striae and Erosion

Ice movement in the western Catskill Mountains is well documented by the presence of glacial striations. Striae directions in the valleys of the East and West Branch Delaware Rivers are in general parallel to the valley walls (Plate 2). Striae on bedrock in the uplands also tend to parallel or trend slightly to the south of the axes of the East and West Branches Delaware River.

Ice movement indicated by striations conforms well with that inferred from erratics. Variations are easily explained by local topographic influence and the patterns of flow suggested by Plate 3 appear to have been dominant during late Wisconsin glaciation. Variations from the regional flow are represented as dashed lines on Plate 3. They reflect ice movements due to local variations in topography.

Rich (1935, p.19) reported that striae in the southern and southwestern Catskills are rare because "...time since the ice was present seems to have been considerably longer than in the northeastern part of the area." Fullerton (1971) shows a Late Wisconsin (Mohawk) drift boundary west of the higher Catskill Mountains. This is farther west than Rich's (1935) Late Wisconsin terminal moraine. While these ice

positions may reflect local ice marginal stands, an age difference cannot be justified by either a striae or drift criterion. All drift examined by me appears fresh and its color is related to local lithology rather than age. Plate 2 clearly demonstrates that striae are abundant in areas where Rich thought they would be rare. This negates any use of striae abundance as criterion for drift age in the Catskills.

Striae are best preserved on the more massive fine-grained graywacke sandstones. Rarely are they found preserved on the shales, redbeds, or thinly bedded graywacke sandstones. This is because of the tendency of the latter to break up or weather more rapidly upon being exposed. Striae are most common where they have also been protected by a layer of till and not subjected to over-riding slope movement.

It is often difficult to determine a unique sense of direction from striae. In particular, highly weathered or shallow striae only give a lineation rather than an exact direction. These are best observed on a wetted surface and sometimes appear not as scratches but as a set of parallel undulations on the bedrock surface with axes trending parallel to the inferred direction of ice movement. Fortunately many of the striae in the western Catskills have a directional sense preserved, most often in the form of a deepening of the scratch or groove in the direction of apparent ice

flow. Rich (1935, p.19) states: "This is produced by a stone or boulder, held in the bottom of the ice, gouging deeper and deeper into the rock until finally it is caught and turned over and suddenly ceases to cut. It is obvious that such scratches will deepen and abruptly disappear in the direction of ice movement." Other directional indicators used include chatter marks and "fern leaf" flakings (Rich, 1935).

Where present on bedrock along a valley wall, striae ascend in the direction of ice movement. This is particularly noticeable south of Margaretville where striae occur on a concave upturned trending surface on the side of the valley (Fig. 3). Another case occurs south of Fishs Eddy where ice flowed up a north-flowing tributary to the East Branch Delaware River.

One unique set of striae is located near Hancock on the south-facing valley wall. This set is composed of striae forming a very tight radius of curvature (Fig. 4) and was developed by ice descending off the uplands into the large valley formed by the juncture of the East and West Branch Delaware Rivers. This is a special situation and additional non-curved grooves parallel to the rock surface in the same location demonstrate that all of the movement was not curved. The curved striae could have been produced by ice flowing from the uplands to replace ice in the valley which had either melted or had been channeled southward through the

double valley of the Delaware River where it flows around an umlaufberg at Hancock (Plate 1i). The curved striae testify to the mobility of the ice which formed them. An alternate hypothesis is that the curved direction reflected by the striae was the predominate movement and the grooves reflect lines of weakness along bedding planes in the rock.

Multiple striae in the western and southern Catskills can occur by local topographic control or by the superposition of striae from two different ice lobes.

Several locations west of Deposit have multiple diverging striae with two to five directions well represented (plate 2). Generally one direction is more pronounced than the others and corresponds to the regional sense of direction. Other directions can usually be related to local topography and probably represent late stage ice movements by a stagnating ice mass. In all observed and measured cases, one direction is oriented perpendicular to the valley trend. Such alignment suggests formation by descending ice from the uplands.

The only other multiple striae observed occur near Monticello where the regional ice trend or about N 190° is crosscut by either a remobilization of the ice or a later advance from between the foothills of the Catskills and the Shawangunk Mountains (Plate 2). The lack of any prominant deposits associated with this region, as well as the topography, suggest the striae were caused by a change in flow

direction rather than a separate advance. The ice in this region never actually ceased to flow but instead when the ice could no longer maintain flow over the Catskills, the impetus for movement came from additional glacier masses to the east. This westerly movement on the plateau west of Ellenville has been well documented by Chamberlin (1883) and Rich (1935). Because of recent exposures by construction of Route 17 to further delineate characteristics of divergent ice in this region. The search has resulted in extending the limit of ice divergence 10 mi farther west than previously documented by Rich (1935) and the uncovering of superimposed striae (Plates 3 and 4).

Rich (1935) reports older appearing drift as well as extensive terraces and alluvial fans within this region and uses their presence to support the idea that this is a region of older drift. I have been unable to support any of these lines of reasoning as a criterion for greater age. To the contrary, I have noted that the westerly trending striae previously mentioned crosscut north-south trending striae suggesting westerly striae were the last to form (Plate 2).

Topographic Control of Ice Flow

Rich (1914) first noted that the Catskill Mountains acted as a barrier to ice flow (1935, p.10) by: "...directing strong ice streams westward up the lower Mohawk Valley

and southward down the Hudson." He also determined that in a similar way the higher parts of the Catskills exerted a strong control on the ice movements within the mountain region.

Rich (1935) delineated three subregions of high topography which he referred to as the northeastern, central, and southern escarpments (Fig. 5). Each of the escarpments is over 3000 ft in elevation and at points exceed 4000 ft. This is in contrast to valleys which are generally about 1500 ft in elevation.

During wastage of the Laurentide ice sheet, a point was reached where the ice was too thin to flow over the Catskill escarpments. Since these barriers roughly occur at right angles to the original ice flow, about 1500-2000 ft of residual dead ice was stranded south of the escarpments. Of particular note in the present study were large masses of debris-laden ice which were left in the valleys of the Beaver Kill, Willowemoc Creek, and the region around Andes, Bagley Brook and the Little Delaware River.

The high relief of the central escarpment was also responsible for the progressive stagnation of large masses of ice along the East Branch Delaware River. The region west of Hancock and Deposit is also noteworthy in this respect because it is characterized by massive upland ice disintegration topography composed primarily of till. This region was the locus of deposition of materials because of a combination

of ice thinning over the central escarpment and lack of topographically controlled ice flow, which was present in the East and West Branches Delaware River.

Summary

Erratics and striae in the Catskills both indicate that direction of flow during the last glaciation was outward from the Adirondack Mountains. They also demonstrate that flow was controlled by local topography. Terrain also played a major role in deglaciation with areas of high relief causing isolation of large masses of ice during retreat.

UNSTRATIFIED GLACIAL DEPOSITS

Till

The till in the western Catskill Mountains is composed almost entirely of material derived from the local bedrock consisting of conglomerates, sandstones, siltstones, and shales. The various colors of the till appear to reflect percentages of local red and gray rocks. Only a few erratics were found incorporated in the till suggesting that most of the material comprising the till was local in origin and subject to short transport distances.

Texturally the tills range in particle size from clay to boulders as much as 3 ft across and, rarely, 6 ft or more. Till clasts observed range from angular to subround and are highly variable in size. Till used as an impervious core in the Downsville Dam has average clay percentages ranging from 7 to 23% (Fluhr, 1964) while that in the Cannonsville Dam has a clay percentage of 17%. Figure 6 shows some seive analyses of impervious materials,(till), used in the construction of both the Downsville and Cannonsville Dams.

Surficial mapping in eleven 15 minute quadrangle maps and the detailed study of hundreds of well logs and New York City Board of Water Supply (B.W.S.) boring records has failed to give evidence for more than one till in the Catskill Mountains. Ample evidence for a pre-Wisconsin glaciation

having covered the region exists in the form of multiple and early tills in eastern Pennsylvania and New Jersey (Sailsbury and others 1902, Bayley and others 1914, Leverett 1934, MacClintock 1940, Peltier 1949, Denny and Lyford 1963, Epstein 1969, and Crowl 1972). Evidence for early or pre-Wisconsin glaciation has been given in central New York by Schmidt (1947) and Bloom (1972).

B.W.S. borings in Baxter and East Brooks between the East and West Branches Delaware River show two tills separated by sand and/or gravel (Fig. 7). A detailed search failed to confirm the two tills. Field observations suggested that the upper till is, in fact, colluvium derived from the local bedrock.

In my opinion the Catskill Mountains were not glaciated during early Wisconsin time although the possibility should not be discounted.

STRATIFIED GLACIAL DEPOSITS

General Statement

Glaciofluvial deposits or washed drift (Flint 1972) includes both ice-contact stratified drift and proglacial stratified drift. The term "ice-contact" is used here in preference to ice-marginal since the latter implies deposition at or on the active margin of a glacier and in this context is not literally applicable to all deposits found in the Catskills. Some of the ice-contact deposits are derived from large masses of ice isolated from the main sheet by the high relief topography and thus cannot be referred to as marginal to an active glacier. Deposits of this type will be considered in detail in reference to their respective geographic locations.

The lithology of the stratified deposits is close to 100% local rock although the size range is highly variable as can be seen from Figure 2. There is a notable occurrence of Adirondack type erratics in the stratified drift although they constitute much less than 1%. A few limestone erratics were found, one in a kame delta near Corbett by Professor Ernest Muller, and five others by the writer in various gravel pits along the East and West Branches Delaware River. Minor amounts of cementation by $CaCO_3$ occur in most localities and pitting from solution is present on the limestone samples collected. This suggests that groundwater

action may have greatly reduced the number of limestone erratics which may have originally existed in the drift.

The color of the drift ranges from predominately gray to a reddish brown depending on the percentage of gray versus red rock in the local bedrock. The color has no relationship to age of the drift since the drift all has a fresh appearance with very little soil profile development.

Valley Trains

Rich (1935) defined valley train as outwash "...held to narrow width by valley walls... It is coarsest where the stream emerged from the glacier." (p. 36). Generally the outwash in the valley trains is composed of coarse gravel and cobbles although many areas are composed of boulders which Rich (1935, p. 37) said "...testify to the former presence of powerful glacial streams." This is particularly true in the valleys of the East and West Branches Delaware River. Rich (1935) further notes the difficulty in distinguishing between river terraces and true outwash. I can attest to this difficulty and have not distinguished between the two on the surficial map. Very few good exposures of outwash are available in the West Branch Delaware River and no fresh exposures were observed along the East Branch Delaware River. The lack of good outcrops prevented the establishment of detailed criteria for distinguishing river terraces from outwash.

Morphologically, outwash in the Catskills ranges from smooth-surfaced planar deposits to deposits with pitted surfaces deposited closer to the ice. Often a gradation from smooth outwash to pitted outwash can be seen such as that near Delhi and above Margaretville. At a few places, notably between Delhi and Hobart, outwash grades into kames or what Trotter (1929) called "outwash moraine". I prefer the term "kame moraine", after Rich (1935), due to the ice-contact nature of the deposits and their close proximity to a local ice marginal position.

As a rule outwash terraces are rare in the western Catskill Mountains, being observed primarily along the upper reaches of the West Branch Delaware River. Rich (1935) reports many miles of outwash terrace remnants below Margaretville. In most cases they have been destroyed by construction or inundated by the Pepacton Reservoir waters.

Ice-Contact Kames and Kame Terraces

The principal types of kames in the western Catskill Mountains are kame deltas, kame moraines and kame terraces. The drift is generally well rounded although minor amounts of till-like material has been noted in both kame deltas and kame terraces. Mudflows or gravity flows occur in some of the kame terraces.

The term "kame moraine" is used as both a mapping and a descriptive unit, particularly along the West Branch, because

it connotes ice-contact deposition in juxtaposition with the terminus of a glacier and therefore locally delineates approximate valley marginal positions. Kame moraines occur as hummocky or kame-and-kettle topography and flat-topped kame deltas (Figs. 8,9). A whole spectrum of forms appear to be present. Kame moraines grade into kame terraces and frequently no distinct morphological boundary can be mapped between them. The kame terraces in the East and West Branches Delaware River increase in elevation up valley from kame moraines at a rate of 10 to 70 ft/mi. The kame terraces are not tracable for more than about 8 mi in any cases observed.

Larger kame deltas are found in the East Branch and were deposited between the ice and the valley sides. In all cases noted, deposits of this type coincide with regions of large masses of residual ice. Examples of this type of deposition are common along the East Branch where ice and/or sediment dams at Harvard, Shinhopple, and Shavertown (Plate 4) created lake levels at 1100, 1160, and 1300 ft respectively during retreat of the ice. No kame terraces could be found associated with the East Branch kame deltas.

The location of kame moraines coincides frequently with valley widening due to the junction of larger tributaries. This appears to be the predominant control for kame moraine locations although extreme bending of the valley such as the location of K7 (Plate 1e) on the West Branch below Walton

may also be a factor. It should be noted that tributaries provide a second sediment source for the development of kame moraines. This additional sediment is probably the reason kame moraines form at the junction of tributaries.

A composite sequence of glaciofluvial sediments in the West Branch is a gradation from outwash to pitted outwash to kame moraine and then into kame terrace. Pitted outwash is infrequently present in the sequence. It is likely that till units can also be included in this sequence as a veneer over the valley walls and at the base of the glacier. Whether valley wall units occur is speculative whereas the basal till is well documented in B.W.S. boring records. The deposition of till units probably pre-dates the deposition of the glaciofluviatiles.

Deglaciation Model

Ice Profiles

A series of theoretical glacier profile curves were generated by computer for the Catskill region. The assumption was made that gradients could be reconstructed by extrapolating between high remnant levels of both kame moraines and kame terraces. This was done in the valleys of the East and West Branches Delaware River in order to determine the profile or profiles of the retreating glacier. It should be noted that these profiles represent the intersection of the

ice with the valley wall and although the ice in the center of the valley was probably higher in elevation and may have been somewhat steeper in gradient, the differences were probably not enough to affect the conclusions of this study. The equation for theoretical profiles (Nye 1952a) was computerized (Appendix A) and used to generate a series of profiles with a basal shear stress value ranging between τ=.005 and 1 bar (Fig. 10). The bedrock slope was assigned a value of 9.6 ft/mi, an average value for the West Branch and the cross sectional profile of the valley was assumed to be a parabola. In no cases were curves with values of τ greater than .05 bars required in the fitting. This is an order of magnitude less than values for profiles of modern day glaciers such as the Unteraar Glacier which has a calculated value of τ=.77 bars (Nye 1952b). These values demonstrate that the ice which formed sequences in the West Branch had wasted well below the minimum profile necessary for flow. Thus the ice which formed sequences in the West Branch was stagnant at the time of sequence formation.

The curves were fitted by eye to kame moraine and terrace remnants by aligning the front of a series of curves (Fig. 10) with a kame moraine position in the valley and determining which of the profiles fits the kame terraces. The 0 ft position (Fig. 10) was always kept in contact with the bedrock floor of the valley. The resulting series of deglaciation profiles for the East and West Branches Delaware

River are shown on Plates 4 and 5.

The mathematically-derived curves representative of glacier profiles were used to delineate depositional sequences from map interpretation, wherever field observations were impossible, such as the region now occupied by the Cannonsville Reservoir. Other positions were checked in the field.

In a few cases it was possible to trace deposits directly from kame moraine into kame terrace in the field, but in all cases the real sequence curves differed from the mathematically generated profiles by being somewhat depressed in their forward regions (Fig. 11). These depressed regions may be the result of collapse due to the melting out of ice-cored kame moraines.

These curves have proved useful in delineating depositional sequences and characterizing the ice which deposited them. The profiles have also made possible the development of the zonal theory of ice separation and sequence deposition described in the following section.

Ice Zone Development

The morphology and character of glacial sediments suggest a mechanism of development that can be referred to as "ice tongue separation". Flint (1942, p.122) gives several reasons for separation of the terminal part of a thinning glacier such as: topographic control, superficial drift,

and stagnation from overloading of englacial debris as the margin: "...basal ice of glaciers may become so full of debris that motion is inhibited, and that the overlying less-burdened ice moves past it."

Rich (1943, p. 95) also describes a mechanism for retreat and detachment: "Thus while the visible ice front retreats by melting, a relatively thin but nevertheless, considerable sheet of ice remains in the valley bottoms, preserved for a time from melting by an insulating blanket of sand and gravel. On account of the relative thinness of the buried ice in the valley bottoms, the visible ice front can retreat only a short distance before it becomes easier for the thick, live ice to shear across and move upward at the head of the thin, buried ice mass than to push the latter forward against the friction on its bed." (Fig. 12).

Rich further attributes this process to elongated, low gradient valleys where glacial outwash would tend to accumulate instead of being carried away as in the steep valleys below mountain glaciers. Thus Rich envisioned a more or less continuous set of kame terraces deposited with retreat of the ice.

Jahns (1941) noted that outwash, kames, and kame terraces at any single marginal position could be grouped into graded sequences. He referred to these as outwash groups, and showed they were generally controlled by a bedrock threshold. He related the length of outwash groups to the

width of the stagnation zone of the ice. Widths of outwash groups in the Connecticut Valley range from 1 to 4.5 mi with an average of 3 mi (Jahns 1941).

Currier (1941, p. 1895) working in Massachusetts stated that "...stagnation-zone retreat may explain the wide spread ice-contact features and the apparent lack of end moraines..." He also suggests this mechanism of retreat should surplant earlier theories of general stagnation and downwasting.

Outwash groups or ice margin depositional sequences in the West Branch Delaware River are somewhat longer than those in the Connecticut Valley. Within any single sequence or group, kame terraces are usually tracable for distances of 5 to 7 mi but rarely farther and never into the uplands. The average distance between sequences is 3 mi in the West Branch Delaware River. Furthermore gradients of the kame terraces range from 10 to 70 ft/mi and are rarely found more than 300 ft above the present floodplain. This is a short distance in an area where valley relief exceeds 1000 ft. This short distance as well as the lack of evidence for ice movement in the deposits in the East and West Branches Delaware River, suggest a detached mode of ice-contact deposition.

Sequences along the West Branch can be grouped into zones, each zone having a vertical succession of kame terraces. Each kame terrace can be paired with a kame moraine with retreat up valley. Most notable of these are Zones 1

and 2 (Plate 5). Each zone ranges from 10 to 15 mi in length and represents progressive stages in deposition from the backwasting and downwasting of the detached zone of ice. The overlapping vertical succession of the sequences within a zone eliminates the possibility of having a separate ice detachment for each sequence.

Using equations for ice profiles (Nye, 1952a, 1952c), profiles for a glacier were generated for both a valley glacier and an ice sheet. The computer programs are included in Appendix A. Fig. 13 shows the relationship between the two profiles, both having the same value of τ (1 bar). The profile of the valley glacier is the steeper profile, therefore during retreat, any reduction in overall profile of the glacier could cause stagnation to that part confined within a valley while that part unconfined on the uplands would still be active. From Fig. 13 it is apparent that in an area such as the West Branch with a relief of 1200 to 1500 ft from 10 to 15 mi of ice would become stagnant and eventually detached in the valley. This length is the same as that of the zone suggesting a zonal method of stagnation and detachment.

Summary

Ice marginal positions in the major valleys described in this study do not relate directly to active ice but instead to the termini of ice detached areas of the retreating

ice sheet. These regions of ice detachment can be divided into two main catagories: (1) in valleys such as those formed in the West Branch, and (2) areas of regional stagnation caused by topographic dismemberment of ice on hillsides from the main retreating glacier. This latter case can be subdivided into those regions characterized by glaciofluvial deposits and regions of massive till deposition.

The length of zones of ice, detached in valleys such as the West Branch are related to relief of the valley in which they are confined. Thus the termini of such zones bear an approximate relationship to the active margin of the retreating glacier. In the West Branch, the margin of the active retreating glacier was probably 10 to 15 mi up valley from the terminus of a given zone at the time of its detachment. The termini of individual zones as well as their termini during progressive stages in their disintegration are well documented by positions of kame moraines in the valley. No features were found which could be correlated with marginal positions of the active retreating glacier either in the valleys or on the uplands.

At the same time as a given kame moraine is being formed, a pair of associated kame terraces is being deposited between the ice and the valley sides. The longest length of kame terrace development possible is the length of the detached zone of ice. Much of the sediment forming the kame terraces and kame moraines appears to be contributed by drainage out

of the uplands. Thus individual sequences of deposition within a zone are most often controlled by the availability of upland sources of water and sediment. This explains the repeated occurrence of kame moraines at the junction of tributaries to the West Branch.

Each sequence of deposition has an associated outwash unit deposited in the form of valley trains. In some cases, the previously deposited kame moraine will act as a dam causing local ponding between sequences. This results in the deposition of lake beds and accounts for some of the deltaic units associated with some of the kame moraines.

All the major kame deltas are located in the East Branch Delaware River. Each individual lake level in the East Branch appears to have been related to a distinct zone of ice stagnation considerably larger than the zones of stagnation in the West Branch. These lake regions are representative of hillside topographic isolation of glacier masses during retreat. In areas of large scale regional stagnation, no correlation has been made between the location of the active ice front and the individual deposits associated with the dead ice. Kame deltas, like kame moraines are associated with tributary junctions but do not have associated ice-contact kame terraces.

REGIONAL DEGLACIATION

Mapping Units

The mapping units used on the surficial map (Plate 1) are generalized to represent the dominant surficial deposit in that region, because the features are too complex to depict in detail. The numbered units on the West Branch represent distinct depositional sequences as described in the text.

The sequences along the upper part of the West Branch frequently have a fan-like form. Although these fans are a complex mixture of outwash, alluvium, and kames, they owe their overall form to the junction of tributaries to the West Branch. Thus the individual sections of any one fan may have numerous genetic origins. For convenience, terms such as forefan, midfan, and apex will be used for location. These terms are not intended to have any genetic reference unless otherwise stated.

East Branch Delaware River

The East Branch Delaware River flows southwest (Fig. 1) and joins the West Branch at Hancock. In most parts it flows parallel to the West Branch. For convenience I have subdivided the East Branch into three sections: (1) The lower section from Hancock to the junction of the Beaver Kill. (2) The middle section from the junction of the Beaver Kill

to Arena. (3) The upper section from Arena to Grand Gorge and east of Margaretville.

Lower Section

The lower part of the East Branch has very poor exposures and outcrops that do exist are poorly preserved. This section was one of massive ice stagnation in the valley, and contained numerous short-lived lakes. A few well-preserved sections as well as boring records support the existence of the lakes. Stagnation also resulted in the blockage of northwest flowing tributaries of the East Branch, and caused small lakes to be backed up into their headwaters. Of particular note in this respect are till plugs along Fish Creek southeast of Fishs Eddy and Trout Brook southeast of the [hamlet] town of East Branch (Plate li). The best documented till plug is on Trout Brook where a complex sequence of till and red lake clay units is exposed. The section is subject to much slumping and during the wetter periods exhibits piping.

E. Branch is a hamlet in the town of Hancock

A series of borings by the New York City Board of Water Supply for a proposed Fishs Eddy damsite south of Hawk Mountain, (Plate li), shows lake beds and glacial gravels capped by what Fluhr (1953) called "mainly impermeable till" on the north side. This cap is more likely a mixture of till and colluvium derived from the south flank of the bedrock projection jutting south from Hawk Mountain. In addition a

profile based on these borings (Fluhr 1953) shows that the bedrock configuration of the valley is "U-shaped" and is approximately three times as wide as the present valley.

East Branch Glacial Lakes

Middle Section

Three glacial lake levels were mapped along the middle section of the East Branch starting approximately at Harvard, Shinhopple, and Shavertown Bridge (Plate 4). Shinhopple is the best exposed and is therefore treated in greater detail. Neither the deposits at Harvard or at Shavertown Bridge levels are sufficiently preserved or exposed to merit more than a cursory description.

Harvard Level

The 1100 ft level near Harvard is determined by correlation of kame delta tops. The dam itself was probably located just south of Harvard where there is a complex till and kame section. The only well exposed section is located about two miles east of Harvard and is a flat topped kame delta very similar to the ones described associated with the Shinhopple level.

Shinhopple Level

Just south of Shinhopple, a large massive till unit

occurs on both sides of the valley. The till ranges in size from clay to boulders greater than 3 ft long. A till fabric (Fig. 14, Plate 1e) shows a very strong orientation parallel to the valley, suggesting the till was deposited by ice moving directly down valley. This till section occurs at a sharp bend in the East Branch, an ideal location for a till plug. At this location the bedrock floor of the valley also climbs abruptly from greater than 185 ft below the present flood plain level at Corbett to only 130 ft below at Shinhopple (plate 4).

Shavertown Level

The presence of a 1300 ft lake level starting near Shavertown Bridge is inferred from topographic maps and what little of the original topography remains above the Pepacton Reservoir. Fluhr (personal communication, 1971) described the presence of kame deposits in the valley of the East Branch prior to the construction of the construction of the Downsville Dam. One of these he recalled as being composed predominately of clay or silt. I interpret this to be a kame delta and although its precise position was not confirmed, it does testify to the existence of a former glacial lake.

The exact location of the dam which created the 1300 ft glacial lake is unknown, but the region around Shavertown contains not only a sharp bend in the East Branch but also

the bedrock is close to the surface (Plate 4). Both of these conditions are topographically conducive to the development of an ice-sediment dam.

Further evidence for a morainic dam is provided by the presence of p-forms (Figs. 15, 16), or plastically sculptured forms on a bedrock ledge just east of the Shavertown Bridge on the north side of the East Branch. Hjulstrom (1935) attributes the formation of p-forms to the presence of an obstacle such as a morainic block which would promote cavitation by sub-glacial streams. After melting of the ice, the morainic block served as a dam for the 1300 ft lake.

Upper Section

East of the Shavertown Bridge set of kame deltas the deglaciation sequences become very much like those in the West Branch and are treated in the same manner (Plate 4). Rich (1935, p. 60) mentioned the existence of gravel terraces at 1350 to 1380 ft between Arena and Margaretville. He states: "In many places these terraces were built upon the ice and slumped down into kames when the ice melted away."

There are some good examples of kame deltas in the Margaretville area with well-developed fore-sets. These are probably the result of only local ponding since no evidence for continuous lake levels could be found. Deglaciation to the east and north of Margaretville is exemplified by relatively low relief kames, kame terraces and eskers.

The esker on the surficial map (Plate 1b) was originally mapped by Rich (1935) and was not reinterpreted in this study. The lack of well-developed terrace gradients and the occurrence of pitted outwash indicates the presence of a number of zones of dead ice in the valley during deglaciation.

The preservation of pitted outwash deposits south of Roxbury suggests that meltwater outflow through Grand Gorge after deglaciation of the East Branch was minimal. It is likely that both Grand Gorge at 1570 ft and the high level notch to the northwest at 2040 ft are the result of numerous glaciations and not restricted to just the latest glacial episode.

Kame Deltas

There are three large kame deltas with good exposures along the East Branch Delaware River between Shinhopple and Downsville. These include the Matson Pit just north of Gregorytown, the Corbett Pit just north of Corbett, and the Town Pit just south of Downsville. These are all located on Plate 1k. Other kame deltas occur in the region but are not as well exposed.

In the following discussion on individual kame deltas, the following ripple drift classification of Jopling and Walker (1968) will be used. This is presented here as an aid to the reader due to the varied classifications of ripple drift in the geologic literature. Type A - The cross-

laminations consist entirely of climbing sets of lee-side laminae. The stoss-side laminae are either partially or completely eroded. This type of ripple drift is composed primarily of sand. Type B - This ripple drift "...is composed of climbing sets of lee side laminae with complete preservation of relatively thick stoss side laminae, and continuity of laminae from one ripple to the next." (Jopling and Walker 1968, p. 973). This ripple drift is largly sand with some silt. Sinusoidal ripple lamination - "The ripple lamination consists of superimposed undulating laminae, usually showing a slight displacement in one direction in successive laminae." (Jopling and Walker 1968, p. 973). The sinusoidal ripple laminations are composed of silt clay and may range from one extreme to the other.

The kame deltas are of twofold origin being formed from deposition by streams flowing from the ice and by sediments contributed by tributaries originating in the uplands. In addition to the deltas near the sides of the valley, large quantities of lake sediments were deposited in front of the deltas and in the center of the valley. A water well near the Corbett Pit in a KOA Campsite penetrated clay from 102 to 135 ft. Other borings near Corbett by the B.W.S. show similar deposits (Fig. 7). In many cases the finer materials were not recovered during the test borings.

The shape of ice in the East Branch was such that streams from both meltwaters of the main glacier and discharge from

tributaries flowing between the ice and the bedrock side of the valley. It was this combination of sources near the ice terminus that provided sediments for the development of the kame deltas.

During the initial stages of delta formation, sediment-laden waters were contributed from both the uplands and the melting ice. At this stage the greatest discharge was through a relatively narrow channel between the valley side and the ice. This high energy environment deposited the lowest exposed unit of boulders, up to 8 in. across, in the Corbett Pit. Such an environment would have been highly variable and directly related to the rate of melting of the ice. As more ice melted, the initial channel would widen into the already existing proglacial lake. This would create a lower flow regime permitting the deposition of much sand and silt from both the ice and the uplands. It is these units that are best exposed in most places and are best seen as steeply dipping fore-sets (Fig. 17). Their direction of dip is usually related to an upland source rather than from the ice.

Matson Pit

The Matson Pit is located in a large kame delta just opposite Gregorytown. The predominant units exposed are steeply dipping fore-sets of material from an upland source. Beds dip about 25°towards 30° south and are composed of fine

sand and silt.

A small section slong the east side of the delta exposed type A ripple drift formed from well-washed sand. This section is representative of deposition off the ice and is depositionally equivalent to the ripple drift section described for the Corbett Pit.

The top of the kame delta is capped in places with up to 14 ft of colluvium. Some of the colluvium is "till like" in appearance and may represent remobilized till deposited onto the delta top in the form of mudflows.

Horizontally laminated silts and clays were exposed by augering at a depth of 6 ft below the present working surface. These represent lake bottom sediments or bottom-set beds over which the delta has prograded.

Corbett Pit

The Corbett Pit is located in the kame delta north of Corbett and directly across the river (Plate le). It not only has ice-contact or ice-derived depositional units but also contains considerable sediments originating from both Barney and Gregory Hollows. Like the preceding description of the Matson Pit, there are large fore-sets dipping away from the valley wall, representative of an upland source. To the east, or ice-contact side of the delta, is a large section of ripple-drift. In the center of the pit at a lower level is a section ranging from steeply dipping sand,

silt, and boulder units to a very chaotic deposition with local ponding and cut-and-fill structures. This lower section probably was deposited during the early stages of kame delta formation by meltwaters flowing out from between the valley wall and the ice.

Of particular note is a small sand body marginal to the lower boulder units. The sand contains a few cobbles and reverse faults and is very similar to one described by Shaw (1972) which he interprets to represent antidune phase of sedimentation. This would place flow well into the upper regime. According to Fahnestock (1962, p. 1435) "The presence of scattered pebbles and cobbles on a sand bed or in a sand deposit is clear evidence that upper regime flows have occurred."

The ripple-drift section (Fig. 18) is well exposed over a distance of about 100 ft. By analogy to a similar sequence of ripple-drift described by Jopling and Walker (1968), the interbedded relationship between sinusoidal and Type B ripple-drift, (Fig. 19), suggests a relatively stable depositional environment with a high suspended to traction load ratio. They interpret the depositional environment to be "...a gently shelving lake floor traversed by gentle currents bearing fine sand, silt, and some clay, with the kame delta prograding from north to south." (p. 983). The sinusoidal and Type B ripple-drift in the Corbett Pit are interpreted to represent bottomsets while the steeply dipping fine

sand and silt in the middle of the section represent fore-sets (Fig. 19). The fore-sets continue upward into the section behind the overlying ripple drift. The cross bedding near the top of the section may represent the top-sets in the sequence. The westerly dip of the fore-sets indicates an ice source for the sequence.

Horizontally laminated silts and clay occur in a pit dug into the floodplain directly south of the kame delta. These are equivalent to the lower laminated silts and clays exposed by augering in the Matson Pit.

Further documentation for the Shinhopple Lake level is suggested by the scoured forms in bedrock on the valley wall above the kame delta (Figs. 20, 21). The exact origin of these features is unknown but they are interpreted to be fluvial thus testifying to the presence of strong meltwater action in this region.

Downsville Pit

The Downsville gravel pit is located in the kame delta just south of Downsville (Plate 1f). The major units exposed are a lower series of westward dipping fore-sets composed of fine sand and silt. The lower fore-set unit ranges in size from sand to cobbles and represents an early progradational stage in delta development. The upper silty unit represents a late stage deposition from an upland source such as described for the previous kame deltas.

Model for East Branch Kame Delta Formation

From the study of numerous exposures and borings in and marginal to the East Branch kame deltas, the following composite model for kame delta formation is proposed.

1. Formation of ice-sediment dam creates a temporary lake as the glacier stagnates and begins to waste upstream from the dam (Plate 4).
2. Major meltwater drainage is channelled between the ice and the valley wall. Sediment supply and meltwater are from both the ice and the uplands.
3. The lowest preserved units in the kame deltas are laminated silts representing the earliest stages of lake infilling. These are in turn covered by the progradation of large foresets of coarse sand and gravel. This gravel is deposited by the stream flowing between the ice and the valley wall and represents a high energy environment. As the ice melts, this stream valley widens into the lake creating a progressively quieter environment.
4. Final deposition is into a low energy lake environment and the materials deposited can be separated into two sources. These materials consist of fine sand, silt, and clay foresets from the uplands and ripple drift sequences prograding outward from the melting ice. Tributary streams play a critical role in both the location of kame deltas and as sediment sources.

Lake Level Variations

Measurements were attempted photogrammetrically along the kame deltas on the East Branch Delaware River to possibly determine amounts of isostatic rebound. This drainage locale is the only one in the study area that provides lakes of suitable extent for such a study. All other lakes were either too small or too ephemeral. Rebound rates determined from measuring the elevations of kame delta tops assume: 1. The tops of the kame deltas either coincide with the lake water level or represent a consistant level above or below the water. 2. The lake was a relatively open water body with free access of water between any incorporated ice blocks. 3. The line of measurement is parallel to the direction of ice retreat. 4. The downstream barrier or dam was not subject to incision during delta formation.

Measurements made from aerial photographs progressively upstream from the location of the Shinhopple Dam show a tilt of 4.4 ft/mi to the north. This is a measurment of rate of dam incision minus rate of rebound. The tilt due to dam incission is formed in the following manner: as the ice backwastes upstream, it progressively deposits kame deltas along its retreating frontal margin. Each of these kame deltas has its upper level controlled by the prevailing lake level at that time. In the case of the East Branch this lake level was continually being lowered by dam incision leaving pro-

gressively lower kame deltas in an upstream direction. The presence of dam incision makes determination of actual rebound rates from kame delta measurments impossible.

Deglaciation of the West Branch Delaware River

Introduction

The West Branch Delaware River trends southwest to Deposit where it makes a sharp bend and flows southeast to Hancock. The West Branch from Deposit trending northeast contains 6 well-defined zones (Plate 5) which are treated here in chronological order of deglaciation. They are discussed individually and subdivided into members or sequences within stagnation zones. For example, sequences 1 through 3 are considered both individually and as progressive stages of the same ice tongue disintegration, Zone 1.

East of Deposit in the valley of Oquaga Creek, a tributary to the West Branch, an esker (or crevasse filling) provides evidence for an ice margin at or near McClure. Here drainage was blocked from flowing south down the Delaware River and was forced westward into the Susquehanna River via Cascade Creek. A well developed bedrock sluiceway at 1380 ft through the divide between east-flowing Oquaga drainage and west-flowing Cascade Creek (Plate 1c) testifies to the large volumes of water which must have flowed across the divide into the Susquehanna River as well as the effectiveness of fluvial erosion.

Zone 1

Sequences 1-3

KM1 is a complex kame deposit and appears to have been primarily deltaic in origin. It contains both cross-bedding and ice-contact structures (Fig. 23). Its upper level is between 1100 and 1120 ft which is also equivalent to the 1120 ft outwash level at Hale Eddy 5 mi downstream (O1, Plate 1h). Both are interpreted to reflect the same temporary water level with an inferred glacially-formed dam just west of Hancock. The outwash deposit at Hale Eddy is probably a delta built into the lake by sediments supplied by Sherman Creek draining dead ice from uplands to the southwest. No exposures were observed in this outwash unit so the interpretations are based on morphologic interpretation.

The most probable locale for the dam impounding the 1100 to 1120 ft level is a group of kames just west of Hancock. This site is topographically suited for a dam as there is a bedrock spur just downstream which would have aided greatly in topographically controlling the glacier thus facilitating dam formation. The upper level of the kames is about 1140 ft and much of the material comprising them is subangular to subround. They also contain numerous boulders up to 2 ft across. These features suggest short transport and rapid deposition.

No exposures were available for examination in the K1

deposit to the north of KM1 but morphologically it appears to be equivalent to KM1, (Plate 1d) having a planar surface at a similar elevation.

KM2, (Plate 1d), is an extensive kame deposit composed entirely of sands and gravels as shown by B.W.S. borings (Fig. 7). It is topographically expressed as a large knoll 110 ft above the present flood plain and now forms part of the Cannonsville Dam. The fence diagrams (Figs. 24, 25, 26) show the relationship of glaciofluvial sediments in the knoll. On the west side of the knoll (Fig. 26) lake beds are not as extensive as those on the east side (Fig. 25), reaching a maximum thickness of 35 ft while on the east side up to 70 ft have been logged. Fluhr (1964) reports these lake beds are composed of varved clays. These clays prove the existence of small lakes between sequences. Some of these lakes may have formed in what Rich (1935) referred to as the fosse (Fig. 12).

B.W.S. borings and well logs reveal that the main bedrock channel is on the south side of the valley along both KM1 and KM2 demonstrating that the West Branch in the region of Stilesville has been diverted about a mile north of its original channel by the glacial deposits.

Sequence 3, (Plate 1d), is under water of the Cannonsville Reservoir. The nature of the inundated deposits is interpreted from detailed B.W.S. contour maps. These maps have a contour interval of 5 ft which facilitated the map-

ping of kame moraines and kame terraces.

Reconstructed glacier profiles (Plate 5) for the ice which deposited the sequences suggests an interrelationship between sequences 1, 2, and 3. With retreat to the north-east there appears to have been a decrease in gradient of the ice. Sequences 1, 2, and 3 also comprise a closely-spaced group and are separated from the following sequence by a much greater distance. These sequences (1, 2, and 3) together comprise parts of a zone of stagnation during re-treat and positions of individual sequences owe their locat-ion within that zone to local topographic controls. The major controls for sequences appear to be either highly constricted positions in the valley or very open sections such as at the junctions of large tributaries. Sequence 1 is located at the junction of Cold Spring Brook, Sequence 2 by a bedrock spur which extends south under the glaciofluvial sediments, and Sequence 3 at the junction of Trout Creek.

Lakes in Tributaries of the West Branch

Lake clays are frequently found recorded in drillers logs taken from some of the larger tributaries of the West Branch. While these lakes may have been connected with larger lakes in the main valley of the West Branch, it is most likely that they were separate water bodies.

During retreat of the main ice mass up valley in the West Branch, large quantities of outwash were deposited at

a much faster rate than in the tributaries. The resulting aggradation of outwash across the tributaries (Fig. 27) acted as a dam, creating short-lived lakes. These lakes persisted until the dams were breached and ponded waters were subsequently drained. A good example of this is at Trout Creek Bridge where B.W.S. borings during the construction of the bridge show up to 18 ft of lake beds overlying outwash (Fig. 7). The sequence is overlain by alluvium which implies that the uplands to the north must have been relatively ice free by the time of lake development. If the overall retreat of the ice was to the north or northeast, analysis of geometry in Trout Creek indicates the active ice margin must have retreated considerably up the West Branch to make Trout Creek ice free at the time of lake development. A close ice margin in the West Branch would have intersected Trout Creek and supplied sufficient outwash to prevent the lake from forming.

Zone 2

Sequences 4-8

The delineation of these sequences was interpreted from borings and detailed topographic maps, both by the Board of Water Supply of New York City. Like Zone 1, Zone 2 represents an ice marginal position and incorporates a number of deglaciation sequences which also decrease in slope upstream

(Plate 5). Sequences 4, 5, and 6 (Plate 1e), located along a very narrow part of the West Branch, occur at points of inflection in the valley. Sequences 4 to 6 are all fairly well developed and each appears to have well developed kame moraines and kame terraces.

Unlike the previous sequences, Sequence 7 is represented only by a small lateral segment, K7, (Plate 1e) 1260 ft in elevation, 80 ft above the present floodplain. K7 is actively being worked for sand and gravel and is composed of stratified ice-contact sands and gravels ranging up to 2 ft across. This indicates a high energy environment at times during the formation of K7.

Erratics are more common in K7 than in most areas but still constitute less than 1 percent of the total composition. Although much of the original surface has been removed, the south side of the deposit is still capped with a thin layer of colluvium derived from hill slopes to the south where much slope movement has taken place. This movement is evidenced by downslope entrainment of numerous blocks and slabs of sandstone.

K7 occupies a unique position in the valley on the south side of a sharp bend. This protected location is probably responsible for its form and preservation. K7's exact sequential position within Zone 2 is unknown as it was not determined whether it is part of a kame moraine or kame terrace. It is the product of very active ice-contact deposit-

ion and its location suggests a terrace remnant.

Sequence 8 grades upward from outwash into what is interpreted as a crevasse filling (Fig. 28). The crevasse filling is composed of very poorly stratified drift with numerous subangular boulders ranging to widths of 3 ft. It is linear in form and trends northeast where it grades into KT8. The lower section of KT8 contains large subangular boulders which are similar to those found in the crevasse filling. These boulders are exposed both in the lower section of a gravel pit just northeast of Pines Settlement and to the rear of a barn about 1000 ft farther east. The upper part of the Pines Settlement gravel pit is primarily sand and silt in the form of long steeply-dipping foreset beds representative of a much quieter depositional environment than in the lower section. The slopes above KT8 are covered with many large joint-controlled blocks of sandstone. It is these large blocks which probably formed the source for the large boulders found in both CV8 and KT8. The unique occurrence of such a large quantity of large boulders requires unusual conditions at the time of deposition. Sequence 8 is interpreted to represent the depositional sequence during final stages in the deterioration of an isolated ice tongue. At this time, a meltwater stream occupied the length now represented by CV8 and KT8. Many of the large blocks of sandstone were subsequently moved from the adjacent slopes into the stream, most likely in the form of a slide or mudflow.

This mode of deposition would also create local ponding and produce an environment into which the overlying sands and silts were deposited.

Upland Ice Margins

There is considerable evidence for upland ice margins along the divide between the East and West Branches of the Delaware River between Deposit and Walton. These are not extensions of the profiles shown in Plate 5, since the ice marginal features are probably the result of active ice just preceding the detached ice phase present during deposition of the valley sequences. Evidence for the ice margins lies in numerous till knobs, moraine-like forms, and swampy regions on the uplands as well as highly developed linear drainage channels extending from the divide into the East Branch. Examples of these are found in Sands, Cadosia, and Read Creeks and Baxter, Trout, Carcass, and Wilson Hollow Brooks. These margins do not represent time lines but rather a line of retreat of ice upstream.

During retreat, the ice margin stood at a point slightly south of Apex (Plate 1d) creating a flat-bottomed sluiceway across the divide and draining into Cadosia Creek. The sluiceway is now a swampy region about 0.5 mi long with an elevation of 1435 ft. This would most likely have been formed when the ice was near or stagnating at Zone 2 (Plate 5). A B.W.S. bore hole along the B.W.S. aqueduct line at

Apex just north of the sluiceway shows more than 47 ft of till with a thin interbedded gravel layer at 18 ft. The presence of the gravel confirms the flow of meltwater through this region during retreat. The boring record lists the unit as being 25 ft of gravel and also distinguishes a possible sand layer at 35 ft. The upper 18 ft of till may be colluvium as is commonly the case in this region. An interpretation consistent with other such regions and the boring is: 1. Deposition by active ice of the lowermost till in the head of the valley trending north from Apex into the West Branch. 2. Retreat of the ice to Zone 2 where meltwaters from the ice flowed over the divide into Cadosa Creek. Deposits representing this time include the gravel layer and possibly interbedded sands and tills. The sluiceway would have been cut at this time. 3. Slope movement depositing the overlying 18 ft following cessation of meltwaters through the sluiceway.

Zone 3

Sequence 9-11

These sequences are located along a fairly straight and uniform section of the West Branch Delaware River (Plate 1e). Individual parts of the sequences such as kame moraines and kame terraces are best preserved along regions of tributary junctions.

Reconstructed profiles of these sequences are poor at best due to the close proximity to each other and the concordance of kame terrace levels. The sequences appear to represent a fairly continuous retreat up valley with little local topographic control.

O9 is predominately composed of outwash with a much smaller amount of lacustrine sediments. The overall shape of the unit is a fan which forces the West Branch against the opposite (south) side of the valley. The apex of the fan is entrenched where it has a flat bottom 50 to 75 ft wide. The source of the sediments in O9 was both from the retreating ice in the West Branch and meltwaters draining Marvin Hollow.

KM9 is composed of sands and gravels capped by a thin colluvial cover. It also is fan shaped and located at the junction of a tributary to the West Branch. KM9 apparently had sediment sources from both the uplands and the ice during its deposition which accounts for its fan shape. A small meltwater channel is carved into the fan along its southeastern end, but the channel appears to have been of minor importance in terms of overall drainage.

A linear feature between Sequences 9 and 10 is interpreted as a crevasse filling (CV10). It is oriented southwest and appears to grade into outwash. No exposures were observed and the interpretation does not take into consideration possible changes in surface morphology during the con-

struction of Route 10.

O10 is very similar to O9 having an entrenched, flat-bottomed stream valley at its apex. The northwest part of O10 is composed of pitted outwash. Exposures in O10 are poor and overgrown but do reveal the material to be coarse gravels and sands.

KM10 and KT10 are located at the bottom of Oxbow Hollow and grade into each other. The kames extend well into the valley and force the West Branch up against bedrock on the south side of the valley. KM10 contains a number of well-preserved examples of stagnant ice topography along the West Branch (Fig. 8). Terraces are best developed along the east part of KT10.

Sequence 11 is very similar to Sequence 10 and would probably be indistinguishable from it if it were not for the bedrock spur which projects into the valley just east of Oxbow Hollow separating them. Terrace development on the south side of the river between Sequences 10 and 11 (KT10 and KM11) suggest a small local lake between Sequences 10 and 11 during retreat of the ice (Fig. 9).

On the south side of the valley Mallory Brook has entrenched an early outwash fan at its apex, dissected much of the lower fan, and is now in the process of building a new lower alluvial fan. Like most of the fan-like features in the valley of the West Branch, much of the material appears to have been contributed from tributaries as well as directly

off the ice. This argues for very wet conditions, and/or large masses of residual ice in the uplands during retreat.

Zone 4

Sequence 12-13

Like previous sequences, Sequences 12 and 13 comprise a zone of stagnation characterized by a decrease in profile gradient with retreat up valley. The individual units comprising Sequences 12 and 13 are fan shaped and show entrenchment at their apices. Much of the forefan parts of these units is recent alluvium and the West Branch is diverted to the opposite side of the valley in all cases. A gravel pit in the northern part of KM12 and 13 exhibits stratified sands and gravels with well-developed ice-contact structures.

The K unit at DeLancey is a complex deposit containing a variety of materials including recent alluvium. Large exposures were unavailable but spot sampling revealed it to be composed of sands and gravels. Many of these sediments appear to have been little reworked by water. A major source during its formation was Bagley Brook which appears to have contained a retreating ice margin at the time as well as a lateral meltwater channel. A temporary ice margin extending from Zone 3 (Plate 5) east along Bagley Brook would have provided the proper elevations, (1400 to 1500 ft) as well as the large quantities of meltwaters necessary to create a

deposit the size of the one now occupying the mouth of Bagley Brook.

The east side of the deposit exhibits a steep face up to 1430 ft where it levels off and grades gently up to 1520 ft. This face is interpreted as an ice-contact surface created against the previously mentioned ice margin.

Zone 5

Sequence 14-15

Sequences 14 and 15 (Plate 1a) are similar in form to Sequences 12 and 13 and may be a continuation of ice disintegration which formed 12 and 13 rather than a separate zone. Except for the gradient of the terraces in sequence 13, there is a decrease in terrace gradient upstream. Plate 1b shows the strong interrelationship between Sequences 12, 13 and the kame at Bagley Brook. The difficulty in separating and defining these individual sequences without adequate exposure in this region, as well as the unusual character of the kame at Bagley Brook, could explain the apparently anomalous gradient of Sequence 13.

Sequence 14 occurs at the junction of Peaks Brook and the Little Delaware River with the West Branch. The best kame moraine exposure in this sequence is located along the north side of the valley between the Little Delaware River and Peaks Brook. It has a noticable reddish color due to a

relatively high percentage of local red sandstones and shales. The high shale content in the kame is suggestive of short transport distances and rapid redeposition. Exposures of local bedrock confirm the existence of red sandstones and shales in the immediate area.

Well-developed kettles are present in the kame moraine on the north side of the valley where the West Branch trends east-west. These kettles are currently being used by the town of Delhi as a sanitary landfill operation.

Easily recognizable kame terraces belonging to Sequence 14 trend up both sides of the West Branch as far as Delhi making the total length of the sequence about 3 mi long. A similar set of terraces occur along the sides of the Little Delaware River for slightly more than 2 mi suggesting that ice was left in the Little Delaware River at the same time as that in the West Branch (Sequence 14).

Another kame moraine lies a few miles farther up the Little Delaware River in the vicinity of Lake Delaware. This is tentatively correlated with Sequence 15 (Plate 1a).

Sequence 15 starts just north of Delhi and is best exposed along the east side of the West Branch. The undifferentiated outwash and alluvium between KM15 and Delhi is in large part composed of pitted outwash. Kame terraces extend up valley from KM15 in both the valley of the West Branch and Elk Brook.

A large elliptical deposit on the west side of the West

Branch starting at the north side of Delhi contains material ranging in size from clay to more than 3 ft in diameter. The composition and chaotic bedding as well as the highly variable roundness of the materials suggests that this deposit originated as a large mudflow. The mudflow was derived from the north from the region of Falls Creek and represents rapid remobilization of material deposited by the ice in that region or deposition directly off the ice. The steep ice-contact face of the deposit in the West Branch testifies to the presence of ice in the West Branch at the time of its formation.

The deposit has resulted in the diversion of Falls Creek to the north where it now flows on bedrock at Watuga Falls. A meltwater channel between the flow and the valley wall (Plate 5) demonstrates that Falls Creek drainage was diverted southward while ice still occupied the valley at the present mouth of Falls Creek.

Zone 6

Sequence 16-19

Sequences 16 through 18 appear to reflect a fairly continuous zone of deglaciation with very little noticeable topographic control except for the junctions of small tributaries. The sequences generally show well-developed pitted outwash plains in front of the kame moraines. These outwash

deposits are often characterized by terracing (Fig. 29). The kame moraines in turn grade into kame terraces and are often indistinguishable from each other.

A well developed meltwater channel 2 mi north of 016 in Wright Brook, as well as the highly aggraded appearance of the lower portion of Wright Brook, indicates the presence of considerable meltwater action after the retreat of the ice in the West Branch to a position east of Bloomville. This would place the ice just south of Kortright Station at the same time that it had retreated east of Bloomville.

Sequence 19 has its location controlled by Griffin Hill just south of Hobart. It is impossible to determine from the available data if it is part of Zone 6 or constitutes a separate zone.

Beaver Kill and Willowemoc Creek

Rich (1935, p.29) described the drift in the Beaver Kill as being predominantly of the "thick drift" type. He reported that: "Most of the drift has the appearance of having been deposited beneath the ice by being plastered into valley bottoms while the ice sheet was moving across the region" (Rich 1935, p.49). This same description is also applicable to drift in the Willowemoc Creek area.

Exploratory work by the New York Board of Water Supply and the Interstate Commission for prospective damsites in the Delaware River basin shows that the pre-glacial valleys

of the Beaver Kill and Willowemoc Creek were considerably larger than at present. This exploratory drilling shows the valleys are filled with glacial drift overridden by a thick layer of colluvium derived from both till and the local bedrock on the adjacent hillslopes. Before glaciation they were comparable in valley width to the East Branch. A boring at the Jersey Brook damsite shows 182 ft of colluvium overlying 172 ft of stratified drift.

At the top of the stratified section is 10 ft of varved silt, sand, and clay as well as another 10 ft of lake clays. The lake beds here, as well as others at Horton (Fig. 7) and in tributaries to the Beaver Kill, suggest the Beaver Kill was blocked by ice to the west creating a lake which would have drained through the 1776 ft sluiceway south of Roscoe (plate 1j). The exact extent of this lake and the detailed deglaciation chronology for the Beaver Kill and Willowemoc Creek is unknown. This is due to the lack of exposure and the presence of colluvium which masks other deposits.

Numerous borings in south-flowing tributaries to the Beaver Kill, notably Fuller Brook (Plate 1i), show thick sequences of outwash overlying lake beds. This indicates meltwater discharge from the uplands when the Beaver Kill was relatively ice free. This discharge may have been from residual stagnant ice in the uplands, but more likely from ice still occupying the middle part of the East Branch and flowing over cols in the divide. Small tributary glaciers

may have moved through some cols for a short time contributing their meltwater flow to the Beaver Kill. An ice marginal position at Harvard or Shinhopple would provide the necessary gradient to permit flowage over the divide into the Beaver Kill.

The glacier that stagnated in the valleys of the Beaver Kill and Willowemoc Creek had a northeast source and moved over the high Catskills. As it thinned it became unable to maintain flowage over the high Catskills thus leaving behind large masses of stagnating or dead ice. One of the most spectacular changes wroght by the declining glacier was the deposition of a large mass of drift east of Willowemoc which plugged Fir Brook headwaters forcing it to drain south into the Neversink River. This resulted in the cutting of a spectacular bedrock sluiceway over 300 ft deep (Plate 1k).

Of particular note is that the region encompassing the valleys of the Beaver Kill and Willowemoc Creek is one which Rich (1935) described as having contained "Moraines and probable snowfields of local wind-drift glaciers of late (?) Wisconsin terminal (?) moraine stage." Although definitely not terminal moraine, it is easy to see how this remnant ice in the valleys may have continued to flow for some time through some of the lower cols in the higher Catskills and be mistaken for local glaciation.

Local Glaciation

Although much of the topography in the Catskills is suggestive of local glaciation, no direct evidence could be found to substantiate Rich's (1935) conclusion that the Catskills had been the locus of valley glaciers at the end of the last glaciation.

Some of Rich's cirque locations such as the one south or Balsam Roundtop (Plate 1g) were visited to look for features which could be correlated with local glaciation. All such features observed showed evidence for much post-glacial slope movement. Certainly any cirque-like features encountered could be accounted for by either slope movement or ice flowing through cols during deglaciation.

Although I cannot support the concept of local glaciation at the end of the last glaciation, the possibility of local glaciers existing at some time prior to the last glaciation should be subjected to further study.

Synthesis of Regional Deglaciation Chronology

Although not the primary concern of this study, a sequence of deglaciation events for the western Catskills and adjoining regions has been worked out. For the convenience of the reader these events are listed below in chronological order.

1. Regional glacial flow pattern to the south and southwest.

2. Stagnation of ice in the Beaver Kill and Willowemoc Creek valleys during ice thinning, with flow only through some of the lower cols.

3. Blockage of southward drainage from the Beaver Kill and Willowemoc Creek by preexisting ice in the East Branch. Cutting of the Roscoe Sluiceway with drainage through Calicoon Creek into the main Delaware River.

4. Stagnation of ice in the East Branch and Gulf Summit region. Temporary margins at McClure, Harvard, Shinhopple, and Shavertown Bridge. Short lived drainage through the sluiceway west of Gulf Summit indicating that this part of the Susquehanna River deglaciated prior to the West Branch.

5. Deglaciation of the West Branch by means of zones of stagnation. During deglaciation of the upper part of the West Branch, large areas to the southeast contained much residual ice in upland areas such as the regions of the Little Delaware River, Bagley Brook, and the area around Andes.

Note: Stages 3, 4, and 5 are not independant events but had some overlap in time.

CONCLUSIONS

1. The surficial deposits in the western Catskills reflect only one glaciation. No evidence for an Early Wisconsin glaciation could be found as suggested by Rich (1935).

2. No evidence for local glaciation was observed in any part of the western Catskills.

3. Ice movement during Late Wisconsin time was southward through the Catskills, radiating outward from the direction of the high peaks region of the Adirondack Mountains.

4. As the Laurentide Ice thinned over the Catskills, large masses of ice were topographically isolated from the retreating ice sheet. This resulted in extensive regions of dead ice.

5. The East Branch deglaciated by means of large-scale ice stagnation. This resulted in the formation of 3 well-doccumented lakes and associated kame deltas. A depositional model for kame deltas in the East Branch is proposed.

6. Deglaciation of the West Branch was by zones of stagnation. These zones are related to both topography and the flow characteristics of ice. Each zone results in the deposition on numerous sequences.

APPENDIX A

```
      ∇PROFILE[⎕]∇
    ∇ S←PROFILE T;NO;H;NO;H1;S
[1]   S←DIST
[2]   H1←0
[3]   HO←T÷0.09016
[4]  START:H←(2×HO×S)*0.5
[5]   H1←H1,H
[6]   S←S+DIST
[7]   →((ρH1)≤(NO))/START
[8]   S←(0,(⍳NO))×DIST
[9]   H←H1×3.28
[10]  S←S÷621.371
[11]  S←S,[1.5] H
    ∇
      ∇PROF[⎕]∇
    ∇ PROF T
[1]   Z PLOTT S←PROFILE T
    ∇
      ∇VALPROF[⎕]∇
    ∇ X←B VALPROF T;HOP;H1;H;X
[1]   B←SLOPE B
[2]   HOP←T÷0.0527
[3]   H←H+X1←0
[4]  START:X←((HOP÷B*2)×(⍟(HOP÷HOP-B×H)))-H÷B
[5]   X1←X1,X
[6]   H←H+H
[7]   →((HOP÷B)≤H)/GO
[8]   →((ρX1)≤NO)/START
[9]  GO:X←X1÷621.371
[10]  H←(0,(⍳((ρX)-1)))×H×3.28
[11]  X←X,[1.5] H
    ∇
      ∇VPROF[⎕]∇
    ∇ B VPROF T;X
[1]   Z PLOTT X←B VALPROF T
    ∇
      NO
5
      H
100
      DIST
10000
      Z
100
```

DESCRIBE

PROFILE	THE FUNCTION PROFILE COMPUTES THE PROFILE FOR AN ICE CAP ON A HORIZONTAL DATUM GIVEN THE BASAL SHEAR STRESS T IN BARS. OUTPUT IS HEIGHT IN FEET AND DISTANCE IN MILES.
PROF	DRIVER FUNCTION FOR PROFILE WHERE T IS BASAL SHEAR STRESS IN BARS. OUTPUT IS A PLOT OF THE ICE CAP PROFILE. REQUIRES PLOTT FROM 1 PLOTFORMAT.
VALPROF	THE FUNCTION VALPROF COMPUTES THE PROFILE FOR A VALLEY GLACIER GIVEN THE BASAL SHEAR STRESS T IN BARS AND THE BEDROCK SLOPE B IN FEET PER MILE. OUTPUT IS HEIGHT IN FEET AND DISTANCE IN MILES.
VPROF	DRIVER FUNCTION FOR VALPROF WHERE T IS BASAL SHEAR STRESS IN BARS AND B IS THE BEDROCK SLOPE IN FEET PER MILE. OUTPUT IS A PLOT OF THE VALLEY GLACIER PROFILE. REQUIRES PLOTT FROM 1 PLOTFORMAT.
SLOPE	THE FUNCTION SLOPE CONVERTS SLOPE FROM FEET PER MILE INTO RADIANS.
NO	VARIABLE USED IN BOTH VALPROF AND PROFILE. DETERMINES NUMBER OF INCREMENTS OF HEIGHT AND DISTANCE TO BE CALCULATED.
H	SIZE OF HEIGHT INCREMENTS IN METERS FOR VALPROF.
DIST	SIZE OF LENGTH INCREMENTS IN METERS FOR PROFILE.
Z	SCALE FACTOR FOR PLOTT FUNCTION.

APPENDIX B

Figures

FIGURE I

LOCATION MAP

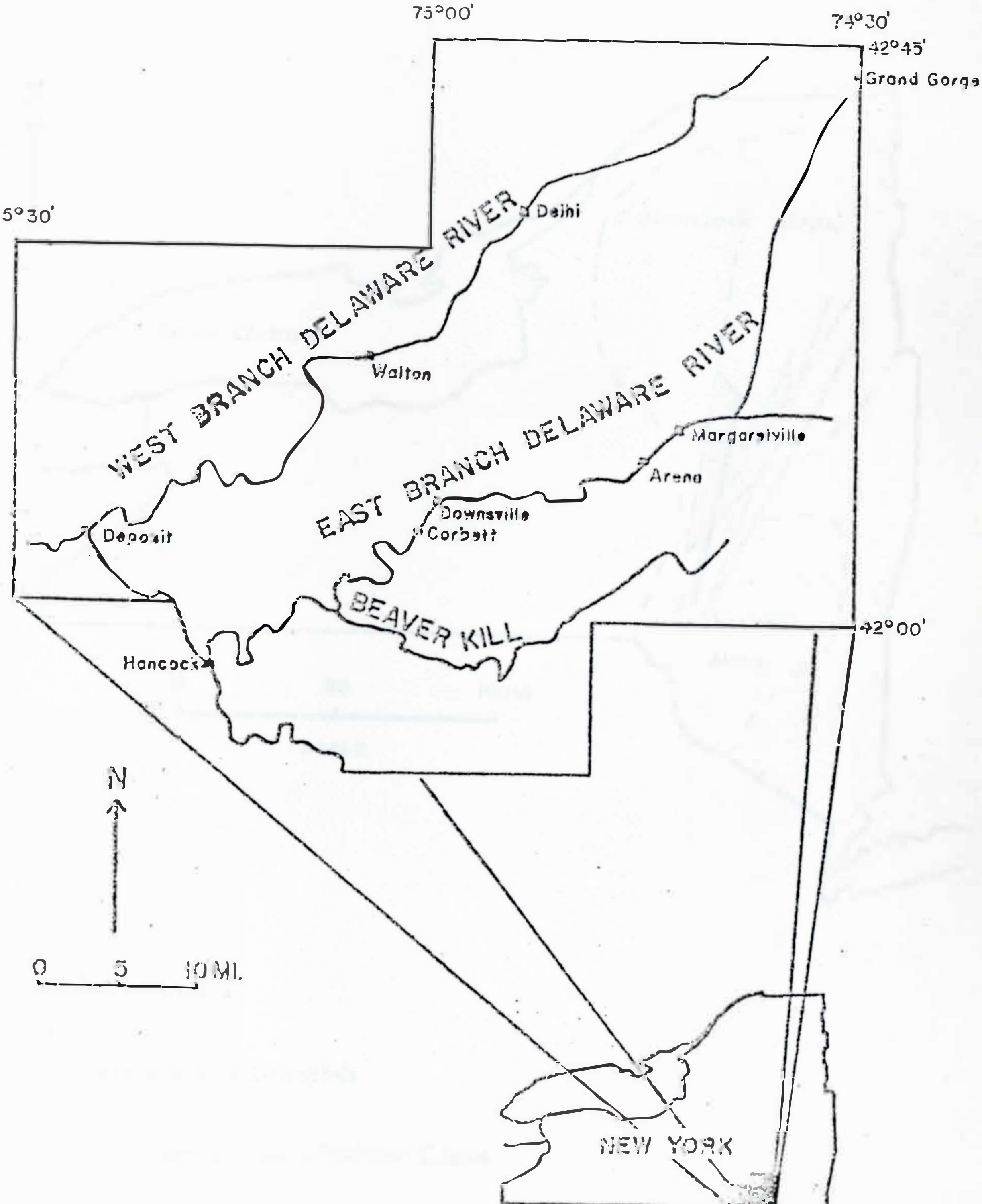
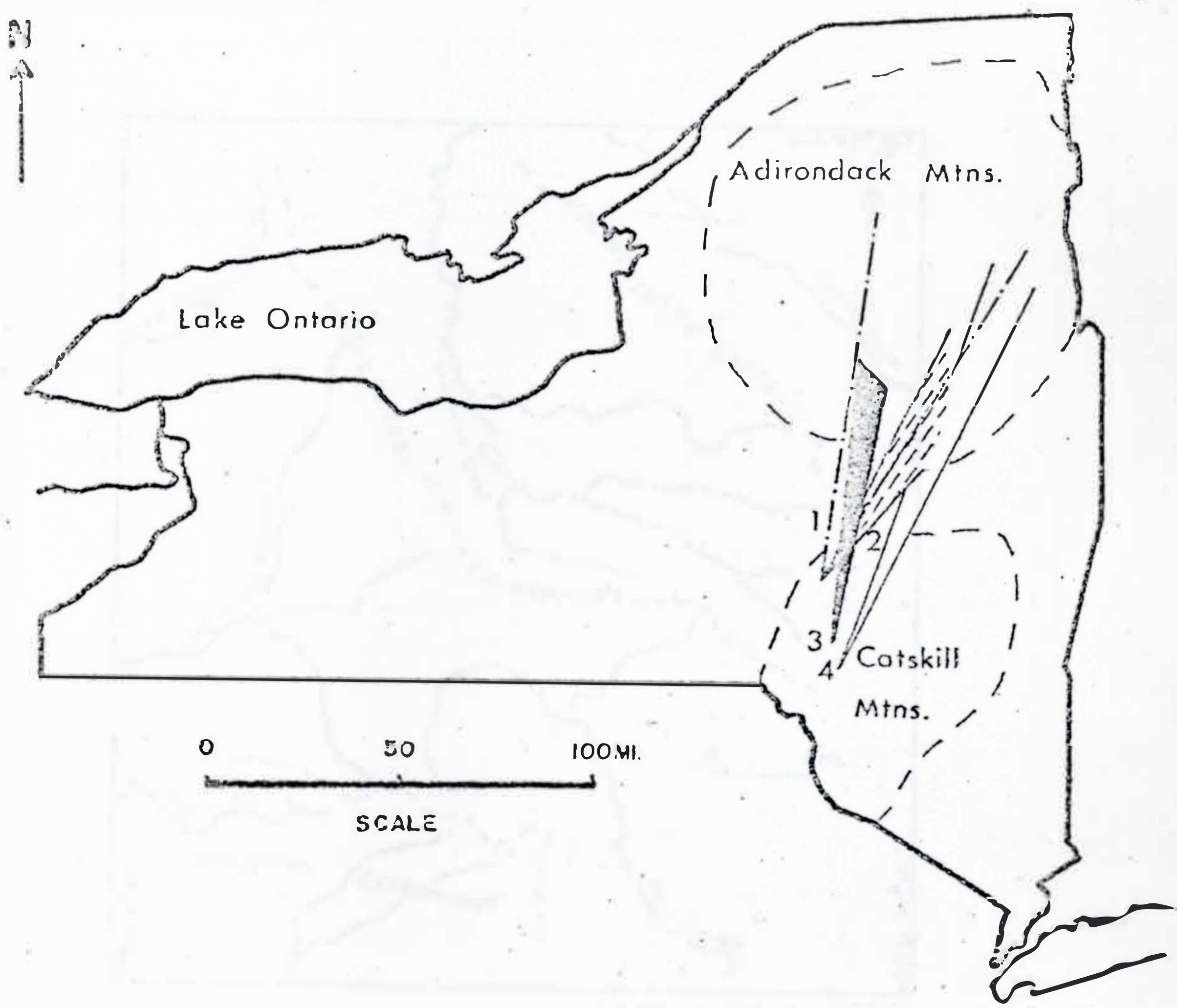


FIGURE 2

Probable Source Area For Catskill Erratics



1. Metanorthosite

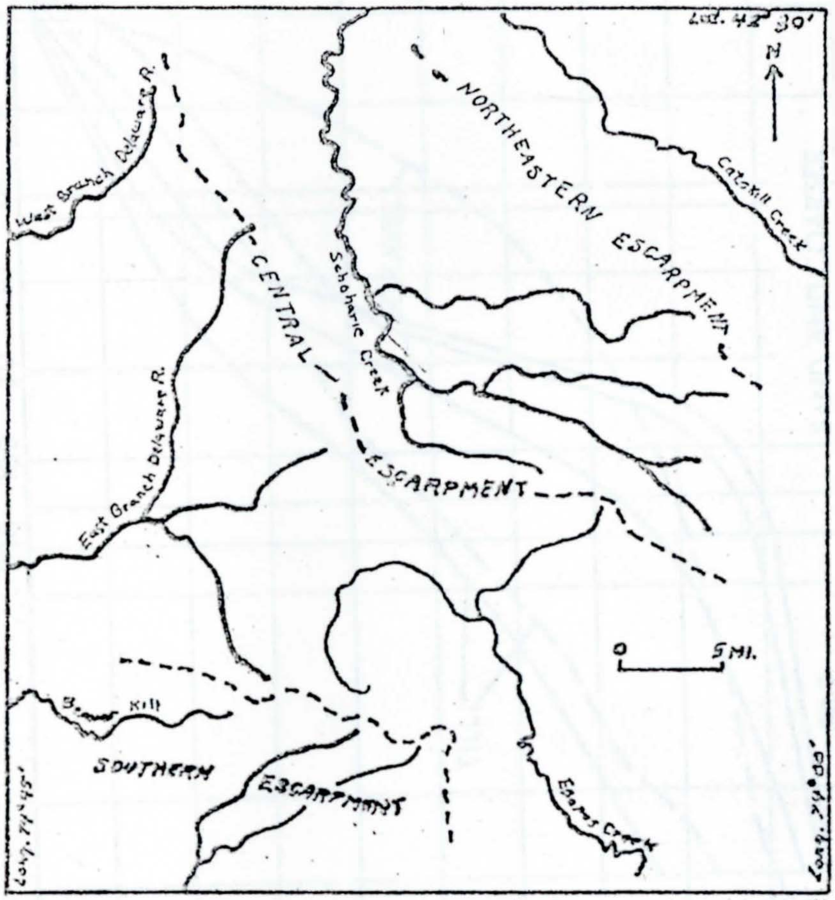
2. Garnet-rich White Granofels

3. Lineated Mylonitic Quartz Feldspar Gneiss

4. Leucogranitic Gneiss

FIGURE 5

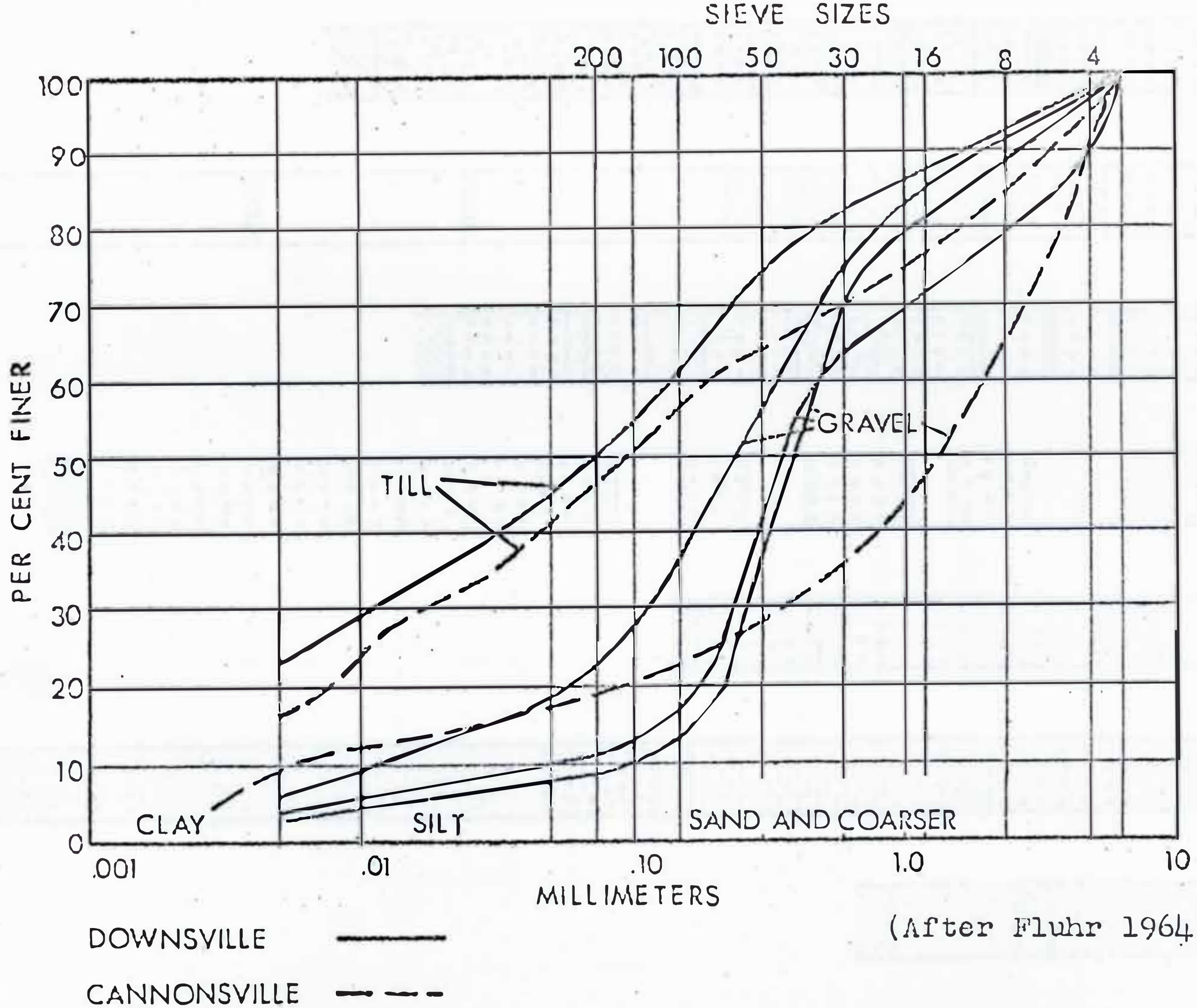
PRINCIPAL GEOMORPHIC AND DRAINAGE FEATURES



(After Rich 1935)

FIGURE 6

SEIVE ANALYSES, EMBANKMENT MATERIALS, CANNONSVILLE AND DOWNSVILLE DAMS



(After Fluhr 1964)

FIGURE 7

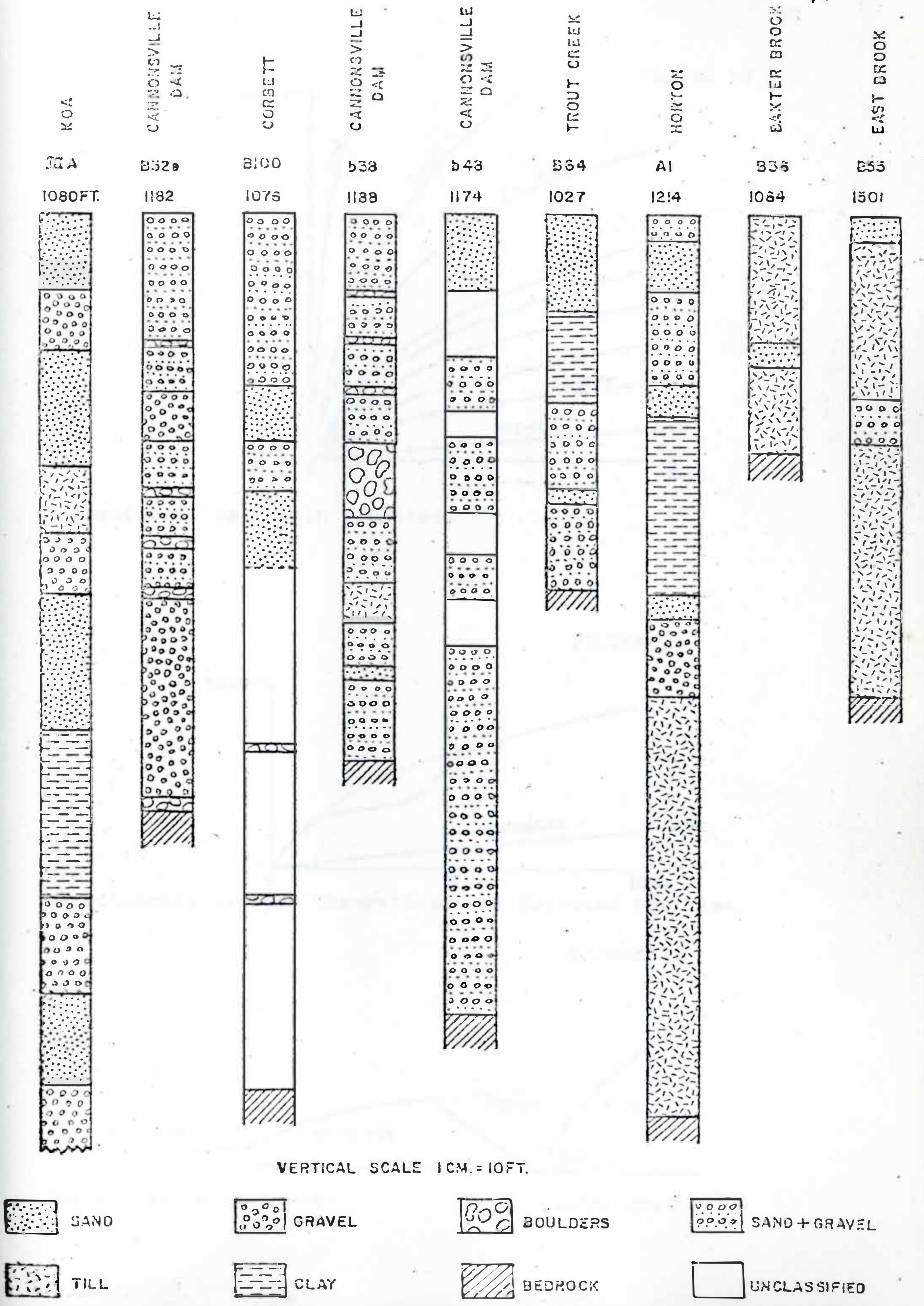
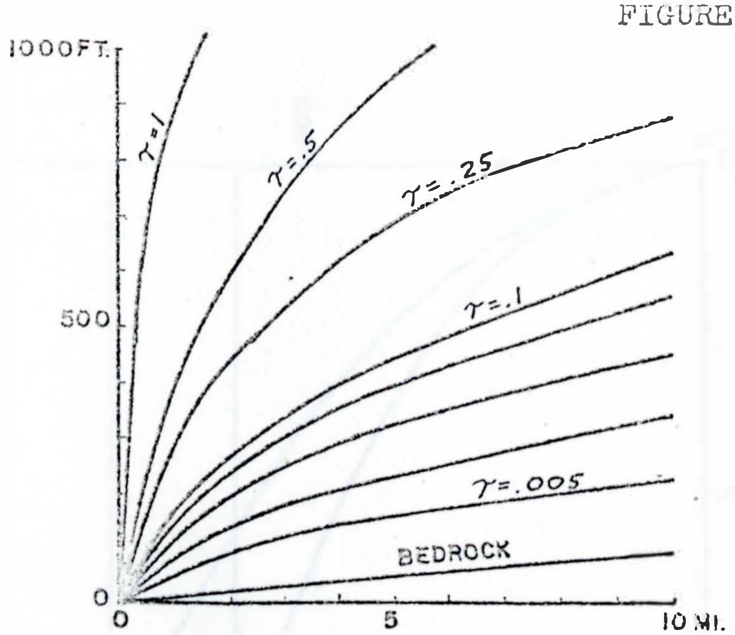
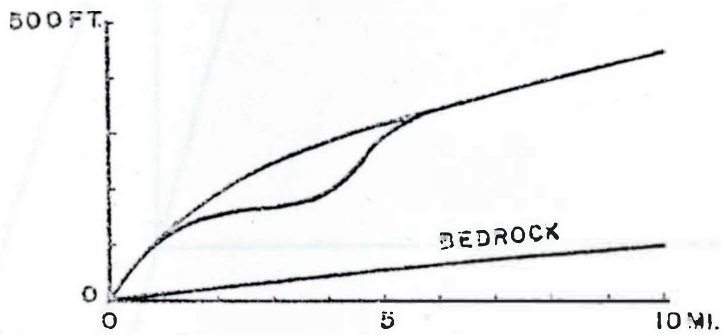

KOA
CANNONSVILLE DAM
CORBETT
CANNONSVILLE DAM
CANNONSVILLE DAM
TROUT CREEK
HORTON
BAXTER BROOK
EAST BROOK
B32a
B100
b38
b43
B64
A1
B36
B55
1080 FT.
1182
1076
1188
1174
1027
1214
1084
1501
VERTICAL SCALE 1 CM. = 10 FT.
SAND
GRAVEL
BOULDERS
SAND + GRAVEL
TILL
CLAY
BEDROCK
UNCLASSIFIED

FIGURE 10



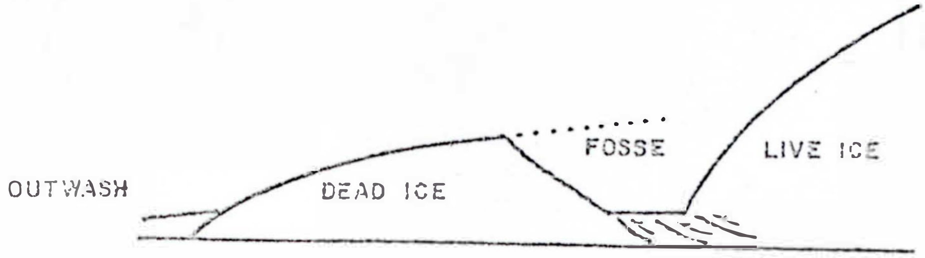
Theoretical Ice Margin Profiles.

FIGURE 11



Relationship between Theoretical and Observed Profiles.

FIGURE 12



Ice Tongue Development.

(AFTER RICH 1943)

FIGURE 13

ICE ZONE FORMATION

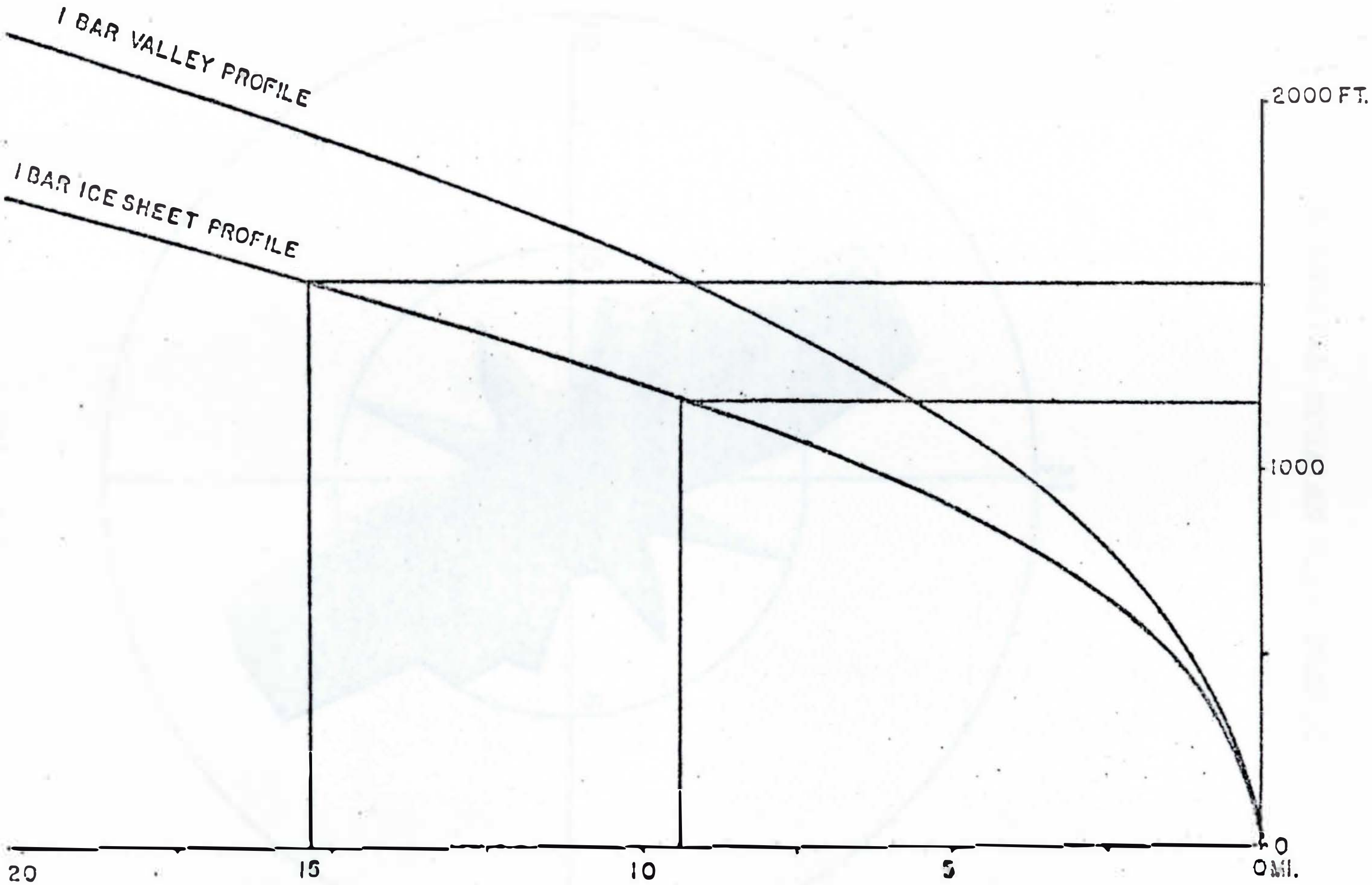
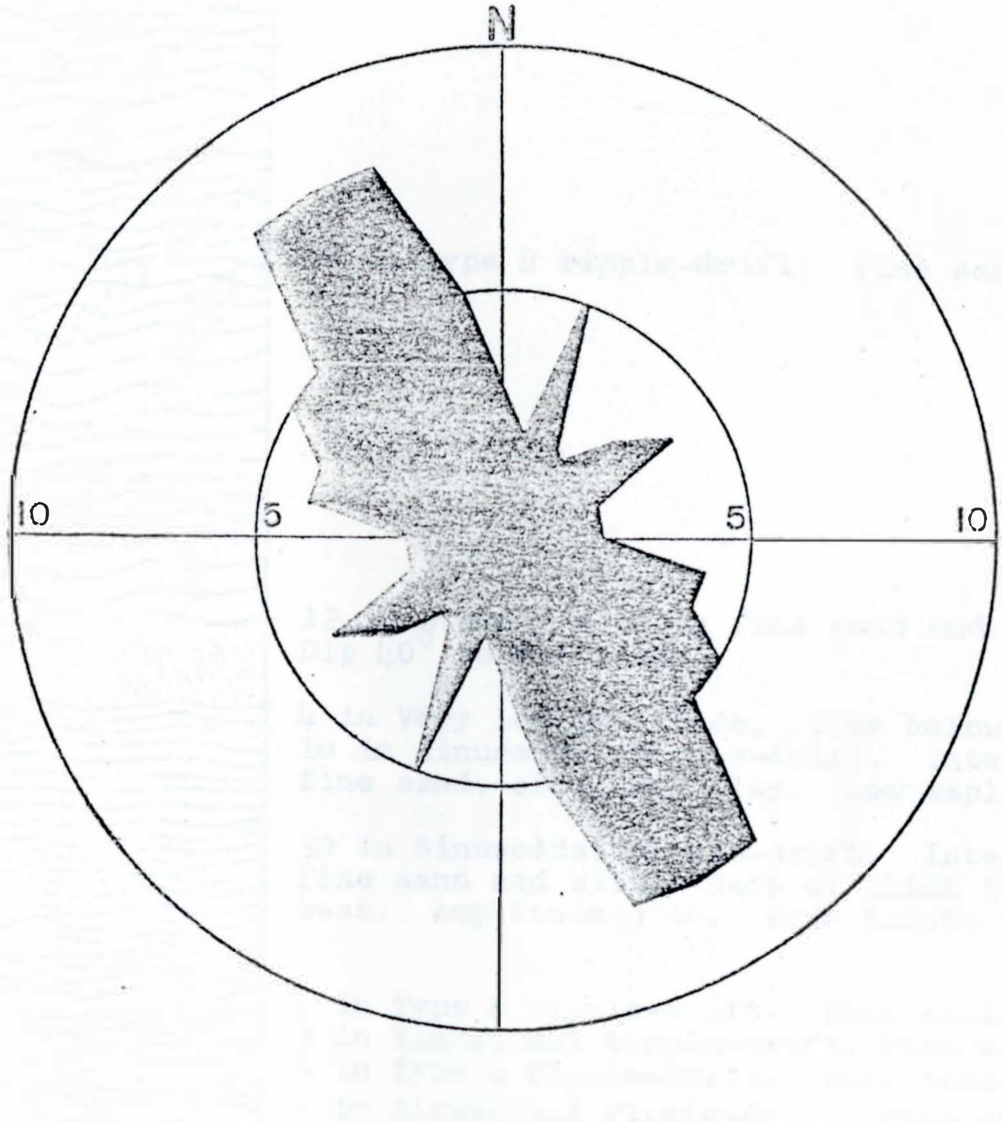


FIGURE 14

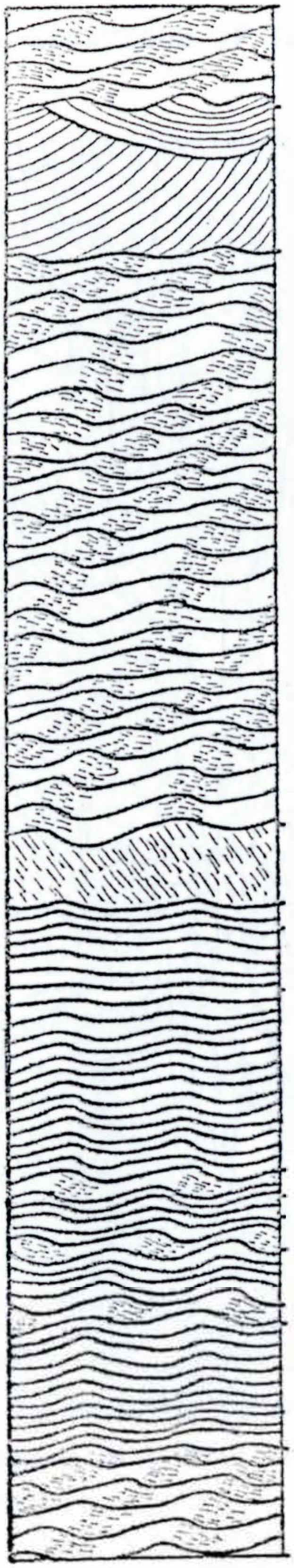
SHINHOPPLE MORAINE TILL FABRIC



N = 75

FIGURE 19

VERTICAL MEASURED SECTION THROUGH RIPPLE-DRIFT, CORBETT PIT



14 in Type B ripple-drift. Fine sand.

22 in Cross-bedding. Fine sand.

96 in Type B ripple-drift. Fine sand.

12 in Steeply dipping fine sand and silt. Dip 40° to the north.

4 in Very low amplitude. Like below but clay.

10 in Sinusoidal ripple-drift. Interbedded fine sand, silt, and clay. Low amplitude.

30 in Sinusoidal ripple-drift. Intergbedded fine sand and silt. Rate of climb 5° to the west. Amplitude 3 in. Wave length 6 in.

4 in Type B ripple-drift. Fine sand.

3 in Sinusoidal ripple-drift. Fine sand, silt.

6 in Type B ripple-drift. Fine sand.

7 in Sinusoidal ripple-drift. Fine sand, silt.

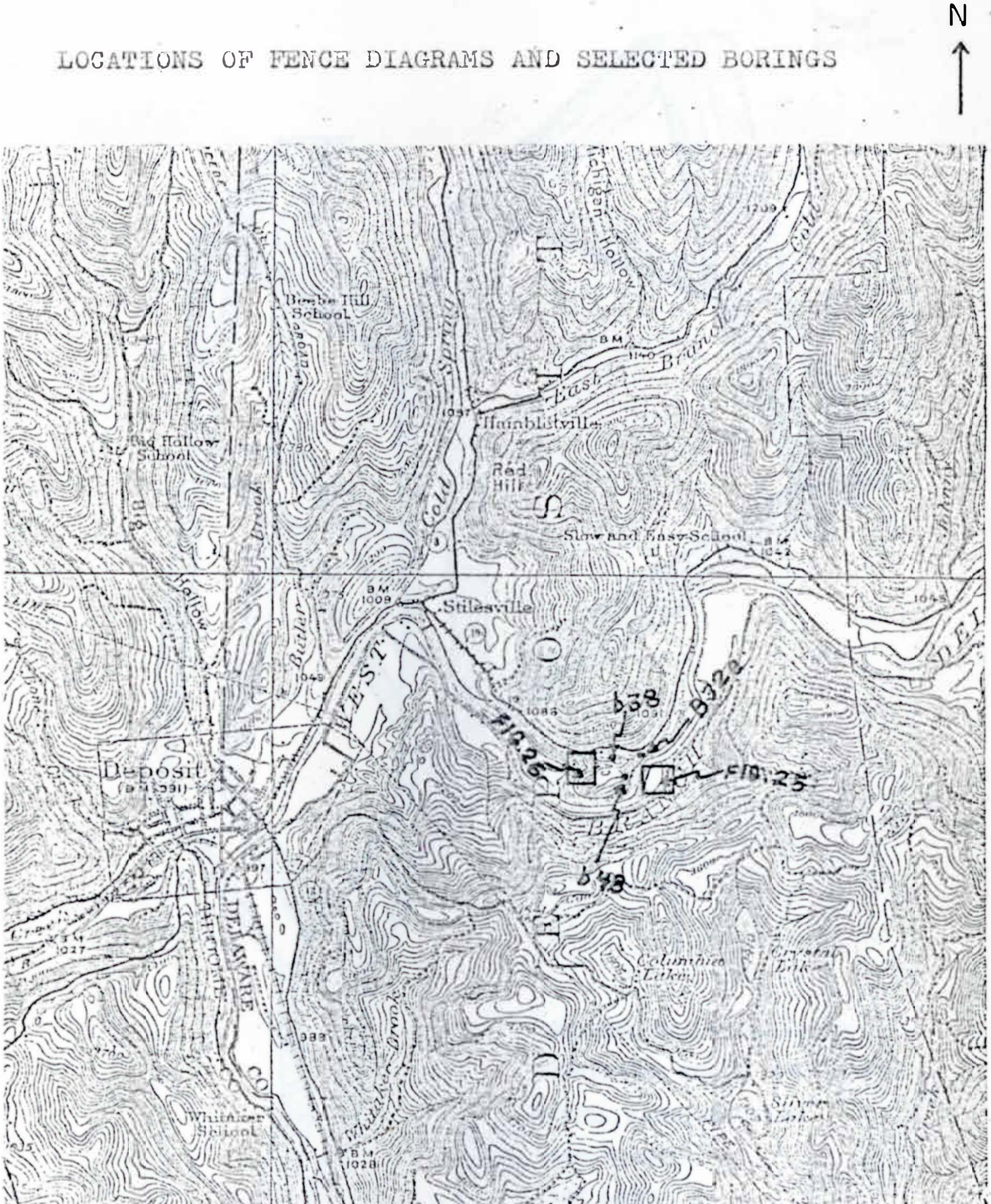
2 in Type B ripple-drift. Fine sand.

22 in Sinusoidal ripple-drift. Interbedded fine sand, silt.

18 in Type B ripple-drift. Fine sand.

FIGURE 24

LOCATIONS OF FENCE DIAGRAMS AND SELECTED BORINGS



Fence diagrams are on Figures 26 and 27. Borings are on Figure 7.

Scale 1 : 62,500

FIGURE 25

FENCE DIAGRAM

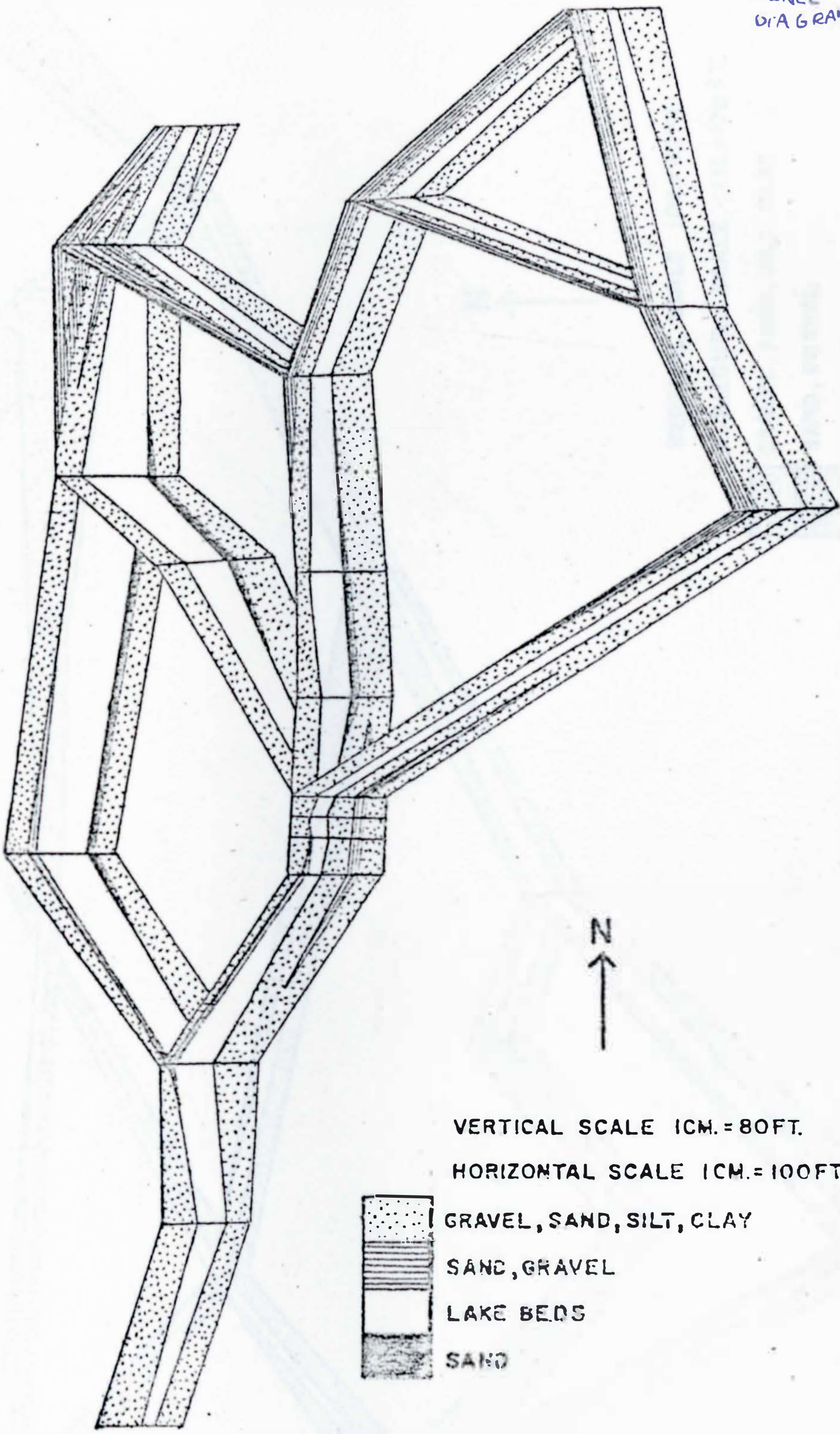


FIGURE 26

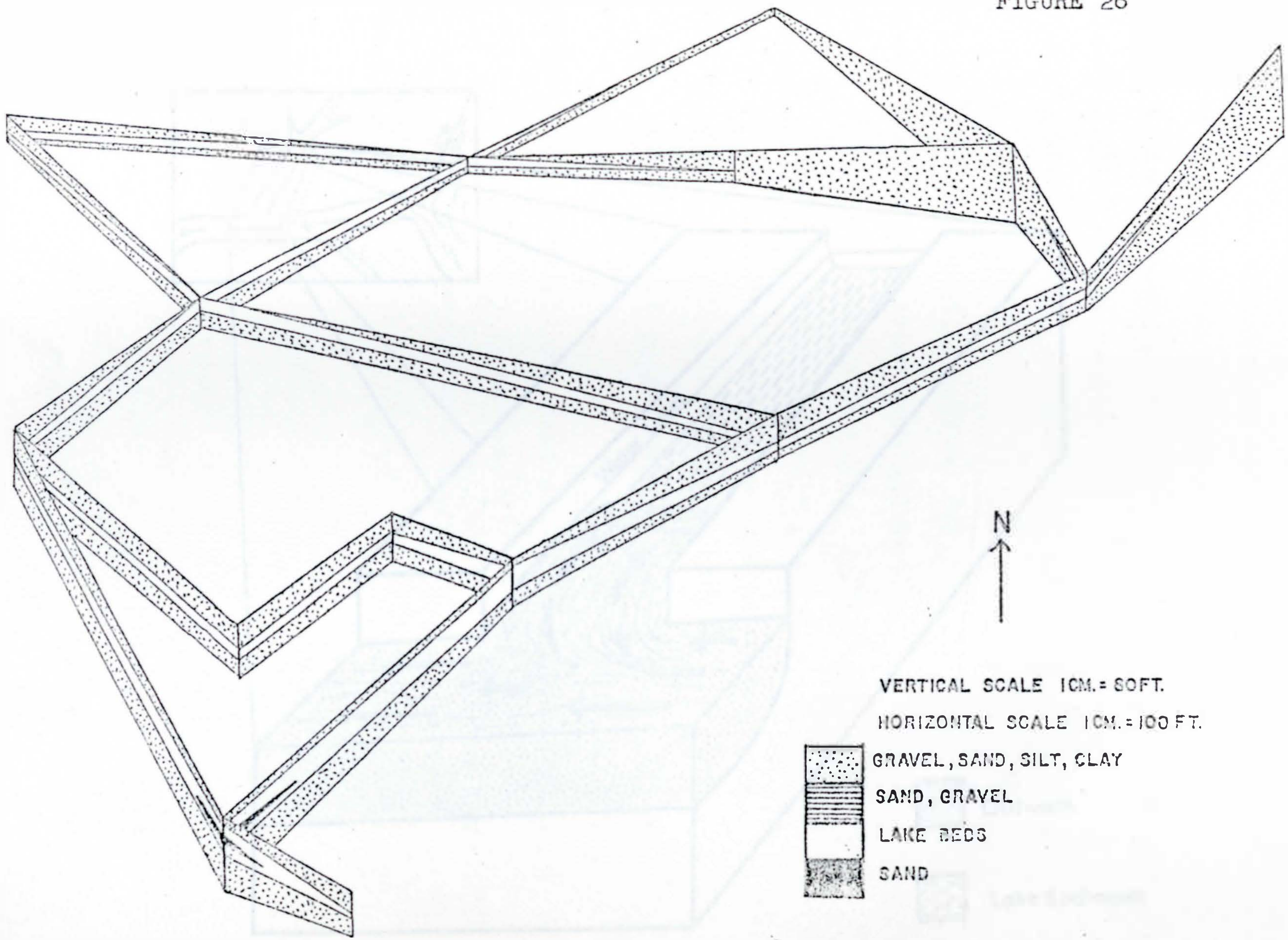

N
VERTICAL SCALE 1CM.= 50FT.
HORIZONTAL SCALE 1CM.= 100 FT.
GRAVEL, SAND, SILT, CLAY
SAND, GRAVEL
LAKE BEDS
SAND

FIGURE 27

TRIBUTARY LAKE DEVELOPMENT BY AGGRADATION IN THE MAIN VALLEY

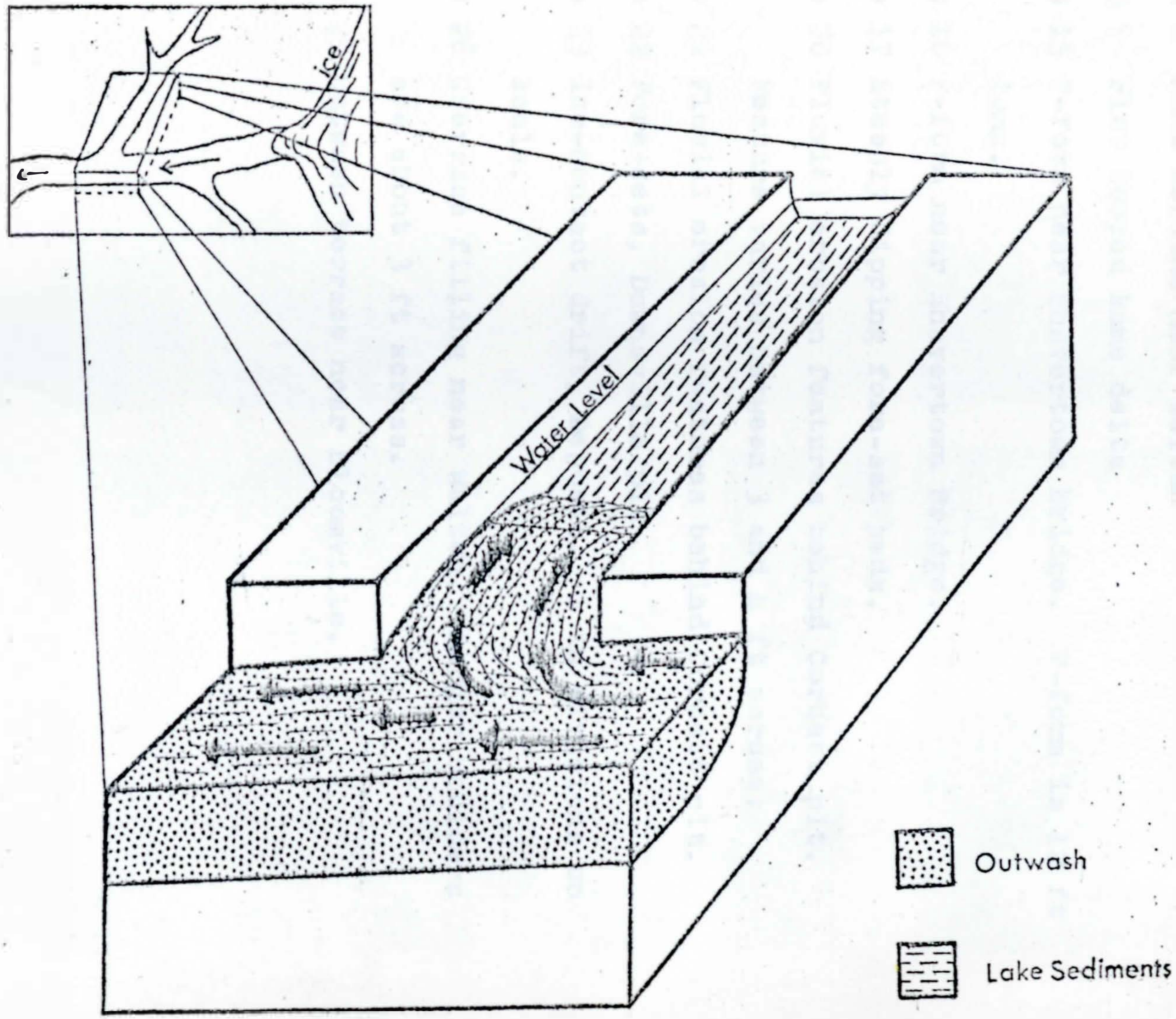


Figure 3 Striae climbing up valley near Margaretville.

Figure 4 Curved striae near Hancock.

Figure 8 Kame moraine near Walton

Figure 9 Flat topped kame delta

Figure 15 P-form near Shavertown Bridge. P-form is 12 ft long.

Figure 16 P-form near Shavertown Bridge.

Figure 17 Steeply dipping fore-set beds.

Figure 20 Fluvial erosion features behind Corbett pit. Feature varies between 3 and 4 ft across.

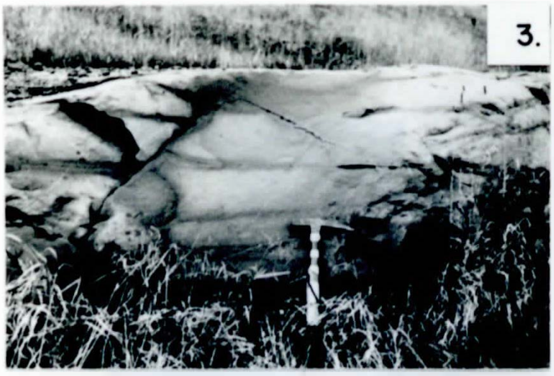
Figure 21 Fluvial erosion features behind Corbett pit.

Figure 22 Fore-sets, Downsville pit

Figure 23 Ice-contact drift, Deposit. 1 in divisions on scale.

Figure 28 Crevasse filling near Walton. Larger boulders are about 3 ft across.

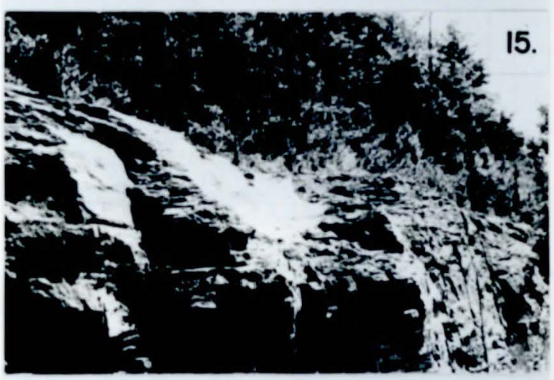
Figure 29 Outwash terrace near Bloomville.


3.


4.


8.


9.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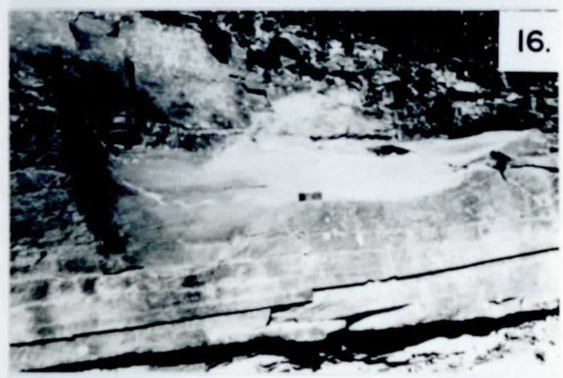
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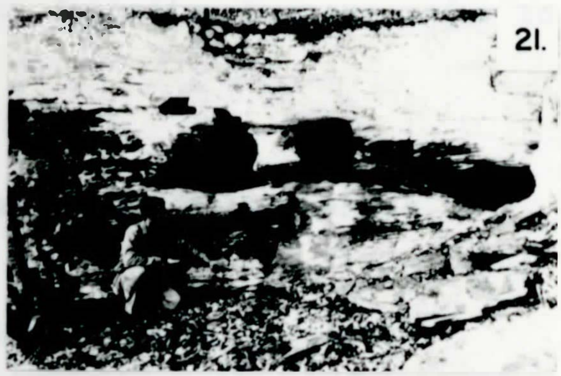
17.


18.


20.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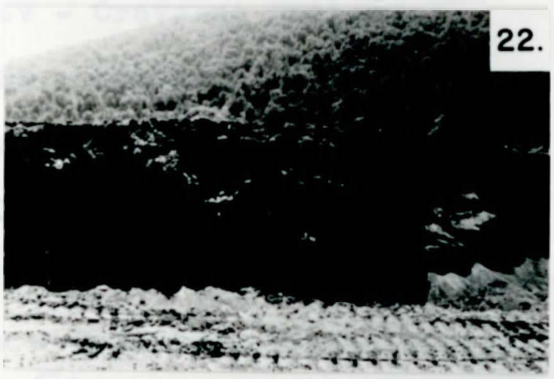
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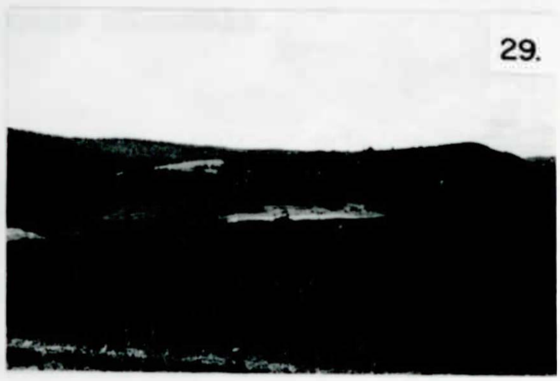
23.


28.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APPENDIX C

Plates

PLATE 1

KEY TO THE RECONNAISSANCE SURFICIAL MAP OF THE WESTERN CATSKILL MOUNTAINS

Key to Mapping Symbols

O (1-16) - Outwash, valley train deposits. Numbers refer to sequences.

K - Undifferentiated kames.

KM (1-16) - Kame moraine. Numbers refer to sequences.

KD - Kame deltas.

KT (1-16) - Kame terrace. Numbers refer to sequences.

CV - Crevasse Filling.

ES - Esker.

S - Mudflow or slump.

TM - Till moraine.

T - Till, includes till knobs. Does not include ground moraine.

u - Undifferentiated outwash and alluvium.

 Proglacial meltwater drainage channels.

 Striae.

 Bedrock sluiceway.

X - Till fabric location.

Key to Locations

15 min. U.S.G.S. Topographic Maps

1a Delhi	1e Walton	1i Long Eddy
1b Hobart	1f Andes	1j Livingston Manor
1c Ninevah	1g Margaretville	1k Neversink
1d Deposit	1h Starrucca	

PLATE Ia


N
0
1
2
3 MI.
ONEONTA
DAVENPORT
KORTRIGHT
MEREDITH
DELHI
BOVINA
STAMFORD
KT15
KT13
KM15
KT14
KM14
KT18
KM-KT17
KT17
O16
O17
O18
KTM
KT
K
U
S

PLATE Ib


N
0
1
2
3 MI.
BLENHEIM
JEFFERSON
HARPERSFIELD
GILBOA
KORTRIGHT
STAMFORD
ROXBURY
BOVINA
MIDDLETOWN
Middle Brook Hill
Maple Hill
Prospect Hill
Potter Hill
Oak Hill
Utsayantha Mt.
Old Clump Hill
West Settlement
Plattekill Mt.
Irish Mt.
Bloomberg Mt.
Gates Roundtop
MOORESVILLE RANGE
SCHOHARIE CO.
DELAWARE CO.
O
K
KM19
O19
KM18
O18
KM-KT18
KT
ES

PLATE Ic


N
0 1 2 3 MI.
A F T O N
Afton
SUSQUEHANNA RIVER
Nineveh Junction
Nineveh
Bettsburg
CHENANGO CO.
BROOME CO.
BOUNDARY LINE
Harpursville
C O L E S V I L L E
W I N D S O R
RIVER

PLATE Id

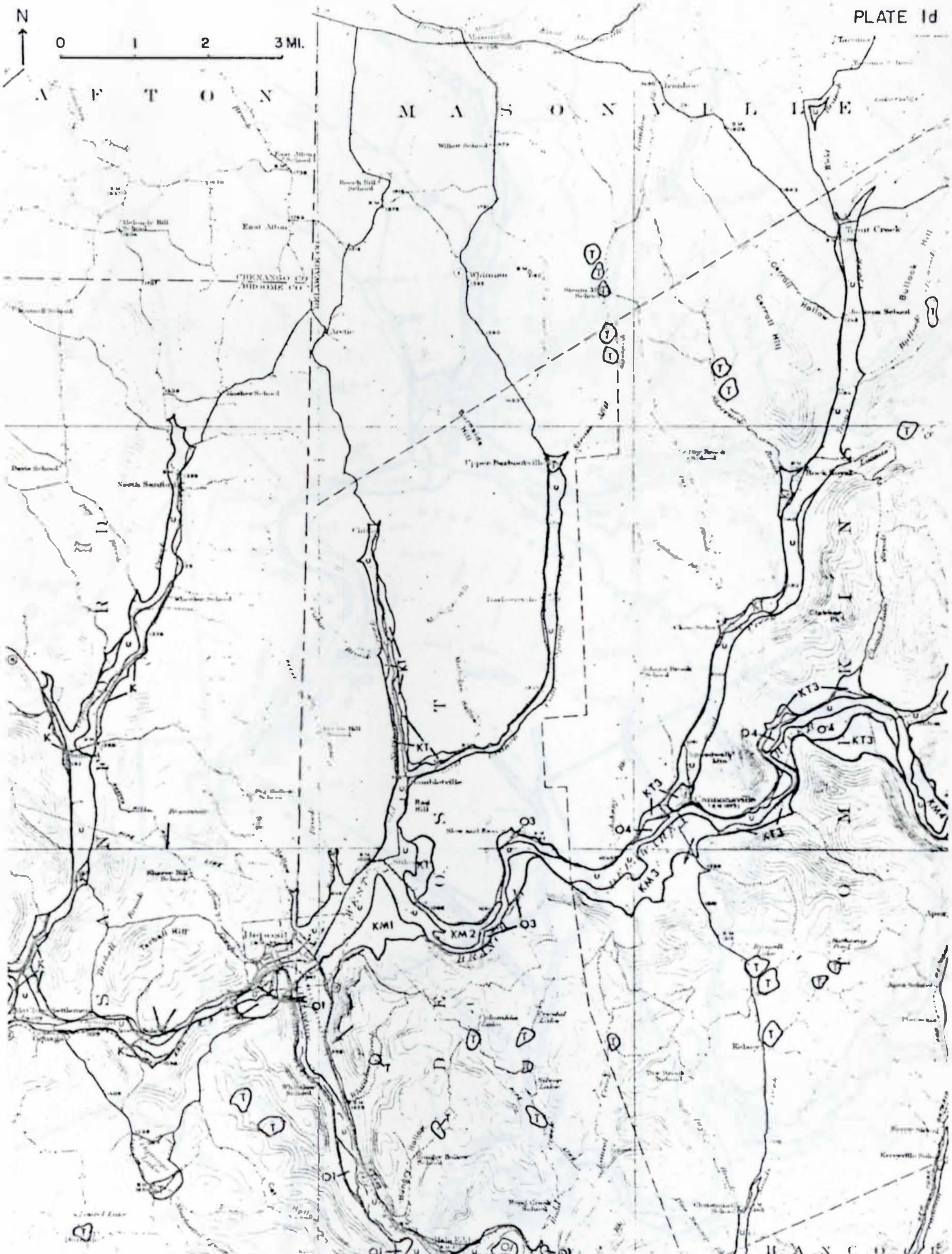
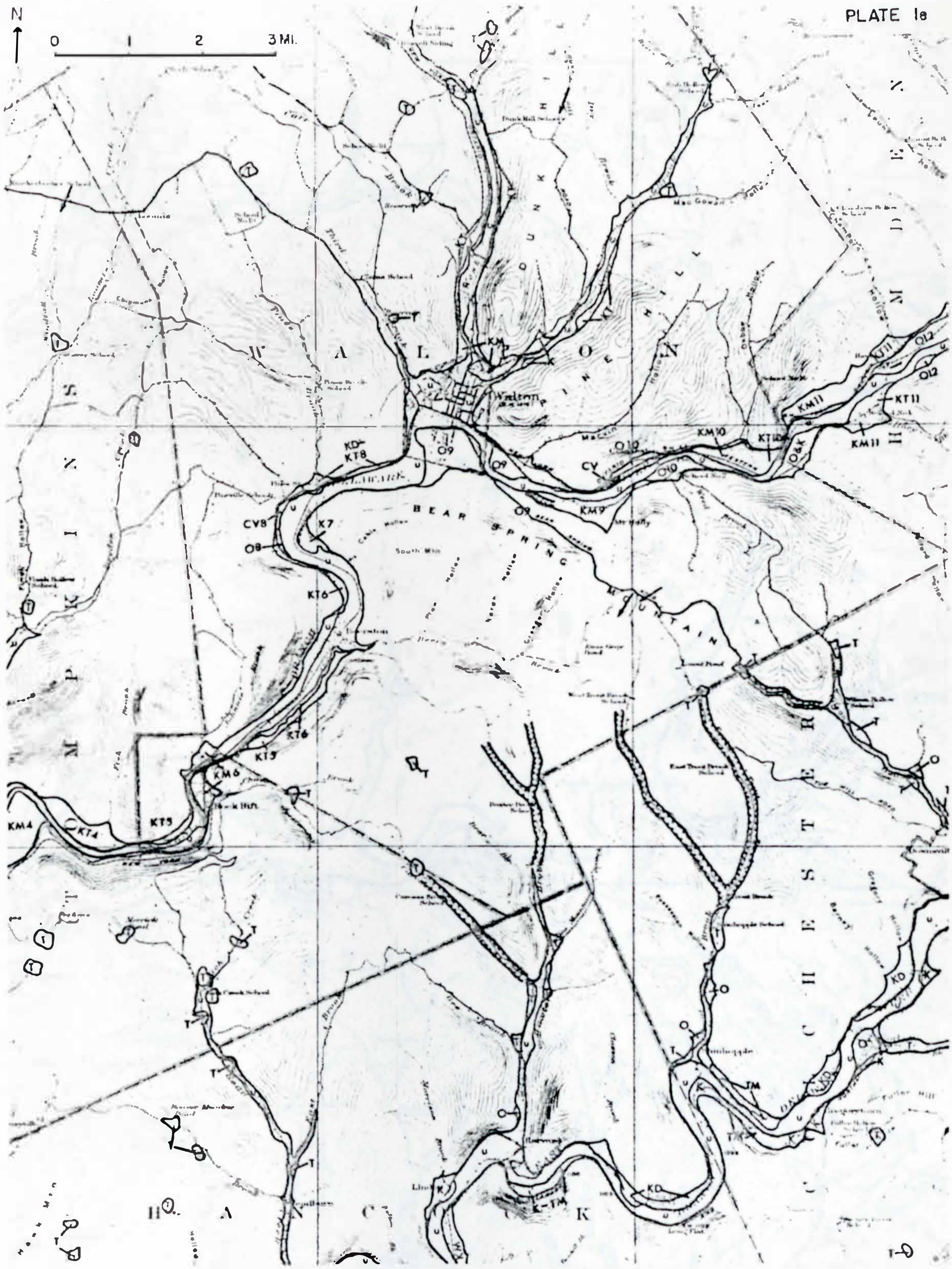

N
0 1 2 3 MI.
AFTON
MASONVILLE
TOMPKINS
DEPOSIT
HANCOCK
Trout Creek
Carroll Hill
Carroll Hollow
Bullock Hill
Whitman
Upper Barbourville
Deposit
KT
KT3
KM1
KM2
KM3
KM4
O1
O3
O4
K
T
U

PLATE 18



N
0
1
2
3 MI.
Walton
BEAR SPRING MOUNTAIN
PINE HILL
DUNK HILL
South Mtn
KM4
KT4
KT5
KM6
KT5
KT6
K7
CV8
O8
KD
KT8
O9
KM9
CY
O10
KM10
KT10
O&K
KM11
KT11
O12
KO
K-TM
TM

PLATE II

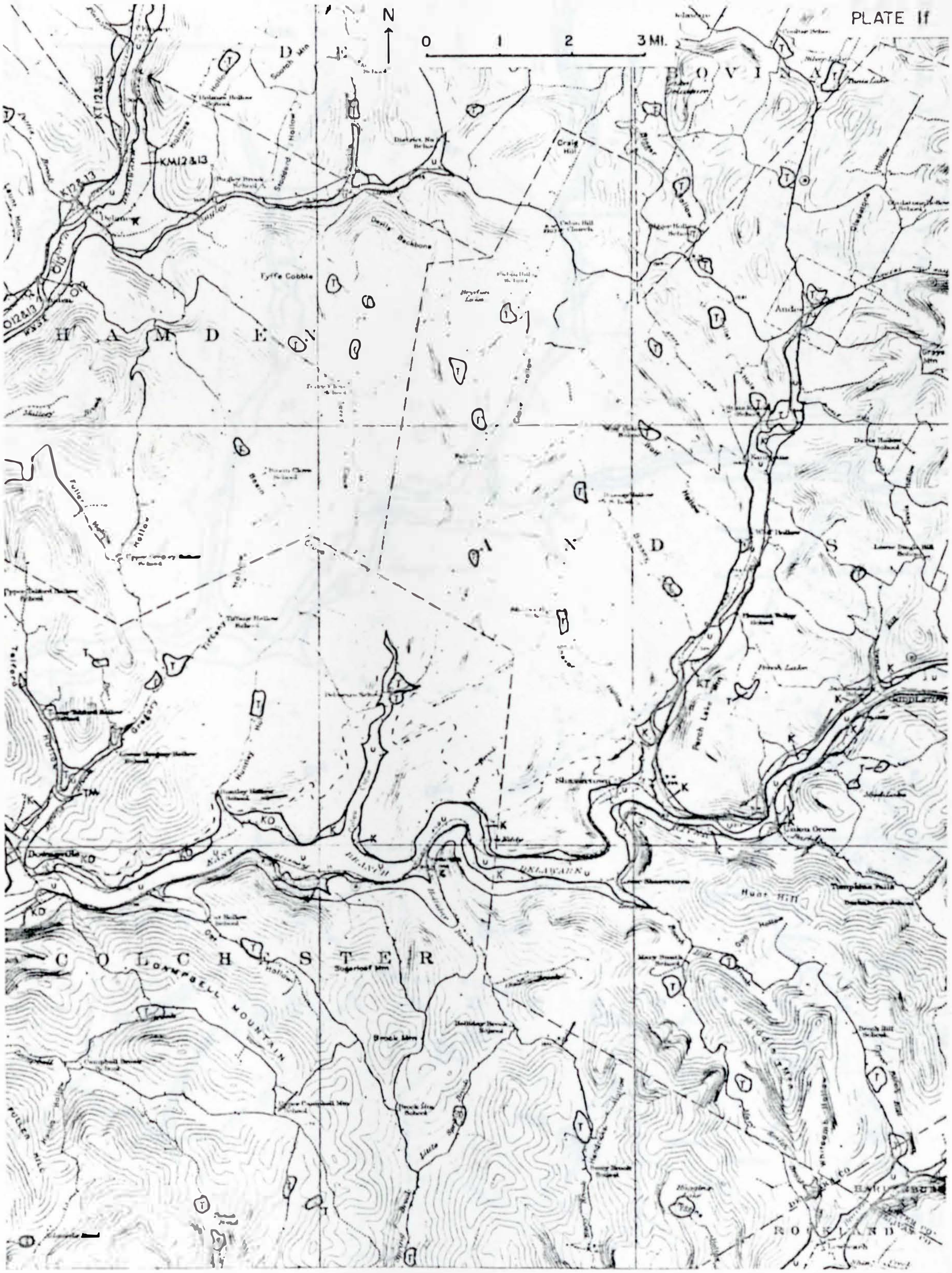

N
0 1 2 3 MI.
HAMDEN
ANDES
BOVINA
COLCHESTER
ROCKLAND
CAMPBELL MOUNTAIN
Fyffe Cobble
Devils Backbone
Craig Hill
Perch Lake
Huer Hill
Middle Mtn
Sugarloaf Mtn
Brock Mtn
FULLER HILL
Telford
Downsville
Shavertown
EAST BRANCH
DELAWARE
KT 12&13
KM12&13
O12&13

PLATE Ig

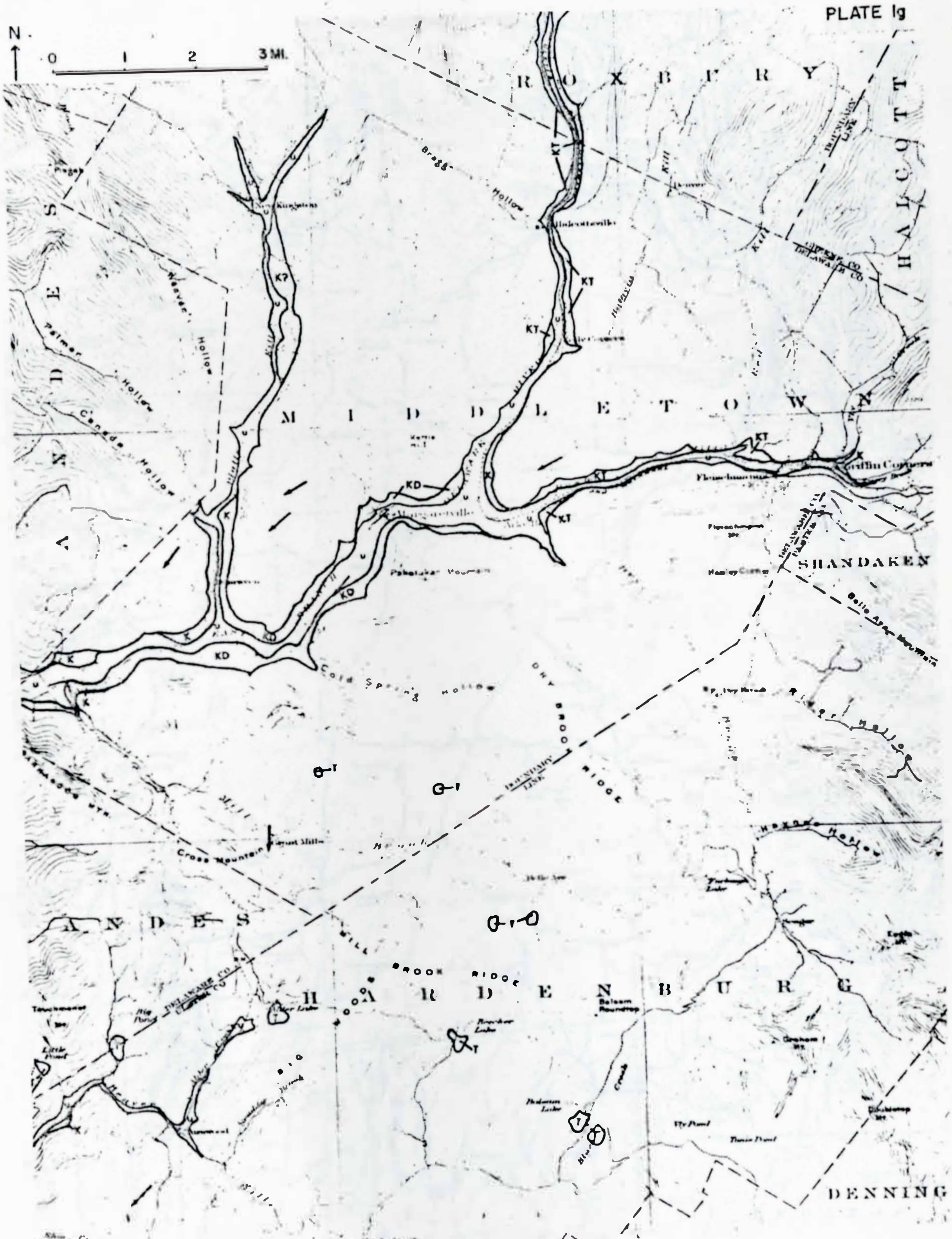

N.
0 1 2 3 MI.
ROXBURY
HALCOTT
MIDDLETOWN
SHANDAKEN
ANDES
HARDENBURG
DENNING
Bragg Hollow
Weaver Hollow
Palmer Hollow
Canada Hollow
Cold Spring Hollow
DRY BROOK RIDGE
MILL BROOK RIDGE
Cross Mountain
Pakatakan Mountain
Belle Ayr Mountain
Margaretville
Fleischmanns
Griffin Corners
New Kingston
Balsam Roundtop
Graham Mt.
Doubletop Mt.
Tunis Pond
Fly Pond
Balsam Lake
Beecher Lake
Kettle Hill
Hazel Hollow
Ridge Hollow
Turner Lake
Big Pond
Little Pond
Touchmenot
Dry Brook
Delaware Co.
Greene Co.
Ulster Co.
KT
KD
K
U

PLATE Ih

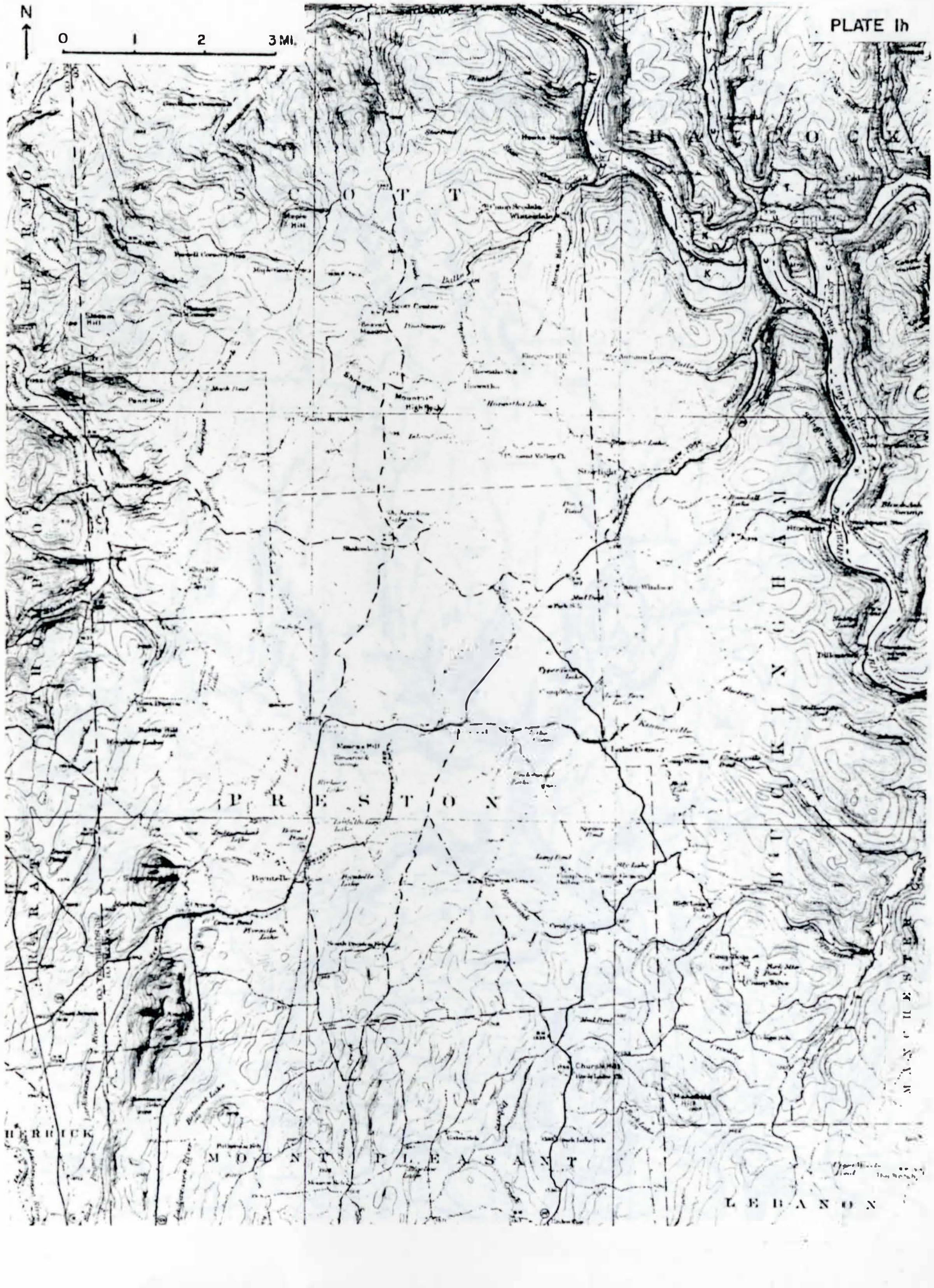

N
0
1
2
3 MI.
S C O T T
H A N C O C K
P R E S T O N
M O U N T P L E A S A N T
L E B A N O N
HERRICK
Starlight
Preston Lake
Hiawatha Lake
Church Hill

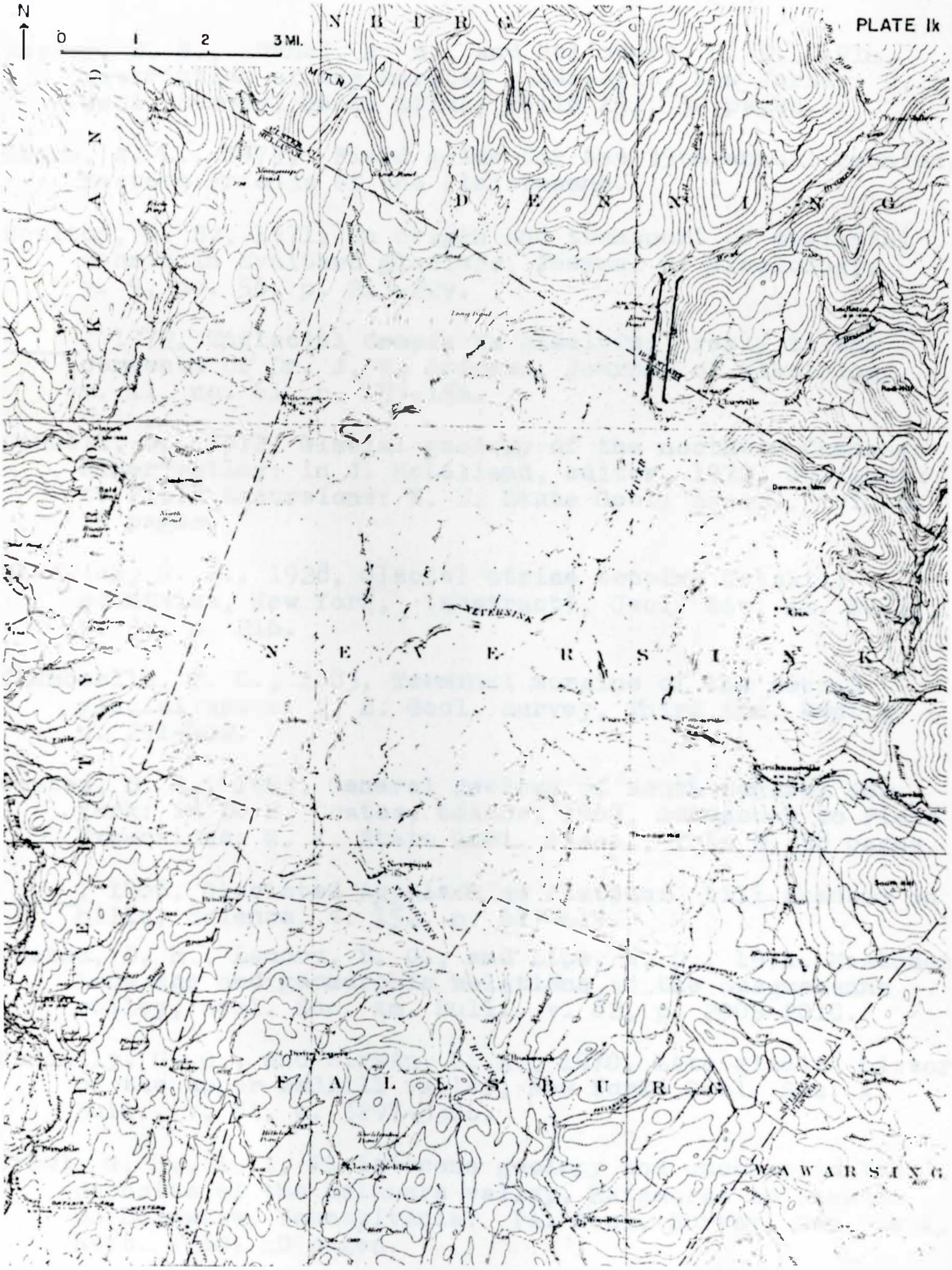
PLATE Ii

N
0
1
2
3 MI.
Johnny Ridge
Bouchoux Hill
Cherry Ridge
FREMONT
MANCHESTER
DELAWARE
DAMASCUS
LEBANON

PLATE Ij


N
0 1 2 3 MI.
COLCHESTER
ROCKLAND
FREMONT
CALLICOON
LIBERTY
DELAWARE
BETHEL
BURNT HILL
RATTLE HILL
Gray Hill
Round Top
Grants Hill
Parkston
Parksville
Youngsville
Jeffersonville
Rose Hill
Elm Hollow
Benton Hollow

PLATE Ix


N
0
1
2
3 MI.
D E N N I N G
N E V E R S I N K
F A L L S B U R G
WAWARSING
NEVERSINK

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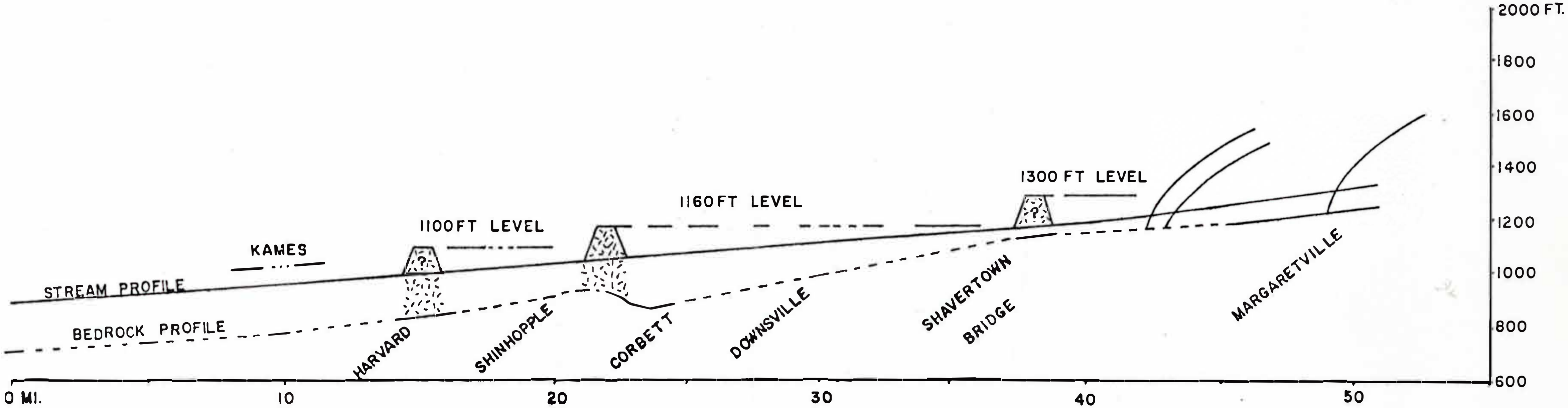
STRIATION MAP

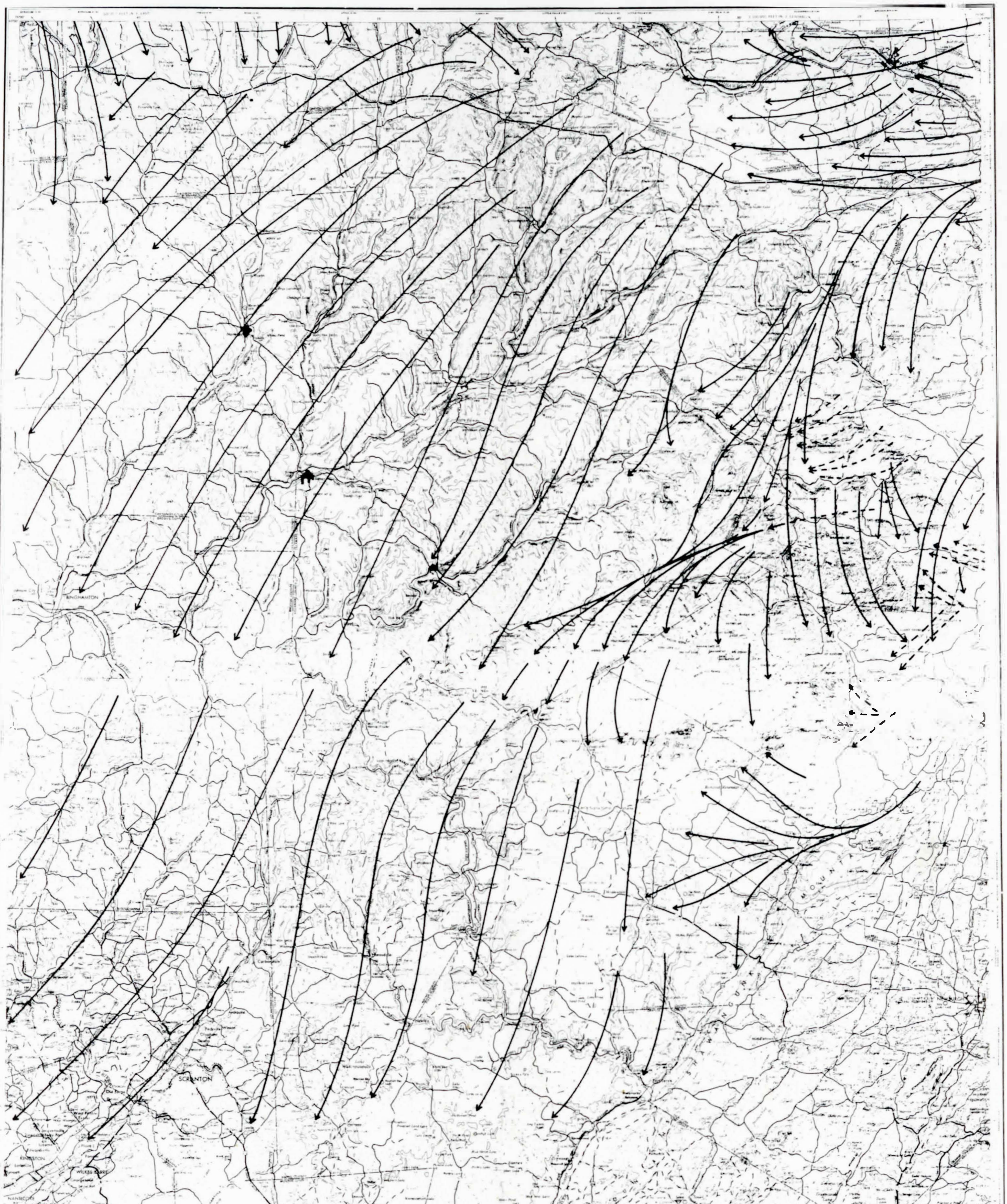
EAST BRANCH DELAWARE RIVER

PLATE 4



REGIONAL ICE MOVEMENT DIRECTIONS

PLATE 3



0 10 20 MI.

N

WEST BRANCH DELAWARE RIVER

PLATE 5

GLACIER PROFILES