GLACIAL GEOLOGY OF THE TAUNTON QUADRANGLE, MASS.

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CONTENTS

ILLUSTRATIONS

TABLES

Page

INTRODUCTION

General Statement

Massachusetts offers a wide array of glacial features, and mapping these features provides an opportunity to arrive at hypotheses which will satisfactorily disclose the origin of the many glaciofluvial forms.

A glimpse of the history of glacial geology in New England shows that prior to 1905 there was a tremendous outpouring of literature produced by some of the great names of early geology in North America--Agassiz, Dana, Upham, Shaler, Tarr, and many others. After the acceptance of the theory of multiple glaciation, the work consisted of reconnaissance mapping and the solving of small areal problems. Between 1905 and 1930, interest in glacial geology shifted to the central and western United States, and little was done in New England. There were, of course, some notable exceptions--the mapping and teaching of J. W. Goldthwait and the work on varved clays by Antevs, for example. A new age of interest and study in glacial geology began in the early 1930's with the introduction of Flint's idea of general stagnation of the ice sheet, with Bryan's emphasis on frost action, wind action, and the periglacial climate, and with Lougee's concentration on glacial water planes, upwarp of the earth's crust, and normal retreat.

The next new development in Pleistocene geology in New England was the introduction of a large scale mapping program in Massachusetts and Rhode Island under the supervision of the United States Geological Survey. This glacial program is aimed at producing basic data necessary for the interpretation of the glacial history of the area and for the application of glacial geology to engineering.

In the past, Massachusetts was mapped by reconnaissance methods with base maps which were inadequate by present topographic standards (Emerson, 1898). For example, the 15 minute quadrangles, on a scale of an inch to a mile, made during the period 1890 to 1900, are of limited use as a mapping base. They were the best maps available then, and it is certain from old correspondence in the files of the Geological Survey that Nathaniel S. Shaler was enthusiastic about them when they first appeared and planned to produce a glacial map of the state based on quadrangle mapping. A perusal of the old glacial manuscript maps on file in the Boston office of the Geological Survey shows that the glacial mapping is very general, and only the most prominent features were found and recorded. This older mapping does not show the detailed relationships of landforms that enable geologists to reconstruct the most nearly complete glacial story.

The enthusiasm generated by Shaler and his colleagues over the appearance of the inch to the mile maps was duplicated fifty years later by Currier and the group of geologists who first worked under his supervision. A new series of two-inch-to-the-mile maps appeared in the late 1930's and are so detailed and the contour interval so small that in this area of fine-grained topography the various features stand revealed in numbers and variety never mapped before. Many landforms that have gone unrecognized or have never been related to one another because of poor vertical control are found to throw new light on the glacial history. Eventually, when the glacial geology of all of Massachusetts is mapped on the scale of two inches to the mile, a detailed explanation of the chronology and mode of ice retreat can be set forth.

Purpose of the Study

The discovery in 1947 of a stratified archaeological site at Titicut, near North Middleboro, Massachusetts, gave an excellent opportunity to combine the disciplines of archaeology and geology. Artifacts found in the humus and in the upper part of the soil at the site presented no special problem to the archaeologists, for many such finds have been made in New England. Archaeological debris found at a lower level, however, apparently was separated from the artifacts in the upper soil by a sterile zone in which few cultural remains appeared. Quartz chips, arrowpoints, charcoal, and hearths were found in this lower level, nearly a meter deep. At first it looked as if the soil profile had developed after the lower culture horizon was covered, indicating a considerable antiquity for the lower zone. The late Professor Kirk Bryan of Harvard recognized the possibility of giving a geologic date to this older material and asked the author to undertake a geologic study in cooperation with an archaeologic study by Frederick Johnson of the R. S. Peabody Foundation for Archaeology. It was felt that too little was known of the general geology near the site, and consequently the first part of the task consisted of a study of the glacial geology of the surrounding area. The glacial geology of the Taunton quadrangle presented here completes one part of this study.

<u>Method of work</u>

The Taunton 7½ minute quadrangle is located in southeastern Massachusetts (Figure 1), and the Titicut site is located on the eastern boundary of the quadrangle.

The general geology of the Taunton quadrangle was mapped over a period of three field seasons, 1949, 1950, and 1951, and the geology has been rechecked on numerous occasions. The field seasons were interrupted several times each summer when the author was called away for short assignments in other areas, as part of the program of cooperative geologic investigations between the United States Geological Survey and the Commonwealth of Massachusetts. During the summer of 1951 the

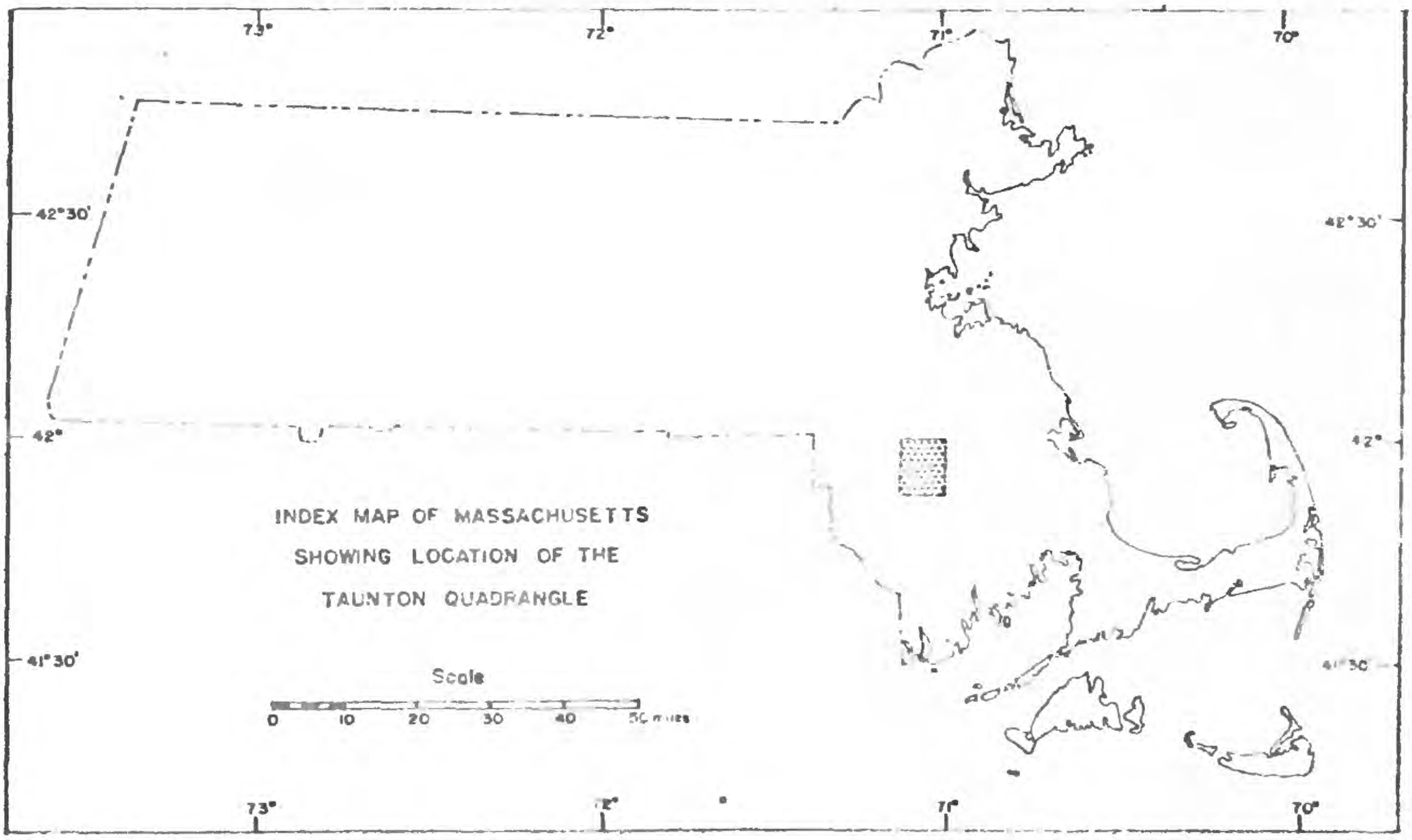
73°
72°
71°
70°
42°30'
42°
41°30'
INDEX MAP OF MASSACHUSETTS
SHOWING LOCATION OF THE
TAUNTON QUADRANGLE
Scale
0
10
20
30
40
50 miles

Figure 1.

project was recessed temporarily while the author went to the Malaspina Glacier, Yakutat Bay, Alaska, for the purpose of increasing his knowledge of the mode of origin of features surrounding contemporary glaciers. The knowledge there gained was directly applied to the problems surrounding New England glacial geology.

A total of about 135 days were spent in the field in the Taunton area, and office studies were carried out in the intervals between field seasons. Laboratory studies were carried out mostly in 1949 and 1950, but some efforts have been directed to sedimentary studies in the ensuing years. The Massachusetts Department of Public Works has cooperated by making their laboratory available for mechanical analyses of the sediments.

The map base used was the United States Geological Survey 7½ minute topographic sheet of the Taunton quadrangle. Natural and artificial exposures were used to investigate the composition and structure of the glacial deposits, and these exposures were supplemented by small holes dug by hand wherever necessary. Aerial photographs, on a scale of 1:2 ,000, were used only as guides in the woods or in the flatter portions of the quadrangle, as it was not practicable to map on them. Exposures in sand or in the swamps were augmented by the use of a 10' segmented hand auger; this was very useful in fine-grained materials but was useless in anything larger than granule gravel.*

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*Throughout this paper the Wentworth size classification (Wentworth, 1922) is used. In this classification boulders exceed 256 mm. (10.08") in greatest diameter, cobbles range from 256 to 64 mm. (2.52"), pebbles from 64 to 4 mm. (.157"), granules from 4 to 2 mm. (.079"), very coarse sand from 2 to 1 mm. (.0394"), coarse sand from 1 to .50 mm. (.0197"), medium sand from .50 to .25 mm. (.0098"), fine sand from .25 to .125 mm. (.0049"), very fine sand from .125 to .0625 mm. (.0025"), silt from .0625 to .0039 mm. (.00015"), and clay particles are less than .0039 mm. in greatest diameter.

The field maps were replotted on drafting paper maps of the same scale and photostated for working out various chronological interpretations.

Acknowledgements

The late Kirk Bryan was the prime instigator for this problem. During the years 1948 to 1950, Professor Bryan and the author made several trips to Titicut together and discussed the problems it presented. In the spring of 1949, Bryan suggested that the problem of the geologic antiquity of the Titicut site would require a more detailed knowledge of the surrounding terrain and decided that it would make a good research problem for a doctoral dissertation. His untimely death before the end of the 1950 field season prevented him from discussing the field evidence and hypotheses presented herein, but many of the ideas stated in this paper may be traced back to him.

Much credit goes to Frederick Johnson, of the R. S.

Peabody Foundation for Archaeology, for his efforts in bringing the problem to the attention of Professor Bryan, and for recognizing the fact that a study of the general geology could play a part in the determination of the age of the site. The Foundation also helped to finance part of the early work in the Taunton area.

Professor Marland P. Billings and Professor John P. Miller of Harvard, and Dr. Charles E. Stearns of Tufts University, have read and criticized the manuscript and have given valuable suggestions and corrections both in content and presentation.

In numerous ways, Dr. Louis W. Currier, United States Geological Survey, has assisted in the problem of mapping the Taunton quadrangle. As the supervisor of the geologic mapping program in Massachusetts, his contributions have been those of teacher and critic in the problems of glacial mapping.

My wife Eleanor J. Hartshorn, has helped with the drafting and has helped to correct and revise the manuscript in all its phases. Mrs. Eleanor B. Towne typed the final copy.

GENERAL SETTING

The Taunton quadrangle occupies an area of about 55 square miles and includes portions of both Bristol and Plymouth Counties. The quadrangle is located entirely within the Seaboard Lowland section of the New England physiographic province (Fenneman, 1938). The area is a region of relatively low relief and in the southwestern part of the quadrangle the Taunton River enters tidewater above the city of Taunton. The highest hill in the area is Prospect Hill, a large kame of sand and gravel that stands slightly more than 200 feet above sea level.

The large sand and gravel masses, which mantle the area, form most of the topographic features. For instance, Prospect Hill and the numerous hills and mesa-like forms surrounding it are composed entirely of stratified drift. The bedrock topography seems to affect the present landscape only in the eastern part of the quadrangle, where three elongate hills with relief of about 100 feet, 110 feet, and 70 feet have a crude northwest-southeast alignment.

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

PRE-PLEISTOCENE HISTORY

General Statement

Pre-Pleistocene events in the Taunton quadrangle must, in large part, be inferred from more general knowledge of the eastern part of Massachusetts. Thick deposits of drift have a tendency to mantle irregularities in the preglacial topography, and have concealed all the bedrock in the area with the exception of about twenty-five outcrops, which total much less than 1% of the area of the quadrangle. However, tentative conclusions concerning the pre-Pleistocene geology and topography can be drawn from the few bedrock outcrops and from the depth to bedrock inferred from well data, seismic profiles, and wash borings.

Stratigraphy

The Taunton quadrangle lies entirely within the Narragansett Basin, a structural and topographic lowland partly submerged to the south by the waters of Narragansett Bay. The rocks within this lowland are mostly sedimentary rocks of Carboniferous to Permian (?) age (Emerson, 1917, p.58) estimated to have an aggregate thickness of 12,000 feet, with a few inliers of pre-Carboniferous rocks (Figure 2).

The Pondville conglomerate is the oldest rock assigned to the Carboniferous, and where it is present at the base of the section it is composed of generally coarse conglomerates lying unconformably on the older rocks (Quinn, 1952). Where the Pondville conglomerate is absent, the base of the section may consist of the characteristically red beds of the Wamsutta formation, or sandstone, felsite, agglomerate, arkose, or shale (Chute, 1950).

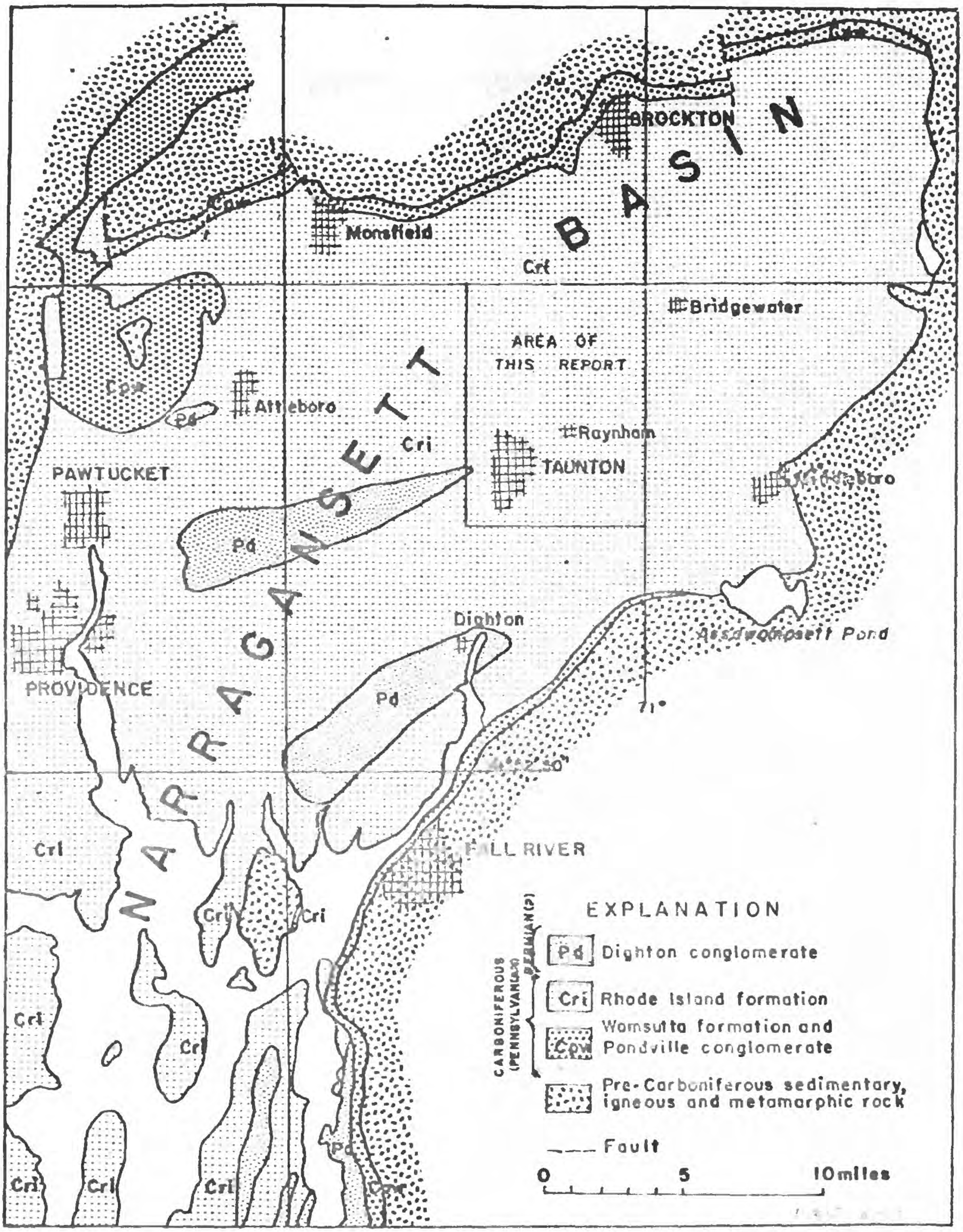

Figure 2. Geology of the Narragansett Basin (from Emerson, 1917, Chute, 1950, Quinn, 1952, and Quinn and Springer, 1954).

The Rhode Island formation occurs above the Pondville conglomerate and the Wamsutta formation, and in places rests directly upon the pre-Pennsylvanian crystalline rocks (Quinn and Springer, 1954). It is the Rhode Island formation alone that crops out within the Taunton quadrangle. In general, the formation consists of shaly and slaty coal-bearing beds, interbedded with sandstones and conglomerates. Coal plants, a few ostracods, and insects of Pennsylvanian age have been found (Emerson, 1917, p.55).

In the Taunton quadrangle the Rhode Island formation consists of an indeterminate sequence of conglomerates, sandstones, shales, and slates, the colors of which range from black through green to light gray. Chute (1950) found that the gray sandstone of the Rhode Island formation (in a specimen taken near the north edge of the Taunton quadrangle) is composed of 50% quartz in angular to subangular grains, 20 to 25% feldspar (much of which is plagioclase), 15% sericite, and minor amounts of carbonate and muscovite.

The Dighton conglomerate, tentatively assigned to the Permian by Emerson (1917, p. 58), is a coarse conglomerate preserved in the deeply downfolded synclines of the basin. Just south of the quadrangle a large excavation disclosed a conglomerate composed of pebbles and cobbles that resembles the Dighton conglomerate. It is possible that the original syncline from which the Dighton conglomerate was named (Figure 2) extends almost to the border of the quadrangle. This cannot be definitely proven until more detailed bedrock mapping is done in the Assonet and Somerset quadrangles.

Structure

The crustal movements of the Appalachian Revolution compressed the sedimentary rocks into a series of long folds that are broader and more open in the middle of the basin and steeper and tighter at the sides (Emerson, 1917, p. 54), and that trend north in the southern part of the area through northeast to east in the northern part of the basin. The fold axes are in general parallel to the sides of the basin.

Jointing and a slaty cleavage are found in the rocks of the basin, although rocks crop out in too few places to permit any regional pattern to be deciphered. Metamorphism has been slight in the Taunton quadrangle, although the rocks in general are well indurated. Some metamorphic minerals, micas and epidote for instance, have been found in the sandstone and shale.

An anticline has been postulated, on a limited amount of evidence, in the northern and western parts of the Taunton quadrangle. The axis of the anticline enters the quadrangle just north of Watson Pond, strikes northeast through the bedrock outcrops south of the Raynham Dog Track (Figure 3) and continues to the east. A syncline

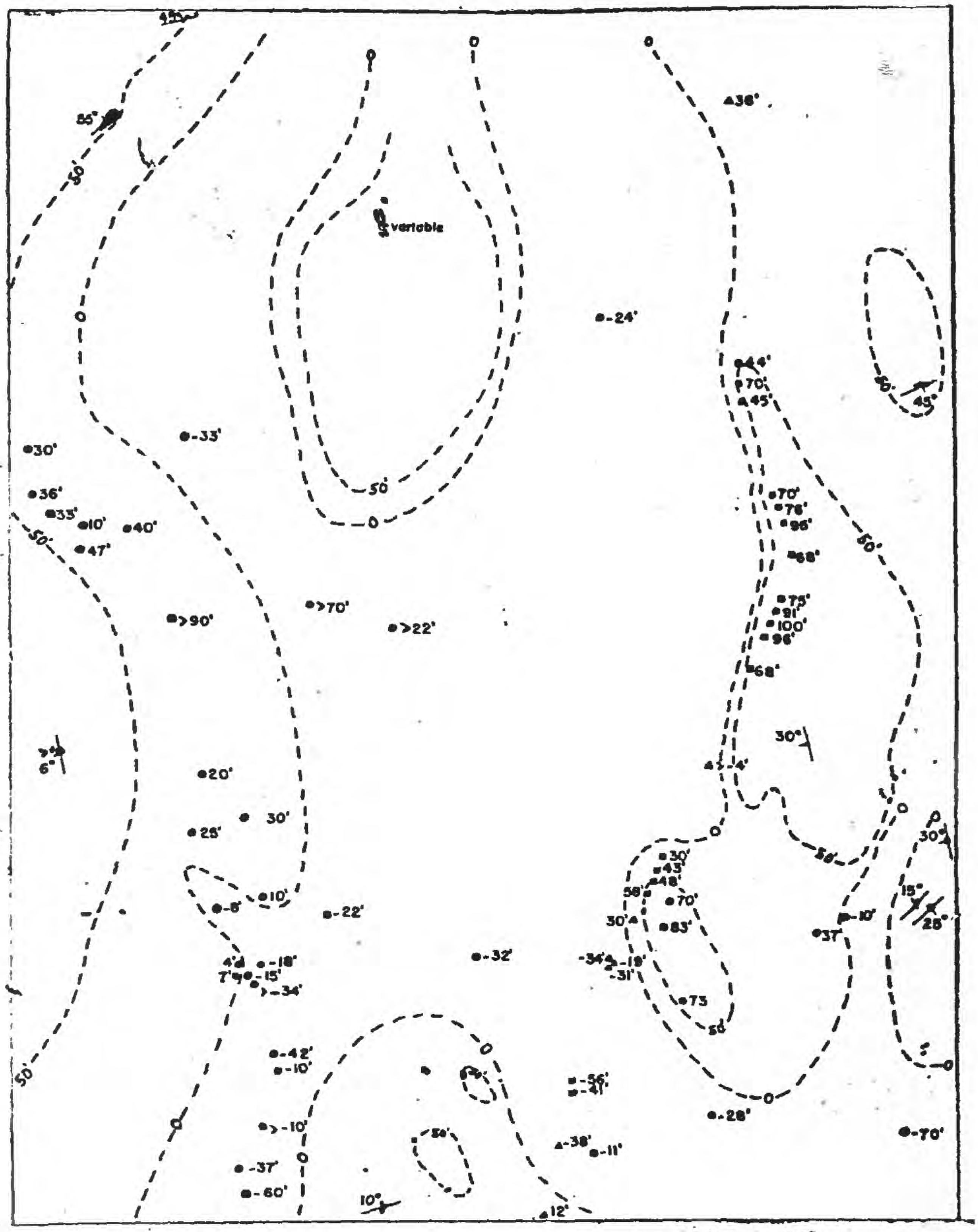

Figure 3. Bedrock Outcrops and Bedrock Topography Taunton Quadrangle

0 1 2 MILES

- Outcrops of Rhode Island formation
- 40° - Dip and strike of bedrock
- Seismic subsurface data
- Wash boring data
- Well data
- 30' - Altitude of bedrock above sea level
- -60' - Altitude of bedrock below sea level
- >70' - Altitude of bedrock deeper than figure shown
- 50' - Contour on bedrock surface

may strike in a north-easterly direction from Weir Village to Gushee Pond. More mapping to the south and west will help to clarify the structure of the quadrangle.

Some of the evidence on which the older geologists based their interpretations of the basin structure is demonstrably wrong. For instance, at an outcrop .7 of a mile south of Scotland, in the northeastern part of the Taunton quadrangle, Woodworth (Shaler, Woodworth, and Foerste, 1899, p. 197) described the rocks thus, "....pebbly sandstones strike nearly east-west and dip about 20° north, forming a low monoclinal ridge with an escarpment facing south". Close examination of the outcrop shows that the dip of the bedding, based on small beds and lenses of sandstone within the general mass of slate and shale, is about N. 65° E. 45° S. Cleavage is very prominent in the outcrop; in the shale near the south end of the outcrop it has an attitude of N. 80° E. 80° N. and in sandier material has an attitude of N. 70° E. 40° N. Quartz is intruded in veins about 1" thick along joints which are post-cleavage in age. It seems obvious that Woodworth measured the well developed cleavage in place of the bedding.

Geologic History

The broad crustal downwarp in this area, which began sometime prior to the deposition of the Pennsylvanian beds, may have formed a shallow basin separated from the sea during all of Pennsylvanian time, as shown by non-marine fossils (Shaler, Woodworth, and Foerste, 1899, p. 202). In this basin, stream, lake, and swamp environments persisted for a long period of time, and gravels, sands, muds, and peaty or vegetal beds accumulated. When lithified, the sediments formed conglomerates, sandstones, shales, and coal beds. A general uplift near the end of the Pennsylvanian Period, or sometime during the period, contributed to the formation of coarse gravels which are now the uppermost rocks in the area.

The bedrock history of the Taunton quadrangle ends with the Pennsylvanian Period, insofar as it can be interpreted from the rocks. However, unconsolidated sands containing glauconite comprise the Marshfield Hills area in Duxbury and Scituate (Chute, in press). These beds are thought to be Tertiary or even Cretaceous in age (Johnson, 1906, p. 313), and may have extended inland across the Taunton quadrangle. Indeed, one physiographic interpretation of the peneplain remnants that appear in New England and the central Atlantic states requires the presence of a broad wedge of Cretaceous sediments reaching far inland (Johnson, 1938).

Repeated uplifts of the land occurred in the Tertiary Period and several incomplete cycles of erosion resulted in deep dissection of the eastern part of Massachusetts and development of well-integrated drainage systems.

These drainage systems flowed in valleys that at present extend several hundred feet below sea level in the Narragansett Bay area and are filled with glacial deposits; this indicates that the land stood several hundred feet higher relative to present sea level at some time in the Tertiary.

Woodworth (Shaler, Woodworth, and Foerste, 1899, p. 200) states that: "The Taunton River exhibits a marked adjustment to the stratigraphy of this portion of the field, although it is heavily masked by glacial drift. The section of the river from Taunton eastward is along the strike of the soft beds and across the strike of the hard beds. It is for this reason that its east-west reaches are long, its north-south courses short. South of Taunton the same adjustment is less perfectly exhibited. These facts indicate a well-excavated preglacial channel."

The evidence now at hand, which was not available to Woodworth, includes borings, seismic data, and well logs. These new data show that there is a well-excavated preglacial channel, but the statement that the river is adjusted to the stratigraphy seems to be untenable.

In the Taunton quadrangle, the Taunton River flows over a definite preglacial valley, which has been the site of large amounts of fluvial and lacustrine sedimentation. A reconstruction of the preglacial topography, with 50 foot contours, is shown in Figure 3. The depression in the preglacial topography followed by the Taunton River may or may not have been a true preglacial valley with a gradient south to the sea, for the glacier may have plucked, eroded, and altered it so that we can no longer discern the original gradient. In general the valley is about thirty to sixty feet below sea level, according to subsurface data. The distribution of available subsurface information is such that the gradient of the ancient stream cannot even be guessed at.

The overall pattern seen in the preglacial topography has controlled the surface arrangement of glacial deposits. There seems to be a general depression running from the northern boundary of the quadrangle to the southern end, surrounding an island of bedrock just north of Raynham. The larger masses of stratified fluvial and lacustrine deposits are concentrated in the preglacial lows; till covers the high areas. A lake occupied the topographic low in the southern part of the quadrangle, and the Taunton River originated as a consequent stream on this lake bottom; the present course of the river is thus dependent on the preglacial topography.

On the other hand, there seems to be no evidence to indicate adjustment of the course of the Taunton River to the stratigraphy and structure of the bedrock of the region. Nine separate stretches of the river trend alternately at approximately right angles and show no correlation between direction and length of the stream course.

The structural attitude of the bedrock can be discerned only along two stretches; one of these in the Bridgewater quadrangle has three outcrops closely grouped about one-half mile from the stream, and the other has one outcrop about the same distance away. In the southeastern corner of the Taunton quadrangle the river is superimposed on bedrock in which no structure can be seen. No evidence has been found in the literature to indicate the structure and attitudes of the rocks south of Taunton, but well records indicate depths to bedrock of seventy feet or more, and the course of the river is a channel between the various large outwash features that congest the area.

PLEISTOCENE HISTORY

Glacial Erosion

Evidence of glacial erosion of bedrock is, in the Taunton quadrangle, confined almost entirely to the evidence provided by the enormous masses of glacial drift which cover the area. It is possible that the glacier merely picked up and redistributed the weathered rocks and preglacial soil cover which were formed since the land surface was last submerged beneath the seas, but the unweathered condition of nearly all of the stones and matrix of the stratified and unstratified drift deposits leads us to believe that they must have been eroded by the ice sheets. Of course, the glacial drift that we see may be the accumulative effort of several ice sheets advancing over the region at different times, each glacial advance contributing to the general bulk of the unweathered material.

At only one locality in the quadrangle is there direct evidence of glacial abrasion. About one mile south of Lake Sabbatia, quarry operators stripped the cover of till and fluvial sands off the bedrock. Striations in the bedrock surface occur at several places around the quarry (Figure 4), and are oriented S. 30° E. The one drumlin in the area and the several till mantled bedrock hills show a similar orientation. Striations in the Bridgewater quadrangle about 10 miles to the east have a direction of S. 27° E.

One piece of evidence, which shows the ability of the ice sheet to erode, is found about 1000 feet north-northwest of the bedrock quarry near Whittenton Junction. An erratic, called by the inhabitants "Castle Rock", measures approximately 17 feet in diameter (Figure 5) and is composed of sandstone and conglomerate, in which the average size of the pebbles is about 3". This boulder could have been derived from a maximum distance of about nine miles to the northwest in the Norton or Mansfield quadrangle. Outcrops of conglomerates and "grits" are reported from the area near Norton and East Norton, about four and one-half miles to the northwest, and it is from

Figure 4. Glacial striations on sandstone of the Rhode Island formation in bedrock quarry about one mile south of Lake Sabbatia.

Figure 5. Castle Rock erratic. Note 10 year old boys on top for scale.

the ledges here that this huge erratic could have been plucked (Woodworth in Shaler, Woodworth and Foerste, 1899, p. 196).

Glacial erosion has been shown to be quite deep in some places in New England, as, for instance, at Iron Mine Hill, Rhode Island (Shaler 1893). The amount of erosion in Massachusetts is generally thought to be great, but actual measurements have been rare. The relatively soft rocks of the Carboniferous Basin must have yielded somewhat to the glaciers, and indeed, considering the short distance from the northern edge of the basin, a tremendous amount of Carboniferous material has been dragged up into the ice and sorted.

Jahns (1943) demonstrated by means of the relation between sheet structure in granites and the existing topography that, in general, 10-15 feet of rock and preglacial regolith have been removed by glacial plucking and abrasion from the stoss (north) slopes of most hills. A somewhat greater amount has been eroded from their summits, east slopes and west slopes. The maximum demonstrable depth, in areas of localized erosion, is in excess of 100 feet. Of course, this deep erosion takes place under circumstances where massively jointed granites and a steep preglacial slope of the hill on the lee side contribute to effective plucking (Jahns, 1943, p. 94).

Glacial erosion was not everywhere effective in New England as shown by isolated localities where the ice sheet has not eroded preglacially weathered rock. An excavation for the Fall River Expressway, just west of the intersection of Route 44 and Orchard Street in Taunton, disclosed the presence of a deeply weathered rock which has somehow been preserved. A section shows the following:

3'	till (at the surface).
26"	gray, soft, weathered, medium to fine sandstone with shaly layers.
28"	yellow gray, soft, weathered sandstone, medium to coarse sand size, complexly intermingled with clay streaks.
18"	sand and fine sandstone, gray, somewhat soft and weathered.
13"	granule or very small pebble size conglomerate, soft and weathered, mostly gray, some iron staining.
2"	brownish clay, horizontal seam, grades upward into harder fine grey sandstones.
14"	soft weathered sandstones of coarse to very coarse sand sizes.
6"	of laminated blue gray clays with stringers of fine sand.

The clays were thought to be either forcibly injected glacial clays in bedrock, hydrothermally decomposed rock, or preglacially weathered rock. Fortunately, a good exposure nearby shored a gradation from shale into a blue clay similar to that found in the section; all phases and grades of disintegration could be seen as the blue black shale graded upward into the clay.

No matter how the soft, decomposed rock originated, its presence shows that soft materials are not necessarily eroded, even though the depth of erosion and the size of the joint blocks plucked away be considerable, as in the case of Castle Rock.

Glacial Deposition

Ice-laid Deposits

Till

General statement Glacial drift dominantly unsorted according to grain size is called till (Flint, 1947, p. 103). Till is the end member of a series which ranges from stratified and well-sorted glacial drift (outwash) to unstratified and unsorted debris (till). An indeterminate zone exists between the two end members where the sediments change from recognizable stratified drift to sediments that may be either outwash or till. Furthermore, thin sand and gravel lenses occur in and are formed as an integral part of otherwise unstratified and unsorted till.

Small patches of water sorted drift generally appear in areas mapped as ground moraine or till, and small areas of till certainly appear in the midst of outwash forms. The limits of time and practicability prevent a precise delineation of all patches of stratified and nonstratified drift. Mapping some poorly sorted and stratified outwash areas as "very sandy till" may slightly distort the glacial history.

The two-till problem The problem of till identification in New England is a difficult one. Two general types of till have been recognized in eastern Massachusetts (Currier, 1941, Jahns, 1941, Moss, 1943, Judson, 1949). One type of till, the "lower" or "old" till, is generally recognized as hard, compact, jointed, clayey, fissile, with relatively few stones, and is distinguished by an olive-drab color. Opposed to this, the "upper" or "new" till is less compact, easy to dig, composed of a sandy matrix with many stones, and, except where it is discolored by present day surface oxidation, is distinctly gray. The two extremes, very clayey drab till or very sandy gray till, appear to represent two distinct bodies of till, but positive identification is difficult in the transition zone between the till types. The crux of the matter is that we have no large body of quantitative data on which to base our differentiation of the tills into two bodies.

Judson (1949) studied the tills in and around Boston in isolated outcrops and came to the conclusion that the two tills represent two substages of glaciation, to which he gave the names "Lexington" and "Boston". Currier (1941) and Jahns (1941, 1953) expressed the opinion that the two tills belong to two different stages of glaciation. Chute (1949, 1950), on the other hand, is of the opinion that the two tills represent either englacial and subglacial till, or that they reflect differences caused by the advance of the ice sheet over different types of bedrock. Moss (1947) identified till samples as "new" or "old" on the basis of color; the "new" till is gray, and the "old" till is muddy brown to olive-drab. Moss also did grain size analyses and found what he believed to be a distinct difference between the two tills (Figure 6).

<u>Laboratory methods</u> In addition to color and other physical properties, mechanical analyses have been used as a basis for distinguishing between the tills of Massachusetts (Crosby, 1934, Lee, 1942, Moss, 1947, Segerstrom in press). Most of these grain size analyses used only four size grades*, but cumulative curves based on these few points do not give a satisfactory base for comparison with other till samples or for statistical manipulation.

*Gravel, greater than 1 mm.; sand, .05 to 1 mm.; silt, .005 to .05 mm.; clay, .001 to .005 mm.

Twenty-six mechanical analyses of till were made for the present study and include twenty-four samples from the Taunton quadrangle and two samples from the Bridgewater quadrangle. Several till samples from the Boston area were analysed and the results of mechanical analyses by other geologists plotted for comparison with the tills of the Taunton area.

Samples were taken from till areas over the entire quadrangle (figure 7), but only a few of these could be analysed. The samples analysed were chosen to represe

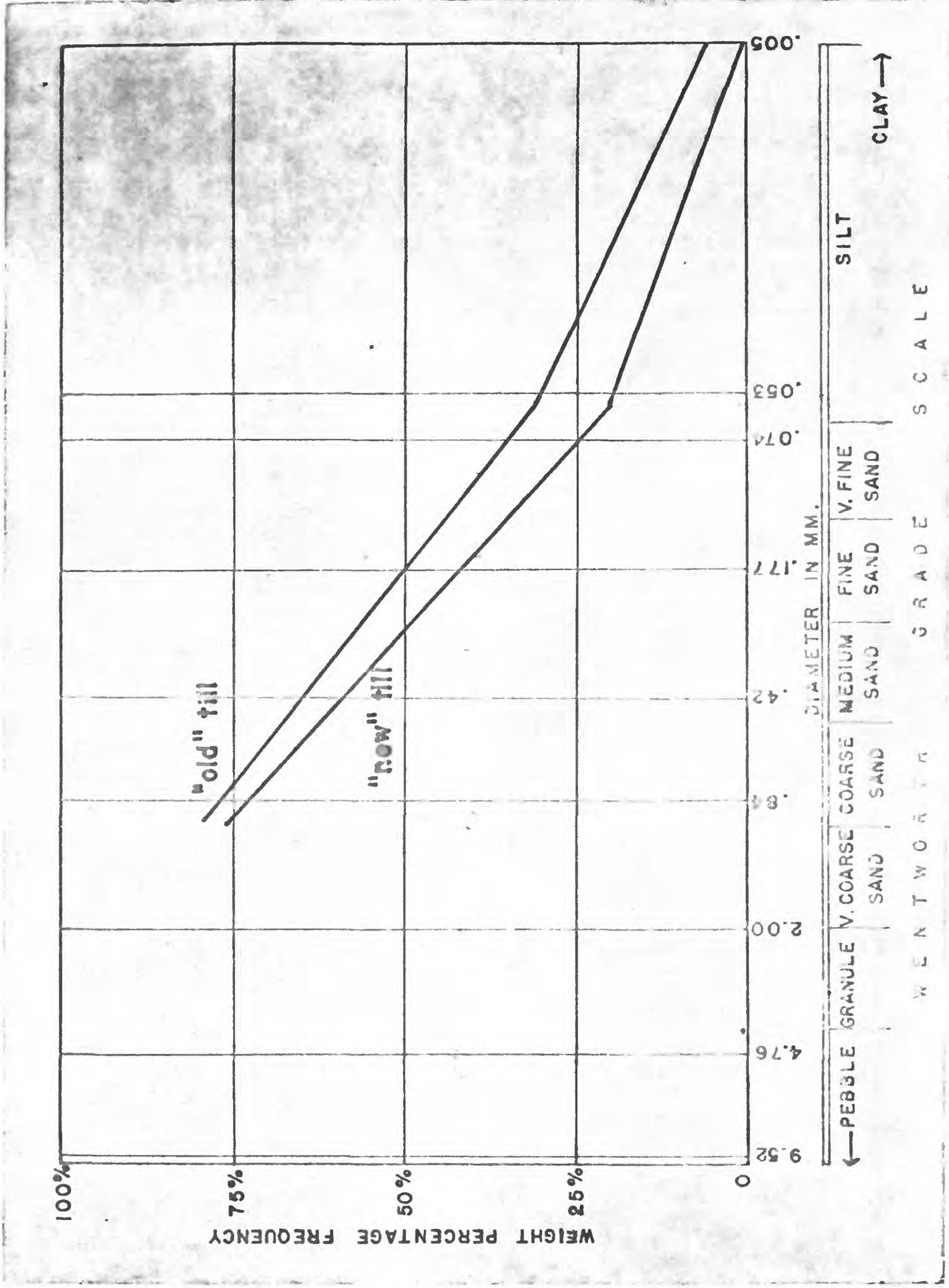

Figure 6. Cumulative curves of Moss' "new" and "old" till.

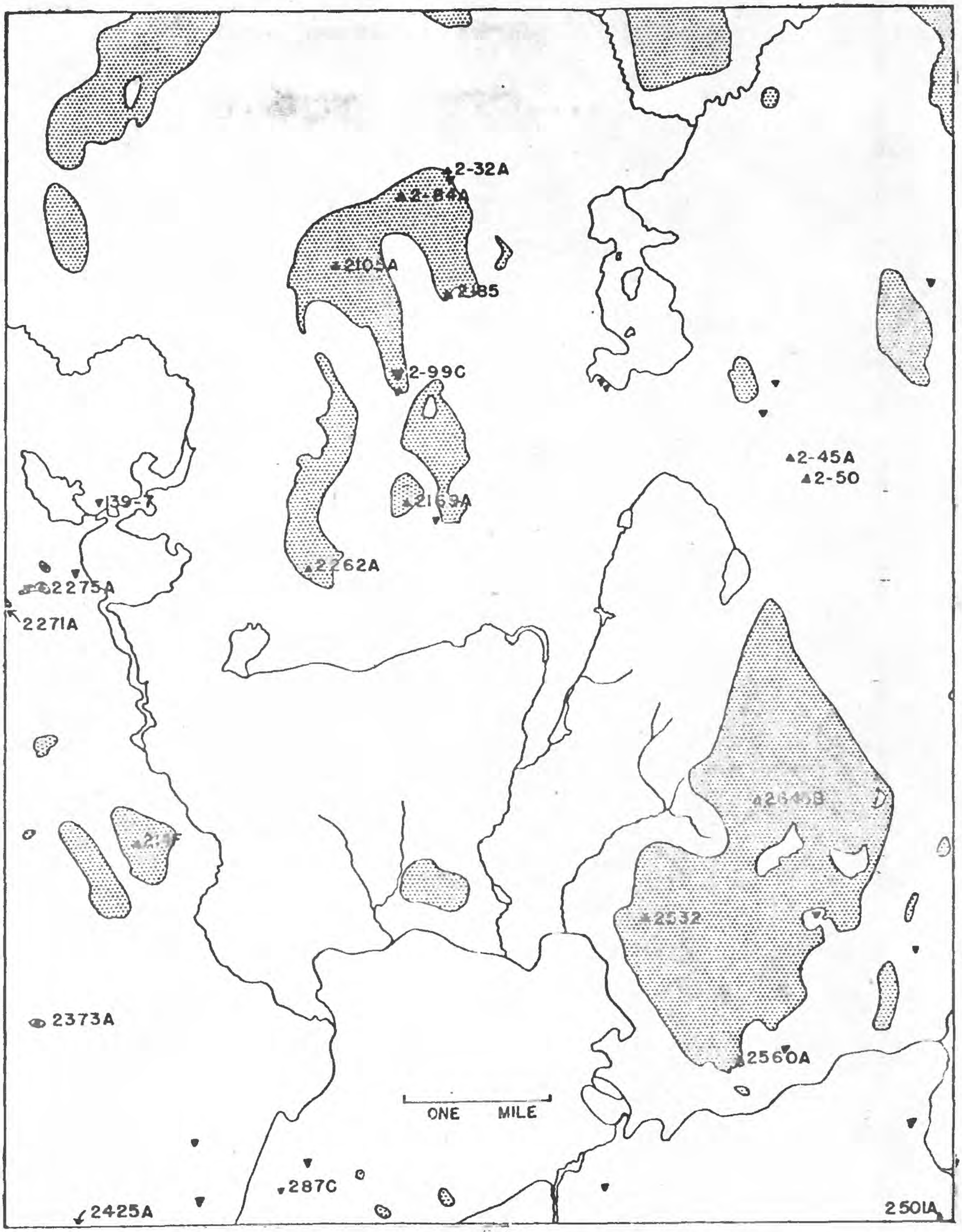

Figure 7. Till Areas and Till Samples, Taunton Quadrangle

- Area of till (ground moraine).

▲2-50 - Till sample

▼ - Till over outwash; ▼139-7 - sample of till over outwash as many areas and types of till as possible. Where the till was exposed in vertical cuts it was very easy to gather a large sample; an area about one foot square was marked out with a shovel and enough till taken to fill a one quart bag or sample box. Areas with large boulders were avoided, but pebbles were included with the sample if they fell within the sampling range.

The samples were dried in the laboratory and examined under artificial light. Color, fissility, mottling, and resistance to crushing were recorded. The sample was then crushed and placed in a set of sieves (Table 1) which were agitated in an automatic shaking machine. Material passing the #270 sieve (.053 mm.) was placed in suspension in a column of water in a large glass cylinder and separated by decantation into silt (between .053 and .005 mm.) and clay (finer than .005 mm.).

Ten points plotted from this operation are close enough together to bring out the continuous nature of the frequency distribution, and the information is plotted on semi-logarithmic graph paper; weight percentage frequency is plotted on the ordinate and grain size along the abscissa. The curve so plotted is a cumulative curve (Krumbein and Pettijohn, 1938, p. 188), and is a "less than" curve. That is, any point on the curve indicates the amount of sediment less than the grain size indicated by the vertical line. For instance, on Figure 8,

Table 1

Grade Limits (diameters)	U. S. Standard Sieve Number
9.520 mm.	3/8"
4.760 mm.	#4
2.000 mm.	#10
.840 mm.	#20
.420 mm.	#40
.177 mm.	#80
.074 mm.	#200
.053 mm.	#270
.005 mm.	by decantation
Finer than .005 mm.	by decantation

sample 2-32 A, the 50% line intercepts the vertical line representing .043 mm; hence, 50% of the sample is finer than .043 mm. On the cumulative curves, only the 25%, 50%, and 75% frequencies are indicated; the necessary statistical figures are derived from these percentages. They are the first quartile, Q1 (75%), the median (50%), and the third quartile, Q3 (25%). The statistical measures, (Krumbein and Pettijohn, 1938, p. 228) used to compare the tills are derived from the quartiles (see Table 2, for instance). The sorting (So) is the Trask "sorting coefficient" (Trask, 1932), a geometric quartile deviation based on the ratio between quartiles, and is found by using the equation:

$$(1) \quad So = \sqrt{Q1/Q3}$$

The sorting coefficient is a ratio between the quartiles, and 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 directly compared, however, because So increases geometrically. The logs of So form an arithmetic series and, by using the $\log_{10}$ So, samples may be directly compared with one another (Krumbein and Pettijohn, 1938, p. 232).

The cumulative curves and the tables of statistical measures presented in this study are useful in comparing the Taunton tills with each other and with tills from other areas. The curves serve a descriptive function, for it is much simpler to remember the shape of a series of graphs than to remember a column of figures. The tables presented with each area of tills being discussed give the statistical measures derived from the cumulative curves. The statistical measures are presented also in one large table at the end of the discussion of the tills. Other tables and cumulative curves are used in the discussion of the eolian mantle, the congeliturbate, and the alluvium.

Till in the Taunton quadrangle Although two tills have been described for much of eastern Massachusetts, the evidence in the Taunton quadrangle seems to indicate one general type of till, similar to the "new" till.

The color of the till in the Taunton quadrangle varies greatly under field conditions from greenish gray to light brown. However, the samples dried and compared under the same light source differ very little indeed. The colors are most generally some shade of grey to yellowish gray (from the Rock Color Chart, National Research Council); pale yellowish brown and light bluish gray are the most common shades; mottling is common in some of the tills and produces a moderate yellowish brown. A few of the tills were plain light grey. None of the tills in the Taunton quadrangle fit the color description of the "old" till; the Taunton samples are exclusively "new" (upper) till on the basis of color.

Detailed discussion of the till samples gathered in the Taunton quadrangle is divided into five parts; four parts are based on geographic distribution, and are followed by a discussion of the origin of these tills, and one section deals with a special type of till. The four geographic areas are not distinct in any way except geographic separation, and the sections provide convenient categories for breaking up the samples into more easily handled groups, both in the discussion and in the number of cumulative curves on one graph. The four areas include (1) the North-central area, a cluster of exposures of ground moraine north of the town of Raynham (Plate I, Figure 7), (2) the Pine Street area, about 2½ miles east of Raynham, (3) the North-west area, which consists of a series of isolated outcrops, and (4) the South-east area, which consists of a large area of ground moraine east of Raynham Center and some isolated outcrops of till.

The North-central area is apparently a bedrock high with a coating of till plastered over it. Five samples of the till were analysed (Figure 8). The samples are listed in Table 2 with the statistical measures derived from the cumulative curves. Samples 2-40C and S26A, which occur in this area, are discussed later.

The till samples studied from this locality were

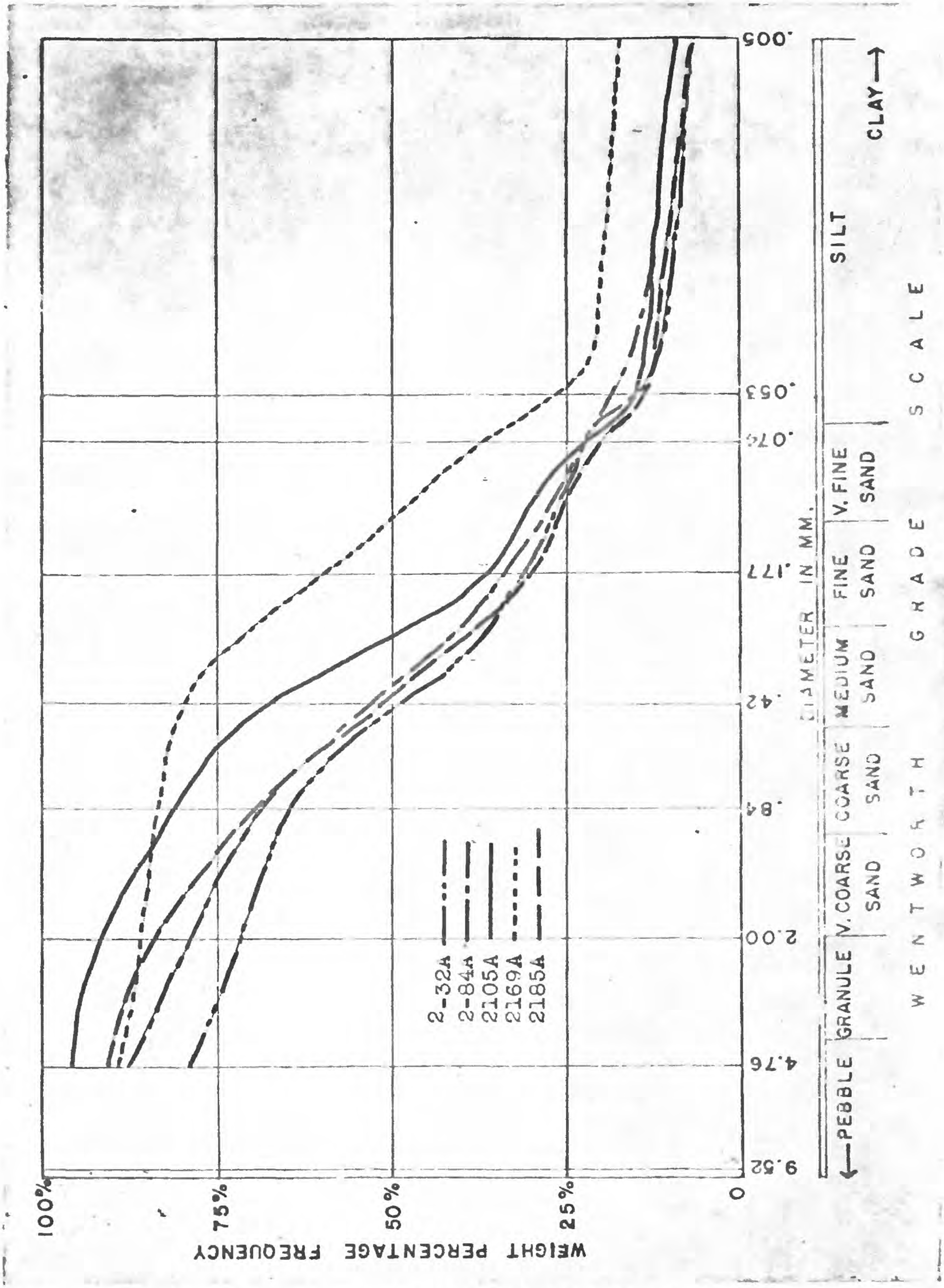

Figure 8. Cumulative curves of till from the North-central till area.

generally grayish yellow to dusky yellow (5Y 8/4 to 5Y 6/4* when dry. Some spots which were lighter in color, approximately gray (N7), seemed to be unoxidized or bleached portions of the till. The clumps handled in the laboratory were moderately tough and coherent when dry; that is, they were crushed in the hands or between the fingers with moderate difficulty. In two of the specimens, 2-32A and 2169A, many of the pebbles were stained black.

*The numerical designation is based on the Munsell system in the Rock-Color Chart designed for geologists and distributed by the National Research Council.

Table 2. North-central Area

Sample	Median (in mm.)	Q1 (in mm.)	Q3 (in mm.)	Sorting (So)	$\log_{10}So$
2-32A	.460	3.00	.088	5.83	.766
2-84A	.385	1.40	.092	3.90	.591
2105A	.265	.560	.077	2.70	.431
2169A	.123	.305	.053	2.40	.380
2185A	.400	1.15	.105	3.32	.521

In the field, sample 2-32A appeared to be a specimen of the "old till" of previous workers. It seemed to be clayey, muddy brown, and it flaked off in slabs or chunks parallel to the surface of the ground. Comparison of this till with the others on the cumulative curves shows that it is really the most sandy of all the tills sampled here, and the moist condition of the till sample in the field influenced the megascopic identification.

Sample 2169A also appeared, at first, to be similar to the "old" till. The till was very difficult to excavate, even with a power shovel, but, unlike most described specimens of "old" till, crumbled when it was dry; the "old" till of the Boston area gets harder with age. However, in the field the till appeared to have a fine sand to silt matrix (the cumulative curve corroborates this); pebbles and cobbles were common; boulders were present but not in large numbers. The till is gray where unweathered, but in part it is stained with iron and hence is rust brown in color.

These two samples show the extremes of texture in this north-central area. The remaining three samples from this area have similarly sandy matrices and predominantly grayish color, thereby resembling the "new" till. Thus, in spite of the aberrant characteristics of some individual samples, it appears that the same general type of till covers all of the north-central part of the Taunton quadrangle and probably exists under a considerable part of the nearby swamp and glaciofluvial deposits.

In the Pine Street area, a small elliptical outcrop of till appears at the north end of an elongate hill of outwash oriented northwest-southeast (Plate I), mapped as till by LaForge and Alden ("Soil map of Massachusetts";

unpublished manuscript map in the files of the United States Geological Survey). The Soil Conservation Survey ("Soils map of Plymouth County", McLendon and Jones, 1912) maps the area as Gloucester soil, which by definition is underlain by till derived from granite or sandstone. However, seismic information shows that the shape of the hill is due to a bedrock core, and a series of trenches dug for water supply in the town of Bridgewater showed till under a sand and gravel veneer that ranges up to about 15 feet thick.

Boulders up to 3 feet in diameter lie on the surface even though the till is about 2½ feet to four feet below the surface in the region where till samples 2-45 and 2-50 were taken. A section at 2-45 shows:

6"	humus and fill.
30"	brown, oxidized fine and medium sand, probably eolian material and frost mixture.
10"	gray fine and medium sand.
6"	pebble and granule gravel
6"	of gray stoney and clayey till (sample 2-45A).

Laboratory size analyses of these two samples show very little difference from those described earlier. They are yellowish gray to dusky yellow (5Y 7/2 to 5Y 6/4) with spots of light gray (N7). A dry clump of 2-45A is much harder to crush than 2-50, which is easily crumbled when dry. The textural difference is indicated on the cumulative curves (Figure 9) and is greater than the difference between "old" and "new" till shown in Moss's cumulative curves of tills in the Boston Basin (Figure 6).

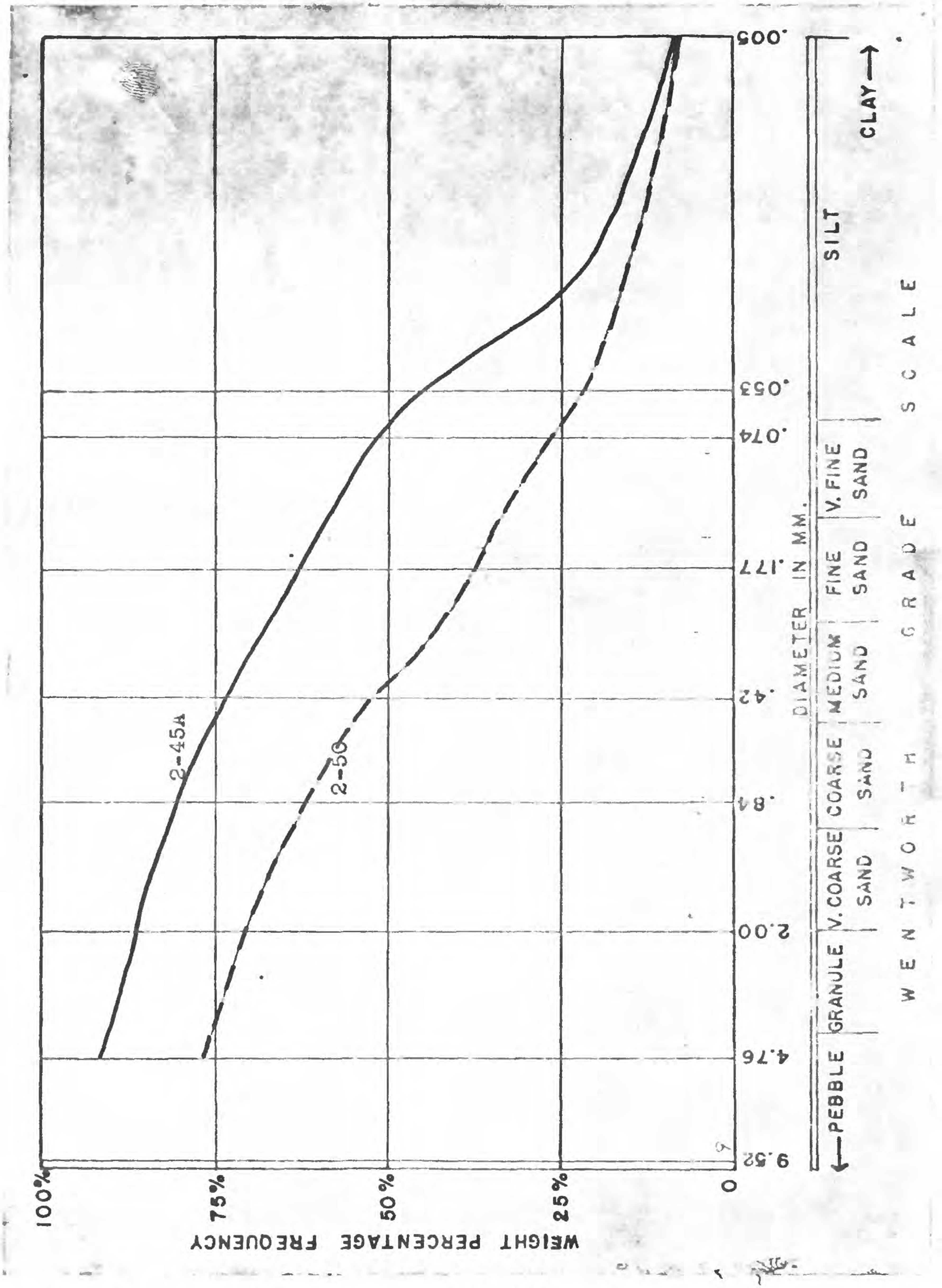

Figure 9. Cumulative curves of till from the Pine Street area.

Table 3. <u>Pine Street Area</u>

Sample	Median (in mm.)	Q1 (in mm.)	Q3 (in mm.)	Sorting (So)	$\log_{10}$So
2-45A	.070	.500	.029	4.15	.618
2-50	.400	4.10	.070	7.656	.884

The first samples described from the <u>South-west area</u> are from several large excavations made for a new hospital west of Lake Sabbatia. Hitherto unknown and unsuspected accumulations of till were found in this area. Some of these occurrences will be discussed later; here we will discuss only those from which samples have been taken.

Sample 2271 was taken from the bottom of an undrained depression in the till surface. A section showed:

4-5' of artificial fill.
2' black organic muck with 1' of clayey material on top, black and greasy; looks like old soil zone and top of bog.
3' of gray to gray green (when moist) till with many stones in it.

This till seemed somewhat clayey in the field, but clumps were moderately easy to crush in the hand when dry; consideration of the cumulative curve (Figure 10) shows that it is coarser than most of the other tills from Taunton. When dry it was a medium light gray color (N7).

Sample 2275A, taken from an excavation to the east of 2271A, is a till resting on bedrock or on a very large boulder. This sample is a very sandy till, and it is very easy to crush clumps in the hand when dry. The color is a light gray in unoxidized or bleached areas;

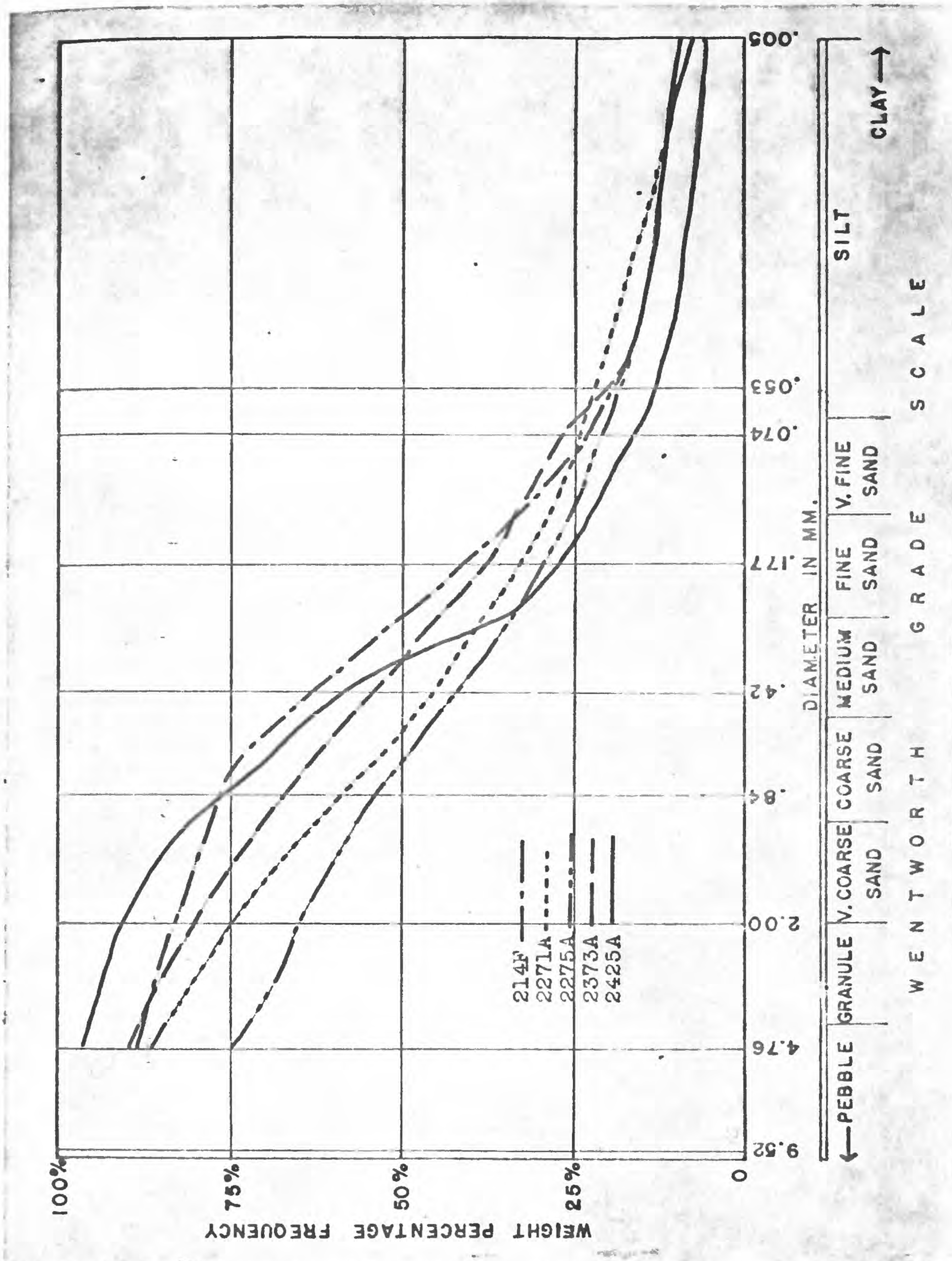

Figure 10. Cumulative curves of till from the South-west till area.

in oxidized areas it is dusky yellow (5Y 6/4).

Table 4. <u>South-west area</u>

Sample	Median (in mm.)	Q1 (in mm.)	Q3 (in mm.)	Sorting (So)	$log_{10}So$
2271A	.540	2.10	.084	5.00	.699
2275A	.680	5.00	.115	6.60	.820

The other samples gathered in the south-west area are listed here with their statistical measures:

Table 5. <u>South-west area</u>

Sample	Median (in mm.)	Q1 (in mm.)	Q3 (in mm.)	Sorting (So)	$log_{10}So$
214F	.265	.800	.085	3.07	.487
2373A	.340	1.43	.065	4.69	.671
2425A	.340	.807	.160	2.25	.352

Sample 214F was taken from an area in the center of a low outcrop of till. It is easily crushed and incoherent when dry, and is yellowish gray (5Y 7/2).

Sample 2373A was taken from the bottom of an excavation where gray blue shale came close to the surface; the till was on the bedrock surface as a thin layer beneath fluvial materials*. The till is light gray in spots where

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*This gives some support to the idea that at any one place in the quadrangle till probably underlies the fluvial material and rests on the bedrock, even if only in a thin layer.

it is unoxidized and dusky yellow (5Y 6/4) where it is oxidized. It is compact in the field, but easy to crush when dry.

Sample 2425A comes from just outside the southern quadrangle boundary, on the northern slope of a drumlin. Although compact enough in the field, it is easy to crush when dry. In color it is light gray (N7). The sample shows a very small percentage of silt and clay sizes despite the fact that it is a drumlin till.

Three samples taken from the South-east area of the quadrangle show generally similar textural characteristics (Figure 11).

Sample 2601A was taken from beneath an outwash cover in the bottom of a kettle and is a very pale orange color (10YR 8/2); it is a clumpy, sandy till, very easy to crumble when dry. Its statistical measures are shown below with those of two other till samples from the southeastern part of the Taunton quadrangle and one till sample (2258A) from close by in the adjacent Bridgewater quadrangle.

The other three tills are closely grouped in texture. In the field 2645B appeared to be olive in color, but in the laboratory it was pale yellowish brown (10YR 7/2). It is a compact till and hard to crumble in the hand.

The other two till samples, 2258A and 2560A are light gray to yellowish gray (N7 to 5Y 7/2) and are sandy feeling and easy to crush in the hand.

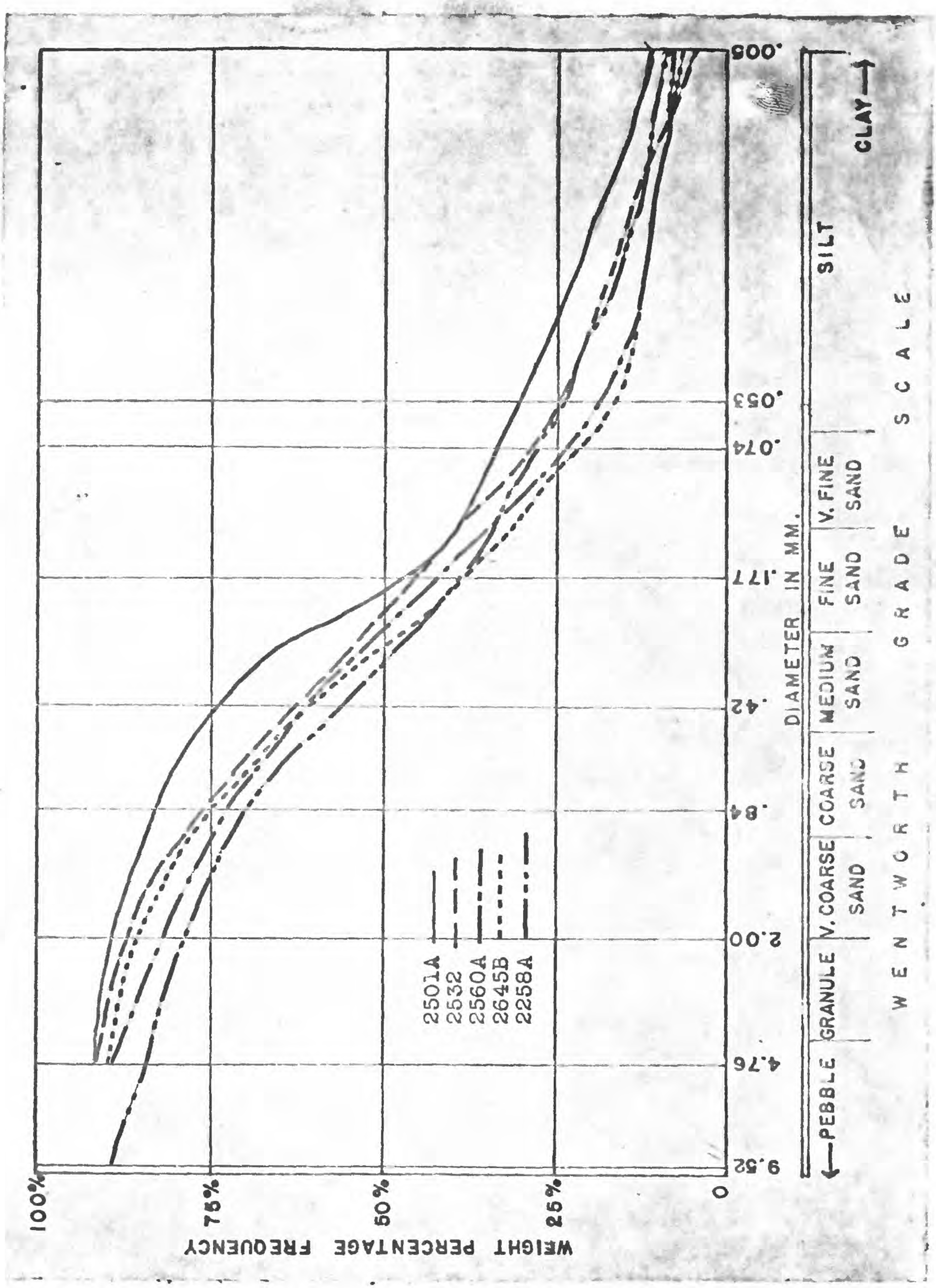


Figure 11. Cumulative curves of till from the South-east till area.

Table 6. <u>South-east Area</u>

Sample	Median (in mm.)	Q1 (in mm.)	Q3 (in mm.)	Sorting (So)	$log_{10}So$
2501A	.193	.460	.030	3.91	.592
2560A	.247	1.03	.079	3.61	.558
2645B	.250	.660	.068	3.13	.496
2258A	.280	1.20	.050	4.90	.690

A road cut along the Fall River Expressway on the north side of Route 44 in Taunton exposed an unusual section of till and fluvial sands and gravels:

- 8" black soil.
- 22" light brown, stony, frost disturbed eolian material.
- 8" gray, unoxidized, sandy, stony frost disturbed eolian material.
- 40" gray green (moist), hard, compact, clayey till; has a horizontal fissility, and breaks out in large blocks; samples 2532 B and E.
- 26" coarse sand, fine gravel, and pebble gravel with many boulders in a continuous bed of variable width.
- 60" light gray, sandy till; samples 2532 D and F.

The tills in this section appear in the reverse order from the classic descriptions of "old" and "new" till. Here the stratigraphically higher till has the characteristics attributed to the "old" till--it is dark, hard, clayey, and has the "obscure undulating cleavage" described by Ross (1947). The lower till shows the characteristics of the "new" till.

Mechanical analyses of the till samples bear out the field descriptions. Samples 2532 B and E, taken from the upper layer of dark till, show a higher clay content.

However, 2532B closely parallels the two samples of sandy till in the coarser grain sizes. The till samples from the lower, sandy till, 2532 D and F, show less clay and silt, but 2532D contains more fine grained material in the sand sizes (Figure 12 and Table 7).

Table 7. <u>Orchard Street Hill</u>

Sample	Median (in mm.)	Q1 (in mm.)	Q3 (in mm.)	Sorting (So)	$\log_{10}$So
2532B	.210	.960	.023	6.45	.810
2532D	.120	.440	.041	3.27	-.515
2532E	.245	1.060	.032	5.75	.760
2532F	.225	.800	.059	3.69	.567

An explanation of the stratigraphy of this section need not require more than one glacial advance to account for the tills. The darker colors of the upper till fade when the till is dried thoroughly and examined under an artificial light; the moisture held in by the greater amounts of clay give the till a darker appearance in the field. The cumulative curves show no more variation than those of the other tills in the area. The conclusion is that the tills belong to one episode of ice advance, but that slight changes in direction of ice movement may have uncovered one of the numerous shaly lenses of the Rhode Island formation.

The macroscopic descriptions and the grain size

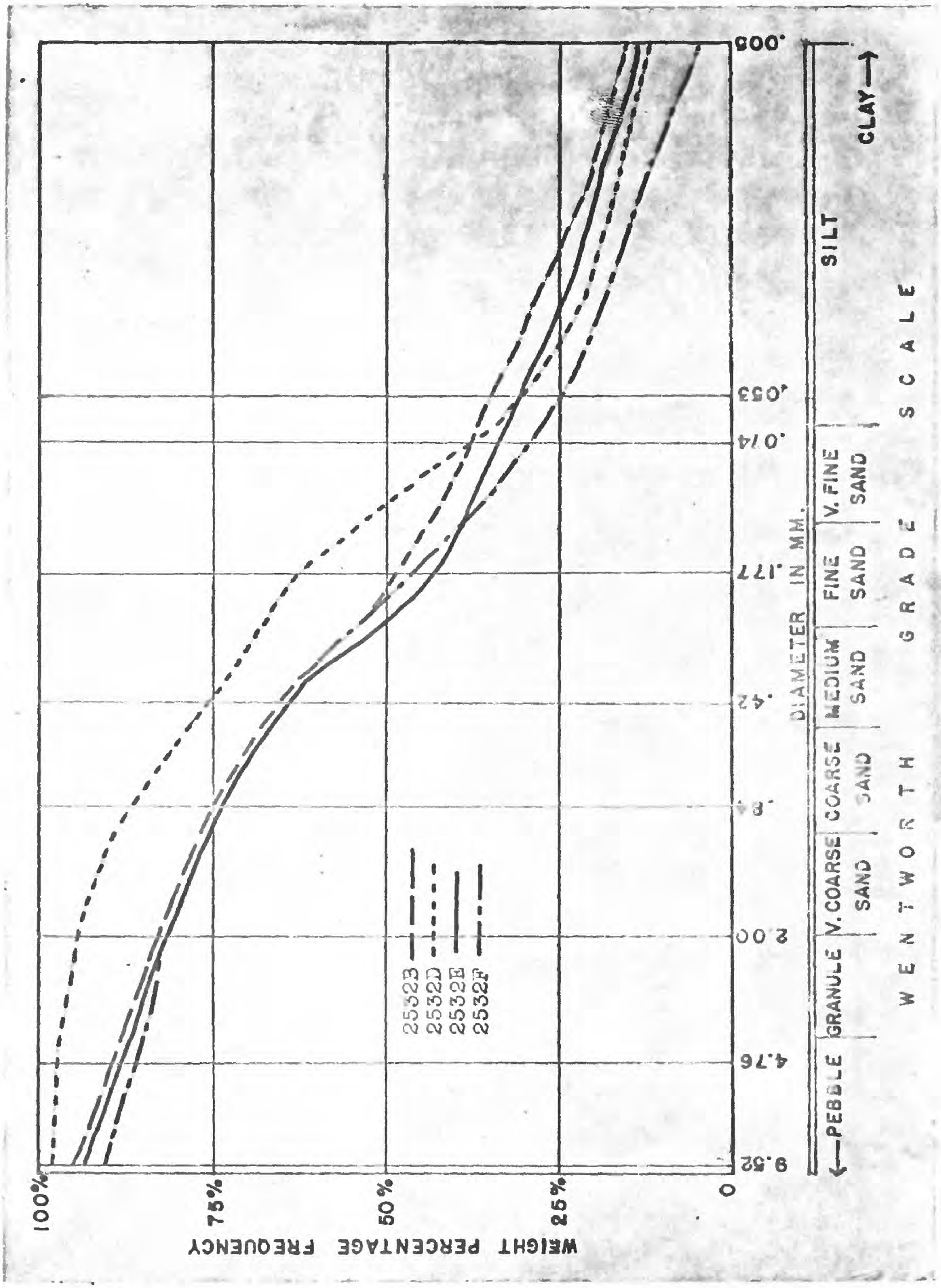


Figure 12. Cumulative curves of till from the Orchard Street hill.

analyses show that in general these tills from the Taunton quadrangle tend to be sandy and silty and are not as clayey as the "old" till of the Boston area. However, the median grain size of all the tills thus far analysed range far beyond the limits of the medians of the "old" and "new" tills described by Moss (Figure 7 and Figure 13). A general description of all the tills in the quadrangle would be: dominantly sandy to silty matrix, generally of some shade of gray to yellowish gray, with a dusky yellow the darkest color when the till is completely dried out. In contrast the "old" tills of the Boston area have a very dark color, even when dry, ranging from olive-drab to dark grey. The Taunton tills are more easily crushed when dry, whereas the "old" tills merely get tougher with age.

<u>Origin of the ground moraine</u> The tills described above comprise the ground moraine, and theories concerning the origin of the till depend upon interpretation of limited data.

According to several authors the till here described is believed to have been of englacial or superglacial origin (Chute, 1949, 1950, Goldthwait, 1949). Chute does not definitely state in the Brockton report (1950) that the "older", brown, slightly more indurated and compact till underlies the gray, more sandy and rather loose till, but he does give their origin as subglacial and englacial.

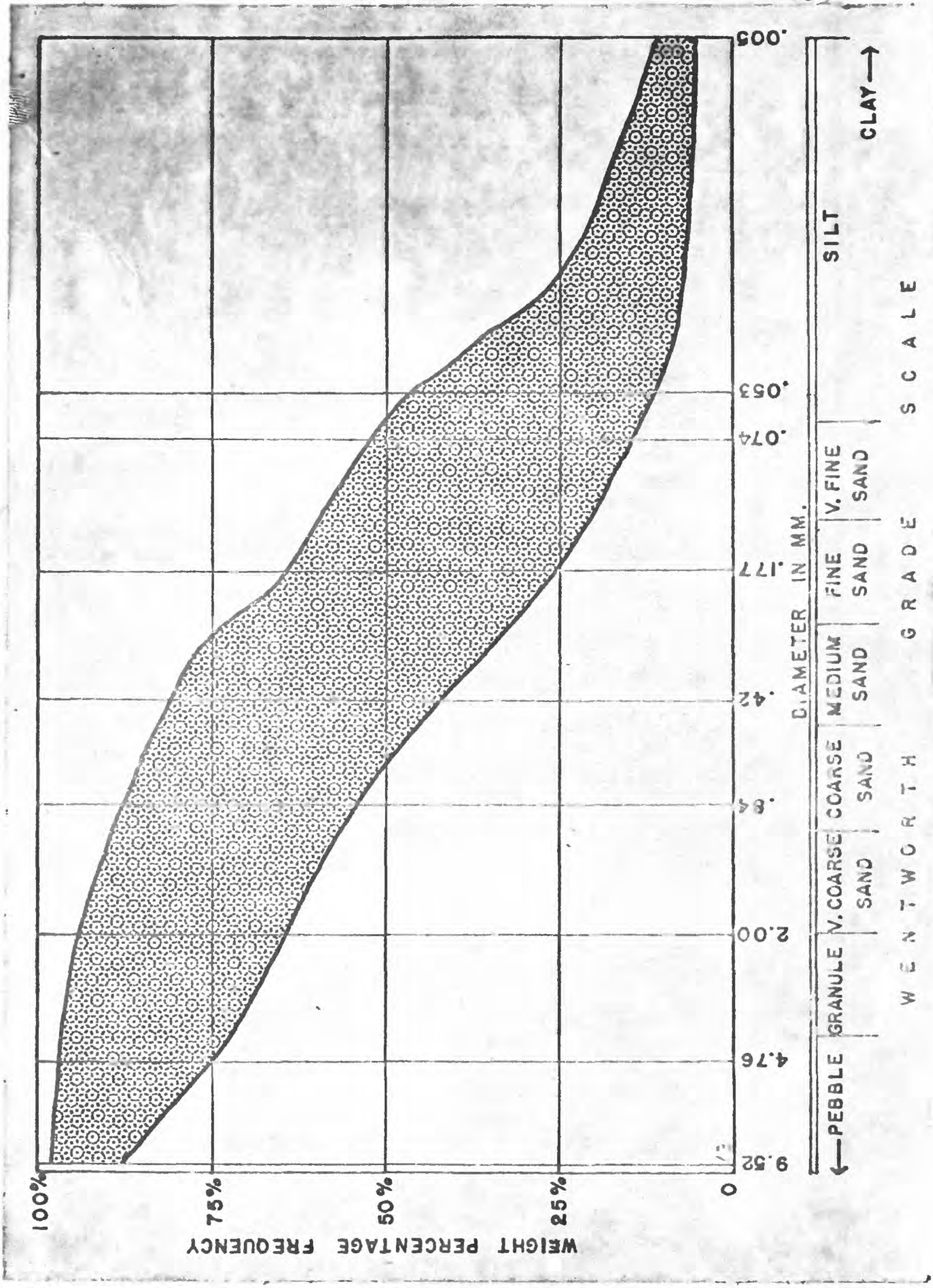


Figure 13. Range in grade size of till from the Taunton quadrangle.

The englacial or superglacial origin attributed to the sandy, gray till, seems to be unprovable. The arguments which Chute has used to call it superglacial (in the process of melting out, all englacial debris finally becomes superglacial debris) are not valid. Boulders which protrude some distance above the ground in the Brockton quadrangle are used to bolster the idea of superglacial origin. "....these boulders were deposited with the superglacial till, as they could not have come to rest in their present positions until the ice had stopped moving. The till that buries the bases of many of these boulders, therefore, is considered to be superglacial till at least to the depth of burial" (Chute 1950). Substantially the same argument is used in the Pawtucket report (1949). When a glacier is advancing, it drags along in its lower portions the subglacial drift or load, which contains a mixture of materials ranging in size from clay to the largest of boulders plucked from bedrock ledges. Any large boulder that is being dragged along the ground in this bottom layer comes to rest when the ice sheet either stops moving forward or when the melting back of the terminus of the glacier exceeds the rate of forward movement and exposes the boulder at the glacier front. Any boulders then in place at or near the bottom of the glacier, in the subglacial drift, will come to rest on the surface of the ground moraine or be buried any depth within the ground moraine.

It is also known that boulders which rest on the surface of the ground moraine may in many instances resist the forward movement of the ice sheet so that the ice will yield and flow plastically over and around the boulder instead of moving it along. In this way, as shown in front of the Sperry and Grinnel glaciers in Montana (Dyson, 1952), and as can be seen in Washburn's photographs of the Woodworth and Schwan glaciers in Alaska, a boulder will be left with the upper part standing high above the ground, and, in some circumstances, with a ridge of till extending downstream from the boulder in the direction of ice flow.

The relatively sandy nature of the till and the looseness and lack of compactness has been attributed to a lack of pressure from overlying ice, and is taken as evidence of superglacial origin. The "old" till, by comparison, is thought to be subglacial, because it has an obscure cleavage or flakiness, generally parallel to the surface of the ground, and attributed to the pressure of overlying ice. It seems more probable, in the Taunton area, at least, and perhaps in all of the area south of the northern rim of the Narragansett Basin, that the looseness and sandy nature of the till is due to the character of the bedrock over which the glacier moved and from which it necessarily derived much of the debris.

The bedrock in this southeastern area is mostly the Rhode Island formation, composed of feldspathic sandstones, dominantly blue gray to gray in color, including some lenses of conglomerates and slaty shales. The till derived from this, whether englacial, superglacial, or subglacial, could only be sandy in texture. It would be strange indeed to get a clayey till from such a sandy source. A black, clayey till, found at only one place, contains a number of flat angular pieces of a black shale, and is obviously derived from some nearby source of shale or slaty shale.

The glacial deposits of Massachusetts can best be interpreted according to the geologist's experience on glaciers, living and dead. The author's studies on the Malaspina Glacier showed that there is little textural difference between tills which are probably subglacial and tills that are sitting on the top of the stagnant ice. The grain size of the tills on the glacier (superglacial tills) runs the gamut from a clayey matrix to a very sandy matrix; the texture seems to depend on the number of cycles of washing the material has gone through.

An explanation of the movement of till on the surface of the Malaspina Glacier may help to clarify the problem of the origin of till in the Taunton quadrangle, even though the glacial climate of the two areas may not be comparable. When the upper surface of ice starts to melt, it begins to release from within it all the particles, from clay to boulders, which have been gathered up by the glacier from the surrounding landscape or which have been deposited on top as the glacier ground its way past bedrock hills. These newly released pieces, together with the original superglacial debris, begin to gather in the hollows and valleys of the irregular ice surface. (Figure 14) If there is very little washing or movement by rills and rivulets of water, then the superglacial till will have a fine grained matrix, and when this till dries and hardens it will be a very compact tough boulder clay. Because the surface of the ice is a constantly changing topographic form, the till which was deposited in one place does not stay there long, but is caught up in the cycle of movement and change, moves downslope as a mudflow, is flushed downslope by sheets of water, or is removed by superglacial streams which erode the till as they would any other unconsolidated surface deposit. In this cycle the till, which may have been emplaced heretofore only by sliding, loses part of its fines as they are taken into suspension by the water and carried away as rock flour. The next time the till body is stopped or interrupted anywhere on its journey, it will be a sandy till, an indeterminate type of till-like deposit with some stratification, or, if the stream action continues, a fluvial deposit.

As the fluvial deposit lives out its short existence

Figure 14. Viscous till mass moving downslope on the surface of the Malaspina Glacier, Alaska.

upon the surface of the ice, before destruction by the ever shifting highs and lows of the topography, more particles are released from their bondage in the neighboring ice, and the whole mass of fluvial material may shift and slowly flow downslope in combination with newly released debris (till); when the mixture reaches the ground it is again a till, with a sandy to gravelly texture and fines in proportion to the amount of original rock flour released from the ice and not washed away.

It does not seem practical, in the light of observations on the Malaspina Glacier, to attribute a certain textural composition or degree of compaction to any type of till, for in the areas where the ice sheet is a stagnating body, as we believe it to have been in Massachusetts, the subglacial and superglacial tills may be texturally nearly indistinguishable.

The ground moraine in the Taunton quadrangle, then, may be superglacial or subglacial; texture and compaction are no indication of origin. However, the large amount of fragments from the Rhode Island formation in the till, compared to the small amount in outwash that flowed some distance above the base of the ice, leads us to believe that most of the ground moraine, despite its sandy texture, is subglacial in origin.

<u>Flowtill</u> A final group of till samples that we have not yet discussed also yields some evidence on super-

glacial tills. These tills are those which from their stratigraphic position in kames, kame plains, or other outwash bodies, appear to be superglacial and are those to which the name "flowtill" is here given; on the map, Plate I, it is indicated as <u>ft</u>. This term has not been found in the literature.

As can be seen from Figure 6, there are numerous areas where till over outwash is recorded (inverted triangle), and these may be divided into two categories.

First is the type in which the till occupies a position over sands and gravels in the lowlands; in many places the whole surface is till-mantled and the map pattern is that of ground moraine. Sample 2-90C (Figure 15; Table 8) is taken from an outcrop at the south end of the North-central till area previously described. The section shows:

	Soil missing.
11"	predominantly brown eolian mantle with stones and ventifacts, grades down into
12"	yellow brown sand, probably eolian, grades down into
28"	gray, hard packed till; sandy, with many pebbles and cobbles, breaks out in flaky lumps.
12"	coarse sand and granule matrix with many pebbles and small cobbles; limonite stained.

It is yellowish gray (5Y 7/2), similar to the other tills found in the Taunton quadrangle. No weathering or staining of any sort was noticed in this till. It was hard-packed in the excavation, but when dried it crumbled as easily as many of the other till samples.

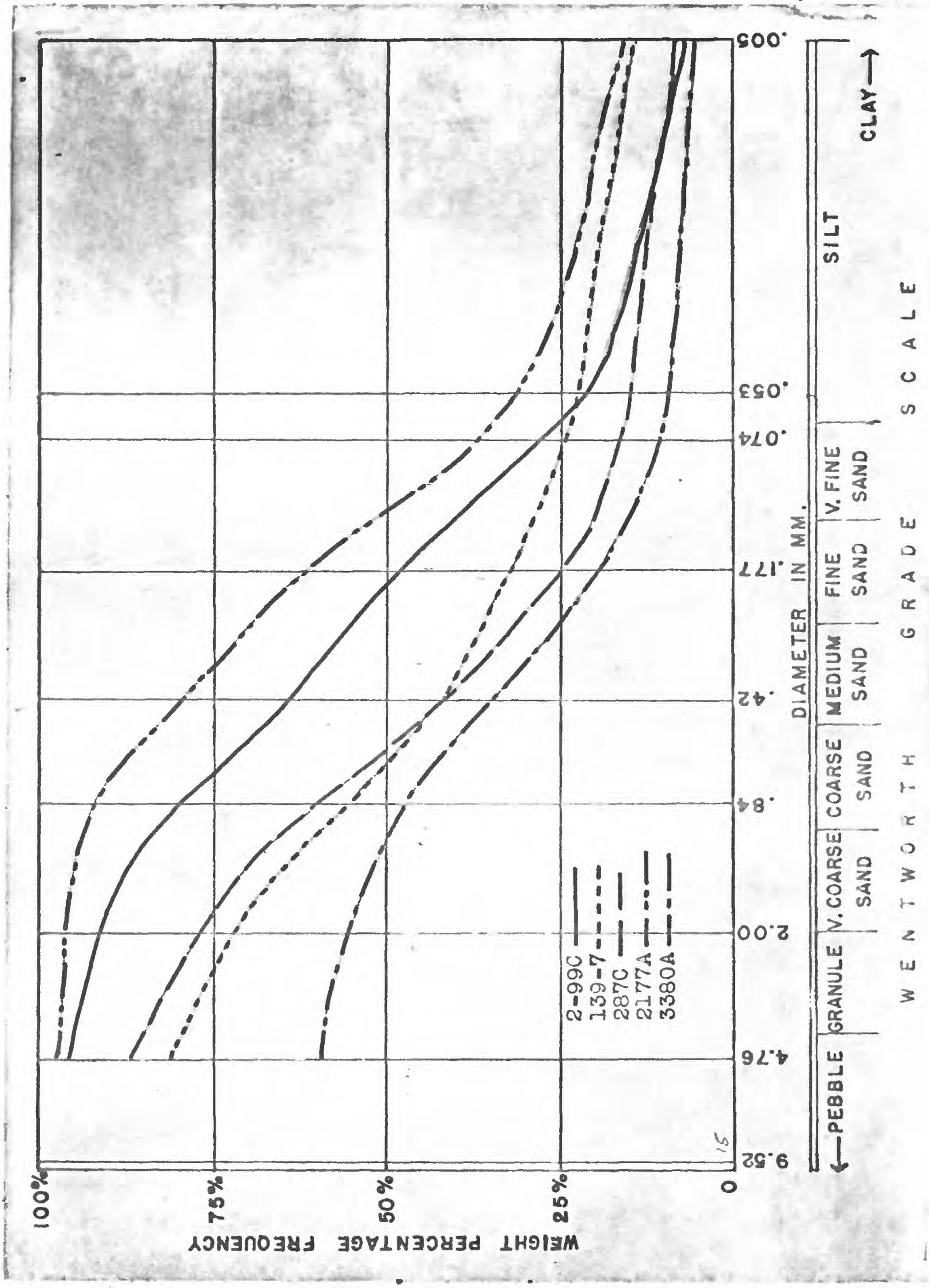


Figure 15. Cumulative curves of flowtills.

Table 8. Flowtill

Sample	Median (in mm.)	Q1 (in mm.)	Q3 (in mm.)	Sorting (So)	$\log_{10}So$
2-99C	0.210	0.750	0.073	3.21	0.505
139-7	.662	2.65	.084	5.62	.750
287C	.600	1.80	.187	3.09	.490
2177A	.118	.345	.029	3.45	.538
3380A	1.18	-----	.265	----	----

Till is interbedded between fluvial sands (Figure 16) in the town of Scotland, about 300 to 500 feet southeast of the intersection of Pleasant Street and Vernon Street. Here a section is as follows:

7" soil, dark and silty.
7" eolian mantle, sandy, yellow brown, bottom indefinite, grades downward into
9" gray, medium sand.
7½" red-brown sand, medium to coarse, iron stained, contains numerous pebbles.
26" till; more clayey in bottom than in top; not so many stones.
17" coarse and very coarse brown sand with pebbles, iron stains.

Till overlies outwash in other moderately flat areas on Elm Street, about .6 mile north of Pleasant Street in Bridgewater, and at the northern end of the North-central till area near sample locality 2-32, and west of Lake Sabbatia.

The second occurrence in which till is found, either overlying fluvial sands and gravels or interstratified with them, is in ice-channel fillings, kames, kame terraces, and kame plains that stand some distance above the sur-

Figure 16. Thin layer of till interbedded with fluvial sand, Scotland, Massachusetts.

rounding terrain. There are approximately a dozen different localities where this occurs.

At least three eskers in the quadrangle contain till masses. One is located about .2 mile east of the intersection of Pine Street and Pleasant Street in Bridgewater, and isolated patches of a sandy gray till (sample 2177A) are found on top of it. Another esker is located west of Lake Sabbatia; here the till is well down in the body of the esker, where it apparently fell from the roof. The third esker has till at the surface; the till forms a lens or mass about 3 feet thick, whose horizontal dimensions are unknown. Erratics on this esker are as large as 18 feet x 10 feet x 7 feet.

Four localities where till occurs in lenses in kames and kame plains will be described here as a general prelude to the problem of the origin of these tills.

A kame plain about 35 feet high is located in the southeastern corner of the quadrangle, at the intersection of Precinct Street and the New York, New Haven, and Hartford Railroad. In a gravel pit excavated into the top of the kame plain we find this section:

3"	soil.
8-15"	eolian mantle with admixture of till; many pebbles, cobbles, boulders; ventifacts.
55-60"	gray sandy till, fine-grained matrix, and numerous large boulders, grades upward into above.
15'	coarse grey sand with numerous pebbles and cobbles of all sizes; the upper 4-6" just beneath the till is hard and cemented.

The till is flat-lying, lens-shaped, and has a diameter estimated at a minimum of 100 feet.

A similar till deposit is located in the kame plain on Judson Street, approximately 1¼ miles northwest of the last locality. Here, the till band ranges from 6 inches to 7 feet thick, and has a moderately even top, conforming to the flat surface of the kame plain and is covered by the eolian mantle and a frost heaved mixture of till and eolian material (Figure 17). The till 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 obviously mined out of the till and now resting on the floor of the pit. The boulders are granite, sandstone, and conglomerate, and the largest seen was about 10 feet x 10 feet x 6 feet with striations on several surfaces. The till is of limited areal extent, but it is impossible to tell exactly how large it originally was. Some cross-sections seem to show that the till lenses out northward from the face of the pit where it was exposed. An approximation of the original size of the till mass would be about 300 feet by 400 feet in a lens shaped body with an average thickness of about 5 feet.

The bedding in the sand underlying the till lens is conformable with the lower surface of the till, and seems to have resulted from deformation of an originally flat-lying bed, which is discordant on the underlying

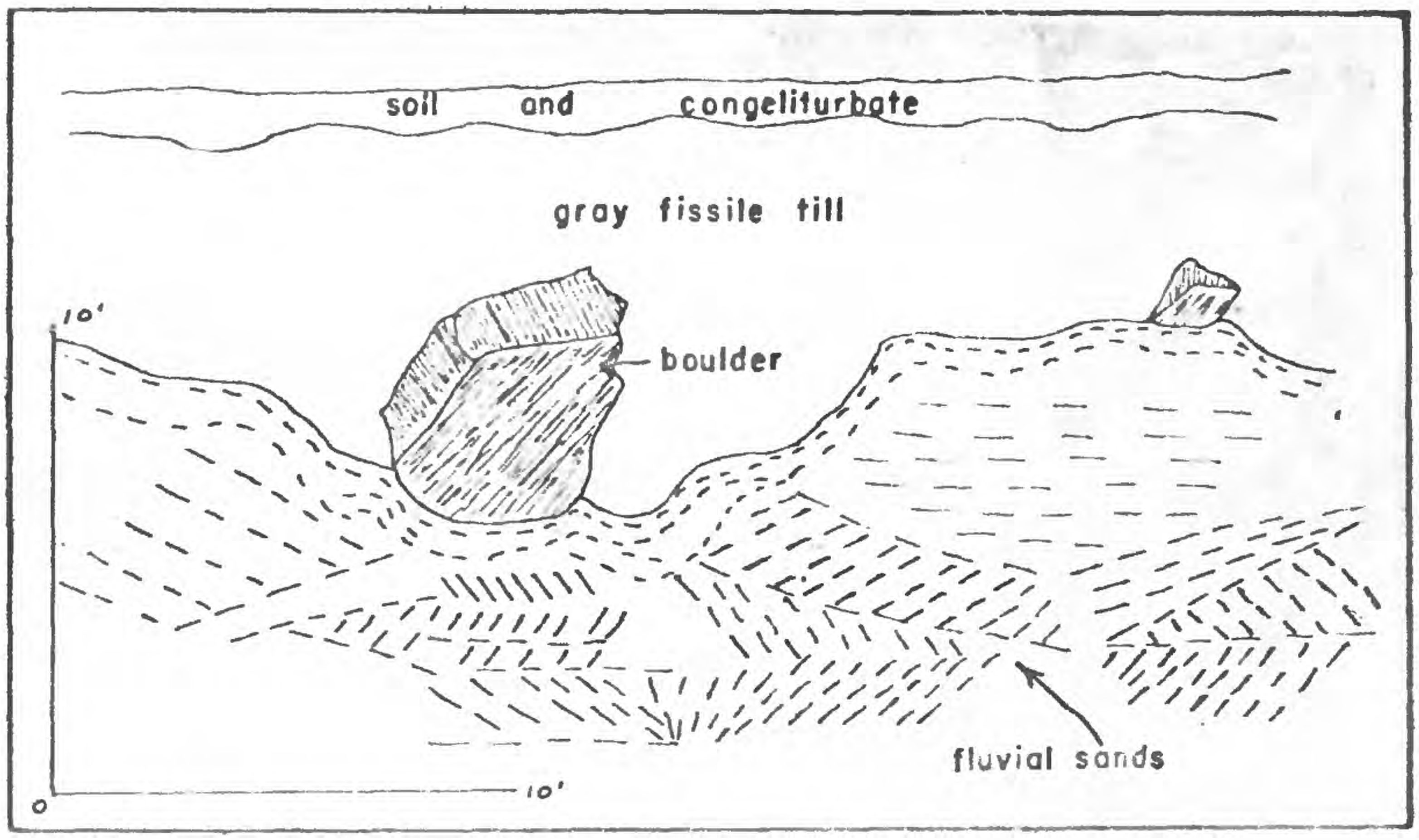


Figure 17. Part of a lens of flowtill overlying cross-bedded fluvial sand in a kame plain, Judson Street, Taunton.

strata. In the sands and gravels lower in the section, the apparent dip of the beds ranges from 15° to 35°, and the strike of the beds varies greatly.

In a large abandoned gravel pit, just south of Weir Village, a high face (Figure 18) shows the following section:

3-4'	fill.
4"	soil.
2-3'	stained, oxidized, disturbed zone--the eolian mantle.
4-6'	till, very light gray when dry, almost impossible to dig with a shovel; has stood in a vertical face for at least six years, sample 287C.
10'	sand, fine sand, silt and clay; general dip 8° to north.
15'	may be in place or may be a block slumped off the vertical face.

A sample of the till (287C) was collected from the vertical face shown in Figure 19 (opposite Figure 18) and analyzed; the statistical measures are found in table 8 and the cumulative curve in Figure 15. This till is very hard and compact when dry but has a smaller percent of silt and clay than any other Taunton till. The color is yellowish grey (5Y 7/2), and in appearance it resembles all the other tills of the area.

The last pit here described is on the northwest shore of Lake Sabbatia, in a large kame plain. Here a narrow lens of till of considerable areal extent is found near the top of the kame plain and extends in a thin band of varying width down the sloping sides of the kame plain to the contact with the nearby formless masses of lower

Figure 18. Flowtill, about 6 feet thick, overlying outwash in a large kame near [illegible] Village.

Figure 19. Till lens interbedded with distorted sand and gravel, near Weir Village.

outwash. A section on the east face of the pit gives an example of the stratigraphy, which changes from place to place within the pit:

6"	soil.
8"	eolian mantle and frost heaved material, ventifacts.
24"	fine to medium, loose, tan, horizontally bedded fluvial sand.
18"	coarse pebble gravel, poorly sorted.
20"	clayey, cemented, unsorted till (sample 139-7).
30"	horizontal bedded medium sand, course sand and small pebble gravel, fine sands, and pebble gravels.
8"	torrentially bedded medium sand, dipping approximately south.
8"	generally horizontal bedded fine sand.
15'	slump.

This till is yellowish-grey (5Y 7/2) with some very sandy spots in it; the thickness ranges from about 6" to 3 feet. It is moderately hard and compact when dry and fairly resistant to crushing in the hand.

For purposes of comparison, a flow till from a kame delta in the Bridgewater quadrangle is included in the cumulative curves (sample 3380A).

It seems obvious from the stratigraphic relationships of these tills that they must be different in origin from the tills which we find spread generally over the Taunton quadrangle. Note, however, that they differ in no way in physical description, color, or grain size from tills mapped as ground moraine. It is their stratigraphic relationship to the outwash that sets them apart.

The till masses described from the four localities above have counterparts in yet another half dozen or more places in the quadrangle. Everywhere the till is grayish, generally of limited extent and greatly varying thickness. The till overlies sands and gravels which are obviously streamlaid; the fluvial materials are generally undisturbed, the till masses are tabular to lens shaped, and the bodies of till may occur at the top of the outwash, capped only by the ubiquitous frost disturbed zone, or they may occur interbedded with the outwash. Numerous boulders occur in the till deposits.

The explanation most generally brought to mind for this phenomenon of till overlying outwash is probably wrong in this instance--the idea of readvance of the ice. The localities detailed here are all alike in one respect--the outwash bodies stand above the surrounding lowlands, and the till masses themselves overlie outwash and are also above the lowlands. The kames, kame terraces, kame plains, and ice-channel fillings were deposited in low spots in the ice or in channels between the ice and hill slopes. Ice contact slopes are characteristic of all these features, and the conditions of deposition are somewhat special, as at present fluvial and even lacustrine deposits end abruptly at scarps that fall away to lower ground. It seems improbable that local and isolated re-advances of the ice would move over these features, deposit a thin layer of till, and then withdraw, for with the disappearance of the active ice fluvial or lacustrine deposition must resume under the same special circumstances detailed above--in depressions surrounded by ice.

One of the most interesting things which comes to a geologist's attention upon the surface of a glacier, especially such a stagnant mass as the Malaspina Glacier, is the summer activity. In any latitude the summer sun is active around the margins of a glacier and melts the ice wherever it can penetrate the mantle of superglacial debris. Water is omnipresent upon the surface of an ice sheet near its borders, and in its journey to the sea it picks up the pieces of debris originally entrapped in the ice and carries them away. As described earlier, bodies of till are temporarily gathered on the ever changing surface of the ice mass. If a till body is saturated with water, it becomes a thick muddy mixture. In the continuous process of inversion of ice topography, the till may find itself at the top of a slope; it may eventually gain enough weight or water content, or get on a slope steep enough to move as a mudflow, carrying boulders and all sizes of debris with it (Figure 20). At the base of the slope, or some distance out upon a flat, the till mass stops; it is superglacial till. When the ice slope leads to the edge of an outwash body (Figure 21), as is often the case, the till will move out over the outwash as a thin body of stony mud. When the till comes to rest

Figure 20. Till flowing down gentle slope as a mudflow on the surface of the Malaspina Glacier, Alaska.

Figure 21. Debris covered ice slope in background passing beneath fluvial sand of outwash plain in foreground. Note semicircular areas of collapse beginning to appear at the ice-contact. Malaspina Glacier, Alaska.

(Figure 22) it will retain the characteristics of the till from which it originated, but because of its peculiar origin and anomalous stratigraphic position (when all vestiges of the parent ice have melted away) it is called flowtill.

Conclusions The till in the Taunton quadrangle, whether of superglacial origin, as in the flowtill, or of subglacial origin, as in the ground moraine, shows essentially the same characteristics. It is some shade of gray, is easily excavated, is composed mostly of sand, and is stony. The characteristics are those of the "new" till of previous authors. Nothing corresponding to the "old" till has been found in the Taunton quadrangle, but this does not show that all the till found is "new" till. It is unfortunate that the till problem has been thought of as being divided up into two neat categories, "new" and "old", for it is most probable that the criteria for distinguishing between the two tills are far from adequate. For instance, fissility, or a rude horizontal cleavage, is cited as one of the outstanding characteristics of the old till, yet Figure 17 shows fissile till overlying sands in a kame plain that must belong to the latest phase of glaciation. Also, a till found near Lexington had all the classical characteristics of the "new" till but included well-developed fissility above an otherwise identical till that showed no fissility.

Figure 22. Flowtill after coming to rest and drying out at the base of an ice slope on the Malaspina Glacier, Alaska.

The quantitative data presented in this paper, in the form of cumulative curves and statistical measures derived from those curves, indicate that the till in the Taunton quadrangle is a sediment of wide range in texture. Figure 13 shows the extreme range of grade sizes in the Taunton till samples. For instance, the median grain size ranges from .062 mm. to .070 mm. Any attempt to classify tills as "new" or "old" on the basis of grain size seems doomed to failure.

When till is released from the ice, either subglacially or englacially, a certain amount of water is also released. The amount of ice removed as meltwater, as opposed to ice removed by evaporation, may determine the grade size of the material left behind, and may also influence the degree of sorting. As seen in Table 9, sorting in the Taunton tills ranges from a low of 2.25 to a high of 7.66. The first till is approximately twice as well sorted as the second. According to Trask (1932), a sediment with a sorting coefficient of less than 2.5 is well sorted, but the well-sorted till above was taken from the north slope of a drumlin. Degree of sorting as a criterion for "new" or "old" till seems to be of limited value.

When the number of till samples is plotted against median grain size (Figure 23A) or against sorting (Figure 23B), the results are discouraging. A slight concentration of samples have medians between .200 mm. and .300 mm.,

Table 9. Statistical measures of till samples

Sample	Median (in mm.)	Q1 (in mm.)	Q3 (in mm.)	Sorting (So)	$\log_{10}$So
139-7	0.662	2.65	0.084	5.62	0.750
214F	.265	.800	.085	3.07	.487
2870	.600	1.80	.187	3.09	.490
2990	.210	.750	.073	3.21	.505
2-32A	.460	3.00	.088	5.83	.766
2-45A	.070	.500	.029	4.15	.618
2-50	.400	4.10	.070	7.66	.884
2-84A	.385	1.40	.092	3.90	.591
2105A	.265	.560	.077	2.70	.431
2169A	.123	.305	.053	2.40	.380
2177A	.118	.345	.029	3.45	.538
2185A	.400	1.15	.105	3.32	.521
2258A	.280	1.20	.050	4.90	.690
2262A	.507	3.00	.167	4.24	.627
2271A	.540	2.10	.084	5.00	.699
2275A	.680	5.00	.115	6.60	.820
2373A	.340	1.43	.066	4.69	.671
2425A	.340	.807	.160	2.25	.352
2501A	.193	.460	.030	3.91	.592
2532B	.210	.960	.023	6.45	.810
2532D	.120	.440	.041	3.27	.515
2532E	.245	1.06	.032	5.75	.760
2532F	.225	.800	.059	3.69	.567
2580A	.247	1.05	.079	3.61	.558
2645B	.250	.860	.088	3.15	.496
Moss "new"	.248	.900	.089	3.66	.564
Moss "old"	.168	.720	.036	4.47	.650
Al-Winthrop Head drumlin	.078	2.00	.005	2.00	3.010

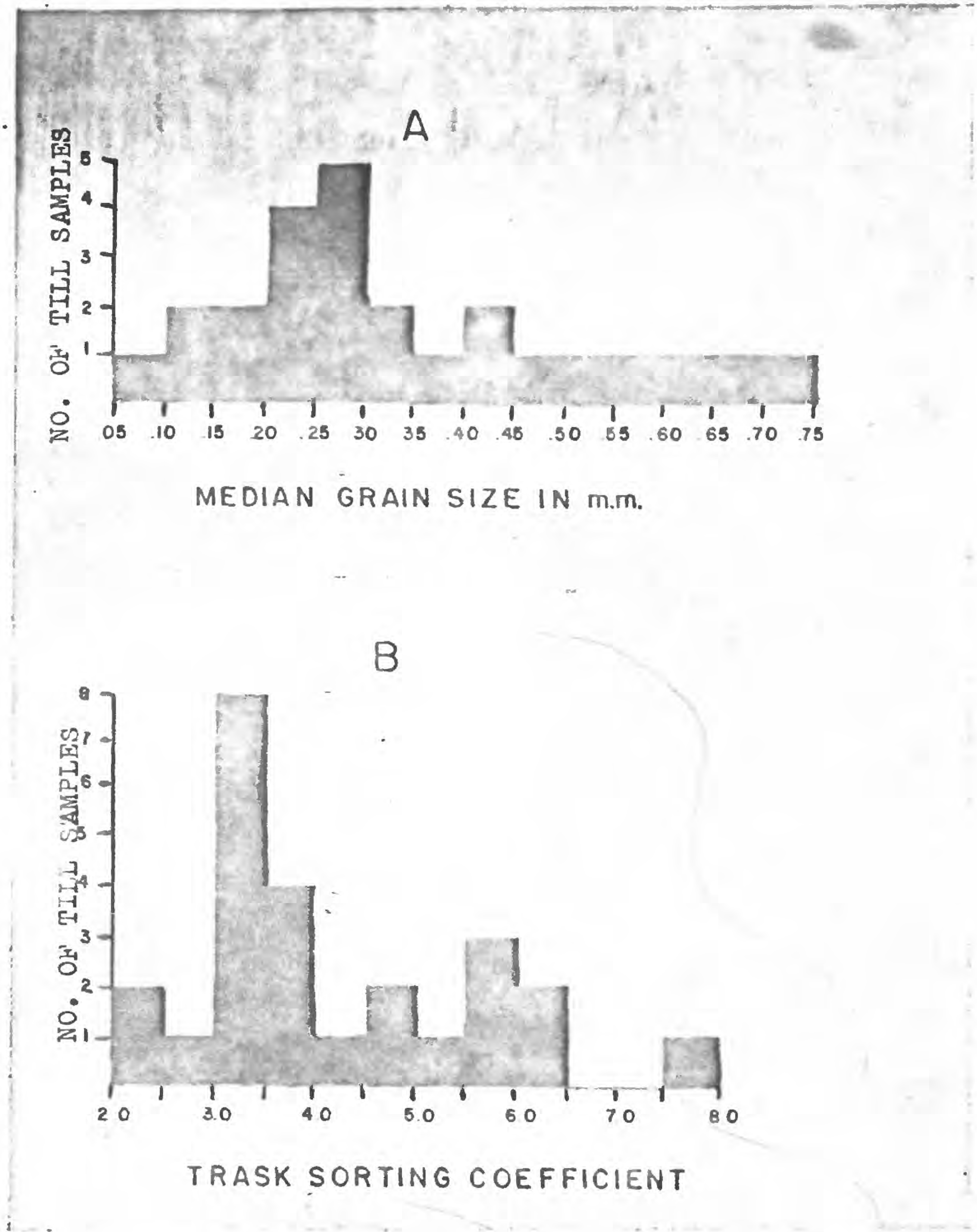


Figure 23A. Diagram showing number of till samples plotted against median grain size.

Figure 23B. Diagram showing number of till samples plotted against Trask sorting coefficient (So).

but almost twice as many samples are scattered over the rest of the median grain sizes. The tills do show a marked concentration in sorting, with almost one half of the total number of samples being concentrated from So 3.0 to So 4.0. This seems to indicate that the tills of the Taunton quadrangle are moderately well-sorted, but not enough statistical data is available to justify comparison with the "old" tills of the Boston area. One sample from the Winthrop Head drumlin in Winthrop, Massachusetts, was analysed for comparison, and shows a sorting coefficient of 20.00.

The flowtills are included in Figure 23, but a separate consideration shows that they share the general groupings of the entire suite of samples. There is no concentration in a plot of median grain sizes, but three out of five samples have a sorting coefficient between 3.0 and 3.5. The flowtills, as previously observed, are texturally and physically similar to the ground moraine tills in every particular.

The conclusion, then, is that the Taunton area, at least, the tills may have similar textures and different origins or entirely different textures and a similar origin.

Moraines

The covering of till that blankets the countryside is called ground moraine. Figure 6 shows the distribution of the ground moraine, as does the map of the surficial geology of the Taunton quadrangle, Plate I. The distribution of the ground moraine is in many cases directly related to bedrock hills, as in the case of the northwest-southeast trending ridges in the southeastern corner of the quadrangle. The ground moraine south of Scotland in the northeastern part of the quadrangle is on a similar bedrock hill. Till is present as ground moraine in other parts of the quadrangle, and may not obviously be associated with the preglacial bedrock topography. Perhaps the best example is the small oval patch of ground moraine about seven-tenths of a mile south of Pine Swamp. The bedrock map, Figure 3, shows that within a half mile to the west and to the south the bedrock is 22 feet and 32 feet below sea level, while the till is at an elevation of about 20 feet.

The surface of the ground moraine is covered with boulders of all shapes and sizes, dominantly of the Rhode Island formation, although many erratics of granitic and volcanic rocks have been transported from north of the Narragansett Basin. The sandstone and conglomerate from the Rhode Island formation make the largest glacial boulders; the largest boulder seen is the Castle Rock erratic. The surface of some of these large boulders are polished and carved by the wind.

No recessional moraines, end moraines, or anything resembling them have been found in this quadrangle. This area is northwest of Cape Cod where a prominent end moraine formed. A short distance to the southeast of Taunton the topography begins to show the effects of general stagnation of the ice sheet instead of oscillations at the farthest extent of the ice. Contrary to the opinion expressed in other papers, however, that the absence of end moraines "....may well denote that the marginal zone of the last ice sheet wasted away to form many individual, essentially stagnant masses of ice within the valleys...." (Jahns, 1953), the absence of end moraines may mean only that the melt-waters in the area were active enough to carry much of the glacial debris away as stratified drift.

Drumlins

There are but two drumlins in the Taunton quadrangle. In the north central part of the quadrangle a drumlin which begins at Algers Corners, and which is low and flat, enters the quadrangle with a generally north-south orientation.

The only drumlin contained wholly within the quadrangle is in the northwest corner. This smooth, streamlined hill has no bedrock outcrops on it and is composed entirely of till. It has an orientation that coincides with the direction of the striations found to the south.

Water-laid deposits

General statement

Glacial debris that has been modified by the action of meltwater streams is called stratified drift or washed drift (Flint, 1947, p. 133). The definition of outwash (Flint, 1947, p. 133) as stratified drift washed out beyond the glacier itself, seems to be too strictly limited for such an area as eastern Massachusetts, where the various forms of outwash intermingled with ice remnants that stagnated and were left behind in the valleys. The division into proglacial stratified drift and ice-contact stratified drift proposed by Flint (1947, p. 133) also serves no useful purpose in Massachusetts where the outwash or proglacial stratified drift is likely to have been deposited in conjunction with ice masses and thus be pitted, kettled, and variously disturbed.

When we are restricted to the glacial landscape which is New England today, it is difficult indeed to imagine all the ways in which a glacier can produce land forms. The study of modern glaciers shows beyond a doubt that the history and deposits of a glacier are extremely complex. The Malaspina Glacier shows very well the relationship between a receding or stagnant glacier and its array of glacial deposits, and for that reason comparisons are drawn here with the ancient glacial deposits of Massachusetts. Even today, on and in front of the

Malaspina Glacier, it is often difficult or impossible to find the source of the deposits. Outwash appears with no visible stream source; lake beds, till, and outwash may be so intricately interwoven that a map cannot show the complex details of distribution. The origin of some features of the glacial landscape can be determined because the process of formation is still going on, or perhaps because the distinctive features left by a process may still be discernible. For example, at one pitted outwash plain on the Malaspina a second, lower level of outwash has been produced by melting of a large, irregular, tabular mass of buried ice. The evidence is clear, because slumping is still going on: small dry stream channels are faulted; moss growing in the channels is torn across the faults; large springs discharging silt-laden water indicate the presence of melting ice beneath the outwash plain. Two similar levels of outwash in Massachusetts would be mapped as two distinct units. Definite separation into two significant levels on the map would rest on other data, such as differences in grain size between the sediments over the two levels, and general relations with other outwash forms. In our local mapping we must choose between two or more alternative origins, but on the glacier there is no question at all of the origin of the two levels of outwash.

The details of the various water-laid deposits in the Taunton quadrangle seem to indicate that most were laid down in contact with bodies of ice not necessarily or even probably connected with the main body of ice, but occurring as blocks and tabular masses of ice that were covered by debris before final melting. At the present time the stratified deposits are characterised by kettles, ice-contact slopes, and slumped and disturbed bedding within the deposit.

The surface of the ice mass in this area must have been largely covered with superglacial debris picked up from the surface of the earth and transported to higher altitudes in the ice. The high local relief of some of the stratified drift deposits make this assumption a necessity. Prospect Hill is a kame 200 feet high, and it is necessary to assume that the streams that helped to build it gathered their load from some higher altitude. The surface of the ice was probably irregular and hummocky, with debris in the hollows and thin deposits or bare ice on the summits, with melt water streams following the low areas and depositing their bedloads of sand and gravel, and, where hollows of larger dimensions appeared, depositing deltas and lacustrine deposits. The generally chaotic appearance of the areas blanketed by superglacial till would be relieved by the somewhat more orderly appearance of areas of stream deposition. The continuous destruction of outwash already built, the continuous changing of stream channels, and the draining of ponds through the opening of other channels would produce a changing sedimentary environment.

The Massachusetts landscape today exhibits only the final events of the glacial history. The story began high up on the ice when the first meltwater streams began to flow among the ridges and hollows. It would be a queer coincidence indeed if all the various forms of stratified drift now present were begun only upon reaching the ground, and yet that is a general assumption in the interpretation of the origin of stratified deposits. The features must in truth start at any and all times during the melting of the ice, and those outwash features with the most irregular surface and the largest and most numerous kettles were probably let down from the greatest thicknesses of ice. Disturbed bedding within the deposit is also evidence for superglacial origin, and conversely, undisturbed bedding shows that final deposition must have taken place on or near the ground. Obviously, on a continental ice sheet, the superglacial features will come into existence and be destroyed many times during the lowering of the ice surface and the consequent reversals of topography by downwastage.

Jahns and Willard (1942) mapped glacial deposits in the Connecticut Valley in units based upon the following criteria of classification: (1) morphology, (2) structure and composition, (3) position, and (4) relative age. Till, of course, is immediately distinguished by its texture and structure. In the Taunton quadrangle (Plate I), ice-channel fillings, kames and kame fields, kame terraces, kame plains, kame deltas, and outwash plains have been differentiated principally by morphology. Undifferentiated outwash is known to be composed of stratified sands and gravels but lacks any characteristic form. Textural variations and structure allow us to differentiate between kame deposits and other forms, such as outwash plains and undifferentiated outwash that occupy the same area.

All the geomorphic names used in glacial geology bear some implication of origin. Of necessity, we must assign names to map units, [illegible] an effort to determine the genesis of the units as nearly as we can. To correlate map units over large areas it is necessary that some uniformity of nomenclature be adhered to.

The surface form of any one glacial feature, such as the kame terrace, ranges from one [illegible] to another. The typical kame terrace is a flat-topped bench with a steep frontal slope facing a valley and a flat tread extending back to a valley wall. How far can this form depart from the typical before it is labelled a different feature? Ice blocks buried by the glacial stream gravels may have been so numerous as to nearly destroy the tread.

the small flat areas which remain do allow reconstruction of the original form--it was a kame terrace in its earliest stage, but is it now? Or if the front of the terrace is much pitted and slumped, then the reentrants and linear projections from the scarp may, according to the interpretations and thoroughness of the observer, be mapped as separate geomorphic units--kames, kame fields, eskers, or crevasse fillings.

It is evident from the discussion above that all our terminology is arbitrary. Glacial features very definitely do grade from one form into another, as, for instance, from smooth, graded outwash to pitted outwash and thence to a collapsed complex of flat-topped hills, kames, eskers, crevasse fillings, and kettle holes. Distinctions between these forms are arbitrary--an effort to separate into discrete units a gradational series of deposits. It is the end limits of the forms that we are trying to define; the varieties of forms within these limits set up by the arbitrary definitions are what we hope to understand. It is clear that the better we understand the phenomena of glacial deposition, the more nearly rational will be our classification and mapping.

Stream deposits

Kames occur in isolated spots in many parts of the quadrangle as individual conical hills and as large irregular features. The form varies widely; the general characteristic is that of an uneven topped deposit of silt, sand, and gravel standing well above the surrounding topography and apparently built in close contact with masses of ice. Some of the kames obviously originated in holes in the ice and collected the load of superglacial streams flowing through the area; ponding occurred in some of the depressions, and small deltas and lake or pond sediments were deposited. Other more extensive kames, such as the group at Prattville, appear to have been built against ice block walls, with numerous isolated blocks or irregular masses of buried ice within the kame itself, as shown by kettle holes and by collapsed and deformed bedding. Some kames and kame fields (an irregular group of kames) appear to have been formed when an outwash plain was deposited on a toe of stagnant ice. Later melting of the buried ice caused the outwash plain to collapse and left chaotic and indefinite forms in place of a smooth, graded outwash plain.

Flowtill is interbedded with the stratified sediments of many kames in the area and provides further evidence of intimate association with ice.

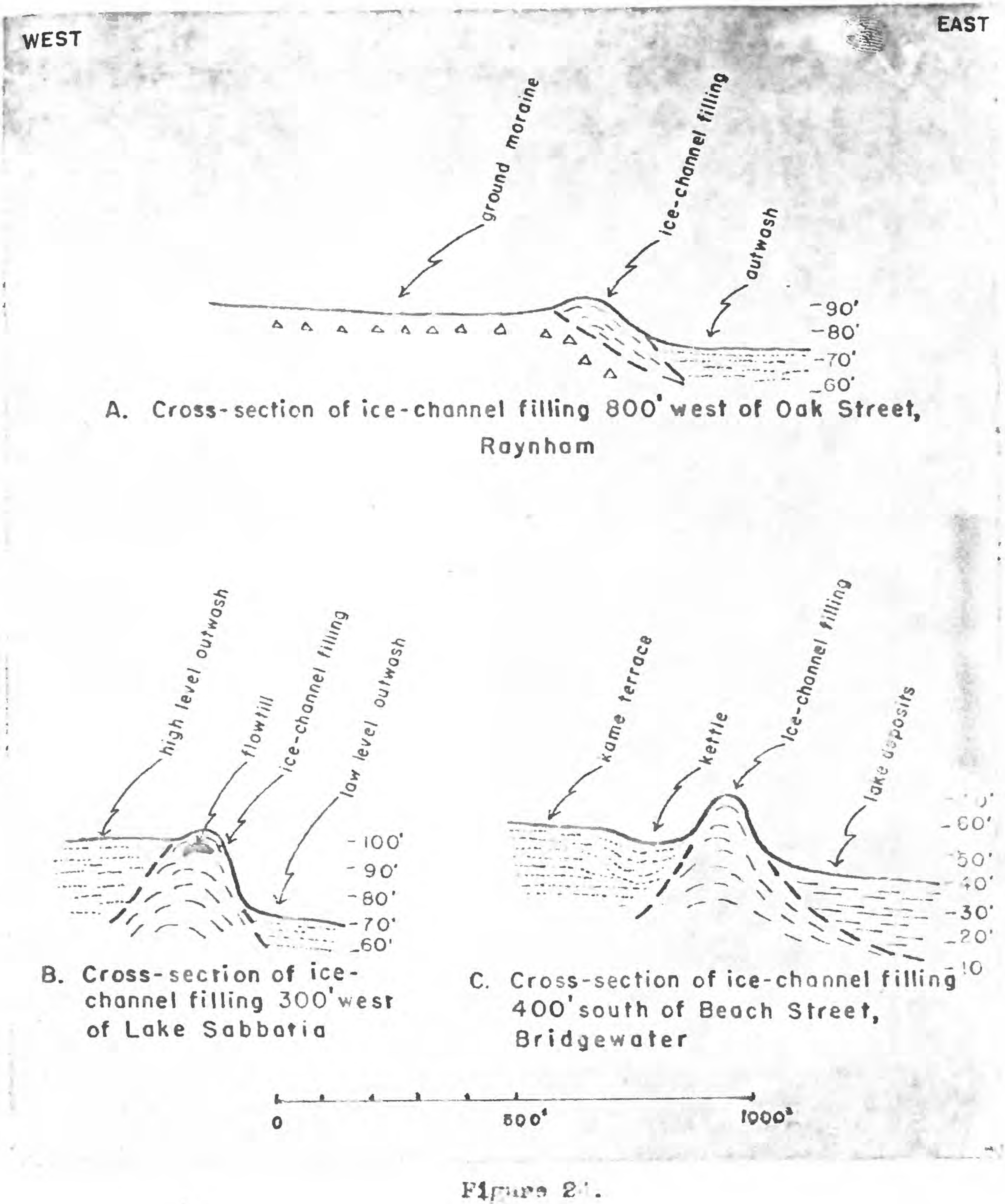
<u>Ice-channel fillings</u> Eskers and crevasse fillings (Flint, 1928) comprise one of the most easily recognizable groups of deposits in the area, yet the origin of the form is generally in doubt. In New England especially, the origin of eskers and crevasse fillings is a topic of considerable controversy (Lougee, 1951, 1953,). Experience

on modern glaciers has shown, however, that there is no unique solution to the problem of the genesis of any one particular glacial feature (Tarr, 1909, Hartshorn, 1952). At the Malaspina Glacier, for instance, the continuing events in front of and on the glacier, suggest at least four different origins for the ice-channel fillings. Many geologists have taken the position that it is impossible to determine the origin of the features called eskers or crevasse fillings, and hence have adopted the non-committal term "ice-channel filling".

Ice-channel fillings in the southern part of the quadrangle appear to be related to kame terraces and similar outwash features. In the northern and central part of the area there are three linear groups of ice-channel fillings. The easternmost group trends south-easterly, but according to the stratigraphic position of parts of the group, all of the ice-channel fillings were not formed at the same time. They are somewhat irregular in plan, have tributaries joining as they would if they were rivers, have undulating crests, separated segments, and the typical cross section with anticlinal bedding. Some of the ice-channel fillings end in kames. The central group of ice-channel fillings contains the longest uninterrupted segment in the area, about seven-tenths of a mile long. A third group, west of Lake Sabbatia, consists principally of small isolated segments.

Figure 24 shows the relation between three ice-channel fillings and the surrounding stratified deposits. The most striking feature is the difference in altitude between the two sides. In each case, the relief is greater on the east than on the west. The ice-channel filling on Oak Street (Figure 24A) is atypical and rests on ground moraine that slopes down to the east. The ice-channel filling on Beach Street (Figure 24C) is approximately 15 feet higher on the east. It was apparently formed in an ice-walled canyon whose western margin melted away first; sand and gravel were banked against the western side while ice remained in the lowland to the east. Lake sediments were then deposited in the lowland and against the margin of the esker and kame terrace. A similar sequence of events took place west of Lake Cabbatis (Figure 24B), where low level outwash was deposited against the eastern side of the esker after higher outwash had been deposited on the western side. Here the difference in elevation is about thirty feet.

The sediments in the ice-channel fillings seem to be nearly the same as those seen in many gravel pits in other fluvial deposits, except that the gravel is generally coarser and perhaps more poorly sorted. Till lenses are present in or on the ice-channel fillings. It seems very likely that ice-channel fillings originated as the beds of streams flowing in open channels or tunnels, and at



A. Cross-section of ice-channel filling 800' west of Oak Street, Raynham

B. Cross-section of ice-channel filling 300' west of Lake Sabbatia

C. Cross-section of ice-channel filling 400' south of Beach Street, Bridgewater

Figure 2[illegible].

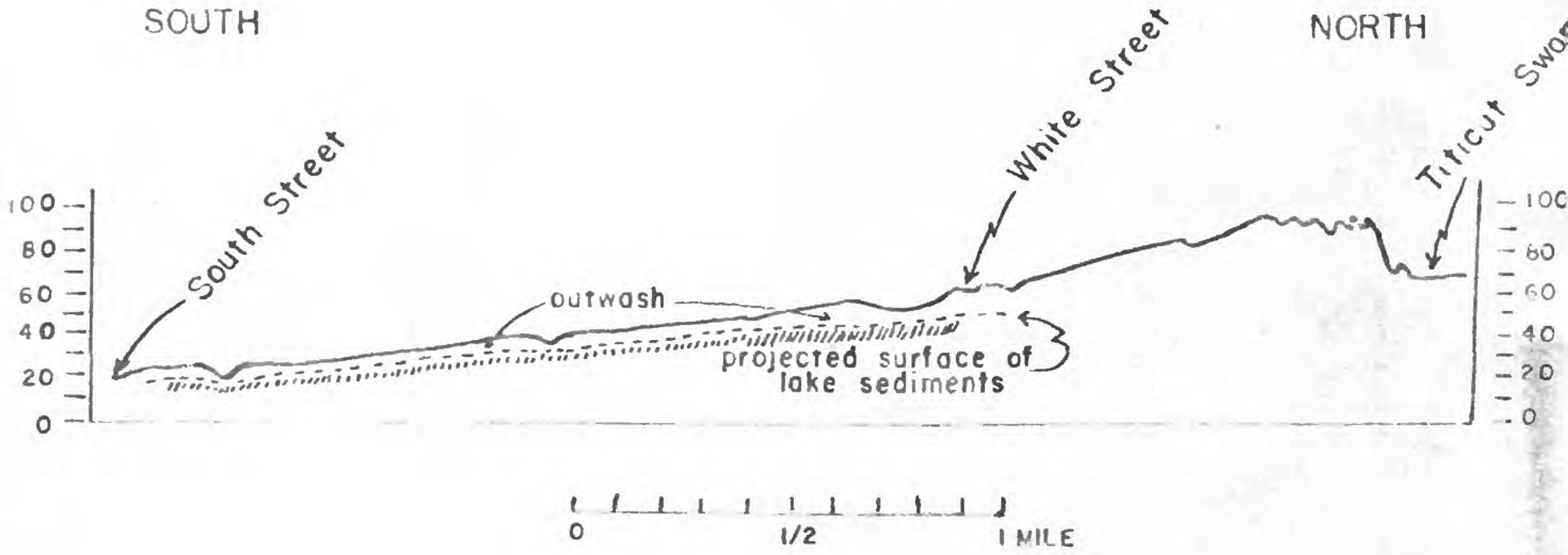
ground level or very near the base of the glacier. It is certain that most if not all of the ice-channel fillings in this area were formed early in the late-glacial history of any one locality and were not related to standing bodies of water, for with few exceptions, ice-channel fillings are absent wherever lake sediments are present.

Outwash At three places within the quadrangle, sediments were laid down as proglacial forms, and the meltwaters formed outwash fans and plains grading from coarse gravel to fine sand downstream. These outwash plains have retained most of their original form and can be mapped as a unit. Other fans or plains in the area probably cannot be recognized because of complexities of deposition or because of slump and destruction of the original surface by ice melting from beneath the outwash.

Most of the city of Taunton is built upon one of these outwash plains. The head of outwash is at an elevation of about ninety feet, and the plain slopes gently to the south. Coarse gravels and sands make up the northern border of the plain along the ice-contact slopes. A few kettles are found near the border, but none are found more than about 500 feet from the edge. Erosion has altered the original shape at the southern margin of the plain, where the sediments are fine-grained sand and silt. This outwash plain seems to be directly associated with the kame delta just to the east, but it is not; it was contained on the east by blocks of ice.

A second outwash plain in the northeastern part of the quadrangle, near Scotland, also has a north-facing ice-contact slope and is approximately a mile long. The gravels at the northern edge are very coarse and include numerous large boulders, but the grain size of the sediments decreases to medium and fine sand at the southern end of the plain.

The largest outwash plain in the area, south of Gushee Pond and Hewett Pond in the central part of the quadrangle, begins at an elevation of about 100 feet on the southern border of two ice block holes (Dead Swamp and Titicut Swamp) and declines gently southward about 23 feet per mile to the vicinity of the Taunton River (Figure 25). If a postglacial tilting of the land of about 5 feet per mile is assumed for this general area, then the original gradient was about 18 feet per mile. The lower end of this plain cannot be traced in detail; it seems to fade out in fine sand and silt that cannot be separated from lake bottom sediments underlying the outwash plain. Ice block holes and kettles are prominent in the northern part of the plain, and include the swamp area just east of Tracy Corner. Postglacial erosion has somewhat altered the original contours of the surface, but enough of the original plain has survived to give a good picture of a proglacial outwash plain.



Profile of outwash plain from Titicut Swamp to South Street, Raynham. Profile drawn along transmission line.

Figure 25.

<u>Kame terraces</u> In a region of low relief such as the Taunton quadrangle, kame terraces are isolated features; long valley sequences that are found elsewhere in Massachusetts (Jahns, 1953) do not appear here. In some instances these kame terraces correspond to the classic definition and are flat-topped terrace forms built by glacial streams in temporary vallies between the downwasting glacier and an adjacent hill slope. Most of the terraces consist of course sand and pebble to cobble gravel, but some are much finer-grained.

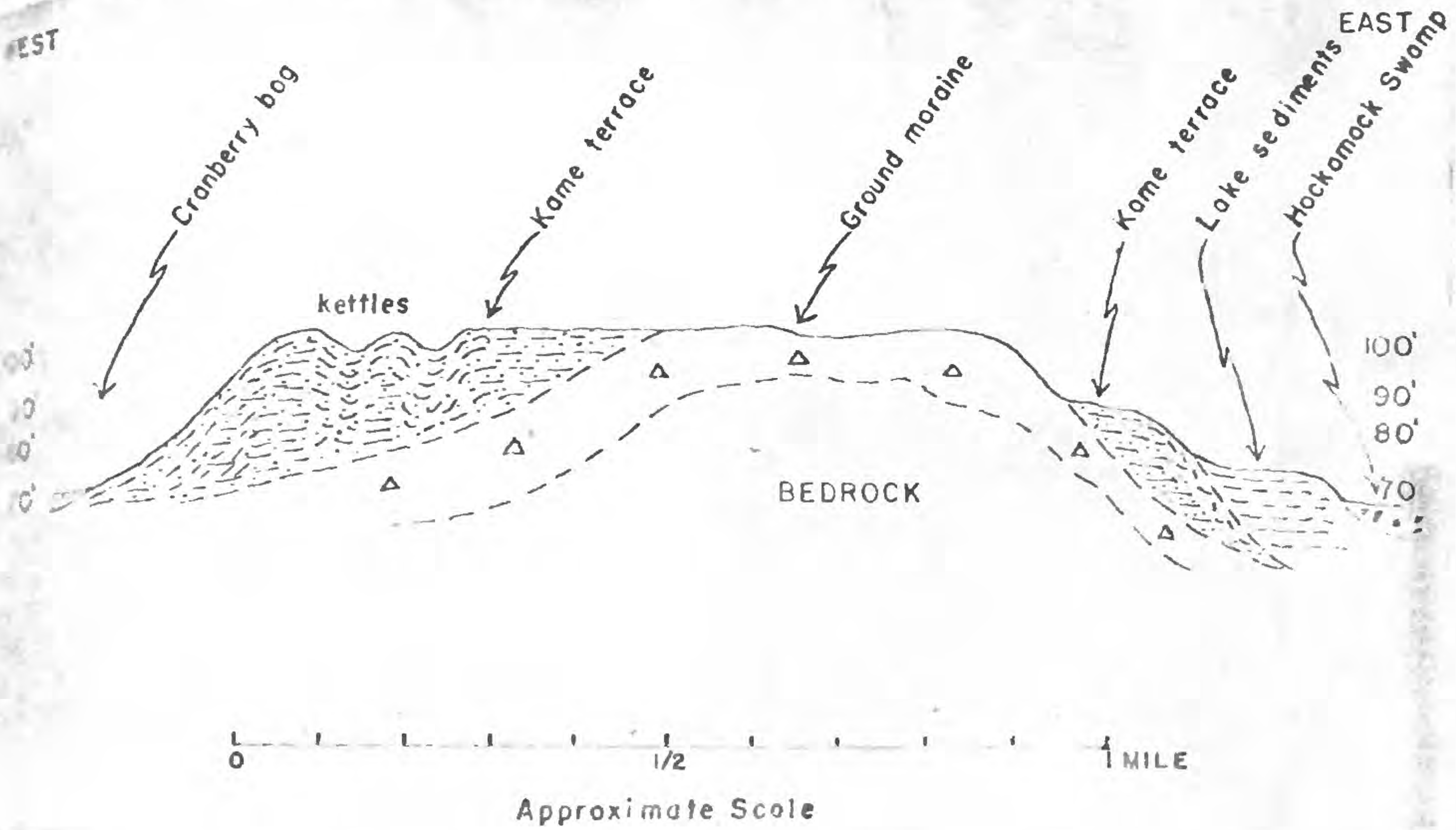
Isolated kame terraces are found on the southern slopes of the Locust Street hill in the southeastern part of the quadrangle. The upper surfaces of these terraces are much deformed and slumped. Other terraces are built on the south ends of hills near East Taunton, where two terraces are found one below the other. Flow till, in a lens about 80 feet by 50 feet in diameter and about five feet thick, is exposed in a gravel pit in the higher terrace giving further proof of the ice-contact origin of the deposits. Ice-channel fillings are associated with this terrace.

The largest area of kame terraces is found near the drumlin in the extreme northwestern section of the quadrangle. The kame terrace surrounding the drumlin is composed of gravel and sand; the terrace to the northwest is the southern end of a larger kame terrace and is dominantly composed of sand. It does not fit the classical definition, for the hill against which it was built was very nearly overrun by sediments (Figure 26), and at present the boundary between the till and the outwash on Dean Street can only be found by digging.

Prospect Hill is surrounded by a kame terrace that is full of kettle holes and bounded by excellent ice-contact scarps.

In the east central part of the area a kame terrace of complex shape is built up against an outwash mantled till hill. This kame terrace surrounds an earlier generation of ice-channel fillings, and at Beach Street on the boundary of the quadrangle, the kame terrace ends at the ice-channel filling. Excavations in the southern part of the kame terrace show that it is composed of materials ranging from very coarse gravel to laminated silty clay (Figure 27).

<u>Kame plains</u> Moderately flat-topped hills of sand and gravel which appear to have been built in holes in the ice are called kame plains (Jahns 1951). These deposits are completely surrounded by ice-contact slopes, and the mode of deposition may be either fluvial or lacustrine; in the latter case they may have been built into water-filled depressions as deltas. Not all deposits so mapped conform strictly to the definition of kame plain. Some of the kame plains have small necks by which they are



Diagrammatic cross-section of kame terrace on Dean Street, in the northwest corner of the Taunton quadrangle

Figure 26.

Figure 27. Fluvial materials range from silt to pebble gravel in a kame terrace one-tenth of a mile north of Beech Street.

attached to neighboring features of the same general altitude, as in the kame plain in the southeastern part of the quadrangle. Others do not show the flatness suggested in the definition but grade from those with a few small kettles to those with a more broken surface. The majority of the kame plains in this area are of fluvial origin, and horizontally bedded sediments are found to be the rule from the base to the summit. Flowtill is present in a number of the kame plains and is another indication of the presence of ice walls during their formation.

The origin of the kame plain is easily deduced in some cases. It is obvious that the kame plain just north of Pine Swamp in the center of the quadrangle is an isolated remnant of what was once a flat-topped, continuous outwash plain, whose various pieces were isolated by the melting out of large masses of buried ice. Some kame plains, as the one just north of Watson Pond in the west central part of the map, seem to be outwash fans laid down in a hole in the ice. When the ice melted most of the fan was left, and the edges were modified to ice-contact slopes.

In general, the origin of the kame plain is somewhat in doubt, for no one has yet precisely detailed how an aggrading stream can build a feature 30 or 40 feet high. One possible origin of the kame plain, however, can be seen on the Malaspina Glacier. Figure 28 shows a large, flat-bottomed valley completely enclosed by walls of ice. The entire area is about 100 to 200 feet above the base of the glacier, and all hill slopes are of ice covered by about 3 feet of superglacial debris. An englacial stream emerges from a tunnel at the far end of the valley and has built a sand and gravel plain of unknown thickness. The stratified deposits are shown in Figure 29, which illustrates an area at the downstream end of the valley where the stream has begun to cut through its own outwash and accomodate itself to a new lower outlet from the basin. Figure 21, previously described, shows one edge of the outwash and collapse of the material to form an ice-contact slope. Numerous small terraces on the far side of the valley will be formless kames when the ice wall beneath them melts away.

If this feature were formed on the ground, the melting of the enclosing ice walls would leave a mesa-like form rising above the surrounding lowlands. There is no reason why such a feature could not form. Superglacial features such as this are formed and destroyed many times in the downwasting of a stagnant ice mass. If the outwash plain is built too far above the ground, it is destroyed by slumping and by streams transporting the material to some other area. If such a feature is built on or very near the ground, the result would be a kame plain.

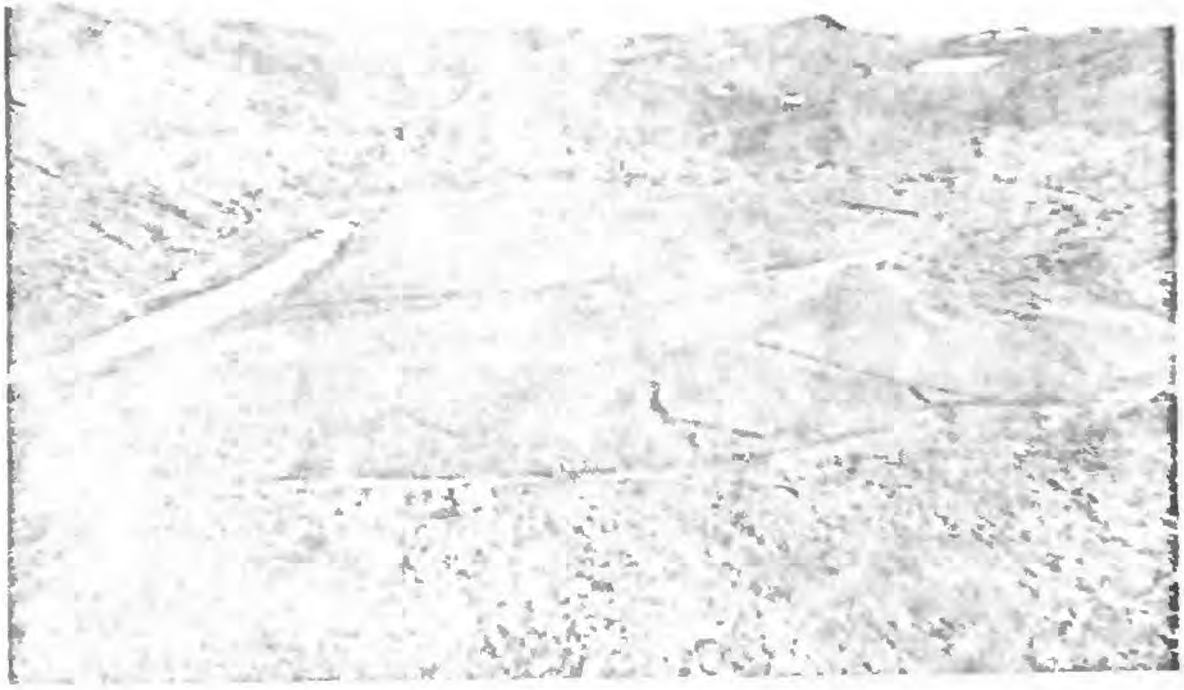


Figure 2[illegible]. Supraglacial outwash plain surrounded by ice walls, Malaspina Glacier, Alaska.

Figure 29. Section showing stratified sand and gravel in superglacial outwash plain shown in Figure 28.

Outwash undifferentiated When all the recognizable combinations of glaciofluvial features have been named, there still remains a large body of outwash to which we hesitate to give any of the conventional names, because the forms are distorted beyond recognition. For such masses the general category of undifferentiated outwash must suffice. This classification is used where meltwater streams flowed in channels which cannot be reconstructed or deduced, where collapse of irregular masses of tabular ice occurred, or where the original deposits were reworked by later meltwater streams. Original gradients, or flat-topped areas which perhaps could be fitted into an original stream pattern still exist here and there, but these areas are in general very small, and no consistent pattern can be seen.

Lake deposits Two lakes of considerable size were present at different times in the Taunton quadrangle. The more southerly lake is indicated by a kame delta and associated lake bottom beds to the south of it; the northern area of lake deposition is indicated by kame deltas in the Brockton quadrangle and by the silt and sand that are spread out to the south as far as Lake Nippenicket and Lake Sabbatia.

One kame delta, in the southeastern corner of the quadrangle has no lake bottom deposits associated with it, but has well-developed forsset bedding and characteristic delta shape. The surface of the water body into which this delta was built was about 45 to 50 feet above present sea level.

The lake sediments in the northern part of the quadrangle are very thick in places. Fine sand and very fine sand 84 feet thick have been found in a driven well on the west shore of Lake Nippenicket. Similar materials 88 feet thick occur on Field Street north of Lake Sabbatia. Fine sand was not deposited in such quantities over all the area covered by the Hockomock Swamp, for coarse sand and fine gravel come to within a few feet of the surface just north of the Raynham Dog Track. The existence of scarps along the edges of the sandy terraces facing the swamp indicates either the presence of streams which trimmed the edges, or the presence of long lasting ice upon the floor of the lake, which lasted at least until the glacial lake had disappeared before it finally melted away.

The best lake deposits are those preserved in the central and southern parts of the quadrangle. A large kame delta, with ice-contact slopes on the northwest side, faces a lowland underlain by sand, silt, varved, and unvarved clay.

The kame delta is about 1.4 miles wide and about four-tenths mile from front to back; the top is a flat to undulating plain. Foreset bedding (Figure 30) dips generally southeastward 25° to 30°, and is overlain by about

Figure 30. Foreset bedding in kame delta west of Raynham Center.

10 feet of coarser topset beds of sand and gravel (Figure 31). This delta was built into water with an elevation of about 80 feet above present sea level.

The sand of the foreset beds can be seen to grade outward into finer sand and silt at the base of the same delta. Farther south, at the Stiles and Hart brick pits north of Weir Village, a section shows the following:

6"	soil.
2-13'	of horizontally bedded sand, fine sand, and silt, and a few granule and small pebble gravel beds showing ripples and crossbedding.
12'	varved clay, homogeneous looking when wet, variable in thickness and composition (Figure 32).

The varved clay has a few erratics embedded in it, and in places the clay is distorted and crumpled. In the absence of any evidence of ice shove, the distortions are attributed to penecontemporaneous slumping.

The kettle holes which dot the surface of the lake plain, and the relation between an ice-channel filling, a kettle hole, and the lake sediments between the Taunton River and Williams Street, show that the lake was formed when there were still masses of stagnant ice lying on the lake bottom. Just south of the intersection of a power line and South Street (in the area mapped as Qw) numerous kettle holes contain coarse to very coarse sand. It is reasonable to assume that the kettle holes did not develop until after sedimentation in the lake had stopped. Along Furnance Brook in the southeast corner of the quadrangle, the lake sediments stop abruptly at an ice-block hole.

Figure 31. Topset beds about 10 feet thick overlying foreset beds shown in Figure 30.

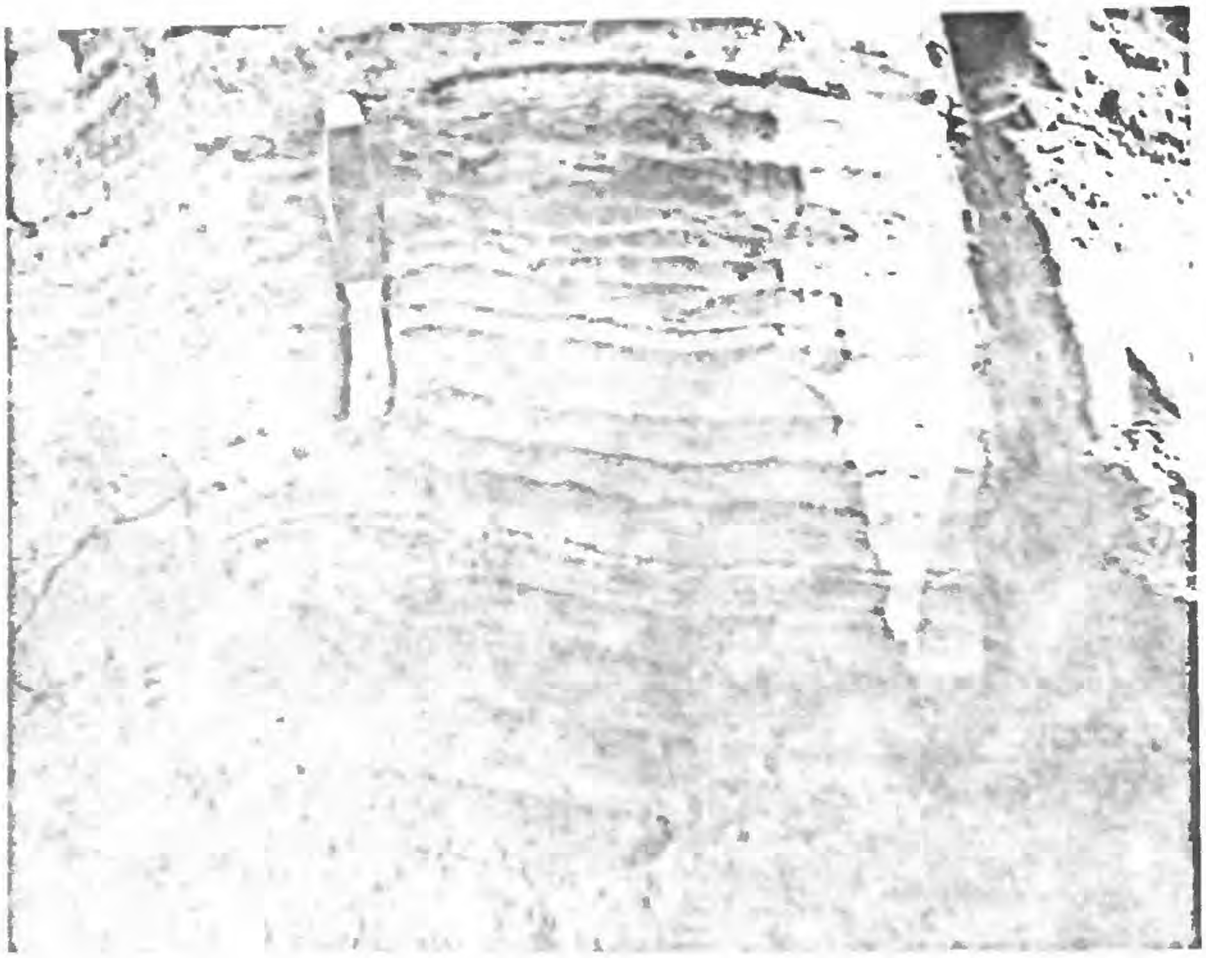


Figure 32. Close-up of varved clay at Stiles and Hart clay pit. Note marked gradation from sand and silt (light grey) to silt and clay (dark).

It is evident that here, too, the ice remained until the lake drained.

The relationship of the Gushee Pond outwash plain to the lake sediments has been touched upon briefly above (Figure 25). Numerous exposures in a water pipe ditch near Raynham Center showed the stratigraphy quite clearly. The lake sand, silt, and clay extend for some distance north of Raynham Center, at least to White Street, where a fine white sand is found under the gravel; this fine sand is assumed to be a continuation of the lake sediments. Near the intersection of South Main Street and Warren Street the outwash is coarse to fine sand, with a few pebbles and cobbles, and it overlies an eroded surface of silt and clay. From this point south it is impossible to tell where the outwash sediments end and the lake sediments begin.

The northern boundary of the lake was determined by the ice front, which at one point terminated against a delta, and elsewhere, south of Gushee Pond, apparently ended in the waters of the lake. No evidence of wave action, shorelines, or any related features were found on the hill to the east, which must have formed the eastern shore of the lake. The boundaries of the lake to the south are vague, but it seems to have been held in by a combination of high ground and ice masses. Further work in the Assonet quadrangle to the south may help to clear up this question.

Wind deposits

General statement

Extensive outwash plains and numerous minor outwash features are characteristic of the southeastern part of Massachusetts. In the latter stages of the retreat of the ice sheet, these outwash plains and other features were sources for wind blown sand and silt which blanketed the area beneath a universal mantle of eolian material. This eolian material, called "loess" by Smith and Fraser (1935), was affected by the intense frost action of late-glacial time; the result is a mixture of eolian material plus other glacial debris. In this paper an attempt was made to discuss the eolian deposits separately.

The first recorded statement that the upper pulverent layer of material might be of wind-borne origin, similar to the great loesses of the Midwest, is found in Woodworth (1899). He had earlier (1894) noted the presence of ventifacts, which he called glyptoliths, on Cape Cod, Marthas Vineyard, at Fresh Pond, and at Grover's Cliff, in places where the sands are not now blowing. Later Woodworth became convinced that the last glaciation blanketed all of New England with a loose, pulverent layer of Wisconsin till (Woodworth and Wigglesworth, 1934), and failed to connect the ventifacts with the material in which they were imbedded. Bryan pointed out (1932) that this layer of loose, unconsolidated material, which was never more than about 2 to 5 feet thick, contained wind-worn stones from top to bottom and hence must have been formed under conditions involving wind work and not burial under glacial ice. Bryan (1935) attempted to use the depth of weathering and the thickness of the wind-blown material to determine the relative ages of the various drift sheets that he postulated to exist in southeastern Massachusetts.

The material is presently believed to be eolian in origin because of its physical properties and field relations. The surficial mantle follows the underlying topography and is in places separated from the underlying deposits by a very sharp textural break. The mantle is ubiquitous, it extends everywhere within the quadrangle; it covers till hills, till lowlands, outwash plains, and outwash features of all kinds. The only place where it is absent is on modern alluvium, some parts of the lake bottom clays, and on some of the narrow ice-channel fillings. We cannot tell if it is present on the surface of the glacial deposits beneath the swamps.

At the present time most of the eolian material lies within the zone of weathering and hence is oxidized to its base; it is buff or chestnut to a yellow or reddish brown, depending apparently on the degree of oxidation, the permeability of the underlying drift, and the height of the water table. The original wind blown material is not often seen because of mixing with the glacial deposits, but in a few places the eolian mantle is thick enough so that the wind-blown sand and silt seems to be almost in its pure state.

The general frost climate that existed during the downwastage and retreat of the last ice sheet churned and heaved the upper layers of soil so that the eolian material thus partakes of the nature of the glacial debris below it; it is gravelly over gravels, it is till-like over tills, and it is sandy over sand. Fortunately this admixture of materials from below has provided the strongest argument about the wind-blown origin of the surface mantle. Above the outwash sands and gravels particularly, and above the till, are numerous pebbles, cobbles, and boulders which have been cut and blasted by the wind.

Ventifacts

Every variety of stone found within the quadrangle has been cut by wind action, but some stones make better ventifacts than others, and as a direct result, some areas show many more ventifacts than others.

The sandstones, shales, and conglomerates of the Rhode Island formation make the fewest and most poorly defined ventifacts, although one or two excellent examples were found. This rock type is locally derived and is found mostly in the till. Over areas of till the eolian mantle contains far fewer ventifacts than it does elsewhere, because the Rhode Island formation contributes most of the stones to the till and does not contribute many ventifacts.

Elsewhere, as on the outwash plains, the stones in the deposit have come from greater distances and consist in great part of granites (especially the varieties of Dedham granite), other igneous intrusives, volcanics, and felsites. These rocks, because of their structure and minerals, easily take a cellophane-like polish and show pitting and grooving on their surfaces more readily. Hence, in an area of outwash, the surface mantle very definitely shows evidence of wind action; the presence of the hundreds of thousands of ventifacts is conclusive evidence that the upper-most layer of glacial deposits was affected by wind action.

The shape of the ventifacts varies from those that have the pyramidal or Dreikanter shape, and which are least numerous, to those in which the joint block surfaces of glacial pebbles are but slightly cut or polished.

The ventifacts range in size from less than one-fourth inch in diameter, from the smallest aggregation of several quartz and feldspar grains, to boulders many feet in diameter. Wentworth and Dickey (1935) claim a lower size limit of about one-half inch for ventifacts, but this figure should be revised downward. A typical wind-cut boulder, with the polished surface, the fluting, and the grooving most often seen, is shown in Figure 33. Orientation of the grooving and fluting on the ventifacts allows no deductions as to the wind direction of the Pleistocene.

Mather, Thiesmeyer, and Goldthwait (1942, p. 1167) give a list of the characteristics of ventifacts that is of inestimable value to anyone striving to familiarize himself with their appearance. The criteria listed are certain proof of the wind-cut origin of the pebbles found in the upper soil layers. Polished surfaces, the best of which resemble a 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, together with the cellophane sheen, is perhaps the most outstanding criterion for recognizing ventifacts in southeastern Massachusetts. Any part of a rock which is harder than other parts will generally stand out in relief when the rock has been wind cut. Quartz (as in the Dedham granite), laminae in sandstones, phenocrysts in volcanic rocks, and fragments in flow breccias, are all examples. In addition to the etching which was thus produced, the wind also produced fluted surfaces, in which the rock shows a series of uneven, discontinuous, concave flutes or groovings. Pits appear on some ventifacts, and probably represent the etching out of softer parts of the rock.

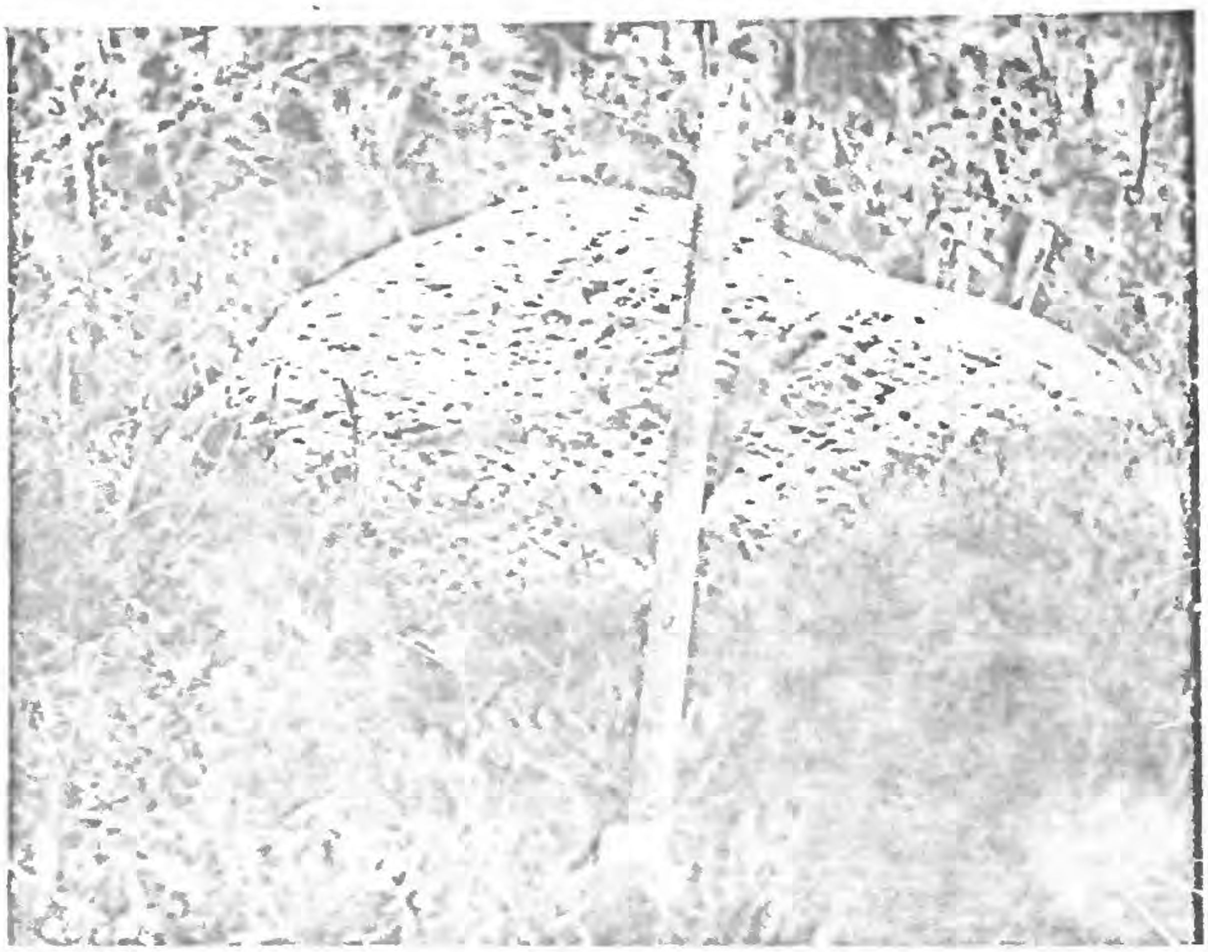


Figure 33. Typical ventifact of Dedham granite found on ground moraine east of Hill Street in the north-central part of the Taunton quadrangle. Note the pits, grooves, and polished surfaces.

Ventifacts in the eolian material appear to have a random orientation of cut surfaces, probably due to frost-action during the time they were cut. They are also scattered through the eolian material from top to bottom, which must indicate either that frost-action was contemporaneous with the cutting or that the cutting took place only in the early stages, and the ventifacts were then buried. Later frost-action distributed them through the upper layers of the soil.

It is obvious that to cut the pebbles on all sides requires turning the stones around all axes at the time of wind cutting. The only process which could have turned the original stones around so they could be cut on all sides is intense frost action or congeliturbation (Bryan, 1946). In the most extreme case a rounded and nearly spheroidal stream pebble was etched and pitted over its entire surface so that it retains its original spheroidal shape with the addition of a wind-cut surface.

Intense frost action took place before and during the period of ventifact cutting. Many rounded stream pebbles have been frost-split, the pieces moved far apart, and the flat frost-riven face itself blasted by the wind and given a high polish. Some of the ventifacts may have been frost-riven after wind action ceased, but this gives no indication whether the frost-action was late-glacial or post-glacial.

The ventifacts do not seem to have been moved far, if at all, since they were cut, for interface edges are generally sharp, and the polish is almost always present.

<u>Eolian mantle</u>

The eolian material at the intersection of Route 44 and Orchard Street in Raynham ranges from 20 inches to about 36 inches thick. The contact between the eolian material and the underlying till is sharp, but individual stones are incorporated in the eolian material and completely surrounded by it. Several ventifacts were found in the eolian material. Grain size analysis of sample 3518A, from the middle of the section, shows a very fine sand with at least 31% clay size material (Figure 34). No sorting values can be derived from the cumulative curves, for the curve does not intersect the third quartile.

Wind borne material at least 5 feet deep is found at other places on this same hill.

Sample J59C is taken from a depth of 13 inches to 17 inches below the surface in sandy eolian material near the Titicut site. The sand was yellow-brown and contained many ventifacts. The cumulative curve (Figure 34) reveals a very well sorted material with a median in the fine sand size. In this sample about 12% of the material is finer than .074 mm. (silt).

A third sample of relatively uncontaminated eolian material was taken from the North-central till area at

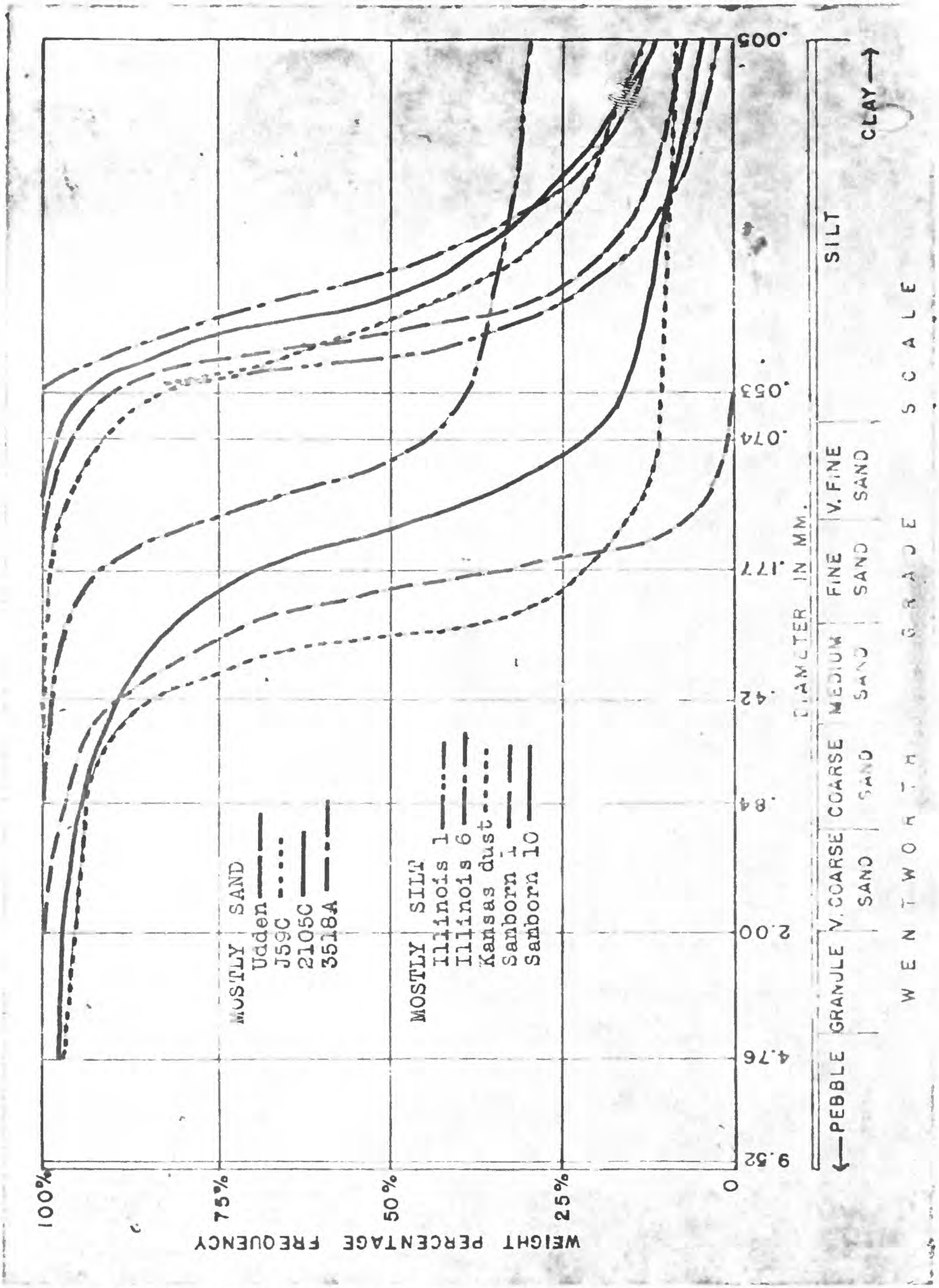


Figure 34. Cumulative curves of eolian material.

locality 2105 (Figure 6). Sample 2105C was gathered from a layer of brown stained medium to very fine sand with ventifacts. This sample also shows good sorting, and the cumulative curve shows a tail of silt and clay size materials similar to that in J59C.

Table 10. Eolian material

Sample	Median (in mm.)	Q1 (in mm.)	Q3 (in mm.)	Sorting (So)	$\log_{10}So$
3518A	0.082	.190	----	----	----
J59C	.245	.300	.185	1.29	.111
2105C	.130	.192	.080	1.55	.190
Iddon	.200	.270	.170	1.26	.101
Kansas dust	.033	.046	.0175	1.63	.212
Sanborn 1	.035	.040	.026	1.24	.093
Sanborn 10	.028	.035	.012	1.71	.233
Illinois 1	.038	.047	.027	1.32	.121
Illinois 6	.023	.031	.013	1.54	.188

Five cumulative curves of loess from Kansas and Illinois are included in Figure 34 and Table 10. Sample D (Kansas dust) is a wind-blown dust gathered during a dust storm and analysed by Swineford and Frye (1945, p. 250) for comparison with the Sanborn loess. Two of their loess samples, Sanborn 1 and Sanborn 10, are included here. Two loesses from Illinois (Smith, 1942, p. 154) include Illinois 1 (six-tenths of a mile from the Mississippi River) and Illinois 6 (14.7 miles from the river).

One cumulative curve showing the average composition of dune sands (Udden, 1898) is included for comparison.

It is obvious from the cumulative curves that the eolian material in Massachusetts is not loess. The eolian mantle in the Taunton quadrangle is composed of medium to fine sand, with some very fine sand. Sample 3518A is an exception with its large quantity of silt and clay size material; however, this locality is about 1500 feet east of a glacial lake bottom that was an adequate source of silt and clay sizes. The conclusion is that the eolian material in the Taunton quadrangle is wind-blown sand and not loess; however, loess is present elsewhere in Massachusetts (Smith and Fraser, 1935, p. 26).

Origin of wind deposits

The time required to cut a ventifact is unknown. Fistrup (1953) found many ventifacts in Peary Land, which has a very arid high arctic climate. On wide stone plains, all the larger stones are polished by the wind; softer sandstones are grooved and hollowed. Some stones are completely faceted, but the greater number have only one polished side because all the storms come from the west; the stones, firmly frozen in the soil, very seldom change position. Fistrup found ancient Eskimo camps where stones were used to hold down the tents and also to enclose the fireplaces. According to the archaeologists these camp sites date from the 16th and 17th centuries. "At these

Eskimo camps it was seen that a complete new faceting of oven big stones was possible in the course of the 200-300 years since the stones were erected in their present position." (Nistrup, 1953, p. 95).

Very few of the ventifacts in the Taunton quadrangle are faceted. Most are merely polished, etched, and fluted on one or more sides. They are scattered through the eolian layer from top to bottom, a distance ranging from about 1 to 6 feet. It seems reasonable to assume that the time required to cut a face, turn the stone several times, repeating the cutting each time, and bury the stone, must be of the order of one hundred to several hundred years.

Cutting of the vent'facts probably began while ice masses still lay in the area and continued while the ice retreated northward. The distribution of the ventifacts through the eolian mantle seems to indicate that it was building up concurrently with the cutting of the stones. Thiesmeyer, Mather, and Goldthwait (1939, p. 1939) thought that cutting took place throughout the time of recession and local readvance of the ice: "General scarcity of wind drifted material on the surface and in kettle holes suggests that even ventifacts in upper soil zones were produced before complete disappearance of the ice blocks." A similar statement (Mather, Thiesmeyer, and Goldthwait 1942, p. 1172) appeared later, but it is a well established fact that the kettle holes do have eolian material in them.

The presence of a continuous eolian cover has been proven in the Taunton quadrangle and it can also be found nearer the Cape.

Hobbs (1943, p. 557) points out that in the warmer season of the year great quantities of meltwater issue from a glacier and form braided streams, large rivers, and many lakes and ponds. When the warmer season ends, the wind blows the dry sand about and produces pebble bands, ventifacts, dunes, and loess deposits. But the wind is an effective agent long before the end of the melt season. On the streams on the front of the Malaspina Glacier, such as Alder Stream, it was noted that it only took one day after long rains for the gravel plains to dry off sufficiently so that slight winds, about 10 miles per hour, would raise dust clouds and sweep across the outwash flats and into the woods on either side of the outwash plain. The dust and sand blew up against various features like eskers where the winds were trapped before proceeding on their way. The sand which can cut and polish is the heavier material carried near the ground and it is easily stopped at high barriers. Perhaps the reason eskers have no ventifacts on them is that the winds dropped the sand momentarily on the windward side and when the sand began to move again it had no great impact energy. The absence of ventifacts on eskers may also show that gravel solifluction, which will be discussed in the next section, is a reality, and the lack of ventifacts and eolian material on eskers merely reflects the fact that the material was moved to the surrounding lower areas.

Congeliturbate

Eolian deposits in southeastern Massachusetts are mixed with the underlying stratified and unstratified glacial drift to form the congeliturbate (Bryan 19[illegible]). Although the eolian material and the congeliturbate can be differentiated in many places, it is, in general, very difficult to separate the two deposits. The eolian deposits were lain down by the wind as a clean, moderately to well-sorted sediment, but either during the process of deposition or at some slightly later time the wind-borne sand, silt, and clay were mixed with the underlying material. At present the congeliturbate includes within it eolian sand and silt, pieces of till, the separated fines that made up the matrix of the till, sand from the fluvial deposits, and stones from the till or from the outwash.

The congeliturbate is a stratigraphic horizon, and can be traced over most of the quadrangle with the notable exception of swamp and modern alluvial areas. Other exceptions are areas of clean sand, silt, or clay, where evidence of frost action is necessarily missing. In sand, the only evidence of frost action may be a finer fraction of wind blown sand blown to the area and churned into the outwash sand, producing a slightly sticky material. In most places ventifacts, scattered from top to bottom throughout the congeliturbate, make it easy to identify the bottom of the layer and thus to estimate the depth of frost action.

Samples gathered by the author, and the studies of sections in the field reveal that the color of the congeliturbate ranges from shades of olive-gray to yellowish-brown or reddish-brown, according to the stage of weathering of the iron-bearing minerals, position in relation to water tables (over relatively impermeable till or permeable outwash), and moisture content. The congeliturbate is loose, pulverent, somewhat coherent in a dry state, and is composed of finer grade sizes mixed with coarser sand and a great variety of pebbles, cobbles, and boulders. Ventifacts are numerous, especially of granitic and porphyritic volcanic rock types.

Size descriptions of the congeliturbate, and the statistical measures derived from them are given in figure 35, and in the following table:

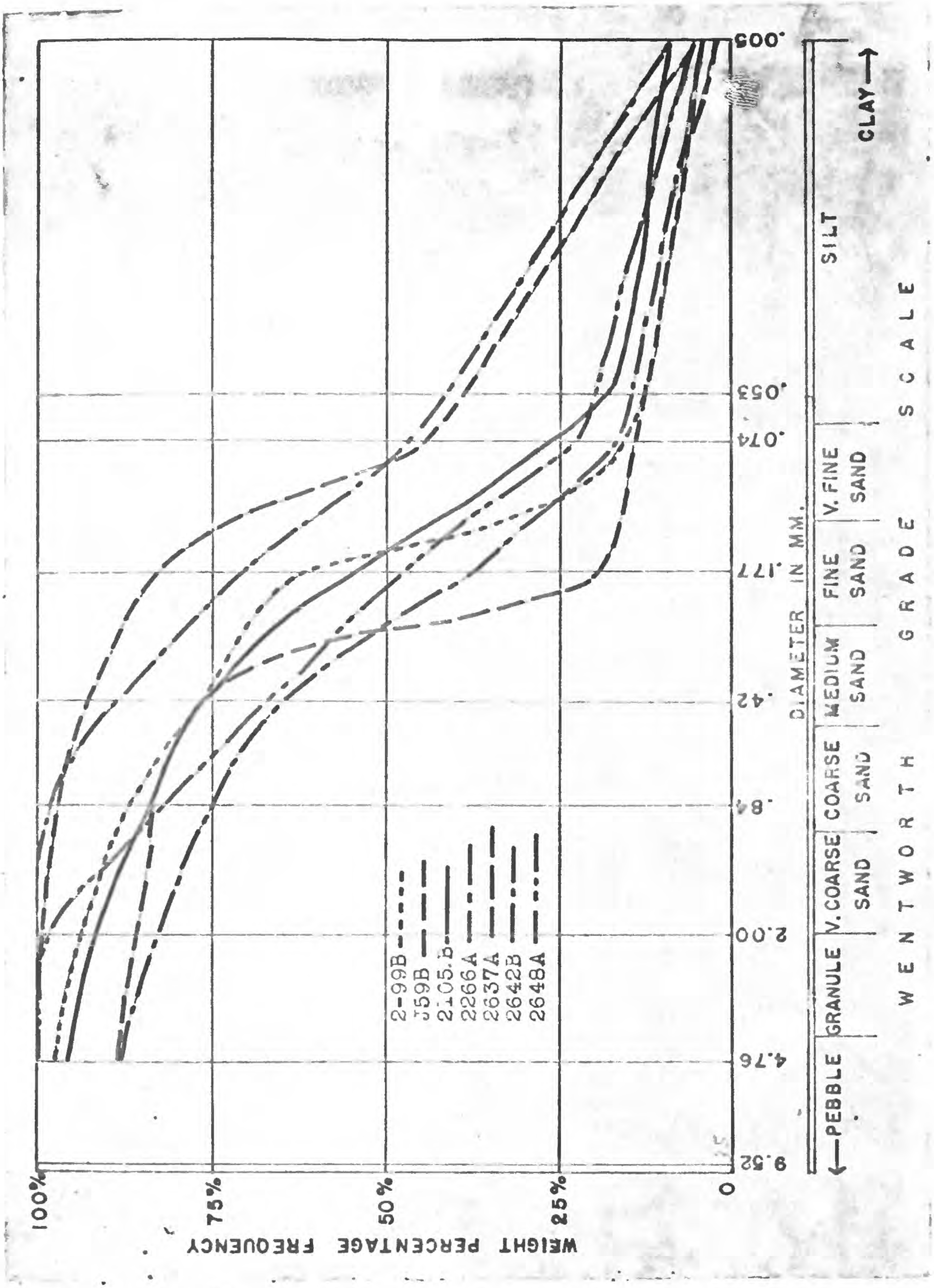


Figure 35. Cumulative curves of congeliturbate.

Table 11. Congeliturbate

Sample	Median (in mm.)	Q1 (in mm.)	Q3 (in mm.)	Sorting (So)	$log_{10}So$
2-99B	0.150	0.370	0.105	1.876	0.274
2105B	.150	.380	.070	2.332	.367
2166A	.250	.840	.105	2.828	.452
J53B	.265	.355	.215	1.3[illegible]	.127
2637A	.088	.145	.019	2.76	.441
2642B	.095	.220	.0155	3.77	.576
2648A	.190	.620	.080	8.81	.945

The samples are not necessarily typical of congeliturbates in the Taunton quadrangle, for the grain size distribution and the sorting of the material can vary tremendously according to the original depth of the wind blown material and to the nature of the material underlying it. For example, in areas where the congeliturbate is about 3 feet or more thick, the underlying deposit generally appears to have been involved only in a very small way; only a few stones are heaved into the upper layer of wind-blown sand. When, however, the mantle is a few inches to about 2 feet thick, the underlying material is thoroughly mixed with the eolian layer and modifies it considerably.

The stones in the congeliturbate differ in rock type in response to the glacial deposits beneath the congeliturbate or a short distance upslope. Where a thin eolian mantle covers a till, the congeliturbate itself has many of the characteristics of the till below and contains mostly angular to subangular stones, generally of the Rhode Island formation. In addition, the congeliturbate over the till will have relatively few ventifacts that can be identified as such, due to a preponderance of unfavorable rock types, and delineating the congeliturbate is difficult.

On the other hand, where a thin layer of eolian material overlies a sandy to gravelly outwash area, the congeliturbate contains rounded, subrounded, or perhaps even some subangular pebbles, cobbles, and boulders. These stones contain a greater percentage of rock types which have come from north of the Narragansett Basin. The rocks in outwash generally have come from greater distances than the rocks in the till, and this fact can be ascertained by comparing the rock types in the outwash* with the rock

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*Some pebbles found in the outwash have come from near Hingham or Mattapan. These are peculiar purple to cherry red felsite breccias which are indicators for the Hyde Park boulder train (Flint 1947, p. 120).

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types in the till. Some of the stones above the outwash are angular, but this is due to late-glacial or postglacial frost action, which in places is known to precede the period of wind-cutting, for the frost riven faces of the stones themselves are wind-cut. The depth of the disturbed zone or congeliturbate is easily determined to be at least the depth to which the ventifacts are found.

The congeliturbates shown in Figure 35 have been gathered from different areas and are derived from different source beds. Samples 2-99B, 2105B, 2637A, and 2642B were taken from congeliturbate overlying till. Sample 2648A came from above a coarse outwash; sample J595 came from above lake beds; sample 2266A came from above fine outwash. Sample 2105B and sample J598 will be discussed in conjunction with a section of till-congeliturbate-eolian sand.

A congeliturbate overlying coarse to very coarse sand is illustrated by sample 2648A, from King Street, just west of the Locust Street hill. The congeliturbate here is about 26 inches thick and lies above a very sharp textural break. The poor sorting (So=[illegible].61) is the result of mixing fine sand from wind blown sources with very coarse sand from the fluvial deposit.

Sample 2-99B came from a section of congeliturbate overlying till in the North-central till area, and the good sorting (So=1.876) reflects the dominance of eolian material in the section.

In a small pit, about two-tenths of a mile south of the intersection of Pleasant Street and Locust Street, a silty to fine sandy yellow brown to yellow tan congeliturbate (sample 2642B) had ventifacts sparingly scattered through it. It overlay a muddy brown, hard, compact till and was thick enough to hide many boulders on the surface of the till.

On a terrace of till just northwest of the last outcrop, a congeliturbate (2637A) contains numerous pebbles, cobbles, and boulders dragged up from a grey to blue compact till beneath. The larger cobbles and boulders (a few of which are ventifacts) have moved during and possibly since wind action, for they are resting on congeliturbate and are completely separated from the till.

Sample 2966A, from Lothrop Street east of Lake Sabbatia, was taken from an area underlain by a clean, well-sorted medium sand, with a few pebbles and cobbles in it. In the field the congeliturbate looked somewhat like a leached and disturbed till, but it contained numerous pebble and cobble size ventifacts and did not grade downward into till. The sorting coefficient, [illegible], falls within the range called "normally sorted" by Trask (1932). This sample does not have "normal" sorting, for the fluvial sands first sorted by the glacial streams were churned into eolian sand that had been sorted by the wind, producing a polygenetic mixture.

Perhaps the best section, one in which there was sufficient material above the till to allow separation of till from the eolian material, was observed in a hole dug by hand on the northwestern slope of a hill in Raynham about eight-tenths of a mile north of the intersection of Bridge Street and Prospect Hill Street. Here, at sample locality 2105, the yellowish gray (5Y 7/2) till at the bottom of the hole had a sandy to silty matrix and many stones and was easy to break into clumps when dry. A sample taken above the till appeared to be a typical congeliturbate, a mixture of the eolian material and the till, from about 23 inches below the surface of the ground. The material was grayish orange (10YR 7/4), and consisted of a mixture of coarse to very fine sand with some silt and clay. Only one ventifact was found in the material which represents the eolian fraction of the soil and came from a depth of 12 inches below the surface of the ground. It was a light reddish-brown sand that seemed to consist mostly of fine to medium sand.

Figure 36 illustrates the transition from the coarser, poorly sorted till at the bottom of the hole, through an intermediate stage of sorting and slightly smaller grain size, up to the well sorted eolian material which had been but slightly mixed with the material from below. The eolian material is twice as well sorted as the till (Table 12).

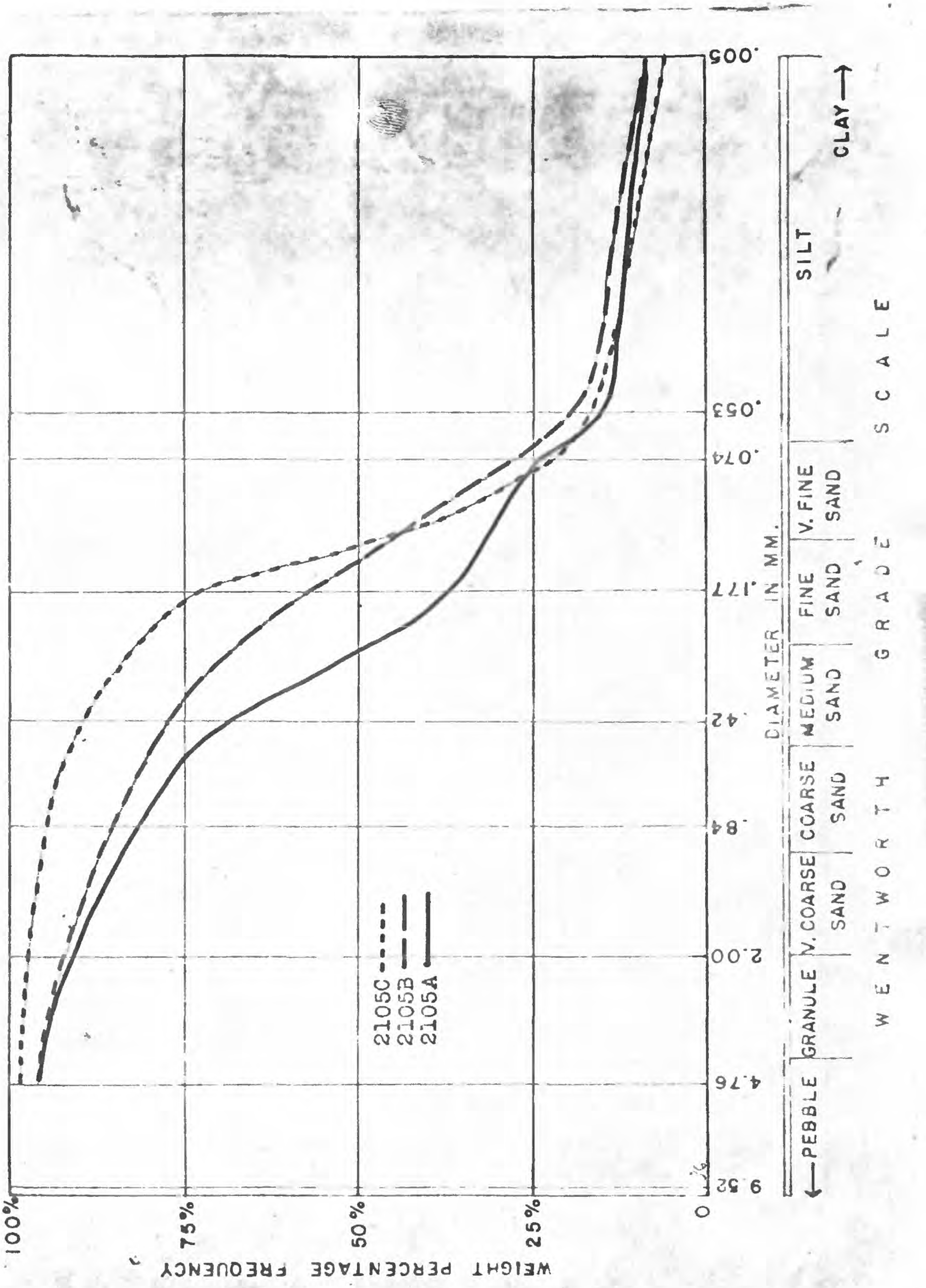

Figure 36. Cumulative curves illustrating transition from till to eolian sand.

Table 12. Transition from till to eolian sand

Sample	Median (in mm.)	Q_1 (in mm.)	Q_3 (in mm.)	Sorting (So)	$\log_{10}So$
2105C	.130	.192	.080	1.55	.190
2105B	.150	.380	.070	2.33	.367
2105A	.265	.560	.077	2.70	.431

A geologic section that introduces a new concept into the problem of the origin of congeliturbate is found on the easternmost edge of the Taunton quadrangle, just south of an ice channel filling at Beach Street. A scarp separates the material of the kame terrace, sand and gravel, from the finer sand, silt, and clay of the lake bottom, and the evidence seems to show that sand and gravel from the kame terrace has moved downslope and out onto the lake plain.

East of the woods road, very near the boundary of the quadrangle, a section in a small sand pit reveals the following section:

- 9" dark soil; bottom moderately sharp.
- 16" yellow-brown to chestnut congeliturbate with numerous ventifacts, fades to a lighter color near the bottom and grades downward into a mixture of eolian material plus underlying material. Sample J59C is from 15-17 inches below the surface; sample J59B is from 26 inches below the surface.
- 18" undisturbed yellow gray, medium sand, appears to be lacustrine; sample J59A was taken from 39 inches below the surface of the ground.

The maximum depth of the ventifacts is taken as the bottom of the congeliturbate. Sample J69C is from the eolian sand. Sample J59B is taken from the bottom of the gradational zone and consists mostly of sand, with few granules; it also contains numerous pebbles, mostly about 2 inches or smaller, including ventifacts of Dedham granite and smaller ventifacts of Salem gabbrodiorite. The larger pebbles and small cobbles seem to be concentrated about 26 to 28 inches below the surface of the ground, near the bottom of the congeliturbate, where they form a pavement on yellow gray sands below. Many of these pebbles and cobbles are wind-cut; some of the fragments are split, and one angular slab of sandstone was found. The congeliturbate is in large measure derived from outwash, for it is composed of sediments and igneous rocks from north of the Basin instead of the various phases of the Rhode Island formation.

Table 13. Transition from lake beds to eolian sand

Sample	Median (in mm.)	Q_1 (in mm.)	Q_3 (in mm.)	Sorting (So)	$\log_{10}$ So
J59C	.245	.300	.185	1.29	.111
J59B	.265	.385	.215	1.34	.127
J59A	.275	.310	.245	1.13	.053

It seems obvious from the cumulative curve (Figure 37 and Table 13), from the field inspection, and from the above description that the lacustrine sands (J59A) below the congeliturbate (J59B) are incapable of furnishing the coarser sand, pebbles and cobbles that are found in the upper layers. A nearby source, upslope, was therefore

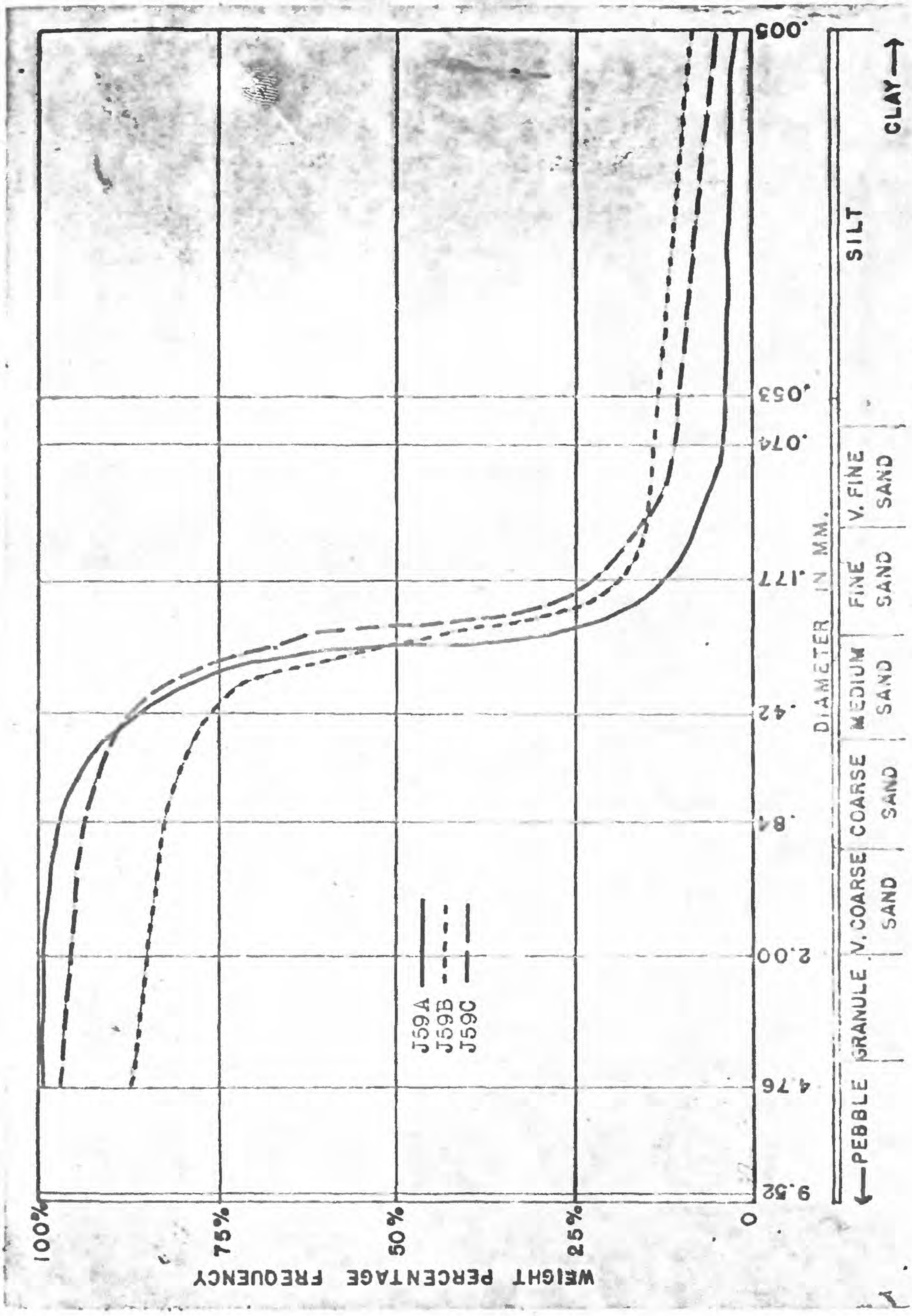

Figure 37. Cumulative curves illustrating transition from lake beds to eolian sand.

sought for the stones. A hole dug to the west of the road showed a stony soil and congeliturbate underlain by fluvial sands and gravels. These materials may have been washed from the kame terrace by the lake before the eolian sands were deposited or may be the outer edges of the kame terrace itself. The sand and gravel from this area or from the kame terrace would account for the pebbles and cobbles in section J59.

Sections like J59 are puzzling, for the only manner by which the stones could have arrived at their present position is soil movement. Yet a stony gravel is not easily moved by solifluction; a clayey soil is more generally thought of as being susceptible to this process. Although there is very little sign of movement of the more clayey till off the hills onto surrounding lowlands, there is ample evidence of movement of gravel off kames and similar features.

Information from the Brockton and Bridgewater quadrangles also shows that pebbles, cobbles, and boulders migrated from stony and bouldery kames or other coarse, high outwash features and moved for some distance down very low slopes onto sand plains. Just north of the Hockomock Swamp in the Brockton quadrangle, a kame about 20 feet high is composed of sands and gravels, has numerous ventifacts in a congeliturbate on top, and is surrounded by clean sands, mapped by Chute (1950) as lake sands. A series of holes, dug at intervals from the base of the kame westward, shows the following:

Hole No. 1, 55 feet west of base of kame: the upper 24 inches is red-brown to brown, very stony, contains numerous ventifacts of Dedham granite and volcanics; at -13 inches a 5 inch Dedham ventifact was found with the cut side down; at -24 inches a more olive, less oxidized zone of tighter material begins, with very few pebbles and no cobbles.

Hole No. 2, 105 feet west of the base of the kame: numerous ventifacts, especially of Dedham granite, found to -20 inches in a typical congeliturbate; stones are very numerous and are extremely common above -22 to -24 inches and include broken wind-cut river cobbles of all types. Below -22 to -24 inches is found a medium sand which grades downward to coarse sand; silt is found 30 inches below the surface; no obvious source exists from which to derive the ventifacts and stones in place.

Hole No. 3, 158 feet west of base of kame: A 30 inch hole shows only a few weathered pebbles, none more than 5 inches beneath the surface; the rest of the material is a moderately poorly sorted medium, coarse, and fine sand with a very few small pebbles ($\frac{1}{2}$" or less), mostly of Dedham granite, but not wind-cut.

These observations seem to indicate that pebbles and cobbles, with perhaps some admixture of sands and silts, moved from the gravel kame under the influence of some process not in action at the present time. The slope of the land at the base of the kame is too low to allow mass movement of materials under the present climate, but movement may have taken place under conditions of intense frost action.

Till, on the other hand, has not been moved by solifluction. For instance, a hole dug on the flat just below a till slope south of Forest Street, about 900 feet west of the intersection with Leonard Street, shows no till over a section of well-sorted medium sand of lacustrine origin.

Another reason to believe there has been very little solifluction off till slopes during the time of intense frost action is that the eolian mantle is very thick on the hills, as at the intersection of Route 44 and Orchard Street in the southeastern section of the quadrangle. This tends to show either that solifluction took place before the eolian mantle was laid down, or else that there was no movement of till. Evidence from outwash areas points to movement of sand and gravel downslope and into the eolian material concurrently with wind cutting and with burial of ventifacts by eolian material.

It seems then that congeliturbate is a mixture of wind-borne sands and silts, of the underlying material, and of the material from somewhere upslope. Congeliturbate is the latest evidence of glacial action within the quadrangle and is a feature of concern in the establishment of the late-glacial history, for it should give some clue to the nature of the late-glacial climate in the area.

Perhaps the best evidence that congeliturbation belongs to the Pleistocene climate, and not to the modern climate, is the presence of ventifacts in the frost heaved material. The ventifacts are cut on all sides, and in many places form a crude pavement at or near the base of the eolian material. The fact that the ventifacts are cut on many sides and then buried beneath the eolian debris indicates that intense frost heaving was going on at the time that they were cut. The activity was limited to the upper layers of the soil, for, as we have seen, the ability of frost action to pull debris up from the subsurface into the congeliturbate is limited where the eolian layer is too deep. Hence the frost action, though intense by modern standards, was confined to a relatively shallow upper layer in the soil. Congeliturbate, and the ventifacts contained in it, are found to a depth of at least 5 feet, which may be taken as an indication of the depth of frost action in late-glacial times.

At the present time, the climate of the Taunton area is mild, and modern frost action is limited.

Some dissenters might point out that tree throw, the churning and consequent movement of the upper soils by uprooting of trees, is a potent factor and may have produced much of the disturbance that we see today. But the rebuttal is very strong--the ventifacts were cut during the period of wind deposition, and the area must have been nearly barren to allow the wind to cut ventifacts everywhere within the quadrangle; hence no trees were present at the time of ventifact cutting and contemporaneous congeliturbation. Some of the rounded stream cobbles and pebbles even have frost-riven surfaces that were cut by the eolian sand of late-glacial time.

Late-glacial history

The last major stand of the ice in southeastern New England is recorded in the Buzzards Bay moraine, the Sandwich moraine, and perhaps the Ellisville moraine (Mather, Goldthwait, and Thiesmeyer, 1942); thereafter the evidence for halts or slight readvances is less clear. One exception is the Fresh Pond moraine in Cambridge.

The manner of retreat of the last ice sheet is still a matter of controversy. One group advocates "normal retreat", in which a steeply sloping solid ice front melted northward faster than the ice could replenish the losses (Lougee 1951, p. 260). However, studies of modern glaciers (Ahlmann, 1935) show that the idea of retreat by melting back of the ice front alone is an anachronism. Ablation on modern glaciers results in thinning of the ice tongue or marginal wedge; the front begins to melt back rapidly only after thinning removes the bulk of the ice. Downwastage, then, is a valid concept, and Massachusetts has topography eminently suited to produce ice thinning and stagnation. The withdrawal of the glacier in this area was effected by stagnation zone retreat (Currier, 1941; Jahns, 1941) in which the ice in a marginal zone, about 3-10 miles wide, ceased to move and was separated from the active ice mass by hilly topography, excess thinning, and burial by glacial sediments. The ice sheet continued to move forward behind this outer zone, and as successive outer zones progressively stagnated and became covered with debris, a tremendous complex of ice-contact deposits was formed. The stagnant zone, measured by stream sequences in the Ayer quadrangle (Jahns 1953), may have averaged about 3 miles in width.

The earliest glaciofluvial features in the quadrangle must be the highest kames, such as Prospect Hill, and the terraces high on the sides of till hills. In the Taunton quadrangle, with no well defined valleys in which to confine the stream flow, the numerous outwash features bear no recognizable relation to one another, and the basis for correlation of most features is very tenuous.

The chronologic diagram of glaciofluvial and glaciolacustrine deposits (Explanation, Plate I) presents a tentative correlation of features within the Taunton quadrangle. The deposits are divided into three major groups, separated by horizontal dashed lines on the diagram and, for general correlation only, subscript numerals are added to the symbols. Thus, a kame terrace on the map will be approximately dated as having formed early or late in the history of the area. It is obvious, however, that the formation of outwash deposits goes on continuously during the downmelting of an ice sheet.

The kame delta in the center of the quadrangle, as well as the lake beds associated with it, is the datum for the glacial chronology. The outwash plain, which starts at Gushee Pond and has a smooth gradient southward, covers the lake beds and is definitely younger than the delta and the lake sediments. Kettle holes on the lake bottom show that some ice blocks lasted during the entire period that the lake was in existence. Varved clay at the Taunton brick pits show that the lake lasted more than 100 years, and the delta probably lasted for the same length of time. The lacustrine sediments appear to be contemporaneous with other lacustrine sands and clays in the Bridgewater quadrangle, and are connected with them through a narrow north-south strait, parallel to the border of the quadrangle. If the lacustrine sediments near Raynham Center are contemporaneous with those to the east of Locust Street hill (no evidence to the contrary has been found), then the relative age of the outwash between Gushee Pond and Scotland can be deduced.

A series of outwash forms, the highest of which is the undifferentiated outwash east of Gushee Pond, appear to end in ice-contact slopes to the south. The highest form (ou) ends in a scarp near Bassett Brook to the southeast; the next lower form, a kame terrace (kt), ends in a scarp to the east and southeast, and north of the kame terrace an outwash plain (ow) also ends in a scarp; all three scarps overlook the lake bottom to the east and southeast. It seems, therefore, that these three outwash forms are all older than the lake and that they must have been built out against ice masses in the lake basin. These units, apparently older than the lake, have an anomalous position with respect to the Gushee Pond outwash plain, for it is definitely younger than the lake. Both the northeastern outwash plain and the Gushee Pond outwash plain head at approximately the same elevation and at first glance appear to be contemporaneous. But if the lake deposits from the kame delta into the Bridgewater area are of the same age, the northeastern outwash plain and the Gushee Pond outwash plain must of necessity be of different ages.

The author's experience on modern glaciers shows that outwash plains that start near each other need not necessarily be related, because the streams which form these plains may arise on or flow out of the ice at any altitude. Some of the streams which built the Taunton outwash features may have emerged from tunnels within the glacier; their altitude would not necessarily be the same as that of nearby streams that flowed in valleys upon the surface of the glacier and that would flow off the glacier at a different altitude. Therefore, in the absence of some direct connection between these outwash features, the lake sediments are used as a datum.

Another series of problems arises with the outwash (k,kp) near Prattville and in the city of Taunton (ow). The body of outwash upon which Taunton is built is apparently related to a kame terrace built around the base of Prospect Hill. It grades southward to the Taunton Common, where the outwash is intermingled with outwash (ou) from sources to the northwest. The Taunton outwash plain has the same altitude at its source as the kame delta to the east, but they cannot be related to each other, for the outwash plain has an east facing scarp that is not deltaic in origin. Proof of this is found in a gravel pit that extends to the base of the outwash plain and does not show any deltaic bedding; another fact is that the contours of the plain do not slope eastward toward the frontal slopes as they would if it were a delta. It seems, then, that an ice block held up the eastern edge of this plain, just as ice held up the eastern slopes of the outwash forms to the northeast. The ice mass which lay in the area now occupied by Pine Swamp must have been in existence from this early date, through the entire life of the lake and the building of the kame delta. It apparently lasted throughout the building of the Cushee Pond outwash plain, for the sand and gravel in the Prattville outwash grades eastward and around the northern end of the delta, where it joins the outwash from the north that covers the lake beds.

An alternative explanation for the origin of the various outwash plains may be devised. When the Taunton outwash plain was being formed, a mass of ice lay in the valley to the east, perhaps extending along the Taunton River valley to the eastern boundary of the Bridgewater quandrangle. This ice block melted first from the area in Taunton and Raynham, creating a depression in which a lake was 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, for reasons which are not apparent today, the meltwater which was discharging from the ice into this drainage area flowed over the lake bottom plains from the area around Prattville, Dead Swamp, and Titicut Swamp.

In the meantime, before the ice masses disappeared from the valley of the Taunton River on the eastern margin of the quadrangle, the undifferentiated outwash along Pine Street hill and the kame terrace to the east of it were formed. The outwash plain in the vicinity of Scotland was built at the time of formation of the Gushee Pond plain, while ice still occupied the Titicut Swamp area and the area around North Middleboro and eastward in the Bridgewater quadrangle. The meltwater flowed off over the ice to some unknown outlet just as it had when the two earlier outwash bodies were formed. The lake basin could only have come into existence later, when the series of deltas and lacustrine deposits which cover much of the central part of the Bridgewater quadrangle were deposited. A major problem is how this lake was maintained at levels approximating 75 feet or so above sea level, when the area around Taunton had drained and had outwash covering the lake deposits at altitudes down to 20 feet above sea level. A possibility exists that ice remnants lingered in the narrow part of the valley between Route 44 and Beach Street. However, this hypothesis seems generally much less probable than the explanation presented earlier. Additional information might easily change the picture as it is presented here.

Prospect Hill must have been one of the earliest outwash features in the area and apparently was formed by streams which poured into a hole in the ice and deposited their load. The kame is not deltaic, although in part the deposits are lacustrine. The relief of this kame, at least 150 feet, is a minimum indication of the height at which superglacial streams carried debris above the base of the glacier, and is also an indication of the minimum thickness of the ice in this area when outwash deposition was being carried on superglacially.

One of the last episodes in the sedimentary history of the quadrangle was the formation of a lake whose deposits cover some of the lowland of the northern part of the area. All the area covered by the Hockomock Swamp is not floored by lake deposits, however, for borings show that in places the bottom is till, and in other places coarse sand and gravel.

Deposition of the eolian mantle and the concurrent intense frost action which mixed the wind deposits with the underlying glacial materials were the last events in the late-glacial history. The mantle of wind-borne sand and silt and the ubiquitous occurrence of ventifacts imply the absence of vegetation in sufficient quantity to restrict eolian activity. The large areas of sand plain, lake bottom, and ground moraine must have been sources for the eolian material, and because all of the quadrangle is covered by an eolian mantle, the source of material must have kept shifting to the north and northwest as new outwash features were formed and new areas of ground moraine laid bare by the disappearance of the ice. The original sources of wind blown sand and dust were in turn covered by wind deposits.

POSTGLACIAL HISTORY

Vegetation must have appeared shortly after the disappearance of the ice from southeastern Massachusetts. At present no one knows when vegetation followed the retreating glacier, but there must have been a lag during which the eolian mantle and its crop of ventifacts were produced. When the first vegetation did appear it was probably in the form of tundra and bog vegetation.

(Deevey, 1951). In low boggy areas, or where lakes still occupied depressions in the surface, the swampy vegetation began to push in and fill the lakes and level off the low areas. In places, aerial photographs show that the final filling of some lakes took place such a short time ago that the form of the lake is still visible. In other cases, such as at Gushee Pond, vegetation is still growing in from the edges of the pond.

The Taunton River and the numerous smaller streams of the quadrangle came into being on the glacial deposits as streams which were either glacial or non-glacial in origin. For instance, the valley of Forge River is cut into the Gushee Pond outwash plain and underlying lake beds as a wide, flat bottomed valley which seems too large for the stream occupying it today. Forge River may have started as a glacial stream originating in the Titicut Swamp area from a lake held in on the south by the outwash gravels. The water escaping through the lake outlet would be relatively clear and not carrying the heavy load characteristic of glacial streams. Such a stream would be able to carve a large channel to accomodate the glacial flow, and when the glacial lake disappeared, or when the ice left the area, the stream would diminish in volume and occupy a smaller channel on the floor of the glacial valley.

A similar glacial origin is postulated for Dam Lot

Brook, which is also an underfit stream. In this case however, the stream originates at some distance south of Titicut Swamp, and its source was probably copious ground water flow through the sands and gravels from the glacial lake on the north.

The Taunton River flows through the area on the sands and silts of the old glacial lake floor. It is superimposed on bedrock at one point. Stream erosion has carved out a large meandering valley, leaving extensive lowland flats veneered with gravel, sand, silt, and clay (alluvium). At many places it is impossible to differentiate glacial material from modern alluvial material.

A sample of alluvial sand was taken from the inside of a meander on the Taunton River. The sample was taken from 30 inches below the surface, and consisted of a clean, well-sorted (So=1.55) fine sand (median .129 mm.), with subordinate very fine sand. It was a light brown color all the way to the base, was slightly coherent, and contained no organic matter.

Terraces on all the small creeks, and on the Taunton River itself, bear no relation to the size of the stream or to similar terraces on neighboring streams. The terrace tops are the original glacial landscape, and in cases where this was a flat plain the terraces have flat surfaces. If the glacial plains have varying elevations, then the height of the terrace above the stream also varies.

Downcutting of the streams may have taken place during a period of lower sea level. Although the land was depressed by the weight of the ice, there probably was not much depression near the margin of the ice sheet. When sea level began to rise again and reach into the upper part of Narragansett Bay the base level of the Taunton River and all its tributaries rose too. The meanders probably started when the stream gradient decreased and aggradation began.

ECONOMIC FEATURES

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

Sand and gravel

The sources of sand and gravel are shown on the geologic map as various forms of outwash deposits, such as ice-channel fillings, kames and kame fields, kame terraces, kame plains, outwash, and undifferentiated outwash. Each one of these deposits has characteristics which enable geologists to predict, in general, the occurrence of gravels, sands, or finer materials.

Ice-channel fillings are generally good sources of coarse sand and gravel. Pebble gravel with sand is common, and boulders are not at all unusual. In places till may appear either as a coating or a lens within the ice-channel filling. Many of the ice-channel fillings in the quadrangle have been or are being exploited as a source of gravel.

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

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

The two kame deltas in the quadrangle are similar to other glacial deltas, and once the feature has been identified, it is easy to predict the material. Generally, the deltas consist of 5 feet to 15 feet of medium cobble gravels to very coarse sandy topset beds that are underlain by finer beds of sand and gravel. Many of the kames and kame plains come under this general classification because they were formed as deltas, but now have collapsed surfaces, and in the case of kame plains show evidence that they were not built out into open water, but into holes in the ice.

Clay

Varved clay and laminated sand and silt have been worked for brick clay in several parts of the area. The Stiles and Hart pit just north of Weir Village, is in varved clay overlain by about 3 to 8 feet of sand and gravel (Figure 38). Another clay pit, in which the material is mostly laminated silt and clay, is located north of Middleboro Road along the Taunton River. Clay suitable for brickmaking is present in many of the lacustrine areas in the southern part of the quadrangle but is not generally utilized.

Figure 38. Cross-bedded sand and fine gravel over varved clay, Stiles and Hart brick pit, Weir Village.

SUMMARY

About 20% of the Taunton quadrangle is covered by ground moraine. The till that comprises the ground moraine is best studied by a combination of field and laboratory work. Field study consisted of mapping the distribution of the till and recording its color, texture, and other physical properties. Laboratory studies consisted mainly of mechanical analyses of till samples, plotting of cumulative curves, and calculation of statistical measures derived from the curves. The quantitative data indicate that the Taunton till has a wide range in texture; sorting ranges from 2.24 to 7.66, and the median grain size ranges from 0.070 to 0.680 mm. In general the till samples are moderately well-sorted, with half of the samples plotted falling between So 3.0 and So 4.0. No till resembling the "old" till of the Boston area is found in the Taunton quadrangle. The color of the till is generally gray to yellowish gray, with pale yellowish brown and light bluish gray to most common colors.

Observation of processes on a modern glacier gives some clues to the formation of till from debris carried in the ice. Till on the surface of an ice sheet frequently changes position during the summer months, because melting of the ice produces large quantities of meltwater. Melting releases the fragments of rock flour and stones from the ice and washes them downhill, where they are mixed

with other debris and perhaps with fluvial or lacustrine material. Thus the character of the till changes during a number of cycles of washing on the surface of the glacier. The superglacial till finally produced may be either clayey or sandy in texture and may appear to be either "subglacial" or "superglacial" according to criteria used by other geologists.

It is impossible to prove whether the ground moraine of the Taunton quadrangle is either superglacial or subglacial, but in view of the map pattern and characteristics of the till, it seems that most of the ground moraine is probably subglacial. The sandstone of the Rhode Island formation, from which the till is derived, accounts for the sandy texture and lack of compaction in the ground moraine.

Flowtill is a coined word used here for the first time. Till masses found in anomalous stratigraphic positions near the borders of outwash features, shown on other evidence to be of ice-contact origin, such as kames, ice-channel fillings, kame terraces, and kame plains, are flat-lying, lens shaped bodies of greatly varying thickness with a general maximum size of about 100 to 200 yards diameter. The till overlies sand and gravel that is obviously streamlaid and generally undisturbed; the till may be either on top of the outwash or interbedded with it. These tills, however, differ in no way in physical description, color, or grain size from the till mapped as ground moraine. It is obvious from the stratigraphic position that the till must be different from the till of the ground moraine. The till masses are thought to originate on the surface of the glacier as water soaked till that flows down ice slopes and onto the neighboring fluvial flats for several hundred yards, where the mudflow comes to rest and dries out; this is flowtill.

Till of superglacial origin, the flowtill, and till of subglacial origin, the ground moraine, show essentially the same characteristics as the "new" till of previous workers. The conclusion is that the Taunton tills may have similar characteristics and different origins, or different characteristics and a similar origin.

Numerous outwash deposits in the area show evidence of having been laid down in contact with ice. The general arrangement of the outwash features suggests stagnation of blocks of ice in various low areas in the topography and the formation of outwash features, including lake beds, around and over ice.

Information from the Malaspina Glacier suggests a method by which kame plains or similar features may be formed. The formation of superglacial outwash plains surrounded by sloping ice walls is commonplace, and it is probable that a similar situation may have arisen many times in Massachusetts. When the ice walls melt away, the stratified drift features remain standing as isolated outwash masses above the surrounding terrain.

A nearly continuous mantle of eolian sand covers most of the quadrangle to a depth of from 2 to 5 feet. Ventifacts, chiefly of Dedham granite and volcanic rocks, are scattered profusely through the eolian sand. Intense frost action must have gone on when the ventifacts were being formed, because they are cut on all sides and are scattered through the eolian mantle from top to bottom.

The uppermost stratigraphic horizon in the area, the congeliturbate, is a mixture of eolian sand and the underlying stratified or unstratified drift. The eolian sand must have been deposited as a clean well-sorted material, but either during deposition or at some later time was mixed with the underlying glacial material by intense frost action. Although quantitative data show similar characteristics for the till and the congeliturbate, a difference can be seen in the field. Ventifacts churned into the congeliturbate help to identify it.

Study of some sections of congeliturbate over undisturbed glacial lake or fine fluvial deposits reveals that in many sections the congeliturbate contains pebbles, cobbles, and boulders that could not possibly have been derived from the clean well-sorted sands directly beneath them. These sections are invariably found within a few hundred feet of gravelly outwash features standing about

20 feet or more above the surrounding low areas. The only conclusion possible from the present evidence is that the pebbles, cobbles, and boulders have migrated down slopes that are too low to permit mass movement under the present climate, and therefore movement took place during the intense frost climate associated with late-glacial time.

The detailed study of the glacial deposits of the Taunton quadrangle, especially of the congeliturbate, gives a background for a study of the geologic antiquity of the Titicut site.

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