Geology of the Taunton Quadrangle, Bristol and Plymouth Counties Massachusetts

By JOSEPH H. HARTSHORN

GEOLOGY OF SELECTED QUADRANGLES IN MASSACHUSETTS

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By Joseph H. Hartshorn

ABSTRACT

The preglacial history of the Taunton quadrangle of southeastern Massachusetts must be inferred from information on other parts of the Narragansett basin of Rhode Island and Massachusetts because the quadrangle is almost entirely covered with glacial deposits. About 25 outcrops of bedrock, consisting of sandstone, shale, and conglomerate of the Rhode Island Formation of Pennsylvanian age, occur in the area. Subsurface data indicate the existence of a large drift-filled preglacial valley below the Taunton River.

Light-gray, yellowish-gray, and pale-yellowish-brown till is exposed over about 20 percent of the Taunton map area. Most of the till is of subglacial origin and was derived predominantly from sandstone of the Rhode Island Formation.

Numerous glaciofluvial deposits in the area show evidence of having been laid down in contact with ice. The general arrangement of the glaciofluvial or glaciolacustrine deposits suggests stagnation of blocks of ice in low areas and the formation of glaciofluvial deposits around and over the blocks. Flat-lying, lens-shaped bodies of flowtill overlie or are interbedded with sand and gravel deposits of ice-contact origin.

Numerous kame plains, kame terraces, ice-channel fillings, kames and kame fields, and large bodies of stratified ice-contact deposits, not easily classifiable, indicate that isolated blocks of ice were present during their formation. Kame deltas and associated lake deposits, including varved clay, cover part of the quadrangle; some lake-bottom deposits are buried beneath younger outwash plains or swamps.

A nearly continuous mantle of eolian sand covers most of the quadrangle to depths ranging from 2 to 5 feet. In places, ventifacts, composed chiefly of Dedham Granodiorite and volcanic rocks, and abraded on all sides, are common throughout the eolian sand.

Intense frost action late in Pleistocene time is suggested by the wind-abraded ventifacts and by congeliturbate—a mixture of clean, well-sorted eolian sand and silt and the underlying stratified or unstratified drift.

INTRODUCTION

The Taunton quadrangle, in southeastern Massachusetts, contains a variety of glacial features whose interrelationship aids in establishing the probable mode by which the last continental ice sheet melted, and, at least in part, in reconstructing the late-glacial history.

The general geology of the Taunton quadrangle was mapped during a total of 135 working days in 1949, 1950, and 1951. The U.S. Geological Survey 7½-minute topographic sheet of the Taunton quadrangle was used as the base map. Aerial photographs were used to a limited extent. The composition and structure of the glacial deposits were observed in natural and artificial exposures. A 14-foot segmented hand auger was used where necessary in fine-grained materials, but it was useless in anything coarser than granule gravel.

ACKNOWLEDGMENTS

The study of the Taunton area was supervised by Prof. Kirk Bryan from its inception in 1949 until the death of Prof. Bryan in 1950. Some of the ideas stated in this paper should properly be credited to him. Frederick Johnson, of the R. S. Peabody Foundation for Archaeology, Andover, Mass., helped interpret the late-glacial chronology, and the Foundation provided financial help in 1949.

Most of the work on which this report is based was done as part of a cooperative program of the U.S. Geological Survey and the Massachusetts Department of Public Works. Mechanical analyses of sediments were made in the Department of Public Works soils laboratory.

GENERAL SETTING

The Taunton quadrange (fig. 1) is an area of about 55 square miles in Bristol and Plymouth Counties. It lies in the Seaboard Lowland section of the New England physiographic province (Fenneman, 1938) and is a region of relatively low relief. The highest point in the area is the crest of Prospect Hill, slightly more than 200 feet above sea level. Most of the topographic features are formed by the large sand and gravel masses that mantle parts of the area. The bedrock topography markedly affects the present landscape only in the eastern part of the quadrangle, where three elongate hills with relief of about 70 feet, 100 feet, and 110 feet show a crude northwest-southeast alinement.

About 18 percent of the area is covered by swamps, the largest being Hockomock Swamp, in the northern part of the quadrangle. One large body of water, Lake Nippenicket, occupies an elongate southward-trending extension of the swamp.

PRE-PLEISTOCENE GEOLOGY AND HISTORY

Pre-Pleistocene events in the Taunton quadrangle must largely be inferred from geologic knowledge of other parts of eastern Massa-

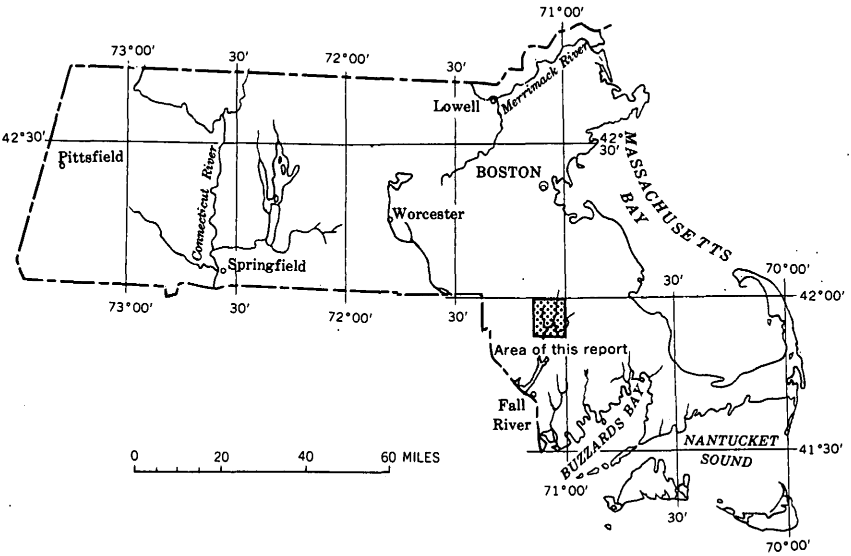

FIGURE 1.—Location of Taunton quadrangle (stippled).

chusetts. Thick deposits of drift obscure the irregularities in the preglacial topography, and bedrock is exposed in only about 25 outcrops, which cover less than 1 percent of the quadrangle. However, general conclusions concerning the pre-Pleistocene geology and topography can be drawn from the few bedrock outcrops and from depths to bedrock recorded in well data, seismic profiles, and wash borings.

STRATIGRAPHY

The Taunton quadrangle lies entirely within the Narragansett basin, a structural basin and topographic lowland that is partly submerged to the south by the waters of Narragansett Bay. The rocks in this basin are sedimentary and of Pennsylvanian age (Emerson, 1917, p. 50; Quinn and Oliver, 1962, p. 68) except for a few pre-Pennsylvanian inliers. Their aggregate thickness is 12,000 feet. Post-Pennsylvanian diabase is found in the Bridgewater quadrangle to the east (Hartshorn, 1960).

The Pondville Conglomerate of Pennsylvanian age, the oldest rock exposed in the basin, lies unconformably on older crystalline rocks (Quinn and Oliver, 1962, p. 63). On the northern rim of the basin where the Pondville Conglomerate is absent, the base of the section in most places consists of the red beds of the Wamsutta Formation, which includes sandstone, felsite, agglomerate, arkose, and shale (Chute, 1950a).

The Rhode Island Formation (Emerson, 1917, p. 54–55; Quinn and Oliver, 1962, p. 64–67) is the most extensive bedrock of the basin. It overlies the Pondville Conglomerate and the Wamsutta Formation, and in places rests directly upon the pre-Pennsylvanian crystalline rocks (Quinn and Springer, 1954). The formation generally consists of black shaly and slaty coal-bearing beds interbedded with variegated shale, sandstone, and conglomerate. The formation contains fossil plants—mostly ferns and seed ferns—ostracodes, pelecypods, worm trails and tubes, and insects of Middle or Late Pennsylvanian age (Emerson, 1917, p. 55; Quinn and Oliver, 1962, p. 67–68).

In the Taunton quadrangle, the Rhode Island Formation is the only bedrock exposed. It occurs in isolated outcrops of conglomerate, sandstone, shale, and slate; the colors are black, purple, blue green, green, or light gray. Because the outcrops are so widely distributed (pl. 1), and because the lithology varies greatly in short distances, only the larger structures have been recorded. However, the data given below may add to the total knowledge of the Narragansett basin.

Bedding at three outcrops of blue-gray to gray fine-grained sandstone, shale, and conglomerate in the northwestern part of the quadrangle strikes northeast. The sandstone at T1[1] contains many scattered pebbles up to half an inch in diameter. In a coarse gray sandstone just north of the quadrangle boundary, lenses of conglomerate contain particles of shale and phyllite and pieces of detrital feldspar up to one-fourth inch in diameter. Chute (1950a) stated that a specimen taken near T1 was composed of 60 percent angular to subangular grains of quartz, 20–25 percent feldspar (much of which is plagioclase), 15 percent sericite, and minor amounts of carbonate and muscovite.

The southern part of outcrop T2 is generally fissile shale and includes some thin lenses of very fine- to fine-grained sandstone. The northern part of this rocky area is sandstone that contains numerous lenses of conglomerate.

In the north-central part of the quadrangle, the New York, New Haven, and Hartford Railroad goes through a 20-foot-deep cut in bedrock (outcrop T3) for about 1,200 feet. Here the Rhode Island Formation is a dark-gray medium- to coarse-grained micaceous sandstone containing numerous scattered cobbles and pebbles and some pebble layers. One thick layer of sandy pebble conglomerate ranges from 10 to 14 inches in thickness, strikes north, and dips 5° E.; other pebbly beds are nearly horizontal. Toward the north end of the outcrop, a lens of conglomerate contains ovoid pebbles up to 3 inches in

[1] Outcrops are labeled T1–T22 on plate 1 for ease of reference.

diameter. In general, the bedding in this lens is nearly horizontal, although dips of as much as 28° appear for short distances. Slickensides on the underside of one ledge plunge 28° S. 10° E.

Fine to very coarse grained sandstone containing pebbles up to 1 inch in diameter occurs in several abandoned quarries in the west-central part of the map area (outcrop area T4). These rocks strike N. 15° W. and dip 6° N. Two-dimensional reddish-brown rusty forms that appear to be carbonized plant remains may be seen on bedding planes. Sheeting nearly parallel to the bedding and to the surface of the ground is evident in one quarry.

There is a bed of gray sandstone containing isolated pebbles and layers of pebble and cobble conglomerate at outcrop T5. Bedding is obscure because the conglomerate occurs in short thick lenses. Pebbles in the conglomerate are as much as 3 inches in diameter.

Outcrops at T6, T7, and T10 are sandstone and conglomerate. Massive gray fine-grained sandstone and shale crop out at T8, and gray-green fissile shale crops out at T9.

In an abandoned bedrock quarry at T11, a gray massive coarse-grained sandstone is exposed, and similar rock crops out at T12, about 2,100 feet to the south. In neither of these outcrops is the bedding apparent.

Interbedded shale and sandstone lenses occur in a conglomerate exposed at T13. Many of the pebbles and cobbles in the conglomerate are composed of quartzite. Some of the shale and sandstone lenses strike N. 73° E. and dip 55° S., but the attitude of the bedding is not consistent.

In an abandoned quarry east of Johnson Street (T14), gray-blue fissile fine-grained sandstone is exposed. Drusy quartz and epidote are present on fracture planes in the rock.

Outcrop T15, in the southeastern part of the quadrangle, consists of fine-grained slightly metamorphosed sandstone that splits rather easily into slabs. Mica is concentrated along the fracture planes. If these are bedding planes, the rock strikes N. 75° W. and dips 15° N., but if differential weathering along other planes indicates bedding, the strike may be about N. 60° W. and the dip 10° S.

The western outcrop at T16 is composed of small-cobble conglomerate interbedded with shale. The eastern outcrop is composed of sandstone and beds of cobble conglomerate.

An outcrop was noted by Woodworth (in Shaler, and others 1899, p. 200) at T17. The rock is a gray medium-grained sandstone containing 10- to 12-foot beds of pebble and cobble conglomerate; the phenoclasts are up to 6 inches in diameter but average about 2 inches.

Most of the pebbles and cobbles are composed of quartz and quartzite; a few are pink felsite.

Outcrops of grayish-purple fine-grained sandstone at T18 and gray coarse-grained sandstone containing pebble bands at T19, together with seismic data, outline the bedrock core (pl. 1) of the hill at Locust Street in Taunton. A similar bedrock core is indicated by T20, on Orchard Street north of U.S. Route 44; this outcrop is described on page D9.

Gray-blue slate and interbedded fine- to medium-grained sandstone beds form a ridge about 400 feet long and less than 100 feet wide in the northeast corner of the quadrangle (T21). Quartz veins as much as 1¼ inches thick occur along several sets of joints. Small beds and lenses of sandstone in the general mass of slate and shale strike about N. 65° E. and dip 45° S. Cleavage is prominent in the outcrop; in the shale near the south end of the bedrock ridge the cleavage strikes N. 80° E. and dips 22° N., and in sandier material near the north end, strikes N. 80° W. and dips 40° N.

Woodworth (in Shaler, and others 1899, p. 197) described this outcrop as follows: "* * * pebbly sandstones strike nearly east-west and dip about 20° north, forming a low monoclinal ridge with an escarpment facing south." Apparently Woodworth misinterpreted cleavage as bedding.

In a hill near Scotland at T22, gray shale crops out in a ditch, indicating that the hill has a bedrock core.

Just south of the quadrangle, conglomerate was exposed 5 feet below the surface of County Street, in a bridge excavation. The conglomerate is composed of pebbles and cobbles of granite, shale, quartzite, sandstone, and fine-grained volcanic(?) rock in a matrix of medium- to very fine-grained sandstone. The pebbles and cobbles are spheroidal to ovoid in shape and usually break free from the matrix when the rock is crushed or broken. The rock, however, may break through the pebbles instead of around them; the large stones appear to break free more easily than the smaller stones. The rock fits the description of the Dighton Conglomerate (Woodworth, p. 184, in Shaler, and others 1899). Therefore, the syncline in which the Dighton Conglomerate was named may extend almost to the southern border of this quadrangle. This cannot be proved until more detailed bedrock mapping is done in the Assonet and Somerset quadrangles.

STRUCTURE

An anticline may be present in the northern half of the Taunton quadrangle. The probable axis extends east-northeast from west of the quadrangle near Watson Pond, through the bedrock outcrops at

T3, and eastward. The axis of a northeastward-striking syncline may enter the quadrangle near the southwest corner and continue east near the Taunton Court House and north of Forest Street (Raynham) near the east edge of the quadrangle. This may be the Taunton syncline (Quinn and Oliver, 1962, p. 70), which strikes toward Taunton from the Norton quadrangle to the west where its presence is indicated by large outcrops of Dighton Conglomerate. More mapping to the south and west may help to clarify the structure of the Taunton area, but details will probably remain obscure because exposures are so few.

GEOLOGIC HISTORY

The Pennsylvanian rocks probably were deposited in the broad crustal downwarp of the Narragansett basin. This basin must have been separated from the sea during all of Pennsylvanian time, because the rocks of Pennsylvanian age in the basin contain nonmarine fossils (Shaler, and others, 1899, p. 202). A general uplift near the end of the Pennsylvanian Period is indicated by the presence of coarse conglomerates that are now the youngest rocks exposed in the area. The folding of the original basin may have been related to a late phase of the Appalachian Revolution, perhaps in Permian (?) time (Quinn and Oliver, 1962, p. 70).

Unconsolidated sands containing glauconite are exposed in the Marshfield Hills area of the Duxbury and Scituate quadrangles, about 22 miles northeast of Taunton (N. E. Chute, oral commun., 1955). These beds are probably either Tertiary or Cretaceous in age (Bowman, 1906, p. 313) and may have extended inland across the Taunton quadrangle. However, uplifts in the Tertiary Period and subsequent erosion resulted in deep dissection of central and eastern Massachusetts and the removal of the sediments from the Taunton area.

Valleys that were formed in the Narragansett Bay area and then were filled with glacial deposits are now well below sea level, indicating that the preglacial land surface was much higher, relative to sea level, than the present land surface. The Taunton River flows above a preglacial valley (pl. 1), whose floor, now covered with glacial drift, is generally about 30–60 feet below sea level. The gradient in the ancient valley has not been determined. In the Bridgewater quadrangle to the east, the Taunton River flows on bedrock at about 10 feet above sea level (Hartshorn, 1960). Northeast of this shallow-bedrock area the Taunton River flows over a preglacial depression that is at least 65 feet below sea level. Hence, the preglacial valleys in the area do not exactly determine the present course of the Taunton River.

PLEISTOCENE GEOLOGY

Unconsolidated deposits of Pleistocene age mantle almost all the Taunton quadrangle. The southeast-moving ice sheet eroded and broke up the bedrock, transported it a short distance, and deposited it as till. Stratified deposits, here classified by landform, are present in great variety. The pattern of ice-contact deposits, proglacial deposits, and glaciolacustrine deposits has been used to reconstruct a late-glacial chronology for the area.

GLACIAL EROSION

Evidence of glacial erosion of bedrock in the Taunton quadrangle is provided by the enormous masses of glacial drift. The unweathered condition of nearly all the stones and the matrix of the stratified and unstratified drift deposits suggests that the material must have been derived from unweathered bedrock. The glacial drift may represent several ice advances, each of which contributed to the bulk of the unweathered material.

The tremendous erosive power of the ice sheet is shown by a glacial boulder just north of the bedrock quarry near Whittenton Junction. The boulder, called Castle Rock by the local inhabitants, measures approximately 29 by 33 by 19 feet. It is composed of sandstone and of pebble and cobble conglomerate whose phenoclasts average about 3 inches in diameter. Outcrops of similar rocks are located about 4½ and 9 miles to the northwest; the more distant are in the Norton and Mansfield quadrangles (Woodworth, in Shaler and others, 1899, p. 196). Therefore, the ice sheet must have moved the boulder at least 4½ miles.

Very deep glacial erosion has been postulated for some places in New England. At Iron Hill, R.I., Shaler (1893, p. 208) estimated that 300 feet of rock had been removed from the hill. In Massachusetts, the relatively soft rocks of the Narragansett basin must have yielded to the glaciers. As it is only a short distance from the north edge of the basin to the Taunton quadrangle, a large amount of material from the Rhode Island Formation must have been dragged up into the ice, released, sorted, and deposited by glacial streams as glaciofluvial and glaciolacustrine landforms.

Jahns (1943) used the relation between sheet structure in granites and existing topography to demonstrate that, in general, 10–15 feet of rock and preglacial regolith were removed by glacial plucking and abrasion from the stoss (north) slopes of most hills in northeastern Massachusetts. A somewhat greater amount was eroded from the summits and east and west slopes of the hills. The deepest erosion took place where well-jointed granites and a steep preglacial slope on the lee side of the hill favored plucking. The maximum demonstrable localized erosion is in excess of 100 feet (Jahns, 1943, p. 94).

Glacial erosion was not so effective everywhere in New England. In numerous localities—for example, in southern Rhode Island (J. P. Schafer, oral commun., 1960)—the ice sheet did not erode preglacial weathered rock. Just west of the intersection of U.S. Route 44 and Orchard Street in Taunton, an excavation for a highway disclosed the presence of deeply weathered rock that has been preserved beneath unweathered till. A section shows:

	Inches
Till, grayish-yellow (oxidized) to light-gray (unoxidized)	36
Sandstone, medium- to fine-grained, gray, soft, weathered; shaly layers	26
Sandstone, medium- to coarse-grained, yellowish-gray, soft, weathered; complexly intermingled with clay streaks	28
Sandstone, fine-grained, gray, somewhat soft, weathered	18
Conglomerate; material granule to very small pebble size; mostly gray; some iron staining; soft; weathered	13
Clay, gray to brown; grades upward into fine-grained sandstone	2
Sandstone, medium to very coarse grained, gray; contains unoriented irregular streamers of clay	14
Clay, laminated, blue-gray; interbedded with lenses and stringers of fine sand	6

A good exposure nearby shows an upward gradation from shale into blue clay similar to that found in the section. The presence of unweathered till at the top of the cut shows that the material below was weathered before the most recent glaciation. Hence, soft materials are not necessarily deeply eroded, even though elsewhere in the quadrangle the depth of erosion and the size of joint blocks plucked away by the glacier may be considerable.

Direct evidence of glacial abrasion was found about a mile south of Lake Sabbatia, where quarry operators had stripped the cover of till and glaciofluvial sand from the bedrock. Striations in the bedrock surface occur at several places around the quarry and are oriented S. 30° E. The one mapped drumlin in the area and several till-mantled bedrock-cored hills are similarly oriented.

GLACIAL DEPOSITS

TILL

According to Flint (1957, p. 109), glacial deposits form a textural series that ranges from stratified and well-sorted glacial drift (glaciofluvial deposits) to unstratified and poorly sorted or nonsorted debris (till). Between these two end members, there is an indeterminate zone in which sediments grade from recognizable stratified drift to sediments that may be either glaciofluvial deposits or till. Furthermore, sand and gravel lenses occur in, and were formed as an integral part of, otherwise unstratified and unsorted till. The scale of the map prevents a precise delineation of all patches of stratified and unstratified drift; therefore, mapping some areas of poorly sorted and stratified glaciofluvial deposits as very sandy till and omitting small kames and terraces may slightly distort the glacial history.

Previously published maps of surficial geology in New England have shown the general covering of till as ground moraine (Chute, 1950b; Jahns, 1953) or as till (Goldsmith, 1962). Flint (1957, p. 131) noted that thin till lacking topographic expression other than that of the immediately underlying bedrock surface is not properly called ground moraine—it is a stratigraphic unit rather than a topographic unit. Till in the Taunton quadrangle has modified the preglacial topography so that the present landforms are more smoothly contoured than the underlying irregular bedrock topography. Hence, the general till cover is mapped as ground moraine.

Ground moraine also implies accumulation beneath a glacier. Possibly, however, at least some part of the till in the Taunton quadrangle accumulated as superglacial debris let down onto the substratum. No sure criteria have been found to distinguish between lodgement till, which is till that has accumulated at the bottom surface of the glacier, and ablation till, which is till that has made its way down onto the substratum as the ice melts away. In the absence of definite proof of superglacial origin, it is assumed that the greater part of the till cover is of subglacial origin and is indeed ground moraine.

The distribution of areas blanketed by till is shown on plate 1. In many places the distribution is directly related to bedrock hills, as on the southeast-trending ridges in the southeast quarter of the quadrangle and in the area south of Scotland, in the northeastern part of the quadrangle.

The color of the till in the Taunton quadrangle varies from dusky yellow to light brown under field conditions—that is, under varying conditions of moisture. However, samples dried and compared under the same light source differ very little. The colors are generally light gray, gray, yellowish gray, and pale yellowish brown (Goddard and others, 1948). Mottling is common in some of the tills and produces a moderate-yellowish-brown color in a lighter colored matrix.

Macroscopic estimates and grain-size analyses show that, in general, the matrices of these tills are dominantly sandy to silty. The rock fragments in the till generally are angular to subangular, and many of them have been modified by glacial abrasion. Numerous fragments are striated on one or more surfaces.

Glacial erratics of granite, granodiorite, and several types of volcanic rocks are found in the quadrangle. These are more numerous in the north, close to the north edge of the Narragansett basin. Most of the large boulders that rest on or project through the till are composed of sandstone and conglomerate from the underlying Rhode Island Formation. The surfaces of some of these large boulders and erratics have been polished and carved by windblown sand.

FIELD AND LABORATORY DATA

In addition to color, induration, pebble lithology, and other physical properties, grain-size analyses have been used as a basis for distinguishing between various types of tills in Massachusetts (Crosby, 1891; Segerstrom, 1955; Moss, oral commun., 1948). Similar analyses have been made for till in New Hampshire (Goldthwait, 1948). Most of these grain-size analyses used only four grades,[2] and cumulative curves based on so few points do not give a satisfactory base for statistical comparison with other samples.

Mechanical analyses were made of 23 samples from the Taunton quadrangle and of 1 from the adjacent Bridgewater quadrangle. The results of these analyses were then compared with the results of many analyses made by other geologists.

Only the matrix of the till was analyzed. Samples contained rocks up to pebble size but were chosen to define the textural character of that part of the till matrix smaller than 64 mm. The Wentworth size classification (Wentworth, 1922) is used in this report for general description of the sediment grain sizes.

In the laboratory, the samples were dried and then examined under artificial light. Color, mottling, fissility, and a crude measure of resistance to crushing (dry strength) were recorded. The crushed sample was placed in a set of U.S. Standard sieves and agitated in an automatic shaking machine. Material passing through the 0.053-mm sieve was placed in suspension in a column of water in a large glass cylinder. Particles finer than 0.005 mm were separated by decanting.

Eight, or less commonly nine, points plotted from this operation were close enough together to illustrate the continuous size-frequency distribution. The sorting coefficient (So) is that of Trask (1932), and is a geometric quartile deviation based on the ratio between quartiles found by using the equation:

$$So = \sqrt{Q_1/Q_3}$$

The sorting coefficient is a ratio between the quartiles; hence, the size factor and the units of measurement are eliminated, and sorting can be used to describe the spread of the curve. Sorting coefficients for different samples cannot be compared directly, however, because

[2] Gravel, > 1 mm; sand. 0.05–1 mm; silt, 0.005–0.05 mm; clay 0.001–0.005 mm.

the sorting coefficient (*So*) increases geometrically. The logarithms of *So* form an arithmetic series, and, by use of the $\log_{10}So$, samples, can be directly compared with one another (Krumbein and Pettijohn, 1938, p. 232).

The shape of the cumulative curves, and the medians, sorting coefficients, and $\log_{10}$ of the sorting coefficients are useful tools for comparing till samples. Such data, both published and unpublished, can be used to compare tills from many parts of New England and may help to establish the origin of the numerous types of till.

GROUND MORAINE

Till samples were gathered from five geographic areas: (1) the north-central area, where a cluster of till exposures was found north of the town of Raynham, (2) the Pine Street area, about 2½ miles east of Raynham, (3) the southwestern area, where there is a series of isolated till outcrops, (4) the southeastern area, where till occurs in a large area east of Raynham Center as well as in some isolated outcrops, and (5) the Orchard Street hill. Flowtill is discussed separately.

North-central area.—The north-central area is apparently a bedrock high covered with till. Five samples of the till were analyzed (fig. 2), and statistical measures derived from the cumulative curves are listed in table 1.

TABLE 1.—*Statistical measures of till samples*

Sample	Median (mm)	Q_1 (mm)	Q_3 (mm)	Sorting coefficient (*So*)	$\log_{10}So$
1	0. 460	3. 00	0. 088	5. 83	0. 766
2	. 385	1. 40	. 092	3. 90	. 591
3A	. 265	. 56	. 077	2. 70	. 431
4	. 123	. 305	. 053	2. 40	. 380
5	. 400	1. 15	. 105	3. 32	. 521
6	. 070	. 50	. 070	4. 15	. 618
7	. 400	4. 10	. 029	7. 66	. 884
8	. 265	. 80	. 085	3. 07	. 487
9	. 540	2. 10	. 084	5. 00	. 699
10	. 340	1. 43	. 068	4. 69	. 671
11	. 340	. 807	. 160	2. 25	. 352
12	. 193	. 46	. 030	3. 91	. 592
13	. 247	1. 03	. 079	3. 61	. 558
14	. 250	. 86	. 088	3. 13	. 496
15	. 280	1. 20	. 050	4. 90	. 690
16	. 210	. 96	. 023	6. 45	. 810
17	. 120	. 44	. 041	3. 27	. 515
18	. 245	1. 06	. 032	5. 75	. 760
19	. 225	. 80	. 059	3. 69	. 567
20	. 662	2. 65	. 084	5. 62	. 750
21	. 600	1. 80	. 187	3. 09	. 490
22C	. 210	. 75	. 073	3. 21	. 505
23	. 118	. 345	. 029	3. 45	. 538
24	. 680	5. 00	. 115	6. 60	. 820

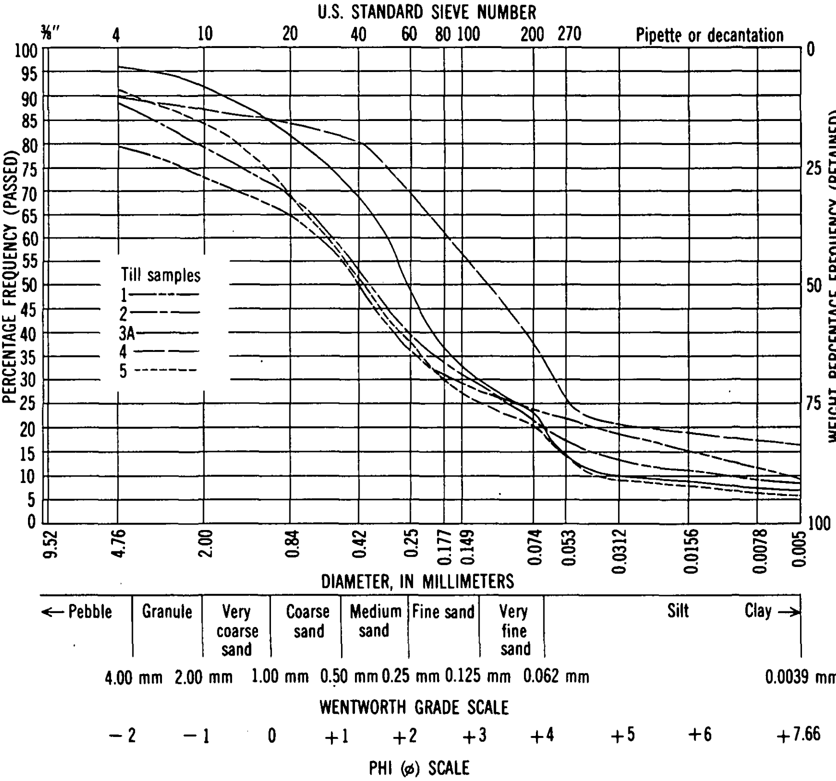

FIGURE 2.—Cumulative curves for grain sizes in till from the north-central area.

The till samples studied from this locality generally were grayish yellow to dusky yellow (5*Y* 8/4 to 5*Y* 6/4) when dry. The numerical designation is based on the Munsell system in the "Rock-Color Chart" (Goddard and others, 1948). Some parts of the till that were lighter in color (near light gray, *N*7) seemed to be unoxidized or bleached. The samples handled in the laboratory were moderately tough and coherent when dry; they could be crushed between the fingers with only moderate difficulty. In samples 1 and 4, many of the pebbles were stained black.

In the field, sample 1 was compact, light olive, and relatively pebble free; it flaked off in slabs parallel to the surface of the ground. Comparison of this till with others represented by the cumulative curves shows that its matrix is more sandy. Combined silt and clay content of the matrix is approximately 20 percent; by extrapolation, clay is assumed to make up about 6 percent of the matrix. The light-olive color faded to dusky yellow (5*Y* 6/4) when the sample was dried in the laboratory, and many spots of light gray (*N*7) were visible. In spite of its hard compact appearance in the field, it was only moderately tough and could be crushed in the hand.

Sample 4 was very difficult to dig, but it crumbled when it was dry. It had a silt-clay content of about 35 percent, and one of the finest grained matrices analyzed. Pebbles and cobbles are common in this till; boulders are present but not abundant. The till is gray where unweathered, various shades of reddish brown where iron stained, and yellowish gray where weathered.

The remaining three samples from this area are moderately compact and tough when dry, difficult to dig in the field, and dusky yellow (5*Y* 6/4) to light gray (*N*7). In spite of the divergence in grain size shown on the cumulative curves, these three samples (2, 3A, and 5) are similar in appearance. This same general type of till seems to cover all of the north-central part of the Taunton quadrangle and probably extends under a considerable part of the nearby swamp and glaciofluvial deposits.

Pine Street area.—In the Pine Street area, a small elliptical patch of till appears at the north end of a hill that is elongated northwest-southeast and veneered with glaciofluvial sediments. This hill was originally mapped as till by LaForge and Alden (written commun., 1921) and as Gloucester sandy loam, a soil underlain by till derived from granite or sandstone, by the Soil Conservation Survey (McLendon and Jones, 1912). However, trenches dug for water pipes along Pine Street in Bridgewater showed as much as 15 feet of sand and gravel over the till.

Boulders as much as 3 feet in diameter occur on the glaciofluvial surface, although the till is about 2½–4 feet below the surface in the area where till samples 6 and 7 were taken. A section where sample 6 was taken shows:

	Inches
Humus and fill	6
Sand, fine- to medium-grained, light-yellowish-brown; probably eolian material and frost mixture	20
Sand, fine- to medium-grained, gray	10
Pebble and granule gravel	6
Till, pebbly, yellowish-gray to dusky-yellow (sample 6)	6

Laboratory analyses of till samples 6 and 7 show considerable textural disparity (fig. 3). The silt-clay content of sample 6 is 48 percent, and the sand content is about 38 percent. Sample 6 is the finest grained till analyzed from the Taunton area. Sample 7, which was taken about 1,000 feet southeast of sample 6, was easily crumbled when dry. Approximately 9 percent of the material in both tills is finer than 0.005 mm.

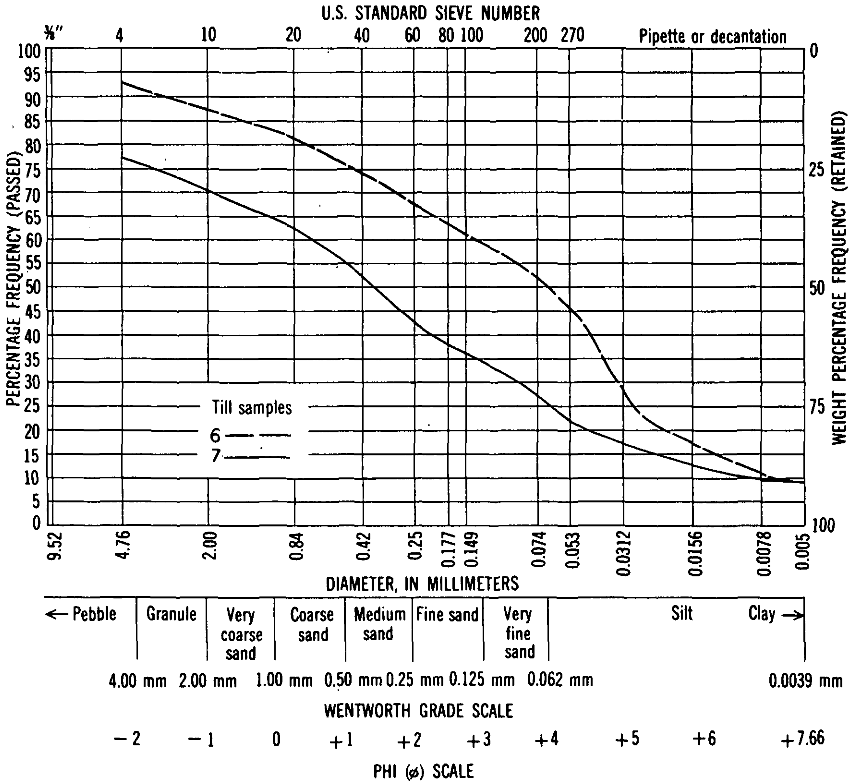

FIGURE 3.—Cumulative curves for grain sizes in till from the Pine Street area.

Both till samples are yellowish gray to dusky yellow (5*Y* 7/2 to 5*Y* 6/4) with spots of light gray (*N*7). The median diameter (table 1), which is in the medium-sand range for sample 7 and almost in the silt range for sample 6, and the dominance of particle sizes coarser than very fine sand in sample 7 and finer than very fine sand in sample 6, indicate clearly that there may be major textural differences in tills that are similarly stony and nearly the same color.

Southwestern area—Sample 9 was taken from a large excavation west of Lake Sabbatia. The position of this till body relative to others nearby indicates that it is part of the ground moraine. A section showed:

	Feet
Artifical fill	4–6
Muck, black, organic	2
Till, gray to pale-olive; many stones	3

This till seemed somewhat tough in the field, but pieces were moderately easy to crush in the hand when dry; the cumulative curve (fig. 4)

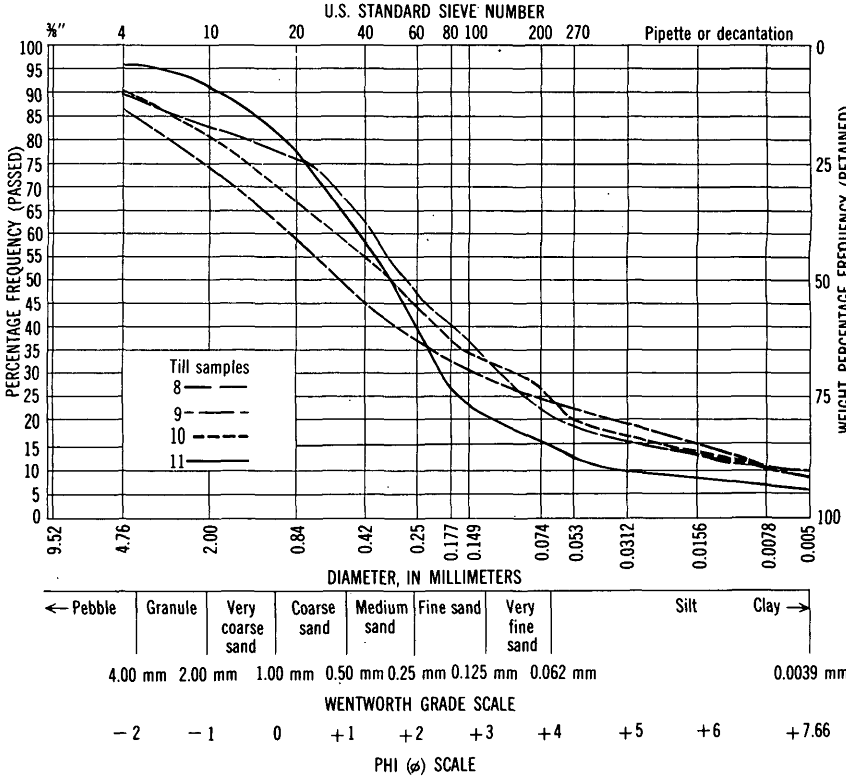

FIGURE 4.—Cumulative curves for grain sizes in till from the southwestern area.

shows that the till is somewhat coarser in texture than most of the other tills from Taunton. When dry, the till was light gray (*N*7).

Sample 8 was taken from the center of a low outcrop of till. It is easily crushed and somewhat incoherent when dry and is yellowish gray (5*Y* 7/2).

Sample 10 was taken from the bottom of an excavation. The bedrock surface was covered by a till layer a few feet thick, and the till layer was overlain by glaciofluvial material. The till is light gray (*N*7) where it is unoxidized and dusky yellow (5*Y* 6/4) where it is oxidized. It is compact in the field but easy to crush when dry.

Sample 11 was taken a few feet outside the south boundary of the quadrangle on Dighton Avenue on the north slope of a drumlin. The till is light gray (*N*7). The sample contained particularly small percentages of silt- and clay-size particles, although drumlins are generally thought to consist of silt- and clay-rich till. Although compact in the field, the sample was easy to crush when dry.

The cumulative curves (fig. 4) show moderately close grouping of the tills from this area. Three of the curves are subparallel and show similar grain size distribution of material finer than medium sand. The curve for sample 11 indicates either that the source was sand and gravel, or that more than the usual degree of sorting occurred during the deposition of the till; a sorting coefficient of 2.25 (table 1) indicates that the matrix of this till was reworked to a degree comparable to that of some glaciofluvial sediments.

Southeastern area.—The textural characteristics of four samples from the southeastern area are generally similar (fig. 5). Sample 12 was taken from beneath outwash in the bottom of a kettle. The till is very pale orange (10*YR* 8/2), sandy, and very easy to crumble when dry. Samples 13 and 14 came from the southeastern part of the Taunton quadrangle, and sample 15 came from the intersection of Center and Vernon Streets in the Bridgewater quadrangle. The tills from which samples 13–15 were taken contain similar amounts of material coarser than very fine sand. In the field sample 14 appeared to be light olive, but in the laboratory it was pale yellowish brown

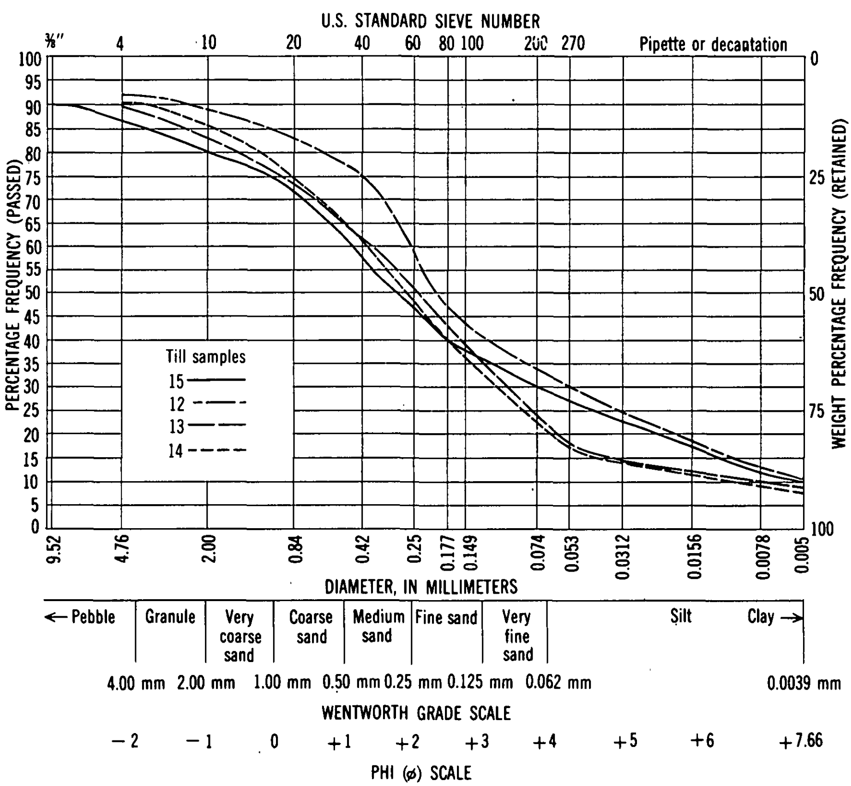

FIGURE 5.—Cumulative curves for grain sizes in till from the southeastern area.

(10*YR* 7/2). It is a compact till and hard to crumble in the hand when dry. Samples 13 and 15 are light gray to yellowish gray (*N*7 to 5*Y* 7/2), sandy, and easy to crush in the hand.

Orchard Street hill.—A roadcut along an expressway southwest of the intersection of Judson Street and Orchard Street in Raynham formerly exposed an unusual section of till (samples 16–19, fig. 6), glaciofluvial sand, and gravel:

	Inches
Soil	8
Eolian material, sandy, stony, light-brown; frost disturbed	22
Eolian material, sandy, stony, gray, unoxidized; frost disturbed	8
Till, light-olive-gray (5*Y* 5/2); clayey matrix; horizontal fissility, breaks off in large blocks; samples 16 and 18 (fig. 6)	40
Sand, coarse, and fine gravel and pebble gravel, containing many boulders, in a continuous bed of variable thickness	26±
Till, light-gray (*N*7), more silty matrix; fissility lacking; samples 17 and 19 (fig. 6)	60

In the field, the upper till (samples 16 and 18) was noticeably finer grained, more compact, and darker than the lower till. However, the

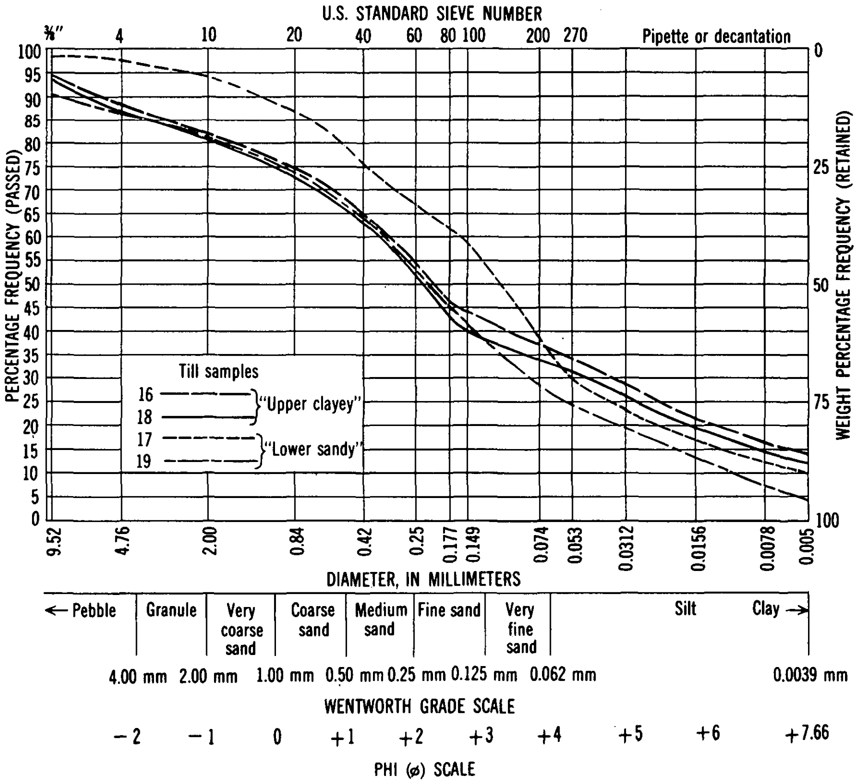

FIGURE 6.—Cumulative curves for grain sizes in till from the Orchard Street hill.

cumulative curve shows only a small difference in silt content between samples 16, 17, and 18—less than 5 percent at 0.005 mm. The matrices of two of the upper till samples, 16 and 18, and of a lower till sample, 19, show a similar grain-size distribution above the fine-sand size.

FLOWTILL

A separate group of samples was studied to obtain evidence of the origin of till in the Taunton quadrangle. The tills in this group occur as sheets or lenses that overlie, or are interbedded with, glaciofluvial sand and gravel. Flowtill also occurs in areas of low relief and on long low hills, mantling a substratum of sand and gravel. About two dozen outcrops of flowtill (Hartshorn, 1958) are indicated on the geologic map (pl. 1).

Sample 22 is flowtill taken from an area of low relief along the railroad between Elm Street and Bridge Street, Raynham. A section shows:

	Inches
Soil removed	?
Eolian mantle, light-brown; contains stones and ventifacts	11
Sand, yellow-brown; contains fewer stones, probably eolian	12
Till, yellowish-gray, compact; sandy matrix; contains many pebbles and cobbles; fissile	28
Sand, coarse, and granule gravel; contains many pebbles and small cobbles; limonite stained	12

The yellowish-gray color (5*Y* 7/2) is similar to that of many other tills of the Taunton quadrangle. Only slight weathering or staining was noticed in this till, assuming that light gray (*N*7) is the unweathered color. The sample was compact and hard to dig in the excavation, but when dried it crumbled as easily as many other till samples. The cumulative curve (fig. 7) shows that the matrix of this till is dominantly sandy; the matrix contains about 22 percent silt and less than 7 percent clay sizes.

Flowtill is interbedded with glaciofluvial sand in a flat area about 300–500 feet southeast of the intersection of Pleasant and Vernon Streets, in the village of Scotland. A section includes:

	Inches
Soil, silty, dark	7
Eolian mantle, sandy, yellow-brown	7
Sand, medium, gray	9
Sand, medium to coarse, moderate-reddish-brown; contains numerous pebbles	8
Flowtill; more clayey at bottom than at top; contains few stones	26
Sand, coarse to very coarse; moderate brown; contains pebbles	17

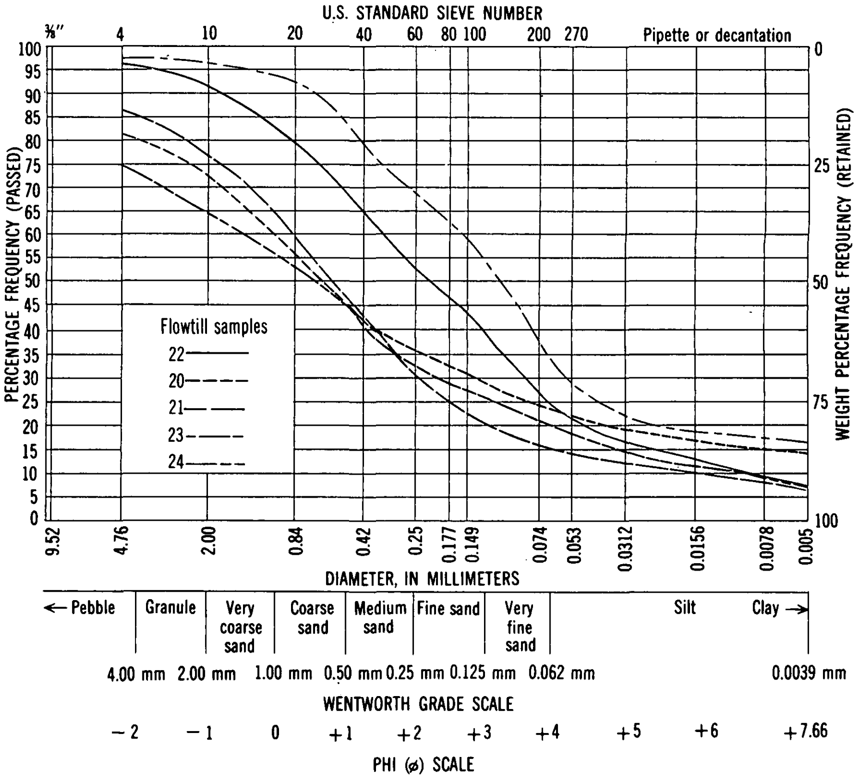

FIGURE 7.—Cumulative curves for grain sizes in flowtills.

During the summer of 1950, many large excavations were made on the grounds of a large State institution about 0.3 mile west of Lake Sabbatia. Numerous exposures of flowtill lenses overlying stratified sand and gravel were noted, and in several of these exposures flowtill was interstratified with outwash. In one large trench, the following composite section was seen:

	Inches
Artificial fill	24
Till and eolian material; mixed by frost	8
Flowtill, gray, compact	56
Gravel, pebble and small-cobble, poorly sorted	10
Gravel, large-cobble and small-boulder, poorly sorted	48

Flowtill (sample 24) from a nearby trench is very sandy and easy to crush in the hand when dry. It is light gray (*N*7) where unoxidized or bleached, and dusky yellow (5*Y* 6/4) where oxidized.

Flowtill overlying, or interbedded with, glaciofluvial sands and gravels occurs in more than a dozen places in ice-contact stratified drift deposits, ice-channel fillings, kames, kame terraces, and kame plains that are above the surrounding terrain. These features have steep bordering slopes (ice-contact slopes) that were formed as a result of contact between isolated masses and blocks of ice and the adjoining stratified drift. Most of the areas of flowtill discussed below were deposited within 100–300 feet of the ice mass; some were deposited even closer to the ice mass.

At least four ice-channel fillings contain flowtill masses. One is about 0.2 mile southeast of the intersection of Pine and Pleasant Streets in Bridgewater; isolated patches of a sandy gray flowtill (sample 23) are on top of it. West of Watson Pond, just outside the quadrangle boundary, flowtill occurs well down in the ice-channel filling; it probably flowed there from adjacent ice slopes before stream deposition ceased. In a third ice-channel filling, west of Lake Sabbatia, flowtill is at the surface; the till forms a lens about 3 feet thick, 30 feet wide, and of unknown length. Erratics here are as large as 18 by 10 by 7 feet. The fourth example is southwest of Lake Nippenicket.

Flowtill commonly occurs as lenses in kames and kame plains in the Taunton quadrangle, but only four such localities are described.

A section through a gravel pit in a kame plain about 35 feet above the surrounding area in the southeast corner of the quadrangle, at the intersection of Church Street and the railroad, shows:

	Feet	*Inches*
Soil	------	3
Eolian mantle with admixture of flowtill; contains many pebbles, cobbles, boulders; ventifacts	------	8–15
Flowtill, sandy, gray; fine-grained matrix; contains numerous large boulders	------	55–60
Sand, coarse, gray; contains numerous pebbles and cobbles; upper 4–6 inches beneath till is hard and cemented	15	-----

Similar flowtill is located on a kame plain on Judson Street, about 1½ miles north-northwest of the last locality. Here the till ranges from 6 inches to 7 feet in thickness, and its moderately even top conforms to the flat surface of the kame plain. The till is covered by eolian material and a frost-heaved mixture of till and eolian material. The flowtill is gray to brownish gray, fissile in places, very hard, stony, and difficult to excavate. Many large boulders are present both in place in the till and mined out of the till and now on the floor of a pit. The boulders are composed of granite, sandstone, and conglomerate; the largest is about 10 by 10 by 6 feet and is striated on several surfaces. Some north-south cross sections indicate that the flowtill lenses out to the north. The original flowtill mass in the pit was probably about 300 by 400 feet in a lens-shaped body with an average thickness of about 5 feet.

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In an abandoned gravel pit at Weir Village, just south of Taunton, a vertical face shows the following section:

	Feet	Inches
Artificial fill	3–4	-----
Soil	------	4
Eolian mantle and frost-heaved material (congeliturbate)	2–3	-----
Flowtill; yellowish gray to very light gray when dry	6	-----
Sand, fine, and silt and clay; general dip 8° N	1–10	-----

Sample 21 of flowtill was collected from a vertical face directly opposite the one described above; the cumulative curve is shown in figure 7. The till is very hard and compact when dry and difficult to dig by hand. In 1963, the till had maintained the same vertical face for at least 15 years.

Another pit is located in a kame plain on the east shore of Watson Pond. A thin lens of flowtill near the top of the kame plain extends as a bed of varying thickness down the sloping sides toward nearby masses of lower outwash. The following section is from the east face of the pit, but the stratigraphy changes from place to place:

	Feet	Inches
Soil	------	6
Eolian mantle and frost-heaved material with ventifacts (congeliturbate)	------	8
Sand, fine to medium, light-brown, loose, horizontally bedded	2	-----
Pebble gravel, poorly sorted	1	6
Flowtill, yellowish-gray to gray, cemented; sample 20	1	8
Sand, medium; coarse sand; small-pebble gravel; fine sand; pebble gravel	2	6
Sand, medium; crossbedding dips nearly south	------	8
Sand, fine; generally horizontal bedding	------	8

Sample 20 is yellowish gray (5*Y* 7/2) and contains more clay-size material than sample 21. The sample also contains some very sandy masses. The flowtill ranges in thickness from about 6 inches to 3 feet on the exposed face of the pit. The sample was moderately hard and compact when dry and fairly resistant to crushing in the hand.

TEXTURAL DATA

At present, quantitative textural data are too few to permit unqualified comparison of the tills in Massachusetts. The grain-size analyses presented in figure 2–7 represent one step in the accumulation of a large number of measurements of physical characteristics. The applications of cumulative curves are limited; therefore, a final solution to the problem of the origin of tills in Massachusetts must depend on field and laboratory studies of fabric, density, mineral composition, lithologic composition, oxidation, and as many other quantitative measurements as can be made.

Grain-size analyses and statistical data indicate that the texture of the till matrix in the Taunton quadrangle covers a wide range. Figures 8 shows the extreme range of grain sizes in the Taunton till samples; for example, the median grain size ranges from 0.68 mm to 0.07 mm. Grain-size analyses of samples collected from ground moraine believed to be the same age show that the matrix ranges widely—from dominantly sandy, with minor amounts of silt and clay, to dominantly silty, with nearly 20 percent clay sizes.

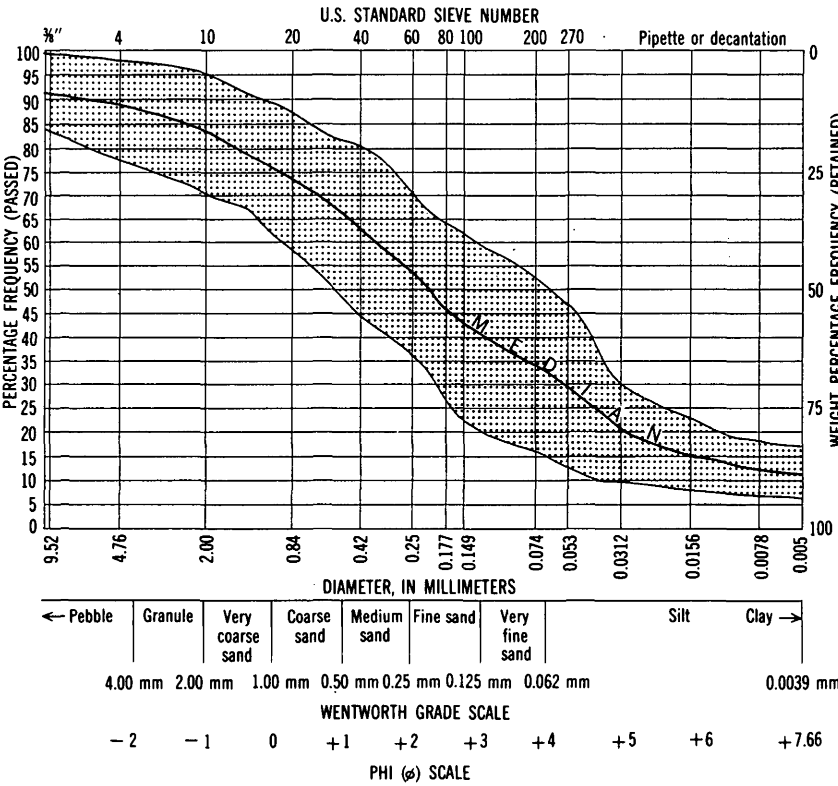

FIGURE 8.—Range in grain size of till from ground moraine.

The sorting coefficient of the matrix of till in the Taunton area (table 1) ranges from a low of 2.25 (sample 11) to a high of 7.66 (sample 7). Determinations of sorting based on the methods of Krumbein and Pettijohn (1938, p. 233), indicate that the best sorted till ($\log_{10}So=0.352$), is 2½ times as well sorted as the most poorly sorted till ($\log_{10}So=0.884$). According to Trask (1932), a sediment with a sorting coefficient of less than 2.5 ($\log_{10}So=0.398$) is well sorted. For example, most glaciofluvial sediments and most postglacial stream sediments that fall in the pebble-sand-silt range have sorting coefficients of less than 2.5. However, sample 11, which has a well-sorted matrix, was taken from the north flank of a drumlin, an area usually associated with subglacial till.

The grain-size analyses of presumed subglacial till (fig. 8) and of flowtill (fig. 7) show that the textures overlap, and the cumulative curves show no basic differences between till of known superglacial origin (flowtill) and till of probable subglacial origin (the general till sheet).

When the number of till samples is plotted against median grain size (fig. 9*A*) or against sorting (fig. 9*B*), the results show no well-defined textural pattern. A slight concentration of samples (11 out of 25) has medians between 0.2 mm and 0.35 mm, but the medians of most samples are scattered over the rest of the scale. A graph of the

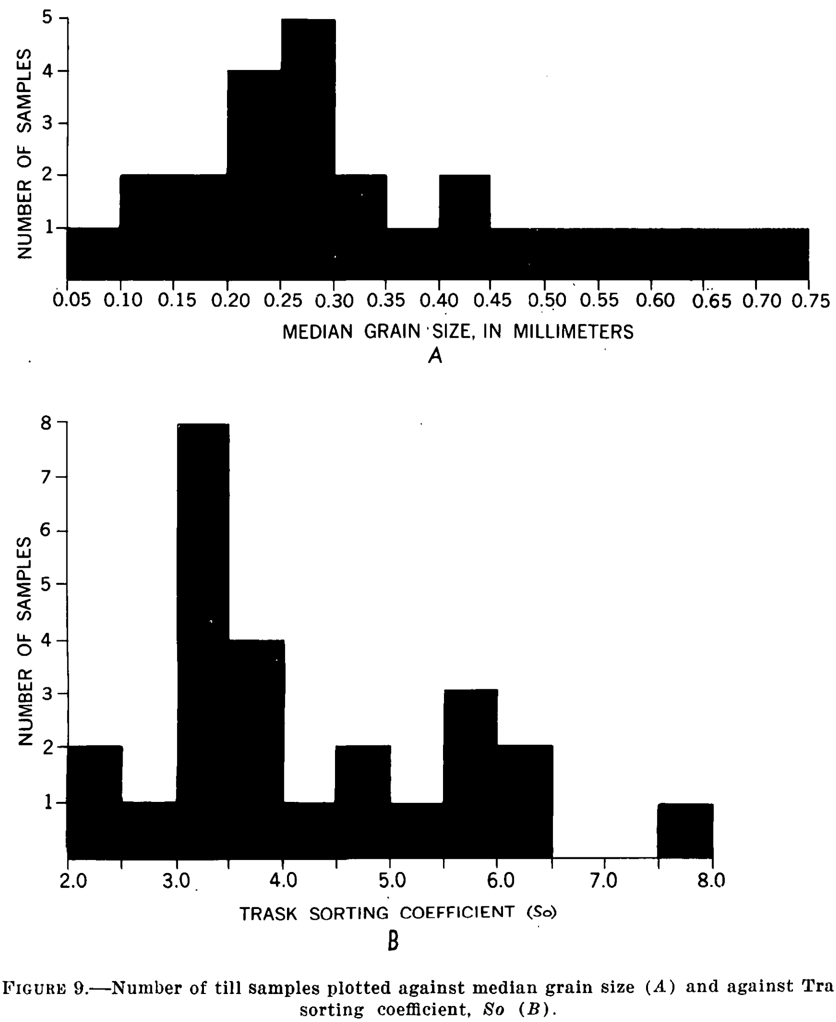

FIGURE 9.—Number of till samples plotted against median grain size (*A*) and against Trask sorting coefficient, *So* (*B*).

tills shows a similar concentration in sorting; the sorting coefficients of almost half the samples (12 out of 25) are concentrated between 3.0 and 4.0. This indicates that many tills in the Taunton quadrangle are moderately sorted. The flowtills are included in figure 9. There is no concentration in median grain size, but three out of five flowtill samples have a sorting coefficient between 3.0 and 3.5.

ORIGIN OF THE TILL

Theories concerning the origin of the till in the Taunton quadrangle depend upon interpretation of sparse data, and the problem of identifying different ages or types of till is a difficult one.

Two general types of till were previously recognized in eastern Massachusetts (Chute, 1950b; Currier, 1941b; Jahns, 1941; Moss, 1943; Judson, 1949). The "lower" or "old" till was described as hard, compact, jointed, clayey, and fissile; as containing relatively few stones; and as distinguished by an olive-drab color. The "upper" or "new" till is less compact, is easy to dig, is composed of a sandy matrix containing many stones, and, except where discolored by recent shallow oxidation, is distinctly gray. The two extremes—clayey olive-drab till and sandy gray till—appear to represent two distinct bodies of till, but in many outcrops positive identification is difficult.

Chute (1950b) noted that both the gray and the brown tills are present in the Brockton quadrangle to the north, and stated that the gray till is superglacial in origin, and the brown till subglacial. Only the gray till, comparable to the "upper" or "new" till, has been found in the Taunton quadrangle; consequently, distinguishing between subglacial and superglacial till is a major problem.

Part of the till mapped as ground moraine in the Brockton quadrangle was presumed by Chute (1950b) to be englacial or superglacial. Chute concluded that boulders that protrude some distance above the ground "were deposited with the superglacial till, as they could not have come to rest in their present positions until the ice had stopped moving." However, it is more likely that any large boulder that was being dragged along the ground in the bottom (subglacial) layers of the moving glacier would come to rest on the substratum either when the ice sheet stopped moving forward or when melting back of the glacier terminus exceeded the rate of forward movement and the boulder was exposed at the glacier front. It is also known that boulders that rest on a subglacial till surface can resist the forward movement of a glacier so that the ice will yield and flow plastically over and around the boulders instead of moving them along, and the boulders will be left protruding above the ground (Dyson, 1952; Flint, 1957, p. 71). Thus, the presence of large boulders in itself is not a criterion of subglacial or superglacial till.

In the Taunton area, the wide range of sorting of the till matrix suggests that the degree of sorting is of limited value as a criterion of superglacial or subglacial till. However, in the limited exposures available, any particular area of till cannot be proved to be subglacial. Some of the sampled and analyzed till, presumed to be subglacial from its position and geographic distribution, may be flowtill that has spread out over ground moraine rather than onto glaciofluvial deposits where it is easily differentiated from subglacial till.

The sandy uncompacted nature of some Massachusetts tills has been attributed to a lack of pressure from overlying ice, and is accepted by some as evidence of superglacial origin. It seems more probable that, in the Taunton area at least, the loose sandy nature of the till is due in part to the sandstone and subordinate lenses of conglomerate and slaty shale over which the glacier moved and from which it derived much of its debris. Subglacial till derived from such a nearby source would generally be sandy in texture.

It does not seem practicable, then, to attribute a certain textural composition or degree of compaction to either subglacial or superglacial till. Thus, in areas where the ice sheet underwent marginal stagnation during retreat, as in Massachusetts, the subglacial and superglacial tills may be nearly indistinguishable texturally.

Lithologic identification of some superglacial and subglacial till is possible in the Taunton area, however, because of the geography and geology of the Narragansett basin. The north boundary of the Taunton quadrangle is about 4–6 miles south of the crystalline rocks that border the Narragansett basin, and in that distance the glacier had ample opportunity to erode the Pennsylvanian rocks of the basin and incorporate them as lower englacial and subglacial load. Part of the subglacial load was dragged along the substratum, which was composed of bedrock, previously deposited till, glaciofluvial and glaciolacustrine sediments from a preceding glaciation, or proglacial sediments of the advancing glacier. The lowest part of the glacier was probably a mixture of ice and rock fragments of many sizes, the rock fragments composing most of the mixture near the bottom and becoming progressively fewer higher in the glacier. The lowest part of the ice-rock mixture was added to the substratum by lodgement or by shearing of the slightly cleaner ice above, thus forming the lodgement till. Because the nearest crystalline rocks were at least 4 miles upglacier at the north boundary of the quadrangle and at least 13 miles upglacier at the south boundary, from 70 to 95 percent of the lodgement till is composed of fragments of sandstone, conglomerate, and shale of the Pennsylvanian Rhode Island Formation.

As the glacier moved southward over the quadrangle, shearing along concave-upward planes in the ice carried Pennsylvanian fragments nearer the surface. In this upper part of the glacier, the rock fragments also included rocks that had traveled far—gabbrodiorite, granodiorite, granite, volcanic rocks, and a few sedimentary rocks. Near the northern basin boundary, the upward-transported sedimentary rocks from the Narragansett basin constituted only a minor part of the debris compared with the nonbasin rocks. For example, at station 6 (table 2), 7 miles downglacier from the first exposures of rocks of the Narragansett basin, only a third of the rocks in the flowtill are from the basin. Continued ice transport across the quadrangle, however, brought up more debris from the sedimentary bedrock floor until the sedimentary rocks outnumbered the nonbasin rocks in the superglacial till. At the southernmost suitable exposure of flowtill in the quadrangle, nearly 12½ miles from the edge of the basin (station 1, table 2), basin rocks compose more than half the pebbles. Flowtill, derived from the superglacial till, is thus composed of a mixture of basin and nonbasin rocks. In the north the nonbasin rocks are generally dominant, and in the south the basin rocks are dominant.

TABLE 2.—*Lithology of flowtill*[1] *and associated gravels*

[B, basin; NB, nonbasin. Counts based on 100 pebbles greater than 1 in. in diameter]

Station (pl. 1)	Miles[2]	Flowtill		Gravel		Remarks
6	7	B	36	B	31	Watson Pond kame plain; flowtill sample alt, 90 ft. Gravel samples from above and below flowtill.
		NB	64	NB	69	
				B	29	
				NB	71	
7	7.5			B	35	Prospect Hill kame; sample alt, 125 ft.
				NB	65	
5	8.8			B	22	Pine Swamp delta topsets; sample alt, 80 ft.
				NB	78	
4	9.2			B	38	Vernon Street kame terrace; sample alt, 85 ft.
				NB	62	
2	11.8	B	52	B	41	Hill Street kame terrace; sample alt, 40 ft.
		NB	48	NB	59	
3	11.9	B	39	B	34	Weir Village kame; sample alt, 85 ft.
		NB	61	NB	66	
1	12.4	B	56	B	20	Precinct Street kame plain; sample alt, 45 ft.
		NB	44	NB	80	

[1] Note that flowtill is derived entirely from superglacial debris.
[2] Miles from north edge of the Narragansett basin, based on a general directon of ice movement S. 15° E. as shown by drumlins. If striae were used (S. 30° E.), distances would be slightly greater, but in the same order.

The generally low percentage of basin rocks in the gravel (table 2) shows that the melt-water streams that produced the ice-contact stratified drift in the Taunton quadrangle originated on the glacier beyond the north boundary of the Narragansett basin and picked up most of their sedimentary load there. The unsystematic variation in gravel lithology from north to south reflects the continuity of melt-water stream courses and the incorporation of different amounts of superglacial till into the bedload of the major superglacial streams.

The explanation most generally advocated for the origin of till above glaciofluvial deposits is readvance of the glacier, but this seems improbable in the Taunton quadrangle. A more likely explanation is that saturated superglacial debris from the stagnant continental glacier moved laterally onto adjacent, lower stratified deposits (Hartshorn, 1958).

A reconstruction of the events that led to the formation of two bodies of flowtill in the Taunton quadrangle is shown in figure 10. The sequence is believed to have been as follows: The stagnant ice broke into isolated masses. Ablation moraine (superglacial debris) accumulated on the surface of the ice (fig. 10*A*). Accumulation of saturated superglacial debris on the ice continued until encroachment of a moderately steep slope undercut the water-soaked body of stony mud. A mudflow moved down the ice slope onto glaciofluvial sediments in a narrow ice valley (fig. 10*B*). A similar concentration of saturated debris occurred on the ice slope facing glaciofluvial deposits being built up between two ice masses. The flowtill moved out onto the ice-contact deposits (fig. 10*C*), and continued sedimentation buried the lens of flowtill beneath more glacial stream deposits (fig. 10*D*). When the ice had completely disappeared from the area, the ice-channel filling remained (fig. 10*E*). The larger ice-contact feature collapsed along its margins, and the formerly flat-lying lens of flowtill slumped to conform to the upper slope of the deposit.

If the flowtill moved out onto then recently uncovered ground moraine, it may never be recognized because of its resemblance either to lodgement till from a sandy bedrock source or to reworked ablation moraine that was let down vertically from the ice. If the flowtill moved laterally onto an area of active glaciofluvial sedimentation, it may be buried under later deposits of glaciofluvial sand and gravel or glaciolacustrine silt and clay. However, flowtill is commonly the latest and uppermost deposit in many ice-contact deposits.

Many of the flowtill bodies that moved out onto glaciofluvial deposits may not have survived to the present. The mudflows were composed of unconsolidated materials deposited on the flood plains of active, constantly shifting streams. The shifting streams could easily undercut and carry away all or part of the flowtill. Such erosion may be the reason why flowtill is less frequently found buried and is commonly found only at the top of glaciofluvial landforms, as in the kame plain on Church Street near the southeast corner of the quadrangle. Furthermore, if a stream were diverted to another depression in the stagnant glacier, or for some reason ceased to flow, any mudflow recently decanted onto the flood plain would be the last unit in the buildup of the glaciofluvial landform. Flowtill buried in the ice-contact deposits may have been preserved either by drying to become

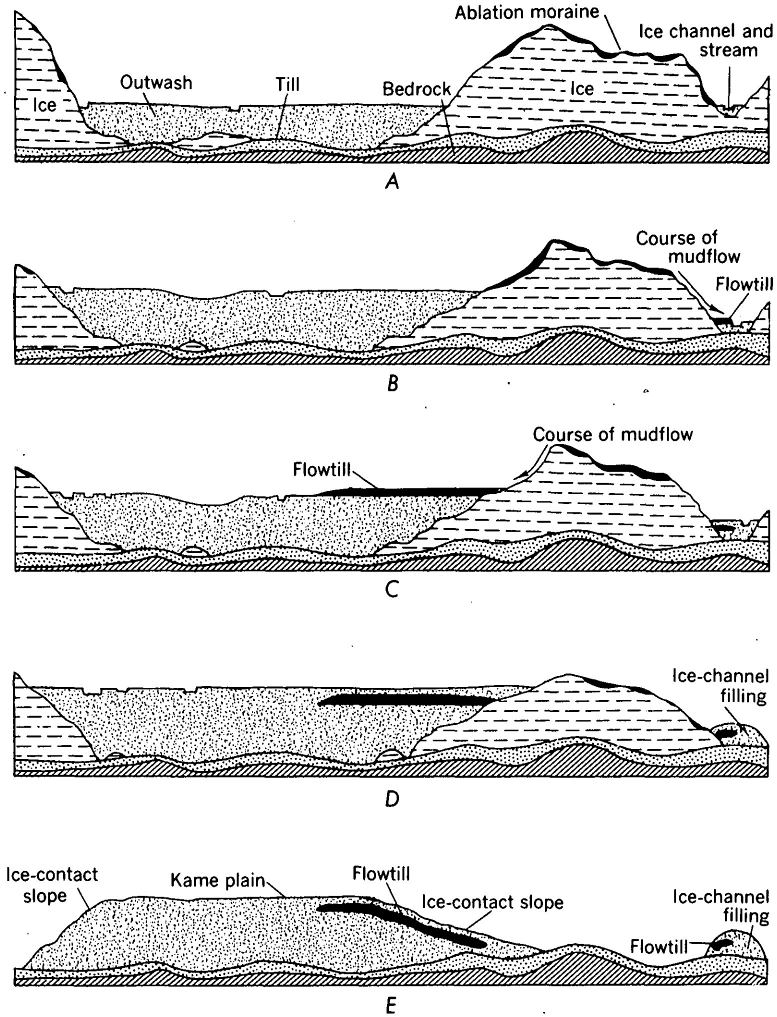

FIGURE 10.—Origin of flowtill. *A*, Ablation moraine accumulating on the surface of stagnant ice. *B*, Mudflow moves off ice onto ice-channel filling. *C*. Mudflow moves off ice onto glaciofluvial plain. *D*, Continued sedimentation on ice-contact deposits. *E*, Complete disappearance of ice; kame plain and ice-channel filling with flowtill lenses left as sharp topographic forms.

a compact mass, and thus becoming more resistant to erosion, or by burial by stream deposits before the entire lens was eroded away.

Some exposures of flowtill distant from ice-contact slopes were probably much closer when the flowtill was deposited. At that time, the ice mass from which the flowtill came was probably next to the present flowtill outcrop. Later melting of the ice block and continued sedimentation filled in the intervening area with sand and gravel. When streamflow through the area ceased after the last ice melted, the flowtill exposure was left far removed from the ice-contact slope.

DRUMLINS

Two well-formed drumlins are present in the Taunton quadrangle, one at the north-central edge of the quadrangle, partly in the Brockton quadrangle (Chute, 1950b) and one wholly within the Taunton quadrangle, in the northwest corner. Bedrock does not crop out on this latter drumlin, which is smooth and streamlined; it may be composed entirely of till. Its orientation (S. 15° E.) is in the same general direction as that of the striations found to the south (S. 30° E.).

Other smoothed till areas from 25 to 75 feet high are found in the quadrangle, but they have not been delineated as separate map units. One such area is just south of Whittenton Junction in Taunton, one is along Orchard Street south of Raynham Center, one is along Locust Street east of Raynham Center, and one is in the village of Scotland, in the northeast corner of the map.

WATER-LAID DEPOSITS

The water-laid deposits of the Taunton area include all glacial debris that has been modified by the action of melt-water streams or of lakes. The sedimentary environment was extremely complex, as indicated by the composition and form of the water-laid drift.

GLACIOFLUVIAL DEPOSITS

Glacial features grade from one form into another; for instance, from smooth graded outwash to pitted outwash and then to a collapsed complex of kame plains, kames, eskers, crevasse fillings, and kettle holes. Terminological distinctions between these forms are an effort to separate a gradational series of deposits into discrete units.

In this report, distinctions between map units are based on texture, morphology, structure, and genesis. Glaciolacustrine deposits are distinguished by texture—fine sand, silt, and clay—and by thin laminae or varves. Undivided glaciofluvial deposits are composed of stratified sand and gravel but lack a characteristic form; hence, texture is the identifying feature. In some places, textural differences are used to distinguish lake deposits from other adjacent forms, such as outwash plains, that are at the same altitude. Ice-channel fillings, kames and kame fields, kame terraces, kame plains, outwash plains, and kame deltas are distinguished chiefly by morphology. Kame deltas, in addition, show the structural features of foreset and topset beds characteristically displayed in glacial deltas. Flowtill is an example of a material distinguished on the basis of genesis; it has the same texture as ground moraine but occurs in a unique stratigraphic position in the stratified drift.

ICE-CHANNEL FILLING

Ice-channel fillings include both eskers (Flint, 1957) and crevasse fillings (Flint, 1928). An esker is a long narrow ice-contact ridge deposited by a swiftly flowing glacial stream under, within, at the edge of, or perhaps even on the glacier. The crevasse filling, on the other hand, represents deposition in the crevasses of a stagnant and broken ice mass. A distinction has been made between eskers and crevasse fillings in some reports (Chute, 1949; Richmond, 1953); but the two forms undoubtedly grade into each other, and they could not be differentiated in the Taunton area. Consequently, the inclusive term "ice-channel filling" has been used instead (Jahns, 1953; Hansen, 1956; Segerstrom, 1955).

Many ice-channel fillings in the southern part of the quadrangle appear to be related to kame terraces and other ice-contact features; that is, the highest parts of the ice-channel fillings are approximately the same height as adjoining kames or kame terraces, and both were probably laid down at the same time with the same base-level control. In the northern and central parts of the area, there are three linear groups of ice-channel fillings. The easternmost group, west of Vernon Street, trends southeastward but probably was not all formed at the same time. The deposits show a somewhat irregular tributary-like plan, uneven crests, separated segments, and pseudoanticlinal bedding. One ice-channel filling ends in a kame. The central group of ice-channel fillings, west of Dead Swamp, contains the longest uninterrupted segment in the area, about 0.7 mile long. A third group, west of Lake Sabbatia, consists principally of small isolated segments.

Figure 11 shows the relations between three ice-channel fillings and the surrounding deposits. The most striking feature of each is the difference in height between the deposits on the two sides. In each relationship, the relief is greater on the east than on the west. The ice-channel filling near Oak Street, about 0.6 mile northeast of Raynham village (fig. 11*A*), rests on ground moraine to the west. West of Lake Sabbatia, glaciofluvial debris was deposited against the east side of the ice-channel filling after sediments had been deposited to a higher level on the west side (fig. 11*B*). Here the difference in altitude is about 30 feet. The land surrounding the ice-channel filling near Beach Street (fig. 11*C*) is approximately 15 feet higher on the west than on the east. This ice-channel filling apparently was formed in an ice-walled valley whose west wall melted away first; sand and gravel were banked against the west side while ice remained in the lowland to the east. Lake sediments were then deposited in the lowland and against the margin of the ice-channel filling and kame terrace.

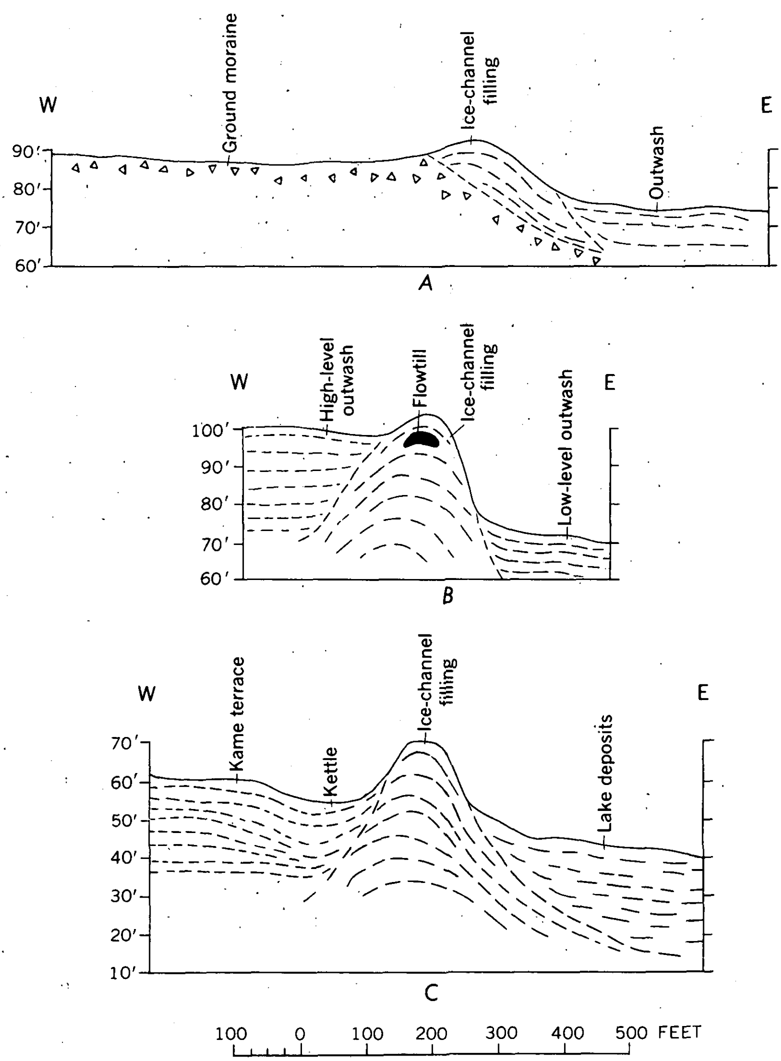

FIGURE 11.—Diagrammatic cross sections of ice-channel fillings. *A*, 800 feet east of Oak Street, Raynham. *B*, 300 feet west of Lake Sabbatia. *C*, 400 feet south of Beach Street, Bridgewater.

KAME OR KAME FIELD

Kames occur in many parts of the quadrangle as individual conical hills and as large irregular features. Though their forms vary widely, kames are generally uneven-topped deposits of gravel, sand, and silt, that stand well above their surroundings and are built by melt-water streams in contact with masses of ice. Two hills just east of Hewett Pond, near the center of the quadrangle, are examples of nearly conical kames. They are 40–60 feet high despite later burial by outwash; the original height may have been as much as 100–125 feet. The largest mapped single-summit kame is Prospect Hill, which is 140 feet high and roughly half a mile across at the base. The largest kame field, located near Prattville, extends more than a mile to the north but has low relief; generally it is no more than 25–35 feet above the surrounding landforms. These three examples show the range in form and size in this one quadrangle.

The glaciofluvial and glaciolacustrine materials in the kames include all grain sizes. Silt and clay lenses as much as 15 feet thick are interstratified with coarser material in several pits. These lenses are interpreted to be the product of quiet-water deposition in water-filled holes in the ice or of slack-water deposition on melt-water flood plains. Sand, commonly showing small-scale foreset bedding, is interbedded with pebbles and, sometimes, cobbles. A few kames contain very large boulders, up to 12 feet across.

The materials in a kame are not necessarily derived from nearby sources in the glacier, but may have been carried great distances by streams flowing over the surface of the glacier, as shown by the many fragments of volcanic and igneous rocks that came from north of the Narragansett basin. Stratification in the kames ranges from poor to excellent. In many places near the margins of kames, the bedding was deformed by slumping, settling, and faulting of the sediment as the supporting ice walls melted away. If continuous slumping occurred during melting of the supporting ice wall, the bedding may parallel the present slope or it may dip at angles up to 90°, with many complex variations between. In other kames, the sediments may have remained in their original horizontal attitude until the ice completely melted away, and then a wedge-shaped slice of the stratified drift fell away, so that the remaining horizontal beds intersect the ice-contact slope.

Flowtill is interbedded with, or overlies, the stratified sediment of many kames in the area, as in the kame group just south of Weir Village. Just west of this locality, at least four kames contain flowtill. In a gravel pit on Highland Street, about a mile west of Weir Village, flowtill ranges in thickness from 0 to about 15 feet and overlies slumped and faulted sand and gravel. On Somerset Street, about 1,800 feet north of the quadrangle boundary, a lens of flowtill that averages a little over 2 feet in thickness is interstratified with sand and gravel. Other deposits of flowtill undoubtedly will be discovered in future excavations.

KAME TERRACE

In a region of low relief and poorly defined valleys such as the Taunton quadrangle, kame terraces are isolated features; long narrow terrace sequences that occur along the valleys elsewhere in Massachusetts (Jahns, 1953) do not appear here. Some kame terraces are flat-topped forms built by glacial streams in temporary valleys between the wasting glacier and an adjacent hill slope. Most terraces consist of coarse sand, pebbles, and cobbles, but some contain finer grained material.

Isolated kame terraces are perched on the south slope of a hill near Locust Street in the southeastern part of the quadrangle. The upper surfaces of these terraces are much deformed and slumped. Other terraces are built on the south end of the hill north of East Taunton, where two terraces lie one below the other. A flowtill lens about 80 by 50 feet in diameter and about 5 feet thick is exposed in a gravel pit in the higher terrace.

The largest area of kame terraces is in the northwest corner of the quadrangle. One kame terrace surrounds a drumlin and is partly bounded by low but distinct ice-contact scarps; to the southeast, however, a gentle slope descends from the terrace surface to the Hockomock Swamp. This low-angle slope is also an ice-contact slope but is less distinct. On the surface of the kame terrace are sandstone and conglomerate boulders up to 6 feet in diameter. The material of the kame terrace ranges from well-sorted medium sand to poorly sorted sand and pebble gravel containing numerous cobbles and a few boulders.

The terrace in the extreme northwest corner of the area is the south end of a larger kame terrace and is dominantly composed of sand containing numerous pebbles and cobbles; the hill against which it was built was very nearly buried by melt-water deposits (fig. 12). The boundary on Dean Street between the ground moraine and the kame terrace is not generally marked by a topographic break. A lower, later kame terrace flanks the hill on the east.

Prospect Hill is partly surrounded by a kame terrace that is pitted with many kettle holes and is bounded by excellent ice-contact scarps. The glaciofluvial material ranges widely in composition, from fine to medium sand containing scattered pebbles to a sandy pebble gravel containing cobbles; one boulder is 8 feet in maximum diameter.

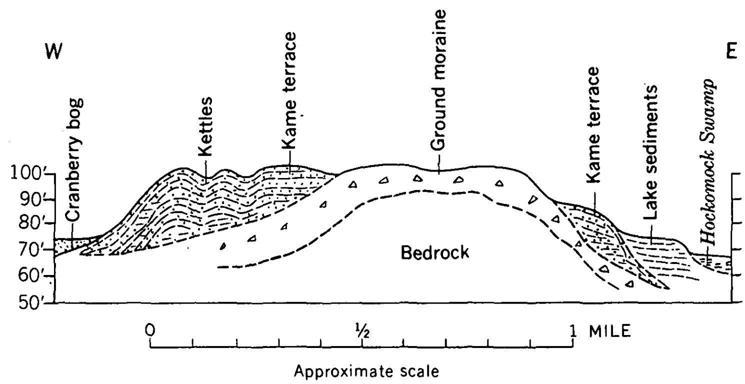

FIGURE 12.—Diagrammatic cross section of kame terrace on Dean Street, in the northwest corner of the quadrangle.

In the north-central part of the quadrangle, a low irregular kame terrace extends east and south from the Raynham Dog Track around a hill of till and glaciofluvial deposits. The kame terrace was apparently built against an ice block that occupied the site of the present Hockomock Swamp. The small grain size of the glaciofluvial materials indicates that the source of the materials was far back on the glacier, and the sediments were probably not locally derived. Generally the material is very fine to coarse sand, with small lenses of pebble gravel and isolated occurrences of pebbles and cobbles. A few boulders, as much as 6 feet in diameter, are found on the surface of the kame terrace and in the gravel pits. Flowtill was found at the surface in one pit, buried nearly 4 feet beneath an eolian layer in another, and beneath a 14-inch bed of coarse sand and small-pebble gravel elsewhere. At the south end of this terrace, just west of Lake Nippenicket, the surface layers contain many pebbles and cobbles and some boulders as much as 4 feet in diameter. Coarse materials in the subsurface include poorly sorted pebble and cobble gravel with a matrix of very coarse sand and granules; the source for this material seems to be relatively near.

In the east-central part of the quadrangle a complex kame terrace was built against an outwash-mantled till hill. This kame terrace surrounds an older group of ice-channel fillings; and at Beach Street, on the boundary of the quadrangle, the kame terrace abuts against one of these ice-channel fillings. Excavations in the southern part of the kame terrace expose materials ranging from very coarse gravel to laminated silty clay.

KAME PLAIN

Moderately flat topped hills of sand and gravel surrounded or nearly surrounded by ice-contact scarps are called kame plains (Jahns, 1951).

The majority of the kame plains in this area are composed of horizontally bedded sediments. Flowtill is sometimes present and is an indication of the presence of ice walls surrounding the kame plains during their formation.

The kame plain along Somerset Street in the southwest corner of the quadrangle has much higher ice-contact slopes along its east margin, probably because the ice was thinner to the west and had a thicker cover of glaciofluvial debris. Boulders on the surface of the kame plain are as much as 8 feet in diameter. Most of the kame plain consists of beds of medium to coarse sand containing numerous pebbles and cobbles, some beds of pebble gravel, and a cap of poorly stratified and crudely sorted pebble gravel.

The kame plain east of Watson Pond in the west-central part of the quadrangle has a fairly flat top and has ice-contact slopes that range from steep scarps approximately at the angle of repose of the sand and gravel to gentle hummocky slopes that grade into lower undivided glaciofluvial deposits. A pit in the southwestern part of the kame plain contains glaciofluvial sand and gravel beds. At one place, a boulder 7 feet in diameter rests on, and partly in, a layer of flowtill; the boulder may have slid into place from the surrounding ice walls during the movement of the flowtill. This layer of flowtill extends for at least 300 feet, ranges from about 6 inches to 3 feet in thickness, and is part of the slumped southern ice-contact slope. (See fig. 10*E*.) Many boulders in the pit are as much as 11 feet in diameter; several bear glacial striations. A section in the southern part of the pit includes:

	Feet	*Inches*
Soil	--	6
Eolian material and congeliturbate	--	8
Sand, fine to medium; horizontal beds	2	--
Pebble gravel, poorly sorted	1	6
Flowtill	1	8
Sand, medium; coarse sand and small pebble gravel; stringer of fine sand; pebble gravel	2	6
Sand, medium, crossbedded	--	8
Sand, fine, horizontally bedded	--	8
Slump; mostly in sand; some gravel	13	--

Both the kame plain east of Prattville and the kame plain east of Lake Nippenicket consist of very fine sand, and some silt in the lower part, overlain by coarser materials. The fine material must have been deposited by melt water that was ponded at this locality. During the final stages of deposition from melt water at Prattville, the water must have had more carrying power, however, for the finer deposits are capped by 3–6 feet of pebble gravel with cobbles and some boulder gravel with a sand and silt matrix.

A kame plain that trends north along Hill Street in the southeastern part of the quadrangle has an even-crested kame-and-kettle surface. Many large boulders, some as large as 10 by 10 by 6 feet, are on the surface and in the gravel pits. At the north end of the kame plain, a pit exposes pebble gravel overlying fine to coarse sand containing some pebbles and cobbles. In places, a lens of flowtill up to 7 feet thick overlies crossbedded glaciofluvial deposits.

The moderately flat topped kame plain south of the Taunton River along Church Street contains some kettles 20–100 feet across and as much as 8 feet deep. Boulders up to 5 feet in diameter are scattered on the surface. A lens of flowtill 100 feet in diameter occurs just under the eolian mantle (p. D21).

OUTWASH PLAIN

At three places within the quadrangle, sediments were laid down either as proglacial deposits or in large open areas uncluttered with ice blocks. The melt water from the glacier formed outwash plains that grade downstream from coarse gravel to fine sand. These outwash plains have retained most of their original form and can be mapped as units.

About half of the built-up area of the city of Taunton is on an outwash plain. From its ice-contact head to the north, at an altitude of about 90 feet, the plain slopes gently to the south. Coarse gravel and sand make up the north border of the plain, which is marked by a few kettles within about 500 feet of the edge. Stream erosion has altered the original shape at the southern margin of the plain, where the sediments are mostly fine sand and silt. Field evidence suggests that this outwash plain was contained on the east by a block of ice and that its mode of deposition was different from that of the kame delta just to the east of it.

Another outwash plain in the northeastern part of the quadrangle, near Scotland, is about a mile long and has a north-facing ice-contact slope that shows collapse topography. The gravel at the north edge of the plain is very coarse and includes many large boulders, but the grain size of the sediments decreases to medium and fine sand at the south end.

The largest outwash plain is south of Gushee and Hewett Ponds, in the central part of the quadrangle. Ice-block holes and kettles are prominent in the northern part of the plain and form a swamp just east of Tracy Corner. The outwash plain begins at an altitude of about 90–100 feet on the south border of two ice-block depressions (Dead Swamp and Titicut Swamp) and slopes gently southward about 23 feet per mile to the Taunton River (fig. 13). If postglacial

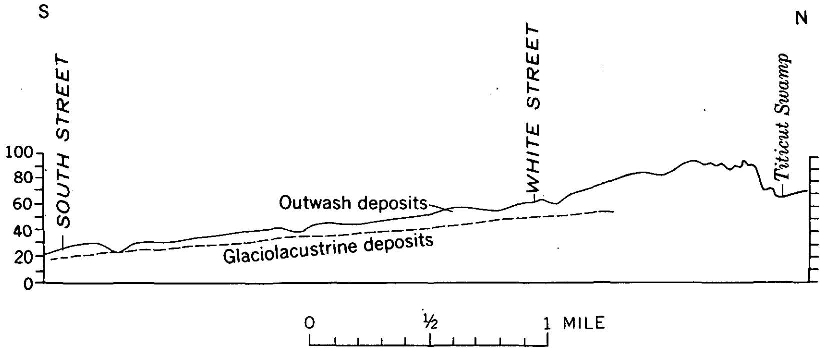

FIGURE 13.—Profile of outwash plain from Titicut Swamp to South Street, Raynham. Profile drawn along power transmission line. Note northerly extension of lacustrine deposits beneath outwash-plain deposits.

tilting of the land of about 4 feet per mile is assumed for this area (extrapolated from Jahns and Willard, 1942 p. 274), then the original gradient was about 19 feet per mile. This is the only place in the quadrangle where an original glacial-stream gradient can be determined.

A pit south of Gushee Pond contains medium to very coarse sand with lenses of pebble and cobble gravel and a few small boulders. Near the ice-contact slope, the outwash-plain topography is hummocky, and the relief is about 6 feet; but such irregularities do not extend more than 100 feet onto the plain.

The lower end of this plain is composed of fine sand and silt that cannot be separated from the lake-bottom sediments that underlie the outwash plain. Where South Main Street crosses Forge River just southwest of Raynham Center, the outwash-plain deposits include interbedded small-pebble gravel and coarse sand. A silty sand with many granules and lenses of coarse sand and pebble gravel occurs about half a mile northeast along South Main Street, and silty very fine sand occurs about 6 feet below the surface.

Flowtill was found in an outwash plain at only one locality in the Taunton quadrangle—just east of Scotland. (See p. D19.) Flowtill does occur however, in an outwash plain less than a mile to the northeast, in the Bridgewater quadrangle (Hartshorn, 1960). Neither outcrop of flowtill is near an ice-contact slope, but both may have been much closer when they were formed.

UNDIVIDED GLACIOFLUVIAL DEPOSITS

Many glaciofluvial forms are difficult to classify under any of the conventional names. Such forms have been grouped in the general category of "undivided glaciofluvial deposits." These forms are gradational between the arbitrarily named landforms. The surfaces of many of the forms are too irregular to be called plains or terraces but are not irregular enough to be called kames. Many low collapsed fringes along the edges of swamps are probably the same age and originated in the same way as higher adjacent landforms.

The largest body of undivided glaciofluvial deposits occurs along the west edge of the quadrangle. The surface is flat to gently rolling and is broken by many kames that rise sharply from the lower surface. The course of the streams that built this landform cannot be determined; no former gradient can be determined, and no evidence of a general decrease in the grain size of materials in any direction has been found.

The undivided glaciofluvial material on the west side of Lake Sabbatia must have been deposited while a large block of ice occupied the lake bottom, because stratified drift lies against the west side of an ice-channel filling at a higher level than on the east side. Although the glaciofluvial deposits do not quite bury the ice-channel filling, they are level with the top in at least one place. Flowtill overlying sand and gravel indicates the proximity of ice during the deposition of the stratified beds.

GLACIOLACUSTRINE DEPOSITS

Two glacial lakes of considerable size were present at different times in the Taunton quadrangle. The existence of the northern lake is indicated by kame deltas in the Brockton quadrangle to the north, and by silt and sand that extend south as far as Lake Nippenicket and Lake Sabbatia. The existence of the southern lake is indicated by the kame delta at Pine Swamp and by associated lake-bottom deposits to the south.

The lake sediments in the northern part of the quadrangle are very thick in places. For example, fine to very fine sand is 84 feet thick in a well on the west shore of Lake Nippenicket, and 88 feet thick in a well on Field Street north of Lake Sabbatia. Fine sand was not deposited in such quantities over all the low area covered by the Hockomock Swamp, however, for coarse sand and fine gravel are within a few feet of the surface just north of the Raynham Dog Track.

Scarps along the edges of the sandy terraces facing Hockomock Swamp indicate either that streams undercut the edges or, more likely, that ice persisted at least until the glacial lake had disappeared.

The lake-bottom deposits and kame deltas in the central and southern parts of the quadrangle are among the most extensive lake deposits in the report area. Although it is built by streams and its upper surface is a glaciofluvial surface, a kame delta is treated as a glaciolacustrine deposit because it is intimately connected with its accompanying lake, both by gradation of sediments from one to the other and by contemporaneity. The characteristic feature of a kame delta is the ice-contact slope where the glacier stood while discharging sediment-laden streams into a standing body of water. The frontal slope of a kame delta has the same free angle of repose as sediments in standing water.

The kame delta in the southeast corner of the quadrangle shows well-developed foreset bedding and a characteristic kame delta shape. The delta was built into a small ice-bordered lake whose surface was about 45–50 feet above present sea level.

The large kame delta just east of Pine Swamp extends from ice-contact slopes on the northwest to a lowland underlain by sand, silt, and varved and unvarved clay on the south and east. The delta is about 1.4 miles wide and about 0.4 mile from front to back; its top is a flat to slightly uneven plain. Foreset beds (fig. 14) dip generally 25–30° SE., grade outward into sand and silt at the base of the kame delta, and are overlain by about 10 feet of coarser topset beds of sand and gravel (fig. 15). This delta was built into a fresh-water lake about 75–80 feet above present sea level.

In a water-main trench near Raynham Center, lake sand, silt, and clay are exposed beneath outwash deposits (fig. 13) at least to White Street, north of Raynham Center, where gray silty clay underlies the outwash gravel. Near the intersection of South Main and Warren Streets, outwash consisting of coarse to fine sand containing a few pebbles and cobbles overlies an eroded surface of gray silt and clay. From here south, both the outwash deposits and the upper part of the lake-bottom deposits are composed of medium to fine sand and are difficult to separate as map units.

Other lake-bottom deposits are present along the Taunton River in the eastern and southern parts of the quadrangle. Varved clay is exposed northwest of the mouth of Cotley River, at the base of the hill at Locust Street, and in the large clay pit north of Weir Village.

At the clay pits north of Weir Village, the following section is exposed on the east face of the pit:

	Feet	*Inches*
Soil	------	6
Sand, medium, horizontally bedded; fine sand and silt; a few granule and small pebble beds; ripple marks and crossbedding	2–13	------
Varved clay and silt; homogeneous appearance when wet; variable in thickness and composition	12+	------

The surface of the clay was eroded before the overlying outwash was laid down by streams whose deposits start at Gushee and Hewett Ponds. Crossbedding in the outwash dips southward.

Antevs (1928, p. 190) counted 41 varves under 2½ feet of sand and 2 feet of massive clay in the clay pit. The total depth of the clay here

FIGURE 14.—Foreset beds in kame delta east of Pine Swamp. Height of exposure about 20 feet.

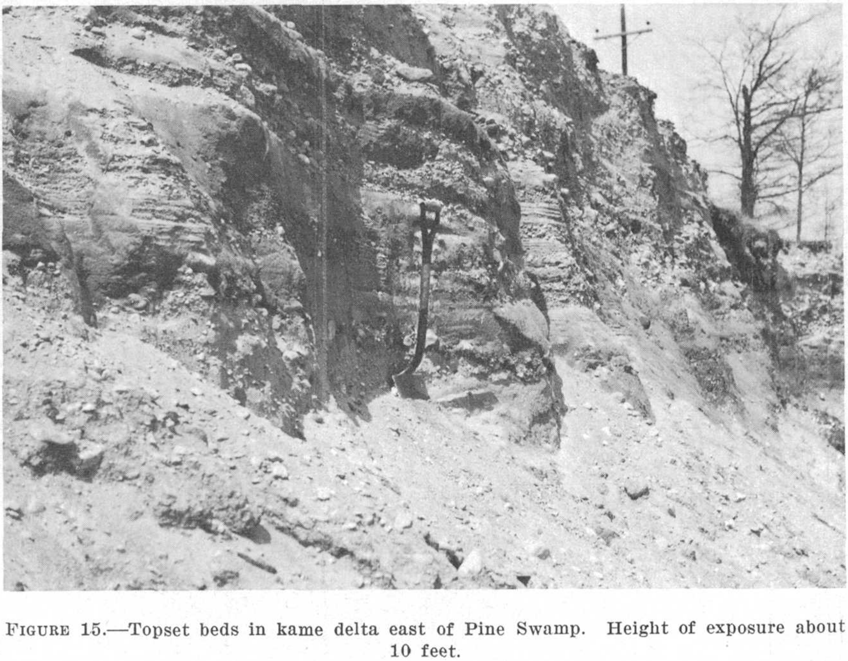

FIGURE 15.—Topset beds in kame delta east of Pine Swamp. Height of exposure about 10 feet.

is not known, and Antevs did not attempt to link these isolated varves with his general retreatal chronology in New England.

Usually the varved clay underlying the outwash is not evenly banded. The varves are formed of summer components of sand and winter components of clay or silt. Numerous sandier and siltier laminae are present within each set of components (fig. 16). The higher varves are sandier than those below, and the summer components are thicker than the winter components. Some of the clay has been distorted by folds and faults, probably the result of penecontemporaneous slump. Large, but uncommon, sandstone erratics as much as 21 feet in maximum dimension were dropped into the clay presumably by ice rafting.

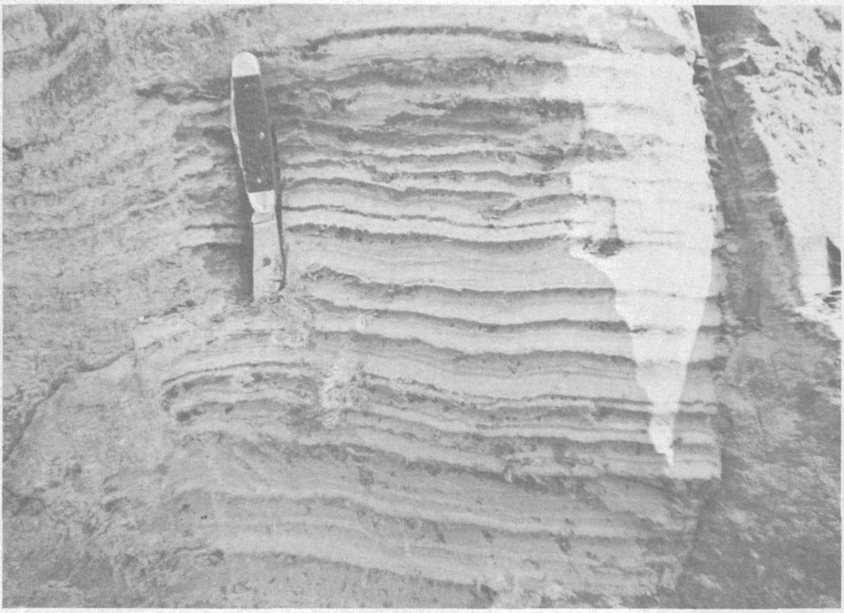

FIGURE 16.—Varved clay at clay pit north of Weir Village. Note marked gradation from sand and silt (light gray) to silt and clay (dark gray).

Between the Taunton River and Williams Street, the lake sediments end in an abrupt scarp that forms the south margin of a kettle hole now occupied by a swamp; an ice-channel filling occupies the northern part of the kettle hole. This relationship, as well as the presence of many other kettle holes on the surface of this lake plain, indicates that the deposits were laid down when masses of stagnant ice still lay in the lake basin. Just south of the intersection of a power line and South Street, numerous kettle holes contain coarse to very coarse sand in an area underlain by fine-grained lake sediments.

The kettle holes probably did not form until after the lake bed had drained. Along Furnace Brook in the extreme southeast corner of the quadrangle, the lake sediments end abruptly with a scarp at an ice-block hole. The ice evidently remained here also until the lake drained.

The altitude of the lake bottom can be determined in part by noting the present altitude of the clay and estimating the amount of postlake erosion that occurred before outwash was deposited. The surface of the clay seems to have been about 20 feet above present sea level near the Taunton Water Works on the Taunton River, about 20 feet at South Street, 38 feet at Raynham Center, and about 48 feet at White Street. The greater part of this rise to the north is probably due to the rise of the surface beneath the lake deposits rather than to postglacial tilt.

The north boundary of the lake was formed by an ice front that lay against the kame delta at Pine Swamp; south of Titicut Swamp, the glacier apparently stood in the waters of the lake. Icebergs probably account for the scattered debris found in the clay. Although the lake must have covered a considerable area, lacustrine sediments have been found only in the lower parts of the basin. The extent of the lake to the south is unknown, but the lake may have been dammed by a combination of high ground and ice masses in the Assonet quadrangle to the south.

ORIGIN OF THE WATER-LAID DEPOSITS

Landforms composed of water-laid deposits originate from the interaction of glacial streams, ponds, lakes, and stagnant blocks of ice left by a retreating glacier.

The manner of retreat of the last ice sheet is still a matter of controversy. Some geologists advocate so-called normal retreat, during which a steeply sloping solid ice front melted northward faster than southward movement could replenish the loss (Lougee and Vander Pyl, 1951, p. 280). However, studies of modern glaciers (Ahlmann, 1935) show that ice margins melt downward as well as backward during retreat. Ablation results in a thinning of the ice tongue or marginal wedge; the front begins to melt back rapidly only after thinning (downwastage) has removed the bulk of the ice. The ice margin stagnates and breaks up when it has become so thin that it can no longer transmit forward motion.

The glacier in eastern Massachusetts withdrew as a result of stagnation-zone retreat (Currier, 1941a; Jahns, 1941); that is, the ice in a marginal zone, about 3–10 miles wide (Jahns, 1953; Hansen, 1956, p. 89), became so thin that it ceased to move. This stagnant ice was separated from the active ice mass by hilly topography, burial by glacial sediments, or a shear zone that progressively encroached on the active ice. As the ice sheet continued to move forward behind this outer zone, parts of the active ice progressively sheared off, stagnated, and became covered with debris. A wide complex of ice-contact deposits was formed in this stagnation zone.

The surface of the ice mass in the Taunton area must have been partly covered with superglacial debris. The high altitude of some of the stratified drift deposits necessitates this assumption. The local relief of the bedrock surface is 100–150 feet in some parts of the quadrangle. Debris plucked and scraped from the topographic highs was thus 100–150 feet up in the glacier to begin with, and upward shearing transported the debris even higher.

The surface of the ice was irregular and hummocky, with debris in the hollows and thin ablation moraine or bare ice on the summits. Melt-water streams followed the low areas and deposited their loads of sand and gravel. Deltas and other lacustrine deposits formed where water was impounded in large hollows. The generally chaotic appearance of the areas blanketed by ablation moraine was accentuated by the somewhat more orderly appearance of the areas covered by stream deposition. The continuous destruction caused by slumping of glaciofluvial deposits already built, the continuous changing of stream channels, and the draining of ponds through newly opened channels produced constantly changing sedimentary environments.

On a stagnating continental ice sheet, superglacial features come into existence and are destroyed many times during the lowering of the ice surface and consequent reversals of topography. Glaciofluvial deposition may start at any time during the melting of the ice. Those stratified features with the most irregular surfaces and the largest and most numerous kettles were probably let down from the greatest thicknesses of ice. Disturbed bedding in a deposit is evidence for superglacial origin or buried blocks of ice; conversely, undisturbed bedding indicates that final deposition may have taken place on, or very near, the subglacial terrain.

Study of the various water-laid deposits in the Taunton quadrangle seems to indicate that many were laid down in contact with bodies of ice that were not necessarily connected with the main body of the glacier but occurred as isolated blocks and tabular masses that were covered by debris before final melting.

ICE-CONTACT SLOPES

Ice-contact slopes (Woodworth, 1899) bound glaciofluvial or glaciolacustrine landforms and owe their shape and inclination to contact with the glacier or isolated blocks of ice during the period of active sedimentation. If the ice face against which the glacial sediments are banked is steeper than the angle of repose of the sediments (about 35°, depending on grain size), then the collapsed slope will incline at the angle of repose, but in the opposite direction from that of the original ice slope. Thus a steep scarp at the proximal edge of a kame delta may slope at almost the same angle, though reversed, as it did when the ice was present (fig. 17*A*); an example is the northwest slope of the kame delta east of Pine Swamp, in the center of the quadrangle.

Very gentle smooth ice-contact slopes of less than the angle of repose probably pass unnoticed in surficial mapping. Such slopes, of perhaps 5°–10°, could have been formed if stratified material had been deposited on a smooth gently sloping wedge of ice (fig. 17*B*). When the thin wedge of ice melts out, the formerly flat-lying deposits assume approximately the reverse of the angle of the ice slope. The present deposit thus forms a mirror image of the ice wedge because where the ice is thinnest the stratified drift slumps the least.

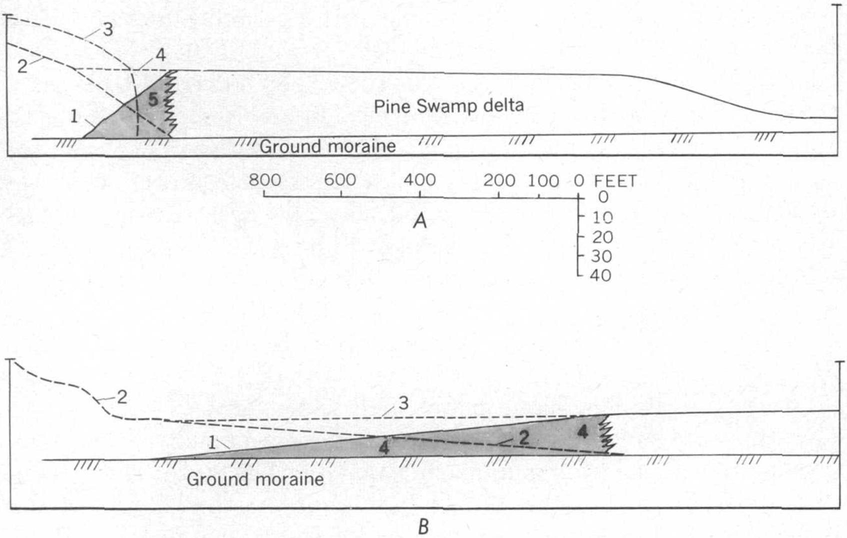

FIGURE 17.—Origin of ice-contact slopes. *A*, Diagrammatic cross section of Pine Swamp delta showing origin of steep ice-contact slope: (1) present-day ice-contact slope; (2) original glacier margin with frontal slope of about 35°; (3) alternative glacier margin with vertical front; (4) surface of delta before collapse of sediments; (5) zone of slumped bedding. *B*, Diagram to show origin of low-angle ice-contact slope: (1) present ice-contact slope; (2) original glacier margin with about a 5° slope on outer edge; (3) surface of glaciofluvial deposit before collapse of sediments; (4) zone of slumped bedding after ice melts.

ICE-CONTACT DEPOSITS

The study of modern glaciers has shown that there is no single solution to the problem of how any one particular feature was formed [3] (Tarr, 1908). At the Malaspina Glacier, Alaska, for instance, continuing events in front of, and on, the glacier suggest at least four different origins for ice-channel fillings (Hartshorn, 1952). Other ice-contact deposits undoubtedly also may originate in several different ways.

Ice-channel fillings in the Taunton area probably were deposited by streams flowing in open channels or tunnels at, or very near, the base of the glacier. Generally it is impossible to tell whether an ice-channel filling was formed in a subglacial tunnel or in an open channel. However, deposition in open channels occurs later in the glacial history. Most, if not all, of the ice-channel fillings in the Taunton area probably were formed in tunnels early in the late-glacial history, because they are surrounded by lower later glacial deposits. The ice-channel fillings definitely were not related to standing bodies of water for, with few exceptions, ice-channel fillings are absent where lake sediments are present.

Till lenses in some of the ice-channel fillings indicate that the deposits may have formed in open channels. (See p. D21.) If a stream was flowing in an open channel, till may have been derived from mudflows off the steep ice walls, as shown in figure 10*B*. In subglacial tunnels, however, stony mud might melt out of englacial debris in the roof of the tunnel and accumulate on the stream bed even after the stream had ceased to flow. Such till may now appear as a compact lens on the surface of the ice-channel filling. The accumulation of englacial debris in ice caves and tunnels has been observed on modern glaciers, although always in much smaller quantities than the large accumulations of flowtill in the ice-channel fillings of the Taunton area.

Kames, kame fields, kame plains, and kame terraces were formed later than the subglacial ice-channel fillings, commonly at the same time as ice-channel fillings in open channels. The 80-foot-high kame north of Hart Street, the 70-foot-high kame northwest of Barstow Pond, the 60-foot-high kame terrace southeast of Barstow Pond, and the connecting segments of ice-channel filling may have all formed as part of the same ice-contact deposit. The presence of flowtill in the kame terrace indicates that glacial ice was present during the later stages of deposition.

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[3] Statement in a letter from the files of the U.S. Geological Survey, from T. C. Chamberlin to N. S. Shaler, dated Apr. 29, 1885:

"I esteem it an especial intellectual benefecence that nature is sufficiently rich in method to accomplish very similar ends by diverse means, and very diverse ends by similar means. This, I conceive, finds abundant illustration in the phenomena of the drift."

Prospect Hill must have been one of the earliest glaciofluvial deposits in the area. Apparently it was formed by streams that poured their load of sediment into a hole in the ice. The height of this kame (at least 140 ft.), is an indication of the height at which superglacial streams, or perhaps streams in englacial tunnels, carried debris. It is also an indication of the minimum thickness of the ice in this area during glaciofluvial deposition.

All the kames were not formed contemporaneously. Landforms in the southern part of the quadrangle are generally older than those to the north; high isolated landforms are generally older than lower ones. The large kame near Weir Village in the southwestern part of the quadrangle is probably older than, for example, the isolated kames in Titicut Swamp, south of Lake Nippenicket. The kame field at Prattville is obviously younger than Prospect Hill.

Kames near each other may be of different ages because of different modes of origin. Some kames, such as Prospect Hill, probably were formed in holes in the ice where the load of through-flowing superglacial streams collected. Other kames were formed by the deposition of small deltas and lake or pond sediments in depressions in the ice. Other, more extensive, groups of kames (or kame fields), such as those at Prattville, apparently were built as glaciofluvial plains against ice walls; numerous isolated blocks, or irregular masses, of ice must have been buried within the kame group itself, as indicated by the prevalence of kettle holes and by collapsed and deformed bedding. Some kames and kame fields may have been formed when an outwash plain was deposited on a toe of stagnant ice. Melting of the buried ice would cause the outwash plain to collapse and form a chaotic and irregular surface in place of a smooth graded plain. The kames west of Elm and Bridge Streets in the north-central part of the quadrangle probably formed first as a smooth-topped kame terrace deposited by streams flowing between ice in the Hockomock Swamp and the central till and bedrock hill. Melting of an irregular ice foot beneath the sediments left a complex mass of gently sloping small hillocks and swales.

The relation between kame plains and kames or kame fields can be seen in the central part of the quadrangle. The kame plains just north of Pine Swamp and south of Britton Street are isolated remnants of a formerly flat-topped continuous outwash plain. The adjacent nearly concordant kames and kame fields at Prattville and to the north represent collapsed outwash. Other kame plains, such as the one just north of Watson Pond in the west-central part of the quadrangle, seem to be glaciofluvial fans laid down in a hole in the ice.

Some kame plains are glaciolacustrine in origin. They may have been built into water-filled depressions in the glacier either as deltas that completely filled the depression from ice wall to ice wall or as bottom deposits that nearly filled a pond before final drainage. Thus, the scarps surrounding the flat-topped plain are ice-contact scarps. Some kame plains have narrow necks by which they are attached to neighboring features of the same general altitude—for example the kame plain and kame delta in the southeast corner of the quadrangle.

WIND ACTION

EOLIAN DEPOSITS

The extensive outwash plains and numerous minor outwash features of the southeastern part of Massachusetts were the source of the windblown sand and silt that almost completely blankets the Taunton area.

The first recorded statement that this upper layer of material in Massachusetts might be of windborne origin, similar to the loess of the Midwest, was made by Woodworth in 1899. He had earlier (1894) noted ventifacts, which he called glyptoliths, on Cape Cod, at Martha's Vineyard, and near Boston. Later he became convinced that the last glaciation blanketed all of New England with a loose layer of Wisconsin till (Woodworth and Wigglesworth, 1934); he did not, however, associate the ventifacts with the material in which they were imbedded. Bryan (1932) pointed out that this thin layer of loose unconsolidated material contained windworn stones from top to bottom in some places and hence must have been deposited by wind rather than by a glacier.

The uppermost material in the Taunton quadrangle is believed to be eolian in origin. In places the upper layer is separated from the underlying glacial deposits by a very sharp textural break. The eolian material covers till hills, till lowlands, outwash plains, and outwash features of all kinds. It is absent only on modern alluvium, on some parts of the lake-bottom clays, and on some narrow ice-channel fillings.

At present, most of the eolian material lies within the zone of weathering and hence is oxidized throughout; it is light brown to yellow or reddish brown, apparently depending on the degree of oxidation, the permeability of the underlying drift, and the height of the water table. In a few places the windblown sand is so thick that it appears to be unmixed with underlying materials. Samples of this sand examined under the binocular microscope contain small to moderate amounts of frosted and pitted sand grains. In a few places the number of frosted grains decreased downward from the eolian sand into undisturbed glaciofluvial or glaciolacustrine sand.

The severe frost action that took place during the retreat of the last ice sheet churned and heaved the upper layers of soil to such an extent that the eolian material commonly resembles the glacial deposit below it. Numerous pebbles, cobbles, and boulders introduced into the surface layers from below were cut and polished by the wind.

The eolian material at the intersection of U.S. Route 44 and Orchard Street in Raynham ranges from 20 to about 36 inches in thickness. The contact between the eolian material and the underlying till is sharp, but the eolian material contains stones, some of them ventifacts, from the till. Sample 25 (table 3), from the middle of the eolian section, consists mostly of very fine sand and about 31 percent clay-size material (fig. 18). No sorting values can be derived from the cumulative curve because the curve does not intersect the third quartile.

Eolian material is at least 5 feet deep at other places near this locality, and nearly 6 feet deep west of Lake Sabbatia.

TABLE 3.—*Statistical measures of eolian material*

[Sample localities are given in accompanying text]

Sample	Median (mm)	Q_1 (mm)	Q_3 (mm)	Sorting (So)	$\log_{10}So$
25	0.082	0.120			
26C	.245	.300	0.185	1.29	0.111
3C	.130	.192	.080	1.55	.190
Udden (dune sand)	.200	.270	.170	1.26	.101
Kansas dust, "D"	.033	.046	.0175	1.63	.212
Sanborn 1 (loess)	.033	.040	.026	1.24	.093
Sanborn 10 (loess)	.028	.035	.012	1.71	.233
Illinois 1 (loess)	.038	.047	.027	1.32	.121
Illinois 6 (loess)	.023	.031	.013	1.54	.188

Sample 26C (table 3) was taken from 13 to 17 inches below the surface about 1,400 feet south of Beach Street. The sand is yellowish brown and contains many ventifacts. The cumulative curve (fig. 18) shows that the material is very well sorted and that its median is in the medium-sand range. In this sample, about 11 percent of the material is finer than sand (0.062 mm).

A third sample of nearly unmixed eolian material was taken from above till at locality 3, in the north-central area (pl. 1). Sample 3C was taken from a layer of brown-stained medium to very fine sand containing ventifacts. This sample also shows good sorting (table 3), and the cumulative curve shows a tail of silt- and clay-size materials similar to that for sample 26C.

For comparison, five cumulative curves of material from Kansas and Illinois are included in figure 18 and summarized in table 3. Sample "D" was taken during a dust storm in Kansas by Swineford and Frye (1945, p. 250). Two of their loess samples, Sanborn 1 and Sanborn 10, are also included. The two loesses from Illinois (Smith, 1942, p. 154) are Illinois 1 (0.6 mile from the Mississippi River) and Illinois 6 (14.7 miles from the river). A cumulative curve showing the average

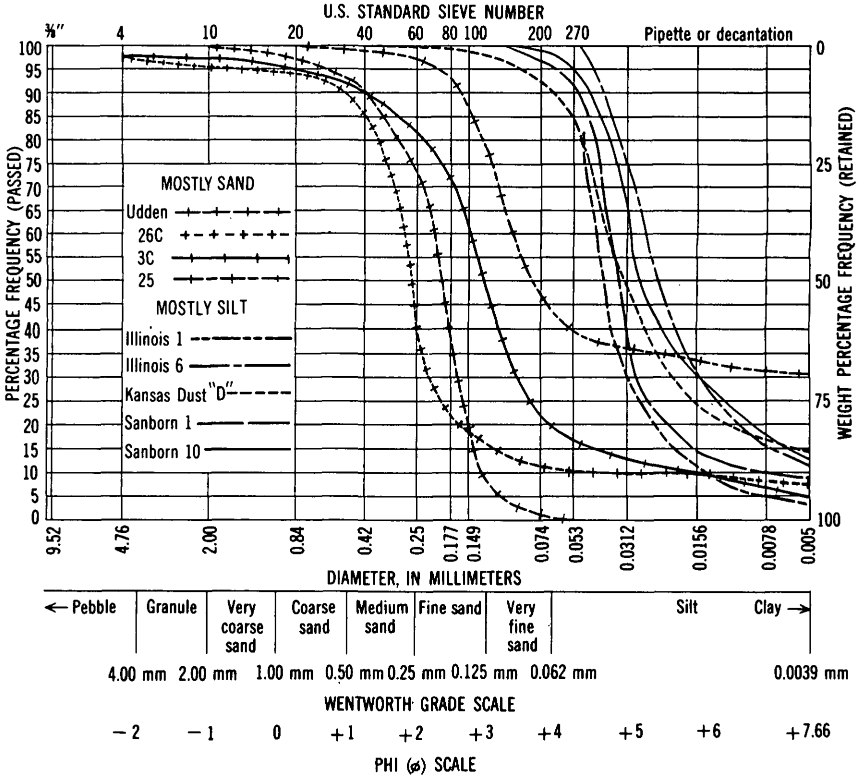

FIGURE 18.—Cumulative curves for grain sizes in eolian material.

composition of dune sands (Udden, 1898) is also included for comparison.

The cumulative curves show that the eolian material in the Taunton quadrangle does not correspond to the definition of loess, in that it does not consist predominantly of silt-size particles. The Kansas dust, the Sanborn loess, and the Illinois loess all are composed of silt-sized material, whereas the eolian material in the Taunton quadrangle is composed mostly of medium and fine sand. Sample 25 is an exception as it contains a larger proportion of silt- and clay-size material; however, locality 25 is about 1,000 feet east of glacial-lake deposits that were a source of silt and clay.

The conclusion is that the eolian material in the Taunton quadrangle is a windblown sand, but not loess; however, loess is present in small quantities elsewhere in Massachusetts (Smith and Fraser, 1935, p. 26).

If the original bleak postglacial landscape of outwash and till had not been covered by the moisture-retentive fine-grained nearly stone free eolian mantle, the farmers of southeastern Massachusetts would have to subsist today on very meager fare.

VENTIFACTS

Fragments of every rock type found in the quadrangle have been cut by wind action. Some rocks are more easily cut and polished by wind action than others, however, and therefore ventifacts are more common in some areas than in others.

The fewest and most poorly defined ventifacts come from the rocks of the Rhode Island Formation, although one or two excellent examples were found. Eolian material overlying till contains far fewer ventifacts than eolian material overlying gravel because most of the rocks in the till were derived from the Rhode Island Formation.

On outwash plains and large kame terraces, the gravel consists mostly of granite, many varieties of Dedham Granodiorite, other igneous intrusive rocks, and volcanic rocks. These rocks, because of their mineral content and texture, are more readily polished, pitted, and grooved than the rocks of the Rhode Island Formation. The presence of countless ventifacts in outwash areas is conclusive evidence that the uppermost layer of the glacial deposits was affected by wind action.

Very few of the ventifacts in the Taunton quadrangle are faceted; most are merely polished, etched, and fluted on one or more sides.

The ventifacts range in size from those composed of a few grains of quartz and feldspar, less than one-eighth inch in diameter, to boulders, many feet in diameter. Wentworth and Dickey (1935) claimed a lower size limit of about one-half inch for ventifacts, but this figure should be revised downward.

Mather, Goldthwait, and Thiesmeyer (1942, p. 1167–1170) listed the characteristics of ventifacts. Polished surfaces, the best of which resemble a slightly wrinkled sheet of cellophane, cut across quartz and feldspar alike. Smooth, greasy surfaces are found on most ventifacts and can easily be felt with the fingers.

Differential etching and polished surfaces are perhaps the most outstanding criteria for recognizing ventifacts in southeastern Massachusetts. Any hard part of a rock will generally stand out in relief when the rock has been wind cut. Quartz in the Dedham Granodiorite, hard laminae in sandstones, and phenocrysts in volcanic rocks, are examples. Pits on some ventifacts probably represent the etching out of softer parts of the rock. In addition to etching, the wind also produces fluted surfaces—a series of uneven discontinuous concave flutes or grooves. Polish is well preserved except in such unfavorable environments as lakes, swamps, and other areas with high water tables.

A valuable criterion (J. P. Schafer, oral commun., 1960) for distinguishing between wind and stream action is that smoothed and polished surfaces extend into concavities in the rock when formed by wind. Tails of matrix behind resistant knobs are a special form of wind etching on bedrock that indicates late-glacial wind direction.

Cut surfaces and grooving and fluting of ventifacts are randomly oriented, and the ventifacts are scattered through the eolian material from top to bottom. Therefore ventifacts give no evidence of the late-glacial wind direction.

Many rounded stream pebbles have been split (presumably by frost action), the pieces moved apart, and the resulting flat faces polished by the wind-blown sand.

Some pebbles are windworn on all sides. One process that could have turned the pebbles so that they could be cut on all sides is intense frost action or congeliturbation (Bryan, 1946); another is undermining of the pebble by removal of the surrounding sand by the wind. One nearly spheroidal stream pebble was etched and pitted by wind over its entire surface but still retained its original shape.

CONGELITURBATE

Eolian deposits in southeastern Massachusetts are mixed with the underlying glacial drift to form congeliturbate—a body of material disturbed by frost action during late-glacial time (Bryan, 1946, p. 640). Eolian material can be distinguished from congeliturbate more easily in some places than in others. The eolian material was laid down by the wind as a moderately well sorted sediment, but later the windborne sand, silt, and clay were mixed with the underlying material. The congeliturbate now includes eolian sand, silt, clay, discrete pieces of till, the separated fines that made up the matrix of the till, sand from the fluvial deposits, silt and clay from the lake deposits, and stones from till or outwash.

Congeliturbate covers most of the quadrangle except the swamps and areas of alluvium. The results of frost action, however, may not be detected in some areas because the underlying material is texturally similar to the eolian layer. In sand, the only evidence of frost action may be a fraction of finer windblown sand churned into the outwash sand to produce a slightly coherent material. In some places, ventifacts scattered from top to bottom throughout the congeliturbate indicate the thickness of the disturbed layer.

The congeliturbate ranges from olive gray to yellowish brown or reddish brown, depending upon the stage of weathering of the iron-bearing minerals, the position in relation to the water table, and the moisture content. The congeliturbate is loose, pulverulent, and weakly coherent in a dry state, and is composed of a mixture of silt and fine and coarse sand, together with a great variety of pebbles, cobbles, and boulders.

Size descriptions of the congeliturbate, and the statistical measures derived from them are given in figure 19 and in table 4.

These samples are useful for comparison but are not necessarily typical of congeliturbates in the Taunton quadrangle because grain-size distribution and sorting of the material vary, depending on the original thickness of the windblown material and the nature of the underlying material. Where the congeliturbate is 3 feet or more

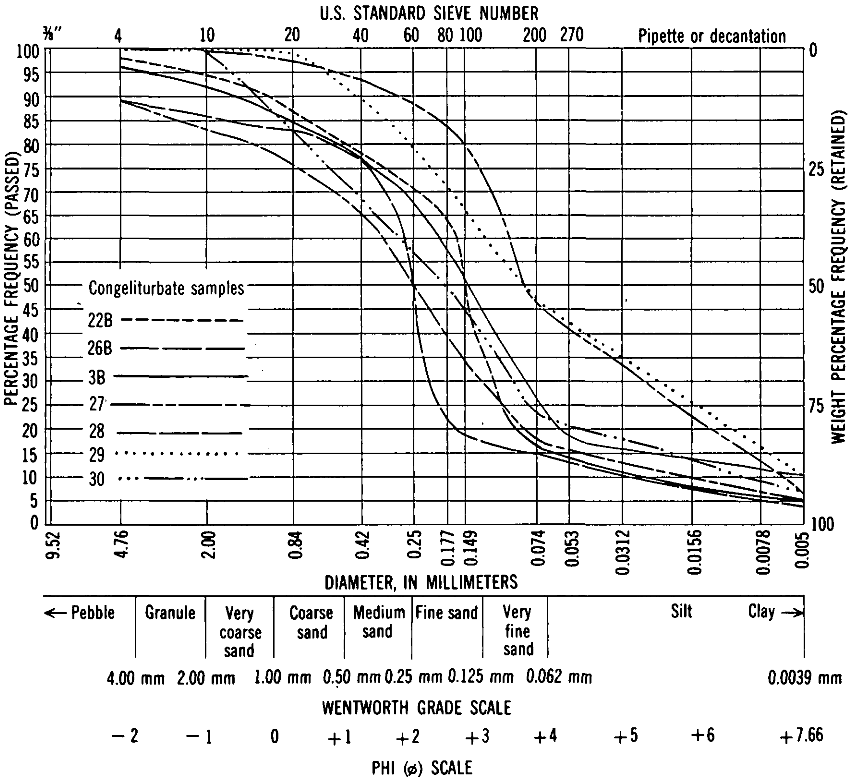

FIGURE 19.—Cumulative curves for grain sizes in congeliturbate.

TABLE 4.—*Statistical measures of congeliturbate*

Sample [1]	Median (mm)	Q_1 (mm)	Q_3 (mm)	Sorting (S_o)	$\log_{10} S_o$
26B (l)	0. 265	0. 385	0. 215	1. 34	0. 127
22B (t)	. 150	. 370	. 105	1. 88	. 274
3B (t)	. 150	. 380	. 070	2. 33	. 367
27 (gf)	. 250	. 840	. 105	2. 83	. 452
28 (t)	. 088	. 145	. 019	2. 76	. 441
29 (t)	. 085	. 220	. 016	3. 77	. 576
30 (gf)	. 190	. 620	. 080	8. 81	. 945

[1] Source material of congeliturbate indicated by symbol: t, till; gf, glaciofluvial material; l, lake.

thick, only a few stones may have been heaved from the underlying deposit into the windblown sand. However, where the mantle is a few inches to about 2 feet thick, the underlying material has generally been thoroughly mixed with the eolian layer.

The underlying glacial deposits determine the types of stones in the congeliturbate. Where a thin eolian mantle covers till, the congeliturbate shows many of the characteristics of the till and contains mostly angular to subangular fragments of the Rhode Island Formation. In addition, congeliturbate over till contains few ventifacts. On the other hand, where a thin layer of eolian material overlies sandy to gravelly glaciofluvial deposits, the congeliturbate contains rounded, subrounded, or even some subangular and angular pebbles, cobbles, and boulders, a high percentage of which are from north of the Narragansett basin. The angular fragments are the result of late-glacial or postglacial frost action, which, in places, preceded the period of wind cutting.

The congeliturbate samples used in preparing figure 19 were gathered from different areas and from different source beds. For example, samples 22B, 3B, 28 and 29 were taken from congeliturbate overlying till; sample 30 came from above a coarse glaciofluvial deposit; sample 26B came from above lake beds; sample 27 came from above fine glaciofluvial deposits.

Sample 30, from King Street just west of the hill at Locust Street, is from congeliturbate about 3 feet thick that lies above a very sharp textural break. The poor sorting ($So=8.81$) is the result of mixing fine windblown sand with the very coarse glaciofluvial sand below.

Sample 22B is from a section of congeliturbate overlying till in the north-central till area; the good sorting ($So=1.88$) indicates a dominance of eolian material in the section.

Sample 29 is from a small pit about 0.2 mile south of the intersection of Pleasant and Locust Streets. The congeliturbate here is yellowish brown to yellowish tan and consists of silt and fine sand. It contains few ventifacts. The congeliturbate is about 2½ feet thick, and it overlies a yellowish-brown hard, compact till.

On a till hillside northwest of the exposure just described, congeliturbate (sample 28) is at least 2 feet thick and contains numerous pebbles, cobbles, and boulders dragged up from gray compact till beneath. Large cobbles and boulders up to 30 inches in diameter, a few of which are ventifacts, were moved during and possibly following the period of wind action. They now lie in, and on, the congeliturbate and are completely separated from the till.

Sample 27 is from near Lothrop Street east of Lake Sabbatia. There the congeliturbate is underlain by a well-sorted medium sand that contains a few pebbles and cobbles. This congeliturbate resembles a disturbed till, but it contains numerous pebble- and cobble-size ventifacts and does not grade downward into till. The sorting coefficient, 2.83, is in the range termed "normally sorted" by Trask (1932).

One section in which the till can be completely separated from the eolian material was observed in a hole dug by hand on the northwest slope of the hill in Raynham about 0.8 mile north of the intersection of Bridge and Prospect Hill Streets. At sample locality 3, the yellowish-gray (5*Y* 7/2) till at the bottom of the hole has a sandy to silty matrix and contains many stones; it is easy to break into clumps when dry (sample 3A). Sample 3B is typical congeliturbate; it is a mixture of eolian material and till taken from about 2 feet below the surface of the ground. This congeliturbate is grayish orange (10*YR* 7/4) and consists of a mixture of coarse to very fine sand with some silt and clay. One ventifact was found in the eolian material (3C) 12 inches below the surface of the ground. The eolian material is fine to medium light-reddish-brown sand. Figure 20 and table 5 illustrate the

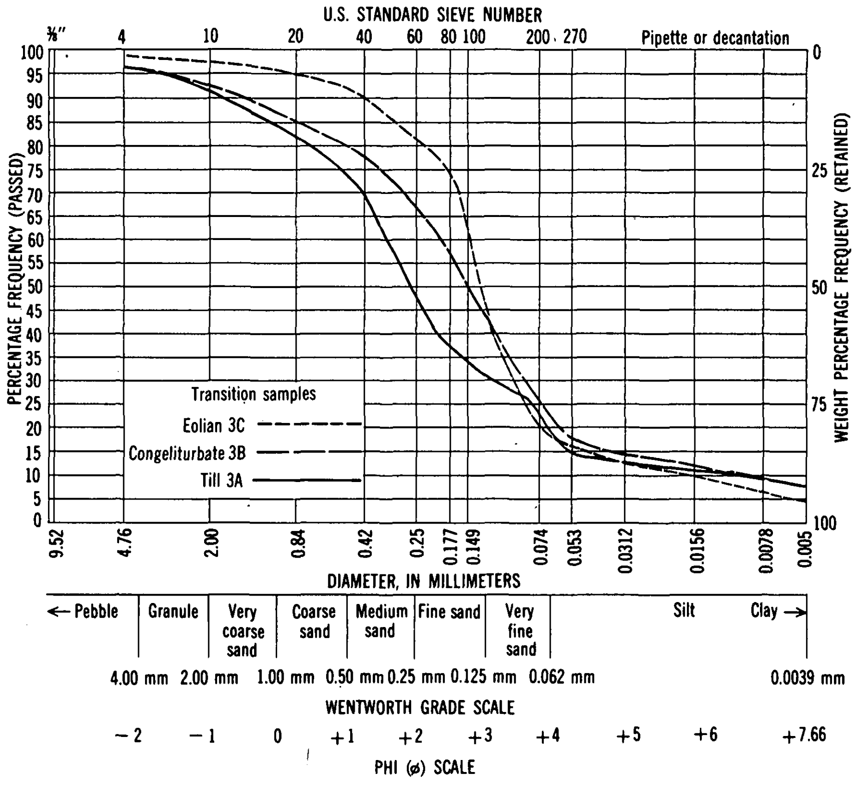

FIGURE 20.—Cumulative curves for grain sizes in material illustrating transition from till to eolian sand.

TABLE 5.—*Statistical measures of the transition from till to eolian sand*

Sample	Median (mm)	Q_1 (mm)	Q_3 (mm)	Sorting (So)	$\log_{10}So$
3C (eolian)	0. 130	0. 192	0. 080	1. 55	0. 190
3B (mixture)	. 150	. 380	. 070	2. 33	. 367
3A (till)	. 265	. 560	. 077	2. 70	. 431

transition from coarser poorly sorted till at the bottom of the hole, through an intermediate stage of sorting and slightly smaller grain size, up to a well-sorted eolian material.

LATE-GLACIAL HISTORY

GENERAL CHRONOLOGY

North-central North America, and perhaps northeastern North America, was covered with ice during at least four major glaciations, most of which were multiple. The first three advances, from oldest to youngest, were the Nebraskan, Kansan, and Illinoian glacial stages. The latest glacial stage, the Wisconsin (or Wisconsinan), is divided into the following substages in the Midwest:

From Frye and Willman (1960)	*From Leighton (1960, table 4)*
Wisconsinan Stage	Wisconsin Stage
Valderan Substage	Valders Substage
Twocreekan Substage	Two Creeks Interstadial
	Mankato Substage
	Bowmanville Interstadial
	Cary Substage
Woodfordian Substage	St. Charles Interstadial
	Tazewell Substage
	Gardena Interstadial
	Iowan Substage
Farmdalian Substage	Farm Creek Interstadial
Altonian Substage	Farmdale Substage

The substages can be distinguished by morphologic differences, truncation of terminal moraines, compositional differences in the till, relations of silt or loess to till and outwash, buried soil profiles, and radiocarbon dates.

The correlation of drift units in New England with sequences developed in the Midwest may be questioned (Flint, 1957, p. 342), but it seems reasonable to give some chronologic frame of reference, tentative though it may be, to the glacial deposits of the Taunton quadrangle.

The surface glacial drift of southern New England is certainly of Wisconsin age, but it has not yet been definitely placed within any Wisconsin stage. One line of evidence indicates a Cary (?) age for the glacial deposits of the Taunton quadrangle. Denny (1956) correlated the Valley Heads (Cary) of southwestern New York with the prominent moraines on Long Island and Cape Cod; this correlation is based on similarities in topography, content of water-laid materials, and evidence of periglacial frost action.

A few radiocarbon dates from organic material that overlies glacial sediments give approximate minimum ages for the last glaciation in southeastern New England. A date of 12,700 ± 300 years B.P. (Before Present) (W–710; Rubin and Alexander, 1960, p. 132) has been obtained for gyttja collected by C. A. Kaye from the bottom of a bog on Martha's Vineyard, and a date of 13,550 ± 460 years B.P. for material from Totoket Bog in southern Connecticut (Y–285; Preston, and others, 1955, p. 4). Slightly organic sandy silt from 10.8 to 11 m below the mud surface on the bottom of Rogers Lake, near Lyme, Conn., gave a date of 14,240 ± 240 years B.P. (Stuiver, and others, 1963, p. 320). At West Lynn, near Boston, Mass., barnacle plates in a marine clay that may have been contemporaneous with the glacial retreat have a date of 14,250 ± 250 years B.P. (W–735; Rubin and Alexander, 1960, p. 133).

The West Lynn date may be from several hundred to more than 1,000 years later than the start of the retreat from southeastern Massachusetts. The radiocarbon age from Rogers Lake suggests that the outermost moraine on Long Island, the Ronkonkoma, is almost certainly in the time range of what has been called Tazewell to Cary. The latest work in Illinois indicates no significant time interval between Tazewell and Cary (Frye and Willman, 1960, p. 8), and the same seems to be true in southern New England. That is, about 15,000 years B.P., the Wisconsin glacier began retreating from the outer moraines through Massachusetts, mostly by stagnation retreat, and had only minor readvances.

Pending further radiocarbon dating, pollen analyses, geologic mapping, and regional syntheses, Tazewell to Cary, or middle Woodfordian, seems to be the most reasonable age for the New England glaciation.

LOCAL CHRONOLOGY

As there are no well-defined valleys in the Taunton quadrangle, the numerous collapsed and uncollapsed glaciofluvial features cannot be linked in sequences as was done elsewhere by Jahns (1953), and the bases for correlation of most features are tenuous. Fieldwork on modern glaciers shows that outwash plains that start near each other are not necessarily related, because the streams that form these plains may arise on, or flow out of, the ice at different altitudes, and may flow at different times. The position of the apex of glaciofluvial fans or outwash plains is eventually controlled by the altitude of base level downstream, by the distance to base level, and by the rate of aggradation. Therefore, the kame delta east of Pine Swamp and the associated lake sediments are used as a chronologic datum.

The lake sediments in the south-central part of the area include varved and unvarved clay. The varves show that the lake may have lasted more than 200 years (Antevs, 1928), and the kame delta probably lasted as long. Kettle holes on the lake bottom show that some ice blocks melted after the lake was drained.

Hyyppä studied the pollen and diatoms in the varved clay near Taunton and concluded that the clay was deposited in a shallow marginal marine environment during the Taunton interstadial stage (1955, p. 209). He believed that the surrounding forests were predominantly deciduous (p. 198). Geologic evidence, however, indicates that the clay was laid down while the glacier that formed the north border of the lake was at the Pine Swamp–Hewett Pond–Gushee Pond line. As soon as the lake disappeared, the sediment that was previously deposited as a kame delta and the associated lake beds formed the large outwash plain that extends from Dead and Titicut Swamps south at least to the Taunton River. It thus seems unlikely that the lake deposits were interstadial or that they were formed during the Tazewell-Cary interval (Hyyppä, 1955, p. 217). The Taunton glacial lake lasted but a few hundred years and was only one episode in the deglaciation of the Taunton quadrangle.

Davis (1961b) identified over 50 different pollen types in the clay. Many of these are unlike those in Quaternary deposits in Massachusetts, and some are similar to pollen types in the Upper Cretaceous, Paleocene, and Eocene sediments in Europe. This indicates that some, if not all, of the pollen in the clay was transported and redeposited from older deposits, presumably the Cretaceous and Tertiary sediments of eastern Massachusetts (Bowman, 1906). Hence, the fossil pollen indicates neither the type of vegetation nor the climatic condition at the time of deposition of the clay.

The lacustrine sediments of the Taunton area seem to be contemporaneous with lacustrine sand, silt, and clay in the Bridgewater quadrangle (Hartshorn, 1960) and connect with them through a narrow north-trending strait along the Taunton River at the east border of the quadrangle. If the lacustrine sediments near Raynham Center are contemporaneous with those at the east border of the quadrangle, the relative ages of the outwash features between Gushee Pond and Scotland can be deduced.

A series of glaciofluvial deposits in the eastern part of the quadrangle seem to end in ice-contact slopes to the south and southeast. The highest landform—the glaciofluvial deposit east of Gushee Pond—ends in a scarp near Bassett Brook; the next lower landform to the east is a kame terrace; north of the kame terrace is a short outwash plain. The south and southeast scarps of all three overlook the former lake bottom to the east and southeast. Therefore, these three outwash deposits seem to be older than the lake and must have been built out against ice masses that occupied the basin later filled by the lake. The position of these deposits is anomalous with respect to the outwash plain at Raynham Center, which is definitely younger than the lake deposits (fig. 14). The outwash plain along Pleasant Street near Scotland and the outwash plain at Raynham Center head at approximately the same altitude and at first glance appear to be contemporaneous. But if the lake deposits from the Pine Swamp kame delta and those in the Bridgewater area are of the same age, the northeastern outwash plain and the outwash plain at Raynham Center must be of different ages.

Another series of problems arises in connection with the glaciofluvial deposits near Prattville and those in the city of Taunton. The body of outwash upon which Taunton is built is apparently related to a kame terrace built around the base of Prospect Hill. The outwash deposits grade southward to the Taunton Court House, where they are intermingled with outwash from sources to the northwest. The head of the outwash plain at Taunton is at the same altitude as the head of the kame delta to the east, but the two cannot be correlative. The outwash plain has an east-facing scarp that is not deltaic, as shown in a pit on East Britannia Street that extends to the base of the outwash plain. Also, the Taunton outwash plain does not slope toward the east-facing slopes, as it would if it were a delta. Apparently an ice block held up the east edge of this plain, just as ice held up the southeast slopes of the glaciofluvial deposits to the northeast. The ice mass that lay in the area now occupied by Pine Swamp must have been present from this early date through the entire life of the lake and the building of the kame delta; that is, it persisted with little change while the lake-basin ice disappeared. The Pine Swamp ice apparently lasted throughout the building of the outwash plain at Raynham Center, because the kames and kame plains around Prattville grade eastward around the north end of the delta and join the outwash plain that covers the lake deposits. The lack of lacustrine deposits on some areas below an altitude of about 75 feet may be attributed to the presence of remnant ice blocks in these areas and to the possibility that silt and clay were deposited only in deep quiet water.

An alternative explanation for the various outwash plains is as follows: When the Taunton outwash plain was being formed, a mass of ice lay in the lowland to the east, perhaps extending along the Taunton River valley to the east boundary of the Bridgewater quadrangle. This ice block melted first from the area around Taunton and Raynham, creating a depression in which a lake formed. The kame delta and the lake beds were laid down at this time, in part over and around lingering remnants of ice in the lake bottom. After the lake drained, melt water flowed over the lake-bottom plains from ice around Prattville, Dead Swamp, and Titicut Swamp. In the meantime, before the ice masses disappeared from the Taunton River valley on the east margin of the quadrangle, the glaciofluvial deposits along Pine Street hill and the kame terrace to the east were formed. The outwash plain near Scotland was formed at the same time as the plain at Raynham Center, while ice still occupied the Titicut Swamp area and the area around North Middleboro and eastward in the Bridgewater quadrangle. The melt water flowed off over, or through, the ice to some unknown outlet just as it had when the earlier glaciofluvial deposits and kame terrace were formed. The eastern, or Bridgewater, lake basin then was formed, and the deltas and lacustrine deposits that cover much of the central part of the Bridgewater quadrangle were deposited. It is difficult to explain, however, why the Bridgewater lake remained at an altitude of about 75 feet, when the Taunton lake had drained, and outwash covered the lake deposits down to an altitude of 20 feet. Possibly ice remnants lingered in the narrow part of the valley between U.S. Route 44 and Beach Street, separating the two lakes and making independent histories possible. However, this hypothesis seems generally less probable than the explanation presented above.

One of the last episodes in the sedimentary history of the quadrangle was the formation of a lake whose deposits cover part of the lowland in the northern part of the area. The deltas of this lake are in the Brockton quadrangle to the north. The floor of the Hockomock Swamp is not all covered by lake deposits, however, for borings show that in some places the bottom is till, and in other places coarse sand and gravel.

Deposition of the eolian mantle and the concurrent intense frost action that mixed the wind deposits with the underlying glacial materials were the last events in the late-glacial history. The mantle of windborne sand and silt and the widespread distribution of ventifacts imply a scarcity of vegetation just after deglaciation. The occurrence of ventifacts throughout the eolian mantle may indicate that the windblown layer was deposited concurrently with the wind-cutting. The large areas of sand plain and lake bottom must have been the main sources for the eolian material. The source of material must have shifted to the north and northwest as the ice retreated and new glaciofluvial features were formed and new areas of ground moraine laid bare by the disappearance of the ice. The earlier sources of windblown sand and silt were covered in turn by later eolian deposits.

The last evidence of glacial influence in the area is the congeliturbate, which resulted from the intense frost action that accompanied the late-glacial climate.

The presence of ventifacts in a frost-heaved layer thicker than the depth of modern frost penetration indicates that congeliturbation was a result of the Pleistocene climate. Congeliturbate is found to a depth of at least 5 feet, which was probably the general depth of frost action in late-glacial times.

POSTGLACIAL HISTORY

Late-glacial time in the Taunton quadrangle ceased when all but a few buried blocks of ice had disappeared from the area, and postglacial time commenced while some collapse of sediment was still going on in isolated kettle holes. The term "postglacial" is used here in a strictly local sense, in accordance with the recommendation of Flint (1957, p. 283) that "Events that occurred within any district while it was covered with glacier ice are referable to glacial time for that district; subsequent events are referable to postglacial time."

Apparently a mosaic of tundra plants and forest vegetation, mostly spruce and pine, followed the retreating ice northward. But because of the probable rapid wasting of the ice and the rate at which scattered areas of bare ground became available, the migration of trees probably could not have kept up with the retreating glacier, even had the climate been favorable (Davis, 1961a, p. 629–630).

In addition to herbaceous plants and scattered trees, bogs were features of the early postglacial landscape. In low wet areas, or where lakes still occupied depressions, swamp vegetation began to encroach, fill the lakes, and level off the low areas. The final filling of some lakes took place such a short time ago that the outline of the lake is still visible on aerial photographs, as at Pine Swamp. In other places, such as at Gushee Pond, vegetation is still growing in from the edges of the pond.

Pollen studies by Davis (1960), on material from a bog near Williams Street southeast of the Taunton Water Works, show a lower spruce pollen zone (A–1, A–2, A–3), an upper spruce pollen zone (A–4), and lower (B–1) and upper (B–2) pine zones. Apparently the underlying sediments, which contain little pollen and include secondary pollen, are stratigraphically equivalent to the herb pollen zone (T or T–3) at other sites.

Many of the streams in the Taunton quadrangle originated as glacial streams. The Forge River at Raynham Center, for example, is cut into the outwash plain and the underlying lake beds and flows through a wide flat-bottomed valley that seems too large in proportion to the size of the river. Thus, Forge River may have originated in the Titicut Swamp area as a glacial stream flowing from a glacial lake dammed on the south by the outwash gravel. The water flowing from the lake would have been swift and able to carve a large channel. When the glacial lake disappeared or when the ice left the area, the stream diminished in volume and today occupies a smaller channel on the floor of the wide late-glacial valley.

An indirect glacial origin is postulated for Dam Lot Brook, which is also an underfit stream. This stream probably originated some distance south of Titicut Swamp, and its source may have been a copious flow of ground water originating in a glacial lake on the north.

The Taunton River flows on the sand, silt, and clay of the old glacial-lake floor except at one place near the east edge of the quadrangle where it is superimposed on bedrock. The river has carved a meandering valley and left extensive lowland flats veneered with alluvium composed of gravel, sand, silt, and clay. At most places it is difficult or impossible to distinguish glacial material from modern alluvium.

A sample of alluvial sand taken from 30 inches below the surface on the inside of a meander consists of a clean well-sorted ($So=1.55$) fine sand (median diameter 0.129 mm), with subordinate very fine sand. It is light brown all the way to the base, is slightly coherent, and contains no organic matter.

Terraces on all the small streams, and on the Taunton River itself, cannot be correlated because they bear no relation to the size of the stream or to similar terraces on neighboring streams. The terrace tops are the original glacial landscape. Where this was a flat plain the terrace surfaces are flat; where the altitude differed, the height of the terrace above the stream also differs.

Although the land was depressed by the weight of the glacier, there probably was not much depression near the margin of the ice sheet, and rising sea level lagged behind deglaciations. Stream downcutting and terrace formation may have taken place largely during the period of lower eustatic sea level.

According to recent work by Bloom (1963), submergence (that is, rise of sea level relative to the land) has been continuous along the

Connecticut coast, and presumably along the coast of southern Massachusetts as well, for at least 7,000 and probably over 11,000 years, with no evidence of pauses or reversals. From about 7,000 years ago to 3,000 years ago the rate of submergence was 0.6 foot per century; from 3,000 years ago to the present, it has been only 0.3 foot per century. When the rise in sea level reached the upper part of Narragansett Bay, the base level of the Taunton River and of all its tributaries was raised. The decreased stream gradients caused aggradation and, possibly, the start of the meanders.

ECONOMIC FEATURES

The mineral resources of the Taunton quadrangle consist of sandstone, sand, gravel, varved clay, loam, and peat. Coal has been reported but never mined commercially.

Bedrock.—The Rhode Island Formation is quarried in three places. Two quarries, one on Hart Street in the southern part of the quadrangle and one a little more than half a mile to the northeast, have long been abandoned. The third quarry, northwest of Whittenton Junction, was temporarily abandoned, but was reopened in 1955. The sandstone there breaks into angular fragments and is now being used as aggregate in concrete. In the past it was used for railroad ballast and perhaps as a building stone.

Sand and gravel.—The numerous sources of sand and gravel are shown on the geologic map. They consist of various forms of stratified drift deposits, such as ice-channel fillings, kames and kame fields, kame terraces, kame plains, outwash plains, and undivided glaciofluvial deposits.

Ice-channel fillings are generally good sources of gravel and coarse sand. The north ends of outwash plains, which were closest to the sources of the glacial streams, are also excellent sources of sand and gravel. Much of the material classified as undivided glaciofluvial deposits had a similar origin and contains clean well-sorted sand and well-rounded gravel.

Kame plains, kames, and kame fields, however, show a great range in composition because they originated under a great variety of conditions. It is impossible to predict the composition of these outwash features with assurance except to say that they are generally composed of sand and gravel.

The kame terraces in the southeastern part of the Taunton quadrangle are generally poorly sorted and contain coarse material. Kame terraces in the other parts of the quadrangle, however, are more like outwash plains, grading from coarse materials near the head to fine sand and gravel at the lower end.

The two kame deltas in the quadrangle consist of 5–15 feet of medium cobble gravel and very coarse sand underlain by finer beds of sand and gravel. Many kames and kame plains have the same general composition because they were formed as deltas.

Clay.—Varved clay and laminated sand and silt have been used as brick clay in several parts of the area. The Stiles and Hart clay pit, just north of Weir Village, is in varved clay overlain by 3–12 feet of sand and gravel. Apparently the area north and east of the present pits has been worked since colonial times. The old workings were shallow, probably because of the high water table, and covered the area south and west of County and Linden Streets. Exploratory pits dug by the present owners went through about 10 feet of disturbed material before reaching glacial clay.

An abandoned clay pit, in which the material is mostly laminated sand and silt with minor amounts of clay, is located east of Williams Street along the Taunton River. There is another abandoned clay pit northeast of Longmeadow Road, about seven-tenths of a mile south of Pine Swamp.

The clay in many of the lacustrine deposits in the southern part of the quadrangle is suitable for brickmaking but is not being utilized at present.

Peat and loam.—Peat was reportedly obtained from parts of the Hockomock Swamp in the latter part of the last century, but records of individual enterprises have not been found. The eolian material, oxidized and mixed with humus near the surface, forms an excellent loam. This loam is stripped from the fields and spread around new homes for growing lawns.

REFERENCES

Ahlmann, H. W., 1935, Scientific results of the Norwegian-Swedish Spitsbergen expedition in 1934. Pt. 5, The Fourteenth of July Glacier: Geog. Annaler, v. 17, p. 167–218.

Antevs, Ernst, 1928, The last glaciation, with special reference to the ice retreat in northeastern North America: Am. Geog. Soc. Research Ser., no. 17, 292 p.

Bloom, A. L., 1963, Submergence of the Connecticut coast: Science, v. 139, p. 332–334.

Bowman, Isaiah, 1906, Northward extension of the Atlantic pre-glacial deposits: Am. Jour. Sci., 4th ser., v. 22, p. 313–325.

Bryan, Kirk, 1932, Geological features in New England ground water supply: New England Water Works Assoc. Jour., v. 50, p. 222–228.

——— 1946, Cryopedology—the study of frozen ground and intensive frost-action with suggestions on nomenclature: Am. Jour. Sci., v. 244, p. 622–642.

Chute, N.E., 1949, Surficial geology of the Pawtucket quadrangle, Rhode Island-Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ–2.

——— 1950a, Bedrock geology of the Brockton quadrangle, Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ–5.

——— 1950b, Surficial geology of the Brockton quadrangle, Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ–6.

Crosby, W. O., 1891, Composition of the till or boulder clay: Boston Soc. Nat. History Proc., v. 25, p. 115–140.

Currier, L. W., 1941a, Disappearance of the last ice sheet in Massachusetts by stagnation zone retreat [abs.]: Geol. Soc. America Bull., v. 52, p. 1895.

——— 1941b, Tills of eastern Massachusetts [abs.]: Geol. Soc. America Bull., v. 52, p. 1895–1896.

Davis, M. B., 1960, A late-glacial pollen diagram from Taunton, Massachusetts: Torrey Bot. Club Bull., v. 87, p. 258–270.

——— 1961a, Pollen diagrams as evidence of late-glacial climatic change in southern New England: New York Acad. Sci. Annals, v. 95, p. 623–631.

——— 1961b, The problem of rebedded pollen in late-glacial sediments at Taunton, Massachusetts: Am. Jour. Sci., v. 259, p. 211–222.

Denny, C. S., 1956, Wisconsin drifts in the Elmira region, New York, and their possible equivalents in New England: Am. Jour. Sci., v. 254, p. 82–95.

Dyson, J. W., 1952, Ice-ridged moraines and their relation to glaciers: Am. Jour. Sci., v. 250, p. 204–211.

Emerson, B. K., 1917, Geology of Massachusetts and Rhode Island: U.S. Geol. Survey Bull. 597, 289 p.

Fenneman, N. M., 1938, Physiography of eastern United States: New York. McGraw-Hill Book Co., 714 p.

Flint, R. F., 1928, Eskers and crevasse fillings: Am. Jour. Sci., 5th ser., v. 15, p. 410–416.

——— 1957, Glacial and Pleistocene geology: New York, John Wiley & Sons, 553 p.

Frye, J. C., and Willman, H. B., 1960, Classification of the Wisconsinan Stage in the Lake Michigan glacial lobe: Illinois State Geol. Survey Circ. 285, 16 p.

Goddard, E. N., chm., and others, 1948, Rock-color chart: Washington, Natl. Research Council (repub. by Geol. Soc. America, 1951), 6 p.

Goldsmith, Richard, 1962, Surficial geology of the Montville quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ–148.

Goldthwait, Lawrence, 1948, Glacial till in New Hampshire: New Hampshire State Plan. and Devel. Comm., Mineral Resources Survey, pt. 10, 11 p.

Hansen, W. R., 1956, Geology and mineral resources of the Hudson and Maynard quadrangles, Massachusetts: U.S. Geol. Survey Bull. 1038, 104 p.

Hartshorn, J. H., 1952, Superglacial and proglacial geology of the Malaspina Glacier, Alaska and its bearing on glacial features in New England [abs.]: Geol. Soc. America Bull., v. 63, p. 1259–1260.

——— 1958, Flowtill in southeastern Massachusetts: Geol. Soc. America Bull., v. 69, p. 477–482.

——— 1960, Geology of the Bridgewater quadrangle, Masachusetts: U.S. Geol. Survey Geol. Quad. Map GQ–127.

Hyyppä, Esa, 1955, On the Pleistocene geology of southeastern New England: Finlande Comm. Géol. Bull., no. 167, p. 155–225.

Jahns, R. H., 1941, Outwash chronology in northeastern Massachusetts [abs.]: Geol. Soc. America Bull., v. 52, p. 1910.

——— 1943, Sheet structure in granites: its origin and use as a measure of glacial erosion in New England: Jour. Geology, v. 51, p. 71–98.

——— 1951, Surficial geology of the Mt. Toby quadrangle, Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ–9.

——— 1953, Surficial geology of the Ayer quadrangle, Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ–21.

Jahns, R. H., and Willard, M. E., 1942, Late Pleistocene and Recent deposits in the Connecticut Valley, Massachusetts: Am. Jour. Sci., v. 240, p. 161–191, 265–287.

Judson, S. S., Jr., 1949, The Pleistocene stratigraphy of Boston, Massachusetts and its relation to the Boylston Street Fishweir, *in* Johnson, F., ed., The Boylston Street Fishweir II: R. S. Peabody Found. for Archaeology Papers, v. 4, no. 1, p. 7–48.

Krumbein, W. C., and Pettijohn, F. J., 1938, Manual of sedimentary petrography: New York, Appleton-Century-Crofts, Inc., 549 p.

Leighton, M. M., 1960, The classification of the Wisconsin Glacial Stage of north central United States: Jour. Geology, v. 68, p. 529–552.

Lougee, R. J., and Vander Pyl, A. W., 1951, Glacial water levels in the Thames-Willimantic river valley [Conn.]: Sci. Monthly, v. 73, p. 275–283.

Mather, K. F., Goldthwait, R. P., and Thiesmeyer, L. R., 1942, Pleistocene geology of western Cape Cod, Massachusetts: Geol. Soc. America Bull., v. 53, p. 1127–1174.

McLendon, W. E., and Jones, G. B., 1912, Soil survey of Plymouth County, Massachusetts: U.S. Dept. Agriculture, Bur. Soils, Advance sheets—field operations, 1911, 41 p.

Moss, J. H., 1943, Two tills in the Concord quadrangle, Massachusetts [abs.]: Geol. Soc. America Bull., v. 54, p. 1826.

Preston, R. S., Person, Elaine, and Deevey, E. S., Jr., 1955, Yale natural radiocarbon measurements II: Science, v. 122, no. 3177, p. 954–960.

Quinn, A. W., and Oliver, W. A., Jr., 1962, Pennsylvanian rocks of New England, *in* Branson, C .C., ed., Pennsylvanian System in the United States: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 60–73.

Quinn, A. W., and Springer, G. H., 1954, Bedrock geology of the Bristol quadrangle and vicinity, Rhode Island–Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ–42.

Richmond, G. M., 1953, Surficial geology of the Georgiaville quadrangle, Rhode Island: U.S. Geol. Survey Geol. Quad. Map GQ–22.

Rubin, Meyer, and Alexander, Corrinne, 1960, U.S. Geological Survey radiocarbon dates V: Am. Jour. Sci., Radiocarbon Supp., v. 2, p. 129–185.

Segerstrom, Kenneth, 1955, Surficial geology of the Williamsburg quadrangle, Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ–80.

Shaler, N. S., 1893, The conditions of erosion beneath deep glaciers, based upon a study of the boulder train from Iron Hill, Cumberland, R.I.: Harvard Coll. Mus. Comp. Zoology Bull., v. 16, p. 185–225.

Shaler, N. S., Woodworth, J. B., and Foerste, A. F., 1899, Geology of the Narragansett Basin: U.S. Geol. Survey Mon. 33, 402 p.

Smith, G. D., 1942, Illinois loess, variations in its properties and distribution, a pedologic interpretation: Illinois Univ. Agr. Expt. Sta. Bull. 490, p. 138–184.

Smith, H. T. U., and Fraser, H. J., 1935, Loess in the vicinity of Boston, Mass.: Am. Jour. Sci., 5th ser., v. 30, p. 16–32.

Stuiver, Minze, Deevey, E. S., Jr., and Rouse, Irving, 1963, Yale natural radiocarbon measurements VIII: Radiocarbon, v. 5, p. 312–341.

Swineford, Ada, and Frye, J. C., 1945, A mechanical analysis of windblown dust compared with analyses of loess: Am. Jour. Sci., v. 243, p. 249–255.

Tarr, R. S., 1908, Some phenomena of the glacier margins in the Yakutat Bay region, Alaska: Zeitschr. Gletscherkunde, v. 3, p. 81–110.

Trask, P. D., 1932, Origin and environment of source sediments of petroleum: Houston, Tex., Am. Petroleum Inst., 323 p.

Udden, J. A., 1898, The mechanical composition of wind deposits: Augustana Libr. Pubs., no. 1, 69 p.

Wentworth, C. K., 1922, A scale of grade and class terms for clastic sediments: Jour. Geology, v. 30, p. 377–392.

Wentworth, C. K., and Dickey, R. I., 1935, Ventifact localities in the United States: Jour. Geology, v. 43, p. 97–104.

Woodworth, J. B., 1894, Post-glacial eolian action in southern New England: Am. Jour. Sci., 3rd ser., v. 47, p. 63–71.

——— 1899, The ice contact in the classification of glacial deposits: Am. Geologist, v. 23, p. 80–86.

Woodworth, J. B., and Wigglesworth, E. B., 1934, Geography and geology of the region including Cape Cod, the Elizabeth Islands, Nantucket, Marthas Vineyard, No Mans Land, and Block Island: Harvard College Mus. Comp. Zoology Mem., v. 52, 322 p.