SURFICIAL GEOLOGY OF THE MOUNT TOM QUADRANGLE, MASSACHUSETTS

by

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72-219

U.S. Geological Survey

OPEN FILE REPORT

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards or nomenclature.

1972

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Abstract

Movement of the last ice sheet in the Mount Tom quadrangle was due south during time of major advance as indicated by striations, drumlins, and indicator stones. Erratics of the Belchertown Tonalite, derived from the northeast portion of the Easthampton quadrangle, have been carried southward a distance of at least 16 miles. The presence of tonalite boulders on the summit of Mount Tom, elevation 1,205 feet, testifies to uplift of erratics through a vertical distance of 1,000 feet.

Three tills are recognized on the basis of color, grain-size parameters, and location: (1) a reddish-brown sandy till occurs west of the Holyoke Basalt ridge, (2) a brown silty till lies east of the basalt ridge, and (3) a grayish-brown till with intermediate grain size occurs in the Easthampton quadrangle and the north-central portion of the Mount Tom quadrangle. The three tills are the same age and are equivalent to the upper till of southern New England.

During deglaciation, readvance occurred from the northeast over a minimum distance of 3.5 miles in the southeast portion of the quadrangle. Evidence for readvance consists of: (1) till over stratified drift, (2) southwest-oriented till fabrics on south-trending drumlins, (3) west-southwest-trending striations cutting south-trending striations, (4) southwest-oriented glaciotectonic structures, and (5) data from borings.

West of the basalt ridge, northward retreat of an active ice margin was punctuated by four stillstands, during which outwash deltas were deposited in proglacial lakes. From oldest to youngest the deposits associated with the four stillstands are named: (1) Paper Mills delta, (2) Barnes delta, (3) Pomeroy Street delta, and (4) White Brook delta. East of the basalt ridge a series of small ice-contact deltas were deposited in high proglacial Lake Hitchcock, which expanded northward with the retreating ice margin. Deposition culminated along the upper east margin of the quadrangle with the formation of a large ice-contact delta named the Holyoke delta.

Continued northward retreat of the ice margin both east and west of the basalt ridge permitted water of Lake Hitchcock to extend through the Holyoke Narrows and into the valleys of the Manhan River and Broad Brook in the north-central portion of the Mount Tom quadrangle. Drainage of Lake Hitchcock 10,700 years ago (Flint, 1956) initiated rapid downcutting by streams, as shown by numerous stream terraces along the Connecticut, Westfield, and Manhan Rivers, and along lesser tributaries.

Introduction

The geology of the Mount Tom area was first published in 1898 as a part of the Holyoke Folio of the Geologic Atlas of the United States. The work was done by Benjamin Kendall Emerson, Professor of Geology at Amherst College from 1872 to 1917. Emerson's 790-page "The Geology of Old Hampshire County" was published as Monograph 29 by the U. S. Geological Survey in the same year. It is interesting to note that the Holyoke sheet covers approximately 910 square miles, the equivalent of over 16 7 1/2-minute quadrangles.

This study is part of a cooperative program of the U. S. Geological Survey and the Massachusetts Department of Public Works to map the surficial and bedrock geology of Massachusetts on the scale of 1:24,000. Quadrangles adjacent to the Mount Tom quadrangle on the south have been published. From east to west they are: (1) the Springfield South quadrangle (Hartshorn and Koteff, 1967a), (2) the West Springfield quadrangle (Colton and Hartshorn, 1971), and (3) the Southwick quadrangle (Schnabel, 1971). The Woronoco quadrangle to the west currently is being mapped by Charles Warren.

The primary purposes of this study were to: (1) map the unconsolidated glacial sediments, (2) develop a stratigraphic column, (3) determine the late Pleistocene history of the Mount Tom area as revealed by the stratigraphic column, and (4) determine the direction of glacial movement through the study of directional features. A significant part of this study was to determine the nature of glacial sediments in the lowland west of the Holyoke Basalt ridge and to relate them to the history of deglaciation of the Connecticut Valley. A secondary purpose was to map the bedrock exposures of the Mount Tom quadrangle in order to produce a preliminary bedrock map.

The geology of the Mount Tom quadrangle was mapped during a total of 44 weeks during 1968 and 1969. The U. S. Geological Survey 7 1/2-minute topographic sheet of the Mount Tom quadrangle was used as a base map. The geology of the area was determined by the study of over 900 natural and man-made exposures.

Acknowledgements

This study was made possible by financial support from the U. S. Geological Survey and the Massachusetts Department of Public Works. A faculty grant to the author from Norwich University helped defray photographic expenses. Computer time was made available through a grant from the University of Massachusetts Research Computing Center.

Special thanks are extended to my advisor, Dr. Joseph H. Hartshorn, Chairman, Department of Geology, University of Massachusetts. He suggested the study and contributed many ideas about the glacial history of the Connecticut Valley that are included here as my own. Dr. Hartshorn read several drafts of the paper and it was improved through his constructive criticism. The paper was also read by Dr. H. T. U. Smith and Dr. G. W. Webb, both of the University of Massachusetts.

John C. Mullen provided valuable field and laboratory assistance and I am grateful for his help. Eugene G. Rhodes wrote the computer program by which grain-size parameters were determined. Homer E. Smith and Harald Krauth of the Norwich University Photography Department printed the photographs and reduced the line drawings. Mrs. Wendell Dole, Norwich University, typed several drafts of the manuscript.

Fellow graduate students at the University of Massachusetts and several colleagues with the U.S. Geological Survey contributed through discussions in the field or office.

Many people in and around the Mount Tom quadrangle helped by contributing information, by giving permission to trespass on their land, and even by helping to dig.

Lastly, my wife Maureen proofread the final copy, and most important, kept the home fires burning.

Geographic description

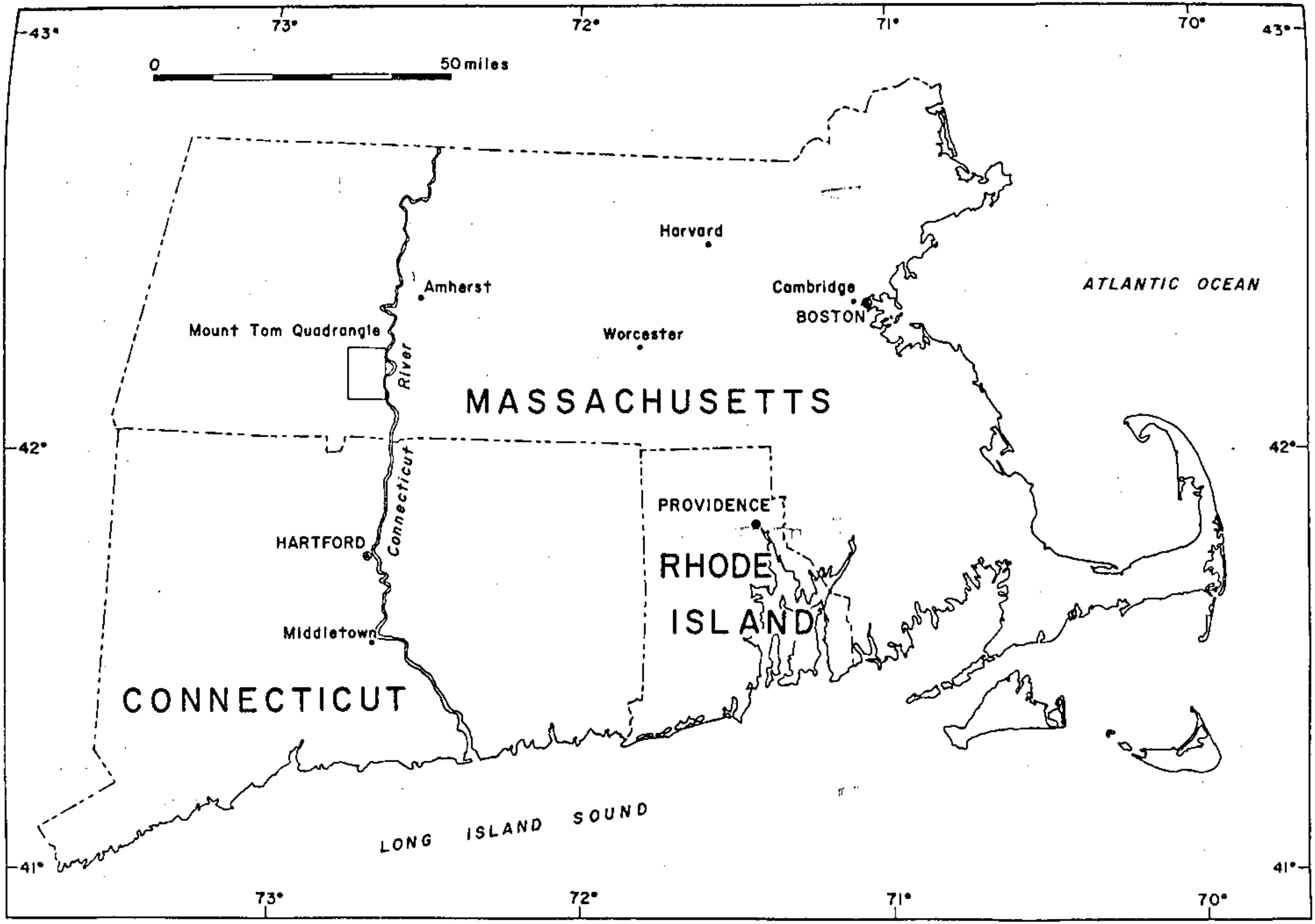
The Mount Tom quadrangle is situated in southwestern Massachusetts on the west side of the Connecticut River valley, known locally as Pioneer Valley (fig. 1). It includes portions of the towns of Easthampton and Southampton in Hampshire County and portions of the town of West Springfield and the cities of Holyoke and Westfield in Hampden County.

The quadrangle includes two densely populated areas: the western one-third of the City of Holyoke (1970 pop. 50,112) and the northeastern one-quarter of the City of Westfield (1970 pop. 31,433). The rural village of Southampton is located in the northwest. The rest of the quadrangle is covered by farmland, wooded uplands, and expanding suburban areas.

The map area is easily accessible as no point in the quadrangle lies more than 0.66 of a mile from a secondary road. The east-west Massachusetts Turnpike crosses the southern portion of the quadrangle, and the north-south Interstate Highway I-91 is located along the eastern edge of the map.

No official U. S. Weather Bureau stations are located within the Mount Tom quadrangle; however, there are stations at Amherst, Holyoke, Knightville Dam, Springfield, Westfield, and Westover Field. The nearest station with a complete temperature and precipitation record is at the former site of the Springfield Armory located 2.5 miles southeast of the

Figure 1. Location of the Mount Tom quadrangle in relation to the southern New England states.



43°
73°
72°
71°
70°
43°
0
50 miles
Harvard
Amherst
Cambridge
BOSTON
ATLANTIC OCEAN
Mount Tom Quadrangle
Worcester
River
MASSACHUSETTS
42°
42°
Connecticut
PROVIDENCE
HARTFORD
RHODE
ISLAND
Middletown
CONNECTICUT
LONG ISLAND SOUND
41°
41°
73°
72°
71°
70°

Figure 1

southeast corner of the Mount Tom quadrangle. The record there, one of the longest in Massachusetts and the nation, goes back to 1848. A climatological summary for the Springfield station (Lautzenheiser, 1969), based on the period 1931 to 1960 by international agreement, shows:

(1) total mean annual precipitation - 46.62 inches

(2) mean January temperature - 28.5°F.

(3) mean July temperature - 74.0°F.

(4) length of growing season - 177 days

The climate is characterized by pleasant summers, moderately cold winters, and ample rainfall (Lautzenheiser, 1969).

Physical features

Topography

Most of the 55 square miles of the Mount Tom quadrangle lie in the Connecticut Valley Lowland section of the New England physiographic province (Fenneman, 1938) (fig. 2). A steeply sloping area in the northwest corner of the quadrangle, comprising only 0.23 of a square mile, lies in the New England Upland section of the province. Williamsburg Granodiorite of Carboniferous age (Willard, 1956) underlies this small area, which is characterized by rugged terrain.

The Connecticut Valley Lowland portion of the quadrangle is underlain by igneous and sedimentary rocks of Triassic age. This area is split into two smaller lowlands by a hogback held

Figure 2. Topography and physiographic subdivisions of the Mount Tom and adjacent quadrangles. For complete drainage pattern and quadrangle names see Figure 3. (Physiographic subdivisions after Fenneman, 1938; topography from U. S. Geol. Survey 1:24,000 quadrangle maps.)

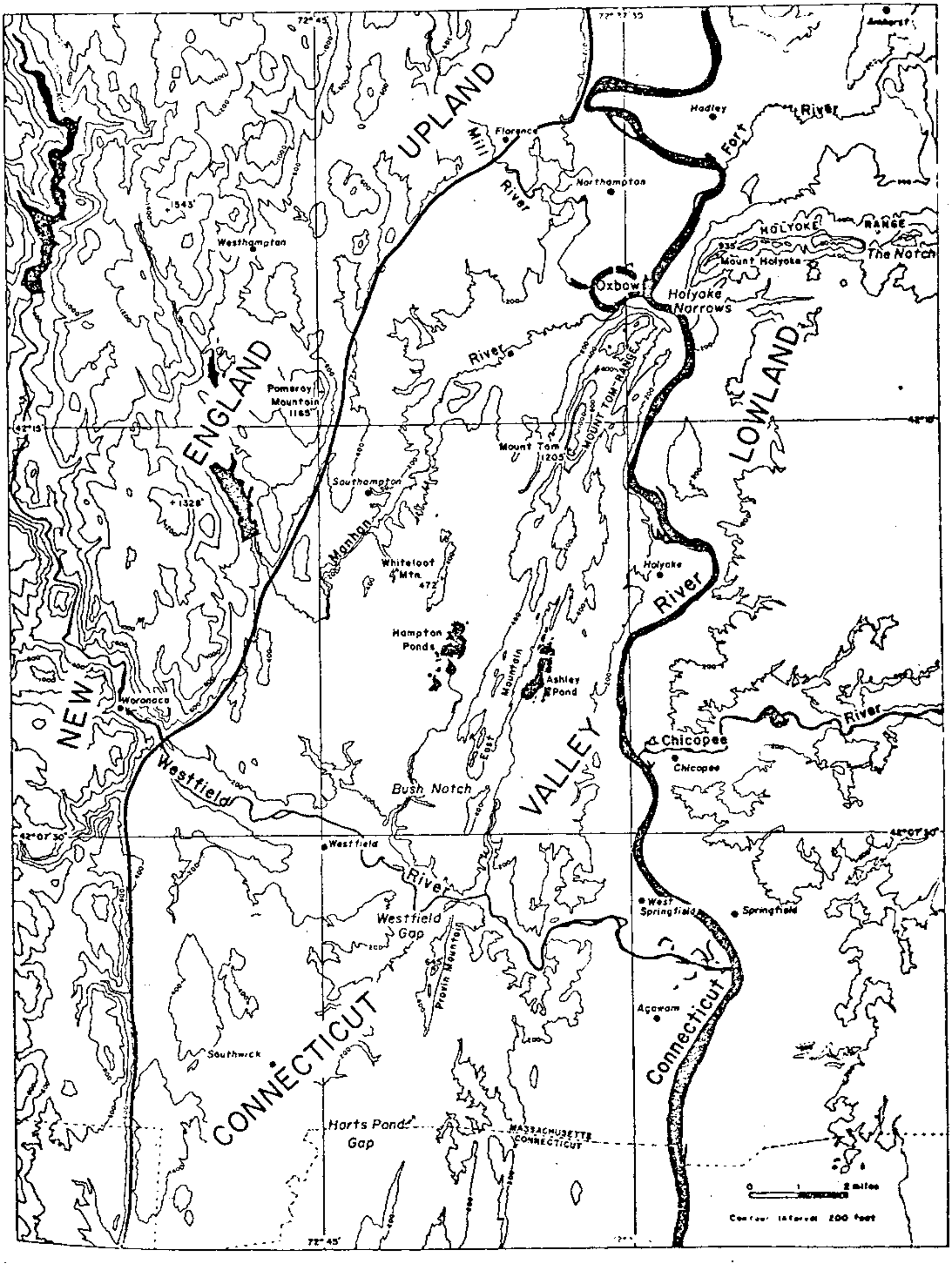

NEW ENGLAND UPLAND
CONNECTICUT VALLEY LOWLAND
Amherst
Hadley
Fort River
Florence
Mill River
Northampton
Westhampton
HOLYOKE RANGE
Mount Holyoke
The Notch
Oxbow
Holyoke Narrows
Pomeroy Mountain 1165
Mount Tom 1205
MOUNT TOM RANGE
Southampton
Manhan River
Whiteloot Mtn. 472
Holyoke
Connecticut River
Hampton Ponds
Ashley Pond
East Mountain
Woronoco
Westfield River
Bush Notch
Chicopee
Chicopee River
Westfield
Westfield Gap
Provin Mountain
West Springfield
Springfield
Agawam
Southwick
Harts Pond Gap
MASSACHUSETTS
CONNECTICUT
Contour interval 200 feet

Figure 2

up by the resistant Holyoke Basalt, which trends north-northeast through the eastern portion of the quadrangle. The bedrock in the western lowland is the Sugarloaf Formation, while the eastern lowland is underlain from west to east by the East Berlin Formation, the Hampden Basalt, and the Portland Arkose. The bedrock in both lowlands is overlain by till, outwash sands and gravels, and by glacial lake sediments. The lowland on the west is characterized by smooth outwash and lacustrine plains, interrupted by north-south trending ridges of Sugarloaf Formation such as at Whiteloaf and Little Mountains. The lowland on the east consists of molded topography which displays a marked north-south parallelism, and which has been buried by younger outwash and lacustrine sediments. Crafts Hill, Bradley Mountain, and Prospect Hill are good examples of streamlined, molded topography or drumlins.

The highest elevation in the quadrangle, approximately 1205 feet, is on the summit of Mount Tom, which is situated in the northeast corner of the quadrangle. Mount Tom also represents the highest elevation anywhere on the Holyoke Basalt Ridge in Massachusetts. The lowest elevation, about 45 feet above sea level, occurs where the Connecticut River leaves the map area just north of the southeast corner of the quadrangle.

Drainage

All surface drainage in the Mount Tom quadrangle ultimately passes to the Connecticut River, which flows into Long Island Sound 62 miles to the south. The drainage system is poorly integrated, as indicated by numerous swamps, ponds, and indirect stream paths. The lack of a well-developed drainage system is the result of continental glaciation.

The Mount Tom quadrangle lies between the Connecticut River, which flows from north to south along the eastern margin of the quadrangle, and the Westfield River, which crosses the southwest corner of the quadrangle (fig. 3). The Westfield River, flowing to the southeast, is a major tributary of the Connecticut River. Excellent examples of water gaps are found where these two streams cross the Holyoke Basalt ridge. The Connecticut crosses the basalt at the Holyoke Narrows 2.5 miles northeast of the Mount Tom quadrangle, while the Westfield crosses the ridge 1.3 miles south of the quadrangle (fig. 2). In each case, the water gap represents the preglacial course of the river presently occupying the water gap. This problem will be discussed later in this paper.

Streams in the southeastern one-ninth of the Mount Tom quadrangle display a marked control by streamlined topography. A stream will run north or south between two streamlined hills or drumlins and then turn eastward toward the Connecticut around the end of a drumlin. If another drumlin lies in its

Figure 3. Drainage map of the Mount Tom and adjacent quadrangles. Quadrangle name in upper left corner of each ninth. (Drainage from U. S. Geol. Survey 1:24,000 quadrangle maps.)

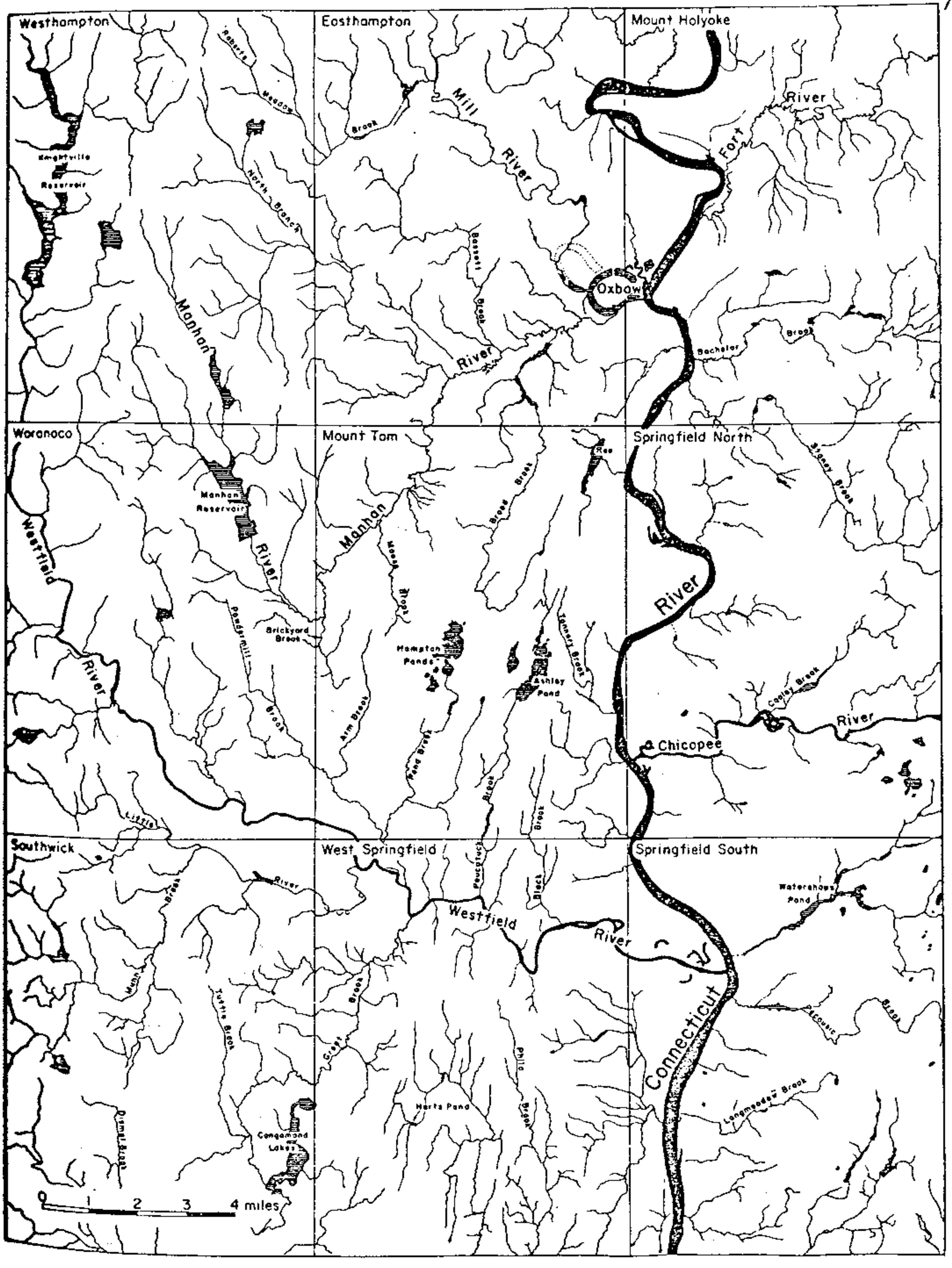

Westhampton
Easthampton
Mount Holyoke
Mill
River
Fort
River
Knightville
Reservoir
Manhan
River
Oxbow
Bachelor
Brook
Woronoco
Mount Tom
Springfield North
Manhan
Reservoir
Westfield
River
Manhan
River
Brickyard
Brook
Hampton
Ponds
Ashley
Pond
Chicopee
River
Little
Southwick
West Springfield
Springfield South
Westfield
River
River
Watershops
Pond
Connecticut
Congamond
Lakes
Longmeadow Brook
0
1
2
3
4 miles

Figure 3

path it will turn north or south, run parallel to the drumlin until it reaches the end of the drumlin where it again turns to the east. The result is a crude subrectangular stream pattern.

Streams in the northern portion of the western lowland flow northward into the Manhan River and into the Connecticut by way of the famed Oxbow, which lies in the southeast portion of the Easthampton quadrangle. Streams in the southern portion of the western lowland flow southward into the Westfield River.

The path of the Manhan River constitutes a good example of stream diversion caused by glaciation (fig. 3). Before it enters the map area at the center of the western edge of the quadrangle the Manhan flows to the south-southeast. As it enters the map area it turns abruptly to the north-northeast through an angle of about 120 degrees. Prior to the last glaciation the Manhan probably flowed southward and directly across the quadrangle to the Westfield River by way of the valley now occupied by Brickyard Brook, which is now a north-flowing tributary of the Manhan. The diversion occurred during deglaciation and was the result of large quantities of outwash gravel and sand being deposited in Brickyard Brook valley by melt-water streams flowing southward from a lobe of ice, the snout of which was situated just south of East Farms. The best evidence for diversion consists of a barbed tributary to Brickyard Brook. This stream flows southward on till-covered bedrock west of Round Hill and then joins Brickyard Brook at an angle of about 65 degrees. In addition, the head of Brickyard Brook flows southwest, also on till-covered bedrock, before turning to the north.

Modern drainage below the shoreline of glacial Lake Hitchcock (see map on page 207) began with the draining of the lake from the Connecticut valley prior to 10,650 years B.P. (Flint, 1956, p. 278).

Weathering

All the rock materials that lie above the ground-water table, and which are not protected by being impermeable or covered by impermeable materials, are subject to rapid weathering. Several types of weathering processes affecting both granular materials and bedrock can be observed in the Mount Tom area.

The most widespread manifestation of this weathering consists of a well-oxidized soil zone 1.8 to 3.0 feet deep in unconsolidated till, silt, sand, and gravel. Where the ground-water table is low and the unconsolidated material is coarse and porous, a partially oxidized zone may extend to a depth of 25 feet. No measurements are available on the depth of weathering of till in the map area, but it is believed to be on the order of 10 feet.

A measure of the amount of weathering that has occurred on bedrock since retreat of the last ice sheet can be gained at outcrops of the Holyoke Basalt on Interstate Highway I-91 at the Holyoke Narrows. Differential weathering has produced as much as one-half inch of relief between the basalt and quartz veins that have filled columnar joints (fig. 4A). Less than 100 feet away and 20 feet lower, outcrops of basalt that have been exposed only recently to weathering processes during construction of I-91 display striated and fluted surfaces (Fig. 4B). Presumably both outcrops were abraded equally by the last ice sheet, and during deglaciation the lower outcrop was covered by sand which has retarded destruction of the glaciated surface while the higher outcrop was left unprotected and weathering has removed as much as one-half inch of basalt and any trace of striations that were ever there.

The mechanical effect of chemical weathering can be observed on the crest of the Mount Tom Range just north of the quadrangle boundary. Coarse-grained basalt pegmatite in the Holyoke Basalt has been exposed since retreat of the last ice sheet. Hydration of plagioclase and augite in the pegmatite has caused the rock to expand and to disintegrate into fragments usually less than 1.0 inch in diameter. The granular material produced is similar to grus formed from granite (fig. 5A).

Figure 4 (A). Outcrop of Holyoke Basalt showing columnar joints filled with quartz veins. Differential weathering has produced 0.25 to 0.50 of an inch of relief on the surface since deglaciation. See Figure 4B and text for location.

(B). Unweathered fluted surface of Holyoke Basalt 100 feet from outcrop shown in Figure 4A, which occurs at the top of the roche moutonnee at the upper right.

A.

B.

Figure 4

Figure 5 (A). Granular material, similar to grus, produced by hydration of plagioclase and augite in basalt pegmatite. Located on the crest of the Mount Tom Range about 400 feet north of the Mount Tom quadrangle.

(B). Crude imbricate structure in talus on the west slope of the Mount Tom Range. Located on the north edge of the Mount Tom quadrangle.

A.

B.

Figure 5

Talus slopes that are well displayed below west-facing cliffs on the Mount Tom Range and East Mountain owe their origin to frost wedging of the Holyoke Basalt (fig. 5B). The talus is a steeply sloping veneer of angular to very angular blade-shaped blocks, which display triangular to parallelogram cross sections. The maximum angle of repose measured on the slope was 38 degrees. Long axes of many of the blocks lie horizontal or plunge up to 10 degrees downslope, producing a crude imbrication.

Cliffs up to 200 feet in height are the source of the talus (fig. 10). Frost wedging along columnar joints and sheeting is believed to be the main process by which blocks are derived from the cliffs. Deciduous trees grow on portions of the talus, suggesting that those areas are relatively inactive except for possible creep. Over 50 percent of the talus slope is not forested and is characterized by varying degrees of lichen cover. Blocks in the lower portion of the slope have a heavy cover of lichen, while those in the higher portions and in certain linear zones which trend directly down the slope from steep gullies in the cliff have little or no lichen cover. This latter fact indicates that the talus is still in the process of formation.

Frost wedging has widened joints in an exposure of the Sugarloaf Formation located on Red Brook just north of Maple Street in Southampton. The effect is similar to, but smaller than, that described by Koteff (1961) for a locality in southeastern Massachusetts. Two sets of joints nearly at right angles to each other have produced rectangular blocks that have moved horizontally with respect to each other on bedding plane surfaces. The effect is believed to be due to late-glacial frost wedging. Blocks produced before or during glaciation would have been moved away as erratics and yet the situation most likely requires more rigorous frost activity than occurs at the present time.

Bedrock geology

The Mount Tom quadrangle is underlain by sedimentary and igneous rocks of the Newark Series of upper Triassic age (Lull, 1917; Emerson, 1917) and by a minor amount of crystalline rock of probable Carboniferous age (Willard, 1956). The Triassic sedimentary rocks are all of continental origin and are dominated by red beds ranging from arkosic conglomerate through arkose (arkosic sandstone) to siltstone and silty shale. Minor sedimentary rock types include calcareous shale, carbonaceous shale, and possibly coal and freshwater limestone. The Triassic igneous rocks are dominated by tholeiitic basalts; however, volcanic agglomerate, breccia, and tuff occur locally at the northeast corner of the quadrangle. The Triassic rocks lie in the northwest portion of a large graben which is tilted 20 to 25 degrees to the east-southeast. The structure is known as the Hartford Basin, as opposed to the smaller subsidiary Deerfield Basin to the north (fig. 6). The two basins together are referred to as the Triassic Basin of Connecticut and Massachusetts or as the Connecticut Valley Basin.

Williamsburg Granodiorite

The type locality for the Williamsburg Granodiorite is the village of Williamsburg in the southwest corner of the Williamsburg quadrangle (Emerson, 1917; Willard 1956). The Williamsburg Granodiorite underlies an area of 0.23 of a square mile on the southeast slopes of Pomeroy Mountain in the northwest corner of the Mount Tom quadrangle (pl. 1). This same area is the only part of the Mount Tom quadrangle that belongs to the New England Upland section of the New England physiographic province (p. 6).

Willard (1956) assigned the Williamsburg Granodiorite to the Carboniferous on the basis that it had not been metamorphosed, and hence is post-Acadian (post-Devonian), and that, being a coarse-grained igneous rock, it predates Triassic sedimentary rocks.

The Williamsburg Granodiorite is light to medium gray in color and consists of fine-to medium-grained biotite granite with some muscovite. The few exposures visited by this author on Pomeroy Mountain were cut by numerous coarse pegmatite dikes

Figure 6. Triassic Basin of Connecticut and Massachusetts showing the location of the Mount Tom quadrangle and subdivision into (1) the Deerfield Basin and (2) the Hartford Basin (after deBoer, 1968).

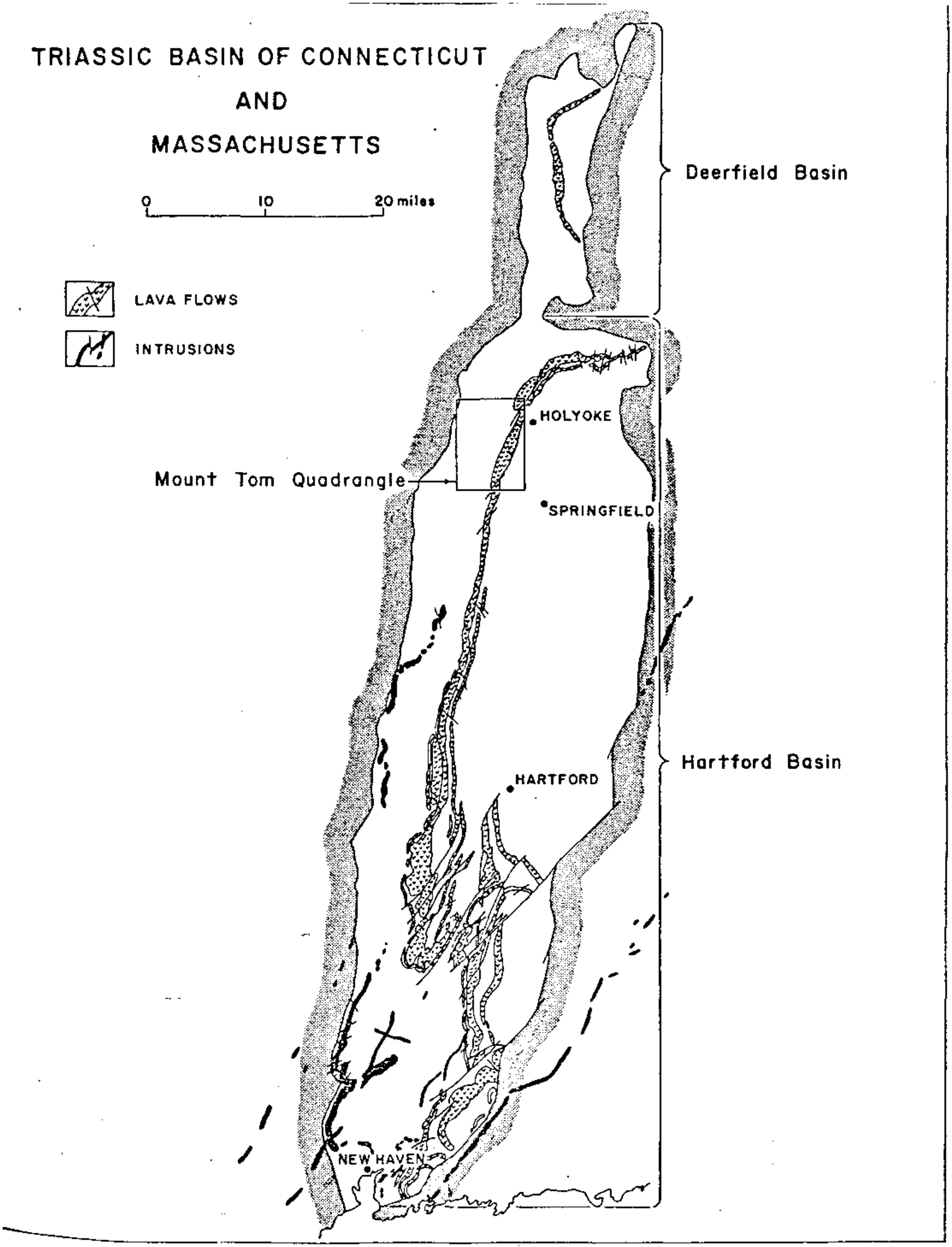

TRIASSIC BASIN OF CONNECTICUT
AND
MASSACHUSETTS
0
10
20 miles
LAVA FLOWS
INTRUSIONS
Deerfield Basin
HOLYOKE
Mount Tom Quadrangle
SPRINGFIELD
Hartford Basin
HARTFORD
NEW HAVEN

Figure 6

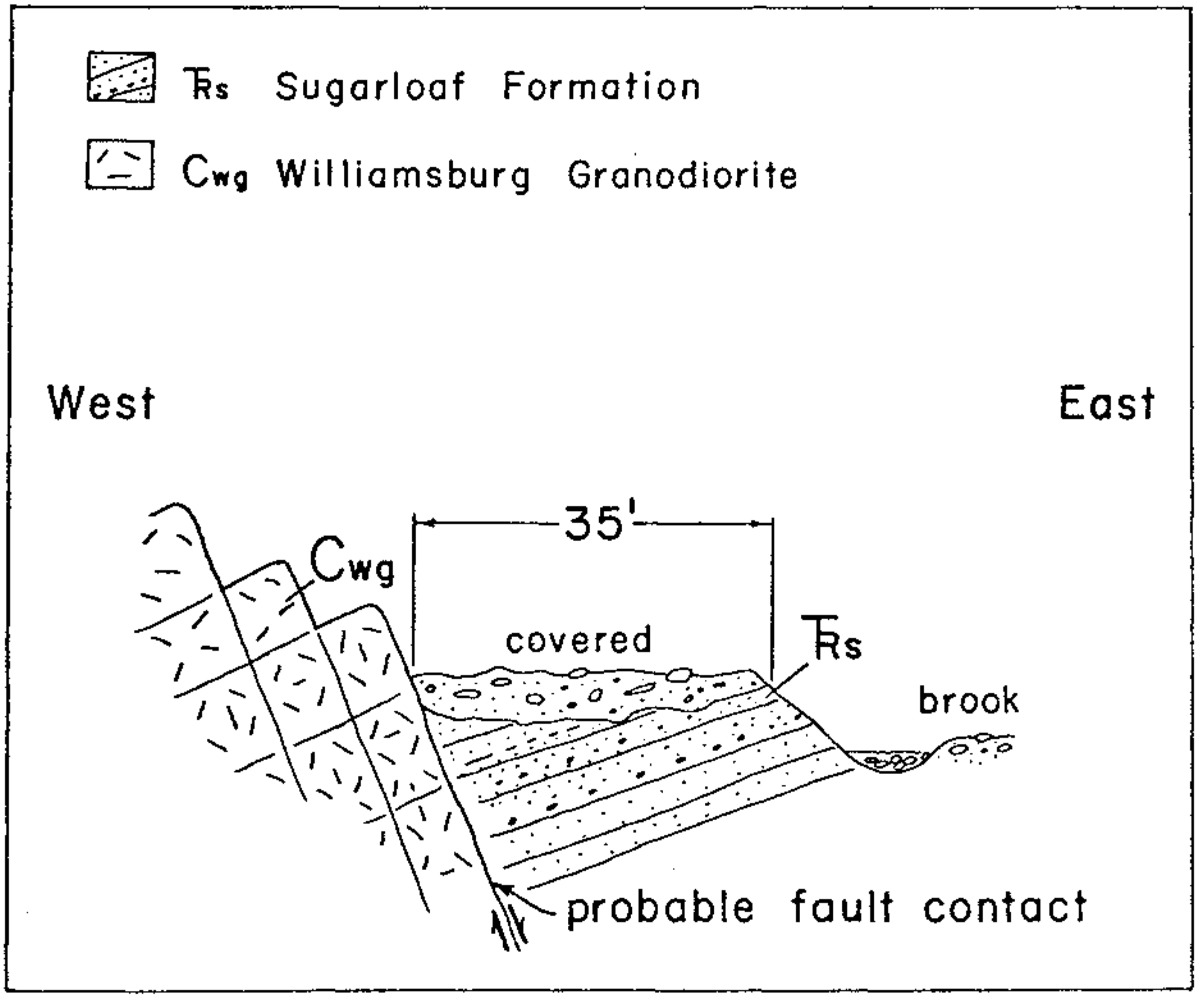
and quartz veins. The Williamsburg Granodiorite is resistant to weathering and erosion and holds up rugged slopes with well-jointed outcrops that appear to have supplied the granitic erratics common in the western portion of the map area.

Carboniferous-Triassic contact

The contact between pre-Triassic crystalline rocks and Triassic rocks on the west side of the Connecticut Valley basin has been a point of discussion since 1878, when Russell related all the Triassic basins in eastern North America to a single anticlinal feature with half-graben structures on its flank (Russell, 1878). Emerson (1917) postulated a Connecticut Valley graben with two border faults; however, Segerstrom (1956) has reported that the western contact appears to be depositional in the Shelburne Falls quadrangle. The western contact has been mapped as a fault in the Tariffville, Conn.-Mass., quadrangle by Schnabel and Eric (1965).

In the Mount Tom quadrangle the contact between the Williamsburg Granodiorite and the Triassic Sugarloaf Arkose is at the foot of the slopes of Pomeroy Mountain and is parallel to the course of Red Brook. About 150 feet west of the junction of Red Brook and the first east-flowing tributary north of Maple Street, the location of the contact can be determined within 35 feet (fig. 7). Gray coarse-grained arkose dips gently to the west at an exposure on the west bank of a bend in the

Figure 7. Cross section showing contact relationships between Carboniferous and Triassic rocks on the west side of the Connecticut Valley Lowland. At right, Triassic arkose dips gently to the west at 10 to 20 degrees. The arkose is covered by glacial debris for a horizontal distance of 35 feet before the first outcrop of Carboniferous granodiorite occurs. Location of section is 1.05 miles N73W of Southampton. (From a field sketch.)



Ŧs Sugarloaf Formation
Cwg Williamsburg Granodiorite
West
East
35'
Cwg
covered
Ŧs
brook
probable fault contact

Figure 7

east-flowing tributary. Outcrops of Williamsburg Granodiorite occur 35 feet to the west and at higher elevations. The available exposures suggest a fault contact rather than a depositional contact between the Williamsburg Granodiorite and the Sugarloaf Arkose in the Mount Tom quadrangle.

Sugarloaf Formation

Emerson (1891) named the Sugarloaf Arkose_/ for its occurrence at Sugarloaf Mountain in the northwest corner of the Mount Toby quadrangle. Willard (1951) renamed the unit the Sugarloaf Formation to include portions of Emerson's original Mount Toby Conglomerate that lie below the Deerfield Diabase (table 1).

_/ Emerson's original spelling was Sugar Loaf arkose (1891), he later changed it to Sugarloaf arkose (1917).

The Sugarloaf Formation underlies about 63 percent of the area of the Mount Tom quadrangle (pl. 1). However, there are relatively few exposures due to its low resistance to weathering and erosion and to the thick cover of glacial drift, particularly in the subsequent valley west of the Holyoke Basalt ridge. Exposures are most prevalent (1) in the area of till-covered bedrock that culminates in Whiteloaf Mountain, (2) along Red Brook and the Manhan River in the vicinity of the village of Southampton, and (3) in a belt just west of the Holyoke Basalt.

Table 1. Correlation chart of upper Triassic Newark Group for the Connecticut Valley Lowland.

	B. K. Emerson 1898a; 1917 Connecticut Valley of Mass.			P. D. Krynine 1950 Central Connecticut	E. P. Lehmann 1959 Middletown Quad., Conn.	F. D. Larsen (this report) Mount Tom Quad., Mass.
NEWARK GROUP	Chicopee Shale	Units in part contemporaneous		Portland arkose	Portland arkose	Portland Arkose
	Granby tuff					
	Hampden basalt		MERIDEN FORMATION	Upper lava flow	Hampden basalt	Hampden Basalt
	Longmeadow sandstone			Upper sedimentary division	East Berlin formation	East Berlin Formation
	Holyoke diabase			Middle lava flow	Holyoke basalt	Holyoke Basalt
				Lower sedimentary division	Shuttle Meadow formation	Sugarloaf Formation
	Talcott diabase			Lower lava flow	Talcott basalt	
	Mt. Toby cong. and Sugarloaf arkose			New Haven arkose	New Haven arkose	

Table 1

Several lithologies characterize the Sugarloaf Formation. They include light to dark reddish-brown arkosic conglomerate, arkose, arkosic siltstone, and arkosic shale. The most common lithology seen in the field is reddish-brown medium- to coarse-grained arkose with or without pebbles. Unweathered arkose and conglomerate contain fresh angular to rounded clasts of granite, gneiss, quartzite, mica, and cleavage fragments of light orange-brown feldspar.

In areas where ground-water infiltration has been active along bedding planes, joints, and faults (for example, along the Carboniferous-Triassic contact), the color of the rocks has been altered from a normal reddish brown to greenish gray. Coarse arkose and arkosic conglomerate that have been reduced and exposed to weathering are often light gray to pinkish gray due to kaolinization of the feldspars.

In many exposures the rock is either poorly indurated or deeply weathered or both. In an excavation for a house on Fomer Road, 1.0 mile southwest of Southampton village, arkosic siltstone was excavated by bulldozer to a depth of 4.0 feet with the same degree of difficulty encountered in excavating loose sandy till or lacustrine clay.

Sedimentary structures encountered in the arkose consist mainly of small- to medium-scale planar crossbedding, imbricated pebbles, and scour-and-fill structure, with occasional occurrence of ripples, mudcracks, worm burrows, and fossil wood. The coarse grain size and the prevalence of planar crossbedding produced by the migration of dunes indicates conditions in the upper portion of the lower flow regime (Harms and Fahnestock, 1965) during fluvial deposition of much of the arkose.

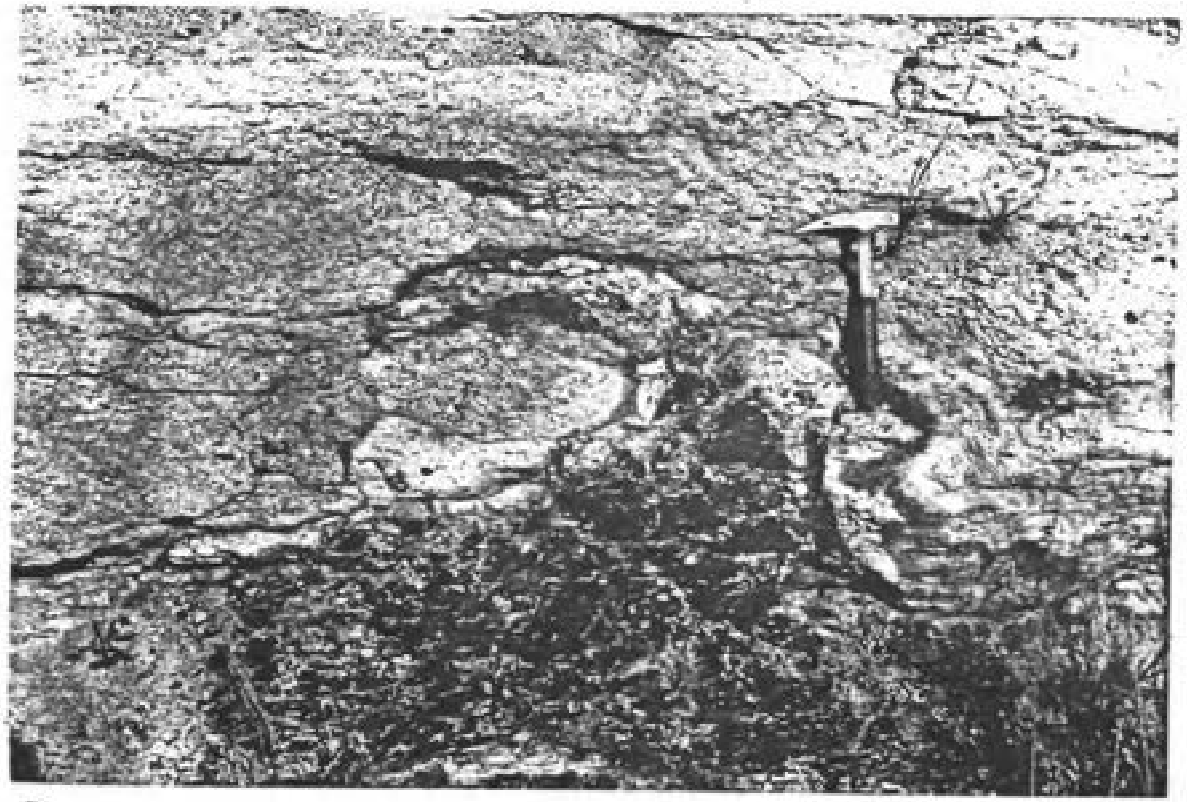
During the course of this study, fossil wood was found in exposures of arkosic conglomerate which lie under and upstream from the highway bridge in Westfield where routes 10 and 202 cross the Westfield River.

An instructive outcrop of the Sugarloaf Formation is situated on the east side of College Highway (Route 10) 0.2 of a mile south of Swanson Corners. In an exposure measuring 150 feet long and 6 to 10 feet high, fluvial crossbedding is exposed in gray arkosic conglomerate (fig. 8A). Two crossbed units are exposed which are each 36 inches thick. The matrix consists of coarse sand to granules with isolated individual pebbles, many of which lie horizontally but would be imbricate to currents traveling down the crossbed slope. A large clast of red arkosic shale measuring 2 feet in diameter and with greenish-gray reduced areas lies at the base of one of the crossbed units. The source of such a clast is suggested by a flame structure at the south end of the exposure (fig. 8B). Here two pillow structures in the overlying conglomerate have pressed down into the red shale, producing a flame structure which has mushroomed one foot up into the conglomerate. Further activity would have resulted in the isolation of a large

Figure 8 (A). Outcrop of Sugarloaf Formation 0.2 of a mile south of Swanson Corners. Fluvial crossbedding and lenticular clast of dark colored shale are at the left. Flame structure with mushroom shape is at the right.

(B). Detail of flame structure in Sugarloaf Formation. Dark rock at bottom is reddish-brown shale which has been forced into overlying gray arkose by rapid loading of sediments during flooding. The upper contact of the shale has been reduced to a greenish-gray color by ground-water activity.

A.



B.

Figure 8

clast of shale within the conglomerate. Inspection of the area below the first clast mentioned above reveals red shale under a crossbed unit, suggesting a possible source for the clast. The environment of this one locality during deposition was one of high energy or flood conditions marked by rapid loading of sediments.

The mean direction and dip of three measured crossbed units is S. 52° E. and 31° respectively. (Note: the above measurements are not corrected for regional tilt). Because most of the crossbedding dips away from the Carboniferous-Triassic contact it appears that the source of sediments lay west-northwest of the contact.

An important outcrop of the Sugarloaf Formation was revealed during construction for Interstate Highway 91 at the Holyoke Narrows in the southwest corner of the Mount Holyoke quadrangle. No exposure in the Mount Tom quadrangle is as extensive and as free from the effects from weathering as this one, which has been described by Brophy and others (1967). The upper part of the Sugarloaf Formation is exposed in a 650-foot section which stretches for 1,300 feet along I-91. The rocks dip 22° to the southeast and are characterized by two lithologies. One consists of boulder beds and sand lenses interrupted at intervals by dark red hematite zones, which probably represent old soil zones on alluvial fans that were covered periodically by flash-flood deposits and mudflows.

The other lithology contains fine-grained arkose with cross-bedding, imbricated pebbles, and plant fragments, which are characteristic of fluviatile deposition.

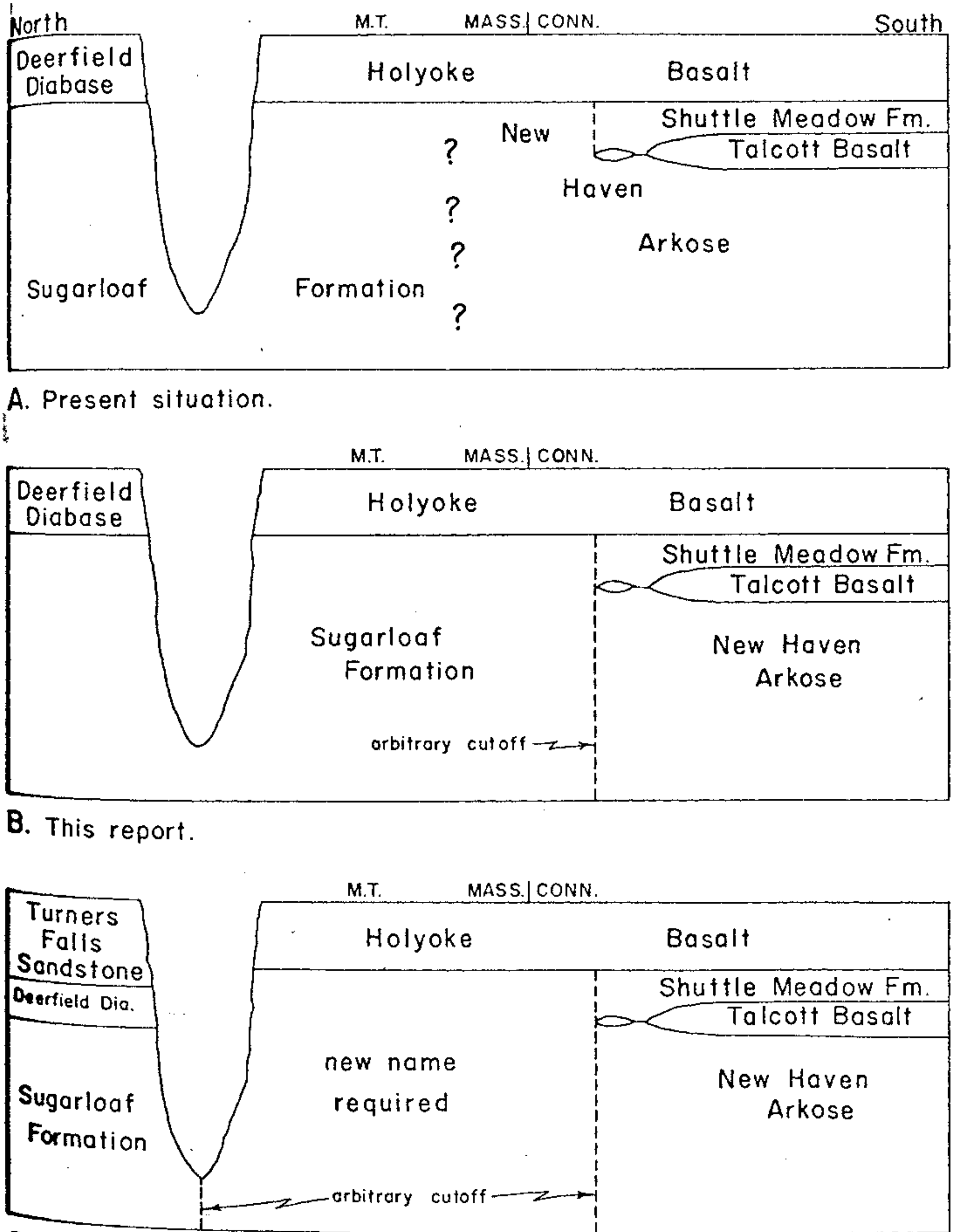
The thickness of the Sugarloaf Formation can only be estimated because of the scarcity of outcrops and exposures of the Carboniferous-Triassic contact. Lack of knowledge about the nature of the floor upon which the arkose lies also plays a role. Inselbergs composed of crystalline rocks rise through the Mount Toby Conglomerate in the Deerfield Basin, indicating that the base of the Triassic is irregular (Emerson, 1898b, p.361; Willard, 1952; Wessel, 1969), and there is no reason to expect anything different in the Mount Tom quadrangle. A graphic solution to the problem can be made by relating a 3,700-foot boring at Northampton (Emerson, 1898b) to the contact with the overlying Holyoke Basalt at the Holyoke Narrows. Assuming (1) a minimum dip of 16° for the arkose at the Narrows (a conservative estimate because the average is 22°), (2) a constant dip for all of the arkose, and (3) a constant thickness unaffected by faulting, the minimum thickness would be 6,500 feet.

In the Mount Tom quadrangle the outcrop width of the Sugarloaf Formation is 5.0 miles, measured between the Williamsburg Granodiorite at the foot of Pomeroy Mountain and the base of the Holyoke Basalt on East Mountain. Making the same assumptions as in the previous paragraph, the thickness would be 7,300 feet. Willard (1952) estimates the thickness of the Sugarloaf Formation to be 6,000 to 8,000 feet in the Greenfield quadrangle. Bain (1941) suggests a thickness of 3,000 to 6,800 feet for the same rocks in the Mount Holyoke quadrangle.

Problems of correlation

Schnabel and Eric (1964, 1965) and Colton and Hartshorn (1966) have extended the use of the term "New Haven Arkose" (Krynine, 1936, 1950) northward into Massachusetts from Connecticut to replace the term "Sugarloaf Formation" (Emerson, 1891; Willard, 1956) (fig. 9A). Extending the New Haven Arkose beyond the northern limit of the Talcott Basalt is in error according to the principle of arbitrary cutoff proposed by Wheeler and Mallory (1953). The New Haven Arkose was originally defined by Krynine (1950) to include those rocks between the western border of the Connecticut Valley lowland up to the base of the Talcott Basalt (Emerson, 1891). The Shuttle Meadow Formation was named by Lehmann (1959) to include those rocks between the top of the Talcott Basalt and the base of the Holyoke Basalt. Any effort to extend the definition of the New Haven Arkose to include rocks equivalent in age to those in the Shuttle Meadow Formation is contrary to the principles set forth by the American Commission on Stratigraphic Nomenclature (1961).

Figure 9. Stratigraphic diagrams illustrating the problem of nomenclature of some upper Triassic rocks in the Connecticut Valley Lowland. The deep cut at the left represents removal of sediments by erosion and separates rocks of the Deerfield Basin (L) from rocks of the Hartford Basin (R) (compare with figure 6).



A. Present situation.

B. This report.

C. Contingency plan.

Figure 9

The solution to the problem could be simple, depending on whether the Deerfield Diabase correlates with the Talcott Basalt or the Holyoke Basalt. The generally accepted correlation has been that of McKee and others (1959), who equated the Deerfield Diabase to the Holyoke Basalt. If this correlation is correct,it would present a clean-cut situation because the upper portion of the Sugarloaf Formation presumably would be the time equivalent of the Shuttle Meadow Formation. Therefore, the Sugarloaf Formation would be the time equivalent of part of the New Haven Arkose, all of the Talcott Basalt and most of the Shuttle Meadow Formation.

Using an arbitrary cutoff (Wheeler and Mallory, 1953) would solve the problem faced by Schnabel and Eric (1965) in naming the rocks north of the last occurrence of the Talcott Basalt in the Windsor Locks quadrangle (fig. 9B). At the geographic point where the Talcott Basalt disappears an arbitrary cutoff is extended perpendicular to the strike of the beds. The Sugarloaf Formation should be extended southward from its type locality to the arbitrary cutoff. South of the arbitrary cutoff the original terminology, New Haven Arkose, Talcott Basalt, and Shuttle Meadow Formation, should prevail (table 1).

However, recent paleomagnetic research by deBoer (1968) and Bowker (1960; data in deBoer, 1968) indicates that the

Deerfield Diabase may be the time equivalent of the Talcott Basalt on the basis of similar paleomagnetic inclinations. DeBoer notes that his correlation is not conclusive because both the Deerfield Diabase and the Holyoke Basalt have relatively low inclinations, and there is considerable overlap in the basic data.

If the Deerfield Diabase correlates with the Talcott Basalt then the Sugarloaf Formation is the rock-stratigraphic equivalent of the New Haven Arkose. Since the Sugarloaf was named first it should take precedence over the New Haven Arkose. This situation would also leave the upper several hundred feet of the arkose without a formal stratigraphic name between the north end of the Talcott Basalt and the point where the Holyoke Basalt ends in the Belchertown quadrangle.

It is here suggested that if further research indicates that the Deerfield Diabase is correlative in time with the Holyoke Basalt, then the Sugarloaf Formation be extended south to an arbitrary cutoff determined by the northernmost exposure of Talcott Basalt. Further, if research proves that the Deerfield Diabase does not correlate with the Holyoke Basalt, then a new unit (unnamed here) be defined as those rocks lying between the crystalline rocks to the west and north (Mt. Warner) and the base of the Holyoke Basalt to the east (fig. 9C). The boundary on the south is the arbitrary cutoff at the north end of the Talcott Basalt. An east-west boundary is placed between crystalline rocks on the west and the westernmost extent of crystalline rocks in the Mt. Warner area in order to separate the Sugarloaf Formation in the Deerfield Basin from the new unit in the northern end of the Hartford Basin.

Radiometric dating that bears on this problem is inconclusive at the present time. H. W. Krueger of Geochron Laboratories, Inc., permitted deBoer (1968) to publish the following dates:

Holyoke lava-flow unit, near type locality, 193 ± 6 m.y.

Deerfield lava-flow unit, near type locality, 191 ± 6 m.y.

There is considerable overlap in these two dates, and the Talcott Basalt has not been dated, therefore a solution to the problem of correlation must await further work.

Holyoke Basalt

The Holyoke Basalt outcrops as a continuous band, 900 to 3,800 feet wide, which trends N. 18° E. from the center of the southern edge to the northeast corner of the Mount Tom quadrangle (pl. 1). The outcrop is part of a discontinuous ridge that stretches west and then south a distance of 64 miles from Dwight, Mass., to Meriden, Conn. At Meriden the ridge is offset by faulting 5 miles to the east where it can be traced southward another 22 miles to the vicinity of New Haven. The Holyoke Basalt is the best exposed rock unit in the quadrangle relative to the area it underlies. It is responsible for spectacular west-facing cliffs on Mount Tom (fig. 10) and for less scenic cliffs on East Mountain. The dip slope of the Holyoke Basalt underlies the east side of the Mount Tom Range. Ski trails at the Mount Tom ski area (Easthampton quadrangle) run essentially on the dip slope of the Holyoke Basalt.

The Holyoke diabase sheet was named by B.K. Emerson (1891, 1898a, 1917) for exposures on Mount Holyoke and the Holyoke Range located in the Mount Holyoke quadrangle (table 1). The Holyoke diabase was included as the Middle lava flow member of the Meriden Formation by Krynine (1950). On the Preliminary Geological Map of Connecticut (Rodgers and others, 1956) the unit was listed as the Holyoke lava member of the Meriden Formation. The U. S. Geological Survey and this report follow the work of Lehmann (1959) who dropped the term Meriden Formation and raised each of the members of the Meriden Formation to formational rank on the basis that each is a mappable unit in the Middletown, Conn., quadrangle.

One main lithology is represented by the Holyoke Basalt. It is a medium to dark-gray, very fine- to fine-grained basalt which changes to a light-brown color on the surface when exposed to weathering. The basalt is dense and homogeneous in texture except for sporadic coarse basalt pegmatite lenses that occur on the crest of the Mount Tom Range (fig. 5A), and which have been reported in the Mount Holyoke Range by Emerson (1917), Balk (1957), and Brophy and others (1968).

Figure 10. West-facing cliffs of Holyoke Basalt in the Mount Tom Range. Both sheeting and columnar jointing are prominent. Large and small slide blocks are being supplied to the talus by frost wedging. View is northward from a point near the boundary of the Mount Tom and Easthampton quadrangles. The Oxbow is located in the upper right. Vertical joint block to the right of center is 17 feet high.

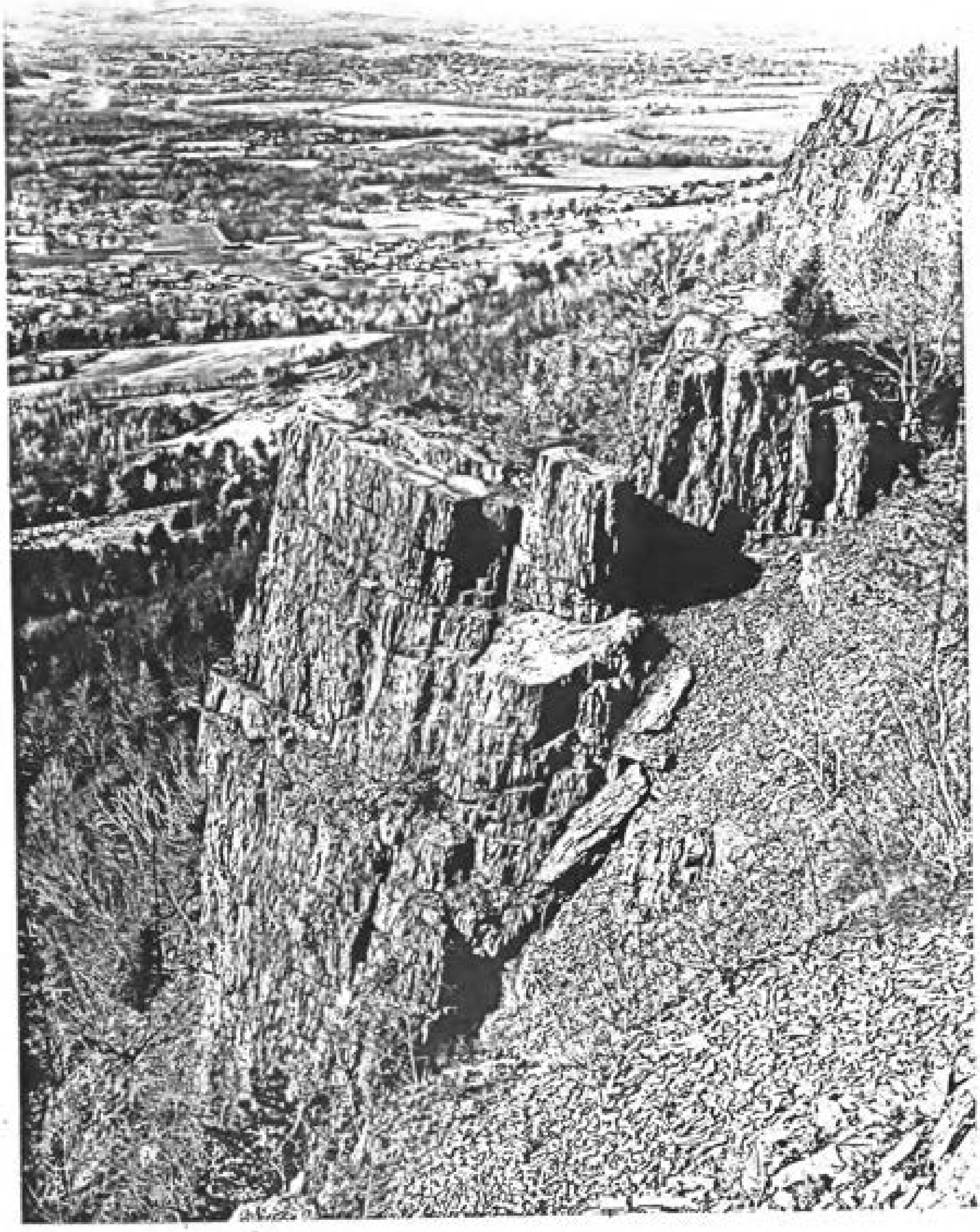


Figure 10.

Recent thin section work by Gutmann (1965) on specimens from the Mount Holyoke quadrangle shows that euhedral plagioclase grains (An_{50} to An_{65}), 0.1 to 2.0 mm. in length, form a felted meshwork and constitute 56 percent of the basalt. Augite constitutes 32 percent and magnetite 4 percent, increasing to 9.8 percent and 12.3 percent at the upper and lower contacts respectively. Mesostasis (glass) comprises 2 to 17.8 percent. Gutmann did not detect any differentiation trends, indicating that crystal settling did not occur during cooling.

The most common feature of the basalt consists of a pervasive jointing which produces columns or polygonal blocks. The columnar jointing is present through a broad vertical range; for example, columns occur from the bottom to the top of the 250-foot cliff on the west side of the Mount Tom Range (fig. 10). Weathered surfaces of the basalt near the top of the Mount Tom ski area reveal two distinct patterns caused by the jointing (fig. 11). In one, the cross sections of the columns are rounded pentagons to octagons, in the other, the cross sections are sharp cornered with triangular and diamond shapes prevailing. The cross-sectional shape of the columns may relate to the vertical position in a flow. In several basalt flows in Yellowstone National Park well-developed hexagonal columns may be observed to grade upward into poorly developed trigonal columns. Further study of this property may confirm the number of flow units in the Holyoke Basalt.

Figure 11. Two surficial expressions of columnar jointing in the Holyoke Basalt as seen near the crest of the Mount Tom Range.

(A) Columns whose cross sections are rounded pentagonal to octagonal forms whose internal angles are mostly obtuse. Location is approximately 0.25 of a mile southwest of top of Mount Tom ski lift.

(B) Columns characterized by fewer sides hence corners are sharper and internal angles are more often acute than in 11A. Location is 200 feet north of top of Mount Tom ski lift.

A.

B.

Figure 11

The columns are not always perpendicular to the base of the basalt. At an outcrop in the Lane Quarry, Westfield, columns appear to radiate from a point in space above the outcrop. A similar situation may be seen at the new exposures along Interstate Highway I-91 in the Holyoke Narrows.

A second type of jointing in the basalt is similar to sheeting and lies roughly perpendicular to the columns and subparallel to the base of the basalt. In the Lane quarry this type of jointing consistently dips in the same direction as the basal contact, but on the Mount Tom cliffs some of these joints are curved and dip at odd angles, producing surfaces similar to glacial pavement (fig. 10). Since the surfaces disappear into joints under larger undisturbed blocks of basalt indications are that the surfaces are a manifestation of jointing rather than glaciation. One is less certain when viewing the uppermost surface with no basalt block resting upon it.

The lower contact of the Holyoke Basalt is exposed in the Lane Quarry, Westfield (fig. 12). A layer of hornfels representing the altered upper three feet of the Sugarloaf Formation underlies the Holyoke Basalt. The hornfels zone is greenish gray in color in contrast to the reddish brown of the underlying arkose. The zone is similar to that described by Chapman (1965) who made a detailed thin-section analysis of the contact between the East Berlin Formation and the Hampden Basalt in Connecticut. Chapman found that the contact metamorphic effects

Figure 12 (A) Conformable contact of the Holyoke Basalt (blocky appearance) and the Sugarloaf Formation (bedded) which has been offset by two normal faults which trend N. 15° E. and dip 75 degrees to the west. Hand of the observer rests on slickensides which plunge directly down the dip of the fault. Location is on the west side of the Lane quarry, Westfield, and on the southern boundary of the Mount Tom quadrangle. View is to the southwest.

(B) Conformable contact of the Holyoke Basalt (dark colored) and the Sugarloaf Formation (light colored, left of lower center and lower right) which has been offset by two normal faults. The fault at the right strikes N. 20° E. and dips 70 degrees to the northwest. Fault surface on the left (dark shadow behind transit) strikes N. 20° E. and dips 45 degrees northwest. Location is in the center of the Lane quarry about 200 feet north of the southern boundary of the Mount Tom quadrangle. View is to the northwest.

A.

B.

Figure 12

in the underlying rocks were the result of both heat and solutions from the basalt.

The contact is relatively smooth and it parallels the bedding in the Sugarloaf Formation. Above the contact the lower 10 feet of the basalt is chaotic, and well developed polygonal jointing in some places does not appear for a distance of 10 feet above the contact.

The irregular outcrop pattern of the Holyoke Basalt (pl. 1) and numerous field observations (fig. 12) indicate that the basalt has been offset by numerous faults with varying amounts of separation. Study of faults on plate 1 and on the bedrock map of the West Springfield quadrangle (Colton and Hartshorn, 1966) indicates that some faults in the Holyoke Basalt occurred prior to eruption of the Hampden Basalt. For example, a major northeast fault at Bush Notch does not appear to cut the Hampden Basalt to the northeast. This would suggest that tensional faulting occurred during deposition of the Newark Group.

Emerson reported the maximum thickness of the Holyoke Basalt to be 400 feet (1917, p. 265) in the Mount Tom-Mount Holyoke area. However, Gutmann (1965) has measured a thickness of 575 feet on Mount Holyoke and 580 feet at the new exposure on Interstate Highway I-91 in the Holyoke Narrows. This is the maximum thickness measured up to the present time. Colton and Hartshorn (1966) estimated the thickness to be 250 to 400 feet in the West Springfield quadrangle. In Connecticut, Lehmann (1959) has calculated the thickness of the Holyoke Basalt to be

450 to 500 feet thick in the Middletown quadrangle. Klein (1968) gives a general figure of 200 meters for the Holyoke Basalt in Connecticut.

Calculations based on width of exposure and dip of strata at the Lane Quarry, Westfield, indicate a thickness of about 560 feet. However, within the quarry six normal faults cut the contact between the Holyoke Basalt and the Sugarloaf Formation (fig. 12A and fig. 12B). The total stratigraphic separation is approximately 60 feet, reducing the apparent thickness to 500 feet. Because the faults parallel columnar jointing in the basalt their presence is easily overlooked, and therefore the true thickness may be much less. The outcrop width narrows to 900 feet west of the Whiting Street Reservoir, indicating a thickness of about 225 feet. However, the reservoir prevents measurement of the actual outcrop width, and because structural relationships are not clear enough for accurate reconstruction of the thickness, the true thickness is probably much greater.

Both of the known extremes in the thickness of the Holyoke Basalt, zero feet reported by Balk (1957, pl. 1) and 580 feet measured by Gutmann (1965), occur in the Mount Holyoke quadrangle. This indicates that there was at least 580 feet of vertical relief in the Mount Holyoke quadrangle when the Holyoke Basalt erupted. Over most of a north-south distance of 70 miles the Holyoke Basalt is continuous (except for faulting) and has a thickness between 300 and 500 feet. These measurements reflect the flatness of the terrain upon which the basalt was extruded and the extreme fluidity of the lava when it erupted.

W. M. Davis (1896) discovered that the Holyoke Basalt is composed of two separate flow units in the vicinity of Meriden and New Britain, Connecticut. This was later confirmed by Lehmann (1959). In the Mount Tom quadrangle there is no apparent evidence that the Holyoke Basalt consists of more than one flow. Brophy and others (1967) have interpreted Gutman's study (1965) in the Mount Holyoke quadrangle to indicate two separate flow units on the basis of grain-size variations. Gutmann, however, was reluctant to distinguish two flows on this basis.

The eruption that produced the Holyoke Basalt is generally considered to have been a fissure flood similar to eruptions that have occurred in Hawaii and Iceland within historic times, and which occurred in the geologic past in the Columbia Plateau in eastern Washington. The eruption was relatively quiet and nonexplosive with the rapid flow of highly fluid basic lava from long fissures or faults in the earth's crust.

Because they have the same paleomagnetic inclination as the Holyoke Basalt, intrusions at West Rock, Mount Carmel, and the Barndoor Hills in Connecticut could be related to fissures or possible sources for the Holyoke Basalt in that state (deBoer, 1968). No known intrusions have been identified in Massachusetts as being possible sources of the Holyoke Basalt. However, the basalt was so fluid that the source area need not have been large.

If we assume that the Hartford Basin was 17 miles wide and 20 miles long and that the Holyoke Basalt had a constant [mean] thickness of 200 feet, then the volume erupted was about 45 cubic miles or 186×10^9 cubic meters. This estimate is about 15.6 times greater than the volume of the famous Laki Fissure eruption of 1783 in Iceland, which has been reported by Bullard (1962) at 12×10^9 cubic meters.

East Berlin Formation

The East Berlin Formation (table 1) occurs as a band, 200 to 3,200 feet wide, which trends north-northeast from the southern edge to the northern edge of the Mount Tom quadrangle (pl. 1). Contacts of the East Berlin Formation with the underlying Holyoke Basalt on the west and with the overlying Hampden Basalt on the east are apparently comformable. The average dip of the formation is 15 to 20 degrees to the east-southeast. Outcrops are common except for the area south of the Massachusetts Turnpike and in the vicinity of Ashley Pond.

The East Berlin Formation was named by Lehmann (1959) for rocks that conformably overlie the Holyoke Basalt and conformably underlie the Hampden Basalt 1.25 miles west-northwest of East Berlin, Connecticut. The type locality is located along Highway 72, where the Hampden Basalt overlies 325 feet of exposed stratigraphic section. Rocks mapped as East Berlin

Formation on plate 1 were originally mapped by Emerson (1898a). Because Emerson included reddish-brown arkose west (stratigraphically lower) of the Holyoke Basalt in the Longmeadow Sandstone it is not considered to be a proper rock-stratigraphic name and has been dropped by the U. S. Geological Survey (Schnabel and Eric, 1964, 1965; Colton and Hartshorn, 1966).

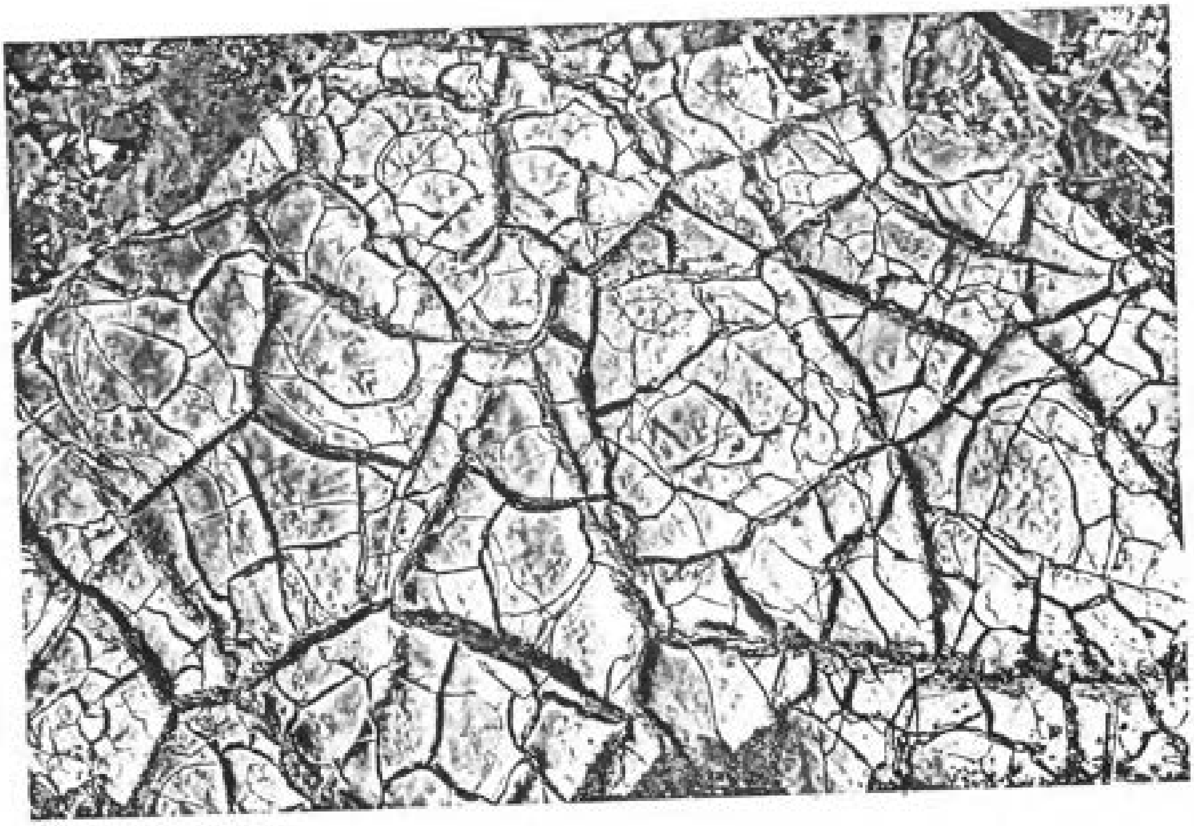
Several lithologies of continental origin are found in the East Berlin Formation. They are light to dark reddish-brown to brown arkose and arkosic siltstone, gray arkosic siltstone and shale, and black siltstone and shale. Arkosic conglomerate, pebbly arkose, and limestone constitute a minor portion of the lithology.

Calculation of the thickness of the East Berlin Formation, based on outcrop width and dips of 15 to 20 degrees, indicates values between 500 to 1125 feet. At the type locality the formation is 550 to 600 feet thick (Lehmann, 1959), and Krynine (1950) lists values of 750 to 900 feet for central Connecticut. For the West Springfield quadrangle Colton and Hartshorn (1966) list the thickness as ranging from 700 to 1,200 feet. The higher calculated thickness for the East Berlin Formation in the Mount Tom and West Springfield quadrangles is in part a function of repetition of beds caused by faulting.

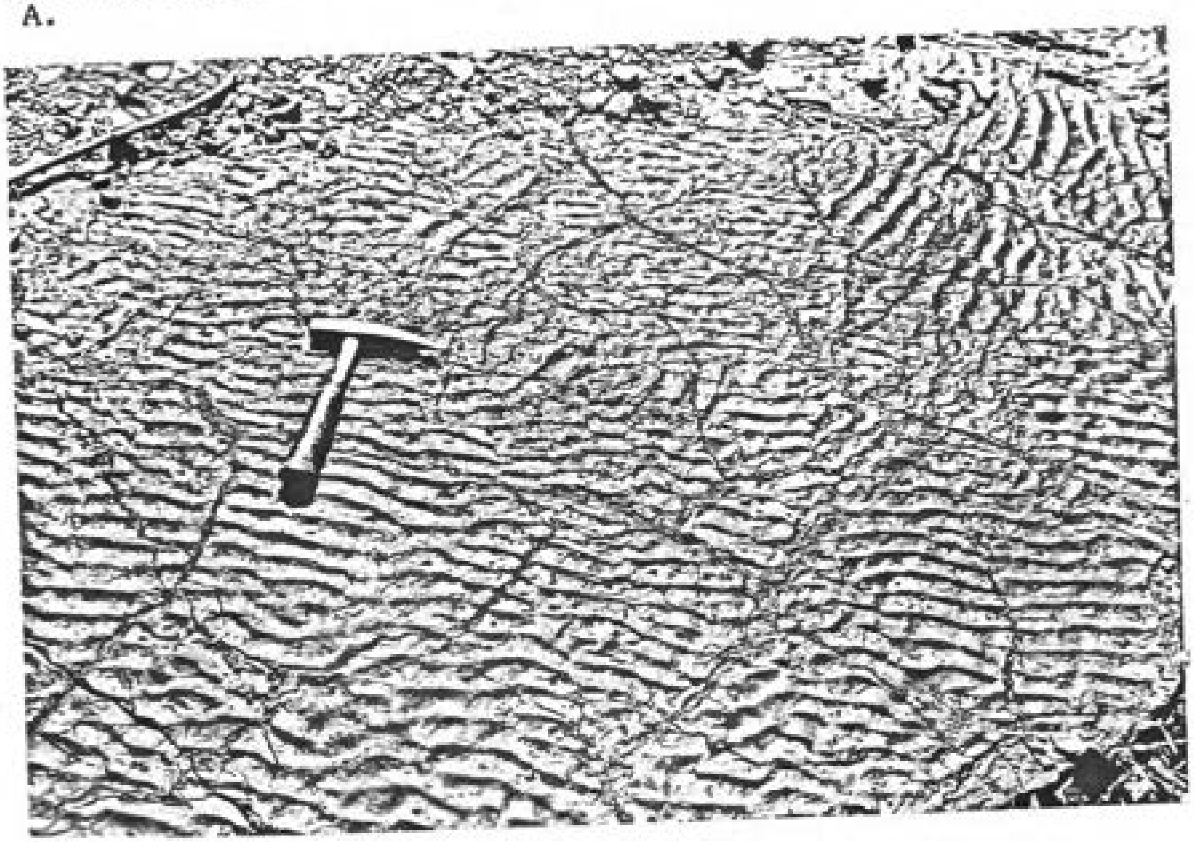
The East Berlin Formation displays a wide variety of sedimentary structures. Mudcracks (fig. 13A) and oscillation ripplemarks (fig. 13B) are ubiquitous and indicate a depositional environment alternating between shallow water and exposed mud-

Figure 13 (A). Mudcracks in fine-grained calcareous siltstone of the East Berlin Formation. Location is on the west side of Interstate I-91 1.0 mile south of the overpass to Mountain Park.

(B). Oscillation ripplemarks (two directions) and mudcracks in reddish-brown arkosic siltstone of the East Berlin Formation. Location is in an abandoned quarry 0.4 of a mile west-northwest of the Holyoke Old Soldiers Home.



A.



B.

Figure 13

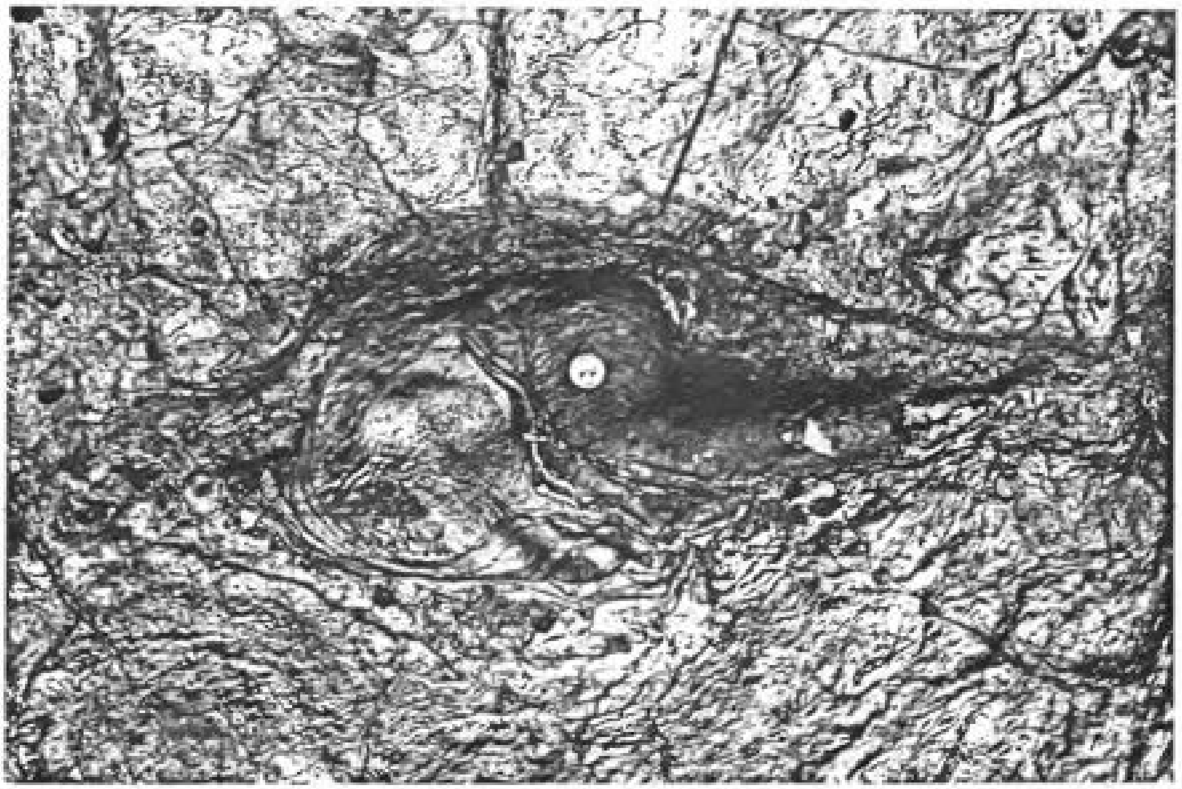
flat. Dinosaur footprints (fig. 14A) occur on the west side of Interstate I-91 0.95 of a mile south of the overpass to Mountain Park and at an abandoned quarry 0.4 of a mile west-northwest of the Holyoke Old Soldiers Home (VA Hospital on topographic map). Raindrop imprints and concretions, 1/4 to 3 inches in diameter, are also common. In addition to the above structures, bedding-plane surfaces of red siltstone display a sheen due to the presence of numerous minute flakes of micaceous minerals. Large pillow structures occur in some siltstone and shale beds (fig. 14B) and presumably are the result of rapid loading of sediments during floods.

The best exposure of the East Berlin Formation occurs on the West side of Cedar Knob, in the northeast corner of the quadrangle, where a new exposure was made during construction of Interstate I-91 (fig. 15A). About 110 feet of section (Sancton, 1970) are exposed below the Hampden Basalt that caps the top of Cedar Knob. The exposure includes black shale, gray siltstone, and reddish-brown siltstone arranged in cyclic sequences similar to those described by Klein, (1968) for the type locality of the East Berlin Formation in Connecticut.

One cycle, (Klein, 1968) consists, from the base upward, of: (1) gray siltstone, (2) black shale, (3) gray siltstone, and (4) reddish-brown siltstone. The reddish-brown siltstone portion of the cycle contains reddish-brown arkose which displays crossbedding (fig. 15B) and represents overbank deposits on a fluvial mudflat. The gray siltstone and black shale re-

Figure 14 (A). Dinosaur footprint (10 inches by 18 inches) filled with shale in reddish-brown arkosic siltstone of the East Berlin Formation. Location is on the west side of Interstate I-91 1.0 mile south of the overpass to Mountain Park.

(B). Pillow structure of siltstone in black shale of the East Berlin Formation. Hammer for scale is lower right of center. Location is on west side of Interstate I-91 immediately north of the overpass to Mountain Park.



A.

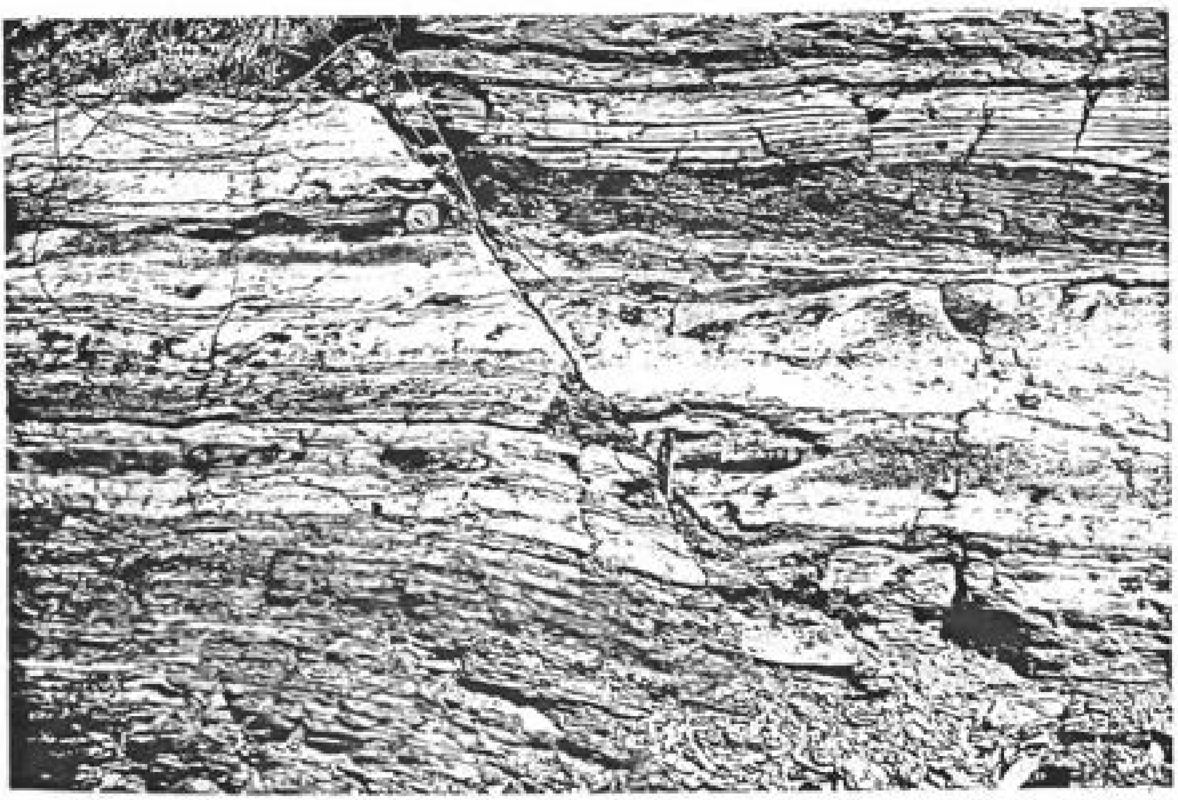
B.

Figure 14

Figure 15 (A). Exposure of the East Berlin Formation on the east side of I-91 just north of the overpass to Mountain Park. Dark rock at lower right is black shale, light gray rock above it is gray siltstone. The slightly darker gray rock above that is reddish-brown arkosic siltstone which contains light-colored bands of arkose deposited in channels. The protrusion from the slope below the birch trees at the left is a large pillow structure (James Wessel, oral commun., 1969). For detail of area within circle see below.

(B). Normal fault in East Berlin Formation. Dark, thin-bedded rock at lower left and upper right is reddish-brown arkosic siltstone formed as overbank deposits. Thick crossbedded units at the right center in light-brown arkose were formed as channel deposits. Transport direction of arkose was toward N. 30° W. The fault strikes N. 72° E., dips 52 degrees southeast. Separation on the fault is shown by the relative position of the Brunton compass on the footwall and the hammer on the hanging wall. Note fault slice, or horse, at bottom and striations (left and upper left) which climb from lower left to upper right. Location of photograph is shown by circle in figure 15A.

A.



B.

Figure 15

present deposition in a lacustrine environment.

Klein (1968) has described three complete cycles below the Hampden Basalt at the type locality and at a second locality. At Cedar Knob only two complete cycles are exposed below the Hampden Basalt, but there may be more below the present exposure. Klein attributes the cycles to a combination of continued fault-trough subsidence and variation in rate of sedimentation, the latter possibly due to climatic controls that have been described by Van Houten (1962, 1964).

The occurrence of similar cyclic sediments capped by Hampden Basalt at Cedar Knob and at the East Berlin type locality is testimony for remarkably uniform conditions of sedimentation over a north-south distance of 45 miles in the Connecticut Valley Lowland during late Triassic time.

Hampden Basalt

The Hampden Basalt (table 1) outcrops as a narrow band approximately 500 feet wide in the southern portion of the quadrangle. The basalt underlies a low ridge that trends N. 19° E. The ridge is straight for 2.6 miles north of the southern boundary of the quadrangle before being offset by a fault (pl. 1). The basalt has no strong topographic expression and outcrops are uncommon for the next 5 miles to the north-northeast due to the presence of thick till deposits associated with a drumlin field west of the City of Holyoke. Three outcrops of basalt within the drumlin field and evidence from the aeromagnetic map of the Mount Tom quadrangle (U. S. Geol. Survey, 1968) suggest that the Hampden Basalt is a continuous mappable unit, and not discontinuous as shown by Emerson (1898a). Further north, the basalt is nearly continuous on the surface for 1.1 miles in the vicinity of Little Mountain and Cedar Knob.

The Hampden Basalt was originally called the "posterior trap" by Percival (1842). Emerson used the term "posterior diabase sheet" in Monograph XXIX on the Geology of Old Hampshire County (1898b),but in the Holyoke Folio of the Geologic Atlas of the United States published in the same year he refers to the "Hampden diabase". The name is apparently for outcrops that stretch southward across Hampden County from a spectacular outcrop at Little Mountain in the northeast corner of the quadrangle (Emerson, 1898b). On the Preliminary Geological Map of Connecticut (Rodgers and others, 1956) the formation was demoted to the "Hampden lava member" of the Meriden Formation. Lehmann (1959) was the first to use the term "Hampden Basalt" and to credit Emerson for his proper rock-stratigraphic terminology. As mentioned earlier (p. 57), the U. S. Geological Survey follows the lead of Lehmann in this matter.

The lithology of the Hampden Basalt is similar to that of the Holyoke Basalt. It is a dark-gray, fine-grained basalt. Chapman (1965) lists four modes for the Hampden Basalt, which average 43.4 percent plagioclase (An 35 to An 63), 33.2 percent augite, 1.4 percent olivine, 16.7 percent antigorite, 3.7 percent opaque minerals, and 1.5 percent accessory minerals.

Chapman made a detailed study of five localities in Connecticut where the Hampden Basalt is considered to be a layered extrusion, with as many as 3 to 8 possible subdivisions (Chapman, 1965). The nature of the subdivisions, whether they are discrete flow units or represent magmatic segregation into layers during one eruption, is a matter of some dispute (deBoer, 1968). Chapman favored the concept of a series of overlapping tongues of a highly fluid lava to produce the succession of units. In the West Springfield quadrangle Colton and Hartshorn (1966) have recognized two units in the basalt. Emerson (1898b, p. 475) cites an exposure on the New York, New Haven and Hartford Railroad 0.3 of a mile NNW. of the summit of Bradley Mountain. Here Emerson noted that the basalt was 120 feet thick and was divided into two beds. The lower unit is 53 feet thick and is composed of large columns except for a 10-foot amygdaloidal zone at the top. The upper unit is 67 feet thick with a 15-foot amygdaloidal zone. Reinspection of this outcrop by this author indicates that, in spite of a heavy present-day cover of vegetation, the description by Emerson is essentially accurate.

Minimum thicknesses of 63 to 100 feet were recorded by Chapman (1965) over a north-south distance of 20 miles. Lehmann calculated the thickness to be 150 to 160 feet in the Middletown, Connecticut, quadrangle about 47 miles south of the exposure at Little Mountain. The evidence for a very flat surface on to which the Hampden Basalt was extruded and for highly fluid basalt during extrusion is obvious.

An easily accessible exposure of the Hampden Basalt is located on the south side of U. S. Route 202 immediately west of Interstate I-91. Calcite-filled amygdules up to 1.5 inches in length are exposed on a glacially polished surface of dark-gray fine-grained basalt. The outcrop is approximately 50 feet long and tapers from a maximum height of 6 feet to 1 foot. The presence of amygdules on a surface which slopes gently (7 to 10 degrees) toward the east suggests that the polished surface may be close to the former top of the Hampden Basalt at this locality.

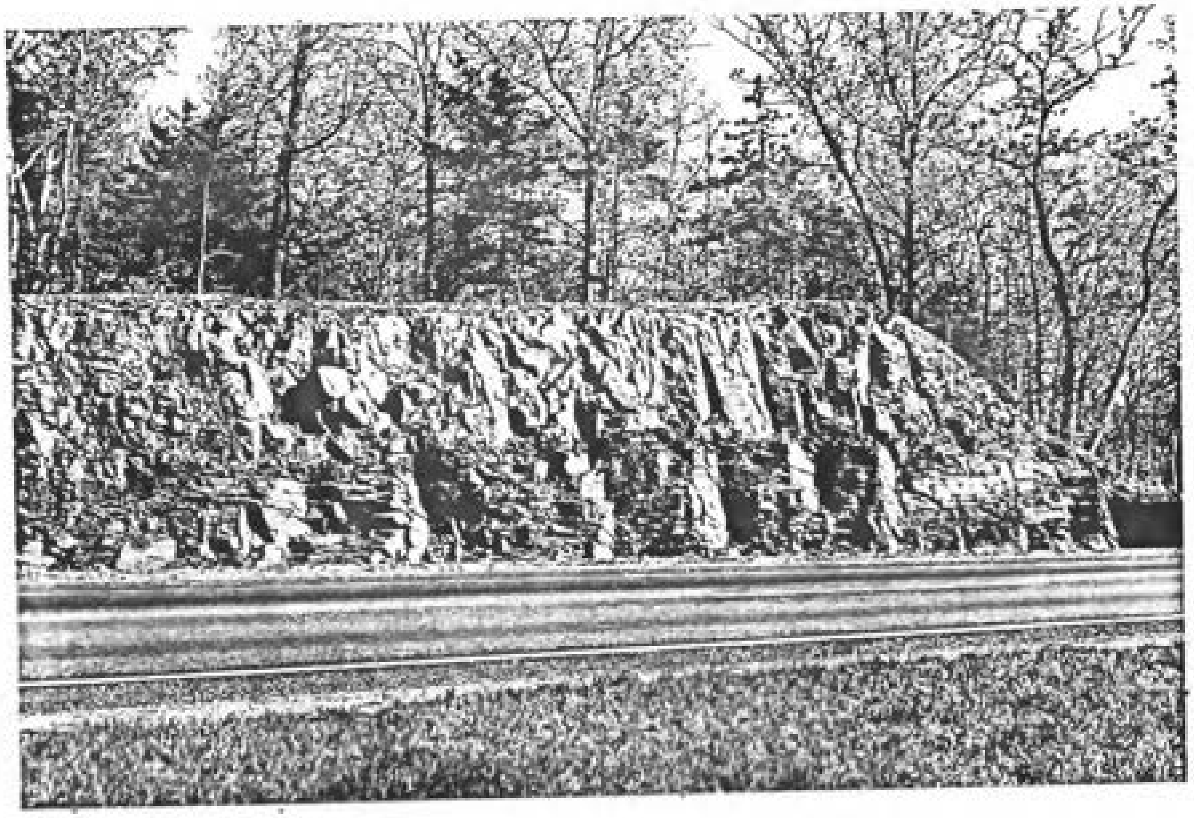
The contact of the Hampden Basalt with the underlying East Berlin Formation may be seen on the east side of Interstate I-91, 0.23 of a mile N. 31° E. of Cedar Knob (fig. 16A). The East Berlin Formation strikes N. 28° E. and dips 20 degrees to the east-southeast. The basalt displays crude columnar jointing and is apparently conformable with the underlying siltstones.

Other Volcanic Rocks

Minor amounts of tuff, agglomerate, and volcanic sandstone occur in the vicinity of Cedar Knob in the northeast corner of the Mount Tom quadrangle. These extrusive rocks appear to be associated with a series of small intrusive plugs that occur in a zone which stretches about 2.5 miles north-northeast from Cedar Knob into the Mount Holyoke quadrangle. One of these

Figure 16 (A). Hampden Basalt resting conformably on East Berlin Formation. Location is on east side of Interstate I-91 0.23 of a mile N. 31° E. of Cedar Knob.

(B). The "Mount Tom Volcanic Plug" (Foose and others, 1968). Massive appearing basalt in the plug at left turns horizontally and overlaps finer textured basalt on lower right. Light-colored rock above guard rail at left is a xenolith of the East Berlin Formation. Location is on the west side of Interstate I-91 0.28 of a mile N. 25° E. of Cedar Knob.



A.

B.

Figure 16

plugs was exposed in cross section during construction of Interstate I-91 and has been described in detail by Foose, Rytuba, and Sheridan (1968). The volcanic plug, unfortunately named the Mount Tom volcanic plug, consists of five separate flow units plus a unit of tuff (fig. 16B). The fifth flow unit rises vertically from the plug and turns horizontally to overlap two earlier flow units. Light-colored tuff in turn covers part of the fifth flow unit (Foose and others, 1968).

Since I have not completed bedrock mapping in the northeast portion of the Mount Tom quadrangle, relationships between the Hampden Basalt, the volcanic plugs, and the extrusive volcanics are not yet clear.

Portland Arkose

The Portland Arkose (table 1) underlies the eastern and southeastern portions of the Mount Tom quadrangle (pl. 1). In spite of the fact that the arkose underlies 16 percent of the area of the quadrangle it is the least well exposed rock unit.

The Portland Arkose was named by Krynine (1950) for a series of coarse-textured arkosic conglomerates and arkoses in the Portland, Connecticut, area. The Portland Arkose in the type locality is defined as those rocks that lie between the Hampden Basalt on the west and the eastern border fault of the Triassic Lowland.

Rocks mapped as Portland Arkose on plate 1 lie east of the Hampden Basalt and extend eastward beyond the Mount Tom quadrangle and across the Springfield North quadrangle to the vicinity of Wilbraham, Massachusetts (Emerson, 1917). In the Mount Tom quadrangle the Portland Arkose includes rocks that were originally mapped by Emerson (1898a) as Longmeadow Sandstone and Chicopee Shale. For reasons given on page 57 these latter two terms are no longer considered proper rock-stratigraphic units. In the case of the Chicopee Shale, Emerson (1898a) included in that unit gray siltstones and shales that lie west of the Hampden Basalt, which is considered to be a time-stratigraphic marker.

The same kinds of lithologies found in the East Berlin Formation occur in the Portland Arkose. They are reddish-brown to brown arkose and arkosic siltstone, gray arkosic siltstone and shale, and black shale. Ripplemarks and mud-cracks are common sedimentary structures that indicate a depositional environment which fluctuated between shallow lacustrine and fluvial mudflat. The thickness of the Portland Arkose is approximately 3,400 feet in the Mount Tom quadrangle, based on a maximum outcrop width of 12,700 feet and an assumed average dip of 15 degrees to the east-southeast.

Most exposures of the Portland Arkose are small and lie along stream beds. The best exposure is inaccessible to the public as it lies on the Massachusetts Turnpike east of and under the overpass for Interstate I-91. Reddish-brown arkose, arkosic siltstone and shale, and gray arkosic siltstone and shale all display ripplemarks and mudcracks on the same bedding plane surfaces. The rocks, exposed over a distance of 300 feet horizontally, strike N. 14° E. and dip 13 degrees to the east-southeast.

Surficial geology

Direction of ice movement

The long axes of 21 drumlins and data from 28 striation localities and 4 till-fabric studies are plotted on figure 17. Directional data are concentrated in the eastern half of the Mount Tom quadrangle. More striation localities occur in the eastern half of the quadrangle because of resistance to weathering and erosion of the bedrock. The lower portion of the Sugarloaf Formation, which underlies the lowland west of the Holyoke Basalt ridge, is easily susceptible to weathering. In the eastern half of the quadrangle the upper portion of the Sugarloaf Formation, the Holyoke Basalt, portions of the East Berlin Formation, and the Hampden Basalt are all resistant to weathering. Striations formed on these latter formations have had a good opportunity to survive postglacial weathering if they were covered by a small amount of glacial debris (p. 16).

The long axes of drumlins show a consistent north-south lineation, whereas striations and till-fabric data are less consistent, being spread over a broad range (due west to S. 55° E.). This is believed to be due to the fact that the drumlins

Figure 17. Outline map of Mount Tom quadrangle showing directional features produced by the movement of the last ice sheet (see text for discussion).

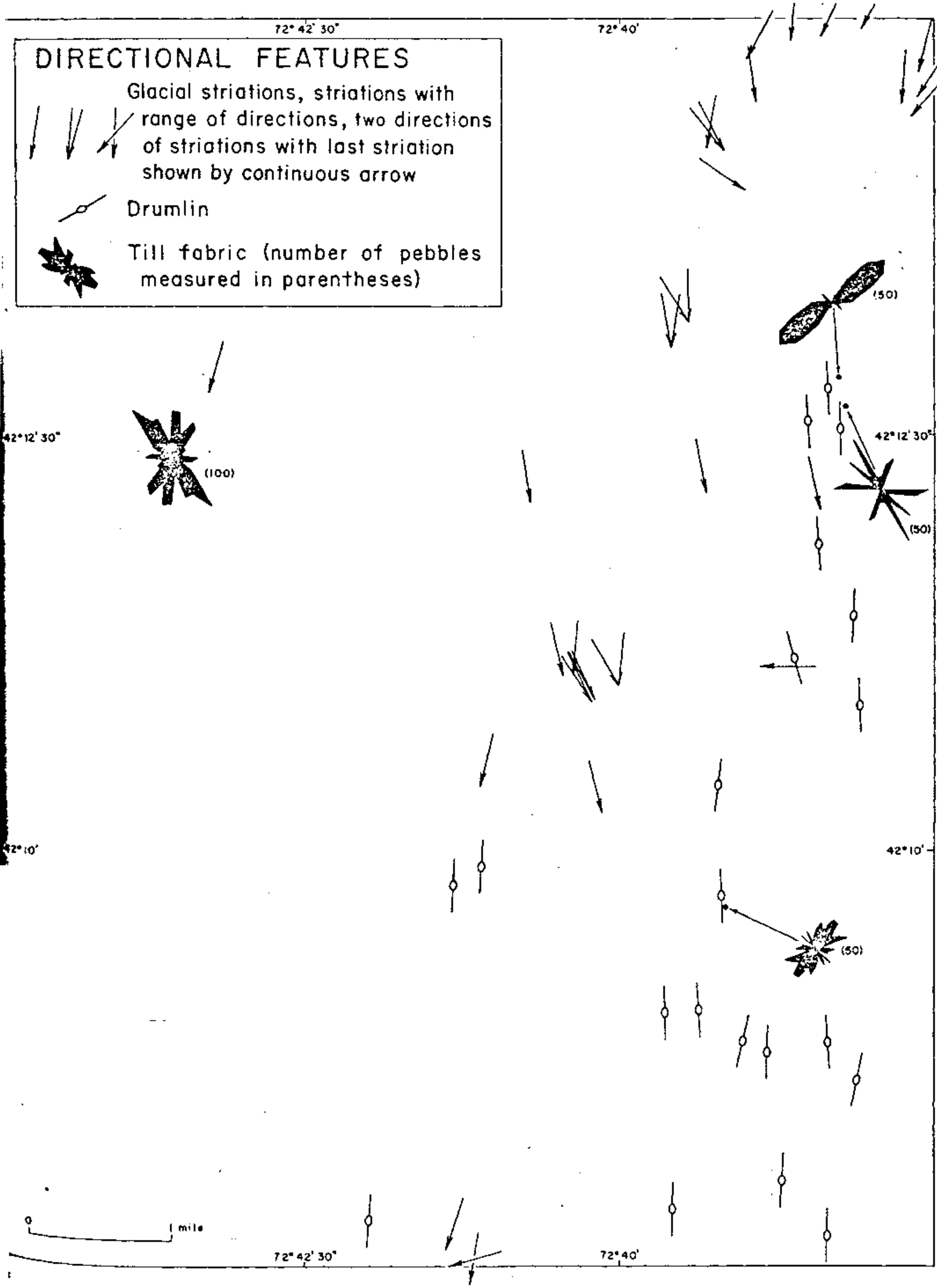

DIRECTIONAL FEATURES
Glacial striations, striations with range of directions, two directions of striations with last striation shown by continuous arrow
Drumlin
Till fabric (number of pebbles measured in parentheses)
72° 42' 30"
72° 40'
42° 12' 30"
42° 10'
(50)
(100)
(50)
(50)
0
1 mile
72° 42' 30"
72° 40'

Figure 17

were molded during maximum activity of the ice when movement was essentially due south. On the other hand, striations and till fabrics were formed much later than the drumlins, presumably just prior to stagnation and disappearance of ice from a particular locality.

While the drumlins were being formed east of the basalt ridge, deep erosion was occurring in the lowland west of the ridge (p.91). The concentration of drumlins east of the ridge may be related in part to the fact that the velocity of the ice was retarded by the basalt ridge during maximum activity of the ice.

Ice movement was southward, as indicated by directional features plotted on figure 17. Roche moutonnée forms, crag and tail, and indicator boulders have not been plotted on figure 17, but these features support the contention that ice movement was to the south and not to the north. Roche moutonnée forms (figs. 19 to 21) and crag and tail (fig. 22A) are discussed on pages 80 to 88.

Erratics of the Belchertown Tonalite have been carried southward into the Mount Tom quadrangle from outcrops in the northeast portion of the Easthampton quadrangle and the southeast portion of the Williamsburg quadrangle (in figure 2 the tonalite underlies the easternmost portion of the New England Upland northeast of Florence). In the field, the tonalite is medium-to coarse-textured granitic rock that appears to be composed mostly of white feldspar (plagioclase) and dark-green to black amphibole (hornblende) with minor amounts of quartz and biotite. Erratics of the tonalite have been moved southward and lifted 1,000 feet vertically to the crest of the Mount Tom Range (fig. 18) and are common both east and west of the basalt ridge.

Erratics of the Portland Arkose, East Berlin Formation, and volcanic rocks associated with the Hampden Basalt are not found north or west of the Holyoke Basalt ridge. On the other hand, erratics of the Sugarloaf Formation are common on and east of the basalt ridge.

The largest erratic encountered during mapping is located on the south end of a small drumlin just west of Snake Pond. It is a block of pebbly arkose from the Sugarloaf Formation, 25 feet long, 20 feet wide, and 10 feet high, and rests on till.

Glacial erosion

Small-scale features

All of the Mount Tom quadrangle was glaciated by the last ice sheet. Striations trending S. 10° E. occur near the summit of Mount Tom at an elevation of 1,205 feet, indicating that glacial abrasion was effective at that elevation. Striations and roche moutonnée forms are common on recently exposed basalt surfaces at an elevation of 1, 130 feet near the top of

Figure 18. Erratic of Belchertown Tonalite resting on pavement of Holyoke Basalt on the crest of the Mount Tom Range. Location is at an elevation of 1,100 feet near the summit of Deadtop, 0.85 of a mile N. 14° E. of the summit of Mount Tom. A smaller erratic of tonalite was found above 1,200 feet elevation on the summit of Mount Tom. The nearest outcrop of Belchertown Tonalite occurs 6.0 miles to the north.

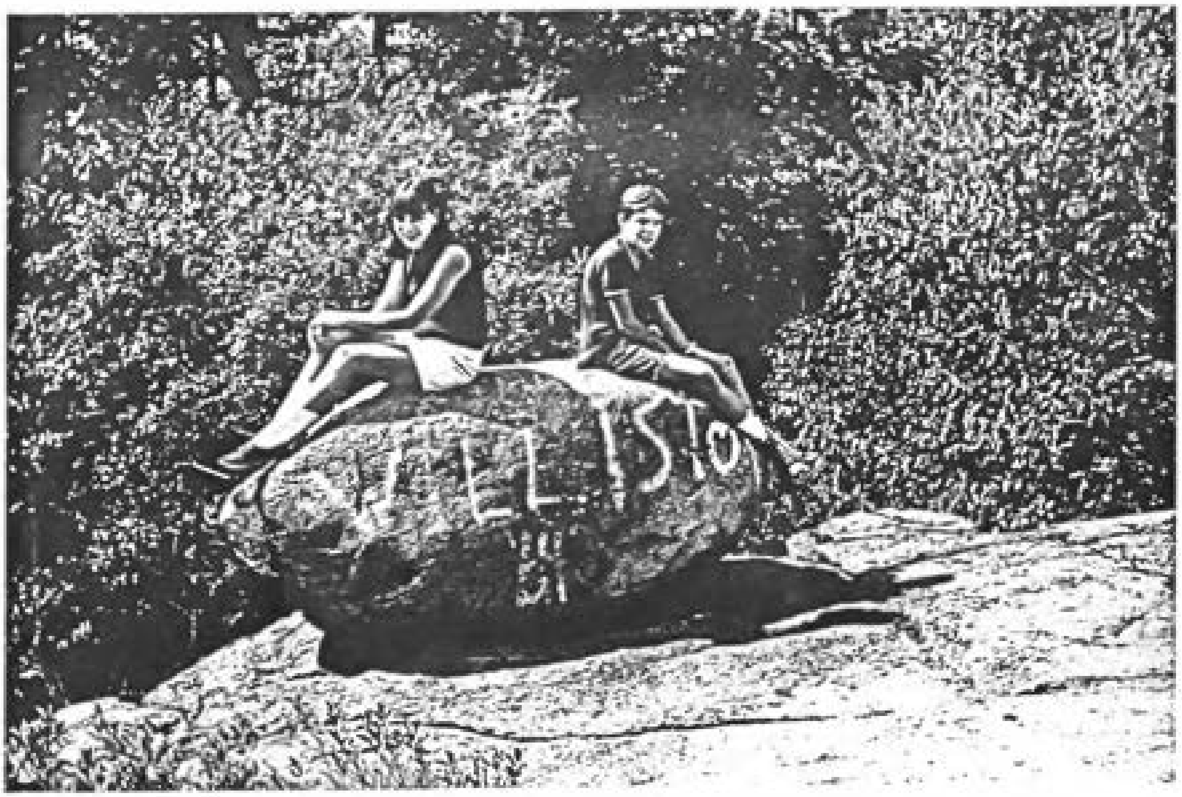


Figure 18.

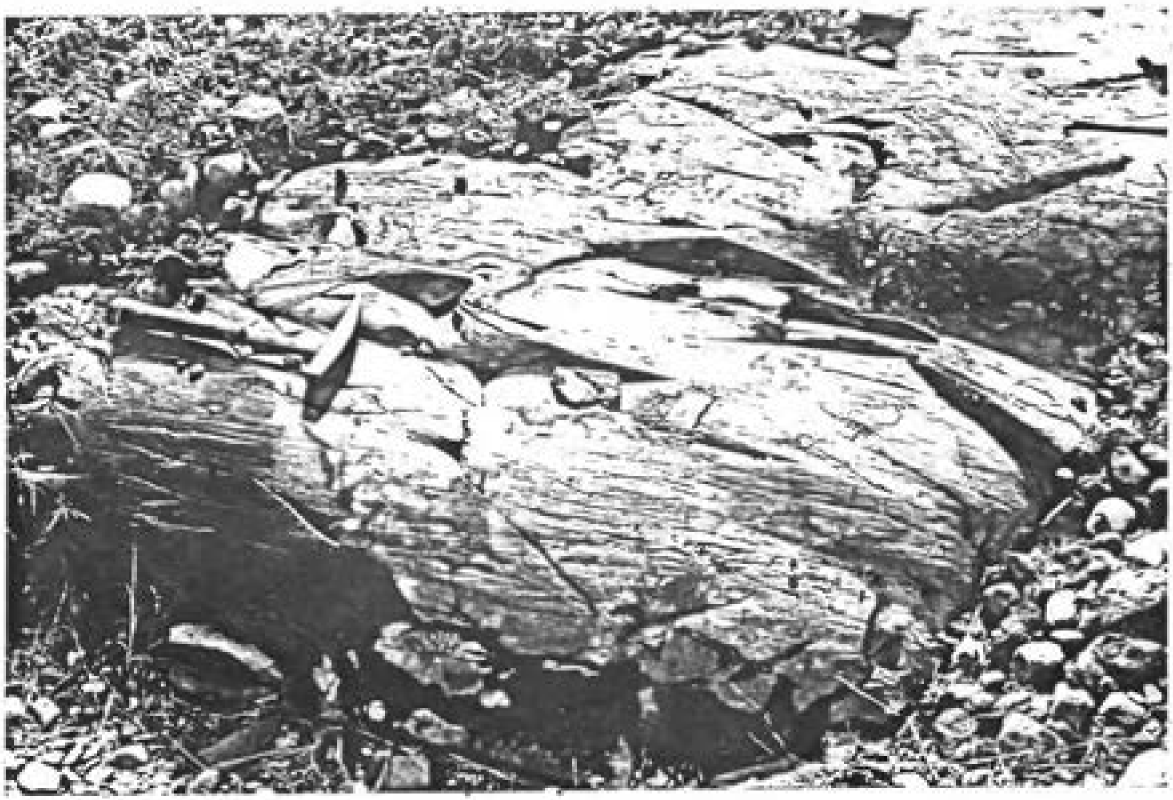
the Mount Tom ski lift (fig. 19A). The summit station is located on the crest of the Mount Tom Range 500 feet north of the Mount Tom quadrangle.

Striations are not found on basalt outcrops that have been exposed to weathering processes since the retreat of the last ice sheet about 13,000 years ago. However, good examples of glacial erosion may be found where basalt surfaces have been exposed recently by man's activities. The Lane Quarry in Westfield is actively engaged in stripping away surficial debris, mostly till, in order to reach the Holyoke Basalt, which is excavated for road metal and other uses. The quarry is located along the crest of East Mountain at the center of the southern margin of the Mount Tom quadrangle. Here the basalt surface is unweathered and displays numerous features such as striations, glacial grooves and roche mountonnée forms which trend S. 15° W. (fig. 19B).

A series of small but spectacular molded bedrock forms have been exposed at excavations for the Interstate Highway I-91 where it crosses the Holyoke Basalt 3.3 miles N. 37° E. from the summit of Mount Tom. The locality, situated in the Mount Holyoke quadrangle, is on the west side of I-91 opposite the power plant of the Holyoke Water and Power Company in the water gap of the Connecticut River. The lower exposures of basalt have been protected from weathering by a cover of coarse sand and gravel, which was removed during construction of I-91.

Figure 19 (A). Glacial striations which trend S. 18° E. at elevation 1,130 feet on Holyoke Basalt near the crest of the Mount Tom Range. Glacial movement was right to left. Location is 150 feet northeast of end of Mount Tom ski lift.

(B). Roche moutonnée forms and striations on Holyoke Basalt at the Lane Quarry, Westfield. Glacial movement, S. 19° E., was from lower left to upper right. Location is 0.1 of a mile north of the southern boundary of the Mount Tom quadrangle.



A.

B.

Figure 19

The higher outcrops of basalt have been exposed since the ice retreated from this area,or at least since the drainage of Lake Hitchcock about 10,710 B.P. (Flint, 1956) (fig. 4).

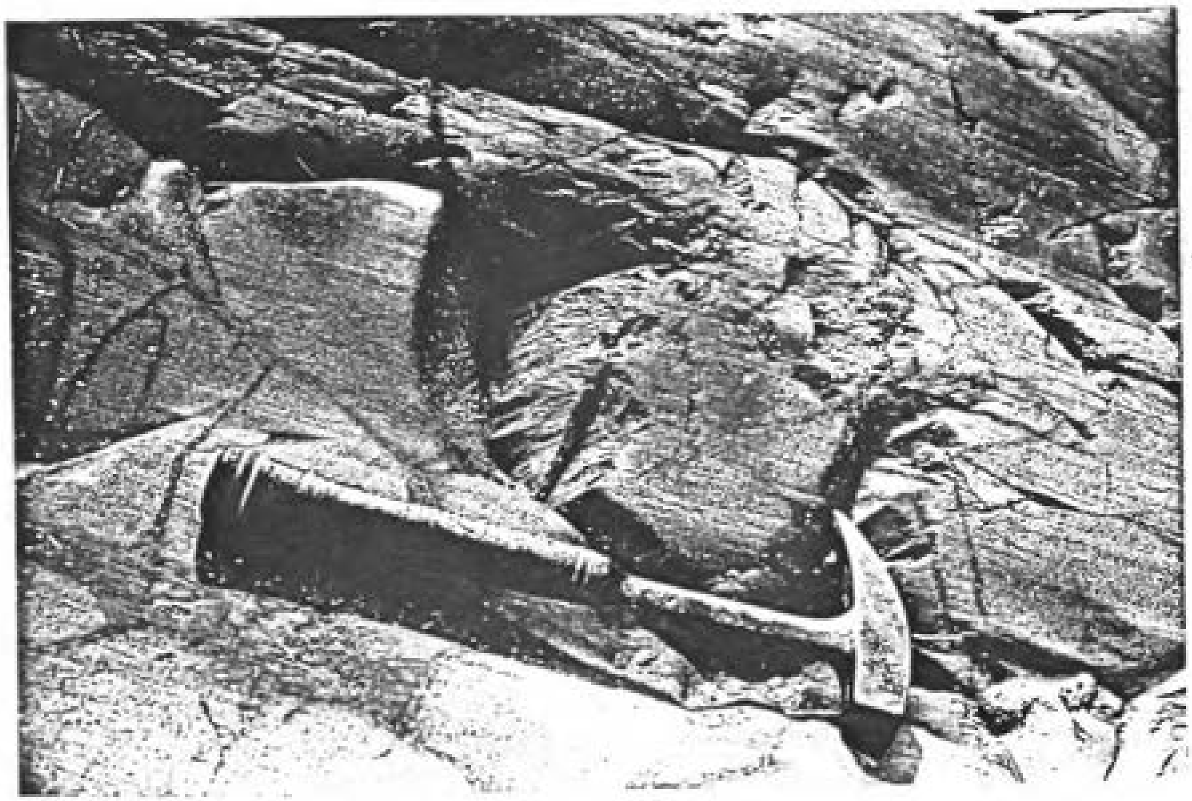
On the lower outcrops the details of glacial abrasion and plucking are clear. The basalt, being dense and relatively homogeneous, has allowed the formation and preservation of the finest hairline scratches and fluting (fig. 20A). Striations diverge at the upglacier end of a roche moutonnée and end at the downglacier portion where plucking predominates. The jointed nature of the basalt has allowed small triangular blocks to be lifted from subhorizontal surfaces. Figure 20B illustrates an instance where plucking occurred late in the erosional history of the surface shown, because the downglacier side of the excavated depression is not striated whereas the edge above it is rounded by abrasion. The upglacier edge of the depression is still quite sharp. The situation is similar to a roche moutonnée in reverse, that is, the plucked surface is on the upglacier side of the depression while the striated side or edge is on the downglacier side.

The presence of columnar jointing on the downglacier end of a roche moutonnée facilitates the plucking process as shown in figure 21A. On the stoss (upglacier) side of the roche moutonnée the basalt columns and veins filling the columnar joints have been truncated by abrasion (fig. 21B).

Figure 20 (A). Striations and roche moutonnée forms on Holyoke Basalt. Glacial movement was right to left. Location is southwest of Interstate I-91 in the Holyoke Narrows, Mount Holyoke quadrangle.

(B). Detail of plucked surface of Holyoke Basalt. Note lack of abrasion and sharp edges on up-glacier (right) side of depression compared to downglacier side. Location: same as figure 20A.

A.



B.

Figure 20

Figure 21 (A). Detail of plucking developed on columns in Holyoke Basalt at downglacier end of roche moutonnée. Glacial movement was right to left. Location: same as figure 20A.

(B). Detail of truncated surface on columns of Holyoke Basalt on stoss side of same roche moutonnée as in figure 21A. Glacial movement was toward observer.

A.

B.

Figure 21

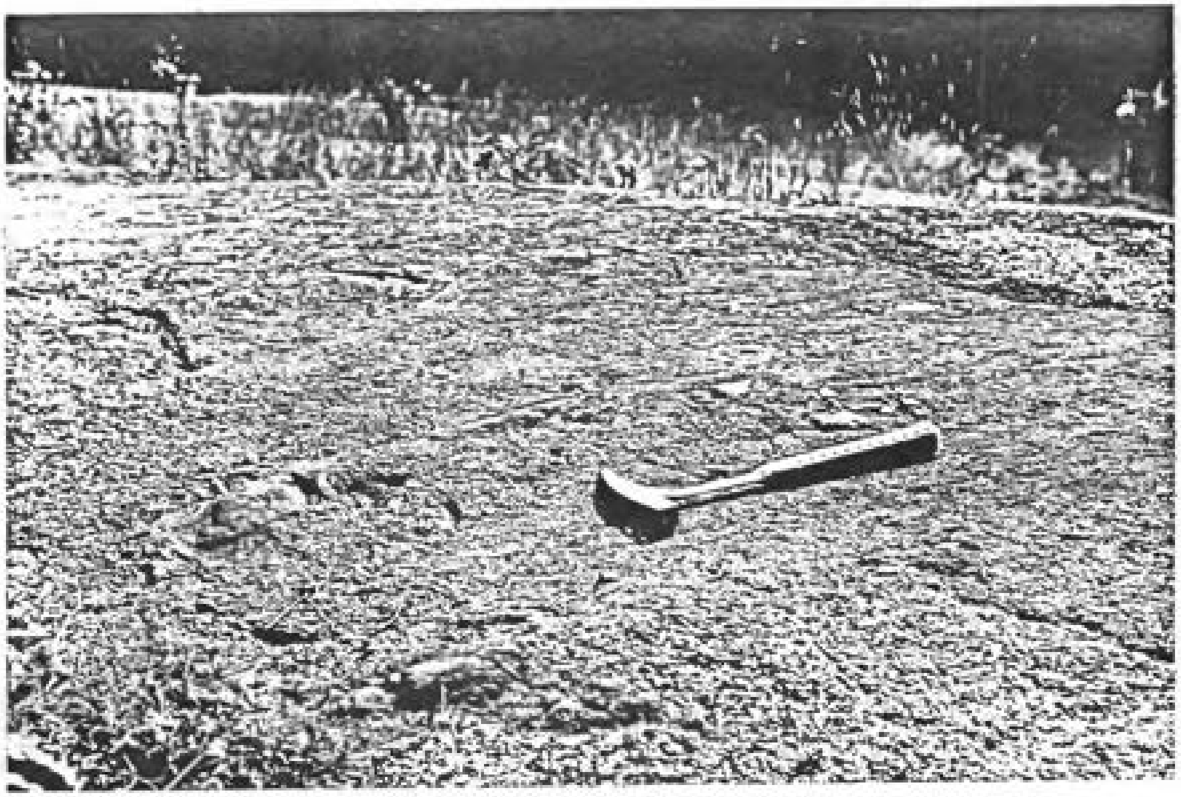
At one locality small-scale crag and tail was observed on bedrock. The locality is behind the Log Cabin Restaurant 0.4 of a mile S. 32° W. of the summit of Mount Tom. An exposure of the Sugarloaf Formation forms a glacial pavement with striations, crag and tail (fig. 22A), and crescentic gouge (fig. 22B). Resistant granitic clasts have prevented abrasion of bedrock in the direction of glacial movement while erosion of bedrock occurred on the upglacier side of the clasts. The crag and tail gives a vector to striations which trend S. 28° E. to S. 40° E.

Large-scale features

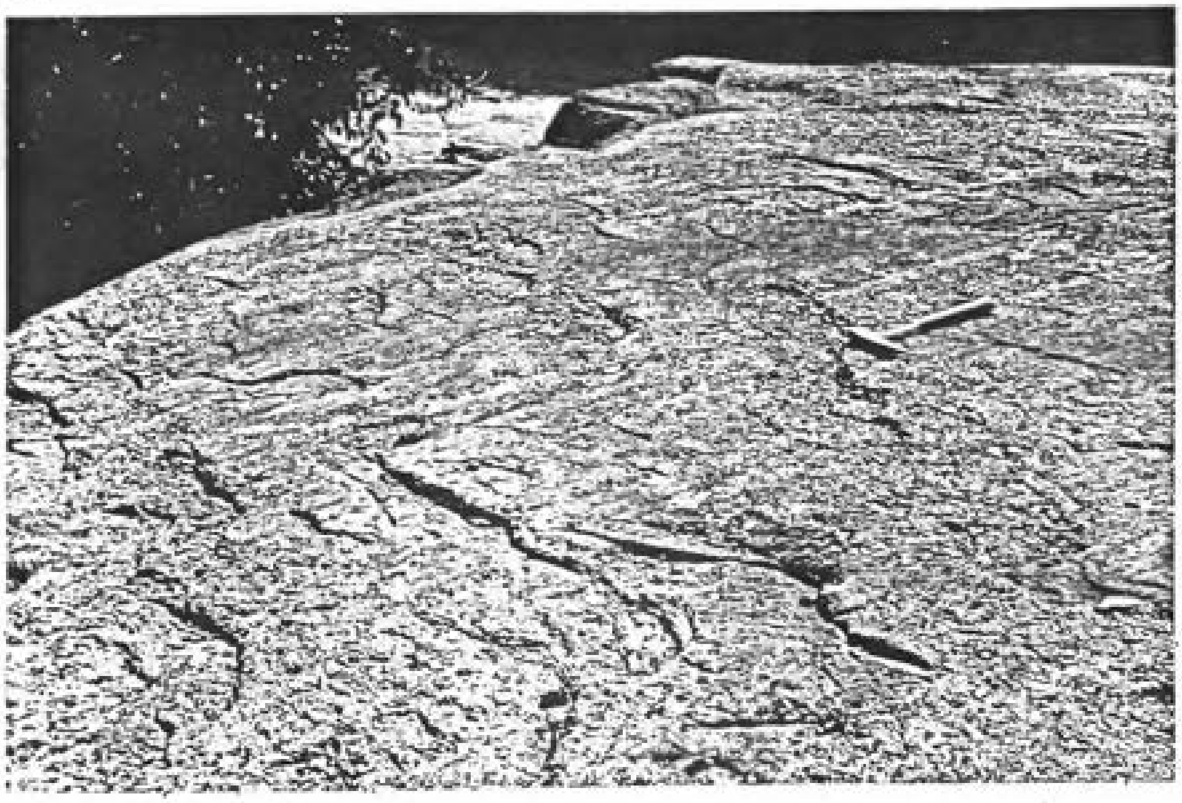
The basin occupied by Ashley and Wright Ponds trends parallel to the strike of the East Berlin Formation and close to the direction of glacial movement. The situation is interesting because the original basin was probably formed by glacial scour, yet the two ponds could be classified as kettles because they are bordered by outwash gravel deposits. During deglaciation a melting block of ice lay in the rock basin while gravel was deposited up to the threshold of the basin. The melt-water source of the gravel disappeared before the ice melted or there would be no water-filled depressions there today. Unlike the man-made Whiting Street Reservoir and the reservoir 0.5 of a mile west of Wright Pond, Ashley and Wright Ponds are natural even though they have been altered slightly for use as reservoirs by the City of Holyoke.

Figure 22 (A). Crag and tail developed on glacial pavement underlain by arkosic conglomerate of the Sugarloaf Formation. Resistant granitic clasts (left and lower left of hammer) have protected bedrock from abrasion on downglacier side. Glacial movement was left to right parallel to hammer. Location is 0.4 of a mile S. 32° W. of the summit of Mount Tom.

(B). Crescentic gouge (chattermarks) produced by glacial erosion of Sugarloaf Formation. Glacial movement was left to right parallel to hammer. Location: same as figure 22A.



A.



B.

Figure 22

Many small basins, presumed to be formed by glacial scour and plucking, occur on the Holyoke Basalt and are occupied today by ponds or swamps.

On a very much larger scale, the origin of the large subsequent valley, 1.0 to 1.5 miles west of and parallel to the Holyoke Basalt ridge, has been a topic of debate since the time of Edward Hitchcock (1841). A misconception, still popular among some local people, is that the Connecticut River carved out this valley when it flowed southward on the west side of the basalt ridge, and that since the retreat of the last ice sheet the Connecticut River was diverted through the water gap at the Holyoke Narrows. This concept requires that the ice sheet or the Connecticut River, or both, formed the water gap at the Holyoke Narrows since advance of the last ice sheet. There are many drawbacks to this idea, not the least of which is the fact that the western lowland of the Triassic valley is essentially a blind passage to the south with no apparent outlet for a stream the size of the Connecticut.

B. K. Emerson (1898b) put the matter to rest in a logical scientific statement that points out that each of the water gaps in the Holyoke Basalt ridge is occupied by the Connecticut River or by one of its major tributaries such as the Deerfield, the Westfield, or the Farmington River. His idea was that an integrated drainage system with the Connecticut as its trunk or main stream was superimposed upon the present structure and topography from a higher erosion surface. When the main stream and its tributaries cut down into the underlying rocks they did so at a rate that allowed them to cut through the Holyoke Basalt and adjacent sedimentary rocks. After each of several glaciations during the Pleistocene, the Connecticut and its tributaries reoccupied each of the original water gaps. In none of the water gaps does the stream flow directly on bedrock, showing that the water gaps are not now being deepened by the streams occupying them (Emerson, 1898b). This suggests that each of the water gaps has been overdeepened by glacial erosion and has subsequently been filled in by debris during deglaciation.

Much evidence (Emerson, 1898b; Jahns, 1966 and 1967; Jahns and Willard, 1942; Foose and Cunningham, 1968; Saines, 1971) indicates that the Connecticut River in Massachusetts is not flowing in the same channel today that it did immediately prior to advance of the last ice sheet. However, there is no evidence suggesting that the Connecticut River and its tributaries did not occupy their water gaps prior to the last glaciation. The trend of the buried channel of the Connecticut River at South Hadley (Emerson, 1898b; Saines, 1971) indicates that it was formed by a stream that occupied the Holyoke Narrows. If we accept the fact that the buried channel is pre-last glacial in age it supports the contention that the ancestral Connecticut River occupied the Holyoke Narrows prior to the last glaciation.

In addition, evidence from recent borings and well data suggests that the large subsequent valley west of the basalt ridge owes its bottom topography to glacial erosion in nonresistant rock. Figure 23 shows elevation of bedrock or till at the bottom of selected borings (solid circles) along the axis of the valley in question. A profile of this data (fig. 24) reveals an undulating bedrock surface with a vertical relief of at least 100 feet. It would be impossible for a portion of any stream to cut 225 feet (the difference between the -85 foot boring and the 140-foot boring to the south) deeper than the adjacent downstream portion of the same stream. Since a glacier is a geologic agent that is known to erode sizable closed depressions, the boring data suggest that the subsequent valley was overdeepened by the continental ice sheet when it encountered erodable rock in the Sugarloaf Formation.

As is common elsewhere in glaciated terrain, the deepest basins occur just upglacier from major constrictions. The deepest boring on figure 23 (elevation -95 feet at the Oxbow) occurs with several other borings that reach below sea level about 1.6 miles northwest of the Holyoke Narrows, which itself has a U-shaped profile when viewed from the northwest. The next deepest boring (elevation -85 feet between Mount Tom and Whiteloaf Mountain, fig. 23) occurs on the upglacier portion of the constriction between Whiteloaf Mountain on the west and East Mountain. This phenomenon is due to increase in the velo-

Figure 23. Outline of the Mount Tom quadrangle and the southern portion of the Easthampton quadrangle showing elevations on bedrock or till-covered bedrock. Solid circles denote elevation at point of refusal in borings, most of which bottomed in bedrock. In some borings it was not ascertained whether the boring ended in bedrock or till. Crosses denote surface elevations on higher ground. See figure 24 for profile of topography and bedrock surface.

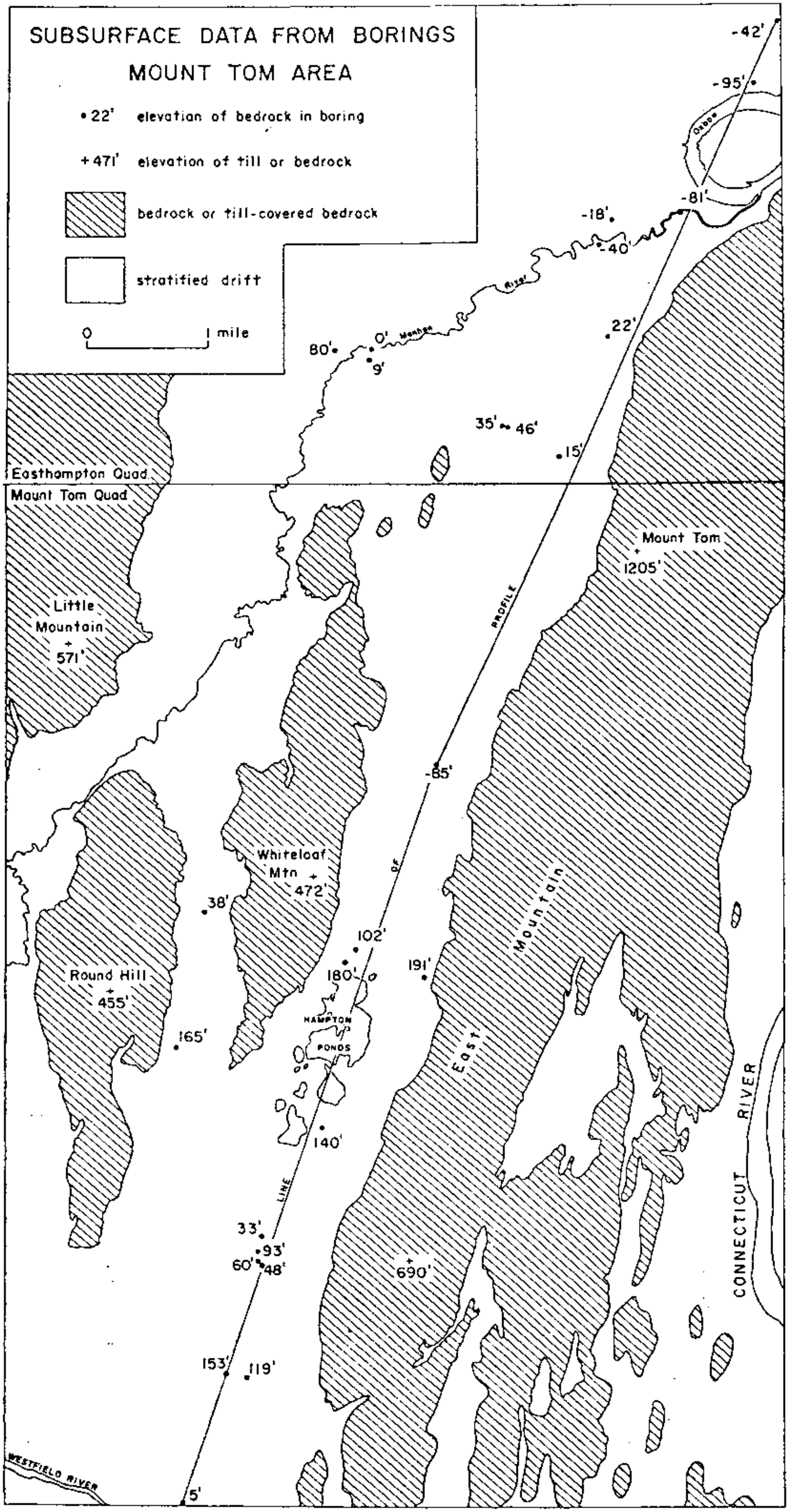

SUBSURFACE DATA FROM BORINGS
MOUNT TOM AREA
• 22' elevation of bedrock in boring
+ 471' elevation of till or bedrock
bedrock or till-covered bedrock
stratified drift
0 1 mile
Easthampton Quad
Mount Tom Quad
Little Mountain 571'
Round Hill 455'
Whiteloaf Mtn 472'
Mount Tom 1205'
East Mountain
690'
HAMPTON PONDS
PROFILE OF LINE
CONNECTICUT RIVER
WESTFIELD RIVER
Manhan River
Oxbow
-42'
-95'
-81'
-18'
-40'
22'
80'
0'
9'
35'
46'
15'
-85'
38'
102'
180'
191'
165'
140'
33'
93'
60'
48'
153'
119'
5'

Figure 24. Profile of topography and bedrock surface in subsequent valley west of Holyoke Basalt ridge. See figure 23 for location of profile.

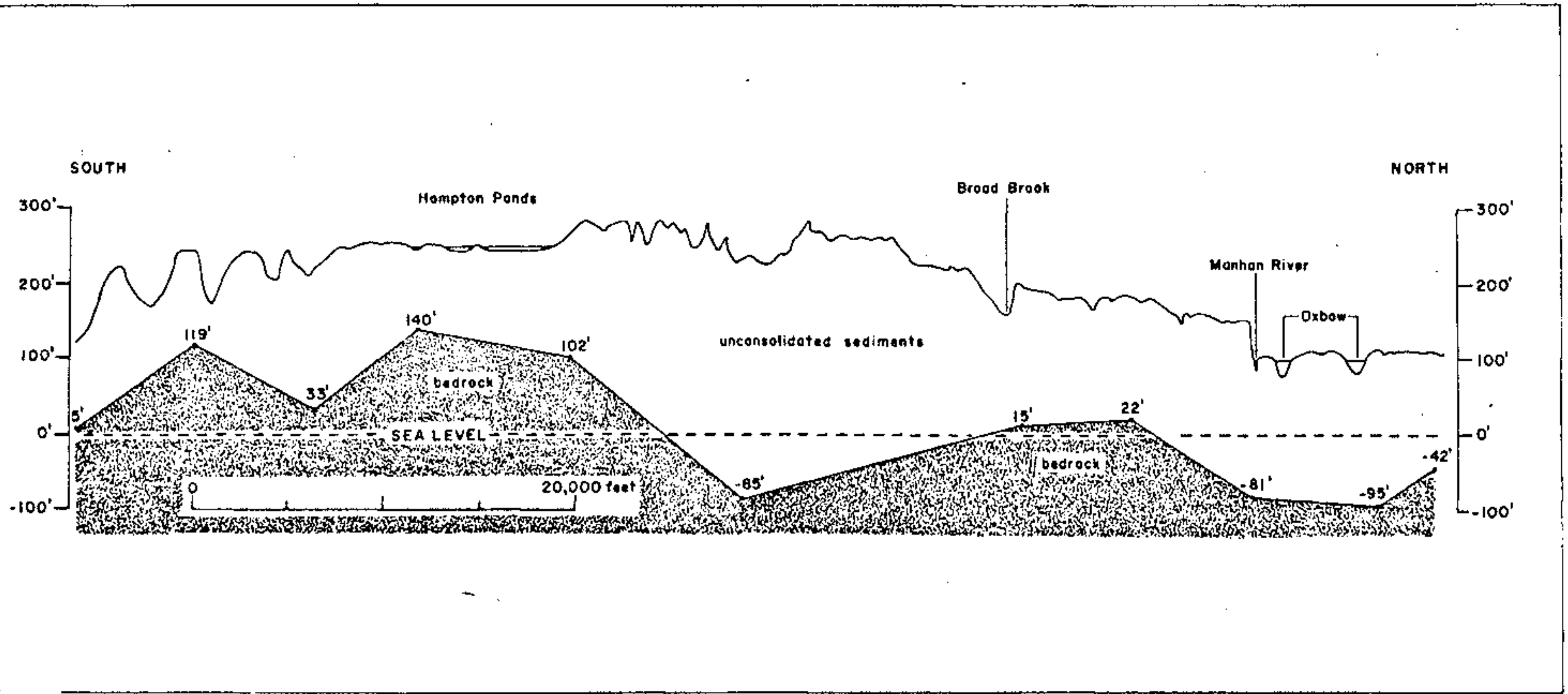

SOUTH
NORTH
300'
200'
100'
0'
-100'
Hampton Ponds
Broad Brook
Manhan River
Oxbow
unconsolidated sediments
bedrock
SEA LEVEL
5'
119'
33'
140'
102'
-85'
15'
22'
-81'
-95'
-42'
0
20,000 feet

Figure 24

city of basal ice where the ice is constricted by the topography.

The present elevation of the surface of the Connecticut River at Northampton is about 100 feet. In pre-last glacial time the Connecticut River could only have been lower in the same area because today it is entrenched in bedrock east of the Mount Tom Range, and therefore its upstream portion is higher than it would be if it had returned to its pre-last glacial channel, which has been described by Emerson (1898b) and Saines (1971). It does not seem probable that the Connecticut occupied the valley west of the basalt ridge because elevations on bedrock at the Hampton Ponds area (fig. 23) all exceed the present elevation of the surface of the Connecticut at Northampton. It would also have been impossible for the Connecticut River to have flowed south along the present course of the Manhan River because bedrock exposures occur on the river at elevations greater than 180 feet between two bedrock ridges covered with till.

Pleistocene sediments

All the Pleistocene sediments found in the Mount Tom quadrangle are believed to relate to the time during and since the last major glacial episode. No evidence found in the Mount Tom quadrangle supports the concept of multiple glaciation; however, evidence was discovered that points to a minor readvance of an active ice front.

A generalized geologic column for the surficial deposits of the Mount Tom quadrangle is presented in table 2. Each of the types of sediments will be discussed in turn from oldest to youngest.

Table 2. Glacial, late-glacial, and postglacial sediments arranged in approximate order of deposition (oldest at the bottom).

Sediments	Geologic time
Alluvium Talus Peat Stream-terrace sediments Eolian sediments	Holocene
Lacustrine sediments Outwash deposits Ice-contact deposits Till (="new till") (="upper till")	Late Wisconsin

Till

Fifty percent of the area of the Mount Tom quadrangle is underlain by till, which is defined as a "sediment of diverse texture and structure deposited by direct glacial action" (Scott and St. Onge, 1969). Three separate varieties of till can be recognized in the Mount Tom quadrangle on the basis of color, grouping on a sand-silt-clay ternary diagram, and sand-to-mud ratio. All three tills are presumed to be related to the last major glaciation of New England, and to be equivalent to each other and to the "upper" till of southern New England. In Massachusetts and Connecticut the "upper" (or "new") till is a loose, sandy till that overlies a more compact, fine-grained till that is known as the "lower" (or "old") till (Schafer and Hartshorn, 1965).

Reddish-brown till

West of the basalt ridge the till is reddish brown (2.5 YR 4/4 to 5YR 4.5/3, moist; the numerical designation is the Munsell notation of color, Munsell Color Company, Inc., 1954) and is often characterized by crude compositional layering. In eight size analyses of reddish-brown till, the matrix (see appendix III for definition) ranges from 68.5 to 73.5 percent sand, 13.6 to 27.4 percent silt, and 2.6 to 15.2 percent clay. Figure 25 shows how the eight analyses cluster around a point approximating 72 percent sand, 20 percent silt, and 8 percent clay. The sand-to-mud ratio is obtained by dividing the weight of sand by the combined weight of silt and clay. Sand-to-mud ratios for the eight analyses of reddish-brown till vary from

Figure 25. Ternary diagram of sand-silt-clay ratio for 19 till samples. The median ratio for reddish-brown till is 72 percent sand, 20 percent silt, and 8 percent clay. The median ratio for brown till is 50 percent sand, 35 percent silt, and 15 percent clay. The median ratio for grayish-brown till is 63 percent sand, 26 percent silt, and 11 percent clay.

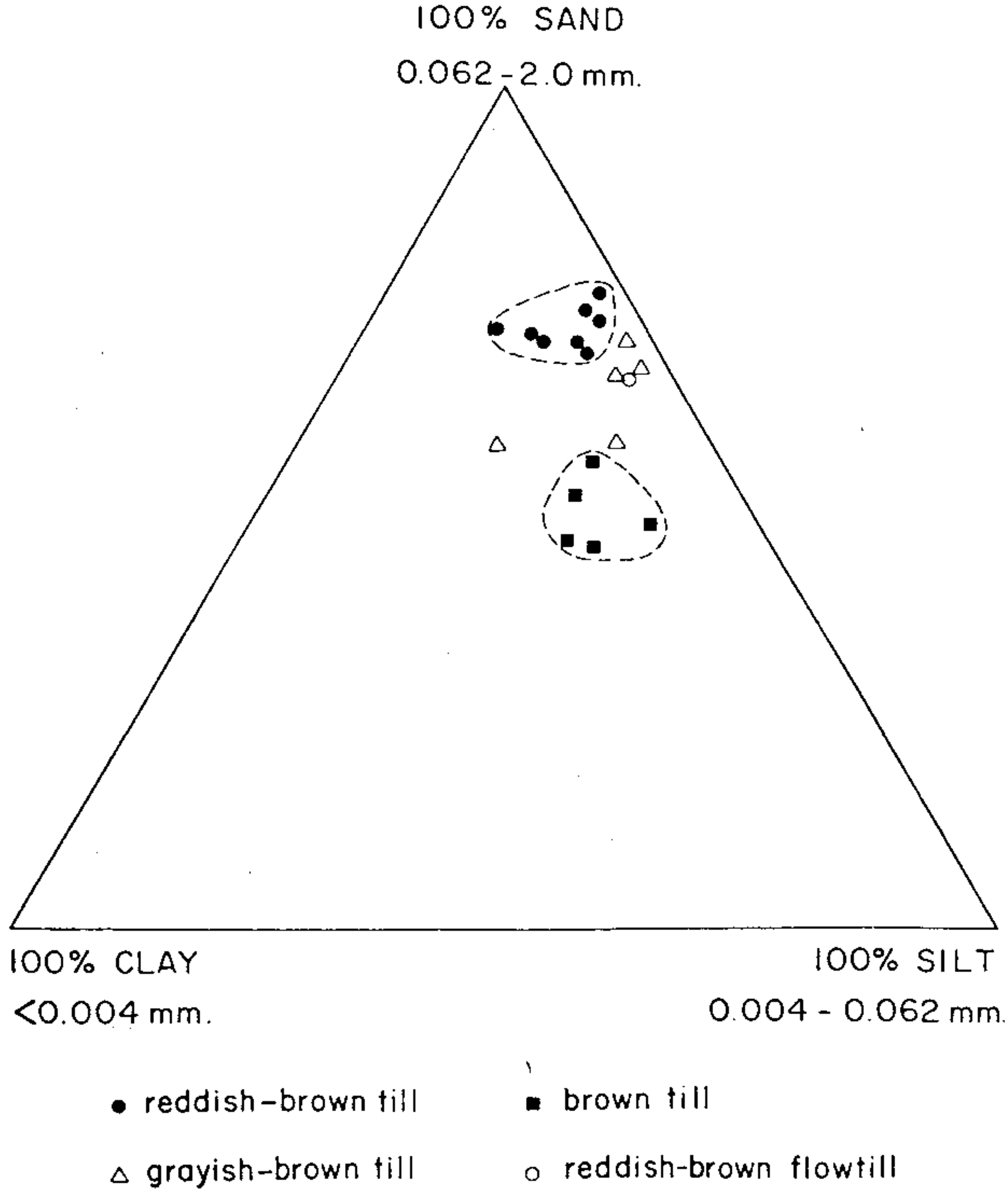

100% SAND
0.062 - 2.0 mm.
100% CLAY
<0.004 mm.
100% SILT
0.004 - 0.062 mm.
reddish-brown till
brown till
grayish-brown till
reddish-brown flowtill

Figure 25

2.23 to 4.71. All the sand-to-mud ratios higher than 1.50 lie west of the Holyoke Basalt ridge (fig. 26).

Grain-size data for the eight analyses also are plotted as cumulative curves on arithmetic probability paper (figs. 27A and 27B) for the purpose of comparison with other till analyses (figs. 28, 29, and 32).

The best exposure of the reddish-brown till was in a temporary roadcut (Loc. 4-110, now graded) on the east side of Route 10, 0.58 of a mile north of Swanson Corners. Twelve feet of loose to compact till were exposed above arkosic conglomerate of the Sugarloaf Formation. No striations were observed due to weathering of the bedrock. The till displayed a crude stratification produced by layers of coarse sand alternating with layers of firm silt and clay. Cumulative curves for grain-size analyses of samples collected at 3, 6, and 9 feet above the bedrock are shown in figure 27B. The curves are quite similar, indicating lack of variation in grain size with depth. The similarity of the curves also serves as a check on laboratory technique. Only 7.5 percent (by weight) of the clasts in a 15.0 pound sample of the till are greater than 3/8 of an inch in diameter and clasts greater than 8 inches in diameter are uncommon.

In a pebble count, only 4 clasts out of 100 are of Triassic origin, while 96 percent are crystalline rocks similar to those of the New England Upland (Loc. 4-110, appendix I).

Figure 26. Outline of Mount Tom quadrangle with location of sand/mud ratios plotted for 15 till samples. Four ratios for grayish-brown till lie in the Easthampton quadrangle to the north. Sand/mud ratios higher than 1.50 lie west of the Holyoke Basalt and those lower than 1.50 lie east of the basalt.

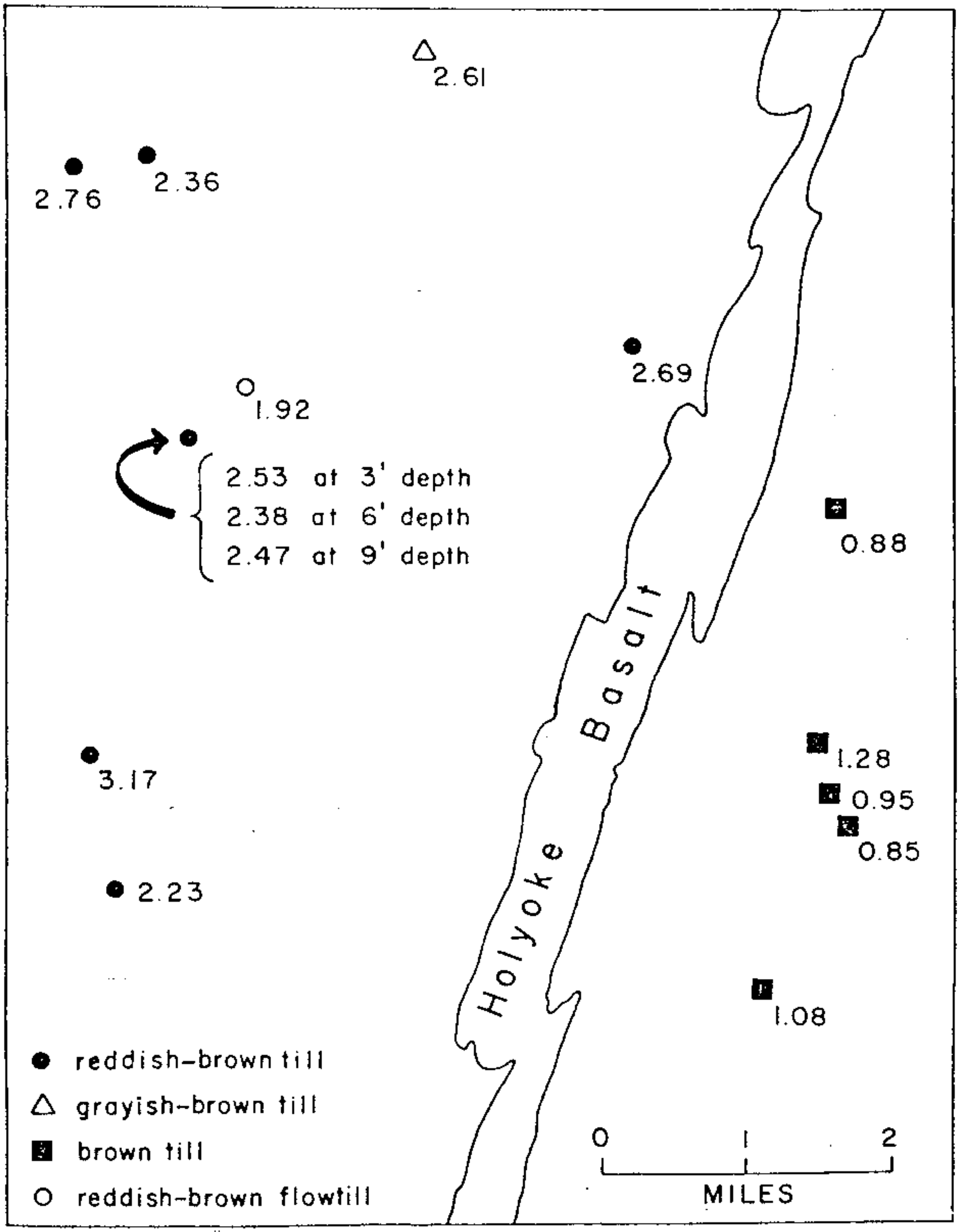

2.61
2.76
2.36
2.69
1.92
2.53 at 3' depth
2.38 at 6' depth
2.47 at 9' depth
0.88
Holyoke Basalt
1.28
0.95
0.85
3.17
2.23
1.08
reddish-brown till
grayish-brown till
brown till
reddish-brown flowtill
0
1
2
MILES

Figure 26

Figure 27 (A). Cumulative curves for five grain-size analyses of reddish-brown till.

(B). Cumulative curves for three grain-size analyses of reddish-brown till at locality 4-110.

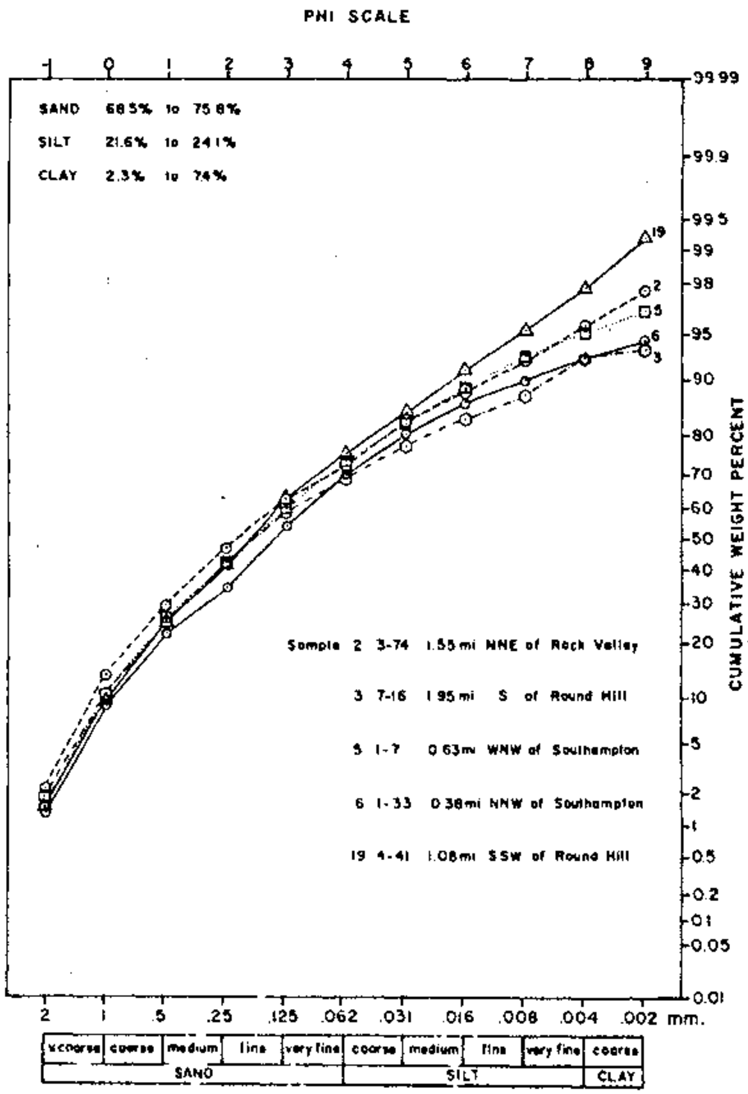


Figure 27A. Grain size of reddish-brown till.

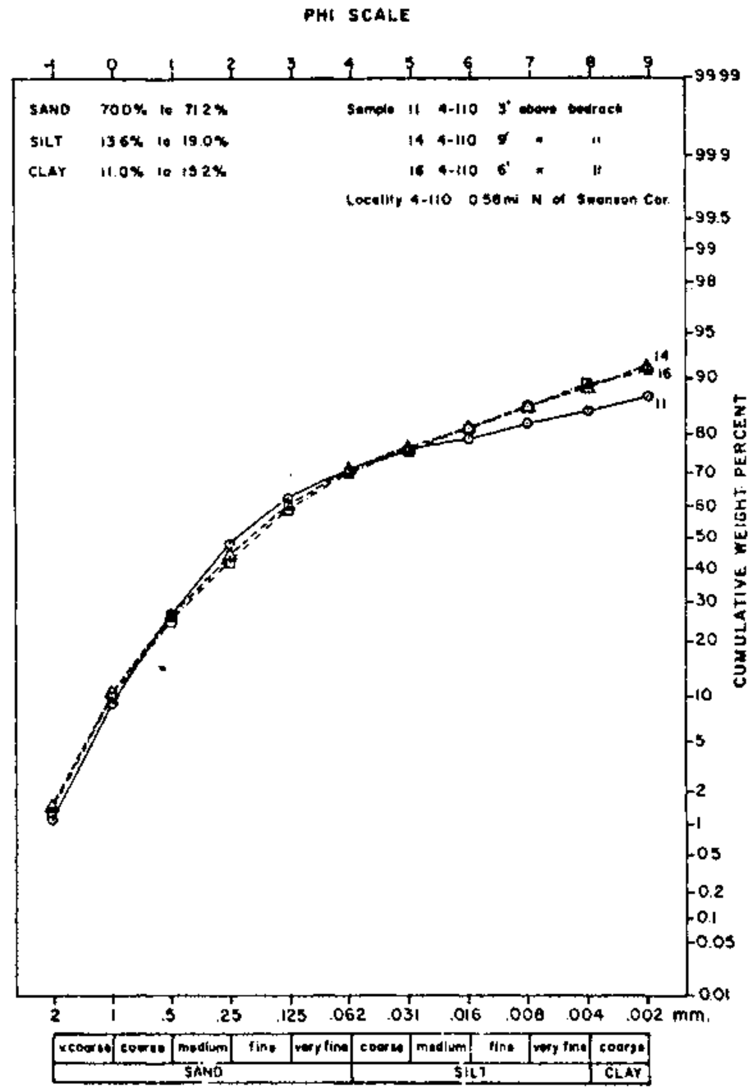


Figure 27B. Grain size of reddish-brown till at Locality 4-110.

This is remarkable in view of the fact that the till rests directly on Triassic bedrock and the nearest source of crystalline rocks lies 2.0 miles to the northwest.

Only 8 percent of 100 pebbles are of Triassic origin in a second pebble count in the reddish-brown till 0.48 of a mile S. 51° W. from the summit of Mount Tom. Of the 86 pebbles of crystalline origin 12 are Belchertown Tonalite. The nearest outcrop of Belchertown Tonalite lies 7.0 miles due north of this second locality (Loc. 3-65A, appendix I).

Two important factors are inherent in pebble-count analysis in the Mount Tom quadrangle. The first is the high resistance to abrasion of crystalline rocks compared to extremely low resistance of Triassic rocks. At some Triassic bedrock localities it is difficult to collect and transport a large sample of rock without breaking it apart (see p. 32). The second factor is the question of the number of clasts in the till derived as second-cycle erosion products from the conglomeratic portions of the Sugarloaf Formation compared to first-cycle clasts from the New England Uplands. The implication is that Triassic rocks supplied the bulk (80 to 90 percent) of the matrix plus a few second-cycle crystalline clasts, while the crystalline rocks of the New England Uplands supplied the bulk of the clasts found in the reddish-brown till.

Locality 4-110 was the only exposure of reddish-brown till where the orientation of pebbles could be conveniently measured for fabric analysis. The orientation of 50 pebbles was measured at each of two faces at right angles to each other, both 5 feet above the bedrock, and by two separate observers. A rose diagram combining the results of both observers is plotted in the northwest quadrant of figure 17. The diagram has strong modes at N. 40° W., due north, and N. 30° E., indicating a complex till fabric (for further discussion of till fabric see appendix II).

Brown till

Brown to dark-brown (7.5YR 4/2, moist) till underlies the terrain east of the basalt ridge. In most exposures greater than three feet in depth the till is compact and displays a well-developed fissility. This characteristic is the ability of the till to separate along irregular, subhorizontal surfaces that do not appear to be related to compositional stratification, as is so common in the reddish-brown till. The exact cause of fissility is unknown, but it is common in tills that are rich in silt (Flint, 1971).

The matrix is composed of 45.6 to 51.3 percent sand, 31.3 to 40.7 percent silt, and 11.2 to 20.8 percent clay, based on five grain-size analyses. The analyses cluster around a point which has a composition of 50 percent sand, 35 percent silt, and 15 percent clay (fig. 25). Sand-to-mud ratios are the lowest of all the tills analyzed and vary between 0.85 and 1.28. The geographic distribution of these low ratios is restricted to the area east of the Holyoke Basalt ridge (fig. 26).

Cumulative curves for the five analyses of brown till are shown in figure 28A. In spite of the fact that 1 of the 5 till samples (7 9-123) is known to be older than at least 2 of the others (8 6-39 and 10 6-45), as based on evidence for readvance of glacial ice, the 5 analyses are notably similar. The similarity is undoubtedly related to the type of bedrock over which the glacier passed in deriving the brown till. Envelopes produced by cumulative curves of the reddish-brown till and the brown till are compared in figure 28B. The two envelopes are completely separate between 2.25ϕ and 6.75ϕ, illustrating again that the reddish-brown till is more coarse grained than the brown till.

Several good exposures were observed in the brown till, the best being located in temporary cuts related to construction activity. At Locality 6-46, 0.3 of a mile west of Mont Marie, 7 to 11.5 feet of brown till rest on thrust-faulted sands. This exposure constitutes the best evidence found in the Mount Tom quadrangle for readvance of ice during late glacial time. This topic is discussed later in this report under the heading "Readvance" (p.205). The middle 5 to 9 feet of the exposure (fig. 51A) is a brown to dark-brown (moist) compact lodgement till which grades upward into a light-brown (dry) ablation till that displays pockets of open-work structure. Cumulative curve 10 6-46 (fig. 28A) is of a sample of lodgement till from this locality. The matrix is firm, displays

Figure 28 (A). Cumulative curves for five grain-size analyses of brown till.

(B). Comparison of envelopes of cumulative curves for reddish-brown and brown tills.

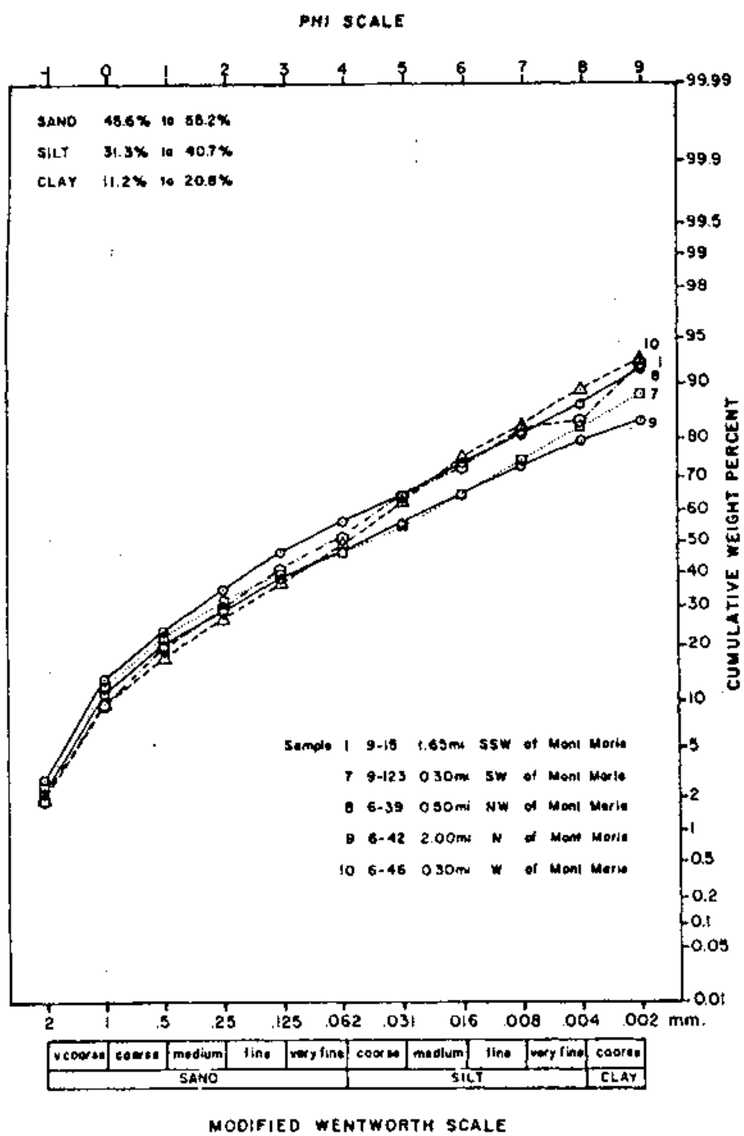


Figure 28A. Grain size of brown till.

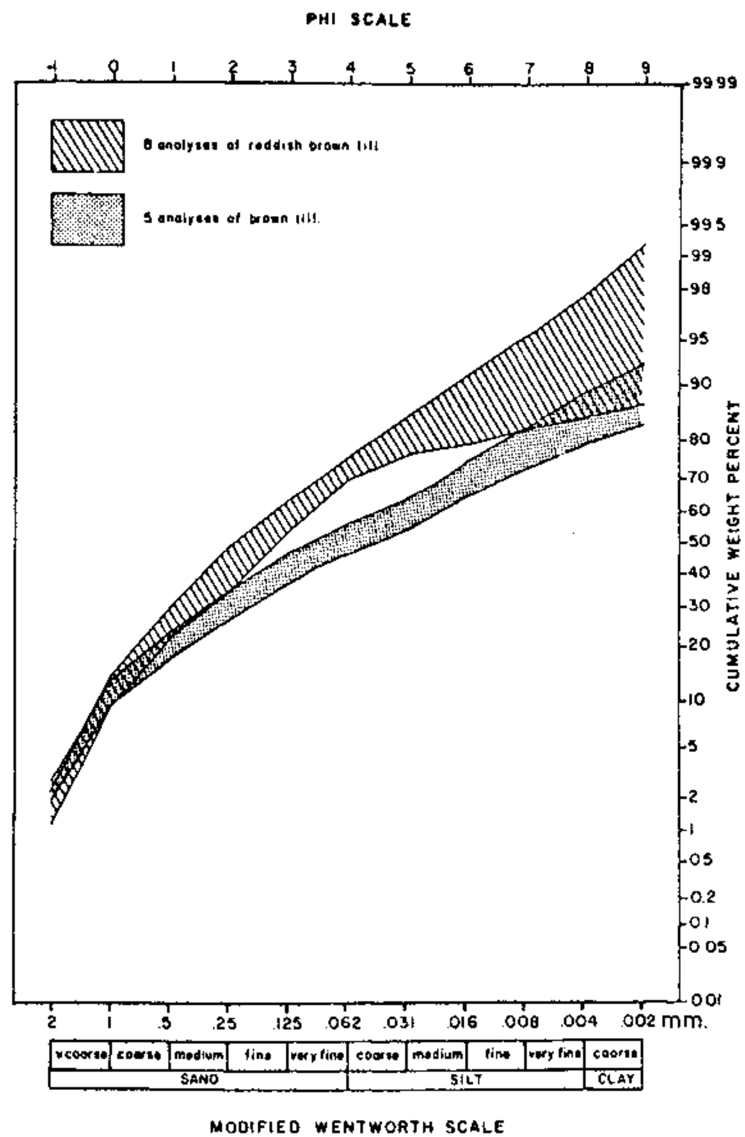


Figure 28B. Comparison of reddish brown and brown tills.

fissility, and consists of 48.0 percent sand, 40.7 percent silt, and 11.2 percent clay. Clasts over 3/8 of an inch in diameter constitute 19.7 percent of the weight of the lodgement till. Numerous clasts display a metallic blue patina, which may be related to ground water activity.

Brief descriptions of exposures of the brown till at Localities 6-39, 9-76, 9-123, and 9-134 are given under the heading "Readvance" on page 205.

Four pebble counts were made in the brown till east of the basalt ridge over a north-south distance of 7 miles. From north to south the percentage of pebbles with a Triassic origin is 91, 93, 77, and 94 for an average of 89 percent. Clasts of brown siltstone and shale from the East Berlin Formation and the Portland Arkose constitute 70, 70, 38, and 60 percent of the same pebble counts, respectively, for an average of 60 percent. This gives a clear indication of the source of the color of the brown till.

Rose diagrams for three till-fabric measurements in the brown till are plotted on the east side of figure 17 (see appendix II for source).

Grayish-brown till

Grayish-brown till (2.5Y 5/2 to 10YR 5/2, moist) occurs in the north-central part of the Mount Tom quadrangle. Because the grayish-brown till is unlike other till found in the quadrangle, but is similar to till found to the north, four samples of grayish-brown till from the Easthampton quadrangle are included in this study.

The till is loose, sandy, and contains numerous clasts with silt caps. The matrix has a broad range of sizes based on five grain-size analyses. It varies from 57.6 to 70.0 percent sand, 20.5 to 32.6 percent silt, and 2.6 to 21.9 percent clay. The analyses are essentially intermediate in composition to the reddish-brown till and the brown till (fig. 25). The average composition is 63 percent sand, 26 percent silt, and 11 percent clay.

The sand-to-mud ratios are 1.38 to 1.99, except for one sample (20 2-91) whose ratio, 2.61, is plotted at the top of figure 26. Cumulative curves for the five analyses of grayish-brown till are shown in figure 29A. The envelope representing grayish-brown till analyses has considerable overlap with envelopes for the reddish-brown and brown tills (fig. 29B).

Several lines of evidence suggest that the till at Locality 2-91 is gradational between grayish-brown tills to the north and reddish-brown tills to the south. (1) The cumulative curve for 20 2-91 falls within the envelope for reddish-brown tills. (2) The sand-silt-clay ratio for 20 2-91 falls just outside the cluster formed by reddish-brown tills. (3) The sand-to-mud ratio is above the range for grayish-brown tills but within the range for reddish-brown tills. (4) Locality 2-91 lies geographically between the grayish-brown tills and the reddish-brown tills.

Figure 29 (A). Cumulative curves for five grain-size analyses of grayish-brown tills.

(B). Comparison of envelopes of cumulative curves for reddish-brown, grayish-brown, and brown tills.

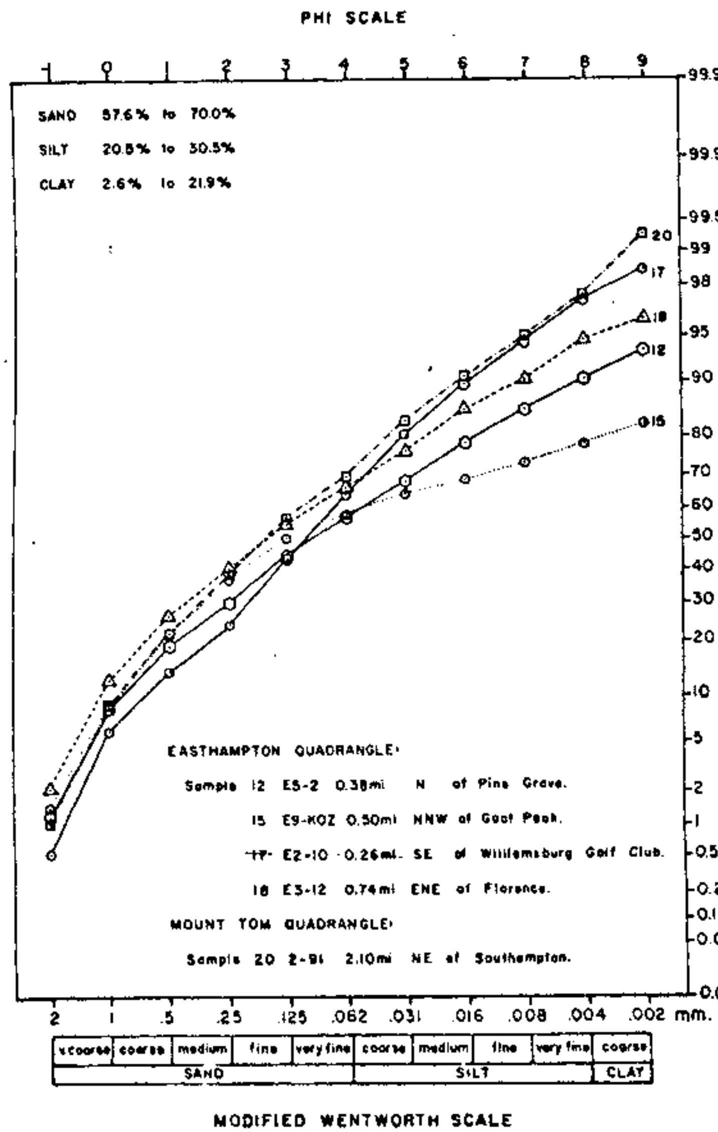


Figure 29A. Grain size of grayish-brown till.

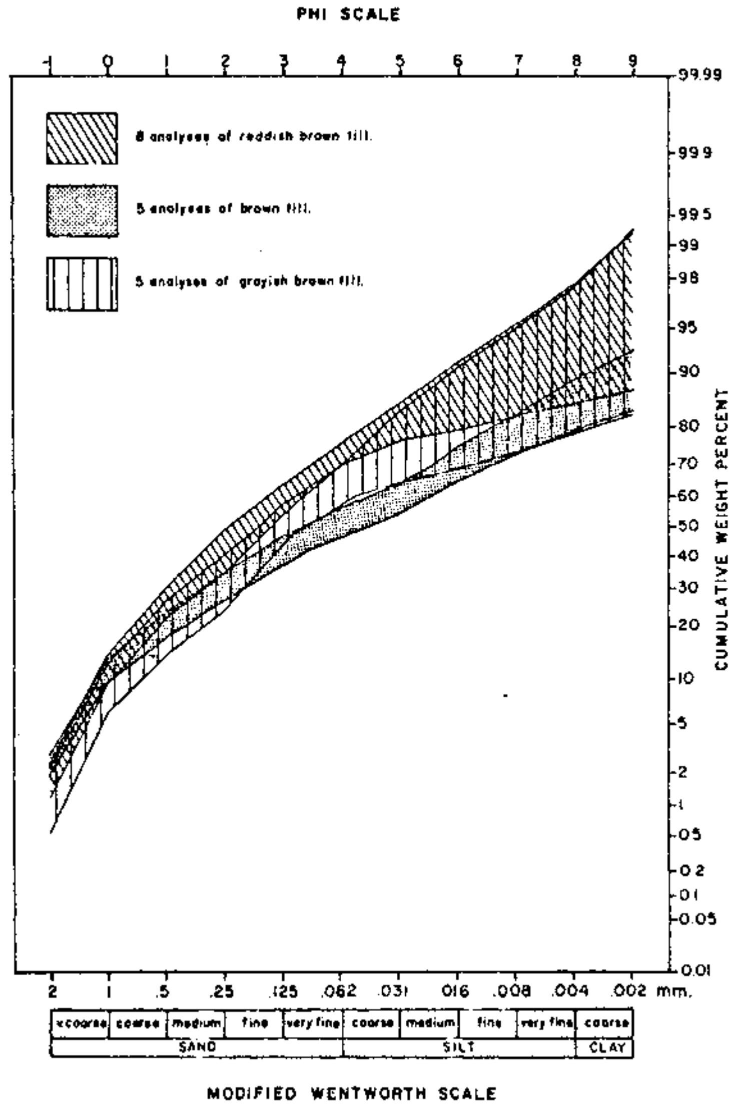


Figure 29B. Comparison of reddish-brown, grayish-brown, and brown tills.

One of the samples is olive (5Y 4.5/3, moist) and is oxidized. It may be related to the "lower" till of southern New England (Schafer and Hartshorn, 1965). The sample (12 E5-2) was collected 0.37 of a mile due north of the intersection of Florence Road and Rocky Hill Road in the Easthampton quadrangle. The till is dense and displays fissility in the upper half of a 4-foot exposure. Many small clasts are of partially decomposed feldspar and granite, indicating a source in the New England Uplands. The till is overlain by 0.7 of a foot of loose sandy till similar to the other four samples of grayish brown till.

No pebble counts or fabric analyses were carried out on the grayish-brown till.

Summary of tills

Three separate tills can be recognized in the Mount Tom area on the basis of color and grain-size composition. The tills are all Late Wisconsin, or Woodfordian (Frye and Willman, 1965), in age.

A sand-rich reddish-brown till is derived mainly from the Sugarloaf Formation and lies west of the Holyoke Basalt ridge. A silt-rich brown till is derived mainly from the East Berlin Formation and the Portland Arkose and lies east of the basalt ridge. A grayish-brown till is derived from rocks of the crystalline upland and is best represented in the Easthampton quadrangle to the north. One till sample, 20 2-91, is intermediate in color and composition between grayish-brown till in the Easthampton quadrangle and reddish-brown till in the Mount Tom quadrangle.

When plotted on a graph of sorting (inclusive graphic standard deviation) versus graphic mean, reddish-brown and brown tills fall into two separate populations, with samples of grayish-brown till maintaining an intermediate position. Figure 30A indicates that reddish-brown till is coarser grained and slightly better sorted than brown till. In a plot of inclusive graphic skewness versus kurtosis three separate populations are maintained (fig. 30B). The reddish-brown till is fine skewed and slightly leptokurtic while the brown till is more symmetrical and platykurtic.

The fact that they can be distinguished on the basis of color and various grain-size parameters suggests that the tills of the Mount Tom quadrangle are locally derived and are intimately related to the bedrock over which they lie.

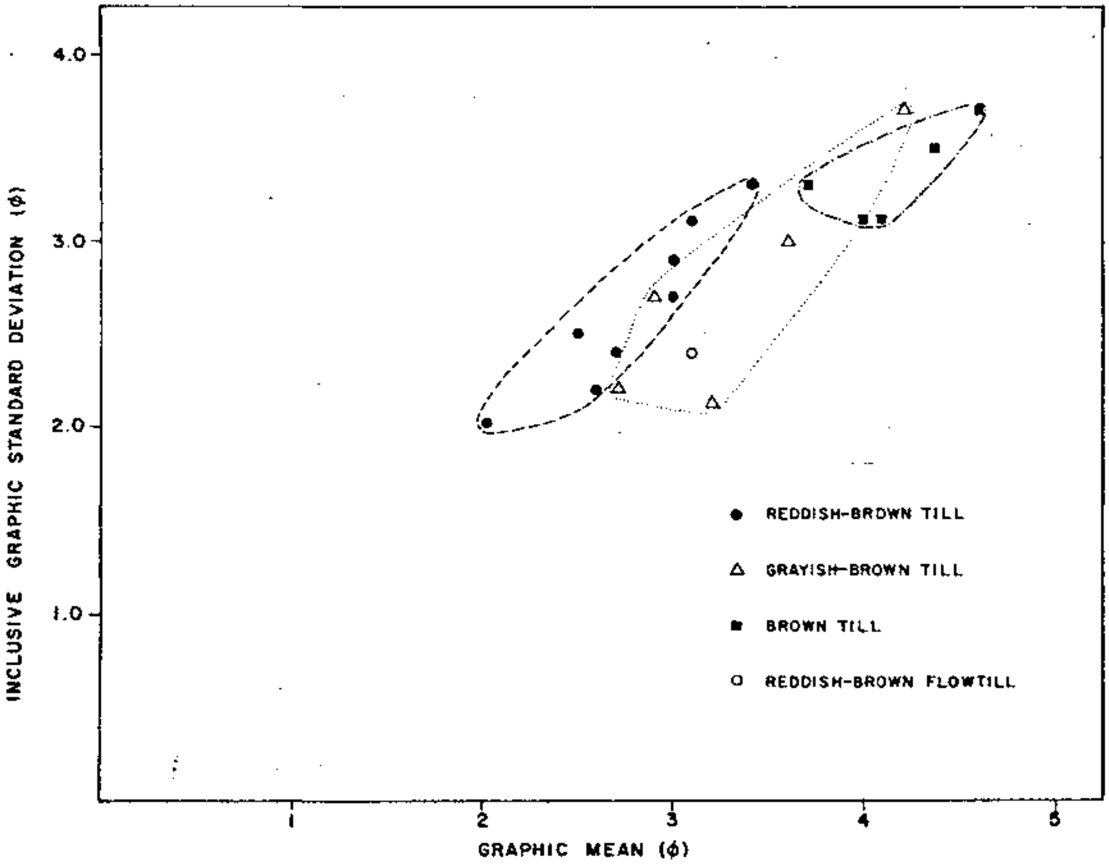
Ice-contact stratified drift

Ice-contact stratified drift is a term used to describe melt-water stream deposits that are deposited in, on, or adjacent to stagnant ice. The criteria used to recognize these deposits are the presence of (1) flowtill interbedded with stratified sediments, (2) collapse structure due to melting of ice below or adjacent to stratified sediments, (3) rapid changes in grain size, (4) large boulders in fine-grained sediment, and (5) layers containing many angular clasts.

Figure 30 (A). Graph of sorting (inclusive graphic standard deviation) versus graphic mean for 19 till samples. Samples of reddish-brown till are better sorted and coarser than samples of brown till.

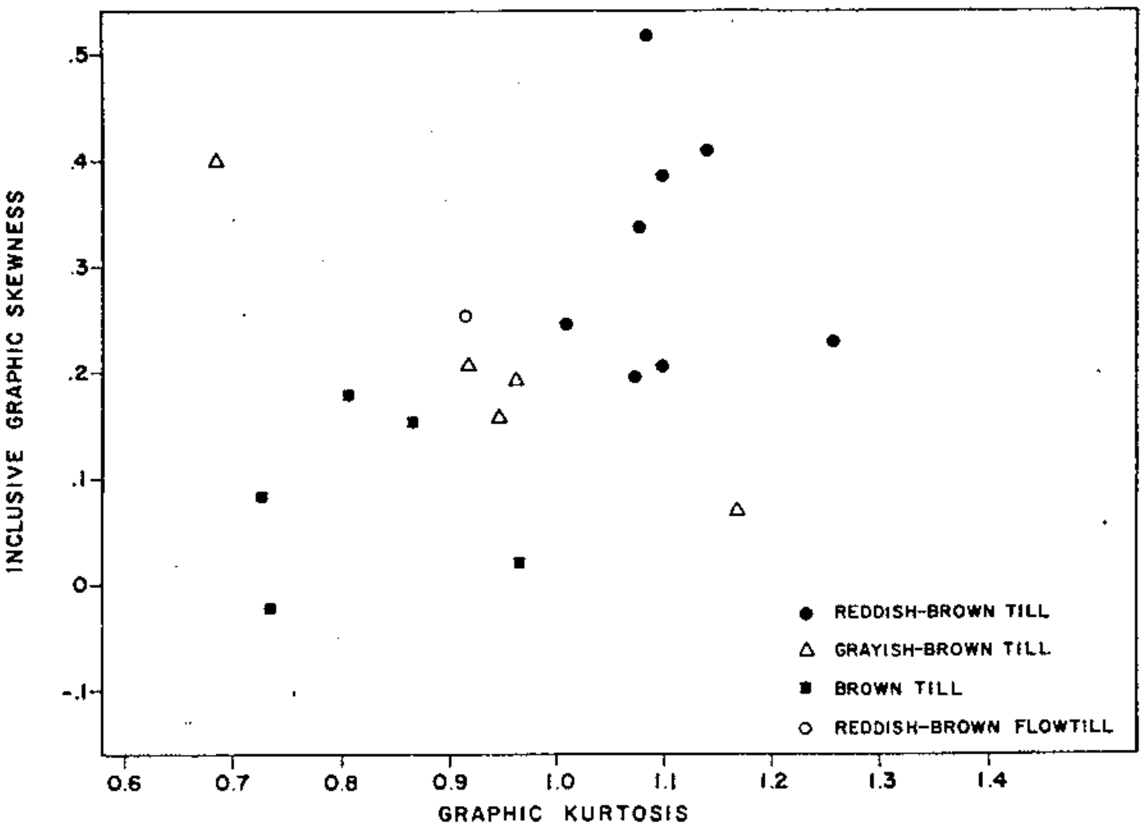
(B). Graph of inclusive graphic skewness versus graphic kurtosis for 19 till samples. The reddish-brown till is fine skewed and slightly leptokurtic while the brown till is more symmetrical and platykurtic.

A.



INCLUSIVE GRAPHIC STANDARD DEVIATION (ϕ)
4.0
3.0
2.0
1.0
1
2
3
4
5
GRAPHIC MEAN (ϕ)
REDDISH-BROWN TILL
GRAYISH-BROWN TILL
BROWN TILL
REDDISH-BROWN FLOWTILL

B.



INCLUSIVE GRAPHIC SKEWNESS
.5
.4
.3
.2
.1
0
-.1
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
GRAPHIC KURTOSIS
REDDISH-BROWN TILL
GRAYISH-BROWN TILL
BROWN TILL
REDDISH-BROWN FLOWTILL

Figure 30

Depending on their morphology, a variety of landforms, composed mostly of ice-contact stratified drift, can be recognized. Such features as ice-channel fillings, kames, and kame terraces are described below. Only those landforms whose sediments display several of the properties listed above have been mapped (pl. 2) as ice-contact stratified drift.

Criteria for recognition

Flowtill

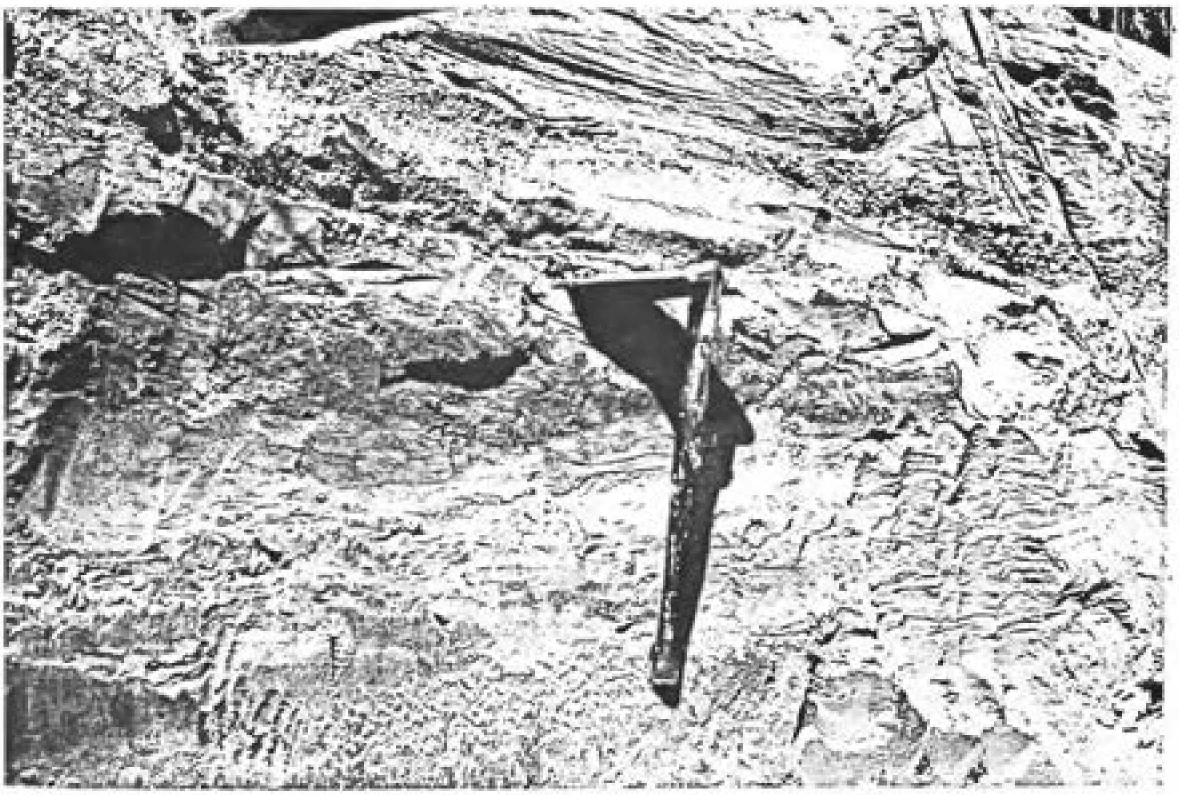
The term flowtill was coined by Hartshorn (1958) to describe poorly sorted superglacial debris that has moved as a mudflow into a local basin where glaciofluvial sand and gravel are being deposited. Its occurrence, interbedded with sand and gravel, is proof that adjacent ice stood higher than the site of deposition at the time of formation. Figure 31A illustrates a mudflow of englacial debris moving onto a surface of ablation moraine from the McBride Remnant in upper Muir Inlet, Alaska. Such a deposit, if made onto, and covered by, outwash would constitute a flowtill interbedded with sand and gravel.

Flowtill is exposed at the Southampton town dump, 1.4 miles S. 25° E. of Southampton village (fig. 31B). The flowtill is up to 2.0 feet thick, is reddish brown (2.5YR 4/4, moist), and contains striated pebbles. A grain-size analysis shows that the matrix is 65.8 percent sand, 29.7 percent silt, and 4.5 percent clay. Such a textural composition falls outside the cluster of reddish-brown tills in the sand-silt-clay ternary

Figure 31 (A). Mudflow of till issuing from shear filling or "squeeze-up" in stagnant ice. McBride Remnant, upper Muir Inlet, Alaska. August 26, 1963.

(B). Reddish-brown flowtill (dark layer) is interbedded with stratified sand and pebbly sand. Flowtill continues to the right under thin surficial cover of sand. Location is at the Southampton town dump 1.4 miles S. 25° E. from Southampton.

A.



B.

Figure 31

diagram (fig. 25). Clasts over 1.0 inch in diameter are uncommon. The sand-to-mud ratio, 1.92 (fig. 26), is lower than all the other reddish-brown tills west of the basalt ridge and may reflect the saturated condition under which the flowtill moved. The cumulative curve for the flowtill is compared to the envelope of cumulative curves for the other reddish-brown tills in figure 32. If the sediments that make up the flowtill had become part of the lodgement till, the cumulative curve for those sediments would probably have fallen inside the envelope for reddish-brown tills.

Occurrences of flowtill worthy of mention are not common in the Mount Tom quadrangle although excellent exposures have been observed in adjacent quadrangles. Several layers of flowtill interbedded with gravel are exposed in a pit just south of Bircham Bend in the Chicopee River in the Springfield North quadrangle. A photograph showing flowtill in ice-contact deposits at the southwest corner of the West Springfield quadrangle can be found in Flint (1971, p. 184).

Other criteria

Deformation or collapse resulting from the melting of ice beneath stratified drift is illustrated in figure 33A. The exposure, now graded, was located in a temporary borrow pit immediately west of I-91, 0.15 of a mile south-southeast of the bridge over the Massachusetts Turnpike. The alternate bands of light and dark sediments that dip to the right (northeast) contain

Figure 32. Cumulative curve representing grain-size analysis of flowtill compared to envelope of cumulative curves for eight grain-size analyses of reddish-brown till.

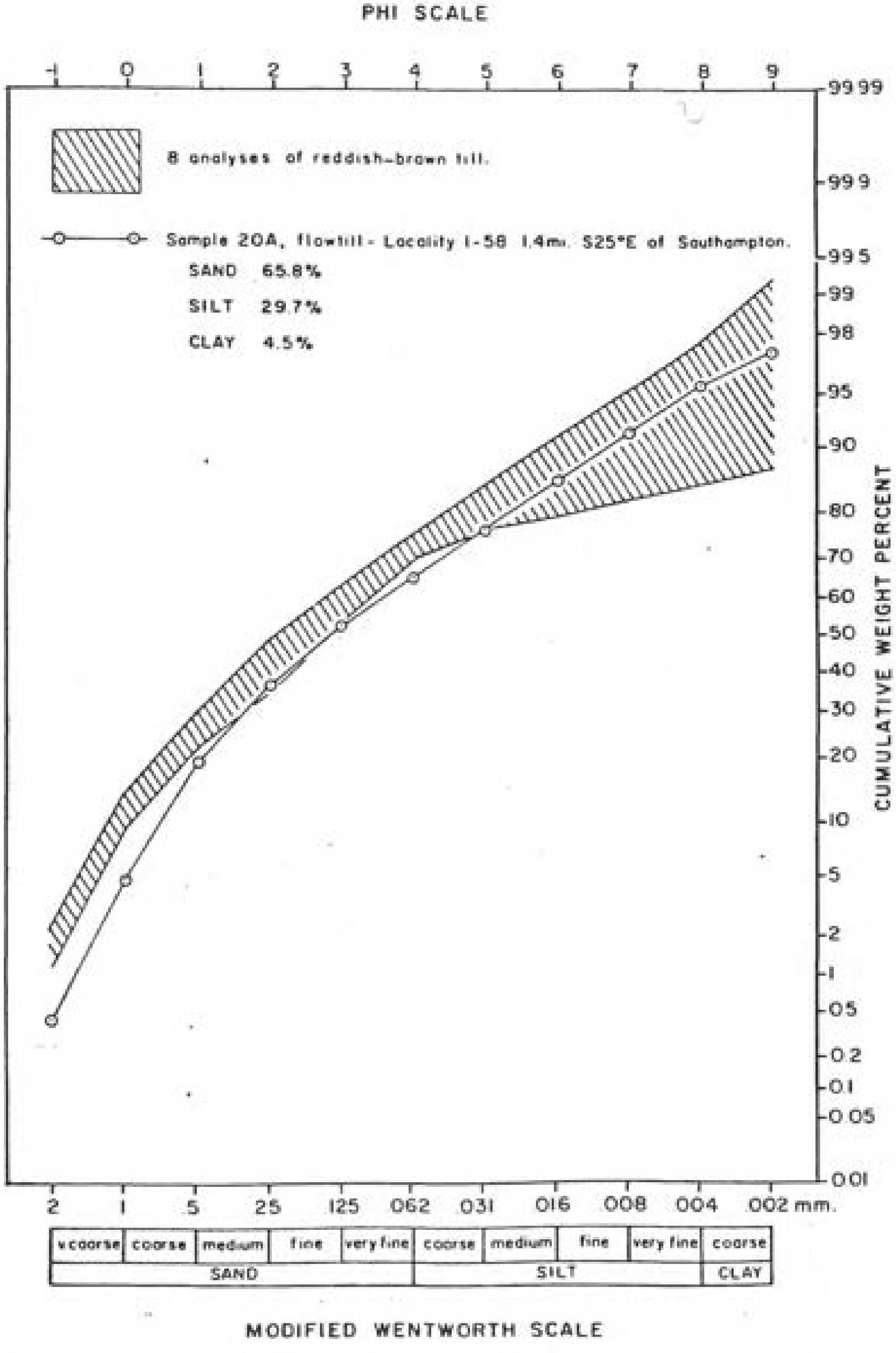


Figure 32. Grain size of flowtill compared to reddish-brown tills.

Figure 33 (A). Ice-contact stratified drift showing collapsed strata. See text for detailed description. Locality is on west side of Interstate I-91 0.15 of a mile south-southeast of the Massachusetts Turnpike.

(B). Ice-contact stratified drift showing wide range of and abrupt change in grain size. Location is 0.33 of a mile N. 16° W. of the summit of Crafts Hill.

A.

B.

Figure 33

current ripples which climbed to the left (southwest) during their formation. The dip is not primary, it is reversed. The depositional surface sloped slightly southwestward when the sediments were deposited. The wedge of light-colored sand, above the uppermost dark layer which dips to the right approximates the shape of the body of ice that melted after the climbing ripples were deposited. The wedge of sand is about 1 foot thick above the observer and 8 feet thick at the right.

Fine-grained sediment to the left of the observer in figure 33B rests on heterogeneous boulder gravel and is overlain by pebbly sand and gravel with angular clasts. This illustrates the rapidly changing depositional environment associated with ice-contact deposits.

As with flowtill, the presence of large boulders in much finer grained sand and gravel (fig. 34A) indicates that adjacent ice stood higher than the site of deposition at the time of formation. Large boulders, observed in 1963 on the McBride Remnant in upper Muir Inlet, Alaska, were seen to slide from the stagnant ice onto an apron of ablation moraine (fig. 34B). If such a boulder slid into a melt-water stream and was later buried by gravel, the result would be the same as seen in figure 34A.

Ice-channel fillings

Ice-channel fillings are narrow elongate ridges composed of ice-contact stratified drift deposited by melt-water streams.

Figure 34 (A). Ice-contact stratified drift with large clast surrounded by much finer grained sediment. Dark sediment below observer's hand is brown lodgement till. Location is 0.57 of a mile S. 18° E. of the summit of Bradley Mountain.

(B). Large erratic which was observed by field party to slide from ice to ablation moraine below. McBride Remnant, upper Muir Inlet, Alaska, July 26, 1963.

A.

B.

Figure 34

They are divided into (1) eskers, which are formed in subglacial and englacial stream tunnels, and (2) crevasse fillings, which are formed in open air channels between and around stagnant blocks of ice (Jahns, 1953). The two grade into each other and occur in a wide range of sizes.

The only ice-channel filling located during this study that could be classified definitely as a subglacial stream tunnel deposit, or esker, is situated just west of Homestead Avenue 0.2 of a mile north of Lower Westfield Road (pl. 2). The esker trends S. 59° W. and is 500 feet long and 10 to 15 feet high. The melt-water stream that deposited the esker flowed uphill from the 300-foot contour southwesterly to a point above the 300-foot contour, indicating that the stream was under hydrostatic pressure. The upper end of the esker grades into a flat area underlain by cobble gravel with well-rounded clasts.

The sediments, typical of ice-contact deposits, include outward dipping sand layers and tightly packed open-work pebble gravel overlapped by cobble gravel. The deposit has been excavated along its length and only small portions remain intact.

Elongate knobs of sand and gravel that rise 20 feet above the surface of the Holyoke delta in the northeast portion of the quadrangle may be part of a buried esker system that fed the north end of the delta.

Only one crevasse filling was mapped during the course of this study. It is a U-shaped ridge of sand situated at the end of the till-covered ridge that extends southward from Whiteloaf Mountain.

Kames

Kames, small isolated hills deposited by melt-water streams in contact with stagnant ice, are mapped at 3 locations on plate 2: (1) at the junction of North and Timberswamp Roads, (2) 0.5 of a mile west of Amostown at the southern edge of the quadrangle, and (3) 0.2 of a mile N. 25° E. from the summit of Bradley Mountain. Each of the kames mapped rests directly on till and consists of an irregular pile, or piles, of sand and gravel.

The sediments exposed in a roadcut at the north end of Timberswamp Road are pebbly coarse sand overlain by cobble gravel with rounded clasts. In the kame west of Amostown the sediment is mostly mottled brown to light-brown fine sand with lenses of pebbly sand, which overlie a poorly sorted dark-brown gravel.

Kame terraces

A kame terrace is a flat-topped landform composed of ice-contact stratified drift that was deposited in a depression or valley formed between a mass of stagnant ice and a till or bedrock slope. The mass of ice is commonly a tongue or lobe that occupies the valley floor, and the till or bedrock slope is commonly the side of a valley. A kame terrace is often linear, and its upper surface slopes in the direction of melt-water drainage at the time of formation. Sediments deposited in contact with the ice subside and collapse into the valley as the ice melts. The ice-sediment contact that originally sloped toward the valley side becomes an irregular "ice-contact" (Woodworth, 1899) that slopes toward the center of the valley. Kame terraces differ from stream terraces in that they are formed by constructional rather than erosional processes.

Kame terraces are well represented in the map area and occur in a variety of sizes. Examples of small isolated kame terraces can be found (1) just east of East Mountain Road 1.0 mile north of the Massachusetts Turnpike, (2) 0.65 of a mile west of Amostown, and (3) 0.33 of a mile N. 16° W. of the summit of Crafts Hill. Figure 33B shows the heterogeneous character of the sediments in this latter deposit.

Large kame terraces are found on the east side of the Moose Brook valley, and several of moderate size are located on the east side of the Broad Brook valley southwest of Mount Tom. As noted by Flint (1971, p. 210), kame terraces are better developed on the east side rather than the west side of north-south trending valleys in New England. The difference is attributed to the greater amount of solar radiation and melting of ice on the east side of a valley during the warmest part of the day (afternoon) when the west side of a valley is apt to be shaded (Flint, 1971).

Two large kame terraces on the east side of the Moose Brook valley were formed by melt-water streams that flowed southward, past stagnant ice blocks on the west, onto the Barnes outwash delta. The evidence for the ice-contact origin of these features is best revealed at the Southampton town dump, a locality already mentioned because of the occurrence there of flowtill (p.121). In addition to the flowtill, an exposure, 15 feet high and 20 feet wide, at the north end of the pit consists entirely of irregular lenses of fine to coarse sand and gravel. Contorted bedding, cut-and-fill structure, and rapid changes in grain size all point to an ice-contact origin for the sediments. A gully near the floor of the pit displays deformed silt and clay, indicating an early glacio-lacustrine phase for the depositional history of the kame terrace.

An elongate ridge with maximum elevation over 260 feet, situated 1.15 miles S. 54° E. from Southampton village, is a kame terrace and is believed to have formed at about the same time as the previous two described terraces. The sediments in a borrow pit on the northeast side consist of fine to medium sand over reddish-brown gravel with coarse sand, granules, and pebbles, which in turn overlies lacustrine silt and clay. This ridge was probably once connected to a similar ridge 0.3 of a mile due east and has been separated from it by the downcutting of Tripple Brook. A series of auger holes and hand-dug pits in this second ridge encountered a wide variety of sediments from pebble gravel to lacustrine silt and clay.

Two levels of kame terraces occur east of Broad Brook southwest of Mount Tom. Those located 1.4 to 2.0 miles southwest of Mount Tom and south of Pomeroy Street have maximum elevations over 300 feet and are graded southward to the Barnes outwash plain. Terraces less than 1.0 mile southwest of Mount Tom have maximum elevations in the range of 275 to 285 feet and are graded southwestward to the Pomeroy Street delta. The higher terraces formed first (Stage II, p.187 and fig.50A) and are contemporaneous with the two large kame terraces on the east side of the Moose Brook valley. The lower terraces are younger (Stage III, p. 196 and fig. 51) and formed at the same time as the Southampton delta.

The bulk of the sediments in both sets of terraces is light-to dark-brown, fine to medium sand and is most likely glaciolacustrine in origin. Cobble gravel with rounded clasts as much as 6 inches in diameter occurs on the top of the largest terrace south of Pomeroy Street. Pebble gravel with a matrix of medium to coarse sand is common on all the terraces. Yellowish-brown fine sand of eolian origin blankets the higher portions of all the terraces to a depth of 3 to 4 feet.

Other deposits

At three localities east of the Holyoke Basalt ridge ice-contact deposits are found buried under lacustrine sediments of Lake Hitchcock. The sediments have been exhumed by erosion by the Connecticut River and by the work of man. Obviously, such deposits display no surficial form but they can be recognized by their characteristic properties; that is, collapsed bedding, wide range, and abrupt change, in grain size.

No grain-size analyses were made on ice-contact stratified drift other than flowtill (sample 20A 1-58).

Pebble counts for two localities west of the basalt ridge average 23.5 percent Triassic clasts. East of the basalt ridge six pebble counts in ice-contact stratified drift contained an average of 74.1 percent Triassic clasts (appendix I).

Outwash

Outwash constitutes sand and gravel that has been carried by high energy melt-water streams and deposited in a proglacial fluvial environment. Melt water originates on the melting glacier, in some cases many miles upglacier from the terminus. The melt water travels on, in, under, and adjacent to the glacier. Melt-water streams acquire the bulk of their load near the terminus of the glacier where the ice is most heavily laden with debris due to ablation. The coarsest sediment is usually deposited close to the terminus while other sediments become finer grained downstream from the terminus. In contrast to ice-contact stratified drift, the sediments are well washed and contain little, if any, silt and clay.

The topographic surface constructed by outwash is called an outwash plain. If the deposit is held in by narrow valley walls the feature is known as a valley train. The former position of a terminus may be marked by the presence of an outwash head, which is an ice-contact slope that drops abruptly from the outwash surface in the upglacier direction. An outwash head represents a temporary stillstand during retreat of the ice, indicating that the economy of the glacier was balanced for a short period of time. Depending on the slope of the subglacial surface exposed during retreat, an outwash head marking a former position of the ice may or may not be present. If the surface slopes down under the glacier, a lake will commonly form when retreat occurs. If a stillstand occurs, outwash sediments will not be deposited until deltaic sediments build up to the level of the lake. However, outwash heads are common in this situation because new outlets for the lake may be uncovered during retreat, permitting the lake to seek a lower level to which new outwash deposits in turn can be graded. On the other hand, if the terrain slopes away from the glacier, outwash heads formed early may be buried by later deposits and leave no trace.

Kettles, or depressions due to melting of stagnant ice beneath glaciofluvial sediments, are common on outwash plains, particularly near the outwash head. Hampton Ponds, located in the center of the quadrangle, are kettles whose lower portions are below the ground-water table, hence they are filled with water.

Outwash deposits in the Mount Tom quadrangle are essentially the topset beds of large deltas built into glacial lakes.

Sediments mapped as outwash on plate 2 are limited to deposits of clean sand and gravel that display structures and characteristics of fluvial deposits and only minor amounts of collapse structure and features of ice-contact stratified drift.

Outwash sand is reddish brown (5YR 4/3, moist) to brown or dark brown (7.5YR 4/4 moist). The sand commonly contains grains of milky quartz, orange feldspar, and muscovite.

Small-to-medium-scale crossbedding and cut-and-fill structures are common (fig. 35). The widespread occurrence of ripple-drift cross-lamination in outwash indicates that accumulation of sand from suspension was rapid (Jopling and Walker, 1968). All current structures in the outwash indicate stream transport toward the south.

Cumulative curves for five grain-size analyses of outwash west of the basalt ridge are shown in figure 36A and for three analyses east of the ridge in figure 36B. The curve for sample 22 7-6A on the Barnes outwash delta is practically identical to that for sample 21 6-47 from the south end of the Holyoke delta.

Outwash sediment is moderately to moderately well sorted 0.51 to 0.92ϕ. Skewness values for the eight analyzed samples range from -.168 to .201, coarse skewed to fine skewed, and kurtosis values are 1.01 to 1.56, mesokurtic to very leptokurtic.

Figure 35. Outwash gravel overlying sand with medium-scale crossbedding formed by migrating sand waves in a fluvial environment. Location on the Barnes outwash plain 1.4 mi. N. 8° W. of the tower at Barnes Airport.

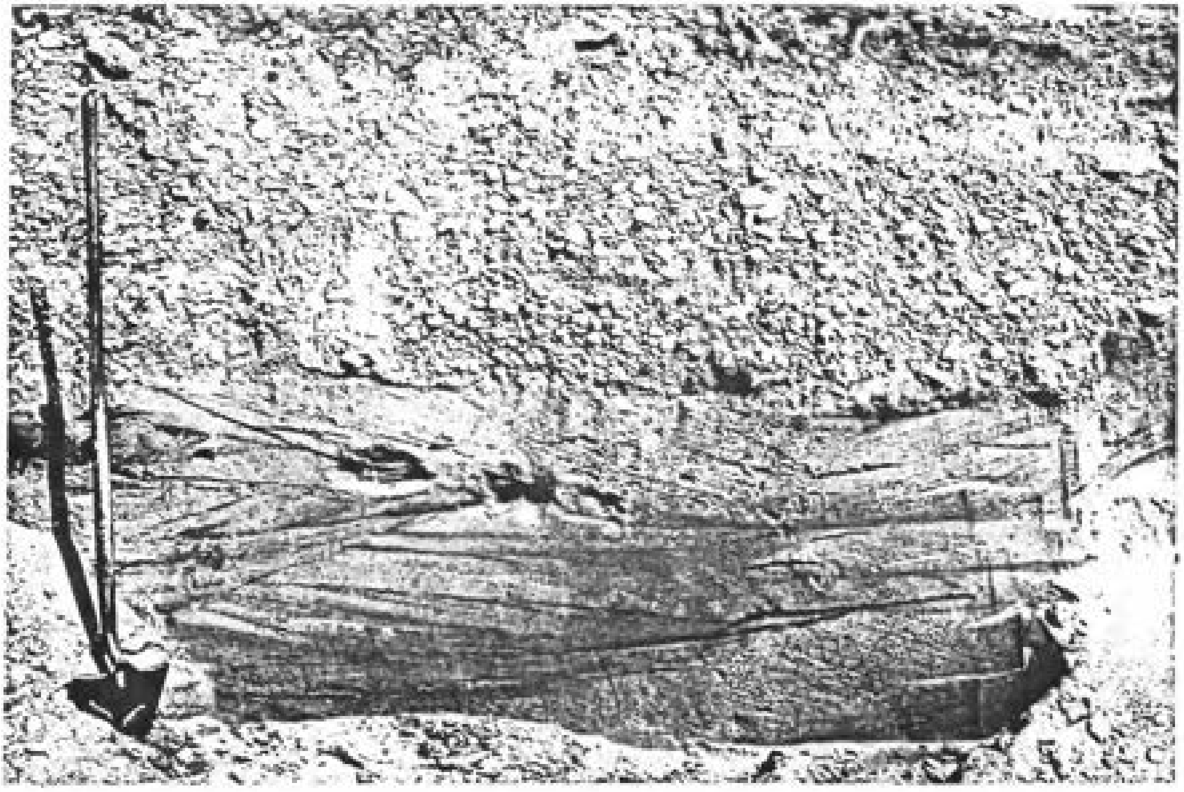


Figure 35

Figure 36 (A). Cumulative curves for five grain-size analyses of outwash sediments west of the basalt ridge.

(B). Cumulative curves for three grain-size analyses of outwash sediments east of the basalt ridge.

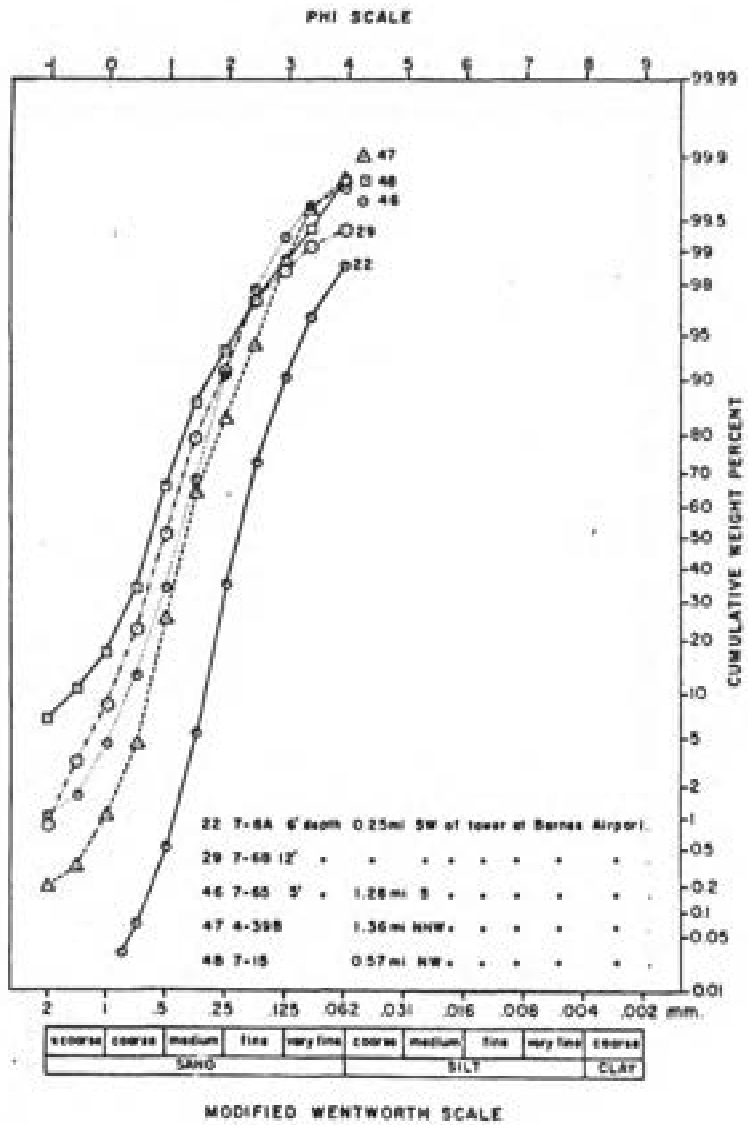


Figure 36A. Grain size of outwash west of basalt ridge.

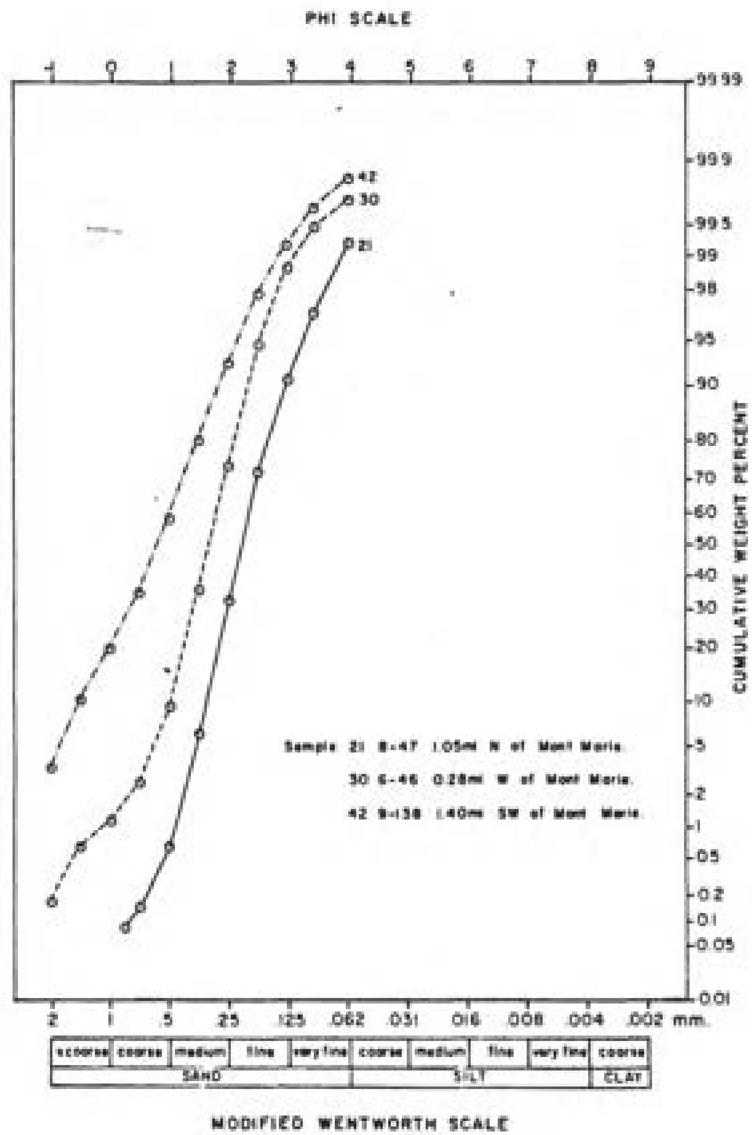


Figure 36B. Grain size of outwash east of basalt ridge.

Glacial-lake sediments

A proglacial lake with an outlet at Harts Pond Gap (fig. 2) developed in the lowland west of the basalt ridge when northward retreat of the ice margin occurred. East of the ridge the ice margin was accompanied by the shoreline of an expanding glacial Lake Hitchcock (p. 179 to 184). Sediments deposited in these lakes have a wide range of grain size, pebble gravel to clay, and display a wide variety of sedimentary structures. Lacustrine sediments occur locally in small patches up to an elevation of 270 feet in the northwest portion of the quadrangle and are consistently found below an elevation of 200 feet in the main stream valleys.

Coarse-grained lacustrine sediments, gravel and sand, are associated with shoreline and deltaic deposits. Shoreline deposits are difficult to recognize and probably would not be identified specifically except for previous work in other areas (Jahns and Willard, 1942; Jahns, 1951; Hartshorn and Colton, 1967). Once the concepts of Lake Hitchcock and its tilted water plane are accepted and recognized then the approximate shoreline can be drawn on the topographic map and depositional features may be related to it. Aprons of beach sand deposited nearshore in Lake Hitchcock were identified in this manner. At the junction of Pleasant and East Street, 1.02 miles S. 57° E. of Southampton village, the former shoreline of Lake Hitchcock is shown nearly surrounding an elongate ridge mapped as Qdw_2 (pl.2).

Sand deposits, mapped as Qb (pl. 2), were deposited in shallow water following wave erosion of ice-contact deposits at this locality. Other beach deposits are found 0.5 of a mile to the south, and along the 200-foot contour just west of the Connecticut River.

Pebble gravel to coarse sand is common in foreset beds of most deltas discussed later in this report (p. 186, 194, and 247; figs. 49A and 50B). The best display of sedimentary structures associated with foreset beds is in a pit 1.65 miles S. 36° W. of Southampton village. Folds resulting from slumping and ball and pillow structure indicate penecontemporaneous deformation due to rapid loading of sediments in the immediate prodelta environment (figs. 37A to 37C). Rapid settling of sand from suspension is suggested by ripple-drift cross-lamination which is continuous on both the stoss and lee sides of ripples (fig. 37D).

Delta foreset beds that have migrated over proximal bottomset beds were exposed temporarily at the Smith Agricultural School, 5.5 miles north of the Mount Tom quadrangle and 1.5 miles northwest of the center of Northampton. Clay-silt varves occur below the exposure, which has the following sequence of sedimentary structures from the base upward: (1) asymmetrical climbing ripples, (2) sinusoidal ripples (Jopling and Walker, 1968), (3) antidunes or backset ripples, and (4) foreset beds (fig. 38A). Plane beds, formed in the upper flow regime, constitute a minor portion of the exposure but serve as an index to flow conditions.

Figure 37. Detail of bedding in prodelta sediments of the Davis Plain delta. Location is in borrow pit 1.65 miles S. 36° W. of Southampton village.

(A). Foreset beds with lens of deformed bedding.

(B). Detail of lens of deformed bedding.

(C). Pillow structures in bottomset beds with clay-silt varves above.

(D). Ripple-drift cross-lamination formed by climbing asymmetrical ripples in bottomset beds.

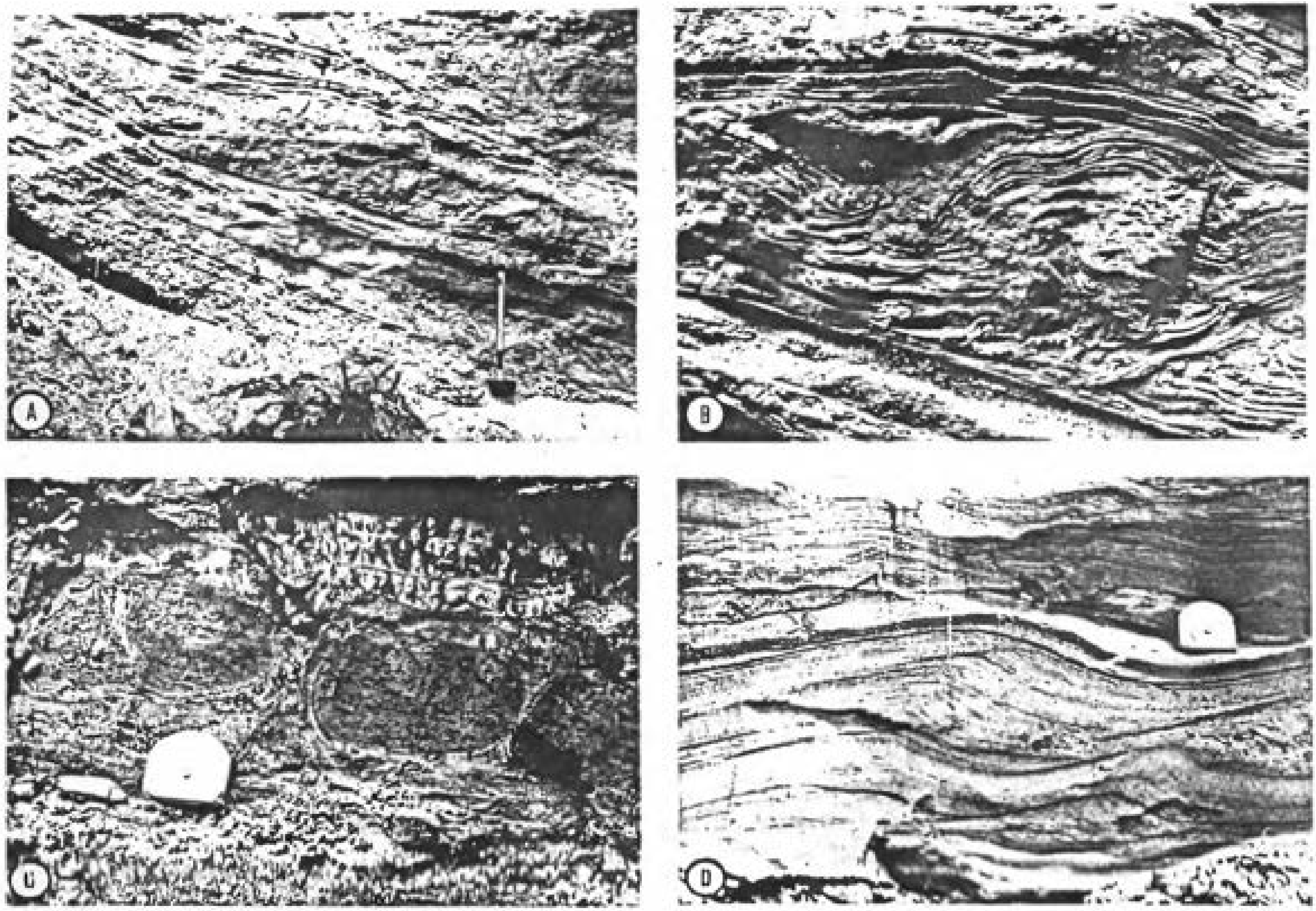
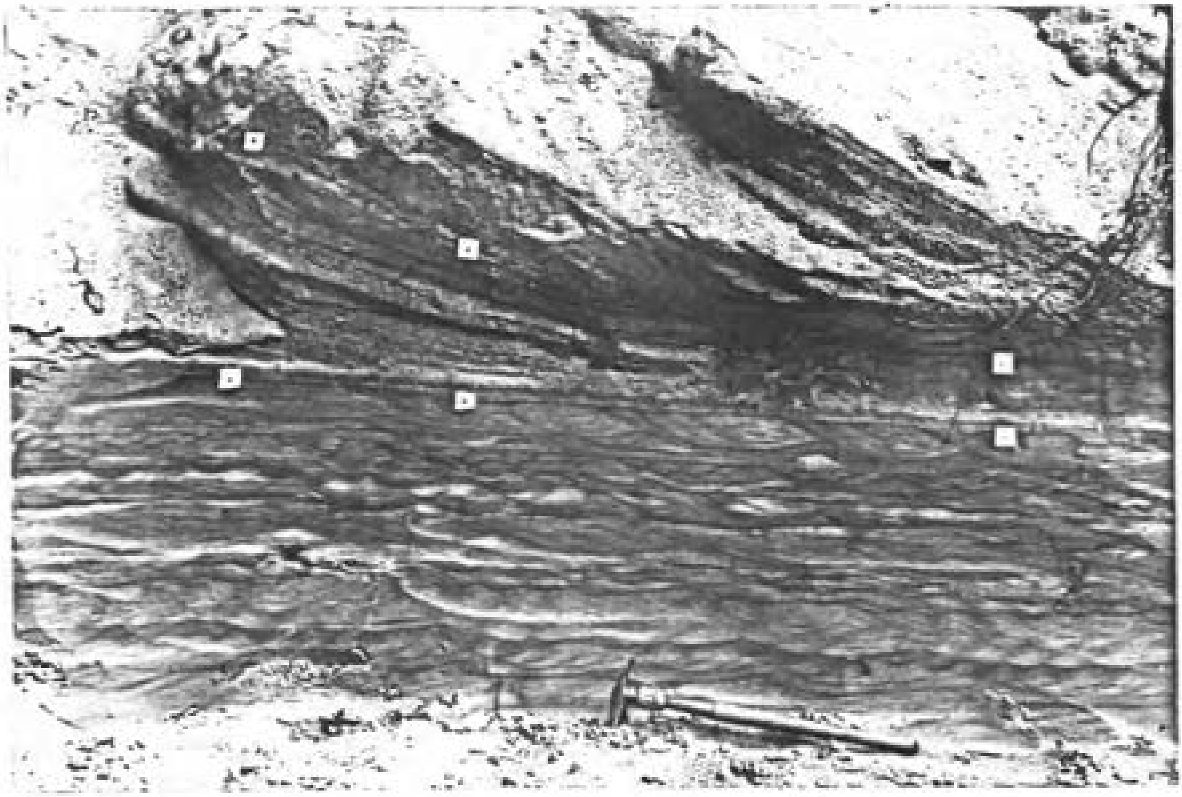


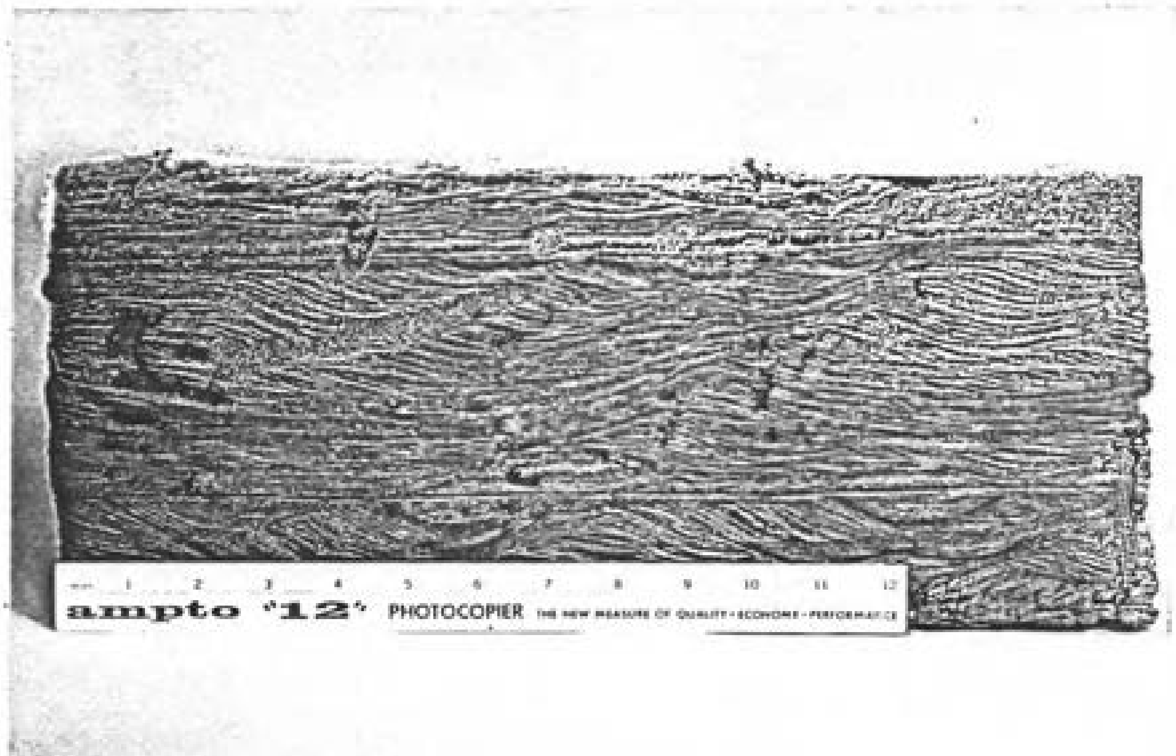
Figure 37

Figure 38 (A). Foreset beds overlying bottomset beds. From the base upward, the sequence of sedimentary structures in the bottomset beds is: (1) climbing ripples (behind and just above shovel), (2) sinusoidal ripples (light-colored layer one-third of the way up the face), (3) antidunes or backset ripples (between light layer and lower row of white tabs), and (4) foreset beds. Current direction is to the right. Note plane beds just above, and four inches below, the clay layer marked by the lower row of white tabs. The same two plane beds appear in photograph of peel taken at lower right tab (see B below). Location is at Smith Agricultural School, Easthampton quadrangle.

(B). Detail of peel of antidune bedding or backset ripples. Orientation of peel is reversed from figure 38A.



A.



B.

Figure 38

Detail structure in a peel of antidunes or backset ripples is shown in figure 38B. The bedding shown in the middle portion of figure 38B is believed to be antidune bedding for the following reasons: (1) apparent growth of the bedform was northeastward, (2) the median grain size of the layer decreases to the southwest from 2.53 to 2.73ϕ in a distance of 40 feet (fig. 39), (3) the layer decreases in thickness to the southwest from 3.5 to 1.7 inches in a distance of 28 feet, (4) the layer dips gently (1.5 degrees) to the southwest, and (5) at the 40-foot mark the antidune bedding grades laterally into sinusoidal ripples.

Lake Hitchcock, in which the bedding formed, was over 40 feet deep at this locality at the time of deposition. This necessitates the development of density underflows, that is, turbidity currents highly charged with suspended particles, to produce the observed sedimentary structures.

In the opinion of Dr. Bryce Hand of Syracuse University (written commun., 1971), the bedding in question is not antidune bedding. Hand offers the suggestion that it was produced by the migration of ripples formed by a countercurrent associated with a large eddy in the water just beyond the prograding delta.

Cumulative curves for grain-size analyses of deltaic sediments at the Smith Agricultural School are presented in figure 39. Curve 32 represents a foreset bed while curves 34, 36, and 38 represent 3 analyses spaced 20 feet apart horizontally in the same bottomset bed that displays antidune bedding.

Figure 39. Cumulative curves for four grain-size analyses of deltaic sediments.

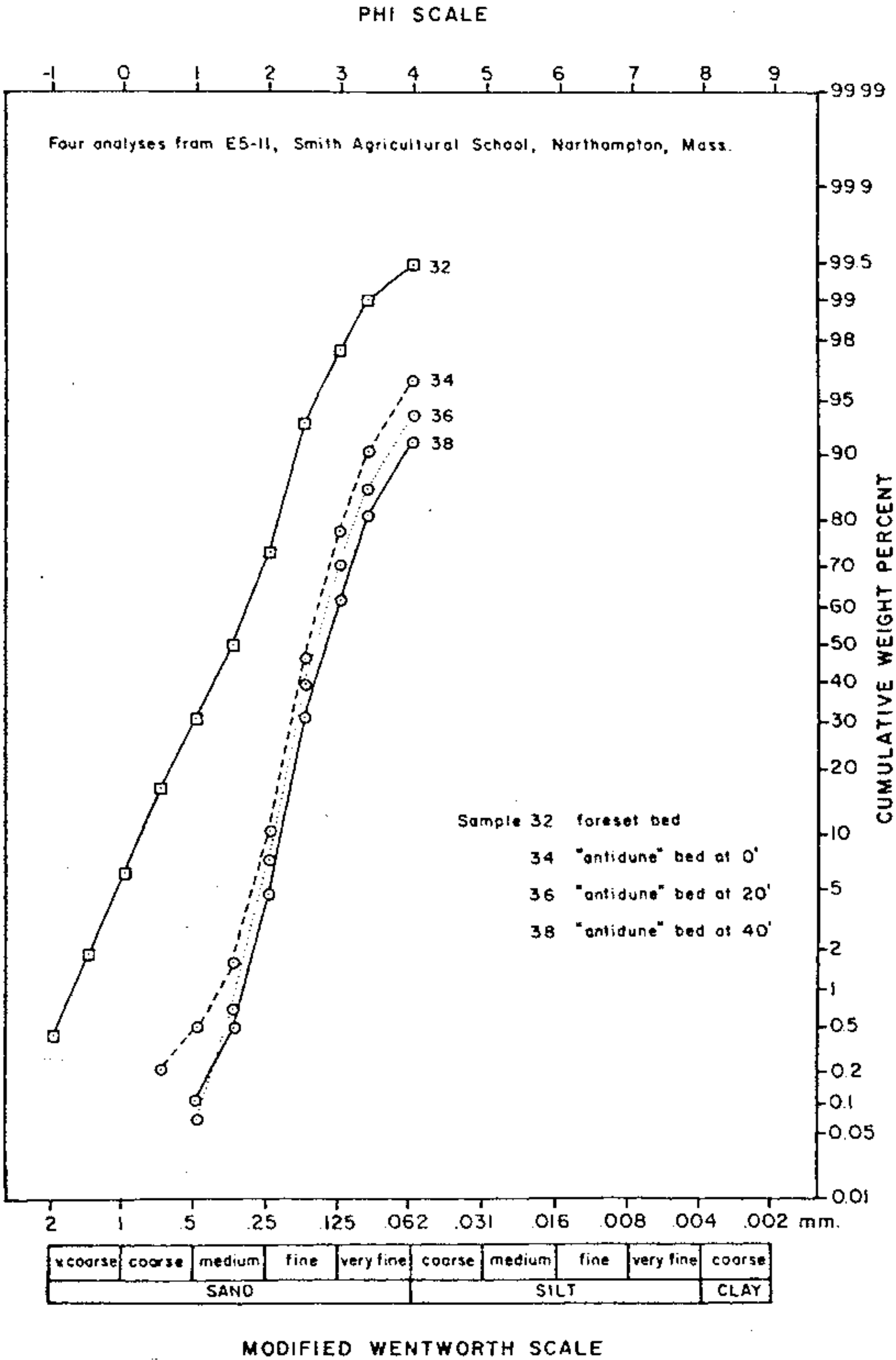


Figure 39 Grain size of deltaic sediments.

Of all the sediments mapped, fine-grained lake-bottom sediments (Qlc, pl. 2) were the easiest to recognize because their grain size alternated in thin beds between silt and clay. Clay layers, 1/4 to 1 inch thick, which occurred at intervals of 1 to 30 inches and which were recovered as discs with a hand auger, are assumed to be the winter portions of varves. A varve is an annual rhythmite or couplet composed of 2 layers: one layer is coarser, being composed mostly of silt or very fine sand, while the other layer is finer, being composed of silt or clay (Flint, 1971). Varves are commonly associated with glacial lakes. The coarse layer is deposited during the melt season when high energy streams enter an open lake and the fine layer settles during the winter when the lake is covered by ice.

Laminations are common in the silt or fine sand portion of varves. The laminations can be observed not only in small exposures but also in samples recovered by hand auger. In addition, the summer portion of a varve often contains small concretionary brown masses of iron oxide.

Banerjee (1967), following DeGeer (1940), Kuenen (1951), and others, suggested that varves are formed from turbidity currents or density underflows. In his oral presentation, Banerjee also compared the clay layer of a varve to the pelagic "e" unit of the Bouma sequence (Bouma, 1962), used to describe the five subdivisions of a turbidite. According to Banerjee, the laminated "d" unit of the Bouma sequence is analogous to the laminated silt layer of a varve. Medium to fine sand displaying ripple-drift cross-lamination within the summer portion of a varve represents the next higher energy level and is analogous to the cross-laminated "c" unit of the Bouma sequence. Varves containing sand with well-developed ripple-drift cross-lamination are proximal, that is, adjacent to their source in comparison to clay-silt varves, which are considered to be distal or more distant from their source. Both types of bedding are characteristic of lake-bottom sediments in the Mount Tom quadrangle and are believed to have been deposited by turbidity currents.

Deposits mapped as Qlc (lacustrine clay) on plate 2 are clay-silt varves defined as thin-bedded lake-bottom sediments in which clay layers constitute more than 10 percent of the thickness. Lake-bottom sediments in which clay constitutes less than 10 percent of the thickness are mapped as Qls (lacustrine sand and silt).

Varved clays in the Mount Tom quadrangle were deposited in glacial Lake Hitchcock, except for clay deposits in the valleys of Brickyard Brook and the Manhan River south of latitude 42° 12' 30". Deposits in these latter valleys have thin clay layers, 1/8 to 1/4 of an inch thick, and are associated with a small proglacial lake formed during retreat (p. 194). Varved clay associated with bottom deposits of Lake Hitchcock are found (1) west of the Connecticut River in the southeast portion of the map area, and (2) in the valleys of the Manhan

River, Moose Brook, and Broad Brook in the northwest and north-central portions of the quadrangle.

Cumulative curves for grain-size analyses of lacustrine sediments are presented in figure 40. All are lake-bottom sediments of Lake Hitchcock and all but one, 53 9-127, are from the northern portion of the quadrangle.

Lacustrine sediment is moderately sorted to poorly sorted, 0.92 to 1.60ϕ. Skewness values for two clay samples are -.556 and -.635, strongly coarse skewed, while the skewness of six silt samples are .083 to .353, near symmetrical to strongly fine skewed. Kurtosis values for two clay samples are 0.81 and 2.29, platykurtic and very leptokurtic; kurtosis for six silt samples ranges from 0.88 to 1.43, platykurtic to leptokurtic.

Late-glacial and postglacial sediments

Eolian sediments

During deglaciation and prior to revegetation of the Mount Tom quadrangle, the land surface was exposed to activity of the wind. The most widespread manifestation of this activity is a layer of windblown fine sand that blankets till-covered upland slopes and stratified drift deposits alike throughout southern New England. The mantle of windblown sand is usually missing on postglacial stream terraces and modern flood plains.

The main characteristic of the eolian mantle is that it is structureless except for soil zones produced by weathering.

Figure 40 (A). Cumulative curves for five grain-size analyses of lacustrine sediments.

(B). Cumulative curves for three grain-size analyses of one varve.

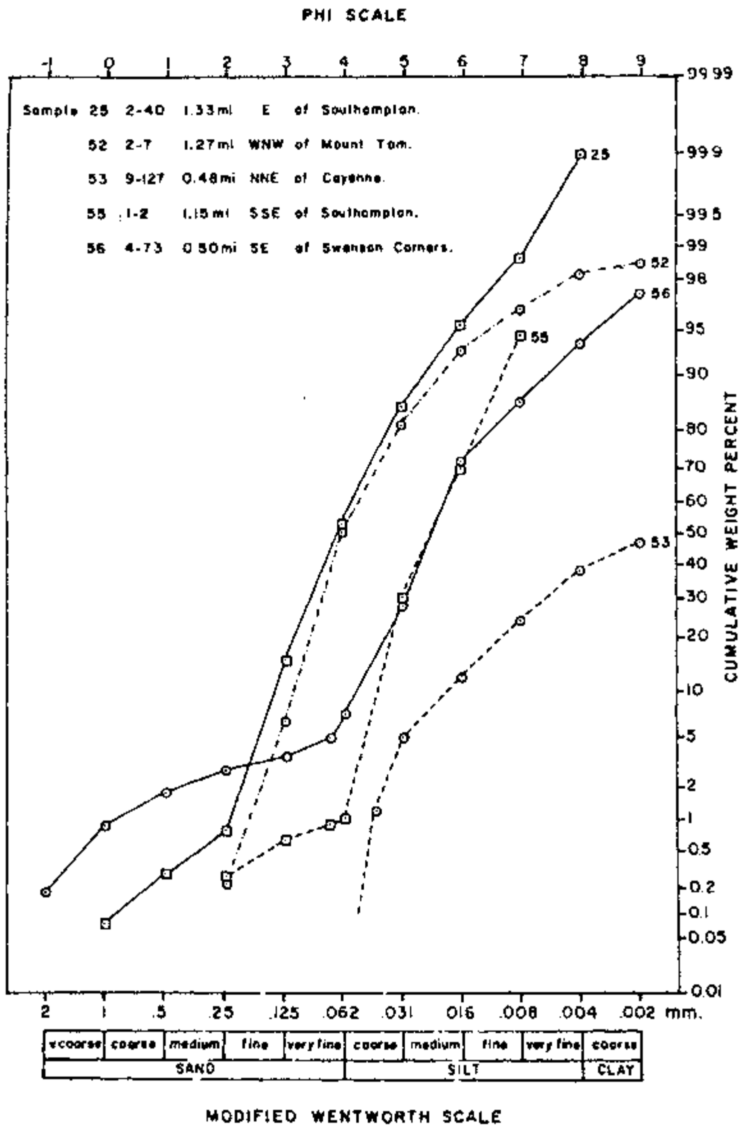


Figure 40A. Grain size of lacustrine sediments.

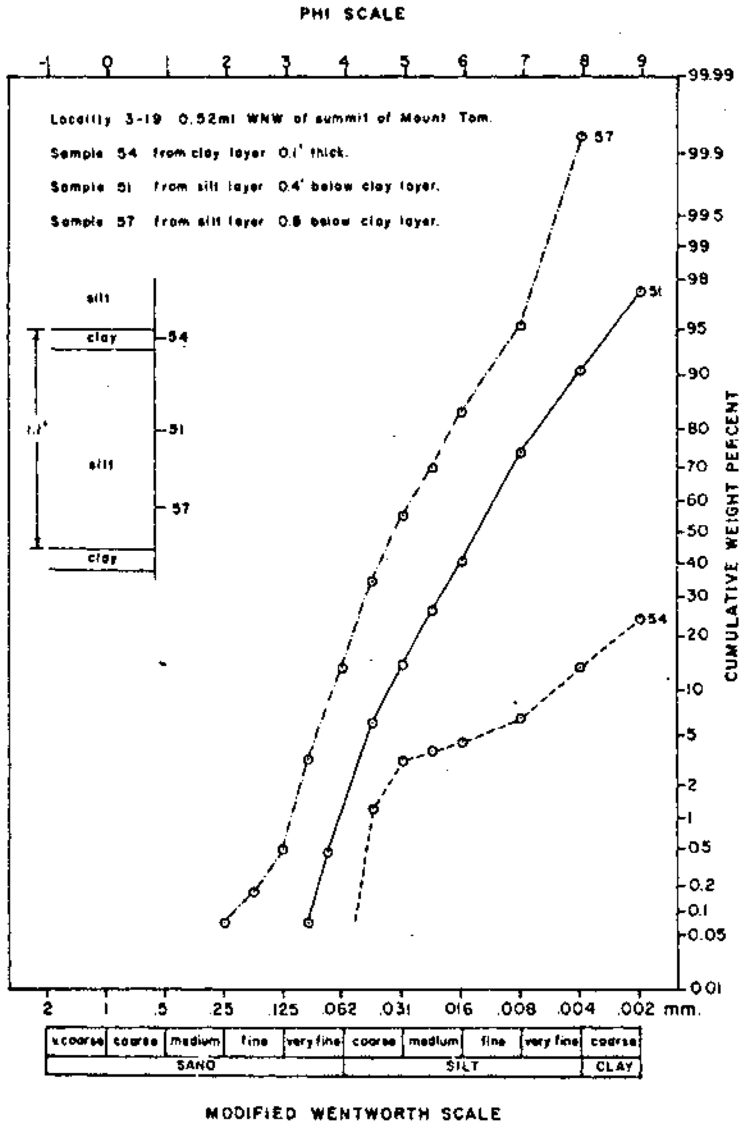


Figure 40B. Three grain-size analyses of one varve.

The upper 0.5 to 1.0 foot of the mantle is a dark-brown to black soil zone rich in organic material. From a depth of 1.0 to 2.0 feet the windblown mantle is usually oxidized to a deep orange brown grading downward to yellow brown. Below 2.0 to 2.5 feet the color is close to the original color of the sediments, light brown to light reddish brown. The contact with underlying sediments can be either sharp or gradational. Angular quartz grains of sand to granule size and wind-abraded pebbles, or ventifacts, can be found distributed throughout the entire thickness of the mantle.

The manner in which the eolian mantle covers the topography is shown in figure 41. Near the crest of a drumlin located 0.5 of a mile west of the Holyoke Basalt ridge and 0.3 of a mile north of the southern boundary of the quadrangle, the eolian mantle is 0.5 of a foot thick. The thickness is known to be greater than 5.0 feet 530 feet west of, and 170 feet east of, the crest of the drumlin. The source of the mantle was outwash deposits to the west and northwest.

The eolian mantle is 4.8 feet thick on a till-covered bedrock slope 1.62 miles S. 31° E. of Southampton village. On a small knob 1.92 miles S. 45° W. of Southampton, eolian fine sand, resting directly on bedrock, is 4.5 feet thick.

Cumulative curves representing grain-size analyses for three samples of the eolian mantle are shown in figure 42A. An envelope representing grain-size analyses of Mississippi

Figure 41. Profile of drumlin showing thickness of eolian mantle. Location is drumlin 0.5 of a mile west of the Holyoke Basalt ridge and 0.3 of a mile north of the southern boundary of the Mount Tom quadrangle.

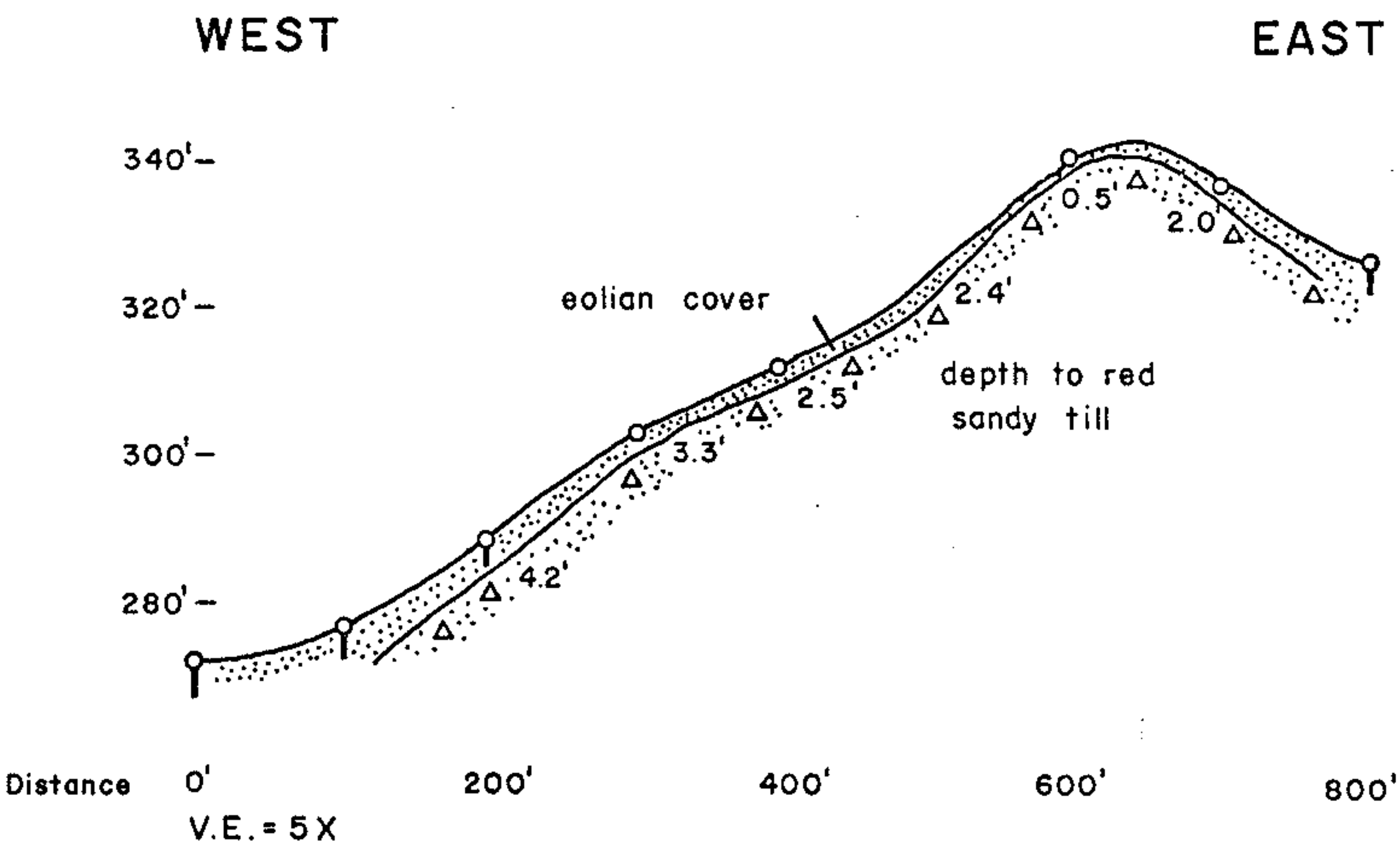

WEST
EAST
340'
320'
300'
280'
eolian cover
depth to red
sandy till
0.5'
2.0'
2.4'
2.5'
3.3'
4.2'
Distance
0'
200'
400'
600'
800'
V.E. = 5X

Figure 41

loess (Snowdon and Priddy, 1968) is included for comparison. Loess is defined as sediment, composed predominantly of silt-sized particles, 0.004 to 0.062 mm., that is deposited by the wind. Of the three samples shown, only 28 3-65B can be called a loess. It is composed of 34.7 percent sand, 54.0 percent silt, and 10.4 percent clay. The other two samples may properly be called loesslike silty sand.

The eolian mantle is poorly sorted to very poorly sorted, 1.78 to 2.30ϕ. Skewness values for three samples range from .089 to .366, near symmetrical to strongly fine skewed, and kurtosis values are 0.87 to 1.47, platykurtic to leptokurtic.

Stabilized sand dunes are a second expression of eolian activity that occurred in postglacial time. Sand dunes, mapped as Qe on plate 2, occur (1) on an outwash delta crossed by Pomeroy and Phelps Streets in the north-central portion of the quadrangle and (2) in a postglacial spillway crossed by Timberswamp Road in the west-central part of the map. A sand dune located immediately south of Phelps Street is a parabolic or U-shaped dune with the U opening toward N. 60° W., the direction of the dominant wind when the dune was formed. Linear dunes at Timberswamp Road also trend N. 60° W.

Cumulative curves for grain-size analyses of dune sand are in figure 42B. The steeper slope of these curves, compared to those in figure 42A, indicates that dune sand is much better sorted than the eolian mantle. Sample 31 2-142B is from a depth of 8.5 feet in the parabolic dune mentioned above.

Figure 42 (A). Cumulative curves for three grain-size analyses of eolian silty sand.

(B). Cumulative curves for five grain-size analyses of eolian sand.

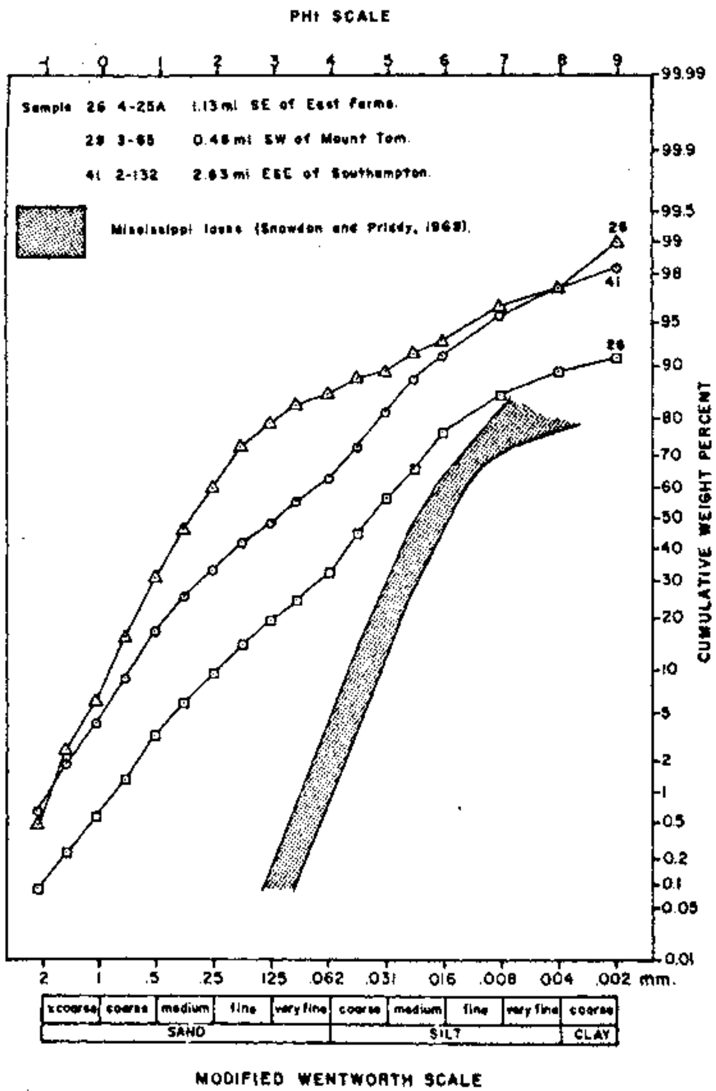


Figure 42A. Grain size of eolian silty sand compared to Mississippi loess.

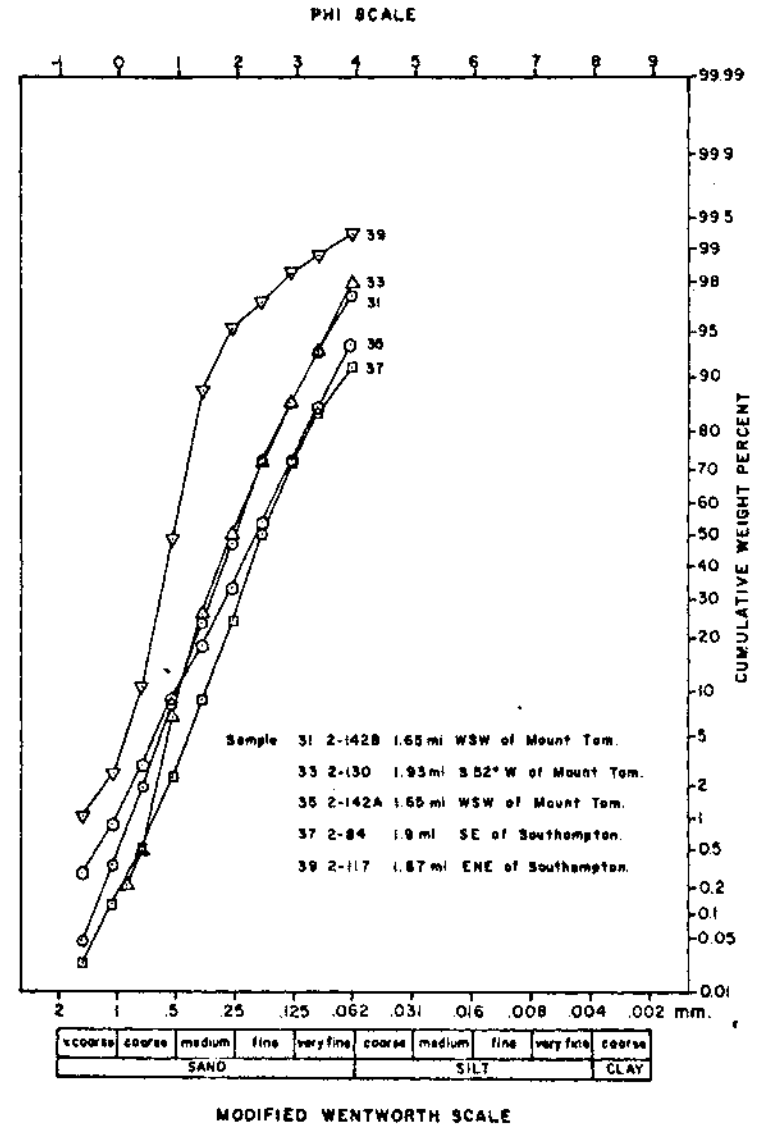


Figure 42B. Grain size of eolian sand.

The cumulative curve shows that 77 percent of the sample is medium and fine sand.

Dune sand is well sorted to poorly sorted, 0.47 to 1.02ϕ. Skewness values for five samples range from -.021 to .148, near symmetrical to fine skewed, and kurtosis values are 0.97 to 1.31, platykurtic to leptokurtic.

Ventifacts

The widespread occurrence of ventifacts associated with eolian sediments is testimony to rigorous abrasion by wind-driven sand. Ventifacts are common in the eolian mantle on the higher ground between the Manhan River and Broad Brook in the north-central portion of the Mount Tom quadrangle.

Abrasion by wind-driven particles is best shown by a polished surface that contains numerous small depressions or concavities. This feature is easily seen by holding a polished surface at a low angle to the light. A sharp ridge, formed where two polished surfaces meet, is a common characteristic of wind-abraded stones. In coarse-textured igneous rocks, the polished surface may appear as a linear fluting.

Ventifacts occur in all sizes from small sand grains to boulders several feet in diameter. The effects of wind abrasion are best revealed on dense crystalline rocks such as granite, diorite, gneiss, quartzite, and fine-grained volcanic rocks.

The first ventifact found during this study was encountered while augering 2.0 feet below the ground surface in eolian fine sand (fig. 43). It is a dense crossbedded orthoquartzite that measures 4.7 x 3.8 x 2.7 inches. As shown in figure 43, the left, center, and right sides are wind-polished facets separated by sharp ridges. On the side away from the observer the stone appears to be a stream-rounded cobble. In contrast, other ventifacts in the Mount Tom quadrangle are polished over their entire surface.

The elevation at 20 ventifact localities has been plotted against their north-south position in the quadrangle (fig. 44). The purpose is to compare the vertical distribution of ventifacts with the tilted water planes of glacial Lake Hitchcock and glacial Lake Westfield. All the ventifacts occur above the former level of Lake Hitchcock. The highest ventifact found was at an elevation of 390 feet on till-covered bedrock.

Once the forest was established in southern New England, ventifacts could not form on till-covered bedrock ridges. Ventifacts could have formed near the former shoreline of Lake Hitchcock; however, there is no preferred distribution of ventifacts associated with the shore of Lake Hitchcock nor have ventifacts been found below the shoreline. The time of formation of the ventifacts found in the Mount Tom quadrangle was immediately after deglaciation and prior to stabilization of sand movement by the growth of pioneer vegetation.

Figure 43. Ventifact of crossbedded orthoquartzite that measures 4.7 x 3.8 x 2.7 inches. Locality where found is 1.02 miles S. 73° W. of the summit of Mount Tom. Photography by Harold Krauth, Norwich University.

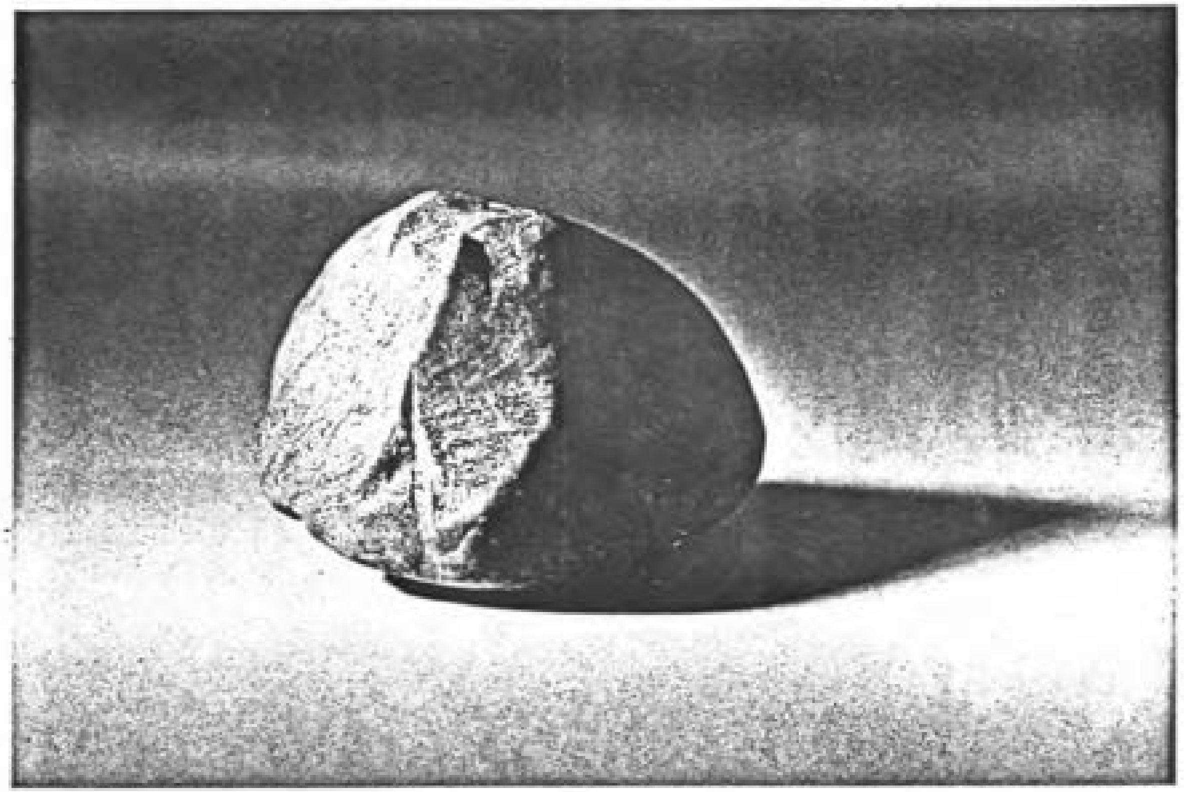
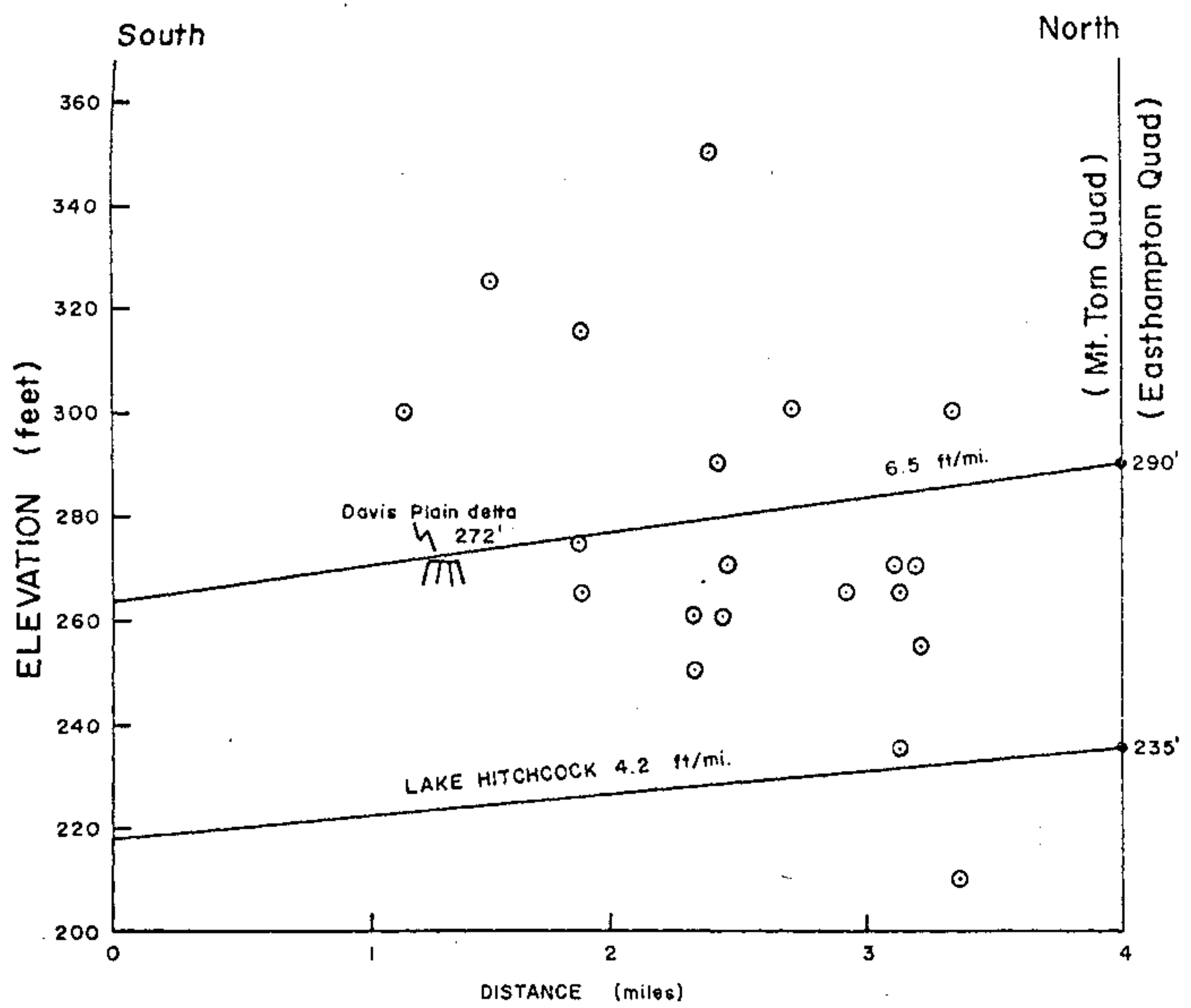


Figure 43

Figure 44. North-south projected profile showing the distribution of 20 ventifacts in relation to the tilted water planes of Lake Hitchcock and Lake Manhan I (upper profile).



South
North
(Mt. Tom Quad)
(Easthampton Quad)
ELEVATION (feet)
360
340
320
300
280
260
240
220
200
6.5 ft/mi.
290'
Davis Plain delta
272'
LAKE HITCHCOCK 4.2 ft/mi.
235'
0
1
2
3
4
DISTANCE (miles)

Figure 44

Stream-terrace deposits

Stream-terrace deposits occur on nonpaired terraces along the Connecticut, Westfield, and Manhan Rivers, and along numerous small tributary streams. The sediment, mapped as Qst on plate 2, invariably is yellowish brown in color and ranges in size from fine sand to pebble gravel. Loose coarse sand is a common constituent. The thickness of stream-terrace deposits ranges from 2 to 10 feet.

The terraces and their sedimentary cover range in age from late-glacial, for example, the wide terraces in the southwest corner of the quadrangle, to post-Lake Hitchcock terraces west of the Connecticut River in the southeast and along the Manhan River in the northwest.

Stream-terrace deposits overlying deltaic sediments were exposed during the summer of 1969 just east of the western edge of the quadrangle 0.2 of a mile north of the Massachusetts Turnpike (fig. 45). The sediment is yellowish-brown fine to coarse sand and pebbly sand. Transport direction to the south and southeast is indicated by ripple-drift cross-lamination and dune bedding. A pebble lag marks the base of stream-terrace deposits at 2 to 6 feet, indicating that a stream channel migrated across the surface. The underlying sand is reddish brown and exhibits the foreset bedding formed in a deltaic environment.

Of 6 pebble counts from stream-terrace deposits, 5 contain 10 percent or fewer clasts of Triassic origin (appendix I). The 6th pebble count is from a terrace on Sandy Mill Brook, a

Figure 45. Stream-terrace deposits overlying deltaic sediments. Observer's left hand marks pebble lag separating the two units. Location is just east of the western edge of Mount Tom quadrangle 0.2 of a mile north of the Massachusetts Turnpike.

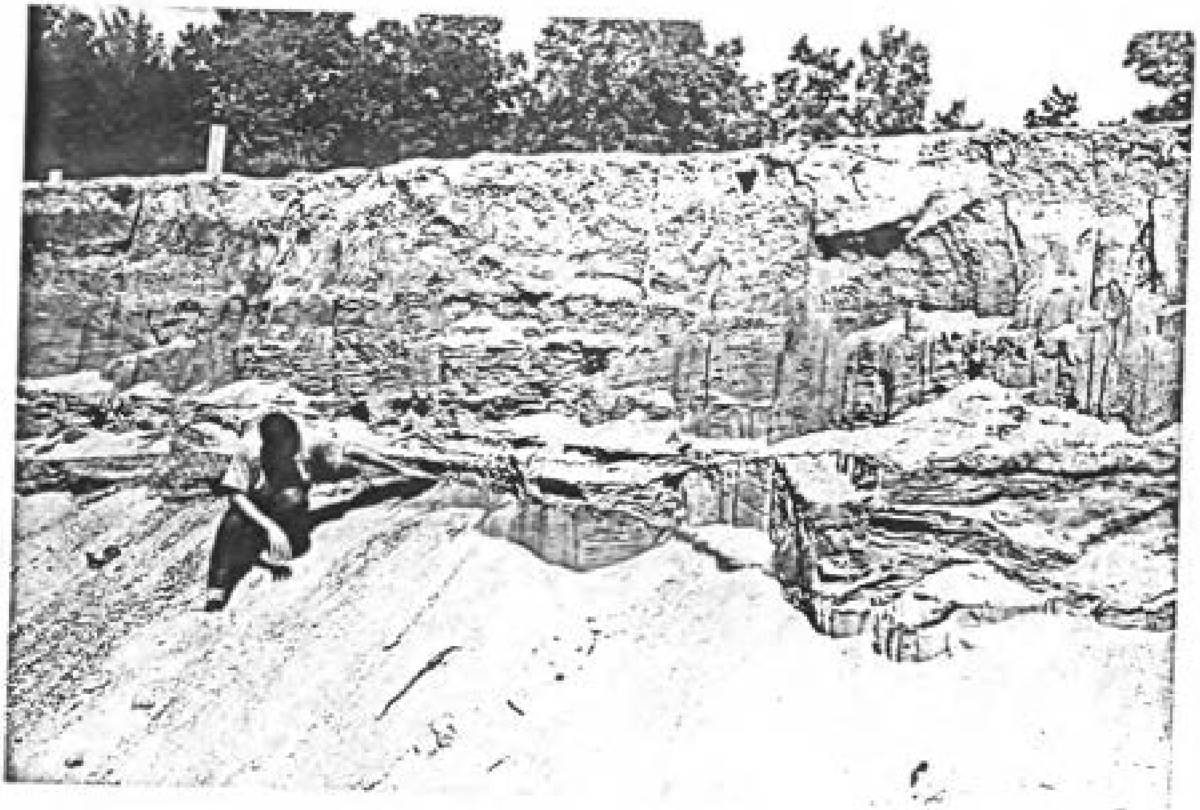


Figure 45

tributary of the Westfield River. It has only 27 percent Triassic clasts in spite of the fact that Sandy Mill Brook drains only Triassic bedrock and the Barnes outwash plain.

Cumulative curves representing four analyses of stream-terrace sand, collected at two localities, are shown in figure 46A. Stream terrace deposits are moderately well sorted to moderately sorted, 0.63 to 0.79ϕ. Skewness values for the four samples range from -.018 to .021, near symmetrical, and kurtosis values are 1.19 to 1.35, leptokurtic.

Swamp deposits

Sediments mapped as Qs on plate 2 are swamp deposits of dark-brown peat, black organic muck, and dark-gray sand, silt, and clay, which fill depressions produced by glacial activity. The depressions include rock-scoured basins, located mainly on the basalt ridge, which are produced by glacial erosion, and kettles formed by the melting of ice blocks in stratified drift. The basins are slowly filled by sediments and organic debris produced by vegetation. No borings were taken in swamps, but the thickness of organic sediment is believed to be about 5 to 15 feet.

Radiocarbon dating of peat elsewhere indicates a mimimum age for deglaciation. No dates are reported from the Mount Tom quadrangle, although peat in the Windsor Locks quadrangle, Conn., has an age of 12,200 yrs B.P. (Colton, 1960).

Figure 46 (A). Cumulative curves for four grain-size analyses of stream terrace sediments at two localities.

(B). Cumulative curves for five grain-size analyses of alluvium.

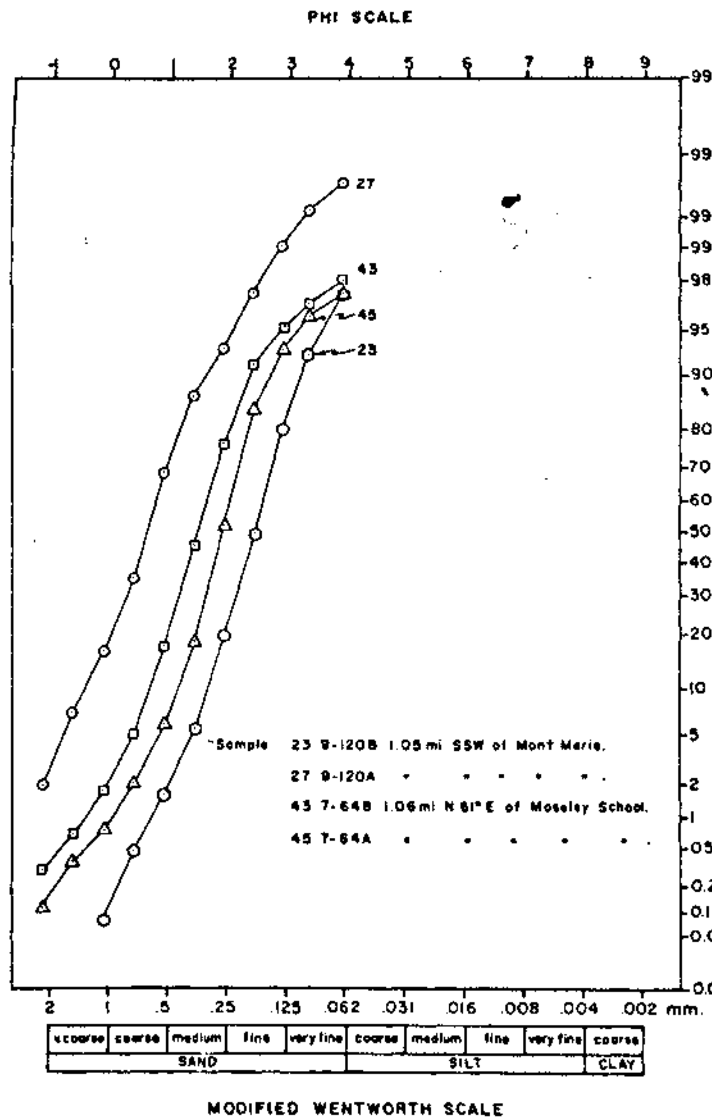


Figure 46A. Grain size of stream-terrace deposits.

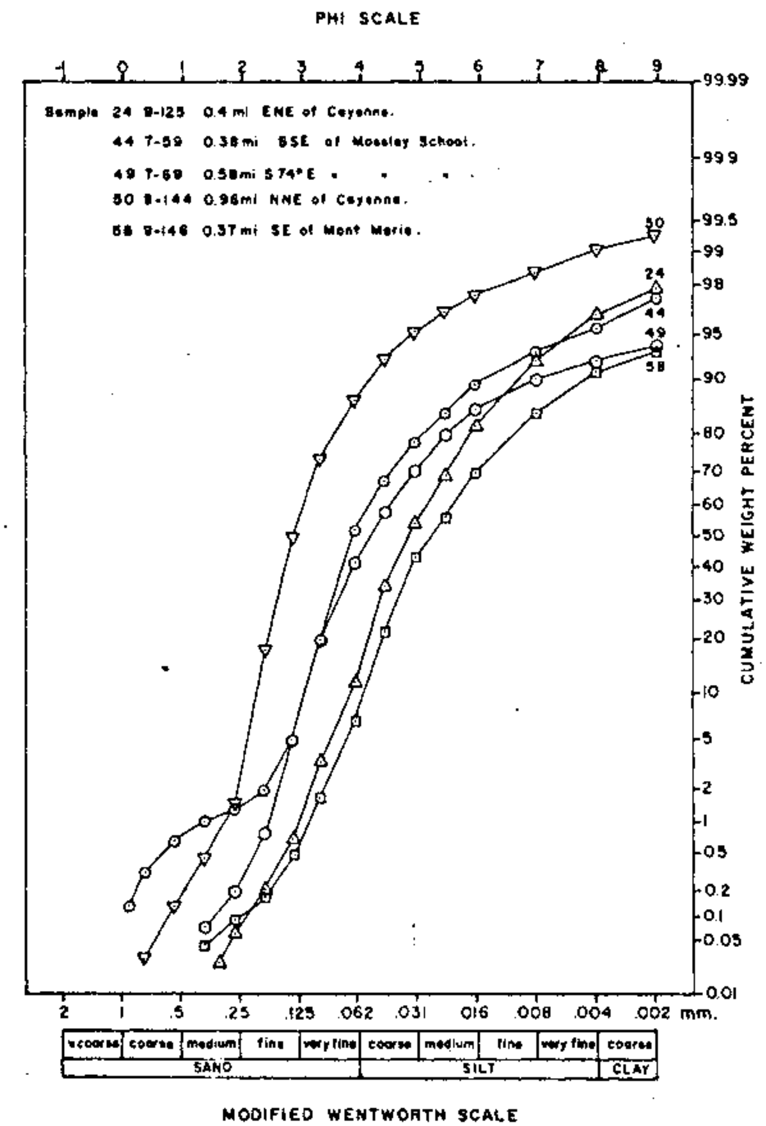


Figure 46B. Grain size of alluvium.

Talus

Slide blocks derived by frost wedging of steep bedrock exposures are mapped as talus (Qta, pl. 2). Talus constitutes a thin veneer, probably over till and bedrock, at the base of west-facing cliffs in the Mount Tom Range and East Mountain. A description of talus is given on page 21 under the heading "Weathering."

Alluvium

Alluvium (Qal, pl. 2) is present on flood plains along all streams but is most extensive along the Connecticut, Westfield, and Manhan Rivers. Flood plains of the Connecticut and Westfield Rivers are broad and well developed and occur 5 to 20 feet above present day streams. The flood plain of the Manhan River is narrow by contrast, and its surface is irregular, being cut by scarps and former channels (Fig. 47).

The sediment is mostly grayish-brown to yellowish-brown fine sand and silt with minor amounts of coarse sand and pebble gravel. Cumulative curves for five grain-size analyses of alluvium are presented in figure 46B. Two curves (44 and 49) represent alluvium of the Westfield River, and three curves (24, 50, and 58) are for alluvium of the Connecticut River. Of the samples taken, those from alluvium are finer grained than stream-terrace deposits. Samples of alluvium are moderately sorted to poorly sorted, 0.73 to 1.58ϕ. Skewness values for

Figure 47. Flood plain of the Manhan River 0.9 of a mile N. 77° E. from Southampton village. View is toward the east-southeast during time of high water, March 25, 1968.

Figure 47

five samples range from .278 to .527, fine skewed to strongly fine skewed, and kurtosis values are 1.15 to 1.48, leptokurtic.

Deglaciation

Glacial Lake Hitchcock

Withdrawal of glacial ice from southern New England was accompanied by the development of a large proglacial lake in the Connecticut Valley Lowland. Since the history of the lake is related to the surficial geology of the Mount Tom area, it will be discussed briefly at this point.

Lougee (1939) named the lake in honor of Edward Hitchcock, who noted in 1818 that clay layers in the vicinity of Deerfield, Massachusetts, could only have settled in the quiet waters of a lake. Hitchcock was principal of Deerfield Academy when he made his observations about the lake which now bears his name. He later became Professor of Geology at Amherst College, then its President, and finally he was named the first State Geologist of Massachusetts (Lougee, 1939). It is an ironic twist of fate that he never accepted the theory of continental glaciation, proposed by Agassiz in 1840, for without it Lake Hitchcock never would have existed.

The first map showing the glacial lake in which Hitchcock's clays were deposited was published by Emerson (1898a) (fig. 48). Emerson named three confluent lakes, Springfield Lake, Hadley Lake, and Montague Lake. The series of lakes as shown never existed either as a single lake or as a series of

Figure 48. "The confluent lakes of the Connecticut Valley" (Emerson, 1898a, p. 7, fig. 2).

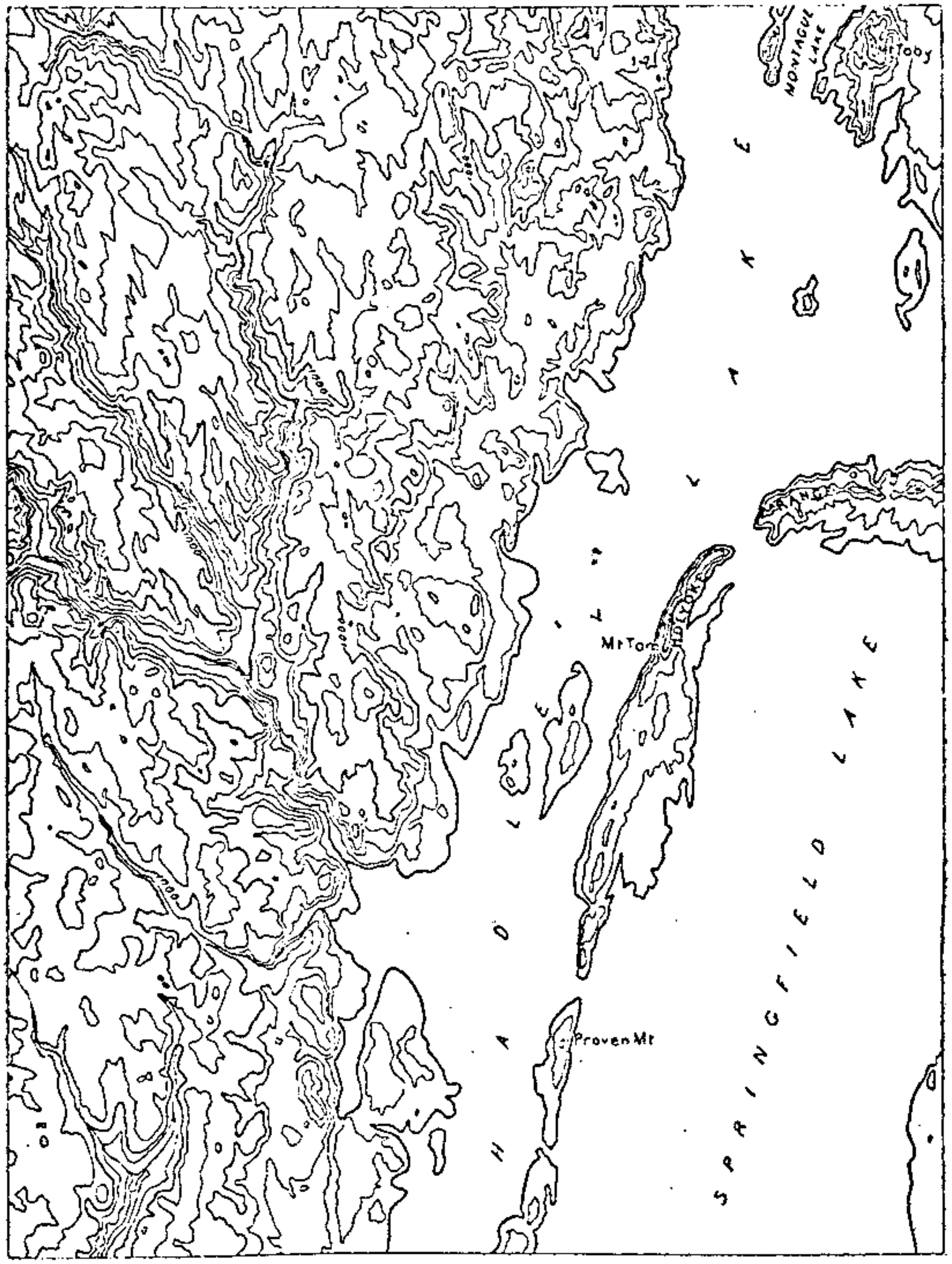

MONTAGUE LAKE
Mt Toby
Mt Tom
Proven Mt
HADLEY LAKE
SPRINGFIELD LAKE

Figure 48

time-transgressive lakes. Comparison with modern maps (this report, pl. 2; Colton and Hartshorn, 1971; Jahns, 1951) suggests that Emerson (1898a) placed the shoreline of the confluent lakes at the highest level at which stratified drift is common.

Lake Hitchcock formed during deglaciation when a large body of stratified drift was deposited across the preglacial course of the Connecticut River at Rocky Hill, Connecticut. The initial spillway for the lake was across the drift dam at an altitude of 125 feet at the present site of Dividend Brook (Hartshorn and Koteff, 1967b). A separate lake developed to the west at an altitude of 100 feet and was controlled by a bedrock-defended spillway at New Britain. Northward retreat of ice from the divide separating the two lakes permitted the higher lake to drop to the level of the second and to abandon the higher threshold at Dividend Brook (Hartshorn and Koteff, 1967b).

The effect was similar to building an artificial earth-fill dam in which the bulk of the dam is composed of unconsolidated sediments while the outlet, or spillway, is lined with concrete. A modern earth-fill dam has a core of clay or other impermeable material that prevents water from passing through the dam. The dam holding Lake Hitchcock at Rocky Hill was large but it was composed of permeable sand and gravel, a fact which led to its ultimate erosion and resultant draining of Lake Hitchcock. It is interesting to speculate what the effects

The quadrangle is 8.6 miles from N to S. If the postglacial tilt is 4.2 feet per mile, it would be 36.12 feet for the quadrangle. If 302 is correct for 42°37'30" N, the lake level should be 338 at the north. Probably both figures are slightly too low, by 5' if the New Britain spillway is at 72 ft (Colton + Hartshorn, 1971), or between 64 to 67 ft [illegible] in that spillway for 5 ft drop.

would have been had the dam at Rocky Hill been composed of impermeable material. Certainly the geography of the Connecticut Valley Lowland would have been different than we see it today.

Continued retreat of the ice margin allowed the lake to expand northward in the Connecticut Valley until eventually it was 150 miles long (Schafer and Hartshorn, 1965). As the ice margin retreated past major tributaries to the Connecticut Valley, large deltas were deposited in Lake Hitchcock. In addition, beaches and other shoreline features developed in response to the open lake. Studies by Jahns and Willard (1942) indicate that, when the elevations of deltas and shoreline features are plotted on a north-south profile, they define a tilted water plane which rises to the north at the rate of 4.2 feet per mile. The tilt of the former shoreline of Lake Hitchcock can best be explained by isostatic uplift due to the removal of the weight of the continental ice sheet. This tilted water plane has an approximate elevation of 202 feet at the southern edge of the Mount Tom quadrangle and 235 feet at the northern edge (pl. 3).

Between the New Britain spillway and the Holyoke Narrows lake deposits define several levels 10 to 30 feet above the tilted water plane just described. These higher deposits are believed to have formed at the edge of a "high" Lake Hitchcock prior to, or during, erosion of till or weathered bedrock in the New Britain spillway. By the time the retreating ice mar-

However, high Lake H is recorded just south of the Narrows (according to p 245) gin reached the Holyoke Narrows, downcutting in the New Britain spillway was slow, due perhaps to firm bedrock, as little evidence for high Lake Hitchcock has been found north of the Holyoke Range.

Lake Hitchcock existed from shortly before 13,000 years ago to between 10,710 and 10,650 years ago when the drift dam at Rocky Hill was breached (Flint, 1956, p. 276).

Pattern of retreat

The presence of major outwash sequences with well-defined outwash heads and evidence for readvance of glacial ice in the southeast portion of the map area permit construction of a series of diagrams that illustrate the general pattern of deglaciation in the Mount Tom quadrangle. At least four distinct phases of late-glacial history are apparent west of the Holyoke Basalt ridge whereas seven phases can be recognized east of the basalt ridge.

West of Holyoke Basalt ridge

Colton and Hartshorn (1971) have described seven separate depositional events in the lowland west of the Holyoke Basalt ridge in the West Springfield quadrangle. The last four depositional sequences described by them are related to a proglacial lake that formed between the retreating ice margin and a threshold in the vicinity of Harts Pond, elevation approximately 215 feet. It is not clear whether the threshold was controlled by a bedrock spillway at Harts Pond or whether it was controlled by a delta built eastward from Harts Pond Gap into Lake Hitchcock.

The ice margin stood south of the Mount Tom quadrangle when the last sequence described by Colton and Hartshorn (1971) was deposited. This is a body of deltaic and lacustrine sediments graded to the outlet at Harts Pond. Northward retreat of the ice margin into the Mount Tom quadrangle was accompanied by an expanding proglacial lake which continued to drain through Harts Pond Gap. The ice margin either retreated directly to a position along Bush Brook (0.6 of a mile north of the southern boundary of the Mount Tom quadrangle), or it retreated an unknown distance to the north and readvanced to the Bush Brook position. The record of a 100.5-foot boring located where the Massachusetts Turnpike crosses the railroad tracks just north of Westfield is as follows:

Boring 235, Test Borings, Massachusetts Turnpike, Sec. E, 1955

topsoil	1.5 feet
fine to medium sand	28.0
varved silt and clay	30.0
till	8.0
varved silt and clay	15.5
till	17.5
total	100.5 feet

If the upper till is not a flowtill the boring denotes the fluctuation of the ice margin in a lake during retreat. The upper till possibly could be a till produced by minor readvance to the Stage I position.

Stage I

Westfield Gap

Westfield Gap (fig. 2) was blocked by stratified drift during Stage I. Sediments mapped as undivided glaciofluvial deposits by Colton and Hartshorn (1971), which lie 0.4 of a mile N. 20° W. and 0.2 of a mile S. 45° W. of Westfield Gap, may constitute erosional remnants of a drift dam which blocked eastward drainage through Westfield Gap. The dam served the proglacial lake which drained through Harts Pond Gap much in the same way that the drift dam at Rocky Hill functioned to divert the water of Lake Hitchcock over the till and bedrock threshold at New Britain. Westfield Gap remained blocked until after completion of Stage II, at which time the drift dam was breached. Lowering of the drift dam was probably accomplished by a combination of headward erosion or sapping on the east and lateral cutting by a melt-water stream on the west.

Paper Mills delta

Deposition in front of the stationary ice margin west of the basalt ridge formed an outwash delta called the Paper Mills delta in this report. The areas mapped as Qdw_1 on plate 2 are erosional remnants of the original deposit which formerly extended to the west. An important exposure occurs just north of Paper Mills Road in a pit operated by the Westfield Sand and Gravel Company. The former level of the lake in which the delta was deposited is indicated by the contact between the topset and foreset bedding (fig. 49A). In practice, measurement is taken of the elevation of the highest undisturbed foreset beds which indicates a minimum possible level for the former lake. The approximate maximum elevation of foreset beds in the Paper Mills delta is 245 feet. The orientation of the foreset beds varies from N. 5° E., 28° SE, to N. 30° E., 25° SE, suggesting a source to the northwest. In a pit 0.6 of a mile due west of the first, bottomset beds are collapsed, indicating that the ice front may not have been far away at the time the foreset beds were deposited. When plotted on a north-south projected profile the surface of the Paper Mills delta (8, pl. 3) appears to lie about 10 feet above the southward extension of the Barnes outwash plain (10, pl. 3), which formed during Stage II (below). The topographic discontinuity separating the two features is assumed to have been located along the line of Bush Brook prior to downcutting by Bush Brook. Therefore, the northern or ice-contact edge of the Paper Mills delta was situated near the present course of Bush Brook (fig. 49B).

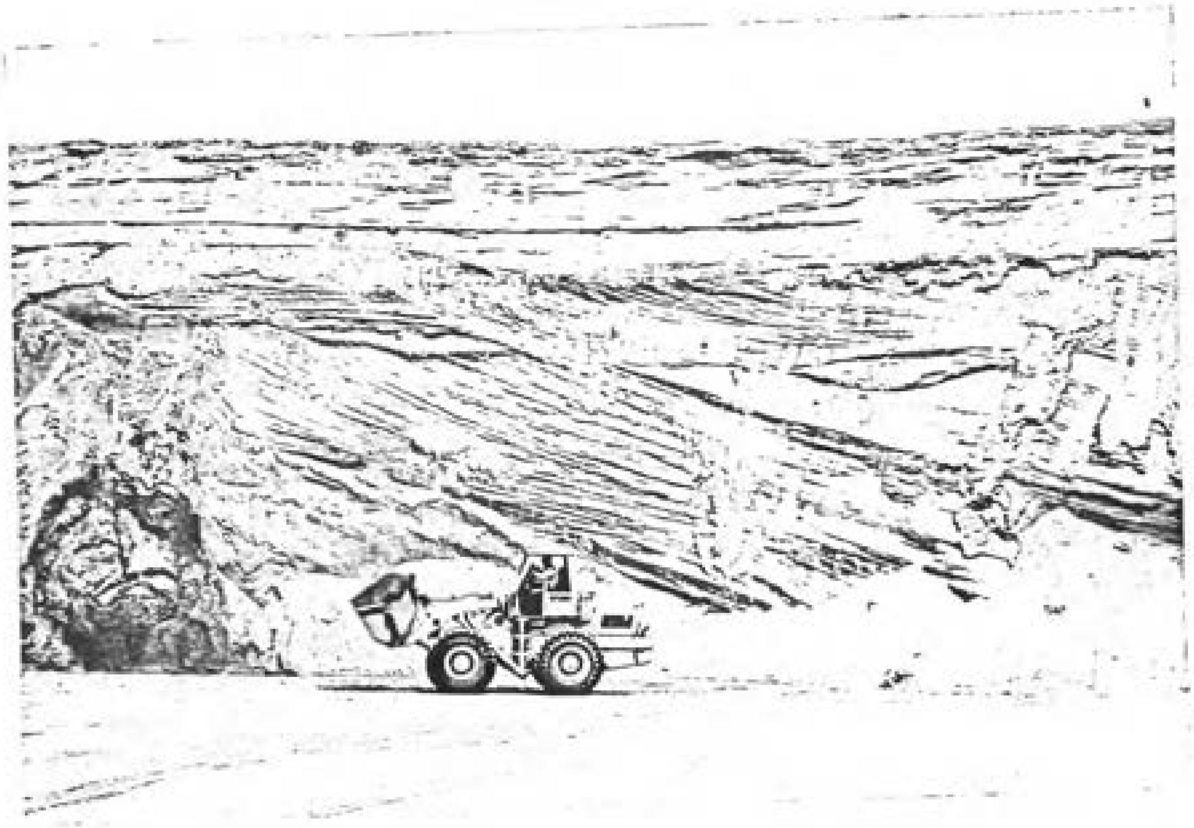
Retreat of the ice margin northward from its position at the Paper Mills delta appears to have been rapid, as large stagnant masses of ice were left in the vicinity of Hampton Ponds and along southern portions of Broad, Moose, and Brickyard Brooks.

Stage II

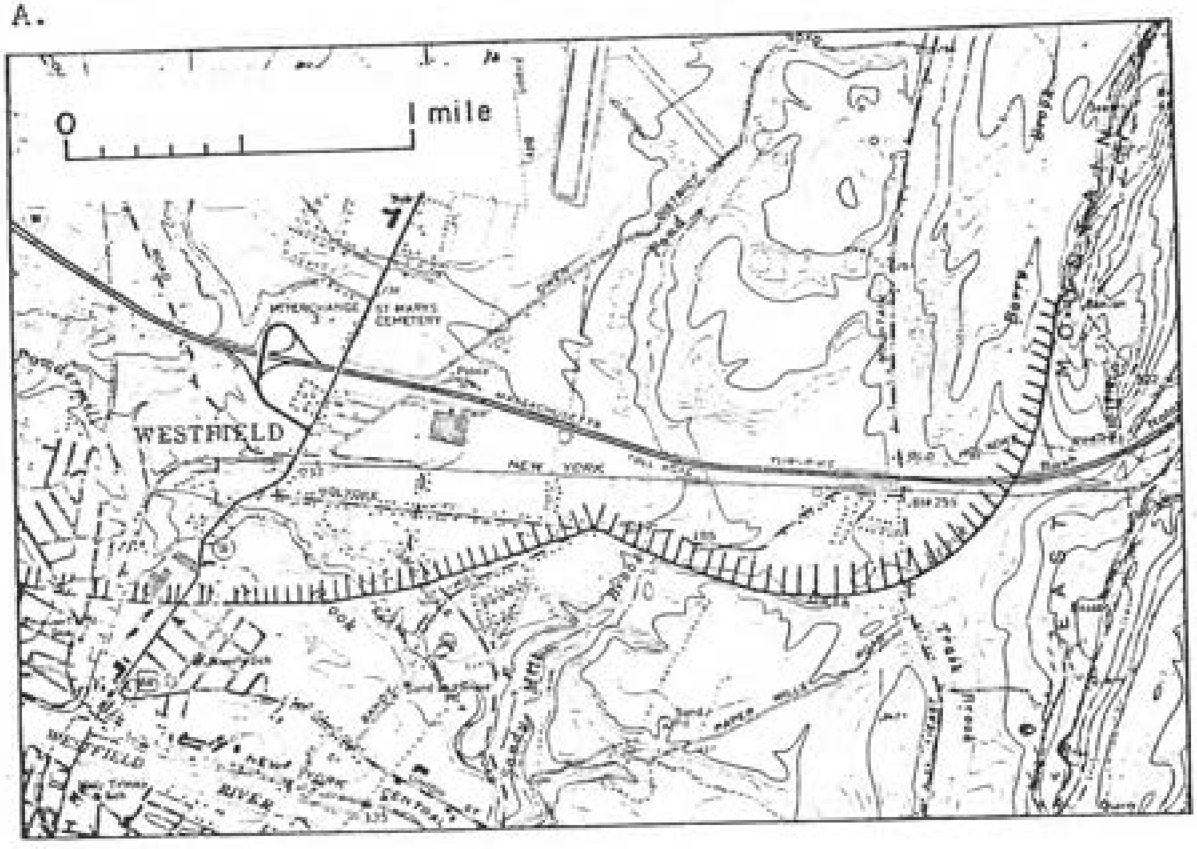
During Stage II, the active ice margin maintained a sinuous position between Little Mountain on the west and Mount Tom

Figure 49 (A). Topset-foreset contact at an approximate elevation of 245 feet in the Paper Mills delta. Exposure is in pit of the Westfield Sand and Gravel Company just north of Paper Mills Road.

(B). Map showing position of the ice margin west of the Holyoke Basalt ridge during Stage I.



A.


0
1 mile
WESTFIELD
INTERCHANGE
ST MARKS CEMETERY
NEW YORK
WESTFIELD
RIVER

B.

Figure 49

on the east (fig. 50A). The ice margin extended further south in the valleys of the Manhan River and Broad Brook than on the till-covered ridge north of Whiteloaf Mountain.

A large complex delta-outwash plain (Qdw_2, pl. 2) was built southward into a proglacial lake from two sources of supply. The main source was an ice margin located 0.3 of a mile south of Pomeroy Street in the north-central part of the map area. A second source was an actual ice margin in the Manhan valley from which melt water drained over and around stagnant ice in the valleys of both Moose Brook and Brickyard Brook.

The Barnes delta-outwash plain _/ is the single largest

_/ The Barnes delta-outwash plain is referred to as the Barnes outwash plain in the remainder of this report.

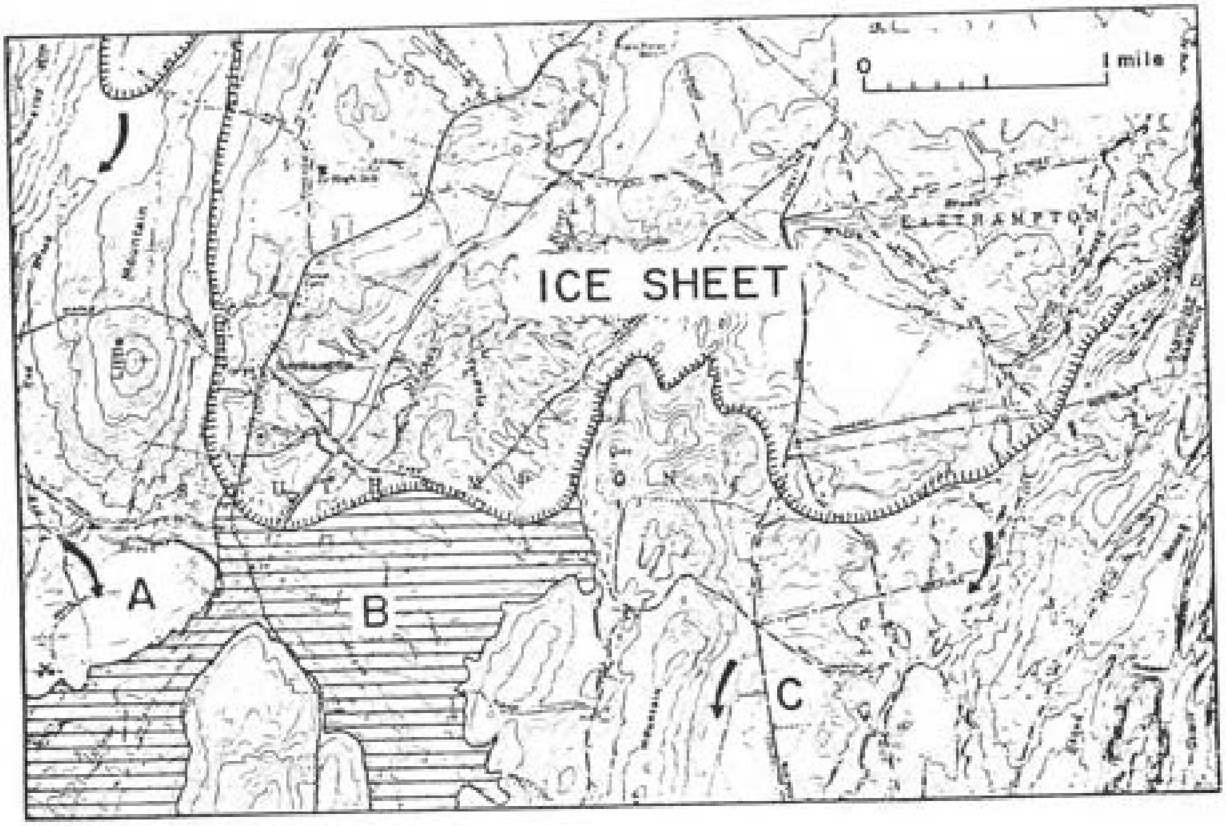
---

depositional landform in the Mount Tom quadrangle, covering an area of more than 10 square miles. The Barnes outwash plain, when completely formed, was contiguous with a large delta-outwash plain built eastward by the Westfield River from its emergence onto the Connecticut Valley Lowland 4 miles northwest of Westfield (fig. 2). An arbitrary boundary between the two features, which shared a common outlet at Harts Pond Gap, is assumed along the present course of the Westfield River in the Mount Tom quadrangle.

The surface of the Barnes outwash plain rises 50 feet in 6.2 miles for an average present-day gradient of 8.1 feet per mile between the Paper Mills delta and the main outwash head. The surface of the upper 1.5 miles of the outwash plain slopes

Figure 50 (A). Map showing position of the ice margin west of the Holyoke Basalt ridge during Stage II. The Davis Plain delta (A) was built into Lake Manhan I (B) which drained to the southwest. The area of Lake Manhan I includes areas of stagnant ice that separated from the ice sheet. Melt-water streams, discharging southward from the ice margin in the valley of Broad Brook, built the Barnes outwash plain (C) to an elevation over 300 feet.

(B). Topset-foreset contact at an approximate elevation of 272 feet in the Davis Plain delta located 1.55 miles S. 42° W. of Southampton village.



A.

B.

Figure 50

at 12.5 feet per mile, while the surface of the next 3.0 miles slopes at 6.7 feet per mile. The lower gradient, if extended on a profile (4, pl. 3), intersects the Harts Pond outlet at 213 feet elevation. This suggests that melt-water from the Barnes outwash plain drained through Harts Pond Gap during Stage II and, further, that the proglacial lake was nearly filled with sediments from the Barnes outwash plain and older deposits at the end of Stage II. The only exception was in the valley of Brickyard Brook and the Manhan River where open water extended north to Little Mountain following the melting of stagnant ice blocks.

The thickness of sediments under the Barnes outwash plain is between 100 and 300 feet as indicated in figure 24, which is based on data from borings. Delta foresets were observed in one deep excavation in sediments of the Barnes outwash plain (fig. 45). Borings for the Massachusetts Turnpike indicate that thick sequences of varved silt and clay occur under a cover of sand (see data on p. 185 for 100-foot boring).

Ice-contact deposits along the east side of Moose Brook (Qdw_2, pl. 2) were held against the valley side by ice, and were graded southward to the Barnes outwash plain. The ice-contact origin of the sediments is shown by the presence of flowtill with striated pebbles and by deformed and collapsed strata exposed at the Southampton town dump 1.4 mi. S. 25° E. of Southampton village (p. 121).

Other kame terraces formed during Stage II are located on the east side of the Manhan valley 1.6 miles S. 17° W. of Southampton village and east of Broad Brook 2.0 miles S. 38° W. of Mount Tom (pl. 2).

Of the three valleys feeding the Barnes outwash plain during Stage II, Brickyard Brook valley was occupied by more stagnant ice and less sediment than the valleys of Moose Brook and Broad Brook. As a consequence, Brickyard Brook valley was the lowest of the three valleys, and during retreat from the Stage II position all glacial melt water west of the basalt ridge was diverted south through the valley of Brickyard Brook.

Northward retreat of the ice in Brickyard Brook valley was accompanied by the development of a small proglacial lake named glacial Lake Manhan I in this report. Information confirming the existence and level of Lake Manhan I in this area comes from a delta at the south end of Little Mountain. This feature is named the Davis Plain delta from a map by the Southampton Conservation Commission (1967). The contact between topset and foreset bedding was observed in the Davis Plain delta at an elevation of 272 feet (fig. 50B), which indicates the former minimum level of Lake Manhan I. The Davis Plain delta was fed by melt water moving southward along Red Brook. Depressions at the northeast edge of the delta mark the margin of active ice during Stage II. Extensive clay deposits, excavated for many years at East Farms, were deposited in the Brickyard Brook valley during Stages II (Lake Manhan I), III (Lake Manhan II), and IV (Lake Manhan III).

The outlet for Lake Manhan I was southward along the western boundary of the Mount Tom quadrangle. The outlet was through ice-contact deposits (Qdw_2) 0.5 of a mile to 2.0 miles south-southeast of East Farms; the outlet is referred to in this report as the Timberswamp channel. The feature is named the Timberswamp channel for the name applied to the area on the 1831 map of the town of Westfield. During Stage II the elevation at the Timberswamp channel was 20 feet higher than the present-day approximate elevation of 235 feet. Shortly after retreat of ice from the Stage II position the outlet stream from Lake Manhan included the entire discharge of melt water from the lobe of ice west of the basalt ridge plus drainage from the upper Manhan valley. The outlet from Lake Manhan I joined with melt water from the valley of the Westfield River and drained through the Holyoke Basalt at Harts Pond Gap.

Erratics of Triassic arkose and siltstone are found on the granitic southeast slopes of Pomeroy Mountain, 0.25 of a mile from, and 250 feet higher than, the nearest Triassic bedrock. Since the contact between crystalline and Triassic rocks trends N. 30° E. (pl. 1), a source to the northeast is suggested. If not directly associated with readvance of ice east of the basalt ridge (p. 205), the presence of the erratics can be explained by radial movement of a lobe of ice as it moved to the Stage II position.

Diversion of drainage

An important change in drainage west of the basalt ridge occurred when the ice margin retreated from the Stage II to the Stage III position. Melt-water drainage that had been passing through Harts Pond Gap was diverted through Westfield Gap. The diversion was probably accomplished by lateral cutting into the drift dam by the large melt-water stream on the west and by headward erosion or sapping on the east (p. 186). Deposits produced by the diversion (5, pl. 3) became part of the Agawam delta complex southeast of Westfield Gap (fig. 2). These deposits rise to elevations over 220 feet and have been mapped by Colton and Hartshorn (1971) as delta deposits.

Prior to the diversion the melt-water stream west of Westfield Gap stood 15 to 20 feet higher than it did after the diversion. Because of the lowering of base level caused by the diversion, headward erosion occurred upstream along the Westfield River and the Timberswamp channel. Vertical downcutting at the Timberswamp channel must have been on the order of 10 to 15 feet, which caused a subsequent lowering of Lake Manhan I to a lower lake referred to here as Lake Manhan II (Stage III, below).

Stage III

During Stage III the active ice margin west of the basalt ridge held a position 1.2 to 1.5 miles north of, and parallel to, that of Stage II (fig. 51). The ice extended further south in the valleys of the Manhan River and Broad Brook than on the ridge between the two valleys.

Glacial Lake Manhan I drained southward through the Tim-

Figure 51. Map showing position of the ice margin west of the Holyoke Basalt ridge during Stage III. Melt water draining southward along the west margin of the ice sheet deposited the Southampton delta (A) in Lake Manhan II (B). In the Broad Brook valley melt water formed the Pomeroy Street delta (C) in a small proglacial lake (D) which drained to the west over a till-covered ridge. Margin of active ice shown by hachured line.

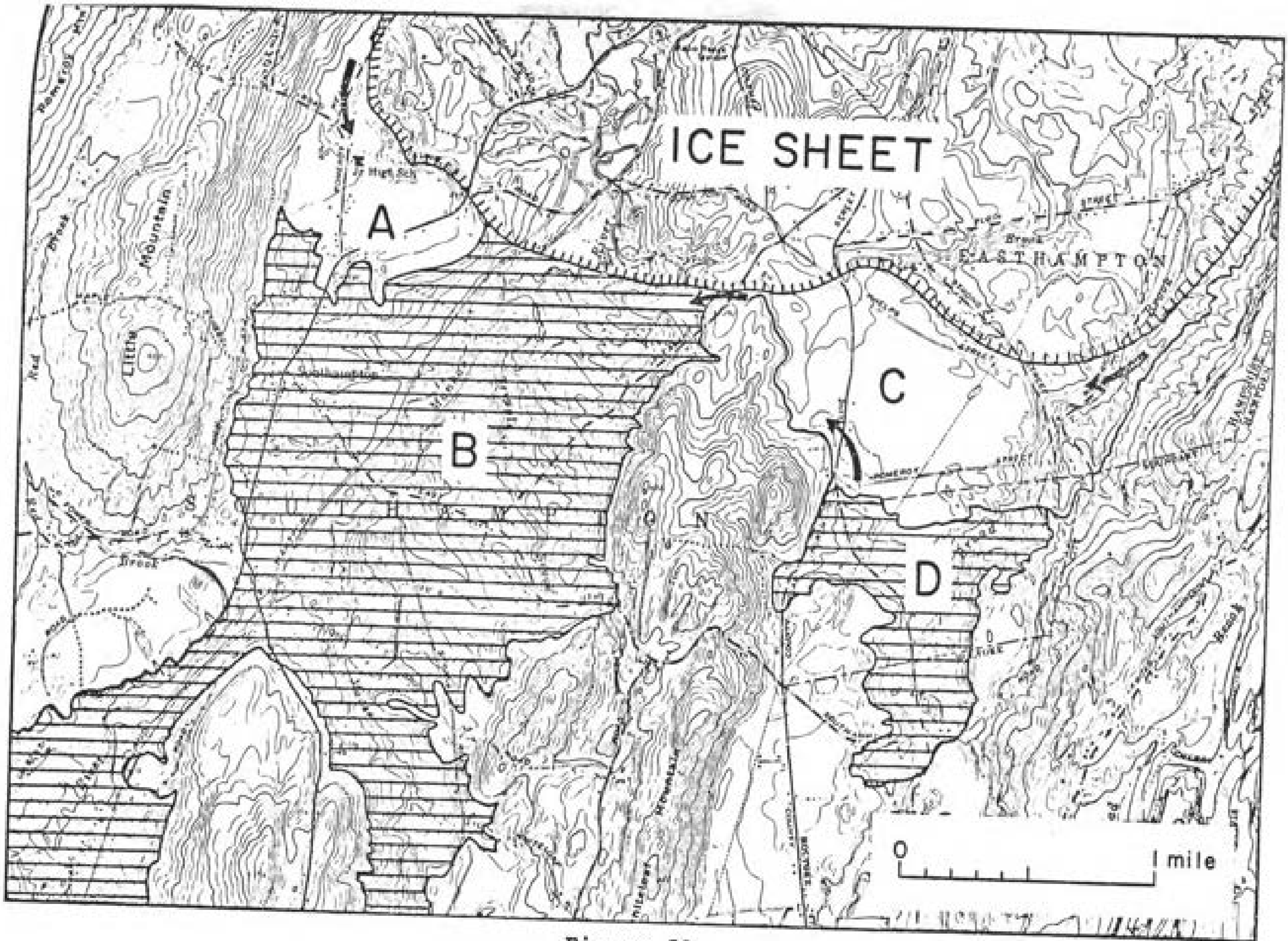


Figure 51

berswamp channel and expanded northward with the retreating ice. The ice margin reached a stillstand 1.0 mile northeast of Southampton village where a classic ice-contact delta (Qdw_3, pl. 2) was deposited by melt-water streams held between the side of Little Mountain and the lobe of ice occupying the Manhan valley. On its northeast side the Southampton delta (24, pl. 3) displays a typical ice-contact slope with depressions that testify to the presence of glacial ice at the time the delta was formed. Shallow exposures on the delta surface reveal gravel and sand with features characteristic of fluvial topset beds. The contact between topset and foreset bedding, which marks the former level of Lake Manhan II, was observed at an approximate elevation of 275 feet in a small pit 0.96 of a mile N. 34° E. of Southampton village. The dip of the foreset beds was to the southeast, indicating transport direction during time of deposition.

Retreat of ice from the Stage II outwash head in the Broad Brook valley was accompanied by the development of a small proglacial lake, whose outlet stream across the till-covered ridge north of Whiteloaf Mountain led into Lake Manhan II. The ice margin maintained a stationary position parallel to, and just northeast of, Phelps Street while a delta with a surface area of about 1.0 square mile was deposited between the ice and the Stage II outwash head to the south. Fluvial crossbedding, exposed in a trench 10 feet deep north of Pomeroy Street and east of the powerline, indicates a transport direction to the west-southwest during deposition of topset beds. No deep exposures were observed in this feature, known here as the Pomeroy Street delta (22, pl. 3).

On the east and the west the Pomeroy Street delta was held in by till-covered bedrock. The outlet to the northwest was over ice or held by ice at an elevation of about 270 feet on the side of a till-covered ridge. A line of boulders across the till slope 0.25 of a mile S. 39° W. of the junction of Pleasant Street and Gunn Road may constitute a lag concentrate produced by erosion of the till by the outlet stream. The outlet stream fed a small ice-contact delta built into Lake Manhan II 1.6 miles N. 77° E. of Southampton village.

Stage IV

Shortly after leaving the Stage III position, the active ice margin appears to have retreated 0.4 of a mile and reached a temporary stillstand in the valleys of both the Manhan River and Broad Brook (fig. 52).

A steep bank, which trends northwest-southeast 0.4 of a mile northeast of the edge of the Southampton delta, appears to mark the position of the ice margin in Lake Manhan III while melt-water streams started to deposit another ice-contact delta. The stillstand was of short duration as only 30 to 40 feet of sand (Qdw_4, pl. 2) was deposited in 60 feet of water in front of the ice before retreat was renewed. On the east side of the Manhan valley 1.6 miles N. 59° E. of Southampton village a second

Figure 52. Map showing position of the ice margin west of the Holyoke Basalt ridge during Stage IV. Lake Manhan III (A) drained southward via the Timberswamp channel 2.0 miles south of the southwest corner of the map area. Melt water discharging around the ice margin built sublacustrine deposits just north of B and C. In the valley of Broad Brook, the White Brook delta (D) was deposited in a small proglacial lake that formed between the ice margin and the Pomeroy Street delta (E). Drainage of the lake (F) south of the Pomeroy Street delta was to the north and then to the west over the till-covered ridge.

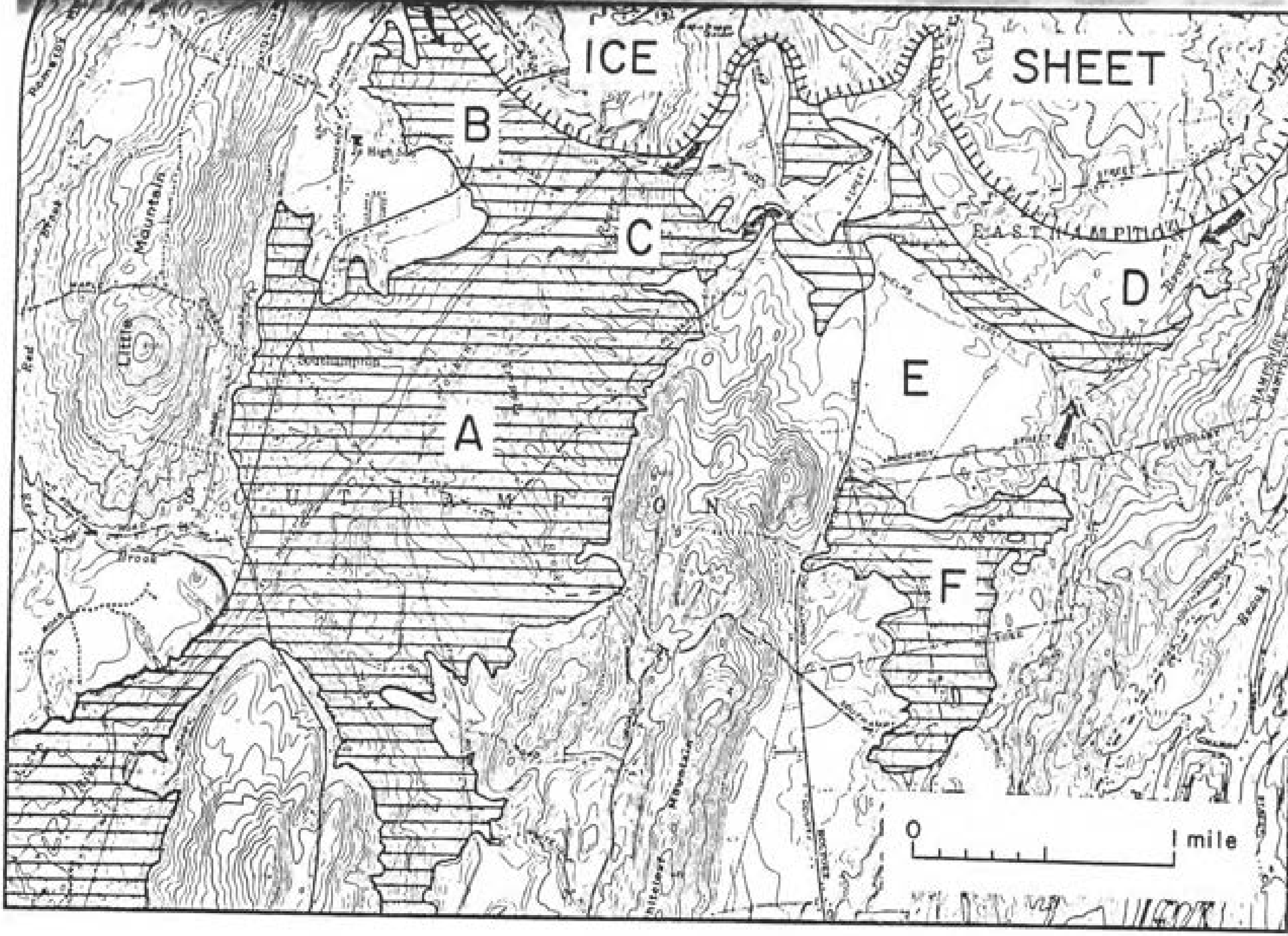

ICE
SHEET
A
B
C
D
E
F
Little Mountain
Southampton
SOUTHAMPTON
EASTHAMPTON
0
1 mile

Figure 52

sand deposit with a maximum elevation of approximately 225 feet was formed in the same manner.

In the Broad Brook valley a similar temporary stillstand occurred 0.4 of a mile northeast of the Pomeroy Street delta. Just northeast of Strong Street a series of closed 260-foot contours appears to mark the crest of an ice-contact delta, here named the White Brook delta (26, pl. 3). Drainage from the White Brook delta escaped westward via a channel (25, pl. 3) which crossed the till-covered ridge just west of the junction of Pleasant Street and Gunn Road. The outlet channel drained into Lake Manhan III, which was at an approximate elevation of 260 feet at this latitude.

Lake Manhan III stood at an elevation of approximately 255 feet on the southeast side of the Davis Plain delta, as shown by a small delta (21, pl 3) built at the mouth of a small gully eroded into the Davis Plain delta. Other surfaces that could represent tops of deltas built into Lake Manhan III at this time occur 1.7 miles S. 32° W. and 0.68 of a mile S. 18° W. of Southampton village.

Drainage from Lake Manhan III continued to pass southward via the Timberswamp channel, which had been downcut to an approximate maximum elevation of 235 feet (13, pl. 3). The outlet stream from Lake Manhan III, cutting laterally to the east, trimmed off the front of the Barnes outwash plain and cut into the Paper Mills delta. Stream-terrace deposits at 225 feet elevation in front of the Paper Mills delta (Qst, pl. 2) rise to over 230 feet elevation in the Timberswamp channel.

Extensive deposits of ice-contact stratified drift at elevations of 285 to 305 feet, 1 to 4 miles north of the Mount Tom quadrangle (28, 30, 31 and 32; pl. 3), appear to have been deposited during Stage IV. Melt-water drainage associated with these deposits was held against the crystalline uplands by the melting lobe of ice and escaped to the south, ultimately passing through Lake Manhan III and the Timberswamp channel. An alternative hypothesis is that the deposits are younger than Stage IV and are graded to a temporary outlet across the melting ice to the Holyoke Narrows (fig. 2). However, similar ice-contact deposits at elevations up to 305 feet occur on the northwest side of the Mount Tom Range (27, pl. 3). Since these deposits display features indicating a transport direction to the south it is suggested that the above-mentioned ice-contact deposits formed during Stage IV.

Lake Hitchcock in the Manhan valley

At the same time that retreat of the ice margin was occurring west of the basalt ridge, retreat of the ice margin east of the basalt ridge was accompanied by a northward-expanding Lake Hitchcock (p. 179). When the ice margin east of the basalt ridge was in the vicinity of the Holyoke Narrows an ice-contact delta was deposited on the southeast side of the water gap. This delta, the Dry Brook delta (29, pl. 3), has a pitted surface and foreset bedding that dips 27° toward N. 46° E. The maximum elevation on the delta is over 270 feet, indicating that the delta was formed in high Lake Hitchcock.

After deposition of the Dry Brook delta, the ice margin withdrew from the Holyoke Narrows and water of Lake Hitchcock extended through the Narrows and along the west side of the Mount Tom Range. In the Mount Tom quadrangle, northward retreat of the ice margin after the temporary stillstand of Stage IV permitted the level of Lake Manhan III to drop below the level of the Timberswamp channel and to the level of Lake Hitchcock (fig. 53). Drainage of the Manhan River, which had passed through Lake Manhan III and the Timberswamp channel, was now diverted to the northeast to an arm of Lake Hitchcock that occupied the Manhan valley. Drainage in Brickyard Brook (14, pl. 3) was to the north into the Manhan valley because the bottom of Lake Manhan III north of the Timberswamp channel sloped in that direction. The sandy flat at an elevation of 225 feet upon which the hamlet of East Farms is located may be a delta surface, the height of which was controlled by the level of Lake Hitchcock in the Manhan valley.

East of the Holyoke Basalt ridge

Readvance

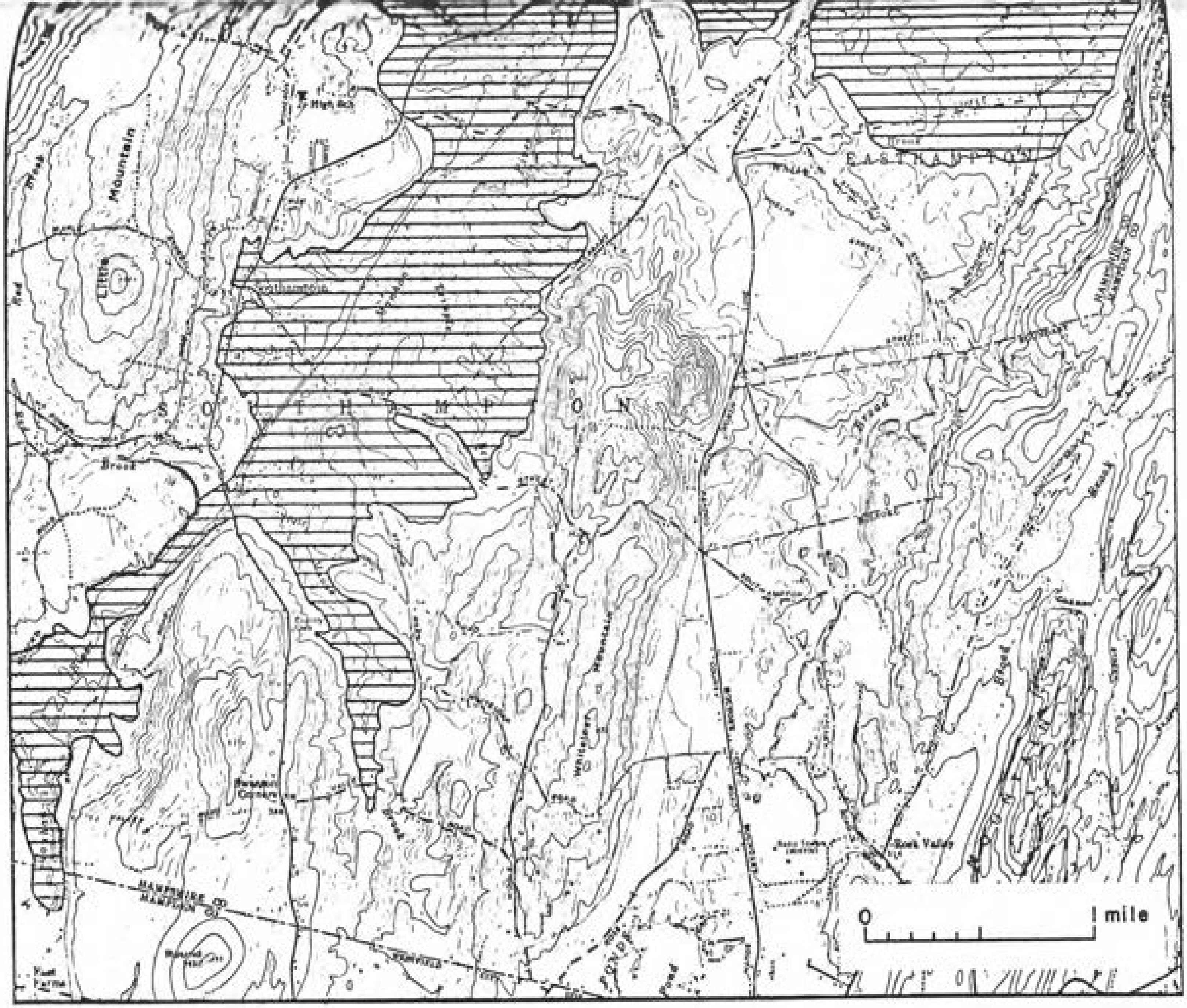
During the early history of deglaciation east of the Holyoke Basalt ridge, the active ice margin retreated at least 3.4 miles north of the southern boundary of the Mount Tom quadrangle. A variety of deltaic, lacustrine, outwash, and ice-contact deposits must have formed at this time. This early retreat was

JnS

[illegible] Plant [illegible].
According to [illegible] [illegible]
level, [illegible] ft above low Lake H level, not 30' [illegible]
[illegible] Lake H.

Supposing that Lake H could get in here (past the Red Rock [illegible]
which blocked it off), there is no stream that could have brought
this "delta." The Manhan R would have deposited a delta
on the NW side of the Brickyard pond, not the S side, and
Brickyard Brook carried only local (rainfall) runoff.

Figure 53. Approximate position of western shoreline of low stable stage of glacial Lake Hitchcock. Drainage of the portion of Lake Hitchcock shown was to the northeast through the Holyoke Narrows.



Little Mountain
Mountain
Broad
Whitelaw Mountain
Rock Valley
EASTHAMPTON
SOUTHAMPTON
HAMPSHIRE CO
HAMPDEN CO
0
mile

Figure 53

followed by readvance of a lobe of ice that moved from northeast to southwest to the Holyoke Basalt ridge and beyond the southern boundary of the Mount Tom quadrangle.

The evidence for readvance consists of: (1) till over stratified drift, (2) till-fabric studies, (3) two directions of striations, (4) glaciotectonic structures, and (5) data from borings. Figure 54 illustrates the localities where the various types of evidence are found. Whether the readvance was a major event or whether it consisted of an oscillating but retreating ice margin, or both, is difficult to ascertain. Also, the time of readvance can only be conjectured but it is tempting to relate it to the readvance that occurred when ice moved to the Stage I position west of the basalt ridge (p. 185).

Till over stratified drift

A composite cross section that illustrates the late-glacial history is located at and near Tannery Brook, which flows into the Connecticut River at the Holyoke City-West Springfield town line (fig. 55). Numerous exposures of reddish-brown lodgement till occur along the stream bed 1,200 feet due west of the Catholic hospital. Till in these exposures is compact and displays fissility. Grain-size analysis 9-123 (fig. 28A) was from a till exposure on Tannery Brook.

Firm lacustrine clay and silt occur at elevations higher than the till on a narrow ridge between Tannery Brook and a south-flowing tributary. Pebbles are numerous in certain por-

Figure 54. Map of southeast part of the Mount Tom quadrangle showing areal distribution of evidence for readvance of glacial ice.

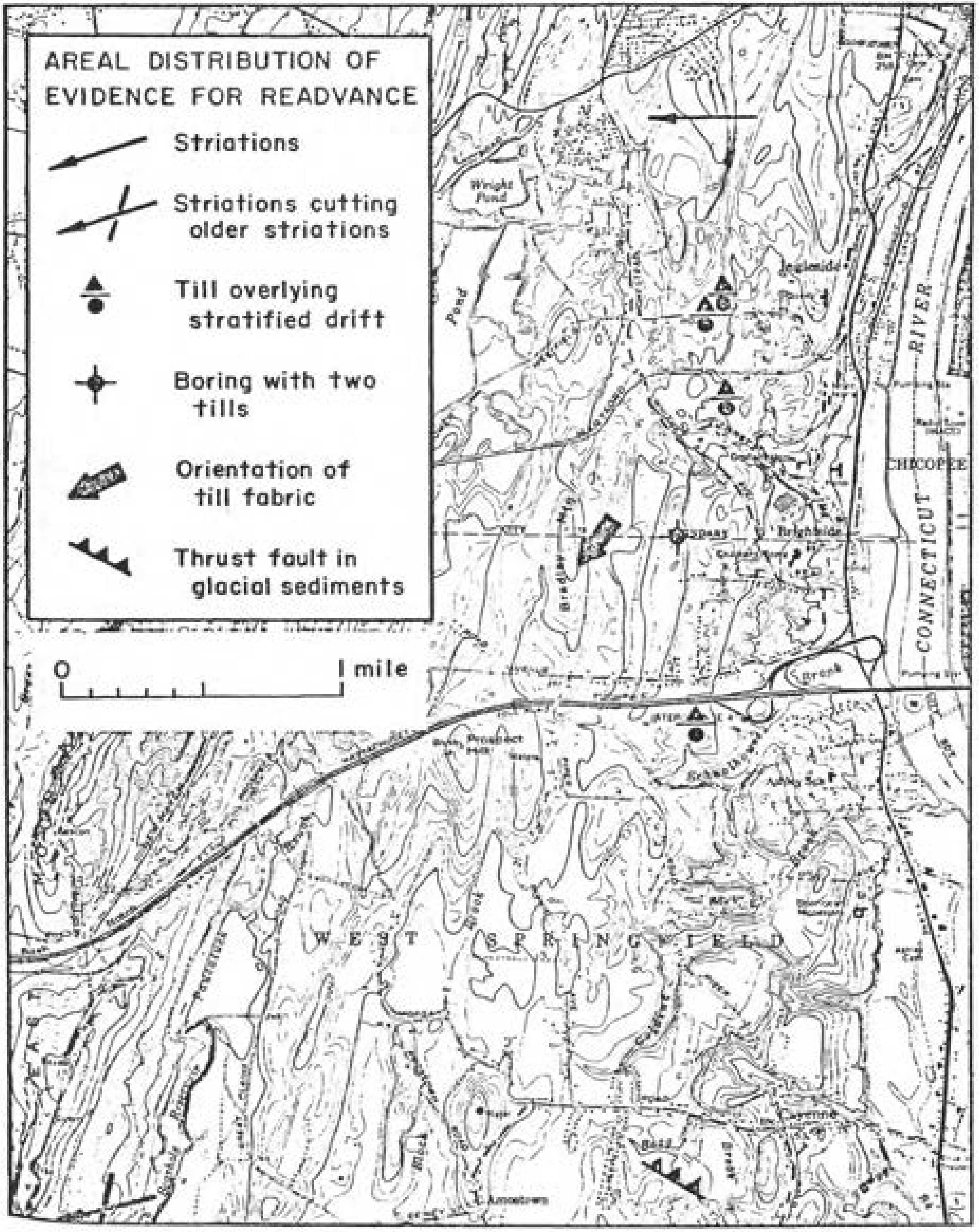
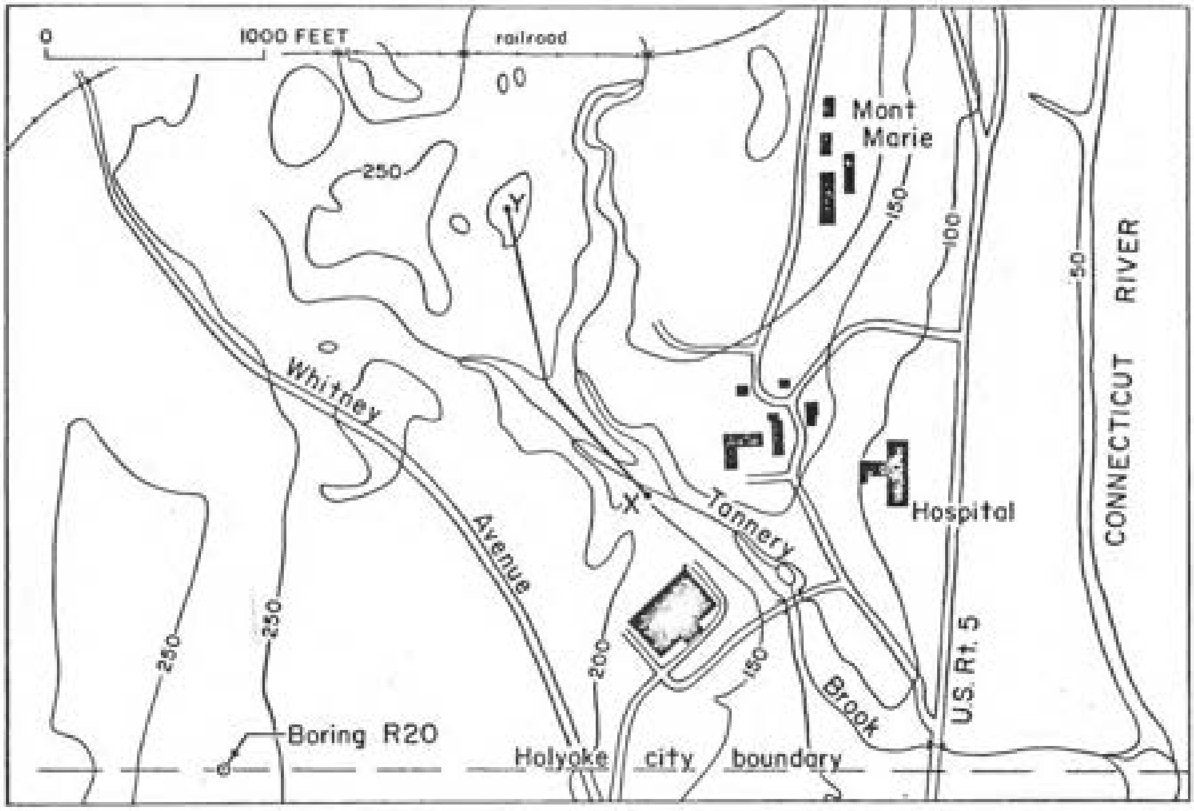

AREAL DISTRIBUTION OF EVIDENCE FOR READVANCE
Striations
Striations cutting older striations
Till overlying stratified drift
Boring with two tills
Orientation of till fabric
Thrust fault in glacial sediments
0
1 mile
Wright Pond
CONNECTICUT RIVER
CHICOPEE
WEST SPRINGFIELD
Brightside
Prospect Hill
Amostown

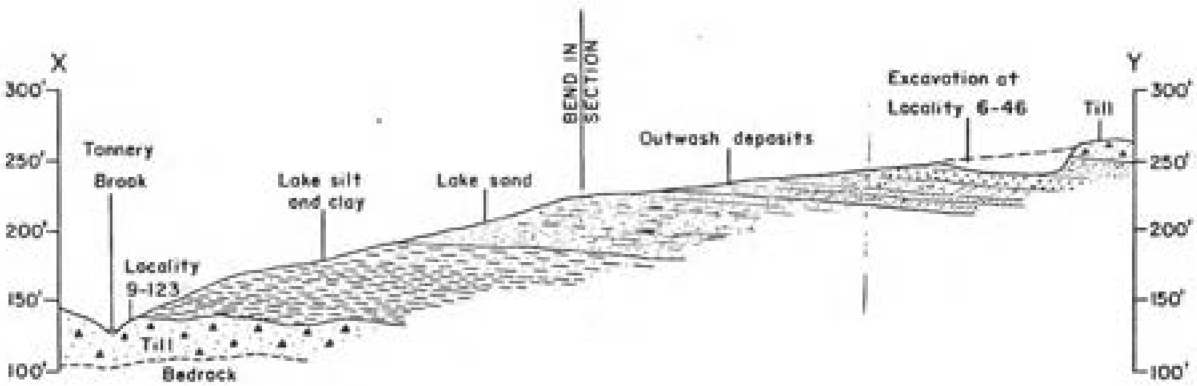
Figure 54

Figure 55 (A). Map showing location of Tannery Brook cross section and boring R20.

(B). Cross section from Tannery Brook to Hill 260, showing outwash (Qow), lacustrine sand (Qls), and lacustrine clay (Qlc) between two till localities (9-123 and 6-46).


0
1000 FEET
railroad
Mont
Marie
250
Y
150
100
50
CONNECTICUT RIVER
Whitney
Avenue
X
Tannery
Hospital
250
250
200
150
Brook
U.S. Rt. 5
Boring R20
Holyoke city boundary

A.


X
Y
300'
250'
200'
150'
100'
BEND IN SECTION
Excavation at Locality 6-46
Till
Outwash deposits
Tannery Brook
Lake silt and clay
Lake sand
Locality 9-123
Till
Bedrock

B.

Figure 55

tions of the clay. About 500 feet due west of the ridge, at an elevation of 230 feet, deformed varved clays strike N. 6° W. and dip 30° to the east.

A critical section was exposed during the summer of 1969 in a temporary borrow pit 2,200 feet northwest of the Catholic hospital. The locality, 6-46, was dug in the side of a small hill with an elevation slightly greater than 260 feet. The exposure was along a curved surface that faced south, southwest, and west (fig. 56A), and measured 22 feet high and 150 feet long.

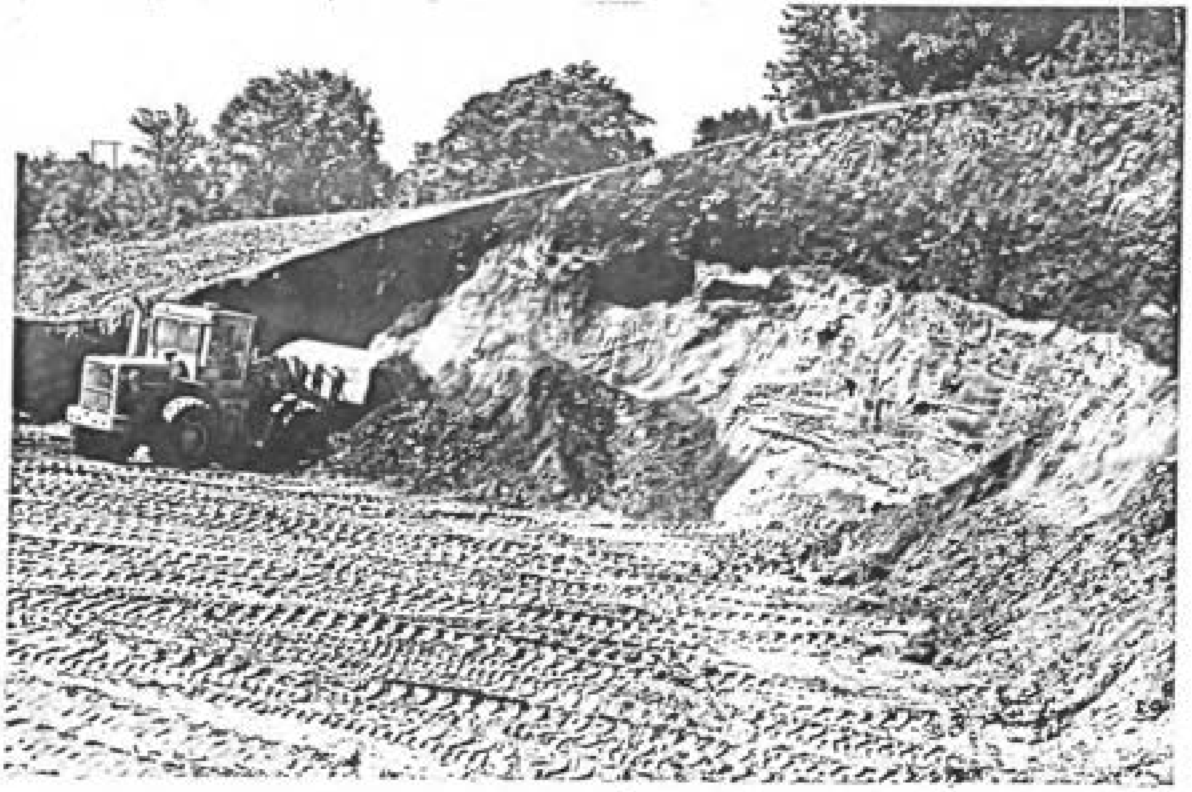
A 5.0-foot auger hole at the bottom of the face revealed brown silt and fine sand. Above this occurred thrust-faulted light-brown fine to coarse sand. The sand is composed of sedimentation units consisting of coarse-granule sand with plane beds of the upper flow regime, which grade upward into fine sand with ripples of the lower flow regime (fig. 56B). The units are 1 to 3 feet in thickness. Crossbedding formed by the migration of dunes in the upper part of the lower flow regime also was observed. The overall aspect is one of fluvial sands deposited in an outwash environment. Layering in the sand has been offset by thrust faults that dip gently to the northeast (fig. 56B).

Overlying the fluvial sand is a zone 0.5 to 3 feet thick which is crudely stratified, and which is composed of slices and lenses of material intermediate in composition between the underlying sands and reddish-brown till above (figs. 57A and 57B). This zone is interpreted to be a shear zone produced by glacial ice overriding fluvial sands.

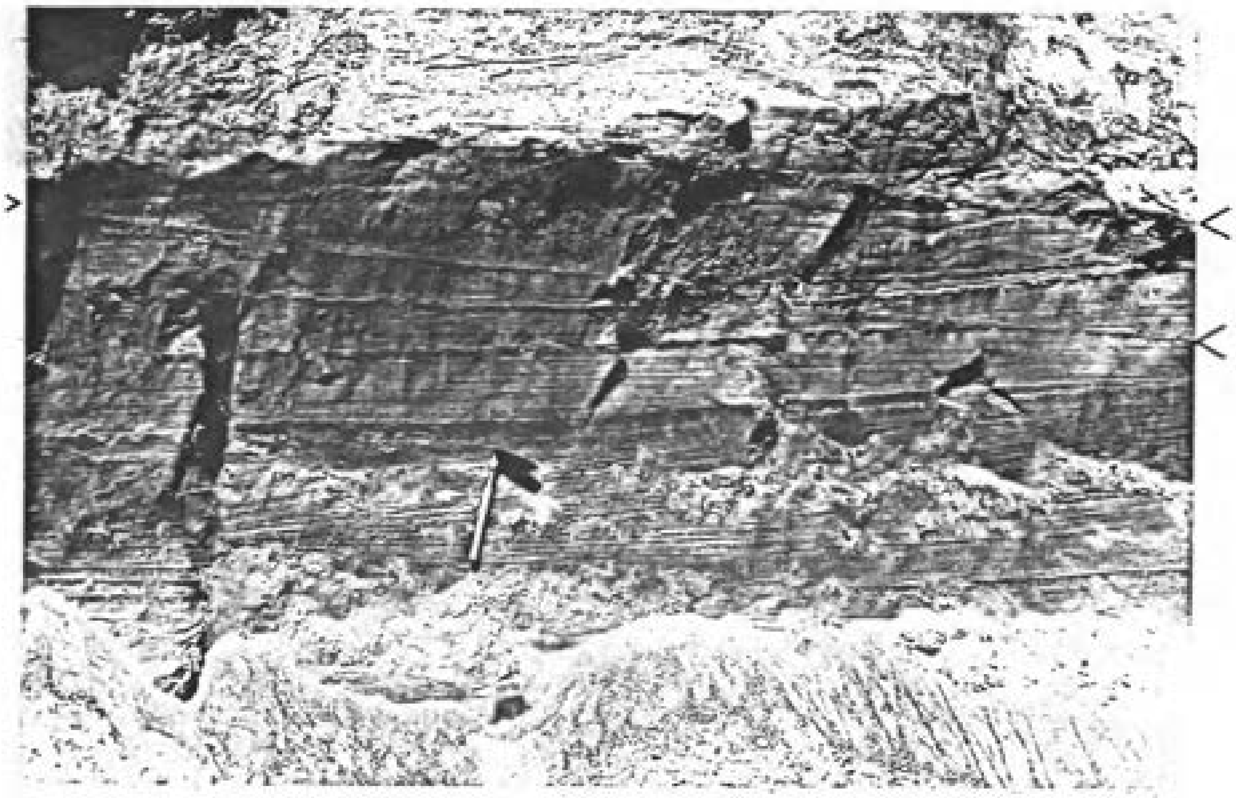
Fig 55B indicates the locality is on line X-Y of 55A, WSW of Mont Morin

Figure 56 (A). Brown till overlying thrust-faulted outwash sand at Locality 6-46. (see fig. 55 for location). Face at the right is 22 feet high.

(B). Thrust-faulted light-brown fine to coarse sand with granule gravel above. Each sedimentation unit consists of coarse granule sand with plane beds of the upper flow regime grading upward into fine sand with ripples of the lower flow regime. Thrust faults, the upper plate of which has moved toward the observer and to the left (southwest), are marked with arrowheads.



A.



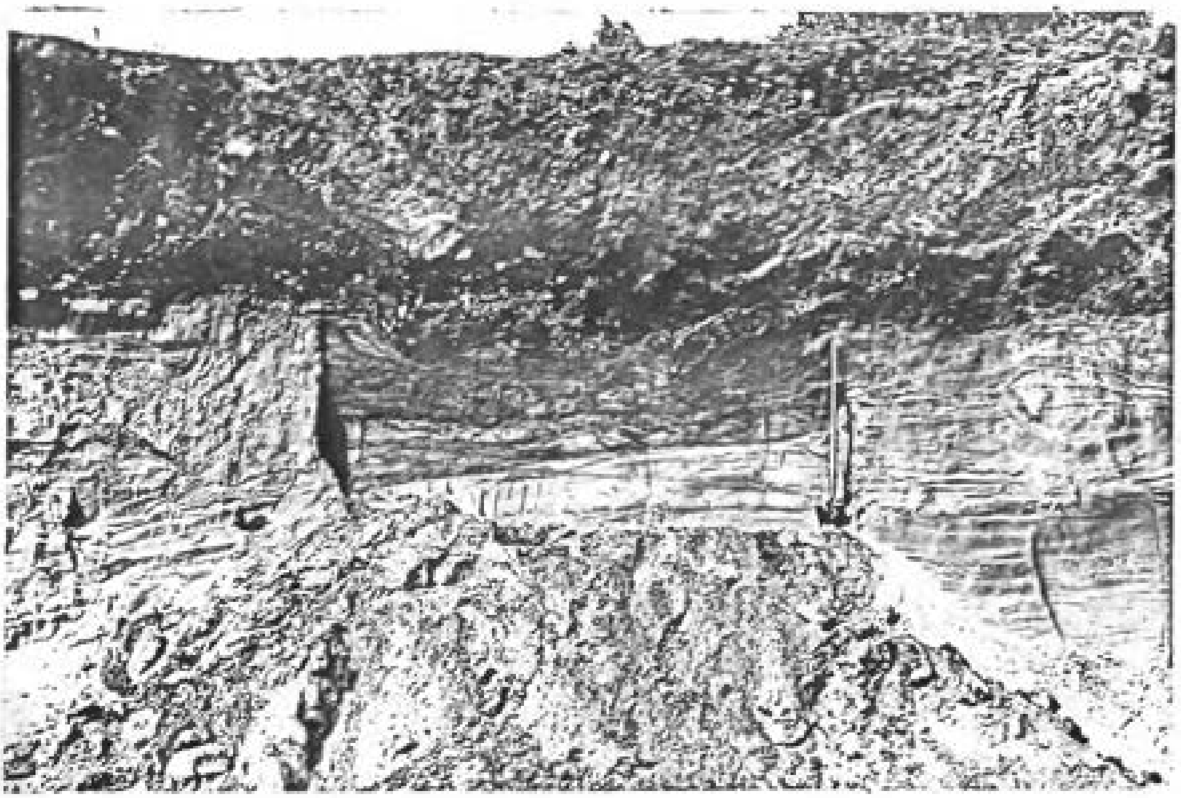
B.

Figure 56

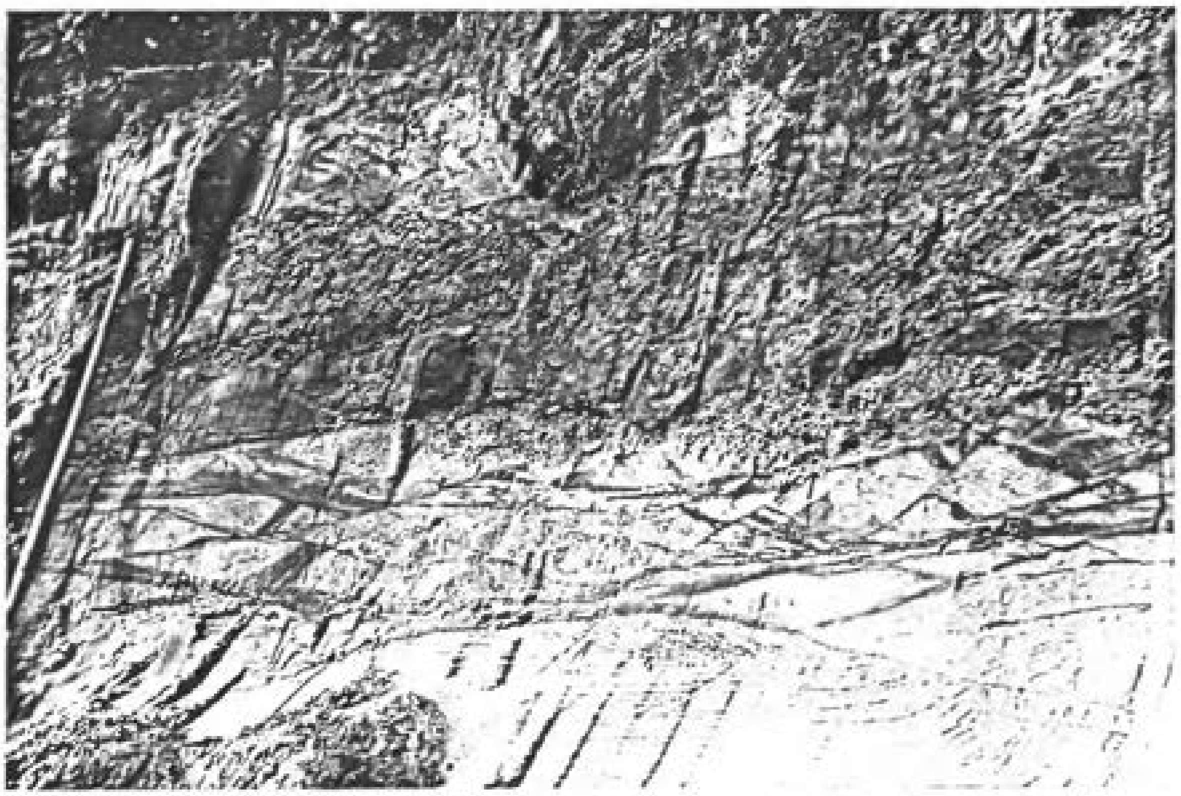
Figure 57 (A). Seven feet of ablation till and lodgement till rest on 2- to 3-foot shear zone which rests in turn upon thrust-faulted outwash sand. Locality 6-46.

(B). Detail of lodgement till (dark, at top), shear zone, and thrust-faulted outwash sand. Locality 6-46.

See fig 56A



A.



B.

Figure 57

Above the shear zone 7 to 11.5 feet of brown lodgement till grades upward into a light-brown to yellow-brown ablation till. The lodgement till is compact and has a firm fine-grained matrix. The ablation till has a coarse-grained matrix of sand, granules, and pebbles. The matrix is sometimes missing entirely, resulting in pockets with open-work structure. Grain-size analysis 10 6-46 (fig. 28A) is of lodgement till from this locality.

Based on figure 55B, the local glacial history of the Tannery Brook area is: (1) advance of ice to produce the till of Loc. 9-123, (2) retreat of ice followed by lacustrine sedimentation, (3) readvance of ice to produce crossbedded outwash sands over lacustrine silt and clay, (4) covering by ice to produce lodgement till and thrust features, and (5) subsequent retreat of ice accompanied by deposition of ablation till.

Other localities where till rests on stratified drift are given by the following directions in relation to the Catholic hospital:

(1)	Loc. 6-39	0.73 mi. N. 36° W.
(2)	Loc. 9-134	0.48 mi. due W.
(3)	Loc. 9-76	1.12 mi. S. 27° W.

Locality 6-39 was a temporary exposure in a ditch along Lower Westfield Road just east of I-91. In a face 180 feet long and 5 to 8 feet deep, a layer of brown fissile till 5 to 6 feet thick was observed to overlie a dark-brown gravel in the central 50 feet of the ditch. Locality 9-134 is at the edge of a shallow borrow pit which has been graded. Brown till was exposed above crossbedded and disturbed sands. The tills exposed at localities 6-46, 6-39, and 9-134 are believed to be the same stratigraphic unit.

Two separate tills were exposed in 1969 at Loc. 9-76 on the west side of a borrow pit that has since been graded. The sequence sand-till-sand-till-sand occurred in a curving exposure 350 feet long and 8 to 12 feet high at an elevation of approximately 210 feet. Both tills display irregular layers of varying composition, which formed by mixing two end members (fig. 58). One end member consists of a brown till, the other of olive-gray clay and dark brownish-red silt of lacustrine origin. Such irregular layering would be expected if an ice margin readvanced or oscillated in a water body such as glacial Lake Hitchcock. The lower till contains less lacustrine material and displays shearing and thrust faults at its base. It is my opinion that the lower till, which is 10 feet thick, represents a longer readvance of ice in the time sense than does the upper till, and that there is a third till at depth which represents the major, or late Wisconsin, advance of ice in this area.

Till-fabric studies

Three till-fabric measurements were made by J. C. Mullen (written commun., 1969) east of the basalt ridge during the course of this study. The results of the three measurements are plotted as rose diagrams on figure 17. Two of the measurements have strong single modes of N. 37° E. and N. 50° E. and support the concept of readvance from the northeast, while the

Figure 58. Stratified till at Locality 9-76, 0.5 of a mile N. 69° W. of Ashley School.

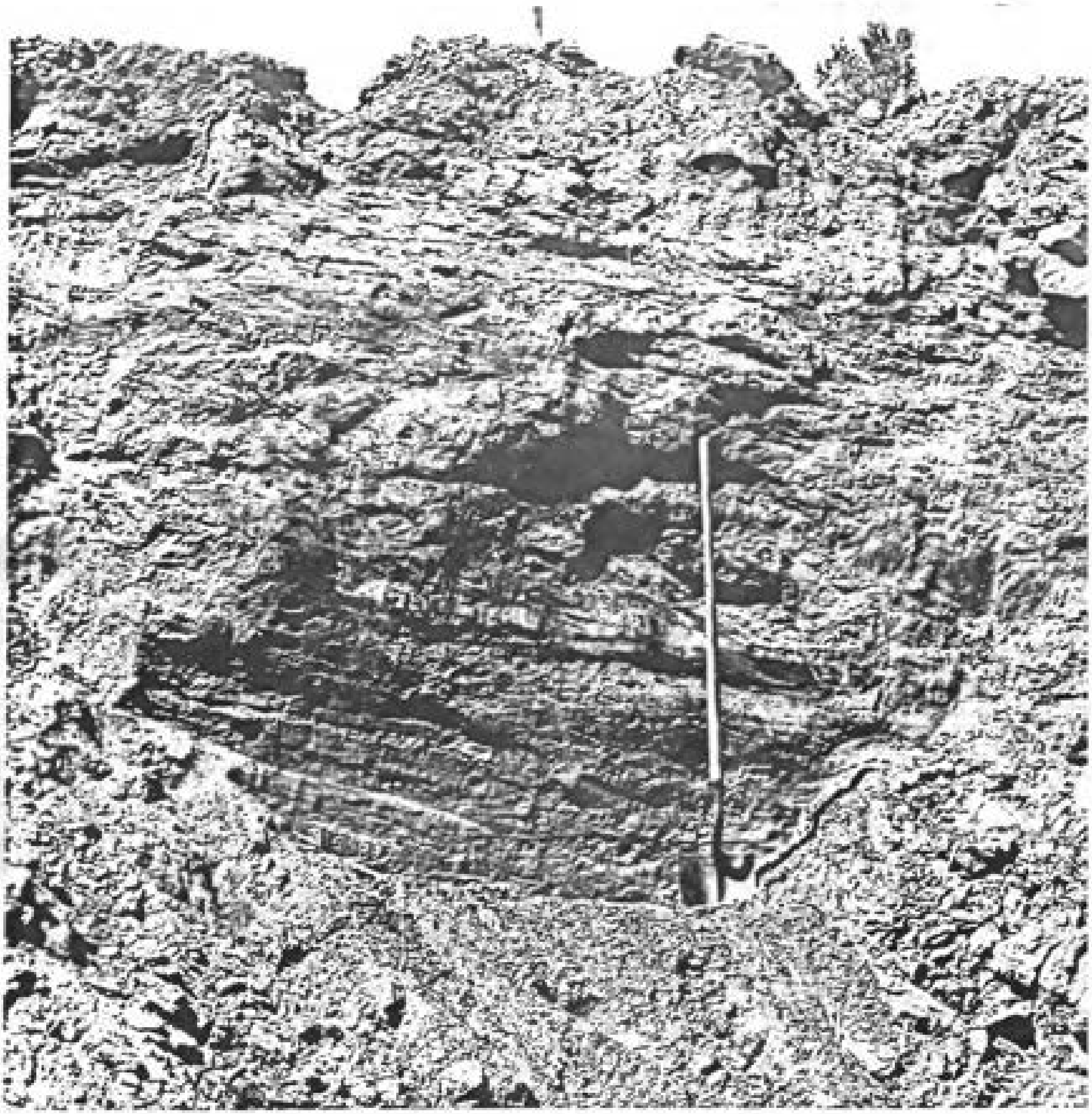


Figure 58

third has four nearly equal and widely scattered modes and is difficult to interpret (appendix II).

Two directions of striations

An exposure on the crest of the basalt ridge at the southern boundary of the Mount Tom quadrangle has two sets of striations, S. 10° W. and S. 75° W. (fig. 59A). The south-trending striations are older and parallel the major streamline molded forms produced during maximum glaciation (fig. 19B). The west-trending striations are younger because they occur on the beveled tops of whalebacks (fig. 59B). It is assumed that the west-trending striations were formed by tools held in thin ice overriding the crests of the whalebacks, while till protected the troughs between whalebacks. If glacial erosion had been more rigorous during readvance, west-trending striations would have formed in the troughs. Since the west-trending striations are younger, occur on the ridge crest, and support other lines of evidence for readvance, such as till fabrics and thrust features, they are believed to be associated with a lobe of glacial ice that readvanced from the northeast.

West-trending striations in the east-central portion of the Mount Tom quadrangle (fig. 17) are probably associated with this readvance.

In the West Springfield quadrangle, Colton and Hartshorn (1971) mapped numerous striations that indicate a southwesterly to westerly movement of glacial ice. These striations are in

Figure 59 (A). Two sets of striations. Striations at upper left trend S. 10° W. and are older than west-trending striations which parallel hammer handle. Location is on the southern edge of the Mount Tom quadrangle at east side of Lane Quarry, Westfield.

(B). Two sets of striations. Striations at top, near hammer, and at bottom trend S. 10° W. (glacial movement was right to left). Striations on whalebacks below and at upper left of hammer trend S. 75° W. (glacial movement was away from observer). Location same as (A) above.

A.

B.

Figure 59

addition to those mapped parallel to the basalt ridge. Colton and Hartshorn also mapped crossing striations on the crest of the basalt ridge at Provin Mountain. They attributed the southwest striations to radial movement of a shrinking Connecticut Valley ice lobe which moved southward down the center of the Connecticut Valley.

All indications in the Mt. Tom quadrangle are that readvance occurred from a sector between east and northeast. It is unlikely that a lobe of ice advancing southward down the Connecticut Valley could move enough ice over and around the Holyoke Range (see Fig. 2) to produce the evidence for readvance found in the southeast portion of the Mount Tom quadrangle without advancing further south than the same position on the west side of the basalt ridge. Therefore, readvance must have been caused by movement of ice into the Connecticut Valley from the New England Uplands to the east-northeast.

Not necessary, unless you can prove no readvance occurred W of the basalt ridge.

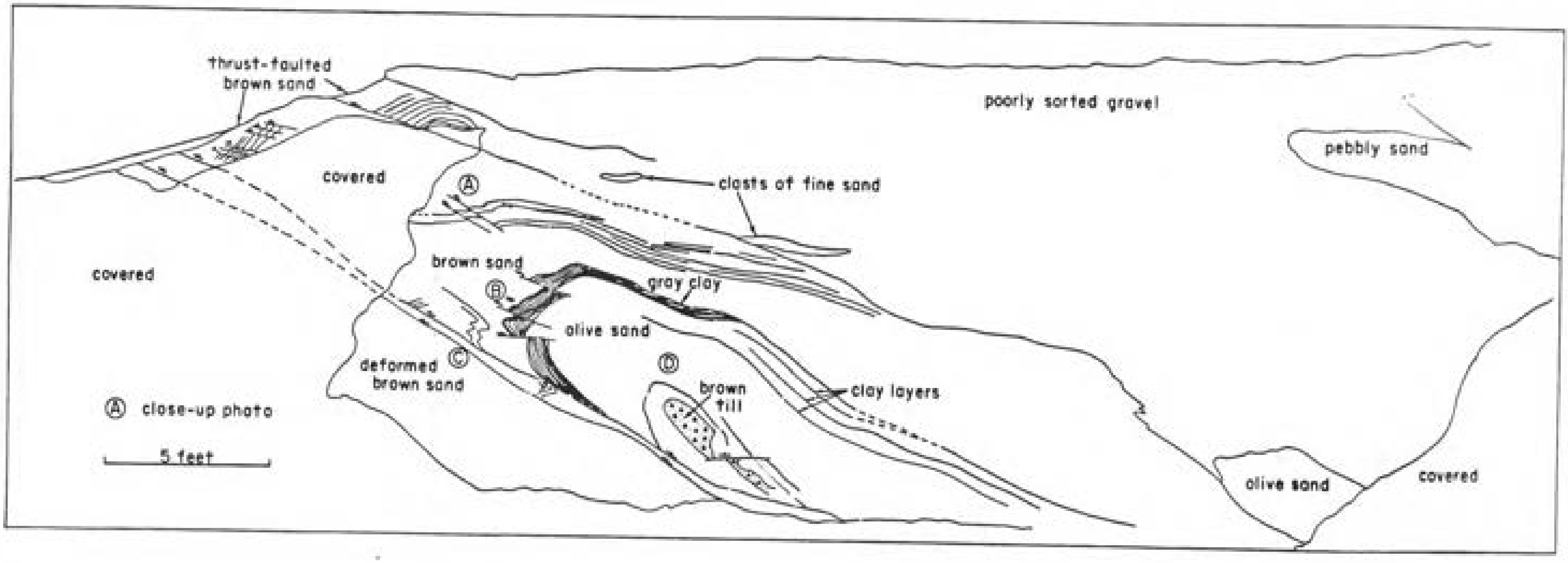
Glaciotectonic structures

Glaciotectonic structures were observed in the Lyncosky pit 0.45 mi. S. 62° W. of the crossroads at Cayenne. In an exposure 40 feet long and 12 feet high, lacustrine sediments have been overturned and thrust-faulted to the southwest in the form of a nappe (fig. 60). An envelope of gray varves and olive lacustrine sands surrounds a core of brown till, all of which are truncated at the base and thrust over brown lacustrine sands. An auger hole 5 feet away from the face under the crest of the

This evidence shows active ice, but need not be a readvance of more than say 100 meters.

Figure 60 (A). View to west-northwest of nappe structure at Locality 9-23A, Lyncosky pit. See text for details.

(B). Line drawing of figure 60A (above). Letters signify location of close-up photographs (see fig. 61A through fig. 62B.


thrust-faulted
brown sand
poorly sorted gravel
pebbly sand
covered
clasts of fine sand
covered
brown sand
gray clay
olive sand
deformed
brown sand
brown
till
clay layers
Ⓐ close-up photo
5 feet
olive sand
covered

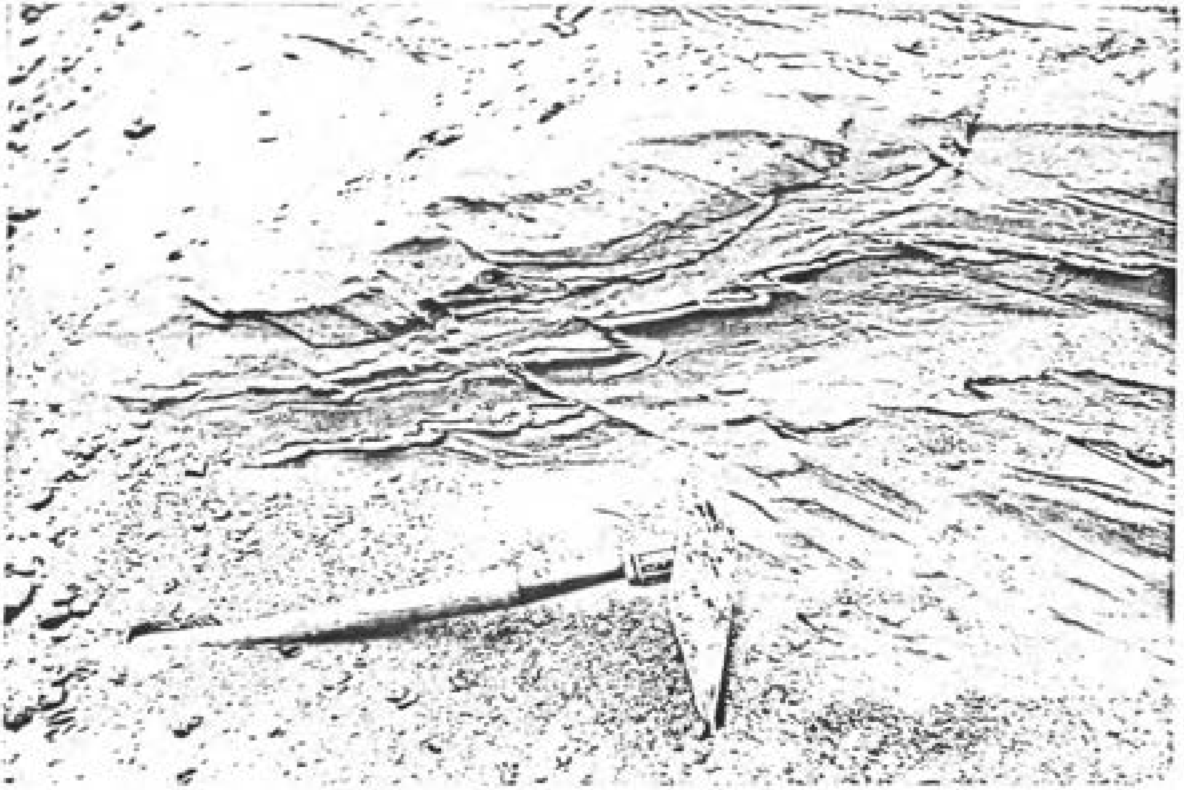
fold in varved clay penetrated 3.0 feet of brown sand, 1.0 foot of gray varves, and 1.0 foot of olive sand. The thrust fault at the base of the nappe structure strikes N. 70° W. and dips 50° to the northeast. Detailed closeup photographs of the thrust-faulted sand, deformed clay and sand, and the till core are shown in figures 61 and 62.

A body of olive sand with gray clay at the northeast base of the exposure probably is an imbricate thrust mass emplaced prior to deposition of an overlying poorly sorted gravel. The gravel contains clasts of fine sand and silt up to 2 feet in length, which are assumed to have been deposited as frozen masses. Certain portions of the gravel are till-like in appearance. Pebbly sand overlying the gravel also may have been emplaced by thrust faulting.

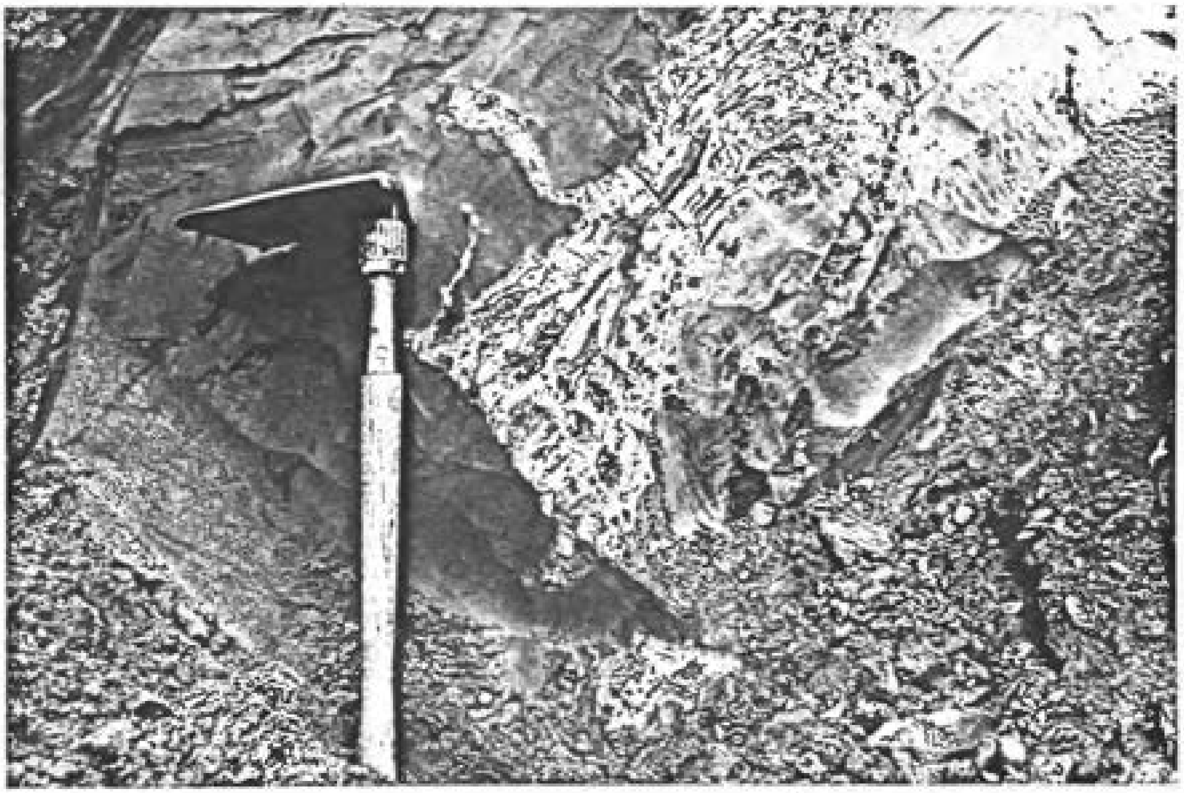
The structure described above may not signify a major readvance of ice but merely an active, oscillating ice margin. Evidence of the same kind of activity is found 700 feet to the south where poorly sorted gravel occurs with clasts of fine sand and silt up to 8 inches in length. The gravel overlies light-brown fine to medium sand that contains crack fillings of dark-brown fine sand (fig. 63A). The structures are unlike those associated with typical frozen-ground phenomena, but they are similar to structures underlying till of the Bridport Readvance (Connally, 1970) in the Champlain Valley, Vermont (fig. 63B). It is assumed that they are a type of glaciotectonic feature resulting from ice advancing over frozen sand, which fractures

Figure 61 (A). Imbricate thrust faults in brown sand. Location A on figure 60B.

(B). Deformed and truncated varves and olive sand (right) thrust over brown sand (left). Location B on figure 60B.



A.



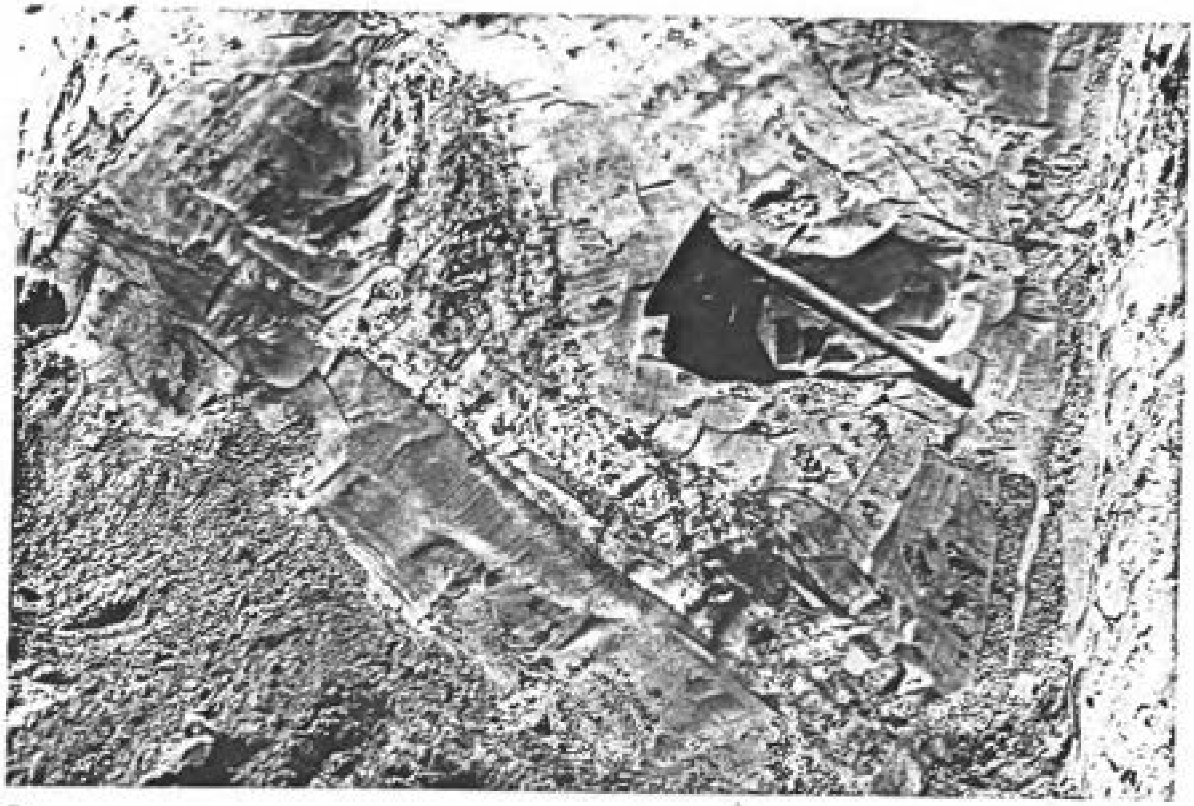
B.

Figure 61

Figure 62 (A). Climbing ripples which have been compressed (right to left) by overriding nappe structure, the base of which is above thrust zone at upper right. Location C on figure 60B.

(B). Core of brown till (left of shovel blade) surrounded by varves and olive sand, which have been all offset to the left (continuation of core is below shadow of shovel blade). Location D on figure 60B.

A.



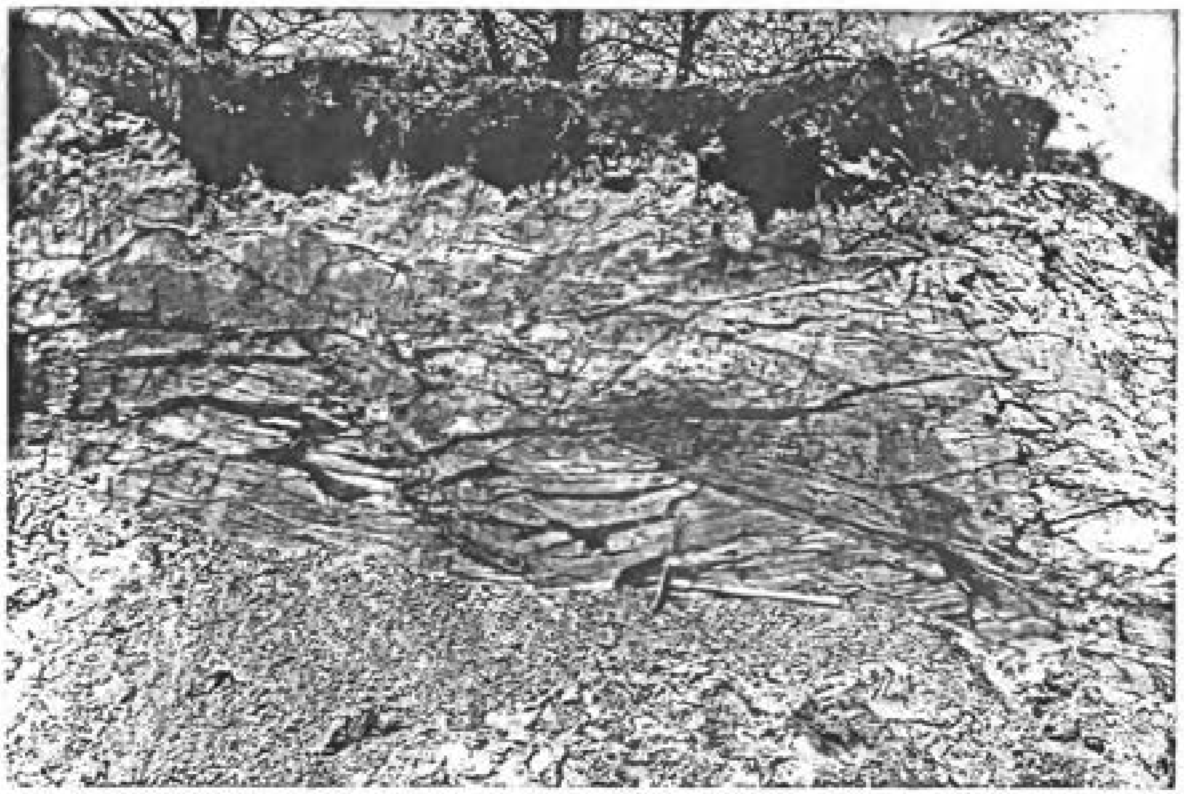
B.

Figure 62

Figure 63. (A). Crack fillings in lacustrine sand. See text for explanation. Locality is in West Springfield town pit at the southern edge of the Mount Tom quadrangle.

(B). Crack fillings in lacustrine sand over-riden by ice of Bridport Readvance. The locality is 1.1 miles east of West Bridport, Vermont. See text for explanation.

A.



B.

Figure 63

when loaded and allows glacial melt water or ground water under pressure to migrate and deposit fine sand. Provided these assumptions are correct, identification of such structures in lacustrine sediments may lead to recognition of readvance where it has not previously been recognized.

Data from borings

Information obtained from borings must be interpreted with caution, particularly when persons with little or no geologic training record the log of the boring. However, some general information can be inferred from the number of blows (recorded in the right hand column) required to advance a 2-inch O.D. (outside diameter) sampler 1 foot by dropping a 140-pound hammer 30 inches. Table 3 is the log of Boring R20 located 0.64 mi. S. 67° W. of the Catholic hospital (see fig. 55 for location). The boring was one of many made in 1964 in preparation for construction of I-91, and is recorded on Sheet 14 of Highway Boring Logs for Federal Aid Project I-91-1(64) 9. Although no mention is made of till, its presence is suggested twice by high values in the right-hand column. The 35.0-foot boring probably has 9.0 feet of till at its base followed in order by 8.0 feet of sand (note low number of blows), 10.0 feet of till, 5.5 feet of sand, and 2.5 feet of brown topsoil. The 10-foot layer of till is assumed to be the readvance till found at localities 6-46, 6-39, and 9-134.

Interpretation of such borings is tenuous at best, and most cannot be interpreted as easily as R20. However, the location and the log of R20 lend supporting evidence to readvance of glacial ice.

Table 3. Log of boring R20

Elevation		Number of blows
269.6		
267.1	Brown Top Soil	5, 7
	Red-Brown Fine to Coarse Sand, Some Fine to Coarse Gravel, Trace Silt	21, 39
261.6		
	Red-Brown Fine to Coarse Sand & Gravel, Trace Silt.	89, 123
W253.35		
251.6		
	Red-Brown Fine to Medium Sand & Silt, Little Fine to Medium Gravel.	39, 41
243.6		
	Red-Brown Fine to Coarse Sand and Gravel, Trace Silt.	139, 174
234.6		

Summary of readvance

Five types of evidence suggest that a lobe of ice readvanced in the southeast part of the Mount Tom quadrangle during late-glacial time. Directional data suggest radial movement from the east-northeast. If the same lobe of ice that formed west-trending striations on the Holyoke Basalt ridge also deposited till over stratified drift west of Mont Marie, the minimum postulated distance for readvance is about 3.5 miles. An alternative hypothesis to a minor readvance is that the ice front underwent an oscillatory retreat in which the ice margin experienced numerous small readvances during a time of general withdrawal. If oscillatory retreat occurred, west-trending striations on the basalt ridge could have been formed at an earlier time than the till was deposited over stratified drift at Mont Marie.

Readvance of an active ice margin during time of general stagnation and retreat of the ice sheet has been documented at several other localities in the Connecticut Valley. Flint (1953) postulated that the last ice sheet readvanced more than 26 kilometers to Middletown, Connecticut (fig. 1). This readvance occurred before 13,000 years ago (Flint, 1956), and before Lake Hitchcock was formed. Readvance in the Mount Tom quadrangle occurred after Lake Hitchcock had formed and the ice margin had retreated 42 miles north of Middletown.

Emerson (1898b) described in detail an exposure at the Camp Meeting cutting, 2.2 miles north of Northampton, Massachusetts, where three bodies of till are separated by thrust-faulted sands. Emerson attributed the three bodies of till to "three readvances of glacial ice." The Camp Meeting cutting lies north of the Holyoke Range and 12.5 miles north of readvance features in the Mount Tom quadrangle. Therefore, readvance at

Northampton occurred separate from, and later than, readvance in the Mount Tom quadrangle.

Retreat of the last ice sheet from New England generally is considered to have taken place by stagnation-zone retreat (Currier, 1941). In stagnation-zone retreat downwasting is the dominant process, and a zone several miles wide along the ice margin becomes so thin that the ice is inactive or stagnant. Although the process of stagnation-zone retreat probably was dominant on the higher elevations of southern New England, retreat of ice in the Connecticut Valley was not by stagnation-zone retreat, but by an active margin.

Non seq. You can have a series of pauses in the downmelting, but the retreats between pauses were the result of downmelting that left stagnant ice remnants in front of the active ice limit.

Retreat of ice

Stage I

Following readvance, the ice margin retreated eastward from the Holyoke Basalt ridge. This permitted deposition of outwash or delta-outwash deposits in the valley of Paucatuck Brook in the south-central part of the map area. The deposits (Qde_1, pl. 2) grade southward into a deltaic plain which was controlled by the level of high Lake Hitchcock in the West Springfield quadrangle (Colton and Hartshorn, 1971). Cobble gravel covers the surface of the outwash plain north of the Massachusetts Turnpike.

Outwash deposits in the vicinity of Ashley Pond are also mapped as Qde_1. The melt water that formed these deposits drained to the south-southwest and continued to supply minor amounts of sediment to the outwash in the Paucatuck Brook valley. The surface of the outwash plain just west of Ashley Pond is characterized by a series of anastomosing melt-water channels which drained to the south. The active ice-margin at the end of Stage I extended north-south along the till ridge just east of Ashley Pond (fig. 64). An esker, which formed in a subglacial stream tunnel (p. 132), climbs the till ridge from the east and grades into outwash deposits on the west. The ice margin must have been situated near the west end of the esker when the esker was formed, and melt-water drainage was to the west.

Stage II

Eastward retreat of the ice margin from the till ridge east of Ashley Pond to the Stage II position (fig. 64) permitted melt-water drainage to pass southward along the east side of the till ridge. Drainage was held against the east side of Bradley Mountain while a kame terrace (Qde_2, pl. 2) was deposited between the ice margin and the till slope. Poorly sorted cobble gravel, which displays angular clasts and abrupt changes in grain size, testifies to the ice-contact origin of the deposit, as does the presence of large boulders in finer grained sediment (fig. 34A). The surface of the terrace slopes to the south with a gradient of 20 feet per mile.

The ice margin maintained a nearly north-south position between Lower Westfield Road on the north and Amostown on the

Figure 64. Southeast part of the Mount Tom quadrangle showing ice-margin positions during six stages of deglaciation.

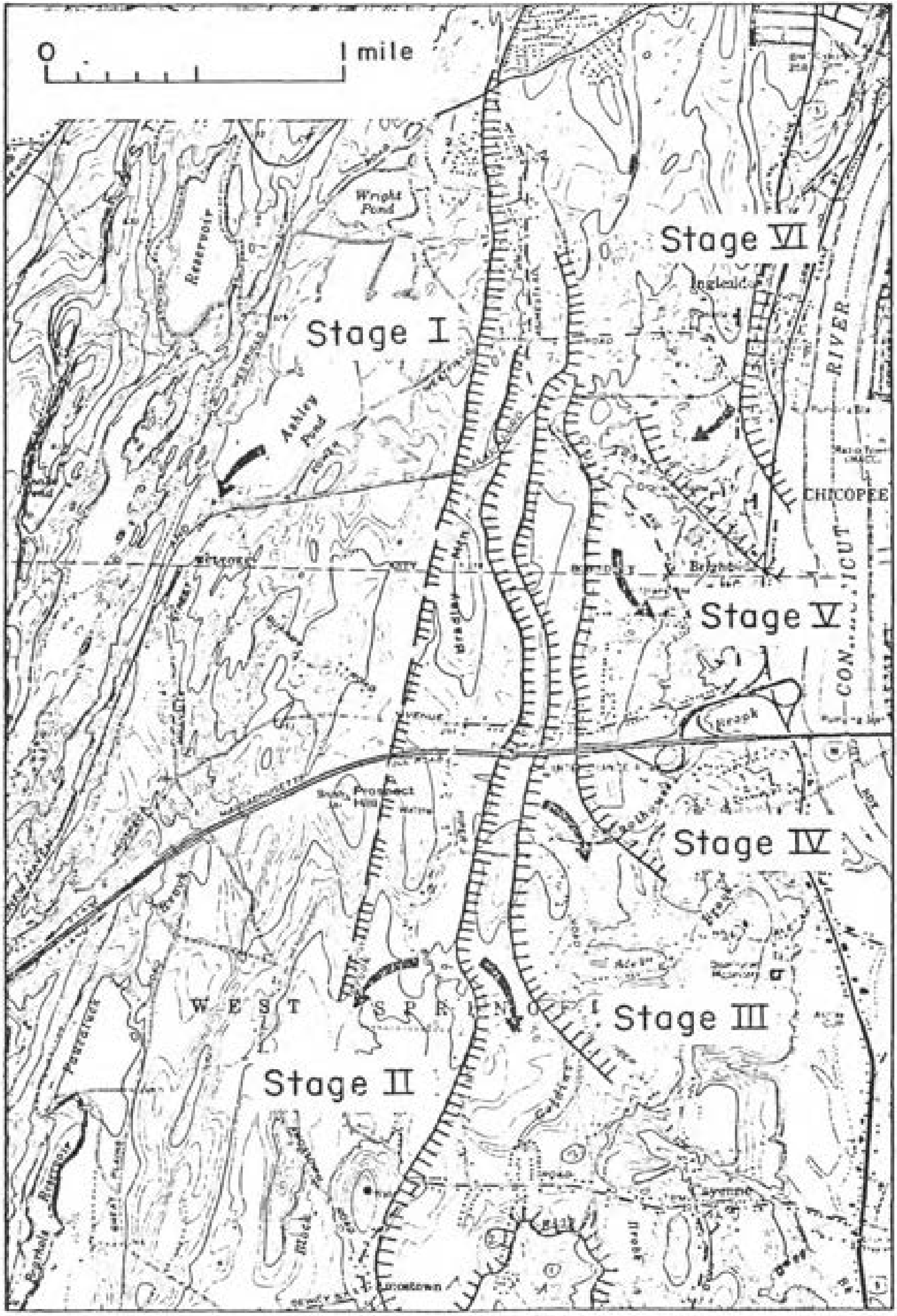

0
1 mile
Stage I
Stage II
Stage III
Stage IV
Stage V
Stage VI
Wright Pond
Reservoir
Ashley Pond
CHICOPEE
CONNECTICUT RIVER
W E S T S P R I N G F I
Prospect Hill

Figure 64

south (fig. 64). Melt water spilled westward into the valley of Block Brook through a low spot in the till ridge. The locality is marked by a sag below 250 feet elevation on Birnie Avenue, 0.7 of a mile S. 24° E. of Prospect Hill. Deposits mapped as Qde_2 (pl. 2) in the lower Block Brook valley are believed to have formed at this time, and grade southward into deposits mapped by Colton and Hartshorn (1971) in the West Springfield quadrangle as delta deposits. Deposits of Qde_2, which lie 0.5 of a mile east of Amostown, include evidence for readvance as found at the Lyncosky pit (p. 225).

Stage III

The north-south ice margin retreated about 0.1 of a mile to the east, with its southern portion retreating further to assume a northwest-southeast orientation (fig. 64). This permitted water of high Lake Hitchcock to enter the Mount Tom quadrangle from the south.

In the valley east of the Stage I ice-margin position, melt-water streams deposited cobble gravel in an outwash plain that slopes to the south with a gradient of 40 feet per mile. This outwash plain, if extended southward, passes under the surface of the kame terrace east of Bradley Mountain, indicating that the outwash plain is a younger feature than the kame terrace. Therefore, the outwash plain has been assigned to Stage III (Qde_3, pl. 2).

Melt water from the outwash plain drained southward in a channel that extends along the east side of the kame terrace.

The former melt-water stream was forced by the ice margin to pass on the west side of an elongate till-covered hill 0.2 of a mile east of the junction of Birnie Avenue and Piper Road. A small ice-contact delta was deposited where the melt-water stream emptied into high Lake Hitchcock, about 1.0 mile northwest of Cayenne (Qde_3, pl. 2). A series of small kettles marks the northeast ice-contact slope of the delta. A good exposure in the delta occurs in a small pit just west of Goldine Brook where deltaic bottomset beds of fine sand are flat-lying and display ripple-drift cross-lamination that dips to the south.

Just south of the Massachusetts Turnpike, withdrawal of the Stage III ice margin toward the east caused the collapse of ice-contact sediments deposited on the retreating ice (fig. 33A).

Stage IV

On the north, the Stage IV ice margin maintained a north-south position along a till-covered ridge 0.35 of a mile east of Bradley Mountain (fig. 64). This forced melt water to travel south partly in the same channel used by the Stage III outlet stream. However, when ice withdrew from the till-covered hill east of the junction of Birnie Avenue and Piper Road, melt water flowed into high Lake Hitchcock by a shorter route than during Stage III.

The deposits formed by the outlet stream where it entered high Lake Hitchcock are clearly of deltaic origin (Qde_4, pl. 2). A borrow pit located 1.0 mile N. 14° W. of Cayenne has horizontal layers of fine to medium sand with ball-and-pillow structure at many levels. This implies rapid loading of sediment in a lacustrine or prodelta environment. A quarter of a mile north of this pit, deltaic foreset beds, dipping to the southeast, were exposed during construction of I-91. The maximum elevation of the foreset beds at 230 feet indicates deposition in high Lake Hitchcock.

Stage V

As the Stage IV north-south ice margin rotated to the northeast, melt water running between the ice margin and the till ridge east of Bradley Mountain discharged into high Lake Hitchcock. It is possible that a series of small deltas were deposited, one behind the other, as the ice margin retreated. Delta foreset beds dipping to the southeast occur over a north-south distance of 0.2 of a mile in an area 0.25 of a mile west of the children's home at Brightside. Deposits produced at this time (Qde_5, pl. 2) include ice-contact deposits formed just southwest of the ice margin, which was situated along the present course of Tanner Brook (fig. 64).

Readvance till (Qtr_1, pl. 2), which overlies stratified drift 0.3 of a mile west of Mont Marie, has already been discussed under the heading "Readvance" (p. 205). If not formed by a major readvance, the till may have been deposited during a minor readvance to the Stage IV ice-margin position.

Stage VI

A change in drainage occurred during retreat of the ice margin from the Stage V to the Stage VI position (fig. 64). Melt water that had traveled southward on the west side of a drumlin 0.5 of a mile due north of Mont Marie was permitted to flow southward on the east side of the drumlin. At Mont Marie, the outlet stream spilled to the southwest between the ice and the south end of the drumlin and into high Lake Hitchcock, where a small delta was deposited (Qde_6, pl. 2). The top 10 to 15 feet of the delta were removed during the construction of a large new building just west of old buildings at Mont Marie. Foreset beds composed of pebble gravel dip to the southwest, suggesting a stream source to the northeast. Deposition was in high Lake Hitchcock, as indicated by the maximum height of foreset beds at 235 feet elevation.

Stage VII

Following a retreat of 4 miles from Mont Marie, the active ice margin maintained a stillstand at the north end of the east edge of the Mount Tom quadrangle. Here, along an ice margin which curved into the adjoining Springfield North quadrangle on the east, a large ice-contact delta was deposited in high Lake Hitchcock. See p. 184 The deposit, called here the Holyoke delta (Qde_7, pl. 2), has a north-south dimension of 3.5 miles and has a present maximum width of 0.75 of a mile extending into the Springfield North quadrangle. The original width was probably greater, having been reduced by lateral cutting of the Connecticut River. The surface of the Holyoke delta slopes to the south at 5.9 feet per mile. The surface is broken by till ridges that were not covered by deltaic sediments and, at the north end, by 20-foot-high ice-contact deposits whose lower portions are buried by deltaic sediments. Most likely the Holyoke delta is a complex structure deposited as a series of small ice-contact deltas that coalesced as later sediments were deposited over earlier ones.

The surface of the Holyoke delta is nearly covered with urban dwellings, cemeteries, parks, and institutional buildings. Natural exposures are not common, and the opportunity to dig temporary pits that have significance is not often presented. However, during the summer of 1969, the internal structure of the Holyoke delta was revealed at three widely separated artificial excavations. Delta-foreset beds were exposed in the Springfield North quadrangle 0.87 of a mile N. 53° E. from the Lynch School, located at the junction of Routes 141 and U. S. 5. The foreset beds were dipping 22 to 26 degrees toward S. 70° E., which implies that the source of sediment was to the northwest in the form of a melt-water stream held against the till-covered bedrock by a lobe of ice. The situation is similar, but on a larger scale, to the southeast dipping foreset beds discussed on page 244.

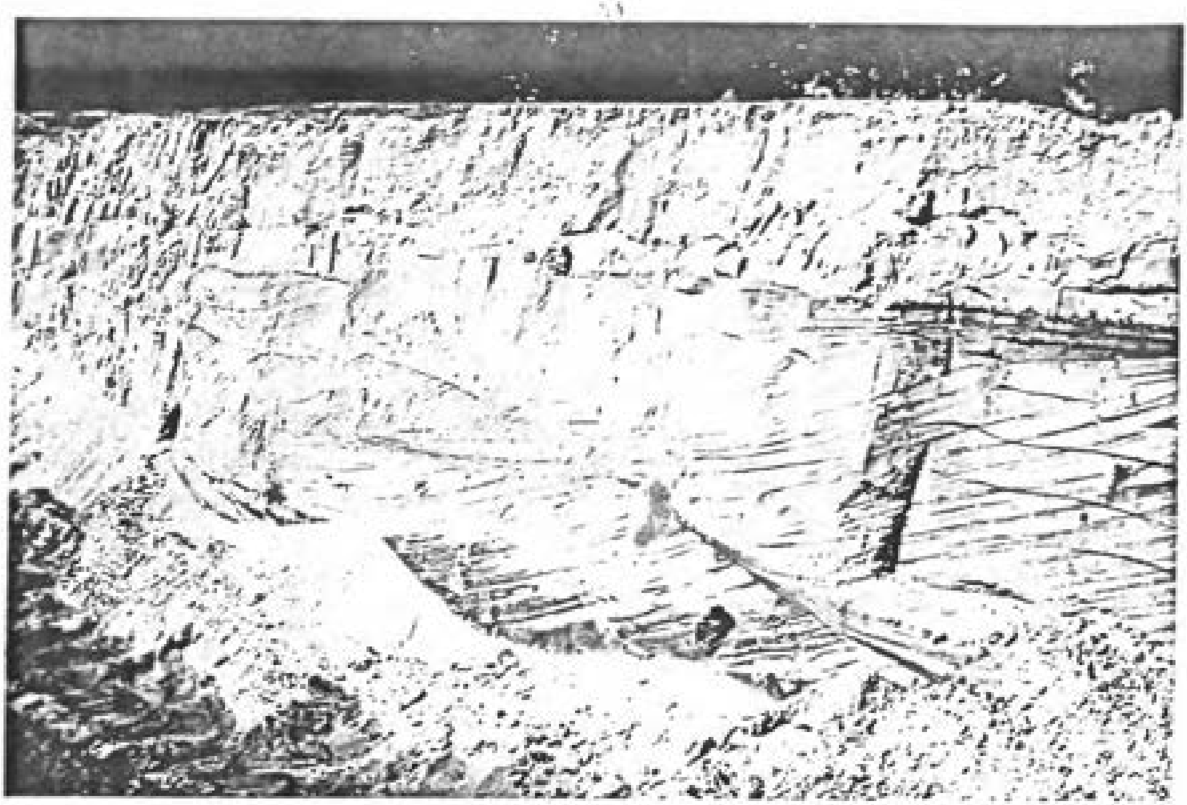
At an excavation immediately southwest of the junction of Routes 141 and U. S. 5, gravel with clasts having an average diameter up to 12 inches was overlain by pebbly coarse sand. Crossbedding dipping to the south and southwest and cut-and-fill structures in the sand indicate a typical fluvial environment of deposition.

A series of excellent exposures was revealed in the Holyoke delta during the course of excavations for a shopping center just south of Calvary Cemetery. After 20 feet of overburden had been removed, two trenches, each 4 to 6 feet deep and 240 and 304 feet long, were dug at right angles to each other. Deltaic foreset bedding was exposed for the full length of the first (shorter) trench and for 200 feet in the second trench. The bedding dips 22 to 25 degrees toward the southeast and reaches a maximum elevation of approximately 240 feet.

In the southern half of the second trench, large-scale trough cross-stratification (Harms and Fahnestock, 1965) or crossbedding was exposed over a lateral distance of 100 feet. The trend of the crossbedding was variable but averaged 26 degrees toward the south within sets ranging from 0.5 to 3.0 feet thick, which dipped northward at 8 to 16 degrees (fig. 65A). A clue to the nature of the crossbedding was given by surfaces left by bottom-loading excavating machines 200 feet west of the middle of the second trench. A near horizontal surface is shown in figure 65B, in which the internal trough-filling characteristic of the crossbedding is well displayed. The trough crossbedding is characteristic of that produced by sand waves (dunes) migrating downstream in a large channel. This is in marked contrast to the quiet lacustrine environment of deposition indicated by the deltaic foresets at the same elevation.

Figure 65 (A). Trough crossbedding exposed in shallow trench trending south-southwest in the Holyoke delta. Location is 0.15 of a mile south-southwest of bench mark 258 at Calvary Cemetery.

(B). Trough crossbedding exposed in horizontal section. Direction of transport was S. 30° E. Location is 200 feet due west of (A) above.



A.

B.

Figure 65

The average of five pebble counts indicates that 25.8 percent of the clasts in the gravel on the Holyoke delta are of Triassic origin while 74.2 percent are of crystalline origin (app. I). This presents an interesting problem inasmuch as (1) the delta lies well within the boundary of Triassic rocks and south of the Holyoke Basalt ridge (fig. 2), and (2) the brown till east of the basalt ridge contains an average of 89 percent clasts of Triassic origin (p. 113). We can assume that high-energy fluvial transport of Triassic brown siltstones and shales results in their rapid attrition in comparison to clasts of crystalline origin.

Postglacial history

The term "postglacial" is used here in the local sense following the recommendation of Flint (1971, p. 384) that "Events that occurred within any district while it was covered with glacier ice are referable to glacial time for that district; subsequent events are referable to postglacial time."

Following the deposition of the Holyoke delta, the ice margin east of the basalt ridge retreated northward from the Mount Tom quadrangle accompanied by an expanding high Lake Hitchcock. The level of Lake Hitchcock at this time was on the order of 15 to 20 feet above the low stable stage. The Dry Brook delta (p. 204) was formed when the ice margin was located at the Holyoke Narrows, 3.9 miles north of the Holyoke delta. Subsequent retreat of ice permitted Lake Hitchcock to extend through the Narrows to the west side of the basalt ridge (p. 205). When ice retreated from the Stage IV position west of the basalt ridge, Lake Manhan III dropped to the level of Lake Hitchcock.

With continued retreat of the ice margin in the Connecticut Valley, Lake Hitchcock expanded northward until it was 150 miles long (Schafer and Hartshorn, 1965) (p. 183). During this time, clay-silt varves (Qlc, pl. 2) were deposited in the Manhan valley in the northwest and along the present course of the Connecticut River in the southeast part of the Mount Tom quadrangle. The portion of Lake Hitchcock north and west of the Holyoke Basalt ridge drained southward through the Holyoke Narrows.

According to Flint (1956), Lake Hitchcock drained about 10,700 years ago when the drift dam at Rocky Hill, Connecticut, was breached (p. 184). This initiated a period of rapid downcutting by the Connecticut River and the lower portions of its tributaries, mainly in lake-bottom sediments, but also in other glacial sediments and bedrock.

At Cayenne in the southeast part of the quadrangle, the Connecticut River cut two distinct terraces in lacustrine sediments. An upper and a lower terrace, at 155 and 125 feet elevation respectively, have 6 to 10 feet of pebble gravel and sand overlying clay-silt varves. During downcutting immediately south of the Holyoke delta, the Connecticut River removed all deposits younger than till.

[illegible] this section is "[illegible] history" (heading on p. 250)

Large areas of stream-terrace deposits in the southwest part of the quadrangle are late-glacial in age and relate to an outlet stream that drained south from the Timberswamp channel and passed through Westfield Gap to Lake Hitchcock (p. 203). Smaller and lower terraces along the Westfield River and its tributaries were formed in postglacial time as a result of downcutting by the Connecticut River caused by the draining of Lake Hitchcock. Superposition of the Westfield River across Triassic bedrock at the southwest corner of the quadrangle also occurred at this time.

In the northwest part of the quadrangle, the Manhan River cut down to till and bedrock for nearly 0.7 of a mile along its course. It then cut laterally into lacustrine sediments on the northwest side of the valley to form a terrace that rises to the southwest from 160 feet to over 200 feet elevation. Following this, the Manhan shifted to the southeast and incised its course at its present position.

In addition to stream-terrace deposits, other sediments that formed in postglacial time include peat (p. 173), talus (p. 21 and p. 176), and alluvium (p. 176). These latter three sediments continue to be formed up to the present time.

An interesting minor feature that probably formed in postglacial time is a fulgurite, a ribbon of silica sand fused by lightning. A specimen collected at the Lyncosky pit, 0.45 of a mile S. 62° W. of Cayenne, is up to 2 inches wide and 0.2 of an inch thick. The specimen decreased in width downward when excavated from the lacustrine sand (Qde_2, pl. 2) in which it was found. The fulgurite could have formed at any time since the deposition of the lacustrine sediments in high Lake Hitchcock.

Summary

An ice sheet moving south from Canada covered all of New England during the Woodfordian Substage of late Wisconsin time. It reached its maximum extent on Long Island about 19,000 years ago (Flint, 1971) at which time ice in the Mount Tom quadrangle probably was several thousand feet thick.

At time of maximum activity, the ice sheet eroded the Sugarloaf Formation 95 feet below sea level at the site of the Oxbow and molded drumlins east of the Holyoke Basalt ridge into a north-south orientation. Evidence that the ice sheet moved southward in the Mount Tom quadrangle includes: (1) striations, (2) roche moutonnée forms, (3) small-scale crag-and-tail, (4) streamline molded forms and (5) an indicator fan. Erratics from the Belchertown Tonalite, which outcrops in the northeast part of the Easthampton quadrangle, have been carried southward at least 16 miles. Tonalite erratics have been uplifted through a vertical distance of at least 1,000 feet to the summit of the Mount Tom Range.

Retreat of the ice sheet from southern Connecticut occurred prior to 14,200 years ago, based on radiocarbon dating of organic silt from the bottom of Rogers Lake, near Lyme, Connecticut (Stuiver and others, 1963). This date gives the oldest minimum radiocarbon age for the deglaciation of southern Connecticut.

Following the Middletown readvance, the ice retreated northward past Rocky Hill, Connecticut, where a body of stratified drift dammed the Connecticut River to form Lake Hitchcock. The lake drained over a till and bedrock threshold at New Britain and expanded northward with the retreating ice margin.

Till was deposited at the base of the ice sheet as ablation of the ice occurred. In the Mount Tom area three tills can be recognized on the basis of color, grain-size parameters, and location. A sandy reddish-brown till overlies the Sugarloaf Formation west of the Holyoke Basalt ridge. East of the basalt ridge a silt-rich brown till overlies the East Berlin Formation, the Hampden Basalt, and the Portland Arkose. A grayish-brown till, derived from crystalline rocks of the New England Upland, is common in the Easthampton quadrangle and underlies the north-central part of the Mount Tom quadrangle. Although the three tills have different physical characteristics and occur in different locations, they are of the same age and are the equivalent of the upper till of southern New England. In the Mount Tom area, tills are closely related to the bedrock over which they lie.

West of the basalt ridge the retreating ice margin was accompanied by an expanding proglacial lake that drained through the gap at Harts Pond. Retreat was characterized by four stillstands during which the ice margin was stationary while ice-contact deltas were deposited in the proglacial lake. From south to north the four deltas are: (1) the Paper Mills delta, (2) the Barnes delta (or outwash plain), (3) the Pomeroy Street delta, and (4) the White Brook delta.

The early history of deglaciation east of the basalt ridge was marked by a readvance of the ice margin over a minimum distance of 3.5 miles. Evidence for the readvance includes: (1) till overlying stratified drift, (2) a southwest-oriented till fabric on a north-south-trending drumlin, (3) west-southwest-trending striations cutting south-trending striations, (4) glaciotectonic structures, and (5) data from borings. Directional features suggest that the readvance was caused by a lobe of ice moving from the northeast or the east-northeast.

After readvance had occurred, a north-south ice margin retreated eastward from the basalt ridge, permitting deposition of outwash deposits in south-draining valleys. As the southern part of the ice margin curved to the southeast to assume a lobate form, high Lake Hitchcock entered the Mount Tom quadrangle from the south. A series of marginal ice-contact deltas were built one behind the other into high Lake Hitchcock as the ice margin withdrew to the north.

The ice front held a final major position along the upper east margin of the Mount Tom quadrangle while the Holyoke delta, the largest of the marginal ice-contact deltas, was deposited.

When ice melted from the Holyoke Narrows, high Lake Hitchcock was able to extend along the west side of the basalt ridge. Retreat of ice from the northernmost outwash head west of the basalt ridge permitted Lake Manhan III to drop to the level of high Lake Hitchcock in the Manhan valley.

It is estimated here that the active ice margin retreated through the Mount Tom quadrangle approximately 13,000 to 13,300 years ago. Retreat of the ice margin through the quadrangle could have taken as few as 50 years or as many as 300 years. Flint (1971, p. 582) is of the opinion that Lake Hitchcock was still in existence 10,700 years ago. If so, Lake Hitchcock endured for more than 2,000 years after the ice sheet withdrew from the Mount Tom quadrangle.

Draining of Lake Hitchcock, some time after 10,700 years ago, initiated a period of rapid downcutting in lacustrine sediments. During this time, the Connecticut River and its tributaries carved several terrace levels below the former shoreline of Lake Hitchcock. Except for minor changes, the landscape that was formed 10,000 years ago in the Mount Tom quadrangle is essentially the same landscape that we observe at the present time.

Economic geology of surficial deposits

Mineral resources from the surficial deposits of the Mount Tom quadrangle include gravel, sand, and varved clay.

Sand and gravel deposits

Numerous sources of sand and gravel are shown on plates 2 and 4. They consist of various forms of stratified drift deposits, such as ice-contact deltas, outwash plains, kame terraces, kames, ice-channel fillings, undifferentiated ice-contact stratified drift, and undifferentiated glaciofluvial deposits.

Outwash plains or topset beds of ice-contact deltas are excellent sources of gravel and coarse sand. The north ends of outwash plains, which were closest to the sources of glacial streams, generally are good sources of cobble gravel or pebble gravel. The foreset beds of ice-contact deltas are good sources of clean sand and pebbly sand.

The only ice-channel filling mapped as an esker, just east of Ashley Pond, contains clean sand and pebble gravel. However, the feature has been removed over much of its length.

Kame terraces, kames, and undifferentiated ice-contact stratified drift show a wide range in grain size because they originated under a great variety of conditions. It is impossible to predict with any degree of accuracy the composition of these ice-contact features except to say that they are generally composed of sand and gravel.

Clay

Varved clay suitable for brickmaking is found in the southeast, west, and northwest parts of the quadrangle. However, there are no active brickyards at the present time.

Until 1969, clay deposits along Brickyard Brook at East Farms had been worked for more than 100 years. The original deposits, now mostly depleted, consisted of laminated fine sand and silt with minor amounts of clay overlain by 5 to 15 feet of sand and gravel. An area bounded by North, Root, and Buck Pond Roads west of the New York, New Haven and Hartford Railroad is completely pockmarked with numerous abandoned clay pits.

Other abandoned clay pits occur east of the Manhan River 0.9 of a mile north-northeast of East Farms, and at a small pond at the center of the northern edge of the quadrangle. Emerson (1898b, p. 700) reported that clay deposits in the Manhan valley east of Southampton village were worked in the 1890's.

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Appendix I, Pebble counts

The results of 32 pebble counts are reported in table 4. The numbers given are percent of a particular lithology from a sample of 100 pebbles and small cobbles between 0.5 of an inch and 4 inches in diameter. The sample was washed, and most pebbles were broken for identification on a fresh surface. Pebbles identified in table 4 as weathered/unknown were so decomposed that their original lithology was not readily apparent. Weathered clasts whose original composition could be ascertained were classified by their original lithology.

The samples were collected from till (6), ice-contact stratified drift (8), outwash deposits (11), stream-terrace deposits (6), and alluvium (1). Each of the above constitutes a heading and, except for alluvium, is subdivided according to location east or west of the Holyoke Basalt ridge.

Rock Type \ Sample	TILL						ICE-CONTACT STRATIFIED DRIFT							
	WEST		EAST				WEST		EAST					
	4-110	3-65A	3-58	6-46	B M-1	9-27	4-54	2-132	3-60	6-74A	6-50	6-59	9-16	9-107
Triassic														
ark. conglomerate					3			9	1			1		
ark. sandstone			17	5	4	5	13	7	1	2	4			3
ark. siltst.+sh.	1	6	70	70	39	61	15	3	46	24	49	49	50	53
gray shale				4		12				8		2	19	2
basalt	3	2	4	12	17	17			23	16	20	23	13	13
volc. tuff					14				9		3	3		4
volc. breccia				2										4
crystalline														
quartzite	30	19	1	2	4	1	18	16	2	14	4	11	2	4
gneiss	1			1	2	1	4	12	3	5			3	4
schist	5			1			8	1				2		
slate/phyllite		4		1										
amphibolite	2	2								3		1		
metarhyolite	2													
vein quartz	18	29	4	1	6		6	24	10	18	11	5	5	4
granitic	24	15	1	1	7	2	32	18	4	7	8	2	3	8
diorite	2	16	1		4	1			1			1		
mafic	2							1						
pegmatite	2	1					4	6		2			2	
aplite dike			2							1				1
contact breccia	6										1			
porphyry								1						
weathered/unknown	2	6						2					3	
Total percent Triassic	4	8	91	93	77	95	28	19	80	50	76	78	82	79
Total percent crystalline	94	86	9	7	23	5	72	79	20	50	24	22	15	21

Table 4. Pebble counts of glacial, late-glacial, and postglacial sediments.

Rock Type \ Sample	OUTWASH										
	WEST					EAST					
	1-38	2-	4-39	4-5	7-9	3-59	SN1-1	3-78	6-47	6-48	9-46
Triassic											
ark. conglomerate		3		5	35	1	5	1		2	2
ark. sandstone			8	7				1		2	2
ark. siltst.+sh.	5	13	2		5	9	5	25	22	13	5
gray shale						4				3	
basalt		16			1	5	3	5	3	3	18
volc. tuff									1		
volc. breccia						6		7		3	
crystalline											
quartzite	13	19	32	10	7	18	22	18	21	13	16
gneiss	4	10	16	2	5	11	8	6	11	11	7
schist	3			7	8	1	3	2	2		
slate/phyllite	4	1	2			1					
amphibolite	1	1					1	1		2	2
metarhyolite		1			1						
vein quartz	7	17	30	14	13	24	28	19	21	27	23
granitic	45	11	8	29	14	12	20	9	10	13	8
diorite			2		8	2			4	3	8
mafic		1						1			2
pegmatite	16			25	3	3		4	3	2	1
aplite dike									2	1	1
contact breccia		3				1				1	4
porphyry							2				
weathered/unknown	2	1		1		2	3	1		1	1
Total percent Triassic	5	32	10	12	41	25	13	39	26	26	27
Total percent crystalline	93	67	90	87	59	73	84	60	74	73	72

Table 4. (continued)

Rock Type \ Sample	STREAM-TERRACE DEPOSITS 3-17	1-5	4-52	7-58	W09-1	7-62	ALLUVIUM 7-59
Triassic							
ark. conglomerate	6	6	1			19	
ark. sandstone	2	3		1		5	1
ark. siltst.+sh.							
gray shale							
basalt	2					3	
volc. tuff							
volc. breccia							
crystalline							
quartzite	28	20	16	40	29	14	34
gneiss	7	1		35	33	8	27
schist	2	1	11	7	17		10
slate/phyllite	2					1	
amphibolite	4	1		6		4	3
metarhyolite							
vein quartz	11	11	8	8	3	22	13
granitic	16	43	38	2	8	14	
diorite	15						
mafic					4	5	
pegmatite	5	14	26		4	3	7
aplite dike							
contact breccia							
porphyry							
weathered/unknown				1	2	2	5
Total percent Triassic	10	9	1	1	0	27	1
Total percent crystalline	90	91	99	98	98	71	94

Table 4. (continued)

Appendix II, Till fabrics

Three till fabrics were measured by John Mullen in brown till east of the basalt ridge. In the method used, stones with a length-to-width ratio greater than 2 to 1 are carefully marked in the field and their orientation measured in the laboratory. The three till fabrics from the brown till are plotted as rose diagrams on the east side of figure 17. Two of the diagrams are unimodal and show ice movement to the southwest, a direction associated with a minor readvance of glacial ice (p. 205). The third diagram is multimodal and is difficult to interpret.

A fourth till-fabric measurement was made in reddish-brown till west of the basalt ridge. The rose diagram shown in the northwest portion of figure 17 was obtained by combining the orientations of 50 pebbles measured on both a north-south face and an east-west face.

Appendix III, Grain-size analyses

Grain-size analyses were made of samples of 52 sediments. Of 19 tills analyzed, 15 samples were from the Mount Tom quadrangle and 4 were from the adjacent Easthampton quadrangle to the north. The remaining 33 samples were sand, silt, and clay from the Mount Tom quadrangle and had the following breakdown by origin: outwash (8), lacustrine (8), stream terrace (4), eolian (8), and alluvium (5).

The analyses were made by John C. Mullen in the Sedimentation Laboratory at the University of Massachusetts during the summer of 1969.

Prior to analysis, location sample numbers were changed by Larsen to a simple numerical sequence to reduce any possible bias by the observer, Mullen. After all analyses were completed the original location number was added to the sequence number by Larsen.

The techniques used for the grain-size analyses are those described by Folk (1968, p. 16-43). Pipette analysis was used for particles between 4.5ϕ and 9ϕ. Particles larger than -1ϕ were removed prior to sieving for all till samples. In essence, this means we define the matrix of till as being composed of particles of sand size and smaller, -1ϕ to 9ϕ, for this report.

Raw grain-size data were punched on IBM cards and fed into a computer with a program designed by Eugene Rhodes to compute grain-size parameters described in Folk (1968). Results of the computations are given in table 5.

Table 5. Grain-size parameters

SEDIMENT TYPE	SAMPLE NUMBER	LOCATION NUMBER	Md	Mz	σ_I	SK_I	K_G
BT	1	9-15	3.71	4.14	3.35	.153	0.87
RBT	2	3-74	2.19	2.49	2.54	.247	1.01
RBT	3	7-16	2.45	3.00	2.91	.337	1.08
RBT	5	1-7	2.49	2.69	2.49	.205	1.10
RBT	6	1-33	2.77	2.98	2.69	.229	1.26
BT	7	9-123	4.46	4.36	3.54	-.024	0.73
BT	8	6-39	3.30	3.70	3.36	.180	0.80
BT	9	6-42	4.29	4.63	3.69	.082	0.73
BT	10	6-46	4.05	4.01	3.10	.019	0.97
RBT	11	4-110	2.08	3.40	3.30	.520	1.08
GBT	12	E5-2	3.28	3.60	2.98	.193	0.96
RBT	14	4-110	2.29	3.09	3.06	.410	1.11
GBT	15	E9-K	2.90	4.19	3.65	.400	0.69
RBT	16	4-110	2.39	3.14	3.05	.385	1.10
GBT	17	E2-10	3.17	3.24	2.13	.069	1.17
GBT	18	E3-12	2.61	2.91	2.75	.206	0.92
RBT	19	4-41	2.37	2.60	2.21	.196	1.07
GBT	20	2-91	2.57	2.75	2.24	.155	0.95
RBF	20A	1-58	2.78	3.14	2.44	.255	0.91
OW	21	6-47	2.21	2.23	0.51	.110	1.13
OW	22	7-6A	2.19	2.22	0.52	.144	1.10
ST	23	9-120B	2.48	2.48	0.63	.007	1.19
AL	24	9-125	4.85	5.01	1.14	.278	1.15
LST	25	2-40	3.83	3.85	1.06	.131	1.03
ES	26	4-25A	1.60	1.86	1.78	.366	1.47
ST	27	9-120A	0.70	0.67	0.79	-.018	1.28
EST	28	3-65B	4.66	4.69	2.30	.091	1.31
OW	29	7-6B	0.97	0.96	0.72	-.002	1.14
OW	30	6-46	1.71	1.69	0.51	-.055	1.07
ES	31	2-142B	2.02	2.04	0.82	.072	1.08