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SURFICIAL AND APPLIED SURFICIAL GEOLOGY

OF THE

BELCHERTOWN QUADRANGLE, MASSACHUSETTS

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ABSTRACT

Till and stratified drift overlie maturely dissected topography in the Belchertown quadrangle, an area that straddles the New England Upland and Connecticut Valley Lowland in central Massachusetts. Lower Paleozoic, massive quartzo-feldspathic gneiss, quartzite and schist of the Pelham dome and Devonian granodiorite and quartz diorite of the Belchertown intrusive complex are in contact with Triassic arkosic fanglomerate and basalt along a lengthy normal fault separating the New England Upland from the Conneticut Valley Lowland. The orientation of striae, roches moutonnees, and streamline ridges indicate that the last Wisconsinan glacier advanced generally south 12° east. This glacier removed several meters of rock from the upland and an unknown larger quantity from the preglacial valley of the Connecticut River. Till is thin in the uplands, but several tens of feet of drift overlie bedrock in the lowland.

Three lithic facies of sandy, clast-rich, non-compact, subarkosic till derived from the three major source rocks rest on bedrock or on highly weathered, compact, clast-poor, fissile probably older till. The mean for all upper till is 69.6% sand, 21.7% silt, and 8.8% clay; lower till consists of 48% sand, 23% silt and 29% clay. Mud-rich, compact, sparsely stony till in drumlins in and along the flank of the Connecticut Valley Lowland is composed of 51.5% sand, 28% silt, and 20.5% clay. Upper tills are facies equivalent deposits of the youngest Wisconsinan drift. Lower till is compact deeply weathered, jointed and stained suggesting it is correlative with other lower till in New England deposited by an earlier Wisconsinan glacier. Drumlin till may be a facies equivalent of lower till or a mud-rich upper till derived from earlier glaciolacustrine deposits.

Upper and lower till of the Belchertown quadrangle is texturally similar to other New England upper and lower tills to which they are equivalent. Both tills are interpreted as lodgment till derived from similar bedrock terrane by two different glaciers. The older glacier incorporated mud-rich saprolite producing a fine grained till, while the younger glacier eroded fresh bedrock or a thin regolith produced by mechanical weathering.

During stagnation zone retreat of the last glacier, stratified drift was deposited by melt water in, on, alongside or down valley from stagnant ice. The absence of stratified drift along upland divides indicates that stagnation did not begin till large nunataks were emergent. Kame terraces, kame deltas, and ice channel fillings indicate that melt water flowed along stagnant ice and emptied into temporary proglacial lakes. As downwasting

progressed, water was able to drain at lower elevation into expanding lakes, the last of which merged with northward-expanding proglacial Lake Hitchcock in the Connecticut Valley. Initial melt water drainage to the southeast was followed by drainage to the southwest to the ancestral Chicopee River. With the opening of the Narrows, Lake Hitchcock expanded northward and eastward to form the Amherst embayment into which melt water from the eastern uplands drained.

Sand and gravel overlying varves in the Amherst embayment was deposited in late-glacial Lake Lawrence, which coalesced with equivalent Lake Hadley through cols between drumlins in the Connecticut Valley Lowland.

Deglaciation of the Belchertown quadrangle probably occurred in a span of about 100 years in the interval 12,000 to 12,500 years B.P.

Unconsolidated sediments of the Belchertown quadrangle are summarized as to their geologic and geotechnical properties for land use planning. Drift as it influences groundwater flow, yield, and quality and as a construction material is assessed. Some environmental degradation has occurred from the indiscriminant disposal of liquid and solid waste as well as injudicious use of road salt.

BELCHERTOWN, MASSACHUSETTS QUADRANGLE

SURFICIAL GEOLOGY

## INTRODUCTION

The Belchertown quadrangle is located in Hampshire County in central Massachusetts in the New England physiographic province (Fig. 1). As defined by Lobeck (1932), Atwood (1940), and Fenneman (1938), the New England province is the probable equivalent of the Piedmont province to the southeast in the Appalachian Highlands, although relief in New England is greater than in the Piedmont. Probable equivalents of the Blue Ridge and the Ridge and Valley physiographic provinces in the Central and Southern Appalachians have not been clearly established in New England. The eastern part of the Belchertown quadrangle is located in the New England Upland section (Fenneman, 1938) which is a dissected plateau of moderate relief developed on Paleozoic and older metamorphic and igneous rocks. The western part of the Belchertown quadrangle is in the Connecticut Valley Lowland section, an area of low relief developed by differential erosion of the weakly consolidated, underlying Triassic sedimentary rocks. The east-west trending, basalt-capped Holyoke Range separates the Connecticut Valley Lowland of the Belchertown quadrangle into two topographic basins. Figure 2 is a map showing generalized bedrock types in the area. Pleistocene glacial deposits veneer the bedrock in the uplands, but the drift is several tens of feet thick in the lowlands.

With the exception of the Fort River which flows southwestward through a small area in the northwestern part of the quadrangle, there are no major streams in the Belchertown quadrangle. The east-central and northeast sections of the quadrangle are drained by small first and second order streams which empty into Quabbin Reservoir in the Swift River drainage basin. Most drainage occurs by way of small streams draining either northwest to the Fort River, or southeast to the Chicopee River. The Chicopee and Fort Rivers empty into the Connecticut River.

The surficial geology was mapped during 1970, 1971, and 1972, using the Belchertown 7-1/2 minute topographic map as a base. Field observation of natural and temporary exposures and hand-dug shovel and auger holes supplemented interpretation of the topographic map and aerial photographs in the compilation of the surficial geologic map. Many excellent temporary exposures were provided by the numerous construction projects undertaken in the area during the course of the project. Samples of drift were collected from natural and temporary exposures for later analyses in laboratory.

This project was undertaken as part of a Ph.D. dissertation under the supervision of Prof. Joseph H. Hartshorn of the Department of Geology and Geography of the University of Massachusetts and Dr. Lincoln R. Page of the U. S. Geological Survey, ~~Geologic Division~~, Boston. Grateful acknowledgment is extended to each for assistance and support during the project. Laboratory work was carried out using the facilities and equipment of the Geology Department of the University of Massachusetts. Profs. John H. Hubert and Ward S. Motts provided information and data. The writer benefitted from numerous discussions among colleagues in the Geology Department too numerous to mention. Thanks are due to many people who freely provided data and access to exposures on private property.

## PRE-PLEISTOCENE GEOLOGY

### Bedrock

#### A. Precambrian and Paleozoic

The New England Upland is underlain by largely Paleozoic and older metamorphic and igneous rocks. Some dike rocks of lithology similar to those in the Connecticut Valley may be of Mesozoic or younger age. Stratigraphically undifferentiated granitic gneiss with some schist, quartzite, and pegmatite comprise the core of the Pelham dome, one of numerous aligned, enigmatic mantled gneiss domes of New England. Emerson (1898) mapped these undifferentiated quartzo-feldspathic gneisses with interbedded quartzite as the Becket gneiss. Robinson (1967) refers to these "core rocks" of uncertain age as the "Pelham gneiss" until they can be further investigated to determine whether a stratigraphic succession can be distinguished. Middle Ordovician to Devonian metasediments which have been metamorphosed to varying grades now occur along the flanks of the Pelham dome. These rocks formerly covered the dome (thus the name "mantle rocks"), but have been stripped away from the core of the dome by Phanerozoic erosion. Only the Middle Ordovician Partridge formation (a rusty-weathering, pyritic, micaceous schist) was observed during field investigation in the Belchertown quadrangle. Exposure of the Partridge formation to the west of the Pelham gneiss in a cellar hole along Kopiac Avenue suggests that the mantle rocks may be folded around the core of the Pelham dome (Robinson, personal communication). Thus, rocks of the Clough or Littleton Formations and/or the Ammonoosuc volcanics may also exist west of the axis of the Pelham dome.

Deformation of pre-Middle Devonian rocks to form the Pelham dome and intrusion of hornblende and biotite bearing quartz diorite and granodiorite (and related rocks) of the Belchertown intrusive complex (Guthrie, 1972) are post-Lower Devonian events that at least in part reflect the Acadian orogeny (Robinson, 1967). Detailed discussions of this deformation may be found in a number of papers which are summarized in Robinson (1967), Rodgers (1970), and Thompson, et al, (1968) and Naylor (1968). Quartz diorite, granodiorite and pegmatite of the unmetamorphosed Belchertown intrusive complex are found in the southeastern and south-central parts of the quadrangle. Intrusion of these rocks during the Devonian period probably intensified the grade of metamorphism in the surrounding rocks (Guthrie, 1972). The topography which has developed on these essentially unfoliated rocks differs from that found in the Pelham dome where glaciation has accentuated the north-northwest trending foliation.

Brittle deformation of these Paleozoic and older rocks along with intrusion of diabase, basalt and pegmatite dikes may have occurred during Triassic and later time. Dikes and sills of basalt and diabase of Triassic age occur in the non-marine sedimentary rocks of the Connecticut Valley suggesting that discordant masses of similar rocks in the uplands are approximately contemporaneous.

B. Triassic

Triassic non-marine, commonly red, fluvial and lacustrine sandstone and conglomerate and interstratified lava flows and sills of diabase and basalt underlie the Connecticut Valley Lowland. These rocks were deposited or intruded into a basin formed by tensional stresses associated with the opening of the North Atlantic Ocean (Bird and Dewey, 1970; Dewey and Bird, 1970). The sediments in the Lowland were deposited largely by streams which originated in the uplands to the east and flowed west into the half graben of the Connecticut Valley.

The eastern boundary of the Connecticut Valley Lowland where Triassic redbeds are in sharp contact with older metamorphic rocks has long been considered as a fault. Willard (1942) interpreted the Triassic basin of the Connecticut Valley as a composite basin formed by several generally north-trending, westward-dipping gravity faults. The age of these faults generally decreases eastward. As the western block is always dropped, the oldest faults in this sequence have been buried by fanglomerates which extended themselves progressively westward. An unknown number of buried faults of unknown throw in the Connecticut Valley have made it difficult to estimate the thickness of these Triassic deposits and the amount of relief between the formerly continuous surfaces of Paleozoic rocks. Emerson (1898) reported a well in Northampton which bottomed in Triassic rocks at a depth of 3700 feet. Rodgers (1968, 1970) indicates that the cumulative displacement along all of these normal faults may be as much as 5 miles.

The Triassic border fault in the Belchertown quadrangle has been mapped from the southern border of the quadrangle to a point north of Lake Holland (see Plate 1). Although the fault was not observed, structurally controlled drainage, changes in topography, and bedrock exposures indicate the position of the fault. North of Lake Holland, no exposures of Triassic rock occur in the Connecticut Valley Lowland in the Belchertown quadrangle. Paleozoic crystalline rocks crop out in the floor of a borrow pit on the east side of Route 9, 6 miles north of North Street. Along with crystalline rocks exposed along Southeast Street (Amherst) just beyond the western margin of the Belchertown quadrangle and an extensive exposure of crystalline rock in Mt. Warner, Triassic rocks in this part of the Connecticut Valley are either very thin or entirely absent. The northeast corner of the adjacent Mt. Holyoke quadrangle was interpreted as Paleozoic metamorphic rock veneered with Quaternary deposits (Balk, 1957).

The Triassic redbeds were originally interpreted as marine sediments deposited by tidal currents in a basin that was sufficiently cool to sustain river ice (Emerson, 1898). In a classic paper, Krynine (1950) interpreted these rocks as consolidated alluvial fans deposited in tectonically controlled basins in an arid environment. Sedimentary structures and facies relationships have confirmed the alluvial fan origin of these redbeds and have permitted subdivision of these rocks into facies deposited in the following environments: (1) proximal and distal sections of alluvial fans, (2) floodplains of braided and meandering streams and (3) lakes which formed when the major southward flowing stream in the Connecticut Valley was blocked by westward growth of one or more alluvial fans. (Wessel, et al, 1967; Klein, 1968; Hubert, personal communication.)

Emerson (1891, 1898) divided the Triassic rocks of the Connecticut Valley in Massachusetts into (from oldest to youngest): (1) the Sugarloaf arkose, (2) the Holyoke diabase, (3) the Longmeadow sandstone, (4) the Granby tuff and (5) the Chicopee shale. Krynine (1950) divided the Connecticut Valley Triassic rocks in Connecticut into units based on their stratigraphic position relative to eruptive rocks as follows:

| | |
|---|---|
| | Portland Formation |
| Hampden Basalt | |
| | East Berlin Formation |
| Holyoke Basalt | |
| | Shuttle Meadow Formation |
| Talcott Basalt | |
| | New Haven Formation |

Krynine's (1950) terminology was extended to the southern Massachusetts border by Rodgers, et al (1956) and then into Massachusetts by Hartshorn and Koteff (1967) who used "East Berlin Formation" in place of "Longmeadow sandstone."

Triassic sedimentary rock in the Connecticut Valley Lowland in the Belchertown quadrangle consists of red, very poorly sorted, unstratified to massively-bedded, arkosic pebble and cobble conglomerate with thin-interbedded, plane-bedded arkosic sandstone. The mud-rich matrix of these rocks generally consists of hematite-stained silt and fine-to-medium sand. This matrix weathers relatively quickly such that after 5 to 10 years of exposure, clasts of cyrstalline rock can usually be removed by hand. These arkosic fanglomerates belong to the "proximal and distal alluvial fan facies" (Klein, 1968) and occur stratigraphically below (north of) and above (south of) the Holyoke diabase (Balk, 1957) in the Mt. Holyoke quadrangle immediately west of the Belchertown quadrangle. Although the trend has been to abandon Emerson's terminology in favor of Krynine's (especially south of the Holyoke Range in Massachusetts), the writer prefers Emerson's nomenclature because: (1) it has precedent in the literature over that of Krynine, and (2) has been used in published literature and maps in adjacent areas (Balk, 1957; Willard, 1951; Wessel, et al, 1967). The Triassic rocks south of the Holyoke basalt are nearly identical with those to the north as proximity to the source area in the eastern uplands controlled the texture of the deposits. Thus, lithologically very similar red fanglomerates belong to the Sugarloaf arkose north of the Holyoke Range and to the Longmeadow sandstone to the south.

Both the Sugarloaf arkose and the Longmeadow sandstone are unfossiliferous in the Belchertown quadrangle. Dinosaur tracks have been reported in the Longmeadow sandstone to the west, but none were observed nor were there any reports of them in the Longmeadow sandstone in the Belchertown quadrangle. Plant and fish fossils are well known from the fine sandstones and shales of the Longmeadow and Chicopee formations.

## GEOMORPHOLOGY

### A. Preglacial

The geologic history of the area between the Devonian and the Triassic periods and the Triassic period and the Pleistocene epoch is little known. Emerson (1898) believed that a south-flowing stream and estuary occupied the present area of the Connecticut Valley before Triassic sedimentation. Clasts in the Triassic fanglomerate suggest removal of a considerable thickness of rock in the eastern uplands in order to expose sillimanite grade metamorphic rocks to erosion by Triassic streams. The suggested depth of erosion implies considerable bedrock relief in pre-Triassic time. Emerson (1898) doubts that the area was worn down to a peneplain by pre-Triassic systems as suggested by Davis (1889). Topography on the pre-Triassic surface of erosion on crystalline rock indicates greater relief than that believed indigenous to peneplain.

The Connecticut Valley Lowland was produced by erosion of a major stream similar in size and location to the present Connecticut River in the post-Triassic, pre-Pleistocene interval. Probable preglacial drainage in the Connecticut Valley was mapped by Emerson who found that the present Connecticut River occupies a channel which is partly preglacial and partly postglacial (Emerson, 1898; Saines, 1971; Motts, 1971). Superposition of the ancestral Connecticut River and its major tributaries occurred during slow uplift in preglacial time and produced bedrock gorges such as those presently found along parts of the Deerfield and Connecticut Rivers. Portions of the present channel of the Connecticut River in thick drift probably correspond with a preglacial channel; those in bedrock are postglacial and imply diversion of the river from its preglacial channel by glaciation. Parts of the preglacial channel of the Connecticut River which is now drift filled have been located by seismic refraction lines and water wells.

Two exposures of thick, preglacial kaolin-rich soil in Hampshire County (Emerson, 1898) along with the Brandon lignite of Vermont (Baarghorn and Spackman, 1949) and a few other localities of preglacial regolith (Goldthwait and Kruger, 1938) suggest that a warm, temperate climate prevailed in New England in the early to middle

Tertiary period. This moderately thick, preglacial loam may in part account for the texture of some of the till overlying bedrock in parts of New England as discussed later.

Widespread fluvial and marine erosion surfaces of the New England Upland which have been hypothesized by many workers and which are summarized in Fenneman (1938) and Thornbury (1965) cannot be accepted in light of current geomorphological concepts without detailed restudy (Flint, 1963).

The present topography of the Belchertown quadrangle has resulted from differential erosion of varying rock types. The major elements of this topography were formed in preglacial time and consist of an upland east of the Triassic border fault, the Connecticut Valley Lowland and the east-west trending Holyoke Range which divides the lowland of the Connecticut Valley into a northern and southern basin. The highland east of the Triassic border fault (hereinafter referred to as the eastern upland) is underlain by granitic and granodioritic gneisses, schists, and quartzites, of the Pelham gneiss and granodiorite and quartz diorite of the Belchertown intrusive complex. As indicated earlier, the Pelham gneiss constitutes the core of the Pelham dome, the axis of which trends approximately north-south and generally bisects the eastern upland. The Belchertown Intrusive Complex occurs in the southcentral part of the area. Relief in the eastern upland is moderate with elevations ranging from about 400 feet along the border fault to 1238 feet at the highest point of Mt. Lincoln. Topography within the eastern upland is generally that of a moderately dissected upland with ridges of resistant rock forming divides between small first and second order streams which drain generally west or southwest into the Connecticut Valley Lowland. Pegmatites outcrop at or near the crests of a number of these ridges suggesting lithologic control by these resistant rocks. Many of the ridges in the Pelham dome, and in particular East Hill and Dodge Hill, exhibit a generally north-northwest trend that reflects glacially accentuated foliation which also strikes north-northwest. Large scale stoss and lee topography is common. Drift deposited on the upstream side of glacially abraded bedrock knobs has produced smooth stoss sides. Plucking by overriding glacial ice has produced very jagged, knobby rock surfaces on the south and southeasst sides of bedrock knobs.

The Connecticut Valley Lowland is an area of generally low relief with elevation ranging from 150 to about 400 feet. The area south of the Holyoke Range is underlain by sand and gravel and forms a gently south to southwestward sloping plain that is generally below 300 feet elevation. Bedrock ridges protrude above this surface. North of the Holyoke Range, the Lawrence Swamp basin is an area of low relief underlain principally by lacustrine silt and clay with a sand veneer. Sand and gravel in kame terraces and deltas generally borders this basin to the east and south. The Holyoke Range is a range of low mountains capped by Triassic diabase and is the exception to this lowland topography. Elevations in the Holyoke Range range up to 920 feet on Long Mountain. A northeast-trending grain to the topography in the northeast part of the town of Granby results from the structure of the underlying arkosic conglomerate of the Longmeadow formation. The Longmeadow in this area strikes northeast and dips southeast forming strike ridges with steeper west facing slopes (scarp slopes) and more gently inclined east facing dip slopes. Between Long Mountain and Arcadia Lake, a number of cols are occupied by streams trending generally normal to the strike of the Holyoke Range. While this is typical for a hogback ridge such as the Holyoke Range, the courses of these streams may be localized by fractures. Bain (1941) has mapped several generally north-trending dip slip faults in this area along which there may have been considerable vertical displacement. Thus, some of these cols through which melt water drained may be structurally controlled.

Unlike the glacially modified upland topography, the topography of the lowlands and the margin of the lowlands is a composite of numerous landforms comprised of Pleistocene drift. Most of these landforms are composed of stratified drift, but a few are composed of till. The tail of a northwest-trending drumlin on the west side of Southeast Street is the southeasternmost in a chain of northwest-trending drumlins which had a significant control on late glacial drainage in the Lawrence Swamp Basin. Landforms composed of stratified drift in the Belchertown quadrangle include kame terraces, kame deltas, channel fillings, outwash and valley train deposits, and a lake plain. Along the flanks of the uplands and along the flanks of the Holyoke Range, kame terraces composed of sand and gravel record levels of melt water drainage controlled by stagnant ice in the lowlands. These landforms which are used to interpret a chronology of deglaciation are discussed later in this report along with the interpreted deglacial chronology.

Unusually thick drift in the basin of Knights Pond has produced a topography in which ridges of stratified drift and till rise above a surface of low relief. In this basin, an unsubstantiated report indicates that a water well west of Gold and Munsell Street does not reach bedrock at a depth of 110 feet. Other wells along Gold Street reach bedrock at depths of greater than 50 feet indicating that this topographic basin probably corresponds to a basin in the underlying crystalline bedrock. Logs of the few wells drilled here are not sufficiently detailed as to distinguish what portion of the unconsolidated material is drift or preglacial regolith.

## PLEISTOCENE GEOLOGY

Unconsolidated deposits of Pleistocene and Holocene age mantle the bedrock in the Belchertown quadrangle. Bedrock and preglacial soils were eroded by one or more southward moving ice sheets and subsequently deposited by the ice as till. Stratified sediments consisting of sand, gravel, silt, and clay were deposited in streams or in lakes fed by melting glacial ice during deglaciation. In the absence of moraines, these stratified sediments, which are classified largely on the basis of landform, are used to interpret a chronology of deglaciation. A veneer of late-glacial and post-glacial eolian silty fine sand as well as Holocene alluvium, stratigraphically overlies Pleistocene deposits.

### A. Glacial Erosion

Glacial erosion is manifest in many forms in the Belchertown quadrangle. Upland streamline ridges, stoss and lee topography, roches moutonnees, and striations, from large to small, respectively, have resulted from glacial erosion. The large volume of drift that is present in the quadrangle resulted from glacial erosion of bedrock and pre-glacial deposits and subsequent redeposition.

The rate of erosion by glaciers is a function of the thickness and rate of movement of the ice, nature and hardness of the basal load of the ice, and erodability of the material being overriden (Flint, 1971, p. 113). The amount of erosion attributed to glaciation varies from a few meters in the Canadian Shield to hundreds of meters in the Finger Lakes Valleys of New York and other deep valleys in Alaska and British Columbia (Flint, 1971, pp. 114-115).

Jahns (1943) studied exfoliated granite knobs in eastern Massachusetts and concluded that only a few meters of rock had been removed by glacial abrasion from the stoss side of these ridges. Concentrated glacial plucking on the lee sides of these knobs resulted in the removal of larger quantities of rock. In a physiographic setting similar to New England, Muller (1963) compared divides north and south of the terminal moraine in southwestern New York and concluded that glacial erosion had removed only a few meters of rock in the uplands, with the depth and intensity of glacial erosion increasing with distance north of the ice border.

Several elongate, streamline (in plan), asymmetrical (in profile) bedrock ridges in the upland exhibit the effect of glacial erosion. The trend of these ridges is north to north-northwest and reflects an accentuation of rock types and foliation with the same trend by glacial erosion. The few striations measured in the upland are parallel to the trend of ridges such as East Hill, Dodge Hill and some of the ridges in the vicinity of Smiths Pasture.

An area of crag and tail topography occurs northeast of Knights Pond. The knobby, steep, south facing slopes are composed of bedrock which was eroded by glacial plucking. Ice moving in a general southerly direction across these ridges deposited a thin veneer of till on the stoss (north) side while removing blocks of rock on the south side by plucking.

Several excellent examples of roches moutonnees occur at the crest of a streamline ridge approximately 0.7 mile north-northeast of Mt. Lincoln. Massive quartzite and quartzose gneiss have been shaped into asymmetrical ridges by overriding glacial ice. Glacial grooves and striations on the stoss side of these features range from north-south to north 20 degrees west, with a median of north 12 degrees west. This orientation is approximately parallel with the strike of the streamline ridge and indicates the direction of flow of the last glacier to override this area.

Striations were found at six other localities in the Belchertown quadrangle (Plate 1). Striations were measured on recently exposed Triassic arkosic conglomerate in and near Bobbin Hollow (Plate 1 and Fig. 3) where the trend of the striae ranged from north-south to south 30 degrees east. However, rapid weathering and deterioration of this rock type upon exposure result in obliteration of striae within a matter of several years. Thus, few striae were observed on this rock type. Quartzite clasts in Triassic arkosic conglomerate hold striations much longer. Rubbing polished and finely striated rock with a pencil will accentuate the micro-relief and reveal the closely-spaced, fine striae on these clasts--especially when observed in low angle, incident light. Striations were reported by Emerson (1898) near the mouth of Forge Pond, but were not seen during this investigation. These striae trend south 8 degrees east and south 15 degrees east. Mineral lineations in gneisses in the uplands have been accentuated by glaciation, and can easily be mistaken for striae upon cursory examination.

Analogous to the case described by Jahns (1943), only a few meters of rock have been removed by glacial erosion from upland ridges in the area. Most of that removed was eroded by plucking from the lee side of bedrock knobs. The depth of erosion by glaciers in the Connecticut Valley Lowlands is difficult to estimate. Several tens of feet of drift overlie bedrock in the valley, but a substantial amount of bedrock removal in the valley undoubtedly occurred during preglacial erosion by the ancestral Connecticut River and its tributaries. While glacial erosion was more intense in the valley, the quantity of rock removed by glaciers cannot be distinguished from that removed by preglacial streams. Deep depressions in the bedrock surface in the Connecticut Valley as in the nearby Springfield South quadrangle (Hartshorn and Koteff, 1967) are probably the result of glaciation. Test borings in the Connecticut Valley at several localities reveal that the present bedrock surface is below sea level--an unlikely result of erosion by streams. The deep basin in which Knights Pond is located is probably due to bedrock structure or preglacial weathering (or both), but probably has been modified by glacial scour.

## B. Glacial Deposits

Drift is the name given to all glacigenic deposits (i.e., deposits which result from glaciation). Drift can be classified on the basis of sorting and genesis into unsorted, glacially deposited material known as till, and sorted, stratified sediment deposited in water and called stratified drift. Till and stratified drift are actually end members of a continuum between unsorted and unstratified material deposited solely by ice and sorted, stratified material deposited only by water. In the zone of stagnating ice where most till deposition occurs (Boulton, 1972), ice and water are present in amounts that vary from place to place and season to season. Thus, till deposited in such an environment has been influenced at least partly by water before finally coming to rest. Crude stratification and lenses of bedded and sorted sand and/or silt occur in upper till in the area and attest to such processes. While the distinction between till and stratified drift is often obvious, the two may be difficult to distinguish in cases where a restricted range of grain sizes may be present in the glacier and a minor amount of winnowing by water occurred in the depositional environment. Thus, till which exhibits a narrow range of grain sizes and some effects of washing may be difficult to distinguish from gravel which is very poorly sorted and stratified because of rapid deposition after short transport by water. Because of the climatic implications of till, it should be distinguished from other similar sediment such as colluvium, and/or mud flow or landslide deposits, and various types of breccias (see Flint, 1971, pp. 152-153).

Till has been classified according to its presumed genesis in accordance with observations dating back to the mid-19th Century (Flint, 1971). Lodgment till (Holmes, 1941) is that which has been deposited from the base of actively moving ice. Lodgment till is generally fine-grained, compact, fissile, and possesses an oriented fabric resulting from the shear of basal ice over freshly deposited material. Ablation till (Sharp, 1949) is deposited during the melting of glacial ice as either a lag deposit, or one originating from repeated flow of superglacial debris to lower elevation. Till which is sandy, friable, stony, poorly consolidated, contains lenses of washed material along with a large number of non-faceted, non-striated angular clasts and lacks a consistent fabric has been interpreted as ablation till. Many of the properties of lodgment till are as much properties of a mud-rich material as they are of material "lodged" by moving glacial ice. Dreimanis and Vagners (1971) have shown that a "terminal grade" for different minerals and combinations thereof is a product of glacial transport. Therefore, interpreting the origin of a till merely on texturally controlled properties could lead to misinterpretation of the origin of till and of the glacial history.

Boulton (1970,1972) indicates that the classification of tills as either lodgment or ablation is oversimplified and ignores important depositional processes which result in misinterpretation of Pleistocene stratigraphy and glacial history. Observation of numerous glaciers in Svalbard suggests that most till is deposited in a terminal zone of debris-laden stagnant ice peripheral to or lying below the zone of actively moving ice. Till is deposited in this stagnant zone of melting ice by a number of processes which occur supraglacially, subglacially, and englacially. Debris which may be systematically or randomly distributed in and on the surface of stagnant ice results in differential melting such that a hummocky topography of ice and saturated material exists in the terminal stagnant ice zone. Mass movement of superglacial water-saturated debris into topographic lows within this zone produces a till-like sediment which he called flow till (Boulton, 1968). Protected from the atmosphere by a blanket of supraglacial material, melting of buried stagnant ice either from top to bottom or bottom to top results in deposition of debris as melt out till (Boulton, 1970, 1972). Similar processes of deposition of till had been discussed earlier by Hartshorn (1958--see below) and Elson (1961) who referred to "melt out till" as "subglacial ablation till." Boulton (1972) proposes that till should be classified according to place of deposition as: (1) supraglacial and (2) subglacial till. He recognizes flow till and melt out tills as varieties of (1), and melt out till and lodgment till as varieties of (2). Although recognizing lodgment till as a variety of subglacial till, he feels that in Svalbard, the proportion of lodgment till, i.e., that deposited at the base of actively moving ice, is very small. Unfortunately, this classification is not readily adaptable to field investigations of till in areas no longer occupied by ice.

Hartshorn (1958) has observed the flow of superglacial debris from higher to lower elevation on and along the stagnating margins of the Malaspina glacier in southeastern Alaska. The resulting deposit resembles till in sediment properties. However, deposition is by mass movement rather than by glacial deposition. Hartshorn introduced the term flowtill for such till-like sediment which was deposited by mass movement. Flowtill is commonly interbedded with and caps stratified drift in Massachusetts where no other evidence of a glacier readvance can be found. A number of flowtills were observed in the Belchertown quadrangle during the course of this investigation. While easily recognized where it caps or is interbedded with stratified drift, as in the Belchertown quadrangle, flowtill is often indistinguishable from lodgment or ablation till when the two are interbedded or superposed. Flowtill resting on upper till at one locality and possibly a second in the area is discussed later.

Till is a complex sediment which, within broad limits, has certain characteristic properties. Till is very poorly sorted and includes a very wide range of grain sizes ranging from huge boulders to fine clay. The proportion of stones in till varies, and is generally a function of availability in source material, resistance to abrasion during transport, and the total distance of transport. The rock types found in the pebble and larger fractions of a till are generally from the local bedrock, but may be from as much as several tens of miles away. Rocks, minerals or elements which are far travelled in drift and which can be traced to a point source are useful as indicators of the direction of ice flow. Dremanis and Vaguers (1971) indicate that two peaks exist in a size distribution curve for any rock type undergoing glacial transport: (1) the pebble or cobble size which diminishes rapidly in a downcurrent direction, and (2) a "terminal grade" for the component minerals after disaggregation of a rock. Most clasts in till are angular to subangular, unless the source material contains well rounded stones. Clasts transported englacially and subglacially tend to be better rounded than those transported superglacially. Clasts in till are often striated and polished, but only very fine-grained macroscopically homogeneous, or nearly monomineralic rock types (e.g., limestone, quartzite, basalt) develop and maintain striations and polish. The shape of clasts in till may reflect source conditions as well as glacial transport. Faceted clasts of some rock types are common in some tills, whereas, others do not show any preferred shape. Holmes (1941) reports that carbonate clasts in tills of central New York approach a pentagonal flatiron shape as a final product of glacial processes.

The compactness of till is variable and is at least partly a function of grain size. Tills with a fine-grained matrix (largely silt and clay) tend to be compact. Silt-rich tills frequently have a subhorizontal parting called fissility (Fig 4). Compactness and fissility may be at least partly a result of the weight of overriding ice. Tills, especially compact tills with a fine-grained matrix, may also possess vertical joints. The combination of horizontal and vertical parting causes some tills to break into small, thin flat masses known to soil scientists as peds. Blockiness is frequently characteristic of tills, even those which are somewhat granular and noncompact.

Elongate particles in many tills exhibit a preferred orientation which may be either parallel or perpendicular to the direction of flow of the ice which deposited them. Holmes (1941) studied the orientation of the elongate clasts of lodgment tills in central New York and found two principal orientations of the long axis. The long axis of most elongate clasts is oriented parallel to the direction of glacier flow; a minor amount showed the long axis perpendicular to the direction of glacier flow. Holmes (1941) suggested that the parallel mode resulted from the shear of overriding glacial ice as the clasts were deposited, whereas the transverse mode resulted from rolling of clasts before entrainment in the till. Glen, Donner and West (1957) found experimentally that elongate clasts become quickly aligned parallel to the direction of flow, whereas the transverse mode develops only after a long time. Parallel and transverse modes were found in both englacial drift and an end moraine of an active ice sheet by Galloway (1956). Harrison (1957) noted that the a-b plane of elongate clasts dipped in an upglacier direction. The plunge of the a-b plane of tills is generally upglacier regardless of whether the long axis is oriented parallel or transverse to glacier flow. In supraglacial flow tills, the a-b plane may dip either up-glacier or downglacier (Boulton, 1968), the latter being an orientation noted by Lindsay (1968) for fabric in mud flows. If a sufficient number of fabric measurements are taken so as to negate the effects of local topography on ice movement, fabric can be used as an indicator of the direction of glacier movement. Microfabrics have been measured in thin section using elongate mineral grains (Harrison, 1957). Evenson (1971) indicates a close correlation between microfabric and macrofabric in some tills in eastern Wisconsin. Several cursory measurements of till fabrics in the Belchertown quadrangle revealed no consistent pattern, a probable consequence of the influence of local topography on the direction of movement of glacial ice which deposited the thin till.

The color of till generally reflects the source materials and in part is the basis for subdivision of upper till of the Belchertown quadrangle into facies. The thickness and characteristics of the weathering profile may serve to distinguish several tills in an area as is true in New England. Tills which are macroscopically indistinguishable when fresh can often be distinguished by the manner in which they weather. Apparently, weathering serves to accentuate properties which are present in the unaltered till, but which are undetectable until weathered.

Till may be mapped on surficial geologic maps as "till" or "ground moraine." The unit "ground moraine" should be restricted to areas in which the till is of sufficient thickness so as to produce a topography different than that of the underlying bedrock. Where the deposit is thin and mantles a bedrock topography, as in the uplands in Belchertown quadrangle, it is best mapped as "till." Thick till which has been molded into streamlined topographic ridges is mapped as drumlins, few of which are found in the area. Till in the Belchertown quadrangle is generally a veneer on bedrock as shown on Plate 2 and in this area is mapped as the unit "till" on Plate 1.

Tills in the Belchertown Quadrangle

Several tills may be distinguished in the Belchertown quadrangle on the basis of texture, color, weathering characteristics, and stone content. Two of these tills are sparsely stony, mud-rich tills which were only seen in and along the margins of the Connecticut Valley Lowland. A "Triassic red" till occurs in drumlins in the Connecticut Valley Lowland and on the north slope of the Holyoke Range. An olive to olive-brown till occurs on the divide immediately adjacent to the Connecticut Valley Lowland in the northwestern part of the quadrangle. A noncompact, stony, friable till is ubiquitous in the uplands and has been subdivided on the basis of color and mineralogy into three facies.

A compact, sparsely stony, highly-weathered, fissile, clay and silt rich till is exposed beneath a sandy till in a road cut on Harkness Road approximately 1000 feet north of Belchertown Road. This till is extremely compact and difficult to dig when dry. Vertical and horizontal joints allow this till to be broken into thin plate-like masses known as peds. Oxides of iron and manganese impart an orangish and purplish (respectively) color to horizontal and vertical partings. This till is very similar in texture, weathering and compactness to a unit called lower till in western Connecticut and described by

Pessl and Shafer (1968). Because of this similarity and its stratigraphic position beneath the sandy till, it is called lower till. Only weathered lower till is exposed in the area, and its color is olive (5Y 5/3.5) when dry and dark grayish-brown to olive-brown (2.5Y 4/3) when damp. Probable lower till was exposed temporarily in two excavations in the northwest corner of Belchertown. Lower till may be present beneath sandy upper till elsewhere in the quadrangle, but no other exposures of it were seen during this investigation. The extremely limited number of exposures of this till make it difficult to characterize the typical topography which is developed on this till.

A massive, compact, sparsely stony, light brown to brown (7.5 YR 5.5/5) to dark brown to strong brown (7.5 YR 4/5) till occurs in drumlins of the Connecticut Valley and on the north slope of the Holyoke Range. The stratigraphic position of this till, informally called drumlin till, is not clear. Similarity of texture and other physical properties suggest that it may be a facies of lower till derived from Triassic sedimentary rocks and restricted to the Connecticut Valley. As sandy upper till does not overlie it anywhere in the quadrangle, it may also be a till deposited by the last glacier which eroded and incorporated a red lacustrine deposit in the lowlands of the Connecticut Valley where such a deposit could have been localized. Smooth, boulder-free, moderate slopes are the characteristic topography formed by this till.

A sandy, noncompact, stony till is ubiquitous in the upland areas of the Belchertown quadrangle and veneers low ridges along the eastern part of the Connecticut Valley. The matrix of this till is generally a moderate to highly silty, very fine sand with fine and some medium sand. Most sand grains are frosted and subangular, but some angular and occasional rounded grains were seen. This till contains lenses and thin beds of washed and stratified material. In many places, such as along Warren Wright Road, the upper part (0-18") of this till is very low in silt and highly stony suggesting penecontemporaneous washing during deposition. Accumulations of very fine sandy silt are common only on the upper surfaces of clasts in this till and are called silt caps. Surfaces of clasts other than the top are usually clean and often surrounded by a one or two grain thick rim of clean sand. This till stratigraphically overlies mud-rich, jointed and weathered till called lower till at the Harkness Road locality and is very similar in physical properties to upper till in western Connecticut (Pessl and Shafer, 1968); thus, it is called upper till. Clasts are very common in the upper till and range up to boulders several feet in diameter. Most clasts are subangular and subrounded, but some angular and rounded clasts, usually of quartzites, can be found in most outcrops. Striated and polished clasts are extremely rare, probably because the coarse grained metamorphic rocks are not readily suited to develop or hold striations or polish during glacial transport. Flat faces do not occur on some clasts, but these probably reflect joint or foliation planes in the source rock and not faceting at the base of the ice. Most clasts in the upper till are sub-spherical (compact to compact bladed of Folk, 1968) in shape, but some approach blades (Zingg, 1935; blade to elongate of Folk, 1968), and, allow measurement of fabric.

Upper till is slightly blocky when damp, but generally dries to a loose, granular sediment. Aggregates of upper till can usually be quickly and easily disaggregated in the fingers. Fissility may be developed in upper till where the matrix is high in silt content (Fig 4). In some places, the total weathering profile developed in upper till and overlying eolian mantle exceeds three feet, but is commonly 22-28 inches deep. Incipient oxidation around clasts of mafic rock was observed in many places below the depth of total weathering.

Terrain underlain by upper till is generally bouldery and hummocky with varying slopes controlled by the thickness of the till and the slope of underlying bedrock. Where upper till is thick and topography is that of the till, slopes are gentle; steep slopes in upper till terrain are those of underlying bedrock veneered thinly by upper till. Well data indicate that a streamlined hill northeast of Gold and Munsell Streets is composed of thick till and thus is a drumlin (Plate 1) composed, at least in part, of upper till. Upper till may be only a veneer on lower till in this drumlin. Pessl and Shafer (1968) observed that upper till does not form drumlins in western Connecticut, but does veneer lower till in drumlins elsewhere in New England. Although the thickness of upper till varies because of the relief of the irregular underlying bedrock surface, it generally does not exceed 10 to 15 feet, and in many cases is no more than a veneer on underlying bedrock topography (Plate 2).

Clasts along with color and mineral composition of the matrix strongly reflect the local source rock such that three facies of upper till can be mapped in the area. These facies are described below.

Three Facies of Upper Till in the Belchertown Quadrangle

The upland facies of upper till is a light olive gray to olive gray to pale olive to olive (5Y 5-6/2-4) till derived from granitic gneisses, quartzites, pegmatites and schists of the Pelham Dome in the northeastern part of the area (Plate 1). The matrix of the upland facies is a silty, fine sand and consists of approximately 95% quartz and feldspar (two-thirds to three-fourths of which is quartz) with minor amounts of rock fragments and heavy minerals. At a construction site along Pelham Road on the adjoining Shutesbury quadrangle to the north, upper till is almost white because of the very high percentage of quartz and the near absence of feldspar and heavy minerals in the matrix. Color variations in the upland facies reflect minor variations in the mineralogy of the underlying source rocks.

The valley facies is a brown to pale brown to yellowish brown to light yellowish brown (10 YR 4-6/3-5--damp color) upper till which occurs mostly west of the Triassic border fault and which is derived largely from the Triassic redbeds of the Connecticut Valley (Plate 1). The matrix of the valley facies is composed of approximately 95% quartz and feldspar with minor amounts of heavy minerals and rock fragments. Forty to sixty percent of the quartz and feldspar grains of the matrix are hematite stained and are derived from the Triassic sediments. It is these sand grains and not a high proportion of arkosic mudstone clasts which gives the till its characteristic color. The rock types in the valley facies are not significantly different from those of the upland facies. Clasts in the valley facies are largely granitic gneisses, quartzites, and pegmatites which were derived principally from the weakly consolidated, easily weathered, Triassic arkosic conglomerate. Before assimilation by overriding Pleistocene ice, these clasts were transported only short distances by streams during the Triassic period. They were subsequently transported only short distances by a glacier before being deposited as part of the till. Thus, no significant changes in shape or rounding were noted in comparing clasts of similar rock types from the valley and upland facies of upper till. Very few pebbles, cobbles and boulders of arkosic conglomerate occur in the valley facies (no more than 2% at any one locality, and usually substantially less). Selective erosion and assimilation of crystalline clasts from the Triassic arkosic conglomerate, or the disaggregation and decomposition of the nonresistant matrix of the arkosic conglomerate during glacial transport probably accounts for the low percentage of redbed clasts in the valley facies of upper till. In places, the percentage of mud in the matrix of the valley facies of upper till is greater than that of the upland facies, but this probably reflects the texture and composition of local mud-rich Triassic source rock.

The Belchertown facies is a pale olive to olive gray to olive (5Y 4-5/3-4--damp colors) upper till derived from granodiorite and associated mafic rocks of the Belchertown Intrusive Complex. This facies is restricted to the southern and southeastern portions of the quadrangle (Plate 1) which are underlain by hornblende and pyroxene bearing granodiorite or quartz diorite of the Belchertown Intrusive Complex. The matrix of the Belchertown facies is composed of approximately 50 to 70% quartz and feldspar, with the balance consisting of heavy minerals (largely amphibole and pyroxene) and rock fragments. Heavy minerals are largely concentrated in the 3.0 to 5.5 phi size range and impart the greenish hue to this facies. Clasts in this facies tend to be slightly more angular than in other facies, and are composed largely of fragments of granodiorite and related rock types from the Belchertown Intrusive Complex.

## Lab Work

Size analyses of the matrix of 31 till samples were performed in the laboratory using sieve and hydrometer techniques as described in Appendix I. Data from the analysis of each sample were plotted as cumulative curves on probability paper. Statistical analyses were then performed on the data using the graphic statistics of Folk (1968) and Inman (1952). Results of statistical analyses are shown in Tables 1 and 2. Sand/mud, sand/silt, and silt/clay ratios were calculated for each sample. The percentage of sand, silt, and clay in each sample were plotted on a ternary diagram (Fig. 5).

TABLE 1

Belchertown Quadrangle Tills

| | Sample No. | % Sand | % Silt | % Clay | S/M | Sa/Si | $\frac{Sa+Si}{Cl}$ | Si/Cl |
|---|---|---|---|---|---|---|---|---|
| $Q_{tu}$ | | | | | | | | |
| | 4 | 81 | 13 | 6 | 4.18 | 6.23 | 15.67 | 2.17 |
| | 6 | 59 | 31 | 10 | 1.44 | 1.90 | 9.00 | 3.1 |
| | 24 | 75 | 19.5 | 5.5 | 2.95 | 3.85 | 17.18 | 3.55 |
| | 50 | 78 | 17.5 | 4.5 | 3.60 | 4.46 | 21.22 | 3.89 |
| | 51 | 76 | 19 | 5 | 3.12 | 4.00 | 19.00 | 3.80 |
| | 53 | 76 | 18 | 6 | 3.26 | 4.22 | 15.67 | 3.00 |
| | 55 | 56 | 36.5 | 7.5 | 1.29 | 1.53 | 12.33 | 4.87 |
| | 58 | 71 | 20 | 9 | 2.50 | 3.55 | 10.11 | 2.20 |
| | 65 | 49 | 41 | 10 | 0.97 | 1.20 | 9.00 | 4.1 |
| | 69 | 80.5 | 11.5 | 8 | 4.13 | 7.00 | 11.50 | 1.44 |
| | 98 | 69.5 | 19.5 | 11 | 2.28 | 3.56 | 8.09 | 1.77 |
| | $\bar{x}$ | 71.3 | 21.5 | 7.2 | 2.91 (3.08 w/o #65) | 4.04 | 12.89 | 3.07 |
| $Q_{tb}$ | | | | | | | | |
| | 57 | 74 | 22 | 4 | 2.84 | 3.36 | 24.00 | 5.5 |
| | 60 | 65 | 27.5 | 7.5 | 1.89 | 2.36 | 12.33 | 5.00 |
| | 61 | 84 | 12 | 4 | 5.16 | 7.00 | 24.00 | 3.00 |
| | 84 | 73 | 20.5 | 6.5 | 2.72 | 3.56 | 14.38 | 3.15 |
| | 86 | 66.5 | 22.5 | 11 | 1.99 | 2.96 | 8.09 | 2.05 |
| | 104 | 66.5 | 23 | 10.5 | 2.00 | 2.89 | 8.52 | 2.19 |
| | 110 | 70 | 20 | 10 | 2.34 | 3.50 | 9.00 | 2.00 |
| | $\bar{x}$ | 69.2 | 22.6 | 8.3 | 2.30 | 3.10 | 11.20 | 3.32 |
| $Q_{tv}$ | | | | | | | | |
| | 62 | 61.5 | 28.5 | 10 | 1.60 | 2.16 | 9.00 | 2.85 |
| | 64 | 74 | 15.5 | 10.5 | 2.83 | 4.77 | 8.52 | 2.82 |
| | 70 | 58.5 | 24.5 | 17 | 1.41 | 2.39 | 4.88 | 1.44 |
| | 96 | 62.5 | 23.5 | 14 | 1.67 | 2.66 | 6.14 | 1.68 |
| | 106 | 68 | 23 | 9 | 2.11 | 2.96 | 10.11 | 2.56 |
| | 108 | 74 | 16 | 10 | 2.86 | 4.63 | 9.00 | 1.60 |
| | 111 | 78 | 14 | 8 | 3.59 | 5.57 | 11.50 | 1.75 |
| | 119 | 76 | 15.5 | 8.5 | 3.17 | 4.90 | 10.76 | 1.82 |
| | 120 | 58 | 29 | 13 | 1.57 | 2.00 | 6.69 | 2.23 |
| | $\bar{x}$ | 67.8 | 21.1 | 11.1 | 2.31 | 3.56 | 8.01 | 2.08 |
| $Q_{td}$ | | | | | | | | |
| | 90 | 51 | 25 | 24 | 1.02 | 2.04 | 3.17 | 1.04 |
| | 114 | 52 | 31 | 17 | 1.07 | 1.68 | 4.88 | 1.82 |
| | $\bar{x}$ | 51.5 | 28 | 20.5 | 1.04 | 1.86 | 3.87 | 1.43 |
| $Q_{tl}$ | | | | | | | | |
| | 77 | 48 | 23 | 29 | 0.94 | 2.09 | 2.45 | 0.79 |

TABLE 2

Folk Graphic Statistics
Belchertown Quadrangle Tills

| | Sample No. | Mode | Median | Sorting $\sigma_1$ | Skewness $S_{K_I}$ | Kurtosis $K_G$ |
|---|---|---|---|---|---|---|
| $Q_{tv}$ | | | | | | |
| | 62 | 3.1ϕ | 3.8 | 3.22 | 0.32 | 1.15 |
| | 64 | 2.0ϕ | 2.8 | 3.20+ | 0.41+ | -- |
| | 70 | 3.2ϕ | 4.1 | 3.80+ | 0.34+ | -- |
| | 96 | 3.1 | 3.9 | 3.22 | 0.41 | 1.02 |
| | 106 | 2.6 | 3.2 | 3.15 | 0.27+ | -- |
| | 108 | 2.4 | 3.1 | 3.01 | 0.45 | 1.30 |
| | 111 | 2.3 | 2.7 | 2.73 | 0.38 | 1.61 |
| | 119 | 2.3 | 2.7 | 2.95 | 0.39 | 1.66 |
| | 120 | 3.2 | 3.8 | 3.66 | 0.38 | 1.28 |
| | $\bar{x}$ | | | 3.16 | 0.33 | |
| $Q_{tb}$ | | | | | | |
| | 60 | 2.7 | 3.37 | 2.82 | 0.40 | 1.14 |
| | 61 | 2.6 | 2.63 | 1.75 | 0.17 | 1.71 |
| | 84 | 2.6 | 3.20 | 2.68 | 0.38 | 1.38 |
| | 86 | 2.8 | 3.47 | 3.09 | 0.37 | 1.08 |
| | 104 | 2.9 | 3.47 | 3.12 | 0.37 | 1.35 |
| | 110 | 2.7 | 3.17 | 3.23 | 0.34 | 1.37 |
| | $\bar{x}$ | | | 2.78 | 0.34 | |
| $Q_{tu}$ | | | | | | |
| | 4 | 2.4ϕ | 2.50ϕ | 1.87 | 0.27 | 1.44 |
| | 6 | 3.2ϕ | 3.90ϕ | 2.85 | 0.38 | 0.98 |
| | 24 | 2.6 | 2.90 | 2.11 | 0.30 | 1.23 |
| | 50 | 2.4 | 2.70 | 2.13 | 0.32 | 1.28 |
| | 51 | 2.8 | 2.97 | 1.99 | 0.25 | 1.50 |
| | 53 | 2.6 | 2.87 | 2.17 | 0.31 | 1.64 |
| | 55 | 3.4 | 3.50 | 2.90 | 0.11 | 0.84 |
| | 57 | 2.6 | 2.87 | 2.09 | 0.25 | 1.23 |
| | 58 | 2.7 | 3.40 | 2.72 | 0.39 | 1.35 |
| | 65 | 4.2 | 4.30 | 2.72 | 0.03 | 0.66 |
| | 69 | 2.2 | 2.77 | 2.57 | 0.42 | 1.57 |
| | 98 | 2.5 | 3.20 | 3.44 | 0.42 | 1.23 |
| | $\bar{x}$ | | | 2.46 | 0.29 | |
| $Q_{tl}$ | | | | 4.65+ | 0.42 | |
| $Q_{td}$ | | | | | | |
| | 90 | | | 4.45 | 0.37 | |
| | 114 | | | 3.75 | 0.20 | |
| ft | 14 | | | 3.62 | 0.17 | |

Grain size statistics indicate that the tills of the Belchertown quadrangle are poorly sorted to extremely poorly sorted, positively skewed, and leptokurtic to very leptokurtic (Folk, 1968). Upper till is better sorted than lower till and drumlin till. Using the minimum and maximum phi sizes for the 5, 16, 25, 50, 75, 84, and 95th percentiles, a cumulative envelope of size distribution in the sand and mud fraction of tills was drawn (Figs. 6 and 7). Although there is some overlap, the envelopes for upper till, drumlin till, and the one curve of lower till are distinct.

Further confirmation of the field separation of tills is indicated by position on a sand-silt-clay ternary diagram and clastic ratios (Table 1 and Fig. 5). Mean values for sand/mud, sand/silt, and silt/clay are higher for upper tills than for either lower till or drumlin till. Clastic ratios for drumlin till are intermediate between upper and lower till, but are closer to those for lower till. Clastic ratios are clearly reflected in the ternary diagram.

The three lithologically controlled facies of upper till while exhibiting some differences, are strikingly similar. The 27 samples of upper till define a distinct field on a sand-silt-clay ternary diagram (Fig. 5). The mean skewness values for samples of upland, valley, and Belchertown facies are very similar and are all positively skewed. Slightly higher mean values of sand/mud and sand/silt ratios for the upland facies suggest that the matrix of this facies is slightly coarser. Values for inclusive graphic standard deviation suggest that the upland facies is the best sorted and the valley facies is the poorest sorted. The mean value for silt/clay ratio suggests that the valley facies of upper till contains a higher percentage of clay in the matrix. The easily weathered and disaggregated mud matrix of the Triassic arkosic conglomerate is the probable source of this difference. Samples 64, 70, and 120 which were collected from exposures two to three feet above arkosic conglomerate have higher percentages of silt and clay in the matrix and reflect proximity to local mud-rich arkosic conglomerate.

## Origin of the Till In The Belchertown Quadrangle

With the exception of flowtill, all tills in the Belchertown quadrangle are considered to be basal tills and probably lodgment till. The very fine-grained, compact, massive till known as lower till possesses few, if any, of the characteristics of ablation till as given in the literature. No lenses or streaks of washed material were found within this till. This till is, therefore, assumed to be a lodgment till, an interpretation similar to that given to it elsewhere in New England (Pessl and Shafer, 1968). The compact, massive "Triassic red" till which has been shaped into streamlined forms and drumlins in the Connecticut Valley Lowland is also considered as a lodgment till. Its fine-grained, compact, massive nature along with its occurrence in streamline forms suggests deposition at the base of an ice sheet. Upper till, as described in the literature, has been considered both as an ablation facies of till deposited by the same ice sheet that deposited lower till or as a lodgment till of a younger glacier. In the Belchertown quadrangle, upper till is considered as a basal till for the following reasons: (1) fresh, unweathered upper till rests upon deeply weathered, jointed, stained and oxidized lower till at the only two-till locality within the quadrangle. The superposition of fresh upon deeply weathered material indicates that a significant length of time separated the deposition of lower till from upper till, during which time the lower till was deeply weathered; (2) a few drumlins composed at least in part of upper till occur in the uplands and indicate that this material must have been deposited at the base of an ice sheet. The till in these drumlins is equivalent to that exposed alongside the drumlins and, thus, is considered basal; (3) the orientation of these drumlins is also parallel to striations on bedrock as well as orientation of streamline molded bedrock ridges in the upland indicating that these drumlins were indeed produced by the last glacier to advance over the area; (4) in several places, upper till rests directly on striated bedrock surfaces; (5) the principal grain sizes in the matrix of upper till are very fine sand and coarse silt. These sizes are indicated as terminal grades for quartz and feldspar by Dreimanis and Vagners (1971), thus indicating that these matrix minerals have been comminuted to a minimum size--a process which must have occurred at or near the base of an ice sheet. Triangular diagrams of basal tills from other areas underlain by quartzose, feldspathic, igneous and metamorphic rocks indicate a similar proportion of sand and mud in tills from such regions (Scott, 1976). Thus, the texture of upper till is principally controlled by che nature of the detritus supplied by source rocks to the glacier which deposited it.

The action of water during deposition of upper till can be seen in several areas of the Belchertown quadrangle, but the volume of the till influenced by water during deposition is minor. Small lenses and thin beds of silt-free sand indicate washing during the depositional process. Up to 18 inches of highly stony, well-washed, sparsely silty material overlie till in a long road cut between North Street and a contact with glaciofluvial deposits along the east side of Warren Wright Road. It is suggested that this upper rind on the till is a washed lag or ablation deposit. A 20-foot exposure in till along the west side of Gulf Road near Scarbrough Pond reveals three to four feet of noncompact, friable gray till resting conformably on moderately compact, gray sandy, but siltier till. After careful observation, the writer concluded that both these materials are part of the upper till. At this locality, the upper noncompact, more sandy material is considered as a possible ablation facies of upper till, a conclusion tentatively reached by Pessl (personal communication) after observation of this exposure.

During the waning stages of glaciation when it is suggested that most till is deposited, the effect of bedrock relief in the uplands exerted its influence on glacial processes. With thinning of the ice, bedrock highs eventually became exposed as nunataks. Debris-rich, basal ice in the lee of such nunataks may have become stagnant and either overridden by more actively moving, cleaner ice, or have begun the process of in situ melting. Thus, it is possible that an environment similar to that described by Boulton (1970) in which melt out tills form, could have existed in the waning phases of the glacial cycle in New England. Some of this upper till may have originated as melt out till (Boulton, 1970, 1972) and account for some of its properties which are considered atypical of basal till. Although these is no conclusive proof, upper till is interpreted as basal till, most of which is probably lodgment till for the number of reasons stated above.

Flowtills are common in the area and are found both interbedded with and capping ice contact stratified drift as well as resting upon upper till. Locations where flowtill was observed are indicated on Plate 1, The Surficial Geologic Map. The matrix of a few of the silt-rich flowtills present in the Belchertown quadrangle is vescicular, a property that has been observed in other mud flow deposits.

### Comparison With Tills From Other Areas of New England

Data from mechanical analyses of upper and lower tills from elsewhere in New England (Crosby, 1891; Goldthwait, 1948; Goldthwait, R. P., 1968; Clebnik, 1973; Larsen, 1972; Moss, 1943; Newton, personal communication; Pessl and Shafer, 1968; Pessl, 1966; Segerstrom, 1955, Campbell, 1975) were plotted on a ternary diagram (Fig. 8) and compared with tills from the Belchertown area. Data from many localities were recalculated to 100% sand and mud where the reported analyses included granules and/or pebbles. A separate ternary diagram (Fig. 9) was constructed for analyses using the U. S. Bureau Soils grade scale on which the limiting particle diameters for sand, silt, and clay differ slightly from those of the Wentworth scale. Plotted means for varying numbers of samples also exhibit distinct fields for upper and lower tills on ternary diagrams. The upper till field is from 55-85% sand, 11-35% silt, and 2-12% clay, with a concentration of points in the range of 69-75% sand, 20-30% silt, and 2-12% clay. Lower tills fall in the range 44-69% sand, 27-37% silt, and 2-29% clay, with a concentration of points in the range 52-62% sand, 21-30% silt, and 16-22% clay.

Upper and lower tills of New England occupy distinct fields on ternary diagrams that overlap and are not mutually exclusive (Figures 8 and 9). The textural similarity between upper tills at widely separated localities and the similarity in texture of lower tills over such a wide area suggests that the observed textures are more than coincidence. The mean composition of the matrix (sand and mud) for 128 samples of upper till from New England is 68% sand, 25% silt, and 6% clay (Figure 8). All but two data points (10 and 24) for upper till on Figure 8 are included within the polygon defined by the mean plus two standard deviations (i.e., the 95% confidence level). These two data points represent analyses of upper till derived from fine grained clastic rocks in the Connecticut valley. This same polygon excludes all data points for lower till except numbers 16 and 30 which fall on its outer perimeter. The mean matrix composition for 64 samples of lower till is 58% sand, 27% silt, and 15% clay. The polygon defined by this mean plus two standard deviations is not nearly as definitive in separating upper and lower till.

However, point 7 which represents nearly 60% of the data exerts an unduly strong bias on the statistics of lower till. While this may be representative of the true grain size population, it is suspected that more similarly performed analyses of lower till, especially from a wider range of areas, are necessary to better define the matrix grain size population for lower till. For upper till, no point on Figure 8 constitutes more than 15% of the sample population and therefore the grain size population of upper till is considered more representative. The writer's confidence is therefore greater in the data for upper till because of: 1) the lack of significant control by analyses from any one locality, 2) the proportionately lower values for standard deviation, and 3) the larger number of samples included in the analysis of upper till (128 versus 64 for lower till).

Similarly, clastic ratios (Table 3) reflect the similarity of most upper tills and most lower tills. The sand/mud ratio of most upper tills is greater than 1.70 (range 1.00 to 3.98, mean of 2.21), while that for most lower tills is less than 1.5 (range .72 to 1.63, mean of 1.09). The areal variability in texture of till within a single till sheet may be a function of local bedrock, source terrane, direction of glacier flow, depositional mechanisms, or post-depositional modification. Deposition as basal or lodgment till may result in a somewhat finer texture than deposition as ablation or melt-out till. Both components may be present in a single till sheet at any locality (see Drake, 1971; Pessl, 1971; Mulholland, 1977) as is suggested by an exposure on Gulf Road near the Pelham Country Club. Lateral variations (facies) reflecting variations of source, and especially local bedrock, may account for some textural

TABLE 3

CLASTIC RATIOS OF NEW ENGLAND TILLS

| AUTHOR | UPPER | | | | LOWER | | | |
|---|---|---|---|---|---|---|---|---|
| | S/M | Sa/Si | $\frac{Sa+Si}{Cl}$ | Si/Cl | S/M | Sa/Si | $\frac{Sa+Si}{Cl}$ | Si/Cl |
| Pessl and Schafer (1968) | | | | | | | | |
| Pomperaug Quadrangle | 1.70 | 2.10 | | 4.29 | 0.89 | 1.24 | 5.67 | 2.53 |
| Waterbury Quadrangle | 1.56 | 1.85 | 15.67 | 5.50 | fresh 0.72 | 0.89 | 8.09 | 4.09 |
| | | | | | ox. 1.13 | 1.39 | 10.11 | 4.22 |
| Pessl (1966) | | | | | | | | |
| Pomfret, Connecticut | | | | | | | | |
| Mashamoquet Brook | 2.23 | 2.37 | 49.0 | 14.50 | 0.92 | 1.00 | 24.0 | 12.00 |
| Goldthwait, L. (1948) | | | | | | | | |
| New Hampshire | 2.23 | 2.88 | 13.29 | 3.43 | 1.63 | 2.82 | 5.25 | 1.38 |
| Newton (Personal Communication) | | | | | | | | |
| W. Ossipee, New Hampshire | | | | | 1.33 | 2.71 | 3.55 | 0.95 |
| Larsen (1972) | | | | | | | | |
| Mt. Tom Quadrangle | | | | | | | | |
| Reddish brown | 2.57 | 3.60 | 11.50 | 2.50 | | | | |
| Grayish brown | 1.70 | 2.42 | 8.09 | 2.36 | | | | |
| Brown | 1.00 | 1.43 | 5.25 | 2.33 | | | | |
| Clebnik (1975) | | | | | | | | |
| Willimantic, Connecticut | | | | | 1.44 | 2.46 | 4.88 | 1.41 |
| Caggiano (1977) | | | | | | | | |
| Belchertown, Mass. Quadrangle | | | | | | | | |
| $Q_{tv}$ | 2.31 | 3.56 | 8.01 | 2.08 | | | | |
| $Q_{tu}$ | 2.91 | 4.40 | 12.89 | 3.07 | | | | |
| $Q_{tb}$ | 2.30 | 3.10 | 11.20 | 3.32 | | | | |
| $Q_{td}$(1) | | | | | 1.06 | 1.80 | 3.87 | 1.37 |
| $Q_{tl}$ | | | | | .92 | 2.09 | 2.45 | .79 |
| Campbell (1975) | | | | | | | | |
| Northfield, Mass. Quadrangle | | | | | | | | |
| $Q_{tc}$ | 3.98 | 4.30 | 49.0 | 9.25 | | | | |
| $Q_{tw}$ | 1.10 | 1.31 | 12.16 | 5.26 | | | | |
| $Q_{tg}$ | | | | | .96 | 1.33 | 6.02 | 2.58 |
| $Q_{tb}$ | | | | | .90 | 1.26 | 5.76 | 2.55 |
| Mulholland (1977) | | | | | | | | |
| Ware, Massachusetts Quadrangle | | | | | | | | |
| $Q_{tu}$ - loose | 2.79 | 3.11 | 37.46 | 8.78 | | | | |
| $Q_{tu}$ - compact | 2.01 | 2.28 | 24.64 | 7.51 | | | | |
| $Q_{tl}$ - lower | | | | | 1.16 | 1.64 | 6.52 | 2.47 |
| Goldthwait, R. P. (1968)(2) | | | | | | | | |
| Wolfeboro/Winnipesaukee Area | 2.70 | 3.04 | 32.33 | 8.0 | | | | |

(1) Classified as lower till for comparison.

(2) All till analyses on upper till (Drake, 1971), but not specifically identified as such.

heterogeneity within a single till sheet as is indicated by various lithic facies in the Belchertown, Mt. Tom, and Northfield quadrangles.

Other clastic ratios similarly suggest textural variations within a single till. The ratio of sand and silt to clay for upper tills is generally high (range 5.25 to 49.0, mean of 20.75), while that for lower tills is much less (range 2.45 to 24.0, mean of 7.18). The ratios of sand to silt and silt to clay which are also shown in Table 3 overlap much more. The ratio of sand to mud as well as the ratio of sand and silt to clay are generally substantially different. Data in Table 4 suggest that these two ratios for upper till are usually at least double those for lower till at any one locality. This same consistency does not seem to be true for the sand/silt and silt/clay ratios. Thus, the textural variation is more than a simple reciprocal relationship of silt and clay or sand and clay. The proportion of clay which is generally considerably higher in lower tills may account for much of the difference in clastic ratios. The clay content of upper till in the Belchertown area generally consists of finely ground quartz in the coarse clay (8-9$\phi$) size range indicative of rock flour. The clay size population of lower till probably contains finer particle sizes and a larger proportion of clay minerals. Thus, it would seem as if analysis of the clay fraction of upper and lower till could provide useful data that may account for many differences in the two tills as well as provide evidence of genesis.

In comparing data from analyses of tills from different localities, the writer assumes that similar methods of analysis were followed. If the analytical techniques vary significantly, then the noted variations or similarities may be as much a product of different methods of analysis as of properties of the tills. If the tills are not properly disaggregated, or a wet type of analysis is not performed, then aggregates of finer sizes are retained on larger opening screens and give erroneously high results for the coarse friction. The writer compared wet and dry sieving techniques on several control samples and found that wet sieving decreased the sand fraction by 30-40%. Similar results for upper and lower tills which can be separated into distinct fields on a ternary diagram suggest that similar methods of analysis were employed and that the results of these different analyses are comparable.

## Hypotheses to Account for the Characteristics Of Upper and Lower Tills of New England

Two texturally distinct tills are reported from many areas of New England (Flint, 1930, 1961; Denny, 1958; Pessl, 1968, 1970; Campbell, 1975; Judson, 1949). Since Pleistocene glacial erosion didn't remove more than a few meters of bedrock from the New England Uplands, these two texturally distinct tills were derived from the same bedrock terrain by one or more glaciers which advanced across New England.

Where till sheets of different glaciations overlie one another in the midwestern United States, the younger tills are progressively finer grained than underlying older tills from which they were derived. The "shielding" of bedrock by older drift and the reworking of older drift by progressively younger glaciers presumably accounts for this characteristic. If the two tills of New England are the products of two distinct glaciations, then the reverse of the situation in the Midwest is encountered; upper till is considerably coarser grained than lower till. This is not surprising, as the relief in New England must have greatly reduced the effect of shielding bedrock.

Several working hypotheses are suggested as to why two texturally distinct tills occur in any one area of New England and why each of these two tills is so texturally consistent throughout the region.

A long interval of preglacial weathering under a similar climate throughout New England would minimize the influence of various lithologies on soil development and lead to the development of a very similar, somewhat homogeneous soil. If the earliest Pleistocene glacier advanced over a thick, mature, preglacial soil in New England, incorporation of such a clayey, silty loam could have led to deposition of a clayey, silty till such as the lower till. The relative scarcity of stones and sand in the lower till suggest chemical alteration of granular, feldspar-rich crystalline rocks and development of a clayey, silty soil during a long period of preglacial weathering. Thick saprolite in the southern Appalachians indicates a lengthy period of intense chemical weathering in that area and suggests that similar saprolite may have developed in preglacial time in areas which were subsequently glaciated. A saprolite in the southeastern Adirondack region of New York is described by Muller (1965). Till extending down into seams in deeply weathered rock (weathered to 10 to 15 feet) in New Hampshire suggests a lengthy period of preglacial weathering (Goldthwait and Kruger, 1938). Quartz/feldspar ratios from lower till in Willimantic, Connecticut (Clebnik, in preparation) are higher than those for upper till from the same area. The lower feldspar content in lower till may be the result of chemical alteration of the feldspar in a lengthy period of preglacial weathering. Thick, kaolin-rich preglacial soil in Hampshire County (Emerson, 1898) and a possible preglacial soil in the Knights Pond basin suggest that such soils may have been widespread in the uplands in preglacial time. Only remnants of this once-continuous regolith are now preserved because of favorable location. The relative homogeneity of lower till in New England suggests that such a thick saprolite may have been incorporated into an early Pleistocene glacier which passed over New England and deposited the lower till.

The texture and composition of upper till correlate much more closely with the bedrock which it overlies. Three facies of lithologically controlled upper till in central Massachusetts have been mapped in the nearby Mt. Tom and Northfield quadrangles (Larsen, 1972; Campbell, 1975) and the Belchertown quadrangle indicating that the last glacier which deposited this till either (1) had direct contact with local bedrock, or (2) incorporated a thin, quartzo-feldspathic regolith produced principally by physical weathering. Sand and coarse silt represent the terminal product of mechanical disintegration of granular rocks, whereas clay is the ultimate product of chemical decomposition of unstable minerals in soils (Folk, 1968). In situ, largely mechanical disintegration of generally coarse-grained, granular cyrstalline bedrock such as occurs in the New England Upland will produce a clay-poor quartzo-feldspathic regolith. Given sufficient time and appropriate climatic and chemical environment, feldspars will alter to clay. Assimilation of granular quartzo-feldspathic regolith along with mechanical abrasion during glacial transport may explain the large proportion of fine sand and coarse silt in the matrix of upper till. Dreimanis and Vagners (1971) report that quartz and feldspar have a "terminal grade" in the fine sand and coarse silt sizes as a result of attrition during glacial transport.

Three facies of upper till in the Belchertown quadrangle and Larsen's (1972) three facies of upper till derived from the East Berlin Formation, the Holyoke diabase and the Portland Arkose in the Mt. Tom quadrangle support the hypothesis that the lithologic composition of upper till is controlled by the local bedrock. Since the source rock for most upper tills is coarse-grained crystalline or sedimentary rocks, it is not surprising that most upper tills fall within a restricted range on a ternary diagram of sand-silt-clay. However, upper tills derived from fine-grained rocks will fall slightly outside this field, as shown by till resting above mud-rich Sugarloaf arkose in the Belchertown quadrangle and till derived from the mud-rich East Berlin formation in the Mt. Tom quadrangle. X-ray analysis of the clay sized fraction indicates that this fraction of upper till from New Hampshire (Drake, 1971) and the 8 and 9 $\phi$ fraction from the Belchertown area is largely quartz and feldspar--rock flour rather than clay minerals. This also supports the hypothesis of mechanical disintegration and abrasion of phaneritic granitic gneisses for the textural control of upper till.

The restricted range of grain sizes in the matrix of upper till may reflect a source in stratified drift deposited during an earlier glaciation. The scarcity of mud in upper till may have resulted from the selective removal of this fraction during earlier fluvial transport. The number of subrounded to rounded clasts in upper till in the Belchertown area could have resulted from incorporation of stones which had been rounded during earlier fluvial transport during either Pleistocene or Triassic time.

Two texturally distinct superposed tills at any one locality in New England have been interpreted as the product of one glaciation. Denny (1958), following Upham (1878), interpreted two texturally distinct superposed tills from the Canaan, New Hampshire area as lodgment and ablation deposits of a single glacier. Number and angularity of clasts, scarcity of striated clasts, poorly developed stratification, lenses of bedded sand, and concentration of boulders on the surface led Denny to interpret the loose, sandy upper till at this locality as an ablation facies. This coarse, gravelly till was never found directly above bedrock, and was always stratigraphically superposed on a compact, fissile, sparsely stony till which Denny called the subglacial or lodgment facies. Denny's descriptions and illustrations suggest the possibility that some of his ablation till may be a flowtill and, therefore, derived from superglacial debris. Drake (1971) "washed" some of his "hard" till in a rotating drum and produced a grain size distribution closely paralleling that of his "soft" till. Texture, fabric, clast shape and structure were used to interpret the "soft till" and the "hard till" as ablation, and lodgment tills, respectively. Pessl, Shafer and Koteff have interpreted Drake's two tills as lodgment and ablation facies of upper till similar to those in Connecticut.

Lenses of sorted and stratified sand in the upper till in the Belchertown area and in western Connecticut, and poorly developed stratification with included bedding in the upper till in the Canaan, New Hampshire area attest to the role of water in the deposition of the youngest till at each locality. The distinction between ablation till and till which has been at least partly influenced by melt water during or before final deposition is not clear. Deposition of till late in the glacial cycle (Goldthwait, 1971) and largely from melting stagnant ice (Boulton, 1972) may account for the similarity between these two glacigenic sediments.

Assuming that most "upper tills" in New England are correlative, as the ternary diagrams of Figs. 5, 8 and 9 suggest, the textural similarity reflects greater control than by random winnowing during deglaciation. The control of texture and composition by local bedrock indicates that the ice was in contact with bedrock and that the textural control is due largely to source materials and glacial processes.

Pessl and Shafer (1968) interpreted the loose, stony, friable, sandy upper till and the highly weathered, jointed, fissile, compact, sparsely stony lower till of western Connecticut as deposits of two distinct glaciations. Differences in fabric, depth of weathering and structure, truncation of lower till structures at the upper till contact, inclusions of lower till in the base of upper till, and the sharp contact of the two tills led them to this interpretation. They suggest that the upper tills may be Woodfordian and the lower till Altonian in age.

In the Belchertown quadrangle, upper till rests on bedrock (in places striated) and at one locality is found superposed on lower till. At the Harkness Road locality, fresh upper till rests on deeply weathered lower till. This evidence supports Pessl and Shafer's (1968) interpretation of upper and lower tills as deposits of separate glaciations.

Pessl and Shafer (1968) hypothesize that upper till may consist of subglacial and superglacial facies. Pessl (1971) recognized three units in a thick section of upper till at his Bakersville Brook locality. The uppermost unit he interpreted as an ablation facies; the basal unit he called the lodgment facies; and the middle unit he interpreted as a subglacial facies analogous with the subglacial ablation till of Elson (1961). The middle unit might also be called a melt out till (Boulton, 1970). Drake (1971) studied many characteristics of "soft" and "hard" tills in east central New Hampshire and concluded that they represented lodgment and ablation till. Subsequent field observation by Shafer, Pessl, Kotef, and Hartshorn led them to interpret Drake's "soft" and "hard" tills as ablation and lodgment facies of upper till. Two to three feet of friable, loose, stony gray till grade down to six to eight feet of more compact, massive, more sparsely stony gray till in an exposure along Gulf Road near the Pelham Country Club. Pessl (personal communication) observed this exposure and agreed with the writer that a lodgment and ablation facies of upper till may be exposed at the Gulf Road locality. Thus, the interpretation of the origin of textural variations in tills at any one locality becomes difficult, and this difficulty is compounded when comparing and interpreting tills from different localities.

The writer suggests that it may be time to restrict the use of the terms upper and lower till except as field terms in any one locality. Through usage, these two terms have come to imply an unestablished regional stratigraphic correlation and synthesis which only continued detailed mapping can confirm. Thus, the younger of two tills in many localities in New England may not be the same unit. Perhaps it is time to adopt the procedure used successfully in the Midwest where tills are thoroughly described and given formation names. Although problems of correlation are then introduced, this procedure will require that more detailed analyses and careful comparison of tills from area to area be employed. Local bedrock controlled variations in extensive, contemporaneous units can then be recognized such that correlative tills may be recognized and the problems of synthesis and interpretation of Pleistocene glaciation in New England may be clarified. Such a procedure should be helpful in determining whether thick till at any locality is the product of depositional processes, or whether some of the observed stratigraphy may have resulted from "stacking" of till (Moran, 1971).

## Age of the Tills

The age of tills in New England is controversial. If "upper" and "lower" tills from many localities are equivalent, then upper till is latest Wisconsin; i.e., Woodfordian (Frye and Willman, 1963). Proponents of the single glaciation hypothesis would interpret lower till as the basal, lodgment facies of the Woodfordian glacier. The writer agrees with Pessl and Shafer (1968) and Pessl and Koteff (1970) that upper and lower till are the products of two separate glaciations, and, for lack of definitive evidence, supports their contention that they are Altonian and Woodfordian in age. Caldwell (1959) obtained a date of greater than 38,000 years B.P. from an organic zone between two tills at New Sharon, Maine. A subsequent date and analysis of wood from that site (Borns and Calkin, 1970) indicates that a glacier overrode a green tree more than 52,000 years ago B.P. Thus, at New Sharon, Maine, the exposed lower till is no younger than Altonian. Borns and Calkin (1970) report two tills of probable Wisconsinan age at several localities in northwestern Maine, and interpret these as lodgment deposits of at least two glaciations. Shilts (1970) describes three tills in southeastern Quebec which are separated by stratified drift containing datable material. Radiocarbon dates indicate a late Wisconsinan age for Lennoxville till, an Early to Middle Wisconsinan age for Chaudier till, and an earliest Wisconsinan age for Johnville till.

If lower till has been derived from a preglacial saprolite, then the glacier which deposited lower till was either the first Pleistocene glacier to advance across New England, or a glacier which assimilated and deposited an earlier drift derived from the preglacial saprolite. No exposures are known from New England where three, superposed, distinct tills are separated by deposits indicating that a lengthy, warm climate intervened between deposition of each till. The two glaciation hypothesis is thus favored. If lower till is Altonian in age, either the record of earlier Pleistocene glaciation in New England has been effaced, or, in contrast to the midwestern United States, New England was not glaciated prior to the Wisconsinan stage. Warren's (1971) evidence for an Illinoian age of lower till is equivocal. The writer suggests that Kaye's (1964b) interpretation of the age of drifts on Martha's Vineyard needs further study. Faulting and the absence of the required number of deeply weathered horizons suggest that marginal oscillations of two Wisconsinan glaciers could have produced the observed features and deposits. The failure to find unequivocal pre-Wisconsinan drift in New England supports this hypothesis.

Since upper till of the Belchertown quadrangle is correlative with upper till of Connecticut (Pessl and Shafer, 1968; Pessl, 1971) and New Hampshire (Pessl and Koteff, 1970), its age is considered as latest Wisconsinan and probably Woodfordian. Lower till which is tentatively correlated with lower till elsewhere in New England is thus earlier Wisconsinan, and probably Altonian. There is no evidence in the Belchertown quadrangle to support an Illinoian or older age for these tills.

Drumlin till in the Belchertown quadrangle is of uncertain age but is most likely Wisconsinan. Texturally, drumlin till resembles lower till more than upper till. Drumlin till is massive and lacks the fissility, jointing and parting of lower till. Its color is such as to overwhelm any staining by oxides of iron and manganese as is common in upland lower till. The texture and stone content of drumlin till suggest that this till is a facies of lower till derived from redbeds of the Connecticut Valley. Alternatively, drumlin till may be latest Wisconsinan, deposited by a glacier which incorporated red glaciolacustrine sediments from an earlier glaciation that were ultimately derived from the mud-rich Triassic rocks. Occurrence of this till in lowlands of the Connecticut Valley in a topographic setting where red, lacustrine sediments might have been deposited supports this hypothesis. Nowhere was upper till found to overlie drumlin till, thus supporting a latest Wisconsinan or Woodfordian age. The northwest orientation of the long axes of drumlins composed of this till agrees with the orientation of streamline ridges and striae suggesting deposition by the youngest or Woodfordian glacier.

# STRATIFIED DRIFT

Sediment deposited in flowing or standing water derived from melting glacial ice is called stratified drift. Generally sorted and stratified sand and gravel deposited by melt water streams is called glaciofluvial stratified drift. Generally well sorted and stratified and often laminated fine sand, silt and clay deposited in standing water of lakes and ponds fed by melting ice or melt water streams is called glaciolacustrine stratified drift. Glaciofluvial and glaciolacustrine stratified drift can be grouped into two broad genetic types distinguished on the abundance of stagnant or detached ice in the environment in which each is deposited. Proglacial stratified drift is deposited in streams and lakes beyond the margin of a glacier but derives its sediment from a melting glacier. Proglacial stratified drift grades into sediment which is deposited on or against decaying ice and which is called ice contact stratified drift. While proglacial and ice contact stratified drift are deposited largely during deglaciation, the latter indicates that downwasting as well as backwasting were significant ablation processes. Stagnant ice may form: (1) one valley wall against which stratified drift is deposited, (2) a superglacial basin receiving water or mass transported detritus, or (3) the walls of a narrow linear valley within or beneath ice in which sand and gravel are deposited. Much of the topography in and along the lowlands of the Belchertown quadrangle is composed of proglacial and ice contact stratified drift that can be further classified on the basis of the landform in which it occurs.

Characteristics of Stratified Drift

The nature of retreat of a glacier can in part be interpreted by the character of the stratified drift which records the deglacial process. The location, nature, and extent of the melting ice margin is recorded by the landforms and sediments indicative of the sedimentary environments which existed at the time of deglaciation. Whether stratified drift was deposited in lakes or streams near a retreating active or stagnant glacial margin or well beyond the margin, can often be interpreted from the remaining landforms and sediments. The depositional processes in lakes and streams which are in contact with ice or well beyond are very similar, but the distinction between these two environments is based on landform and the character of the sediments and post-depositional changes induced by melting ice.

Glaciofluvial stratified drift, whether ice contact or proglacial, exhibits many similarities in sedimentary characteristics. These sediments are deposited in similar sedimentary environments which consist of a broad apron of braided melt water streams either adjacent to or down valley from a melting glacier. Thus, the sedimentary characteristics of the sediments deposited on these broad alluvial fans are similar. At their proximal ends, these fans generally consist of very coarse cobble and boulder gravel with a minor amount of sand as matrix (McDonald and Banerjee, 1971; Bradley, et al, 1972; Boothroyd, 1972). Large subangular to subrounded clasts oriented with their long axes normal to the direction of current flow and with a-b planes dipping upcurrent, are characteristic of the upper outwash fan of the Scott glacier in southeastern Alaska (Boothroyd, 1972). Moving down fan, the slopes, clast size, and percentage of clasts in the Scott outwash decreases. Gravel is deposited under upper flow regime conditions in both channels and on interchannel longitudinal bars in upper fan areas, but is concentrated on bar surfaces in midfan areas where shallow depth of water produces upper flow regime conditions. The percentage of sand increases in outwash down fan where it occurs as plane bedded or planar cross-bedded, sorted sand in transverse bars. Several facies of braided glaciofluvial deposits can be seen in Fig 10, a cross-section through typical sediment of a kame terrace in the Belchertown quadrangle. A similar progression from poorly sorted cobble gravel to well sorted and planar cross-bedded sand several miles downcurrent can be seen in the Belchertown quadrangle from the head of outwash north of Lake Holland downcurrent in the direction of Forge Pond. The slope of this outwash fan decreases in a manner similar to that described by Boothroyd (1972), Gustavson (1972), Bradley, et al (1972) and McDonald and Banerjee (1971). The percentage of sand and gravel and the sedimentary structures in glaciofluvial stratified drift vary depending upon the characteristics of the environment of deposition.

The distinction between proglacial and ice contact glaciofluvial sediments is based on modification of the original sedimentary characteristics by the melting of detached or stagnant ice masses beneath,

adjacent to, or within the sediments. Stagnant ice which formed one wall of a valley in which glacioflucial sediments were deposited may be reflected as a scarp at the edge of a kame terrace similar to many seen in the area. This scarp may be modified by postglacial mass movement. The upper surface of a kame terrace commonly contains kettles such as those that are seen 6/10 of a mile southeast of Dwight along Route 9. Exposures in ice contact stratified drift often reveal non-tectonic structures which have resulted from melting out of confining or supporting masses of glacial ice. Flowtill interbedded with or capping such masses of ice contact stratified drift is common and indicates the presence of a nearby mass of stagnant ice from which debris flowed.
In summary, proglacial glaciofluvial sediments can be distinguished from ice contact glaciofluvial deposits on the basis of: (1) a terrace scarp, (2) abundance of kettles, (3) internal structures produced by the collapse of metling of confining ice, and (4) flowtill.

The nature of glaciolacustrine stratified drift is a function of the available energy in the environment of deposition. The ertrance of a melt water stream into a lake is marked by a significant reduction in energy and deposition of coarse sand and gravel in the form of a delta. Glaciolacustrine deltas consist of two elements: (1) sand and gravel deposited by melt water streams as an extension of the fluvial plain and which are known as topset beds (or delta plain), and (2) steeply dipping beds formed by the avalanching of sand down the edge of the delta toward the lake bottom. The latter beds are known as the foreset beds (prodelta slope). Shoreward deposits (Jahns and Willard, 1942) include sand and gravel deposited on beaches and as spits, bars, deltas, and bottom sediment in shallow water. Several relict Pleistocene deltas which are shown on Plate 1 record the levels of lakes dammed by melting glacial ice during deglaciation.

Rhythmic laminated couplets of silt and clay which are deposited in low energy, deep waters of glacial lakes are known as rhythmites and have been interpreted as annual deposits or varves (Emerson, 1898; deGeer, 1912). Ashley (1972) and Gustavson (1972) have shown that the silt and fine sand of rhythmites are deposited from the traction and suspended loads of density underflows during the melting or summer season. The clay unit in a varve is deposited from suspension during the season of greatly reduced inflow of sediment or winter. A turbidity current origin for glaciolacustrine varves was earlier proposed by Emerson (1898), deGeer (1912) and Kuenen (1951). Ashley (1972) confirmed the turbidite origin for glaciolacustrine varves in glacial Lake Hitchcock and classified varves into three groups based on the relative thickness of silt and clay units. Varves of group 1 have clay thickness greater than silt thickness; those of group 2 have clay thickness approximately equal to that of silt thickness; and those of group 3 have a clay thickness less than silt thickness. The silt (summer) unit of group 3 varves was found to consist of several graded laminae whereas the clay (winter) units are graded continuously from bottom to top. She further showed that the distribution of group 1, 2 and 3 varves is a function of distance from a source of inflowing detritus. Group 3 varves occur near large deltas where underflows during the melt season contribute a significant amount of silt and fine sand to the lake bottom. Group 1 varves are deposited in low energy lacustrine environments very far from the mouth of glacial melt water streams where little silt is received. Gustavson (1972) and Ashley (1972) have shown that the proportion of silt and sand to clay greatly increases from distal varves to proximal varves as a reflection of proximity to sediment source. Cyclic sequences of bedforms composed of graded sand and silt on the prodelta slope grade into proximal varves on the lake bottom and represent cyclic current deposition, perhaps on an annual cycle (Gustavson, et al, 1975). Group 2 and 3 varves occur in the Lawrence Swamp basin and were deposited in late Wisconsinan glacial Lake Hitchcock.

Proglacial glaciolacustrine deposits may be distinguished from ice contact glaciolacustrine deposits by the same criteria used for the distinction of proglacial and ice contact glaciofluvial sediment. The only exception is that a terrace scarp which is common at the edges of ice contact terraces of glaciofluvial stratified drift is not commonly observed along the margins of ice contact glaciolacustrine deposits except for deltas deposited in contact with melting glacial ice. Most ice contact glaciolacustrine stratified drift in the Belchertown quadrangle consists of deltas in which collapse structures are present. Collapsed, laminated, glaciolacustrine sand and silt with some interbedded flowtill occurs in a few localities.

Several feet of well sorted, fine and medium sand which overlie the varves in the Lawrence Swamp basin were deposited in the shallow water of a short-lived, late-glacial lake, Lake Lawrence.

Isolated, small deposits of laminated silt and clay with some fine sand which are several feet thick are interbedded with glaciofluvial sand and gravel at several localities in the Belchertown quadrangle. These sediments were deposited in local, isolated kettle ponds in environments where glaciofluvial sedimentation was dominant.

Since glaciofluvial ice contact stratified drift is deposited in many environments on, in, under or against stagnant glacial ice, it is further classified as to the landform in which it occurs. The landform often reveals the character of the environment and the proximity to an ice margin in which the glaciofluvial ice contact stratified drift was deposited. Landforms composed of ice contact glaciofluvial stratified drift in the area include channel fillings, kame terraces, and kame deltas.

## Landforms Composed of Glaciofluvial Ice Contact Stratified Drift

### Ice Channel Fillings

Ice channel fillings are linear ridges of sand and gravel deposited in melt water streams confined by stagnant ice. Eskers are a generally curvilinear type of ice channel filling deposited in ice-walled tunnels by subglacial or englacial streams. Crevasse fillings are linear ridges of sand and gravel deposited in large fractures (or crevasses) open to the sky. All linear ridges of sand and gravel in the Belchertown Quadrangle are mapped as channel fillings becuase it was not possible to determine whether they were deposited in confined tunnels in or under the ice, or in fractures open to the sky (Jahns, 1953). Longitudinal exposures in ice channel fillings reveal the typical sedimentary structures of glaciofluvial deposits discussed earlier, sometimes with collapse present. Cross-sections often reveal a pseudo-anticlinal bedding produced by normal faulting and collapse of marginal sediments formerly in contact with ice.

The valleys of Jabish and Broad Brooks contain several ice channel fillings (Plate 1) which indicate the crevassed and "porous" nature of stagnant ice during deglaciation. Very coarse cobble and boulder gravel is exposed in a roadcut in a steep sided ridge at the intersection of Jenson and Johnson Streets. This arcuate ridge has an uneven, hummocky crestline which is due in part to collapse. Deposition of the gravel between confining walls of ice occurred before the surrounding finer textured sand and gravel was deposited at lower elevation.

The sinuous, linear, hummocky ridges along the western edge of the valley of Broad Brook between Turkey Hill and Springfield Roads are composed of ice contact stratified drift. The topography indicates that sedimentation began in a channel confined by walls of stagnant ice. An ice channel filling one-half mile farther southeast continues this alignment at an elevation which suggests synchronous deposition along a downstream stretch of this same melt water stream. With westward melting of stagnant ice, glaciofluvial sediments were deposited between the ridge and the valley wall and up to the level of the crest of the channel filling. Thus, the landform was probably initiated as a channel filling which subsequent deposition changed to a kame terrace. Alternatively, the irregular edge of the kame terrace could have resulted from deposition of sediment on and into a highly embayed, irregular mass of stagnant ice. In either case, a mass of stagnant glacial ice controlled melt water drainage in the valley of Broad Brook.

Exposures in a ridge of coarse cobble gravel in a borrow pit near the Belchertown village water supply pumphouse indicate collapse of the sediment in contact with melting glacial ice. The attitude of bedding changes from horizontal to nearly vertical in a width of 10 feet as shown on Fig 11.

The southeast-trending ice channel filling 0.2 miles west of Routes 202 and 21 was deposited in a tunnel beneath stagnant ice as an esker. The edge of the ice beneath which the stream flowed is shown by an ice contact slope just south of this ridge at the northern end of a kettled and boulder strewn outwash plain. Route 202 runs approximately parallel with and a few hundred feet south of this ice contact slope.

The ice channel filling 300 feet north of Jabish Brook and Aldrich Street was deposited into a linear opening (possibly an enlarged crevasse) in stagnant ice which lay in that valley.

The channel fillings near Knights Pond (Plate 1) and the coarse glaciofluvial sandy pebble gravel in this basin indicate that this depression was occupied by stagnant ice onto and beneath which stratified drift was deposited. Although no bedding was exposed in the north-trending channel filling, surface boulders at the south end and a progression from coarse sand and gravel at the south end to fine sand at the northern end indicate northward drainage of the melt water stream that deposited this sediment. Alden (1924), following Emerson (1898), interpreted this basin fill as lacustrine sand deposited while ice was still present in this upland basin.

Other ice channel fillings occur in the valley of Jabish Brook between Route 21 and Allen Street, 0.2 miles west of Hamilton Street, and northwest of Scarboro Pond.

### Kame Terraces

Terraces composed of stratified drift which was deposited between a valley wall and a mass of stagnant ice are called kame terraces (see Flint, 1971). These generally flat-topped masses of sand and gravel were deposited by streams flowing in temporary valleys between the receding glacier and a rock wall. The presence of ice during deposition is indicated by kettles, included flowtill, collapse structures, and ice contact slopes on the valley margins. Streams which deposited these sediments were graded to baselevels controlled largely by stagnant ice and which were higher than the present ones.

Many kame terraces in the Belchertown quadrangle (Plate 1) terminate in deltas indicating that the melt water streams which deposited the sediments were graded to standing bodies of water. Figure 12 illustrates such an environment of deposition where an ice marginal stream is building a modern delta as it enters Lituya Bay adjacent to the Crillon glacier in southeastern Alaska. Recession of this glacier will leave a terrace of sand and gravel terminating in a delta much like those in the Belchertown area. The elevation of the contact between the topset beds (glaciofluvial delta plain) and the foreset beds (lacustrine prodelta slope) indicates the approximate elevation of the lake into which such a melt water stream flowed. Deltas occur at the ends of kame terraces: (1) on Barton Street near Route 202, (2) on Gulf Road near Dwight Cemetery, (3) about 1000 feet east of the intersection of Allen Street and Route 202, (4) on Warren Wright Road between North Street and the Central Vermont railroad tracks, and (5) on Wilson Street west of the hamlet of Dwight. A complex of deltas, actually many delta lobes, occurs along the western edge of the kame terrace which borders the Connecticut Valley Lowland north of Station Road. With recession of the ice northward, the point of entry of these melt water streams into standing water slowly shifted farther and farther north. Each major point of discharge of melt water into this ice margin is now the axis of a lobe of a delta. Thus, a succession of progressively younger delta lobes was built into a northward expanding lake whose margin was controlled by ice. Many of the melt water streams which deposited kame terraces in the Belchertown quadrangle drained southward out of the quadrangle and were tributaries of the Chicopee River at the end of which is a very large delta. Westover Air Force Base is located on the delta plain of this delta in Lake Hitchcock.

Where deglaciation is largely by stagnation zone retreat, kame terraces can be used to interpret a relative history of ice thinning and retreat. Following Jahns (1953), a chronology of melt water drainage can be deduced by interpreting decreasing elevations of successive kame terraces and/or changes of outlets as indications of progressive thinning and melting of stagnant ice in lowland areas. Such a chronology of melt water drainage is given later in this report.

The ice contact glaciofluvial sediments in the kame terraces are sand and gravel, with minor amounts of interbedded silt and clay and some flowtill. The gravel is very poorly stratified pebble and cobble gravel usually in a matrix of fine to medium sand typical of interchannel longitudinal bars in a braided stream. Clasts are generally subrounded to rounded, sub-spherical to bladed (Zingg, 1935). Elongate stones are imbricate with a-b planes dipping upstream and with long axes normal to current direction. Plane bedded and planar cross bedded sand is commonly interbedded in these deposits and is typical for braided stream deposits (Fig. 10). Interbedded sands are much better sorted, and are commonly in the range of fine to medium sand. Most kame terrace deposits contain a sufficient amount of fine sand and silt so as to be classified as well graded (Unified Soil Classification--see Plate 1). Cut and fill, and some collapse structures occur in these ice contact deposits. Locally, lenses of laminated fine sand and silt with some clay represent kettle pond fillings.

## Flowtill

Flowtill is present in several areas in the Belchertown quadrangle (Plate 1), but no distinct characteristic landforms are attributable solely to flowtill. Flowtill commonly occurs as lenses or beds of poorly sorted, till-like sediment which is either interbedded with or caps stratified drift. Thick accumulations of superglacial debris which have flowed into low spots on stagnant ice may form characteristic topographic forms upon melting of the underlying ice (Gravenor and Kupsch, 1959). While no such landforms are recognized in the Belchertown quadrangle, the flat topped character of two ridges in the area are attributed to a capping layer of flowtill. One of these is a flat-topped ridge at 460 feet elevation which occurs on the east side of the Central Vermont Railroad tracks approximately 0.4 mile north of the Jackson Street crossing. Triassic "red" extremely compact, sparsely stony, vesicular clayey silt overlies upper till. As this deposit occurs in a terrain of crystalline bedrock, this material must have flowed from a mass of nearby stagnant ice and could not be a colluvial deposit from adjacent soil or rock. There is no drift of this character immediately adjacent to this flat-topped ridge. The second ridge occurs on the south side of U. S. Route 202 approximately 0.2 mile west of Barton Street. A somewhat streamlined, oval shaped, nearly flat-topped ridge with a crest elevation of 410 feet is capped by till of a peculiar character. Several holes dug in this material indicate that it is a gray sandy till with interbedded laminae of silt and fine sand. It is suggested that during deglaciation of this immediate area, the top of this streamlined ridge became ice free and was surrounded by slightly higher stagnant ice. Highly fluid superglacial debris flowed into this low and came to rest as a nearly flat surface which now forms the top of this ridge.

These two occurrences suggest: (1) flowtill may add the finishing touches to a topographic form of other origin, and (2) flowtill where it is distinct from the local till and clearly not derived from local material can be recognized where it overlies till.

Deltas

Deltas form at the confluence of a stream and a standing body of water and generally have a distinctive, nearly flat-topped triangular plan. Most deltas in the Belchertown quadrangle occur at the downstream ends of kame terraces and mark the point of discharge of melt water streams into proglacial lakes as discussed above. Deltas built onto or against glacial ice and which later partially collapse are called kame deltas. Most of the deltas in the Belchertown quadrangle were built at least in part against ice, but few collapse structures were observed--partly because of a lack of good exposures. Deltas with kettles in the delta plain indicate the presence of ice in the immediate vicinity during deposition. Such deltas occur near Dwight Cemetery and west of the intersection of Harkness and Belchertown Roads in Amherst. These deltas were initially deposited in contact with ice, but lost contact with ice during the expansion of lakes into which they were deposited.

The delta on Wilson Street, and the several delta lobes north of Station Road were built into Lake Hitchcock, a large, late-glacial lake in the Connecticut Valley which was dammed by drift at Rocky Hill, Connecticut.

The Warren Wright Road and Wilson Street deltas display the characteristic landform for which these deposits are named.

Head of Outwash

A morphologically distinctive mass of stratified drift formed by deposition in contact with ice and which grades into valley train deposits is called a head of outwash (Flint, 1971). Swell and swale topography of moderate relief often with an ice contact proximal slope and numerous kettles are characteristic of such a deposit. The collapsed and highly kettled valley plug at an altitude of 350 feet north of Lake Holland is a head of outwash.

Landforms Composed of Proglacial
Glaciofluvial Stratified Drift

Valley Train

Stratified drift which fills a valley from wall to wall and which is deposited by melt water streams discharging from a glacier upvalley is called valley train. It is transitional upvalley into a head of outwash. From a head of outwash north of Lake Holland, melt water streams drained south and thence southwest along the present valley of Bachelor Brook depositing sand and gravel which now forms extensive valley train deposits. These deposits range from collapsed, coarse pebble gravel with interbedded, collapsed, lacustrine silt, sand and flowtill near the ice contact to well sorted sand with minor amounts of interbedded gravel several miles downstream near Granby High School. The gradation in slope, texture, and depositional environments of a fan of glaciofluvial deposits is discussed earlier. Lake Holland along with Arcadia and Metacomet Lakes are kettle ponds in this valley train formed by collapse of sediment into positions formerly occupied by detached masses of stagnant ice. A series of smaller kettles occur near St. Hyacinths Seminary and College in Granby.

## Landforms Composed of Glaciolacustrine Stratified Drift

Landforms composed of glaciolacustrine stratified drift are controlled by the texture of the deposits and include deltas, beaches, spits and bars, and lake plain. Deltas are triangular shaped, generally flat-topped deposits of sand and gravel with a fairly steep edge that approximately corresponds with the foreset beds or prodelta slope. The sedimentology and location of glaciolacustrine deltas was discussed earlier. Spits and bars are generally elongate ridges composed of moderate to well sorted sand that was deposited by the action of shallow currents and waves. Beaches are gently sloping benches that may be both erosional and depositional in origin. Waves in shallow water may erode a notch in headlands while building a gently sloping, moderately well sorted deposit of sand and/or gravel in embayments. The texture of beach deposits is a function of available sediment supply and energy generated by waves and currents in shallow water. The embayment of Lake Hitchcock which was present in the Belchertown quadrangle in latest Wisconsinan time was a sedimentary environment of low energy. The shoreline of this lake is recorded by poorly developed erosional notches in the topography. Other than deltas, no beach sediments are clearly recognizable in the area. Shoreward deposits in the Belchertown quadrangle consist chiefly of sloping masses of sand built into lakes as part of a kame terrace. No spits or bars were recognized in the area.

## LATE-GLACIAL & POSTGLACIAL DEPOSITS

### Eolian Mantle

Pitted, polished, and fluted stones in silty fine sand and fine sandy silt that caps the drift in eastern Massachusetts were interpreted as eolian by Woodworth (1894) who called them glyptoliths. He originally interpreted the sediment containing these glyptoliths as an eolian deposit (Woodworth, 1899), but after finding this deposit over much of New England, decided that it was a loose till deposited by the last glacier (Woodworth and Wigglesworth, 1934). Clasts in this deposit were presumably moved upward from underlying drift by intense frost action during a late Pleistocene periglacial climate in southern New England (Bryan, 1932). Once in the upper sand and silt, they were modified by the wind to form ventifacts. Further evidence of late glacial eolian activity in Massachusetts is afforded by stabilized dunes and wind abraded bedrock to the south in the Connecticut Valley (Hartshorn, 1962).

A deposit of silt and very fine sand containing a few to many largely angular clasts of varying size mantles the glacial deposits in the Belchertown quadrangle. The thickness of this ubiquitous deposit ranges from a few inches to several feet at changes of slope, but averages between 6 and 18 inches. It occurs on slopes, uplands, and in valley bottoms with no consistent pattern of thickness. The deposit is totally oxidized except where it exceeds three feet in thickness. Without this unit, the agricultural potential of the area would be considerably lower. Following Hartshorn, this deposit is termed the eolian mantle.

Boulders up to three feet in diameter are exposed in and atop a soil horizon composed of silty, very fine sand in a borrow pit on Allen Street (Plate 1). Thirty to forty feet of very well sorted and bedded fine and fine to medium sand with no interbedded gravel underlies this soil. At this site, derivation of the boulders from the underlying drift is an impossibility. Boulders on the surface of this deposit and in the upper three feet must have been derived from a nearby ice mass. The matrix of this soil is largely of eolian origin.

Clast fabric is present in the loam overlying many glaciofluvial gravel deposits. Either frost action was not active at such localities, or the loam is derived from soil forming processes and is not eolian sediment. During frost heaving, any original clast fabric would be destroyed (Black, personal communication).

Alluvium

Sediment deposited by modern streams is mapped as alluvium. It occurs on the floodplains of the Fort River and other modern streams. Each sedimentation unit of alluvium is moderate to well sorted, but superposition of sedimentation units which have been deposited under different conditions of discharge and sediment load give alluvium an overall poorly sorted character. Many streams in the Belchertown quadrangle have swamps along their floodplains. Peat, muck, and organic matter constitute a part of the alluvium in these areas, but such deposits are not separately designated on Plate 1. Abandoned channel segments of the Fort River which contain peat and muck stand out on aerial photographs as sinuous, linear swamps.

Alluvium consists largely of silt and sand with minor amounts of rounded water worn gravel. Laminae in alluvium are readily visible because of the color contrast between brown organic-rich sand and silt and gray non-organic sediment.

Stream Terrace

A marginal bench higher than the present floodplain in a valley is a terrace. A terrace composed of alluvium indicates that a former floodplain has been incised due to uplift, a change in discharge, or a change in base level of the stream in the valley. The alluvial terrace along the Fort River (Plate 1) probably reflects a change in its base level. The sediment in this terrace is mostly sand and silt similar to that observed in the present floodplain of the Fort River.

Artificial Fill

Artificial fill is mapped in areas which have been extensively filled by man. The earth material added to maintain the grade along a road or railroad constitutes artificial fill. Trash fills, such as the sanitary landfills for the towns of Amherst and Belchertown, are separately mapped.

Swamp Deposits

Organic matter intermixed with some silt, clay, and sand accumulates in poorly drained areas and is mapped as swamp deposits. Deposits where peat is known to exceed three feet (as in peat bogs) are separately mapped.

## ECONOMIC RESOURCES

Bedrock

The Holyoke diabase is extensively quarried for road metal along the crest of the Holyoke Range 1.4 miles west of the western boundary of the quadrangle. The Holyoke diabase is continuous with the diabase in the Belchertown quadrangle (Balk, 1957) but no quarrying operations exist in the area in this unit at present. The writer does not know of any which have existed in the historic past.

A small quantity of gneiss has been removed from a now abandoned quarry 0.2 miles northeast of the east end of Kopiac Avenue. The extracted rock was probably used by local residents as building stone.

Tremolite asbestos was quarried during colonial times from a now abandoned, small working near Smith's Pasture. This site is presently frequented by amateur mineral collectors.

Surficial Deposits

Large quantities of sand and gravel have been removed from the many borrow pits in the area (Plate 1). Glaciofluvial stratified drift deposits are generally well graded and good sources of sand and gravel.

Well sorted (poorly graded) sand can generally be obtained from the lower part of the foreset beds of deltas. The occurrence of flowtill, large boulders, lacustrine silt, clay, and fine sand may detract from the suitability of material for borrow. However, suitability for borrow should be evaluated separately as the specifications for aggregate vary with intended use. The presence of a shallow water table may limit the volume of material available for easy extraction. Each site proposed for borrow should receive a careful site study to determine the volume of suitable material available. Glaciofluvial sand and gravel have been successfully used as fill on a variety of construction projects in the area.

Varved clay was once extensively quarried and used for the manufacture of bricks in southeast Amherst as it is today elsewhere in New England. Intermixed clay and brick fragments were seen by the writer and were reported in drilling logs of water wells near Hop Brook and the Central Vermont Railroad tracks in the vicinity of long abandoned clay pits associated with the manufacture of bricks. These pits ceased operation prior to World War II, but were open and used by Antevs (1922) in his classic study of Connecticut Valley varves.

Groundwater is available from wells drilled into bedrock or from most surficial deposits where suitable thicknesses are found. Where upper till is thick enough to give several feet of saturated thickness, 0.5 to 10 GPM have been obtained from dug wells. The yield of wells in upper till is largely a function of texturally-controlled permeability and saturated thickness. Dug and driven wells in stratified drift yield approximately 50 to 250 GPM depending on the saturated thickness penetrated, the overall texture of the deposits, and the extent of development of the well. Wells dug in gravel yield larger quantities of water than those dug in sand. The Town of Amherst obtains much of its water supply from an artesian aquifer underlying Lawrence Swamp. A few tens of feet of varved clay overlie and confine water in several tens of feet of buried sand and gravel from which water is obtained. Some wells drilled into this buried sand and gravel flow freely; the potentiometric surface for the confined water is well above the top of the buried sand and gravel.

The quality of water obtained from wells in surficial deposits is variable. Contamination by septic tanks, road salt, and dry wells, is a common cause of reduced quality in groundwater as the result of man's activities. The total natural iron and manganese content of water in these unconsolidated aquifers often exceeds the maximum limits set by the U. S. Department of Public Health. Test wells drilled into the confined aquifer beneath Lawrence Swamp show a wide range of iron and manganese content. Some test wells yield water of inadequate quality for public consumption, while nearby wells yield potable water with only one-tenth as much iron and managanese. These two constituents (especially the iron) do not constitute a known health hazard when present in water above certain concentrations. However, porcelain fixtures will become stained and water well screens and water pipes will become readily clogged when total iron and manganese exceed 0.3 ppm in groundwater. The well screens in driven wells in the Belchertown Municipal water supplies are periodically cleaned by reverse pumping so as to free the screens of accumulated iron.

The groundwater yield of bedrock wells varies from less than 1 GPM to greater than 50 GPM, with most bedrock wells yielding 2-20 GPM. Variations in yield for bedrock wells probably reflect the size and spacing of intercepted bedrock fractures which contain and channel the movement of the water. The quality of water obtained from bedrock wells is generally good. However, careless contamination of surface water and ground water in surficial deposits could ultimately lead to pollution of water contained in bedrock fractures.

## ENVIRONMENTAL GEOLOGY

### Basic Geological Information

Geological information pursuant to land use planning has recently been termed environmental geology. Environmental geology has focused on effective communication of geological information from geologists, the suppliers of data, to planners, engineers, and resource personnel, the users of geologic data. Hill and Thomas (1972) describe the need for geological information in planning for the use of land and water so as to derive the maximum social benefit with a minimum of environmental degradation. The hazards and constraints to development imposed by geology vary from region to region because of differing geologic environments; but a sound understanding of geologic materials, principles and processes is essential to prudent use and management of the land. The Connecticut Valley Urban Project of the U. S. Geological Survey is compiling and supplementing existing geologic data to produce a series of simple, easy to read, single subject maps which give geologic parameters necessary for effective and efficient land use planning. Plates 2 through 5 are prints of stable base overlays prepared for the Connecticut Valley Urban Project and show different aspects of the geology of the Belchertown quadrangle necessary for effective land use planning. It is emphasized that these maps are intended for reconnaissance level planning only and are intended to show general patterns of geologic information. They are not intended to provide detailed geology at a particular small site. Supplementary test drilling, geologic and/or geophysical investigation will be required to assess site geologic conditions.

Geologic information useful for planning and management of the environment in the Belchertown quadrangle falls into four major categories: landscape characteristics or geomorphology, hydrogeology, bedrock information, and surficial deposits. For reconnaissance planning purposes, slopes can be read directly off U. S. Geological Survey 7-1/2 minute topographic quadrangle maps such as the Belchertown quadrangle. Slopes influence stability of rock and drift in valley sides, rates of runoff and erosion, rates of infiltration, and routes of movement of groundwater. Natural slopes in the Belchertown quadrangle are generally stable, but seeps along the contact of materials of different permeability reduce stability and need to be considered in excavation for civil structures. Plate 1 shows areas where boulders are concentrated on the ground surface. Large boulders limit the ease of excavation and on slopes present hazards to be reckoned with. Concentrations of boulders are common on the surface where depth of rock is a matter of a few feet.

Information on surface and groundwater is essential to proper land use planning. The quality of water in surface streams along with base flow and annual fluctuations in discharge are principal concerns in planning for many civil projects. Areas that are prone to frequent floods severely limit man's use of the land. The Fort River and Hop Brook have flooded portions of the Lawrence Swamp basin on several occasions during historic time. Most streams in the area, particularly those in the uplands, have fairly steep flow duration curves indicative of large fluctuations in discharge as a result of poor water storage capabilities within their drainage basin. Information on the quality and quantity of water in Cadwell Creek and the Fort River can be obtained from the U. S. Geological Survey, Water Resources Division which maintains a gaging station on each of these streams.

Groundwater occurs in both surficial and bedrock aquifers in the area as discussed previously. Interstitial groundwater under phreatic conditions occurs in most surficial deposits in the area. Permeability and transmissibility are controlled by the texture of these deposits. Approximate yields and quality of water in surficial deposits is discussed earlier. Groundwater under artesian head is obtained from sand and gravel beneath glaciolacustrine varves under Lawrence Swamp. The quality and quantity of Lawrence Swamp groundwater is discussed in a previous section of this report. Efforts are presently being made to protect this aquifer from contamination and pollution by man's activity. This problem is discussed in the following section of this report.

Most of the serious environmental concerns in the Belchertown area are concerned with protection of groundwater resources, some examples of which are given in the following section of this report. Depth to groundwater is a major concern in the stability of surficial deposits as well as in the placement of septic tank disposal fields. Depth to groundwater fluctuates seasonally through a vertical distance of several feet. During the course of this investigation, the water level in till in the upland was observed to fluctuate through a vertical distance of approximately 2 feet. Vertical fluctuation of the water table in sand and gravel deposits will be several times as great.

Bedrock information which was not the prime concern of this investigation is essential for proper planning. The distribution of rock types, their mineralogy, their structure, and weathering characteristics need to be considered in planning. Planar features considered as defects in engineering investigations are of particular concern. The attitude and spacing of bedding or foliation, along with joints and faults influences the stability of materials on slopes as well as the movement of groundwater. Excavations for roads and other civil structures must take these planar features into consideration. Sulphate and sulphide minerals present engineering problems, and therefore, their presence and distribution in the rock must be known. Special concrete must be placed in areas where water and sulfate minerals are in contact so as to prevent the deleterious effects of sulfuric acid. Volume expansion caused by weathering of pyrite can result in problems of heaving. Depth of weathering influences the stability and engineering characteristics of rock and must, therefore, be known.

Pyritic schists of the Partridge formation are present in the area and present problems because of rapid weathering and schistosity leading to unstable soils, especially on slopes. The topography of the buried bedrock exerts an influence on the movement of water and therefore is of concern in the placement of wells and disposal fields.

The texture, stratigraphic succession, and thickness of drift units is a major concern for planning in the Belchertown quadrangle. A materials map (Plate 2) which was derived from the surficial geologic map shows the distribution of till and swamp deposits as well as the texture of stratified drift. Thickness of the drift in the Belchertown quadrangle is shown on Plate 3. The till shown on Plate 2 is mostly upper till, but there may be areas where thin, sandy upper till is underlain by dense, more compact silt rich lower till, thus underscoring the need for site investigation. Drumlin till is of significance because of its higher plasticity, lower shear strength and poor permeability and drainage characteristics. A problem encountered in land use on drumlin till is given in a later section of this report. Sand and gravel are useful as fill and aggregate and, thus, constitute economic resources in the area which should not be zoned so as to prevent removal. The suitability of a particular deposit depends upon its intended use and must be evaluated for each deposit and each instance of usage. The thickness and texture of these deposits influence their suitability for development of wells, as well as their ease of acceptance of liquid effluent. As many homes in the area draw water from as well as dispose waste in stratified drift deposits of relatively high permeability, extreme caution must be urged in the location of water wells, dry wells, and septic tank leaching fields. Improper placement of wells and septic tanks may lead to overlapping of the cone of depression surrounding the well and the cone of recharge surrounding the leaching field, thus leading to recycling of effluent into the water supply. Where drift is less than 10 feet thick (Plate 3), bedrock outcrops are abundant and depth to bedrock is generally only a few feet. Caution must be exercised in locating and placing septic tanks in such areas. Improper location of septic tanks and wells in such areas can lead to serious problems of pollution such as those described by Altoff (1970) in the Town of Granby. The thickness and permeability of surficial material, depth to the water table, and routes of movement of groundwater impose geological limitations for the disposal of liquid and solid waste. Recharge areas for artesian aquifers, such as that underlying Lawrence Swamp, must be protected from pollution by man's activity.

Plate 3 shows a deep depression in the bedrock surface in the vicinity of St. Hyacinths's Seminary in Granby as well as the Granby High School. The pattern of depth to bedrock suggests the possibility of a buried bedrock valley in this area. Drift-filled buried valleys are important in the design and location of structures, as well as their potential for groundwater supplies if they are filled with coarse stratified drift. The Town of South Hadley, Massachusetts obtains much of its water supply from a series of wells located in a buried valley.

The depth to and thickness of glaciolacustrine varved clay, respectively, is shown on Plates 4 and 5. The engineering characteristics of this cohesive soil are given later in this report. Varved clay is also of significance for the effect that it exerts on the rate and direction of movement of groundwater. The varved clay underlying Lawrence Swamp is a confining layer causing the water in the underlying sand and gravel to exist under artesian pressures.

Examples of Environmental Problems in the Area

The major environmental concern in the Belchertown quadrangle at present is water pollution. Most homes obtain water from wells and discharge sewage into septic tanks. Usually, the aquifer is also the recipient of sewage. Overlapping of the cone of depression surrounding a shallow well and the recharge mound from a discharging septic tank can lead to an undesirable recycling of sewage into a water supply. Closely spaced houses with septic tanks on slopes where drift is thin can have a similar effect. Flow of septic tank effluent along the bedrock surface can lead to contamination of wells downslope. Many homeowners have drilled wells into bedrock to avoid the risk of contamination of a shallow well by septic tank effluent.

The failure to consider the direction and rate of movement of surface and subsurface fluid has caused some degradation and pollution of water. The following examples will illustrate problems which currently exist.

Rice and Bay, in several unpublished reports, have shown that surface and groundwater have become contaminated in the area because of man's activities. Driven wells in glaciofluvial sand and gravel along Jabish Brook supply water for the village of Belchertown and the Belchertown State School. Analyses of water from both well fields by the Massachusetts Department of Public Health indicate a periodically fluctuating but steadily rising chloride content. Road salt stored unprotected at the Belchertown Highway Department garage and salt placed on highways has been slowly moving downslope into the aquifer supplying these wells. Chloride levels are highest each year in early spring and decline the following fall to levels higher than those of the preceding autumn. Chloride concentrations in late winter and early spring now exceed 250 mg/1, the limit recommended by the U. S. Public Health Service for drinking water.

Rice and Bay have also found chloride contamination in several domestic wells near Routes 9, 21 and 202, as well as isolated instances along some country roads in Pelham and Belchertown. Highway road salt is the probable source of the chloride. Water from some of these wells has been declared unfit for consumption by health authorities.

Motts and Saines (1969) have shown that the deterioration of water quality in Massachusetts correlates with human activities. Contamination of water supplies by road salt is one of several types of contamination documented in their report.

Coliform bacteria which are indigenous to the intestinal track of man and animals are used as a measure of contamination of water by sewage. Rice, Bay, and students in Geology 387 at the University of Massachusetts, Amherst have taken samples periodically from Jabish and Lampson Brooks for analysis by the Massachusetts Department of Public Health. Coliform bacteria well in excess of the limit set by the U. S. Public Health Service (1962) have been found in these streams. Faulty septic tanks and a faulty sewage treatment plant are the assumed sources of the pollution. The coliform bacteria concentration has been sufficiently high at times as to militate against use of Lampson Brook water for irrigation of a strawberry farm. Analyses of water from a drainage ditch on the south side of Orchard Road indicate that newly installed septic systems in drumlin till south of the ditch are malfunctioning. Septic tank effluent is not percolating into, but is draining downslope along the surface of the clayey, silty drumlin till. Continued downslope drainage of sewage may lead to contamination of the artesian aquifer beneath Lawrence Swamp from which Amherst obtains much of its municipal water supply.

All towns in the Belchertown quadrangle presently dispose of solid waste in sanitary landfills. Zanoni (1972) and Hughes, et al (1971) recommended that the hydrogeology of the area of a proposed landfill be determined so that the landfill can be located, designed, and operated in a safe, non-polluting manner. Cartwright and Sherman (1969, p. 7) state that "...gravel pits are rarely, if ever, acceptable refuse disposal sites from the hydrogeologic standpoint." They further state that landfills should be located preferably in deposits of low permeability so as to retard the movement of leachate and to remove some of the organisms present in leachate. Sanitary landfill sites in the Belchertown quadrangle have generally been selected so as to fill large depressions left after extraction of sand and gravel. Hydrogeologic studies did not precede the dumping of solid waste at these sites.

Concern has been expressed that leachate from the Amherst-Pelham sanitary landfill may pollute the groundwater in the Brickyard Well Field which supplies the Town of Amherst. The Brickyard Well Field is located approximately 2,500 feet west of and 90 feet lower than the landfill which is in highly permeable glaciofluvial sand and gravel. The well field was installed long after dumping of refuse at the landfill site. Test drilling has indicated that the landfill is located in the recharge area of the Lawrence Swamp artesian aquifer, and that material of low permeability which could modify and retard the movement of leachate is absent beneath the landfill and between the landfill and the aquifer (Motts, 1972). The quality and movement of leachate is now being monitored in observation wells installed several years after pumping of the water supply wells began. To date, a slight rise in chloride has been reported in the groundwater of the Brickyard Wells. In a similar situation in Geneseo, Illinois, a slight rise in chloride was the first indication of the movement of leachate from the town dump into the municipal wells which were located down the hydrologic gradient from the dump. Subsequent rise in hardness and sulfates in the water of the town wells led to drilling of additional wells elsewhere to augment the town supply (Motts, 1972).

No data have been gathered to determine the quality or direction and rate of movement of leachate from landfills used by the Town of Belchertown and the Belchertown State School. Confining material of low permeability which could retard the movement of leachate and remove some constituents is not known at either site. Thus, unmodified leachate will probably move down the hydrologic gradient and into nearby streams and aquifers.

## ENGINEERING GEOLOGY

### Characteristics of the Drift

Reconnaissance level planning is greatly facilitated by a knowledge of the engineering characteristics of drift. Such information can enable the planner or engineer to plan the location of roads and buildings and to initiate design estimates. The distribution of grain sizes in tills shown on Figures 6 and 7, can be used to classify soils according to the Unified Soil Classification System (U.S.C.S.) and these categories can in turn be used to give general engineering characteristics of the various drift units. It is emphasized that these are only for reconnaissance level planning and must be supplemented by detailed testing and investigation of material at a particular site. Such estimates are, however, useful in avoiding especially detrimental soil conditions where better conditions are available in nearby areas.

Soils (sediments) which contain significant quantities of fine-grained materials (silt and clay) present the most serious limitations for the design of civil structures. Therefore, most engineering tests quantify the properties and behavior of such cohesive soils. Varved clay and drumlin till are the only extensive cohesive deposits in the Belchertown area. Lower till is moderately cohesive and may underlie sandy upper till in many areas, but its full extent is unknown. Lower till and varved clay are not mapped as surficial units anywhere in the area, but are present at depths of 3 to 10 feet such that they are of concern.

Table 4 shows that the varved clays which underlie the Lawrence Swamp Basin are inorganic clays of high plasticity (Unified Soil Classification Symbol CH). They are impervious (coefficient of permeability [k] less than $10^{-7}$), and have a moderate susceptibility to frost action -- especially the silt and fine sand members. Around the margins of the Lawrence Swamp Basin, varved clays inhibit drainage along the contact with overlying sand and thus can present problems of slope stability and susceptibility to frost action. When compacted and saturated, they have very poor shear strength and high compressibility. As a construction material they are poorly workable and are generally removed from most localities when possible. When unavoidable, overconsolidated stiff clays can be used as a foundation material with spread footings, but it is most desirable to remove this material when possible.

Lower till and drumlin till are similar in their scarcity of gravel and relative abundance of silt and clay. In the matrix of these tills (the fraction finer than the U. S. Standard Sieve No. 10), the percent sand is approximately equivalent to the combined percentage of silt and clay. In terms of the Unified Soil Classification, the textural composition of these two tills places them somewhere along the boundary of poorly graded silty sands (SM) and inorganic silts and very fine sands (ML). These two tills are semipervious to impervious (k of $10^{-5}$ to $10^{-7}$) and are moderately to highly susceptible to frost action. Because of jointing, weathered tills of this type are especially susceptible to frost action. When compacted and saturated they have poor to fair shear strength and medium compressibility. As a construction material, both these materials are considered as fair. When wet, they are negotiable with some difficulty by track and wheeled vehicles; when dry, they are dense, firm and compact, sometimes presenting difficulty in excavation. They are sufficiently dense to have joints in both fresh and weathered material. Joints are closely spaced, near vertical and horizontal in weathered material, causing lower till to break into small thin plate-like masses known to soil scientists as peds. Joints in unweathered till are spaced at 1/2 to several meters such that upon excavation the material often breaks out in large blocks. Not only do these tills have low stone content (averaging 9 to 12 percent in the samples tested), they are generally free of large boulders of the type typically found in upper till.

Upper till is generally a firm to very firm, poorly to moderately graded, sand and silt mixture (SM). Upper till is generally quite stony, with the samples analyzed averaging about 20 percent gravel. In places where upper till has been washed (i.e., had fines selectively winnowed by the action of running water), it may border on a poorly graded gravel (GM). In places the gravel content may average as much as 50 percent, with a large percentage of these clasts being cobbles and boulders. It is fairly common for terrain underlain by upper till to be boulder strewn. Upper till is generally semipervious with coefficients of permeability ranging from $10^{-3}$ to $10^{-5}$. However, the permeability of this material is highly variable and may be considerably better in places where it has been washed and is highly stony compared to other places where it is silt rich and less pervious. Depending on its texture, upper till may have slight to high susceptibility to frost heaving. When compacted and saturated, its compressibility is generally low and its shear strength is generally good. As a construction material, its workability is fair to good depending upon its texture and boulder content. Note that while there are geologically significant differences between the upland, valley, and Belchertown facies of upper till, the engineering characteristics of this material are essentially the same. The abundant supply of sand and gravel in the Belchertown quadrangle serves as a source for borrow. However, in upland communities where there is very little glaciofluvial sand and gravel, upper till is commonly used as a borrow material. A general summary of the characteristics of upper till is given in Table I.

Water-laid deposits of sand and gravel are abundant in the Belchertown quadrangle. These units were deposited in both ice contact and proglacial positions. Generally speaking, there is more uniformity among sands and gravels deposited in a proglacial environment. Sand and gravel deposited in an ice contact position commonly contains interbedded and fairly thick lenses of silt and fine sand which were deposited in temporary lakes on or adjacent to stagnating ice. Flowtill containing more than 10 percent silt and clay is commonly interbedded in ice contact deposits. The textural contrast between adjacent units may be very great in ice contact deposits and is often enhanced by collapse structures that developed at the time of melting glacial ice.

Generally speaking, sand and gravel deposited in an ice contact environment is well graded gravel or a gravel-sand mixture with little or no fines. As shown on Plate 1, the gravel in the Belchertown quadrangle may be dominantly pebble gravel or cobble gravel, or a combination of pebble and cobble gravel. Some boulders are present in some areas, especially those adjacent to a former ice margin. Interbedded in these well graded gravels are poorly to well graded sand (SP to SW). Sometimes thick and often discontinuous lenses of silty sands and poorly graded sand-silt mixtures (SM) are found within ice contact sand and gravel deposits. In ice contact glaciofluvial deposits one may find poorly to well graded gravels, poorly to well graded sands, with some interbedded silty sands and poorly graded sands. Therefore, each area proposed to be used for borrow must be given a detailed investigation so as to determine the texture and distribution of various grain sizes in the deposit. The heterogeneity of these deposits merit careful consideration, as the material in any one deposit may meet specifications for one intended use and not for another.

The greatest uniformity of any glaciofluvial deposits in the area is found in the proglacial valley train deposits that occur within the Bachelor Brook Valley. Exposures in this material indicate that it is largely poorly to well graded sand with only minor amounts of interbedded, generally small pebble grave. However, these proglacial valley train deposits grade upvalley into coarser textured ice contact glaciofluvial deposits in a head of outwash north of Lake Holland. Therefore, the proportion of interbedded gravel within the valley train deposits is a function of location in the valley from which they are extracted. These sand and gravel deposits are very pervious with coefficients of permeability commonly on the order of $10^{-1}$ centimeters per second. Except for interbedded silt and fine sand, these deposits have a very low susceptibility to frost action. These materials are generally of good to excellent workability. When compacted and saturated, their compressibility is negligible and their shear strength is good to excellent.

Both glaciofluvial and ice contact stratified drift have been extensively used for borrow in the Belchertown quadrangle. The volume of material available for extraction is generally a function of the depth to water at a particular locality. Interbedded flowtill, or laminated silty and sandy kettle pond fillings within glaciofluvial ice contact deposits may limit the amount of material which meets specifications for an intended use. As flowtill is commonly the surficial unit in many sand and gravel deposits, it is recommended that initial test pits be dug at least 10 feet deep in order to check on the quality of material.

Alluvial and stream terrace deposits generally are silty sands to poorly graded sand-silt mixtures (SM). They are only semipervious to impervious with coefficients of permeability approximately that of upper tills. Along floodplains, they are typically poorly drained with a high water table. In places, they are interbedded with or interfinger with organic silts and organic silt clays of low plasticity (OL). When compacted and saturated, these materials have poor to fair shear strength and medium compressibility. As construction materials, their workability is fair.

The ubiquitous eolian deposits which mantle the drift are generally silty fine sand with varying amounts of pebbles, cobbles or boulders included within. These deposits are generally semipervious to impervious. When compacted and saturated, their shear strength is good and their compressibility is low. Since these deposits rarely exceed 2 feet in thickness, they are most often and easily removed so as to get to underlying material on which foundations can bear.

Peat is present in only minor amounts in the Belchertown quadrangle. It may occur interbedded or as lenses in alluvium along floodplains, or in poorly drained former channels along floodplains. Only one small peat bog occurs within the quadrangle. This bog is found approximately .4 mile northeast of the intersection of George Hannum and Boardman Streets.

A summary of the characteristics of all drift units present within the Belchertown quadrangle is given in Table 4.

## Seismicity--Possible Role of Drift

Earthquakes have recently received increasing attention because of the risks for critical structures such as dams and nuclear power plants. Some of the damage can result from modification of earthquake-generated waves in passing from rock through overlying unconsolidated material to the surface. Areas blanketed by unconsolidated material may experience amplification or attenuation of ground motion or liquefaction. Earthquake waves in passing from rock through loose, low-density unconsolidated materials can become amplified leading to unusually severe damage for an earthquake of a given intensity. Loose, water-saturated sand and silt may liquefy because of increased pore pressure and reduced shear strength induced by the passage of seismic waves.

Generalizations regarding the density and water content of unconsolidated units in the Belchertown quadrangle are difficult to make. The density of unconsolidated materials varies with water content, degree of consolidation, and grain size. Till, particularly cohesive till, is generally firm to dense material. Water-saturated fine sand and silt such as in floodplains is especially susceptible to liquefaction. Density and degree of saturation are properties of drift units which must be evaluated at a particular site to determine the susceptibility for amplification or liquefaction.

No earthquake epicenters have been reported within the Belchertown quadrangle, but several low intensity events have occurred in the Connecticut Valley and in the Eastern Uplands of southern Massachusetts. Earthquakes ranging up to Modified Mercalli Intensity VIII have occurred in the vicinity of East Haddam, Connecticut (Coffman and von Hake, 1973; Smith, 1966). Eastern Massachusetts and southeastern New Hampshire have had relatively frequent earthquakes with Intensities ranging up to Modified Mercalli Intensity VIII. In addition, eastern Massachusetts has experienced vibratory ground motion from earthquakes with epicenters in the western Atlantic and in the St. Lawrence Valley. The felt areas for some of these larger events include the area of the Belchertown quadrangle such that Algermissen (1969) has included the Belchertown area in a zone 2 in his seismic risk map of the United States. An area designated as zone 2 can expect earthquakes with Intensities ranging up to Modified Mercalli Intensity VII within the area.

No specific effects of earthquakes in the Belchertown area have been reported, nor were they observed in the field. However, it is reasonable to assume that the area has experienced vibratory ground motion from a number of earthquakes that have occurred within a 100-mile radius. Because of the seismicity of the region, and the nature of the drift, the effects of vibratory ground motion should be considered in an investigation of a site in southcentral Massachusetts that is mantled with unconsolidated sediment. Sedimentary structures, some of which are similar to those reported as a result of earthquake effects (Sims, 1973) have been observed in the Belchertown quadrangle, but have been interpreted as the result of nontectonic processes induced by the melting of glacial ice.

# CHRONOLOGY

## Introduction

Moraines which mark the terminus of a glacier are rare in New England and occur only in southern Connecticut, Rhode Island, and Cape Cod. The Ronkonkama and Harbor Hill moraines of Long Island mark the margins of one or more glaciers which passed over New England. North of the Charlestown moraine (Kaye, 1960) in southeastern Connecticut and southern Rhode Island, a linear concentration of boulders, named the Ledyard moraine by Goldsmith (1960), marks the northernmost and latest known active terminus of the last Pleistocene glacier to have covered Massachusetts. North of the Ledyard moraine, deglaciation was by stagnation zone retreat (Currier, 1941) rather than by retreat of an active terminus along which moraines were deposited during temporary halts. When the melting terminal zone of the glacier became too thin to flow, the ice stagnated. With melting of ice below divides, the terminal zone of the ice became separated into residual lobes of ice which occupied valleys and lowlands and which controlled melt-water drainage. Stagnant ice masses block some outlets thereby controlling the routes used by melt water. Stagnant ice also controlled the base level of melt-water streams, and functioned as a valley wall against which melt-water streams deposited sand and gravel. These ice marginal sand and gravel deposits remain as kame terraces above the present valley floors. As deglaciation progressed, new and lower outlets became available for drainage. Thus, a series of kame terrace deposits graded to progressively lower outlets reveal much of the history of deglaciation.

In the absence of recessional moraines, kame terraces have been used to interpret a chronology of melt-water drainage and ice recession in the Belchertown quadrangle. Jahns (1953) defined an outwash sequence as the deposits of melt water following a specific route. Shafer (1961) clarified the meaning of outwash sequence as melt-water deposits "laid down contemporaneously with one another, by melt-water streams controlled by a common outlet or base level and (were) aggraded to a common sloping surface." Thus, a series of sediments that were deposited by melt water at progressively lower elevations reflects stagnant ice which controlled the outlet and/or the base level of melt-water streams. The head of a sequence is frequently marked by thick ice contact deposits containing numerous kettles and flowtill as is the case for Qbb2 north of Lake Holland. A scarp reflecting the contact of ice and sediment is also frequently found as at the head of Qbb2 and Qd1. In the Belchertown quadrangle, deltas occur at the ends of sequences Qth1, Qd1, Qd2, and Qd4 where melt-water streams entered ice-marginal lakes. The elevations of these temporary, proglacial lakes can be determined by measuring the altitude of the contact of topset and forest beds in the deltas.

Detailed surficial geologic mapping by geologists of the U. S. Geological Survey has enabled further refinement of the sequence concept (Koteff, 1974). Koteff (1974) has distinguished eight different types of morphologic sequences based on environment of deposition and presence or absence of an ice contact head of outwash. The fluvial ice contact sequence (SC) and the fluvial-lacustrine ice contact sequence (SLC) are the most common types of morphologic sequences found within the Belchertown quadrangle. Fluvial non-ice contact sequences (SNC) are also present within the area.

Belchertown Quadrangle

The ultimate receiving basin and thus base level for most melt-water streams in the Belchertown quadrangle was Lake Hitchcock--a large body of water imponded between a drift dam at Rocky Hill, Connecticut and the retreating ice margin in the Connecticut valley. The morphology and elevation of terraces in the Belchertown quadrangle were, however, controlled by more ephemeral base levels such as bedrock or ice-controlled spillways. Earliest melt-water drainage was southeast to the Chicopee River and thence into Lake Hitchcock. Melting of stagnant ice southeast of Metacomet Lake allowed melt water to later drain southwest at lower elevation to the Chicopee River. Deglaciation of the col at the east end of the Holyoke Range then permitted flow of melt water into temporary proglacial lakes north of the Holyoke Range which eventually merged with Lake Hitchcock.

Unlike the situation in Wisconsin (Black, R. F., personal communication), stagnant ice features do not occur on the summits of divides in the Belchertown area and in most of New England. Apparently, the glacier remained active while nunataks were emergent until thinning reached the point at which flow was impossible, or emergent highlands physically separated masses of ice from the active glacier. It is at such altitudes where stagnant ice features are first found. Analogs of the late glacial environment in the area may be found today in southeastern Alaska where the Malaspina Burroughs and plateau glaciers are melting (Hortshorn and Ashley, 1972; Goethwait, 1974).

Flowtill, ice channel fillings, and glaciofluvial deposits attest to early, high-level stagnation of glacial ice in the basin south-east of Mt. Lincoln. As the ice thinned, the emergence of Mt. Lincoln, West Hill and highlands north and south of Knights Pond isolated a mass of ice in the Knights Pond basin which became stagnant. Water from the emergent highlands drained into the basin and along, over and through the mass of stagnant ice. Melt water drained out of the Knights Pond basin by way of several outlets at different elevations. The highest outlet which is located west of Gold and Munsell Streets at an altitude of 995 feet permitted early drainage southward out of the basin. Later and lower drainage occurred by way of outlets at 950 and 920 feet elevation into Jabish Brook, and westward at 920 feet into Scarboro Brook. Centripetal drainage onto melting and collapsing stagnant ice has left a large deposit of sand and gravel in this basin which cannot be easily separated into the deposits of streams using any one outlet. While all these deposits are not of identical age, they are grouped as one since clear evidence for separation into distinct sequences is not present. Much of the sand and gravel in this basin may have been deposited onto stagnant ice which, upon melting caused collapse that obscures the detailed history of deglaciation. Till and stratified drift in this basin are in places very difficult to distinguish. Along with kettles and channel fillings, these lines of evidence suggest an environment of highly broken and permeable ice on which deposition, mass movement, and winnowing were common.

Stagnant ice in the vicinity of Scarboro Pond blocked drainage and controlled the base level of melt-water streams so as to permit deposition of sand and gravel against and into the ice. Deposition of stratified drift in this upland basin occurred after deglaciation of the higher, adjacent Knights' Pond basin. Flowtill in an ice channel filling is exposed in a roadcut on Gulf Road and indicates the presence of stagnant ice in the area.

Small deposits of sand and gravel which cannot be related to any outlet occur at 870 and 730 feet altitude in the Swift River drainage basin, and at 680, 580, 550 and 470 feet altitude in the Connecticut River drainage basin. The melt-water streams which deposited these sediments apparently flowed back on or into ice.

Beginning at an altitude of 690 feet, a series of kame terraces and valley train deposits grade to progressively lower outlets reflecting melting of stagnant ice. Kame terraces in the vicinity of Warner Street indicate that melt water initially drained eastward into the Swift River. With melting of stagnant ice in the Jabish Brook valley, drainage shifted southward into the Jabish Brook drainage basin. Early drainage in the Jabish Brook basin was by way of an unnamed tributary between Old Enfield Road and Warner Street, but shifted to approximately the present course of Jabish Brook with melting of ice in the upper reaches of Jabish Brook valley. Kame terraces in the Jabish Brook valley indicate the highly cavernous nature of stagnant ice which controlled the long profile of melt-water streams in this valley. The lowest levels of sand and gravel in Jabish Brook valley are approximately coincident in elevation and time with stratified drift in the Broad Brook valley. Long, narrow tongues of ice in these valleys form a continuous head of outwash that was deposited by streams which graded southeastward into the Chicopee River. Highly irregular ice-contact slopes, numerous kettles, and ice channel fillings indicate the highly fractured and cavernous nature of the stagnant ice which lay in these valleys. While several levels of drainage and terraces may have existed in this valley, collapse and post-glacial modification have made the distinction of such stages impossible such that only one sequence has been mapped (Qse4).

Melting of stagnant ice southeast of Metacomet Lake permitted melt water to drain southwestward at lower elevation in the Bachelor Brook drainage basin. Several small kame terraces east and southeast of Metacomet Lake which cannot be related to any specific outlet record early ice-marginal drainage to the southwest into the Bachelor Brook valley. Retreat of ice at approximately the same time allowed melt water to drain southwestward along the north slope of Turkey Hill. Continued withdrawal of ice opened successively lower outlets at 370 and 340 feet altitude along Turkey Hill. When the ice uncovered the Weston Brook outlet at 310 feet altitude, a long glacio-fluvial sequence heading east of Arcadia Lake came into being. Numerous kettles, collapse structure and channel fillings indicate the highly fractured and cavernous nature of the ice which lay in this valley at this time. This sequence may be correlative with the one which was deposited by melt water draining southward by way of Stony Brook.

With further melting of stagnant ice, melt water flowed southwestward from an ice terminus in Bachelor Brook valley, depositing sand and gravel en route to the Bachelor Brook outlet at 250 feet altitude. Bachelor Brook terminated in the Pearl City Plain, a delta into Lake Hitchcock about two miles west of the quadrangle border. Melt water flowing south-southwest out of the Holyoke range deposited sand and gravel against ice in Bachelor Brook valley. Whether ice occupied the entire width of Bachelor Brook valley, or only the northern part of the valley when sequence Obb1 was deposited is not certain. Ice was present in Bachelor Brook valley 0.65 miles south of Pond Hill at least during the early stage of deposition of sequence Qbh2. A terrace scarp at that location indicates that melt water, at least initially, flowed south through a col between two bedrock ridges before flowing east at slightly lower elevation to join melt-water streams in Bachelor Brook valley, at a point about 1/2 mile south of Bay Road and Stebbins Street. Melt water which flowed east along the north slope of the Holyoke Range drained through the col at 350 feet altitude near Bobbin Hollow and thence flowed south into Bachelor Brook valley. These relationships indicate the synchroniety of ice stagnation and deglaciation north and south of the Holyoke Range.

As the ice in Bachelor Brook valley melted, melt-water streams increased in length northeastward until the gap between the Holyoke Range and the eastern uplands was opened. Fluvial erosion of decaying glacial ice detached masses of ice which were buried by glaciofluvial sediments. Subsequent melting of these ice masses produced the kettles of Metacomet Lake, Arcadia Lake, and Lake Holland. The thick kettled and collapsed valley fill indicates that glacial ice fronted in this gap for some time and controlled the base level of melt-water streams while supplying water and sediment for the outwash which heads in this area.

As stagnant ice continued to melt and withdraw from the Holyoke Range and the eastern uplands, water was imponded in the Lawrence Swamp basin. Temporary lakes dammed by stagnant ice and draining through the Belchertown outlet became the base levels for melt-water streams which flowed southeastward along the eastern uplands. Deltas at the downstream ends of sequences Qd1 and Qd2 indicate the levels of imponded water in the Lawrence Swamp basin. Excellent exposures in Qd3 indicate that this sequence was deposited by an eastward flowing melt-water stream which was at least partly in contact with ice and which was graded to an expanding lake in the Lawrence Swamp basin. As ice continued to melt, the expanding lake in the Lawrence Swamp basin became confluent with the northward expanding waters of Lake Hitchcock--a large, late-glacial lake in the Connecticut Valley which was imponded by a drift dam at Rocky Hill, Connecticut, and which drained by way of a bedrock spillway at New Britain, Connecticut. Lake Hitchcock expanded into the Lawrence Swamp basin probably during deposition of Qd3. Melting of an ice plug between Mt. Nonotuck and the Holyoke Range allowed water to enter the basin through lows in a line of southeast-trending drumlins. Sequences Qd4 and Qeh were deposited by melt-water streams graded to Lake Hitchcock. The terminus of Qd4 is a delta. Qeh is a kame terrace, the western edge of which is composed of numerous delta lobes where melt-water streams entered Lake Hitchcock. Numerous kettles, collapse structure, and the absence of any large drainage basin from which to derive water and sediment indicate that this sequence was deposited in contact with ice standing in the Lawrence Swamp basin. The sub-lake portions of Qd3 and Qeh were modified by mass movement and deposition of sand in the shallow waters of Lake Hitchcock. Several tens of feet of varved silt and clay (Plates 4 and 5) were deposited in the embayment of Lake Hitchcock in Lawrence Swamp.

Flowtill, collapse structure, abrupt textural variations, planar cross bedding, and imbricate clasts of compact blade shape in poorly sorted pebble and cobble gravel indicate that the sediments of Qd3 were deposited by an eastward flowing stream. Some of these sediments occur at elevations below the level of Lake Hitchcock such that an outlet for the depositing stream seems to be missing. Several Possibilities are suggested by this occurrence, but the problem remains. Much of the material could have been deposited on ice such that a gradient to an outlet existed at the time of deposition. Collapse and settlement would have occurred during melting of the buried stagnant ice which may have taken several tens of years judging from rates of melting of buried ice masses in southeastern Alaska (Goldthwait, 1974; hartshorn, personal communication). The absence of topographic evidence for an ice marginal environment of deposition may have been obliterated by collapse, or by reworking of these sediments in the shallow water of Lake Hitchcock in post-depositional time. The possibility of a temporary low level lake into which such a stream could flow is also suggested. Planar cross bedded sand at 210 feet elevation between two drumlins in the adjacent Mt. Holyoke quadrangle to the west also suggests this. At least two stages of Lake Hitchcock are known south of the Holyoke Range, with the two becoming confluent after communication was established between two lakes at different elevations (Hartshorn and Colton, 1967). Such an occurrence suggests that lakes in isolated basins such as the Lawrence Swamp basin could have existed for short periods of time, but it is difficult to conceive that the isolated lake would have been of lower elevation than that of the main Connecticut Valley lake. The large mass of sand and gravel in Dry Brook Hill south of the Holyoke Range has been recently interpreted as a kame complex (Saines, 1973) suggesting that glacial ice remained for some time in and slightly south of the narrows between Mt. Nonotuck and the Holyoke Range. While such a mass of ice would have blocked communication between ponded water on either side of the divide, it is only speculative to suggest such an occurrence as the evidence is equivocal. No stratigraphic evidence of a retreat and readvance was found in the

Belchertown quadrangle, but a minor readvance has been found from evidence in the Mt. Tom quadrangle to the southwest (Larsen, 1972). The possibility that a minor retreat and readvance significantly affected water levels in Lake Hitchcock seems remote, but possible.

A series of aligned drumlins which trend southeast and which are separated by sand and gravel deposits played a significant role in the late Pleistocene history of the lowlands north of the Holyoke Range. Ashley (1972) and Gustavson (1972) have shown the influence of lake bottom topography on density undercurrents which deposit the coarse fraction of glaciolacustrine varves. West of the drumlin barrier in Amherst and Hadley, clay thickness is greater than that for silt in the varved glaciolacustrine rhythmites of Lake Hitchcock (Ashley, 1972). Melt-water streams which deposited the sand and gravel of sequence Qeh continued down the delta foreset slopes as density undercurrents. Convolute lamination, ball and pillow structure, sheared clay units, and climbing ripples near the base of the prodelta slope indicate rapid deposition of silt and fine sand from density underflows. Sand and most of the coarse silt was deposited either in the deltas or on the lake bottom in the Lawrence Swamp basin. Only clay and fine silt in suspension were transported westward across this barrier to become deposited in varves.

When the Rocky Hill, Connecticut dam was breached at about 10,700 years B.P., Lake Hitchcock was drained. During the drainage of Lake Hitchcock, water was imponded at low altitude for a short time north of the Holyoke Range (Jahns and Lattman, 1962). This lake, Lake Hadley, served as the base level for a temporary, low level lake which was imponded in the Lawrence Swamp basin. A series of southeast-trending drumlins separated by sand and gravel deposits occur along the western rim of the Lawrence Swamp basin. During Lake Hitchcock drainage, water which was imponded east of and below this barrier could not drain westward until Lake Hadley was drained and the Fort River breached the barrier. Johns (1967) estimates that Lake Hadley lasted about 50 years. Several feet of sand were deposited in this low level lake, Lake Lawrence, before it drained. A stream draining into Lake Lawrence at the eastern end of the Lawrence Swamp basin incised previously deposited sand and gravel. This stream deposited an alluvial fan above the 180 foot altitude of the lake, and a delta where the stream entered Lake Lawrence. The very gently sloping sand plain west of Warren Wright Road is the top surface of this delta.

Wave-cut benches or notches, and well sorted sediments containing sedimentary structures and bedforms indicative of beach and nearshore sedimentation do not occur in the embayment of Lake Hitchcock in the Lawrence Swamp basin. Modification of previously deposited glaciofluvial sediments in the nearshore zone was extremely minor. This evidence suggests that the nearshore environment in this embayment of Lake Hitchcock was one of very low energy. Any waves generated by katabatic winds and northwest winds of long fetch were modified by passage through the series of aligned drumlins which stood as islands in the lake. Wave refraction and interference of refracted waves on the lee side of these islands reduced the energy of any waves so as to significantly reduce their geologic effectiveness in eroding and transporting sediment in the nearshore zone. Beach features reported elsewhere in Lake Hitchcock (Colton and Cushman, 1962) do not occur in this area. The sand and gravel deposits separating the drumlins were not deposited by longshore currents generated by wave refraction around the drumlin islands. The altitude of some of these deposits indicate that they would have had to have been deposited by currents at a depth of more than 50 feet in Lake Hitchcock, a highly unlikely event. The texture and sedimentary structures in these deposits suggest that they might be glaciofluvial. If the level of Lake Hitchcock fluctuated, spits and tombolos could have been deposited between the drumlins in a lower stage of Lake Hitchcock. A thick cover of insulating sediment along with location on the north slope of the Holyoke Range suggest that buried stagnant ice may have remained for some time along the southern margin of the Lawrence Swamp Basin. Such an occurrence would help explain the abundance of collapse structures and absence of beaches in this area.

Absolute ages from which one can determine the time and possibly the rate of deglaciation are rare in New England and the Connecticut Valley. No organic material suitable for radiocarbon dating was obtained from the Belchertown quadrangle. A possible peat bog north of George Hannum Street in sequence Qsw3 may yield wood fragments if probed. Interpretation of aerial photographs indicates that more bogs may be present in the area. In the absence of absolute ages, it is not possible to determine specific dates or rates of deglaciation.

Crude estimates of the rate of deglaciation can be made using the rate of deglaciation of the Malaspina Glacier in southeastern Alaska--a piedmont glacier which is stagnant along its periphery and probably similar in many characteristics to the terminus of the waning glacier in New England. Gustavson (personal communication) estimates the rate of retreat of the stagnant ice terminus of the Malaspina to be approximately 150 m/yr where the terminus is on land. This suggests that, at a minimum, deglaciation of the Belchertown quadrangle took a few hundred years. Such a crude estimate assumes similar rates of melting under similar conditions--assumptions which may be ill founded in fact.

The dates and length of existence of Lake Hitchcock, to which most melt-water streams in the area were graded, can provide information on the time and rate of deglaciation in the area. By correlating and counting varves in the Connecticut Valley, Antevs (1922) estimated that Lake Hitchcock existed for 4,100 years. Flint (1956) estimated the maximum existence of the lake at 3,000 years based on radiocarbon dates. Using these estimates of the duration of Lake Hitchcock, one can calculate average rates of recession of the glacier for the 185 miles from Rocky Hill, Connecticut to Lyme, New Hampshire. These rates of recession can be used to calculate the time necessary for the ice to recede from the Chicopee River to the northern border of the Belchertown quadrangle. Since Broad Brook and Jabish Brook are tributary to the Chicopee River, and since sequence Qeh was deposited against the ice, the time for deglaciation of this stretch of the Connecticut Valley can be used as an approximate time for deglaciation of the Belchertown quadrangle. So calculated, retreat of ice from the Chicopee River to the northern border of the Belchertown quadrangle took between 231 and 308 years (Table 5). Thus, total deglaciation of the Belchertown quadrange is a matter of a few hundred years, an estimate that agrees with the time and rate of deglaciation of similar terrain in Alaska (Goldthwait, 1974).

## Post-Glacial Chronology

In post-glacial time, eolian and fluvial activity, mass movement, and soil formation have added the finishing touches to the present landscape. Post-glacial wind blowing across unvegetated drift removed and redeposited some of this sediment as an extensive mantle of silt and fine sand. Clasts within the eolian mantle are presumably derived from underlying sediments by intense frost action which characterized late-glacial and early post-glacial time in New England. Ventifacts within the eolian mantle indicate the strength and duration of post-glacial winds and the abundance of blowing sand at this time. Wind has reworked unvegetated sand into dunes in Chicopee and Longmeadow, Massachusetts (Schafer & Hartshorn, 1965). No dunes were found in the Belchertown quadrangle.

Post-glacial stream activity has made the floodplains which are present along most streams. A change in base level or hydrologic regime of the Fort River has led to incision of an earlier floodplain, remnants of which are now a stream terrace.

## THE PLEISTOCENE IN NEW ENGLAND

Evidence for pre-Wisconsinan glaciation in New England is equivocal. Fuller (1914) in a classic work, mapped and described Pleistocene units on Long Island and made some tentative correlations with Pleistocene units on Cape Cod. While his mapping can rarely be improved today, he, unfortunately, arbitrarily matched his stratigraphy with that of the classic four-stage Pleistocene section in the midwestern United States. Woodworth and Wigglesworth (1934) mapped and determined the stratigraphy of Cape Cod and the offshore Islands, but unfortunately, matched their stratigraphy with that of Fuller (1914). Kaye (1964a,b) found seven drift units on Martha's Vineyard, and four in the Boston basin (Kaye, 1961), but also correlated his stratigraphic succession with the four stages of the Pleistocene in the Midwest.

Recent work has shown that the Laurentide ice sheet advanced and retreated several times during the 70,000 plus years of Wisconsinan time. In Illinois, Willman and Frye (1970) have recognized five substages of Wisconsinan age, three of which are glacial. They have also divided the Illinoian of Illinois into at least three substages. Since the extent of recession during an interstadial is not of the order of magnitude of an interglacial, soils, weathering profiles, and non-glacial deposits in any one area cannot be assumed to be interglacial deposits without confirmation by some dating technique. They may have developed during a minor recession of a glacier. Since radiocarbon dates are most reliable for 35,000 years and cannot be determined on material more than 50,000 years old, an absolute chronology for all but the latest Wisconsinan has not yet been determined.

Based on paleotemperature analysis of fossil-bearing Pleistocene units, Gustavson (1976) has telescoped much of the Pleistocene stratigraphy of Long Island and Nantucket into the Wisconsinan. The failure of earlier workers to correctly interpret environments of deposition led to the spurious correlation of texturally similar materials originally named the "Gardiners Clay" and the "Jacob Sand" by Fuller. The "Gardiners Clay" of much of Long Island is a glacio-lacustrine unit deposited in advance of the ice which deposited the Montauk Till. It is not correlative with marine "Gardiners Clay" in the type area on Gardiners Island, New York, described by Fuller. Similarly, the "Jacob Sand" in its type area on Jacobs Hill, Long Island is not correlative with material identified as "Jacob Sand" on Gardiners Island by Fuller (1914). [See Schafer and Hartshorn (1965) for a more detailed account of the various interpretations of the "Gardiners Clay".] The "glacio-lacustrine Gardiners Clay" and the "Jacob Sand" of Long Island are considered as members of the Manhasset formation and represent deposition in lakes and streams in advance of the glacier which deposited the Montauk Till (Upson, 1970; Gustavson, 1976). Incorporation of a block of Montauk Till into the Ronkonkama moraine suggests that deposition of the Montauk Till predates the Ronkonkama moraine. The age of the Montauk Till is Wisconsinan, but it may be Altonian as suggested by Gustavson (1976) or early Woodfordian (Connally and Sirkin, 1973). The Ronkonkama and Harbor Hill moraines along with the Roslyn Till which caps these moraines in western and central Long Island are considered as products of a waxing and waning Woodfordian glacier by Connally and Sirkin (1973).

Retreat from the Woodfordian Ronkonkama moraine had begun by 17,000 years B.P. (Sirkin, et al, 1970). The Woodfordian glacier generally retreated continuously, but with minor readvances interrupting the general pattern of retreat. A retreating, but oscillating glacier margin, has been found for both the Hudson-Champlain and the Erie-Ontario lobes of the Woodfordian glacier (Connally and Sirkin, 1973; Dreimanis and Karrow, 1972; Dreimanis and Goldthwait, 1973). A number of smaller moraines and segments thereof occur north of the terminal Woodfordian moraine (Ronkonkama, Vineyard and Nantucket moraines), but it is not clear whether they represent: (1) deposits during minor stillstands along a continually receding glacier, or (2) deposits of minor readvances by a generally waning glacier. The Harbor Hill, Charlestown, Buzzards Bay and Sandwich moraines are generally parallel to and north of the Woodfordian terminal moraines. These moraines contain abundant stratified drift and are interpreted as recessional moraines deposited during a temporary stillstand of the receding Woodfordian glacier. The Old Saybrook and Madison moraines (Flint and Gebert, 1976) similarly occur north of and parallel to the Harbor Hill-Charlestown-Buzzards Bay moraines and are also interpreted as recessional deposits of the Woodfordian glacier. A radiocarbon date of 14,240 ± 240 years B.P. (Stuiver and others, 1963), from sediment beneath Rogers Lake in Connecticut (Davis, 1969) indicates that the Old Saybrook moraine was deposited approximately 14,000 years ago. The Ledyard moraine (Goldsmith, 1960) is yet another northeast trending recessional moraine in southeastern Connecticut. The abundance of stratified drift and the absence of moraines north of the Ledyard moraine indicate that dissipation of the ice was largely by stagnation zone retreat (Courier, 1941).

Readvances of the late Wisconsinan glacier are evident in eastern Massachusetts, the Connecticut Valley, and the Hudson Valley of New York. The Cambridge, Middletown, and Rosendale readvances indicate waxing of at least minor lobes of the late Wisconsinan glacier which may be correlative (Connally and Sirkin, 1973; Schafer and Hartshorn, 1965). Borns (1973) suggests that the Middletown and Cambridge readvances may not be physically or chronologically connected because: (1) there are no deposits connecting the sediments which record these readvances and (2) neither readvance is well dated radiometrically. The Middletown readvance in the Connecticut Valley temporarily imponded water into which a large volume of stratified drift was deposited. This mass of stratified drift formed a dam for a large lake which expanded northward as the ice receded toward Lyme, New Hampshire. This northward expanding lake which was named Lake Hitchcock by Lougee (1939) served as the ultimate base level for all melt water drainage in the Belchertown quadrangle. Lake Hitchcock drained at approximately 10,700 years ago (Flint, 1956), thereby initiating the present hydrologic regime in the Connecticut Valley.

Since unequivocal deposits of pre-Sangamon age are not known anywhere in New England, all the drift in the Belchertown quadrangle is of Wisconsinan age. No distinct evidence of a readvance or marginal oscillation was found in the Belchertown quadrangle, but a readvance of at least 3-1/2 miles was found by Larsen (1972) in the nearby Mt. Tom quadrangle. Basal lower till in the Belchertown quadrangle and elsewhere in New England is jointed, stained, deeply oxidized, and overlain by fresh, unweathered friable upper till. As discussed earlier, this suggests that the lower till may be Altonian while the upper till is Woodfordian in age. Similarity of the lower till of New England and the Montauk Till of Long Island suggests that they may be correlative and, therefore, that both are Altonian. No moraines, radiometrically datable material, or ice marginal deposits that can be traced out of the Connecticut Valley were found in the Belchertown quadrangle. Ephemeral ice marginal positions along kame terraces and heads of outwash allow development of a relative chronology of deglaciation, but no absolute ages can be assigned. The relative chronology and probable lengths of time for deglaciation of the Belchertown quadrangle are given earlier.

The paucity of radiometrically dated Pleistocene deposits in New England allows only estimates of the absolute chronology for deglaciation of the Connecticut Valley and the Belchertown quadrangle. The Middletown readvance which established Lake Hitchcock is dated at about 13,000 years B.P. The only other radiometric date for Lake Hitchcock is a bog-bottom date of 12,200 $\pm$ 350 B.P. from the base of a bog on the Farmington River delta in Suffield, Connecticut (Colton, 1961). The duration of Lake Hitchcock is radiometrically dated at about 2300 years. Antevs (1922) from varve counts between Rocky Hill, Connecticut and St. Johnsbury, Vermont estimated the duration of a proglacial lake at 4100 years. Subsequent work has shown that Lake Hitchcock extended only as far as Lyme, New Hampshire. Antevs counted varves from Lake Hitchcock and its successor Lake Upham. Using Antevs' 4100-year duration of Connecticut Valley lakes, the estimated average rate of retreat of the Connecticut Valley ice is 73 meters per year. Using a 3000-year Lake Hitchcock, the estimated average rate of retreat of Connecticut Valley ice is 81 meters per year. These rates of retreat for Connecticut Valley ice are in general agreement with those determined by Connally and Sirkin (1973) for retreat of ice of the Hudson Valley from western Long Island to the Glens Falls, New York area. Using these estimated rates of retreat of Connecticut Valley ice, and considering the distance from the Rocky Hill drift dam to the southern border of the Belchertown quadrangle as 68 km (42 mi), estimates of the age and duration of deglaciation of the Belchertown quadrangle are given in Table 5. The ages in Table 5 should not be considered as absolute, but only as estimates. Climatic fluctuations affecting the volume of ice melted annually, minor oscillations of the terminus, different rates of retreat for ice on land versus water, and insulating surface debris all probably resulted in highly variable rates of deglaciation. However, taken as a generalization, the dates in Table 5 suggest that except for residual buried masses of stagnant ice, deglaciation of the Belchertown quadrangle was completed by 12,000 years B.P. The date from the Farmington delta is in accord with this timetable. It is hoped that at some time in the future a quaking bog located 0.4 miles north-northeast of George Hannum and Boardman Streets can be probed for radiometrically datable carbon that may confirm these estimates.

| MAP SYMBOL | UNIT | OCCURRENCE AND DESCRIPTION | USCS SOIL TYPE | APPROXIMATE VALUE OF K (CM/SEC) | PERMEABILITY: DRAINAGE | PERMEABILITY: AQUIFER POTENTIAL | EASE OF EXCAVATION | SLOPE STABILITY | FROST SUSCEPTIBILITY | ENGINEERING PROPERTIES (WHEN COMPACTED AND SATURATED): SHEAR STRENGTH | ENGINEERING PROPERTIES (WHEN COMPACTED AND SATURATED): COMPRESSIBILITY | PRESENT OR POTENTIAL USE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $Q_{af}$ | Artificial Fill | Generally sand and gravel extracted from local borrow pits and used as fill or subgrade along roads, railroads, bridge embankments. Mostly compacted during construction and use. | GW-GP | $10^{0}$ to $10^{-3}$ | Generally good but varies with silt content and compactness. | --- | Easy | Generally good, especially where compacted. | Low | Good to excellent | Negligible | Borrow, fill, subgrade |
| $Q_s$ | Swamp Deposits | Non-compact, poorly sorted silt and clay with varying but generally high amounts of peat, muck and organic matter. In poorly drained depressions and along poorly drained floodplains. | OL-OH PT | $<1 \times 10^{-7}$ | Very Poor | Very poor; very low transmissibility. | Difficult by hand; easy by machine. | Very low | Very high | Poor | High | Peat for use on gardens and lawns. |
| $Q_{al}$ | Alluvium | Non-compact, moderately sorted slightly to moderately gravelly silt; silty fine, fine, and fine to medium sand mixed with varying amounts of organic material. Generally bedded. Grades to swamp deposits in abandoned channels and poorly drained floodplains. | GM-GC SM SC ML OL | Highly Variable | Fair to Poor | Low to high transmissibility and storage coefficients depending on proportion of silt, clay and organic matter. | Good, but impaired by high water. | Low to moderate depending on water and silt content. | Moderate to high | Good to poor as a function of texture. | Very low to moderate | In places can be used as low grade fill. |
| $Q_{st}$ | Stream Terrace Deposits | Non-compact, commonly stone free, moderately sorted and stratified, interbedded silt, silty fine sand and fine sand in stream terraces. | SP-SM | $1 \times 10^{-3}$ to $1 \times 10^{-5}$ | Generally good on surface depending on depth of ground water and silt content. | Moderate transmissibility and storage coefficient--usable where sufficient saturated thickness occurs. | Good | Good where vegetated; fair where barren--will fail till angle of repose reached--may fail along planes or contacts of low permeability. | Moderate to high; especially where water table is high. | Moderate to good | Low | May be used as low grade fill. |
| $Q_{ls}$ | Lacustrine Sand | Non-compact, generally stone free, well sorted and stratified fine and fine to medium sand deposited on old lake bottom. Overlies varved clay and silt in Lawrence Swamp Basin. | SP | $1 \times 10^{-1}$ to $1 \times 10^{-3}$ | Generally good except where high water table occurs. | Moderate to high transmissibility and storage coefficients. | Good to very good except where high water table occurs. | Fair--will generally fail until angle of repose for sand is attained. | Moderate--especially where high water table exists | Good | Very low | May be used for borrow. |
| $Q_{lc}$* | Lacustrine Silt and Clay | Laminated rhythmically bedded fine sandy silt and clay in Lawrence Swamp Lowland where it was deposited in Lake Hitchcock. Clays contain chlorite and illite. | CL-CH | $<10^{-7}$ | Very Poor | None. | Easy to difficult depending on moisture content. | Generally poor--seeps common at contact with more permeable material. | High | Poor to fair | Moderate to high | Formerly used for manufacture of bricks. |
| $Q_{gf}$ | Glacio-fluvial Deposits (Not differentiated as to sequences) | Generally poorly sorted, crudely stratified sandy pebble or cobble gravel interbedded with moderate to well sorted fine to medium, medium, medium to coarse, or coarse sand. May contain thin, local lenses of silt or silty fine sand, or flowtill. Textural changes commonly very abrupt. | GW-GP/SW-SP SM | $10^{0}$ to $10^{-3}$ | Excellent | Very good--where sufficient saturated thickness is present. Very high coefficients of transmissibility and storage. | Very easy (except where cemented by oxides of iron and/or manganese). | Generally stable in moderate to steep slopes. | Very low | Good to excellent | Negligible | Borrow, fill, aggregate. |
| $Q_{tu}$ $Q_{tv}$ $Q_{tb}$ $Q_{ft}$ | Upper Till | Slightly compact, slightly blocky, friable, non-sorted and non-stratified silty sand, gravel, and boulders with traces of clay. Color variable with location (Facies))--$Q_{tu}$ ( ), $Q_{tv}$ ( ), and $Q_{tb}$ ( ). Generally a veneer of less than 10 ft. thickness in uplands except in Drumlins. Upper 2-3 ft. may be very loose, sandy gravel. Boulders (<2 ft.) generally common. Terrain commonly bouldery. | SM-GM | $1 \times 10^{-3}$ to $1 \times 10^{-5}$ | Fair to moderately good. | Will give low to moderate yields where sufficient saturated thickness is present. Generally low transmissibility. | Fair to good--largely a function of size and percentage of boulders. | Generally fair to moderately stable except in steep cuts where it overlies rock or sediment of very low permeability. | Slight to high | Generally good | Negligible to low | Generally poor subgrade for roads; may be used as low grade fill, especially if not bouldery. |
| $Q_{tl}$* | Lower Till | Very compact, highly weathered, jointed, fissile sand/ silt with clay and some gravel. Generally few boulders. Not exposed as a surficial unit, but may underlie upper till at many localities such as along Harkness Rd. | SM-ML | $1 \times 10^{-5}$ to $1 \times 10^{-7}$ | Generally very poor. | Very low transmissibility and storage coefficients. | Generally poor because of compactness when dry or poor drainage when wet. | Will generally stand in moderate to steep slopes. | Moderate to high | Good to fair | Low | May be useful as an impervious lining, but otherwise not generally usable. |
| $Q_{td}$ | Drumlin Till | Compact, massive, stone-poor clay and silt with fine sand. Low plasticity. Occurs in drumlins in Connecticut valley and along north front of Holyoke Range. | SM-ML | $1 \times 10^{-5}$ to $1 \times 10^{-7}$ | Generally very poor. | Very low transmissibility and storage coefficients. | Generally poor because of compactness when dry or poor drainage when wet. | Will generally stand in moderate to steep slopes. | Moderate to high | Good to fair | Low | May be useful as an impervious lining, but otherwise not generally usable. |

*Not exposed, but may underlie other units at shallow depth so as to be of concern for construction.

(1) A ubiquitous thin cover of silt and very fine sand, the Eolian Mantle, is excluded because it rarely exceeds 3 feet in thickness and is, therefore, not a major concern in planning or construction.

TABLE 5

| Estimated Average Rate of Recession (1) | Time for Deglaciation From Rocky Hill To Southern Border Of Belchertown Quad | Belchertown Quadrangle | | |
|---|---|---|---|---|
| | | Approximate Beginning of Deglaciation (Years BP) | Approximate Duration of Deglaciation (Years) | Approximate Completion of Deglaciation (Years BP) |
| 73 m/yr (2) | 932 years | 12068 | 54 | 12014 |
| 105 m/yr (3) | 647 years | 12353 | 39 | 12314 |
| 81 m/yr (4) | 840 years | 12160 | 49 | 12111 |
| 150 m/yr (5) | 453 years | 12547 | 27 | 12520 |
| 112 m/yr (6) | 607 years | 12393 | 36 | 12357 |

(1) Assuming Lake Hitchcock began 13000 BP.

(2) Using Antev's (1922) 4100 year varve chronology.

(3) Using 2300 year duration of Lake Hitchcock from $C^{14}$ dates.

(4) Using 3000 year duration of Lake Hitchcock.

(5) Estimated average rate for recession of terrestrial portion of Malsaspina Glacier, Alaska (Gustavson, Pers. Comm.).

(6) Estimated average rate of recession from the Lower Hudson Valley to the Glens Falls, New York area (Connally & Sirkin, 1973).

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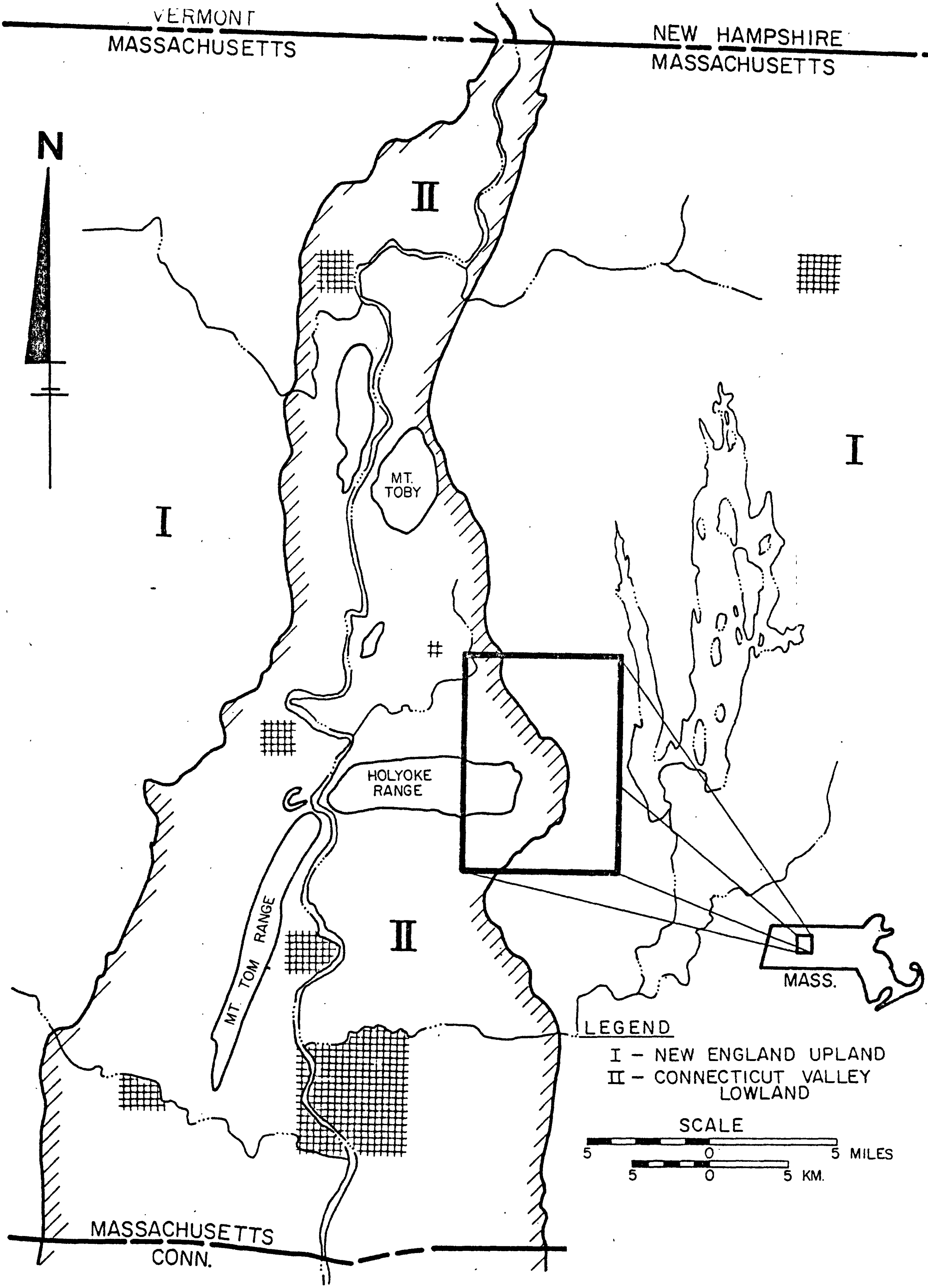



FIG. I PHYSIOGRAPHY AND LOCATION OF THE BELCHERTOWN QUADRANGLE MASSACHUSETTS

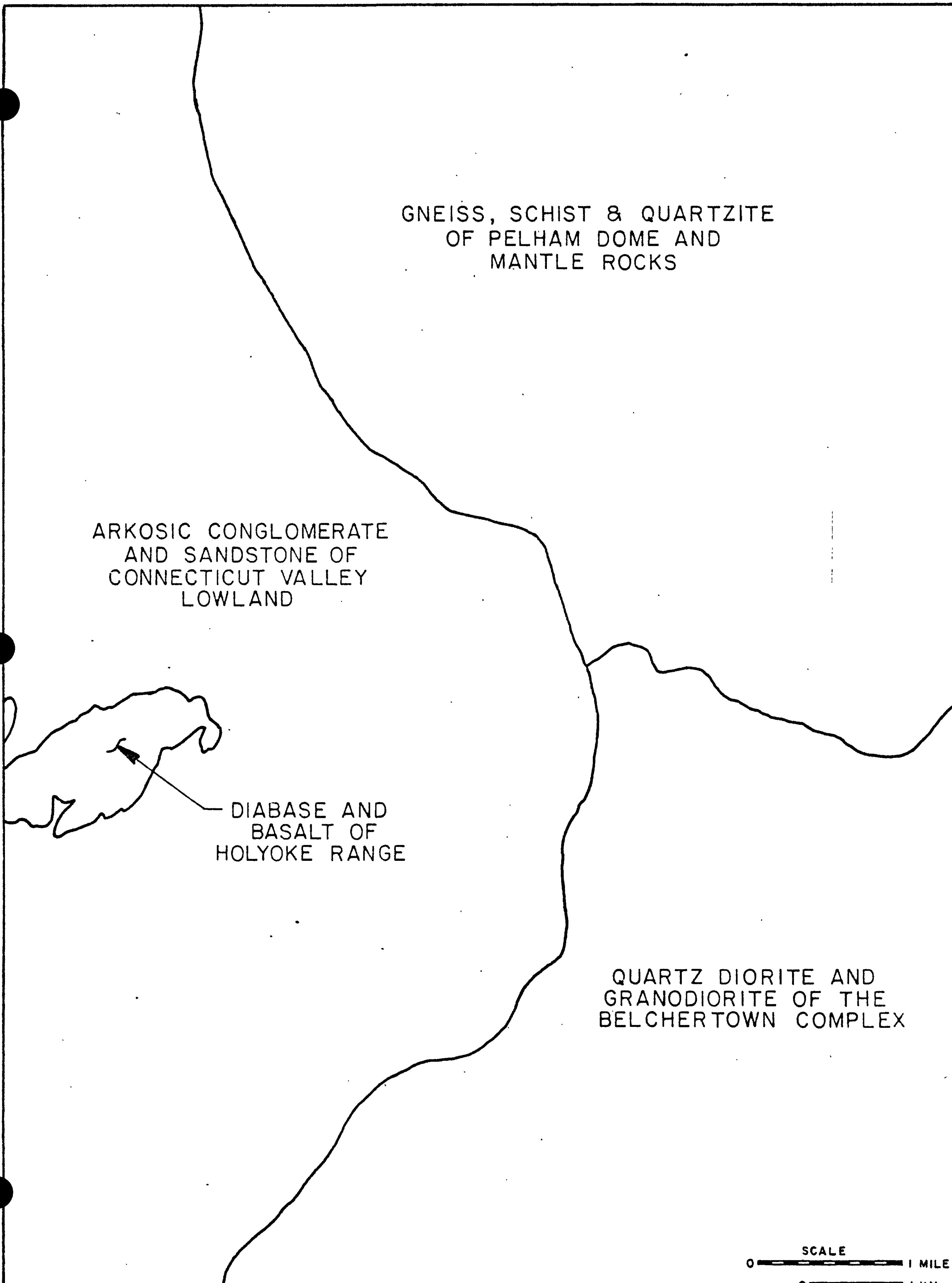



FIGURE 2 - GENERALIZED BEDROCK MAP

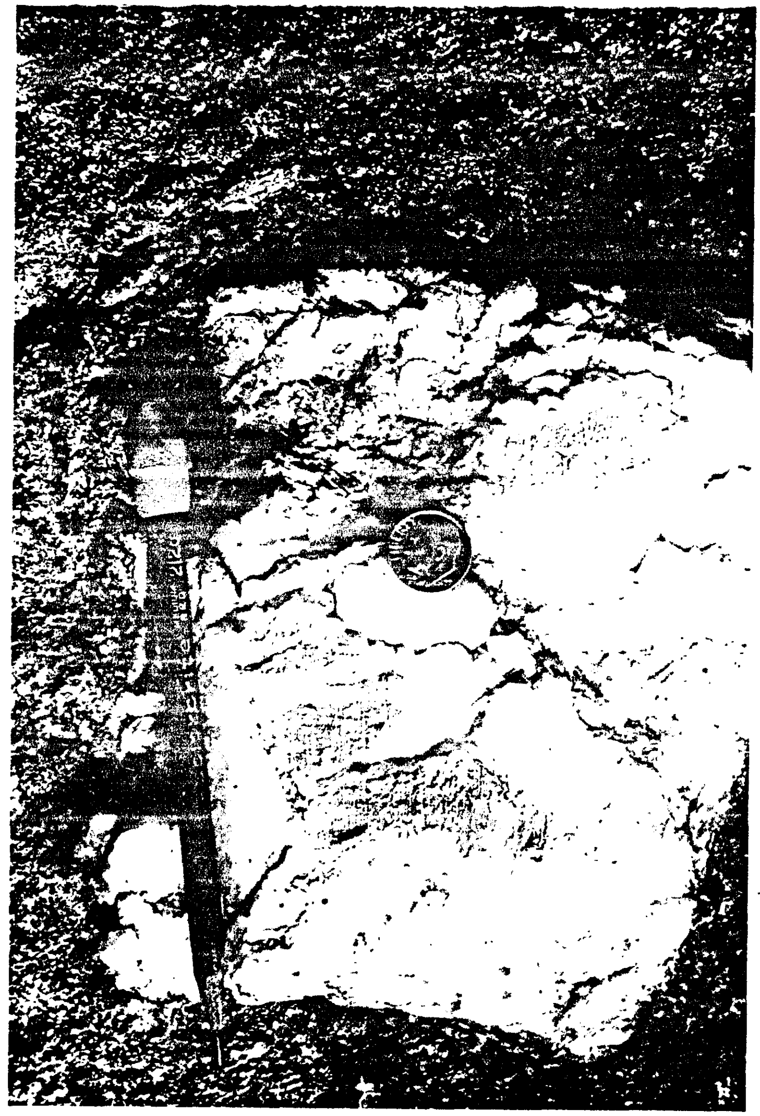


FIGURE 3 -- PENCIL-ENHANCED FINE STRIAE ON QUARTZITE PEBBLE IN ARKOSIC CONGLOMERATE. PENCIL POINTS IN DIRECTION OF GLACIER FLOW

FIGURE 4 -- FISSILITY IN SILT-RICH UPPER TILL

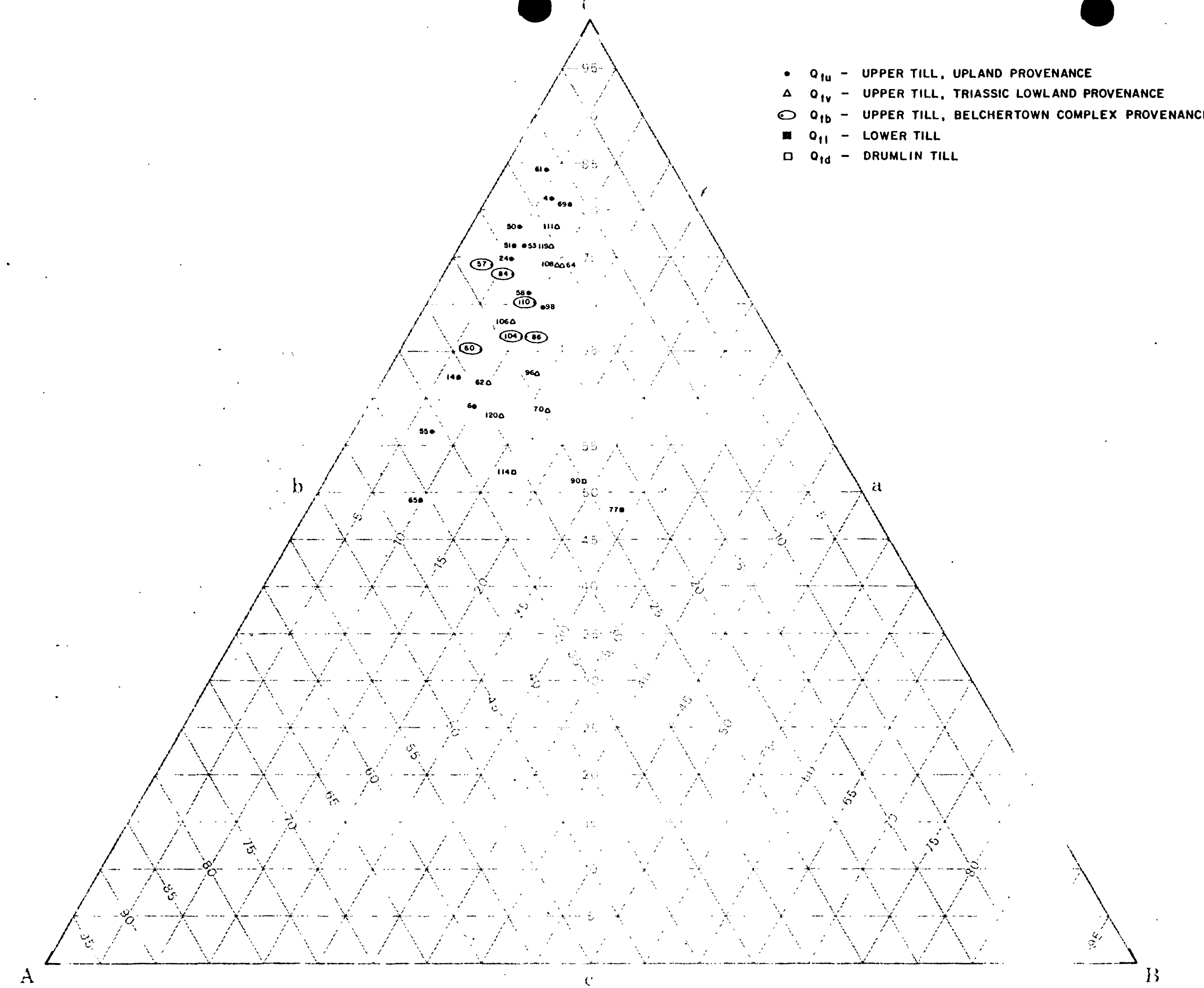



FIGURE 5 TILL OF THE BELCHERTOWN QUADRANGLE

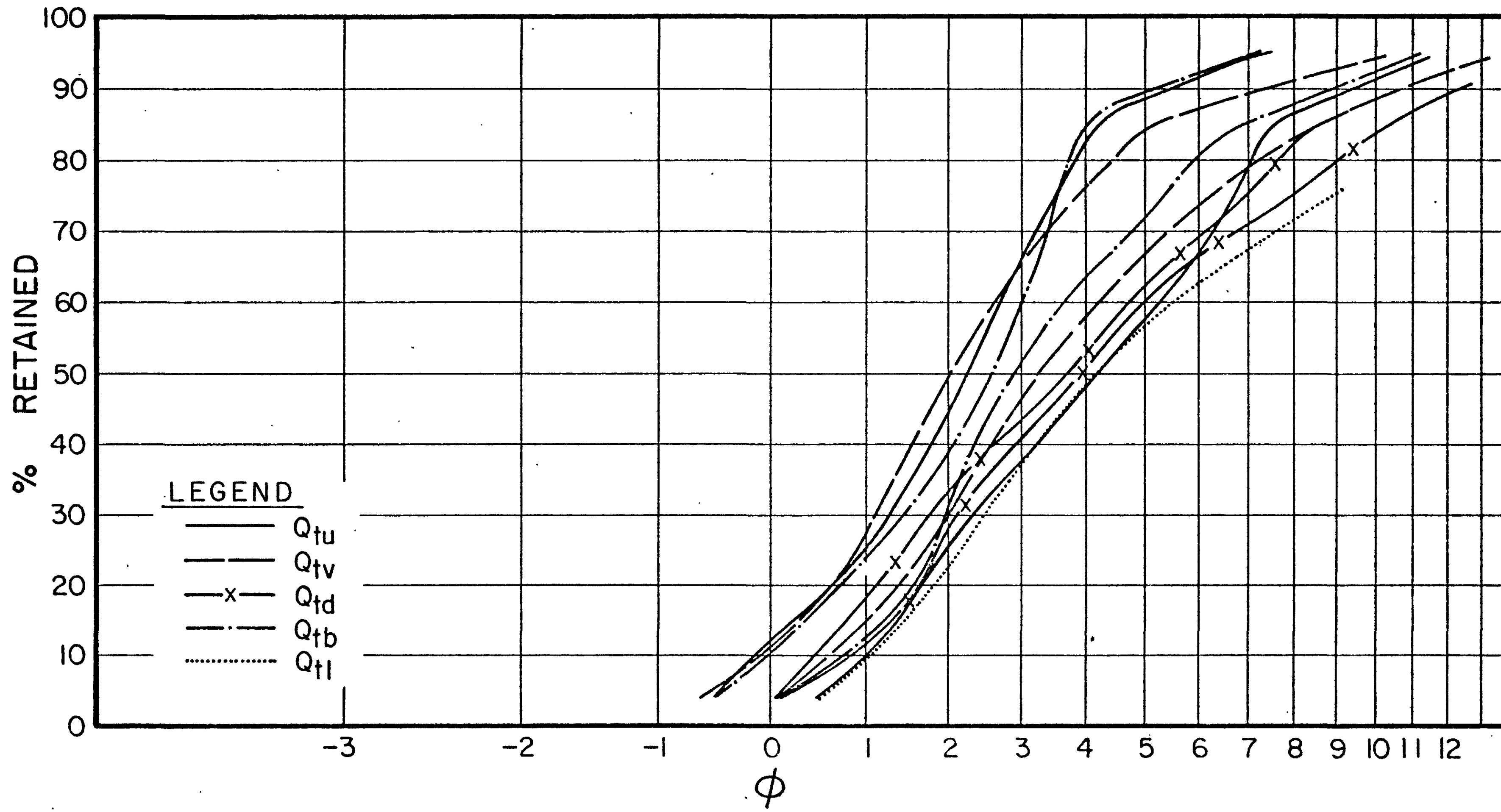



FIG. 6 TILLS OF BELCHERTOWN QUADRANGLE

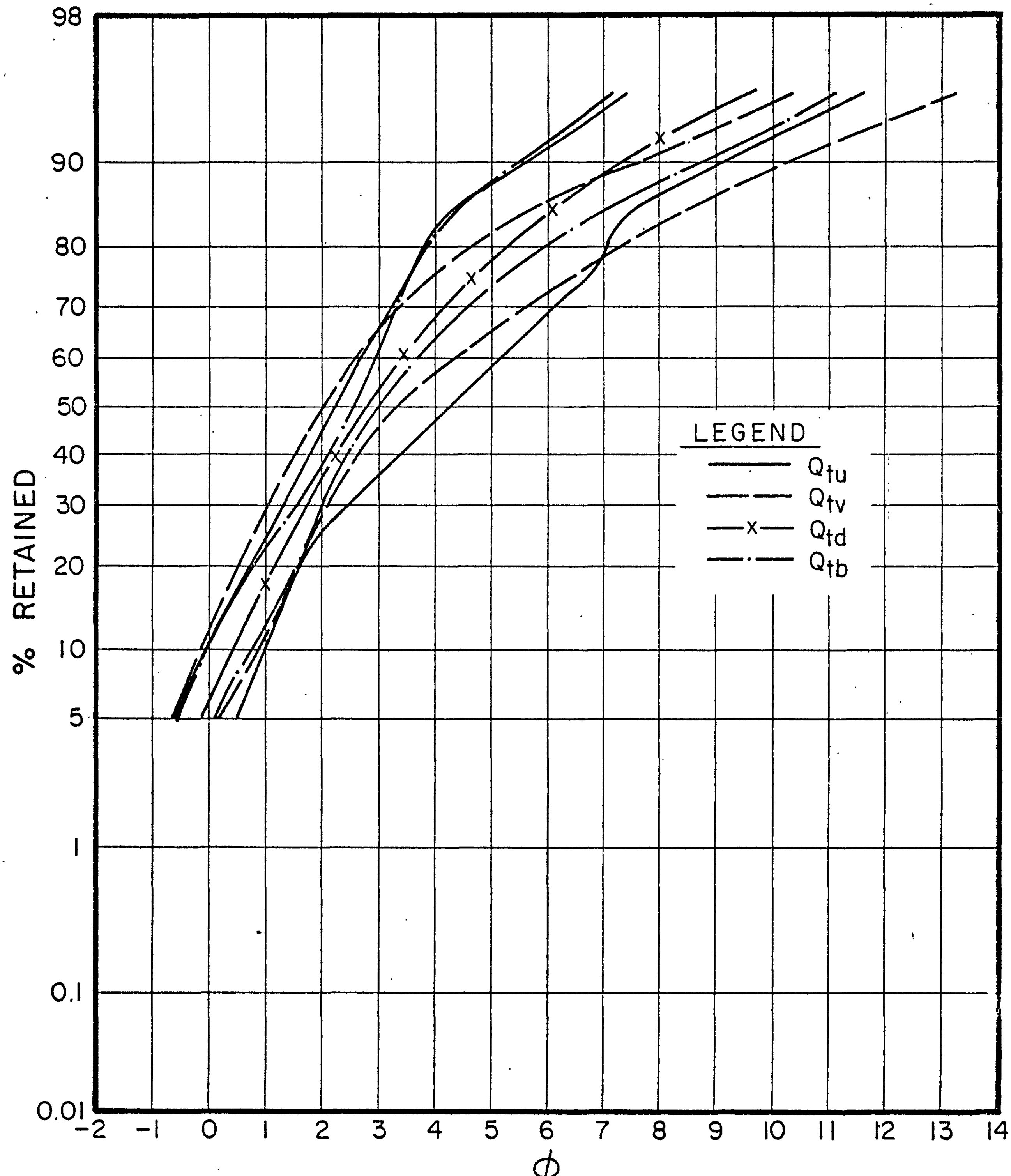



FIG. 7 TILLS OF BELCHERTOWN QUADRANGLE

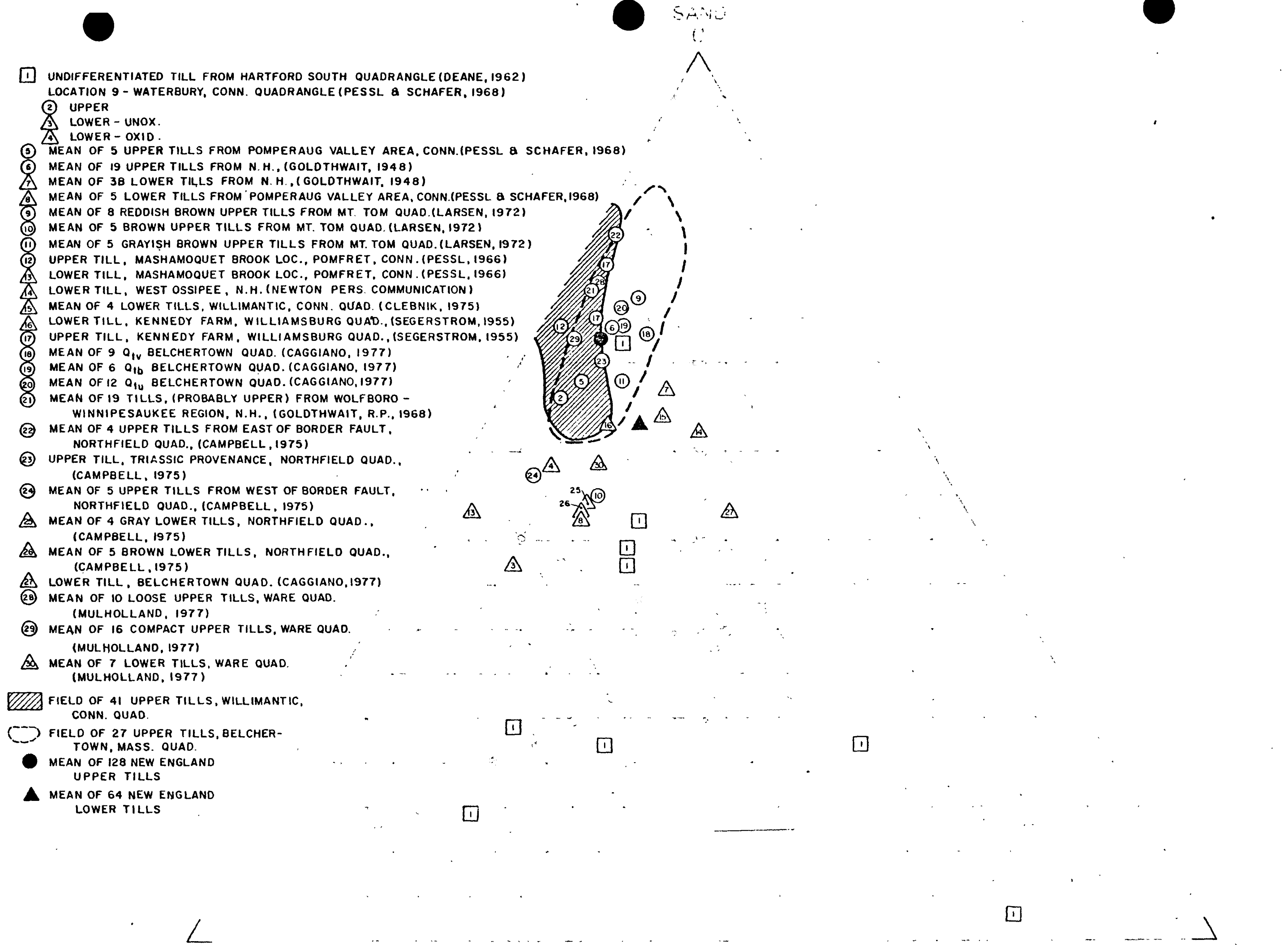



FIGURE 8 TILLS OF NEW ENGLAND (WENTWORTH GRADE SCALE)

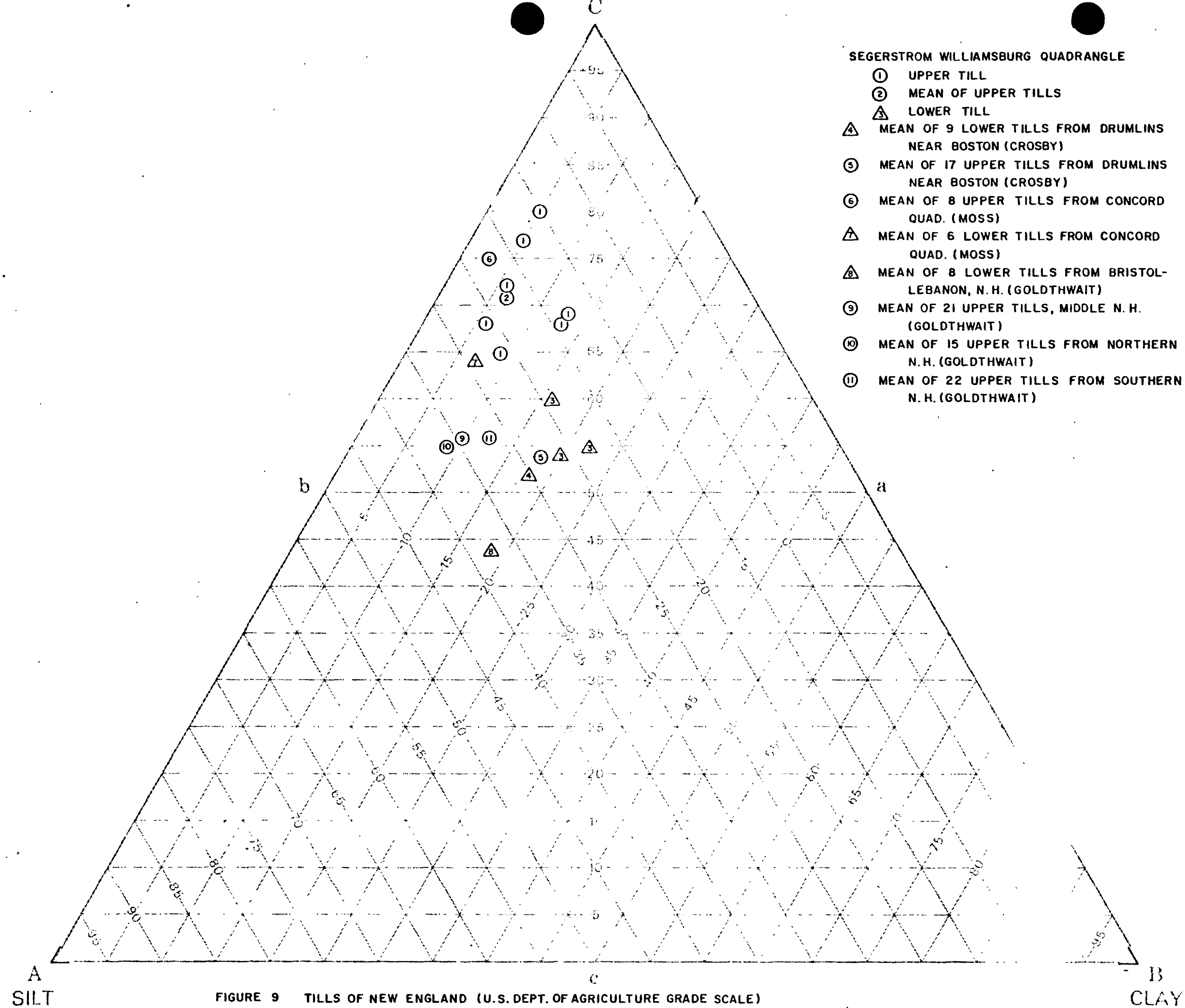



FIGURE 9 TILLS OF NEW ENGLAND (U.S. DEPT. OF AGRICULTURE GRADE SCALE)

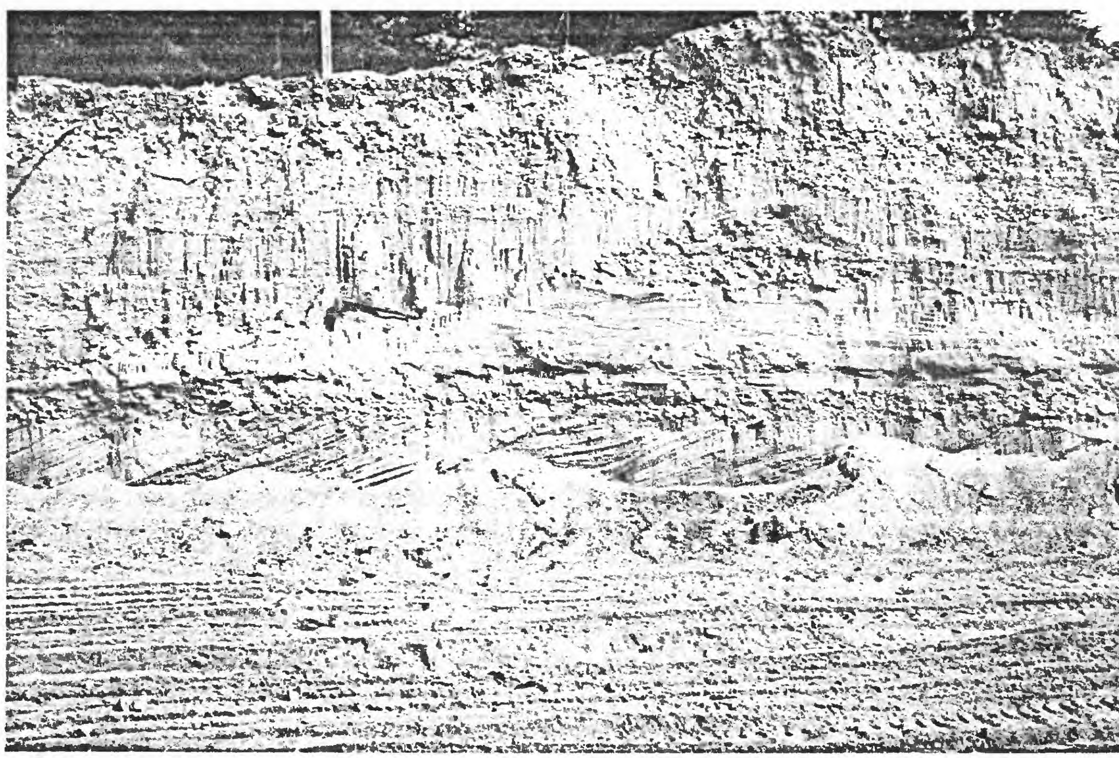


FIGURE 10 -- BRAIDED STREAM DEPOSITS IN KAME TERRACE

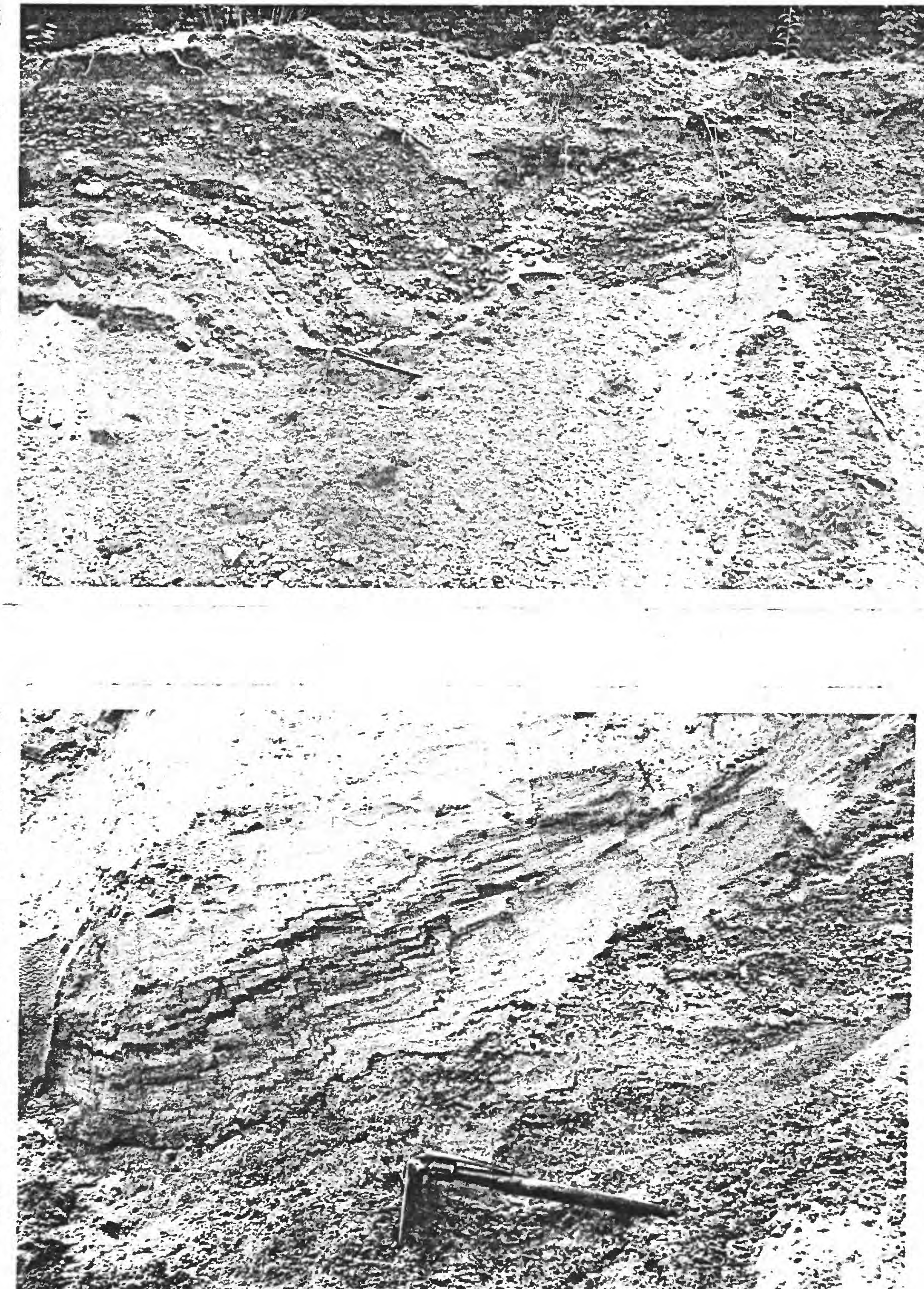


FIGURE 11 -- COLLAPSE IN ICE-CONTACT STRATIFIED DRIFT

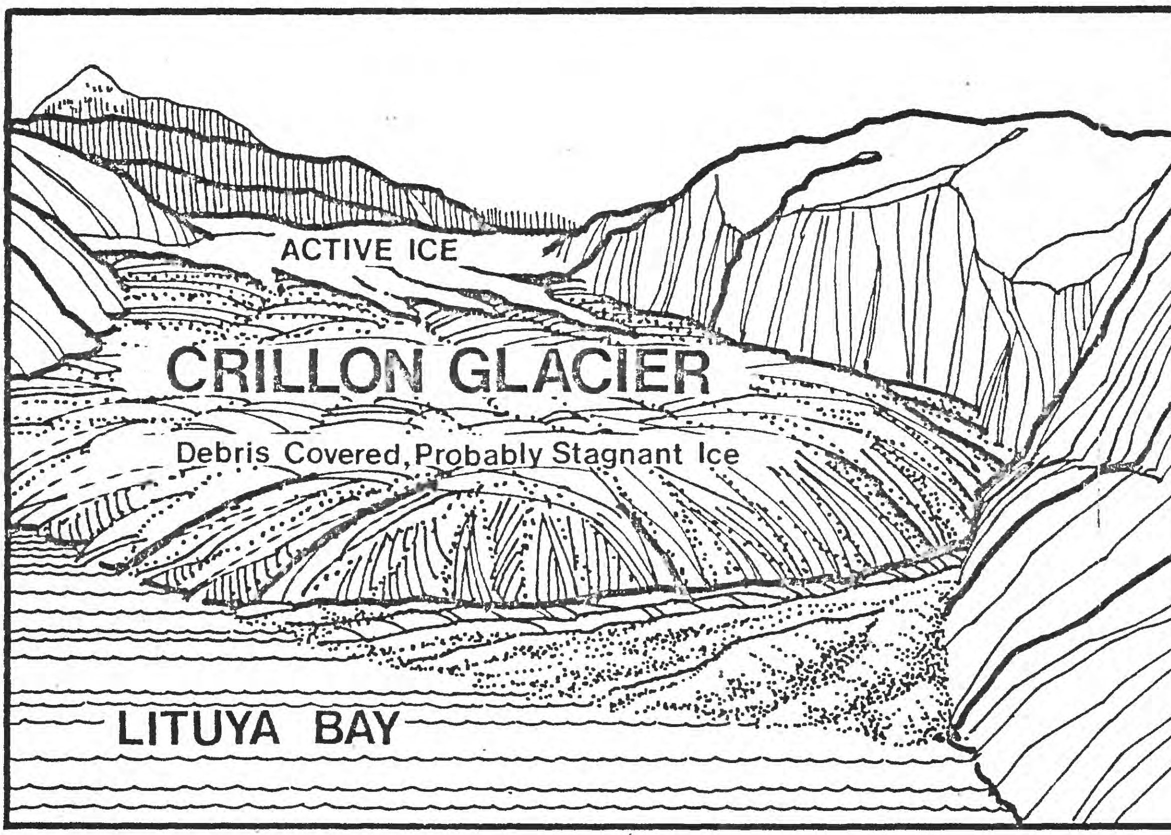



FIG. 12 DEPOSITIONAL ENVIRONMENT OF KAME TERRACE ALONG CRILLON GLACIER AND DELTA INTO LITUYA BAY, ALASKA. ANALOG OF DEPOSITIONAL ENVIRONMENTS IN BELCHERTOWN QUADRANGLE.

# EXPLANATION

## PLATE 2

## MATERIALS MAP

cg

### Cobble gravel

Gravel composed largely of cobbles, but commonly includes pebbles in varying amounts. Commonly in a matrix of sand which may constitute up to 50 % of the deposit. Frequently contains small boulders, especially in the upper few feet. Locally, small lenses of sand and silt may occur within.

pg

### Pebble gravel

Gravel composed largely of pebbles, but commonly contains cobbles in varying amounts. Commonly in a matrix of sand which may constitute up to 50% of the deposit. Locally, small lenses of sand and silt may occur within.

sg

### Sand and gravel

Sand and gravel interbedded such that neither material is clearly dominant. Locally, minor amounts of silt or clay may occur within.

s

### Sand

Generally moderately to well sorted sand, frequently containing pebbles and/or cobbles in varying amounts. Locally, minor amounts of gravel, or silt and clay may occur within.

f

### FINE DEPOSITS

Very fine sand, silt, and clay as heterogeneous mixture or as discrete moderate to well sorted and interbedded sand and silt or silt and clay. Locally, minor amounts of sand or gravel may occur within.

## TILL

Very poorly sorted, non-stratified, generally friable, non-compact silt, sand, pebbles and cobbles with some boulders and some clay. May contain thin local units of moderately sorted sand. Commonly less than 10 feet thick, but may be thicker in drumlins or basins in underlying rock. May overlie $t_c$ at shallow depth.

$\boxed{t_c}$

## CLAYEY TILL

Very poorly sorted, non-stratified, compact clay and silt with some sand and generally few pebbles and cobbles---occassional boulders. Common in drumlins and north slopes of steep ridges in Connecticut Valley Lowland.

$\boxed{sw}$

## SWAMP DEPOSITS

Clay, silt and sand with varying but usually high proportion of peat and decaying organic matter and few pebbles. Common in poorly drained areas. Thickness variable and largely unknown.

$\boxed{af(t)}$

## ARTIFICAL FILL

Natural earth material of variable composition emplaced by man for subgrade along roads, highways, bridge abutments, railroads etc. aft indicates trash fill at landfill sites.

NOTE: Generalized map of materials based upon limited observations in the field and on interpretation of topographic maps and aerial photographs. This map should be used for reconnaissance level planning only and should be preceded by additional field work where detailed site information is required.

(200)
R29,
no. 77-633

EXPLANATION

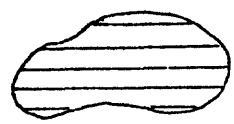
PLATE 3

BELCHERTOWN, MASSACHUSETTS QUADRANGLE

J. A. Caggiano, Jr.

Distribution of Bedrock Outcrops and Areas of Thin Drift, inferred maximum thickness 10 feet.

BEDROCK OUTCROP



THIN DRIFT

Area of abundant bedrock exposures where surficial deposits are thin (less than 10 feet).

SUBSURFACE DATA

⊙42

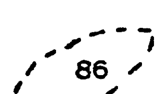
Location of drift-thickness data, number indicates depth to bedrock in feet.

⊙34°

Location of drift-thickness data. Number indicates depth of well or test boring which has reported refusal. Depth may be depth to bedrock, but should probably be considered minimum depth to bedrock.

⊙22⁺

Location of drift-thickness data. Number indicates depth of well or test boring which failed to reach bedrock.




Location of drift-thickness data. Number indicates mean depth to bedrock of several wells drilled in 1954. Wells were drilled in the general area outlined.

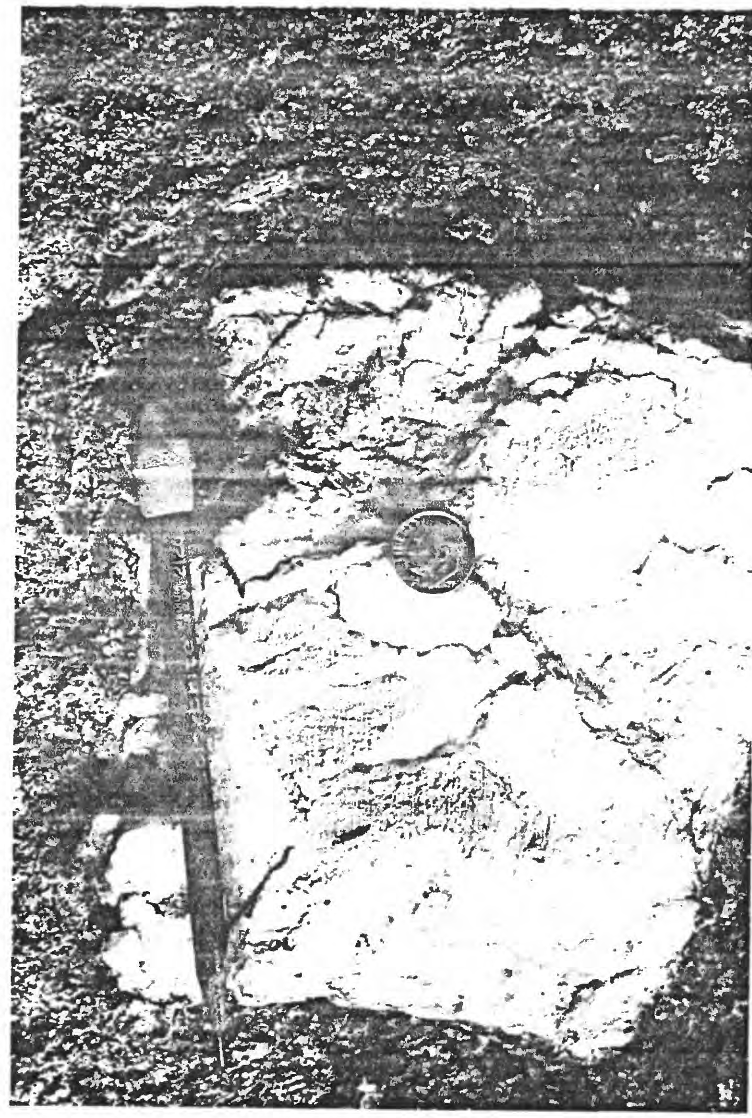


FIGURE 3 -- PENCIL-ENHANCED FINE STRIAE ON QUARTZITE PEBBLE IN ARKOSIC CONGLOMERATE. PENCIL POINTS IN DIRECTION OF GLACIER FLOW

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# EXPLANATION

## PLATE 1

## SURFICIAL GEOLOGIC MAP

A mantle of windblown silt and very fine sand which commonly contains pebbles and cobbles derived from underlying material and moved upward by frost action blankets the glacial deposits over much of the area. This mantle is commonly 18-24 inches thick, but may be thicker in places---especially at breaks in slope. THIS EOLIAN MANTLE IS NOT SEPARATELY MAPPED.

Holocene

Qs

SWAMP DEPOSITS

Sand, silt, and clay, commonly bluish-gray, with varying amounts of peat and organic matter. Occurs in poorly drained areas.

Qsp

SWAMP DEPOSITS

Swamp deposits where peat and organic matter are known to exceed three feet.

Qal

ALLUVIUM

Sand, silt, and gravel deposited along present floodplains. Stippled where poorly drained and includes organic matter in varying amounts.

Qst

STREAM TERRACE DEPOSITS

Sand, gravel, and silt deposited in postglacial time by streams graded to base levels higher than the present. Forms terraces along major streams.

GLACIOLACUSTRINE DEPOSITS

Qls

LACUSTRINE SAND

Well sorted and stratified lacustrine sand with minor amounts of gravel and silt deposited in or into Lake Lawrence during drainage of Lake Hitchcock.

STREAM DEPOSITS

Qf

ALLUVIAL FAN DEPOSITS

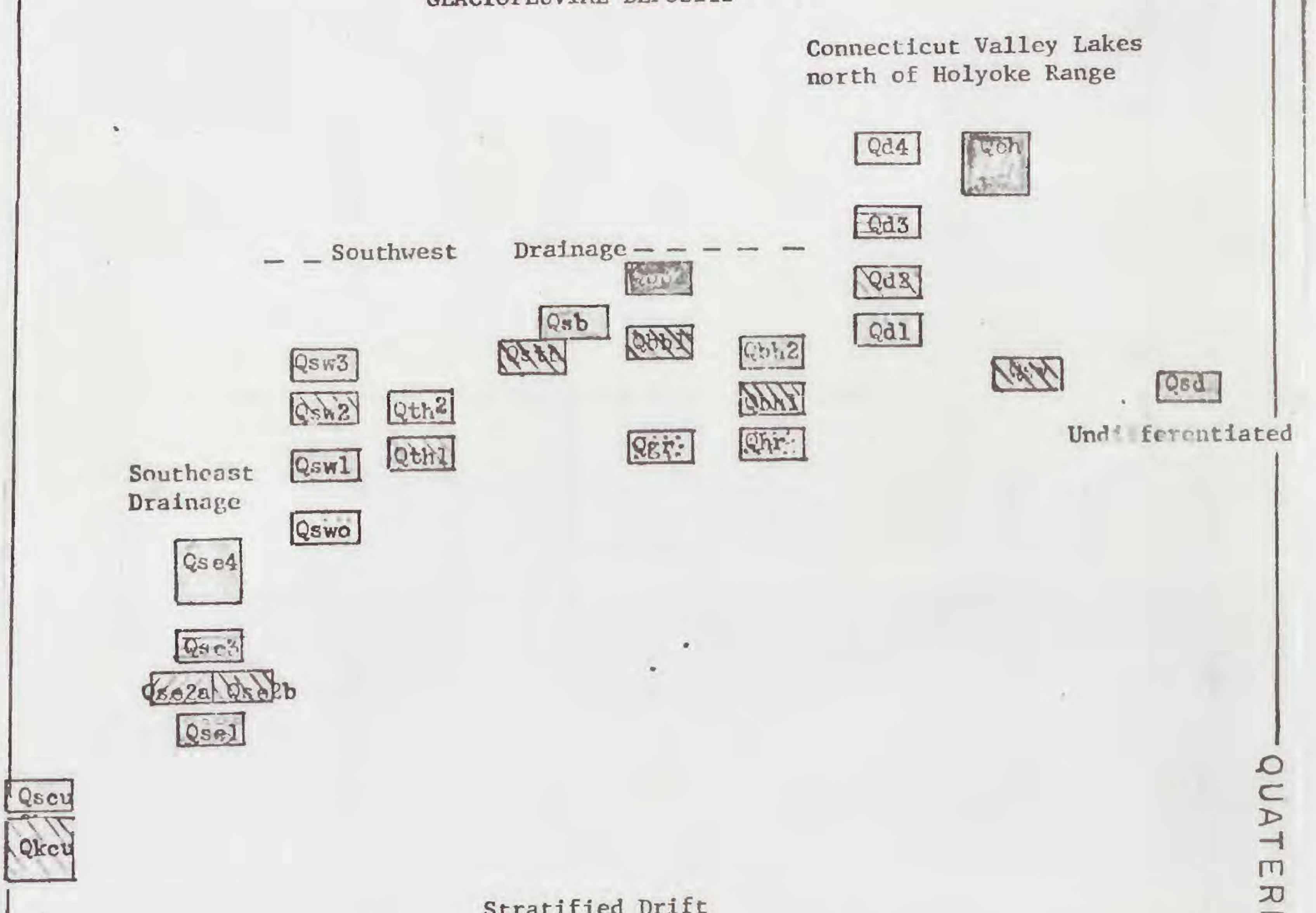
Moderate to well sorted sand and gravel deposited by streams on an alluvial fan during drainage of Lake Hitchcock.

Qlhs

LAKE HITCHCOCK SHOREWARD DEPOSITS

Moderate to well sorted sand and gravel deposited in shallow portions of Lake Hitchcock or immediate predecessors. Includes prodelta slope deposits and reworked ice contact glaciofluvial material, especially along north flank of Holyoke Range. Fluvial deposits of delta plain at distal ends of sequences are mapped as part of glaciofluvial deposits with which they are continuous.

GLACIOFLUVIAL DEPOSITS




QUATERNARY

Pleistocene

Stratified Drift

Sand, gravel and silt deposited in melt water streams and temporary lakes. Landforms include kame terraces, kame deltas, channel fillings and heads of outwash as mapped. Lacustrine units separately mapped. A numbered unit indicates deposits graded to a common base level. Some numbered units may represent composite of several melt water drainage stages, but collapse and post-depositional modification has obscured relationships. Numbers indicate relative order of deposition, with 1 oldest for any stage of drainage. Correlation and relative dating from area to area is tentative. Small local units not clearly related to an outlet and not part of sequence are indicated as Qsd.

## TILL

Poorly sorted, unstratified mixture of silt, sand, pebbles, cobbles, and boulders (with minor amounts of clay) deposited by glacier ice. May include minor amounts of washed sand in lenses or surficial veneer.

Qft

FLOWTILL

Till-like sediment deposited by mass movement of material off topographically higher ice mass. Also occurs as lenses and beds of till interbedded with sand and gravel where it is indicated by ft where not extensive enough to be separately mapped.

UPPER TILL

Granular, non-compact, stony and boulder sandy upper till which may locally be overlain by or include minor amounts of washed sand. Generally less than 30 feet and often less than 10 feet thick except in drumlins or basins in the underlying bedrock topography.

Qtv | Qtu | Qtb

Qtv--a pale brown to light reddish brown (Munsell Color Chart designation) facies of upper till derived from Triassic rocks of the Connecticut valley. Occurs in the western part of the area.

Qtu--a yellowish gray to light olive gray. (Munsell Color Chart designation) facies of upper till derived from Paleozoic granitic gneiss, quartzite, and schist of the eastern uplands. Occurs in the eastern part of the area.

Qtb--a greenish gray (color not on Munsell Color Chart) facies of upper till derived from the Belchertown tonalite and associated mafic rocks. Contains abundant amphibole and pyroxene. Occurs in the southeastern part of the area.

Qtd

Massive, compact, pale brown (Munsell Color Chart designation) clay and silt rich till with few clasts. Occurs in drumlins in the Connecticut valley and along the north slope of the Holyoke Range. Thickness commonly exceeds 20 feet in drumlins.

Qtl

LOWER TILL

Deeply weathered, jointed, fissile, well indurated, clay and silt rich till with few clasts. Staining with oxides of iron and manganese is common along joints. Exposed only at the base of one road cut and temporarily in excavations where it is indicated by t. Thickness unknown, but probably underlies upper till in many areas where no exposures occur.

## BEDROCK

TRIASSIC/JURASSIC

Stratigraphically unassigned unit(s) of Triassic arkosic pebble and cobble conglomerate. Single outcrop indicated by solid color; numerous outcrops in areas of thin drift indicated by ruled pattern.

Stratigraphically unassigned unit(s) of Triassic basalt, tuff, or diabase. Single outcrop indicated by solid color; numerous outcrops in areas of thin drift indicated by ruled pattern.

Pre-TRIASSIC

Paleozoic granitic gneiss and schist with minor amount of quartzite and pegmatite. Single outcrop indicated by solid color; numerous outcrops in areas of thin drift indicated by ruled pattern.

Artificial Fill

af---earth materials emplaced by man.

aft--trash fill emplaced by man in landfill sites.

Ruled pattern indicates areas where filling and grading have obscured the original materials and topography.

Contact

Dashed where approximately located; dotted where concealed.

Generalized shoreline of Glacial Lake Hitchcock in non-depositional areas. Based on measured topset-foreset contact and projection of "water plane" of Lake Hitchcock northward.

\+ + + + + +

Boundary of municipal landfill site.

Ŧ

Approximate location of Ŧ border fault. Ŧ on downdropped side.

Bouldery areas

Morphology

Outline (dashed where approximate) of topography considered to be a good example of a characteristic landform composed largely of stratified drift. Type of landform indicated by:

cf---ice channel filling

d---delta

kp--kame plain

Active Inactive

Borrow Pits

Extent of large pits shown by hachures. Small pits located at intersection of lines of symbol.

Inactive Quarries

Melt Water Spillway

Arrow shows inferred direction of flow.

Melt Water Channel

Arrow shows inferred direction of flow.

Striations

Point of observation at tip of arrow.

Drumlin

Streamlined, ice-shaped ridge composed largely of till. Long axis parallel to inferred direction of glacier flow.

Streamlined Ridge

Streamlined, ice-shaped ridge composed largely of bedrock. Long axis parallel to inferred direction of glacier flow.

MATERIALS CLASSIFICATION

| | |
|---|---|
| CG | Cobble Gravel |
| PG | Pebble Gravel |
| SG | Sand and Gravel |
| S | Sand |
| ST | Silt |

Unified Soil Classification System

| | |
|---|---|
| GW | Well Graded Gravel |
| GP | Poorly Graded Gravel |
| SW | Well Graded Sand |
| SP | Poorly Graded Sand |
| GM | Silty Gravel |

$$\frac{10'\ \text{PG (GW)}}{5'\ \text{S (SP)}}$$

Generalized stratigraphy of superposed materials in borrow pits. Generalized U.S.C.S. type shown in parenthesis.