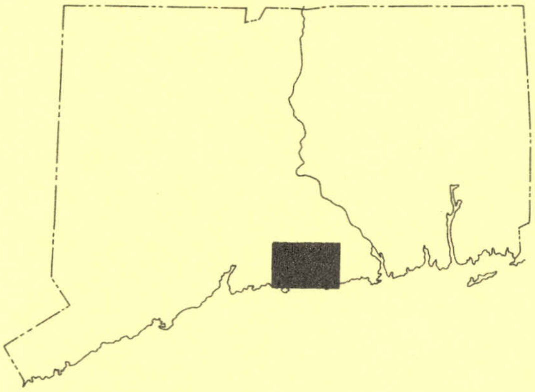
The Surficial Geology of the Guilford and Clinton Quadrangles

WITH MAP

Open Plate 1 Open Plate 2

Open Figure 4

BY RICHARD FOSTER FLINT



STATE GEOLOGICAL AND NATURAL HISTORY SURVEY
OF CONNECTICUT

A DIVISION OF THE DEPARTMENT OF AGRICULTURE
AND NATURAL RESOURCES

1971

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BY RICHARD FOSTER FLINT
Yale University

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The Surficial Geology of the Guilford and Clinton Quadrangles

by

Richard Foster Flint

ABSTRACT

The Guilford and Clinton quadrangles lie in the southwestern part of the Eastern Highland of Connecticut, and include a part of Long Island Sound. Features made by glacial erosion include striations, grooves, stoss-and-lee knobs, and streamline hills. Till covers much of the area, although over many hills and ridges it is thin or absent. The glacial features are believed to have resulted from the passage of a thick ice sheet southeastward across the area. During deglaciation, end moraines were built along the margin of the ice sheet in the coastal belt and, farther north, stratified drift was deposited in the form of valley trains in the principal valleys. The character and distribution of the stratified drift indicate that early in the latest deglaciation the ice sheet maintained an irregular front across the southern part of the map area, but that thereafter the ice melted downward to form irregular residual masses along major valleys.

While valley trains were being built up, wind removed material from them and deposited it as a thin covering of sand and silt over adjacent areas. The valley trains were dissected in postglacial time by streams, which deposited thin bands of alluvium on valley floors. Swamp and marsh deposits have accumulated in many shallow basins in bedrock and glacial drift. Most of the marshes along the shore are tidal marshes, a result of the postglacial rise of sea level against the land.

Substances of actual or potential economic value include ground water, sand and gravel, till, and humus. In places the terrain has been conspicuously altered by artificial filling.

INTRODUCTION

The area represented by the Guilford quadrangle and the Clinton quadrangle (fig. 1) lies along the coast of Connecticut and falls almost entirely within the Eastern Highland region (fig. 2); the northwestern

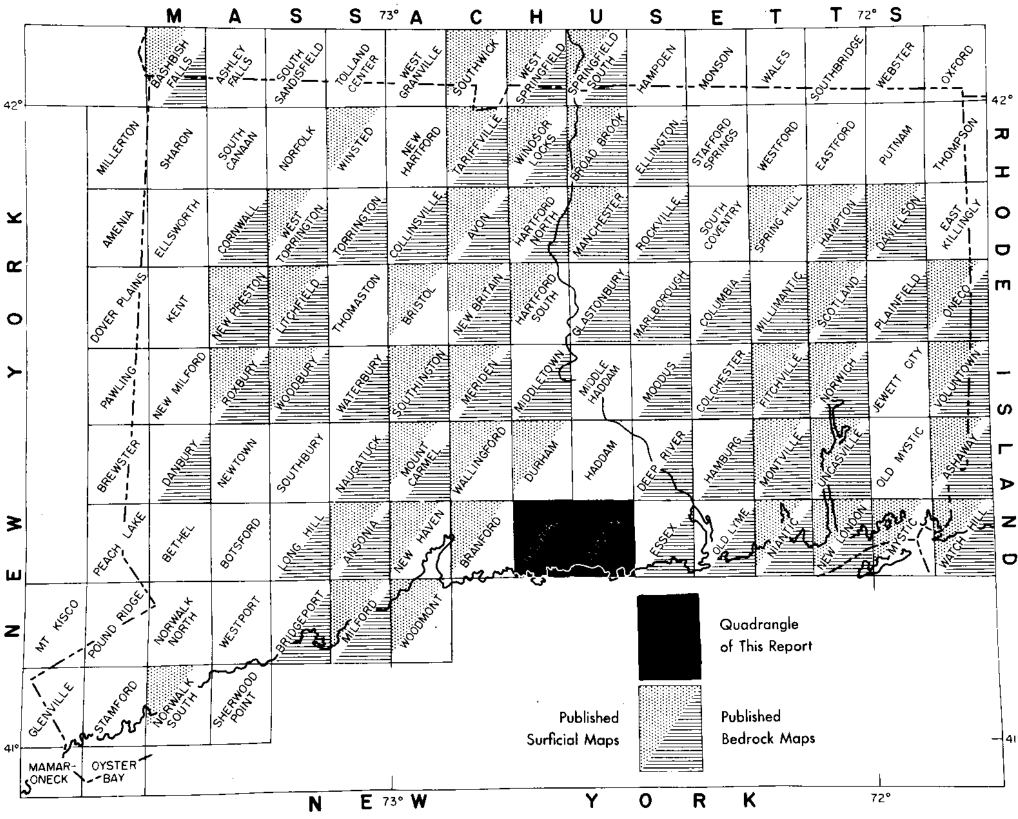

Fig. 1. Index map of Connecticut showing locations of the Guilford and Clinton quadrangles and of other published quadrangle maps.

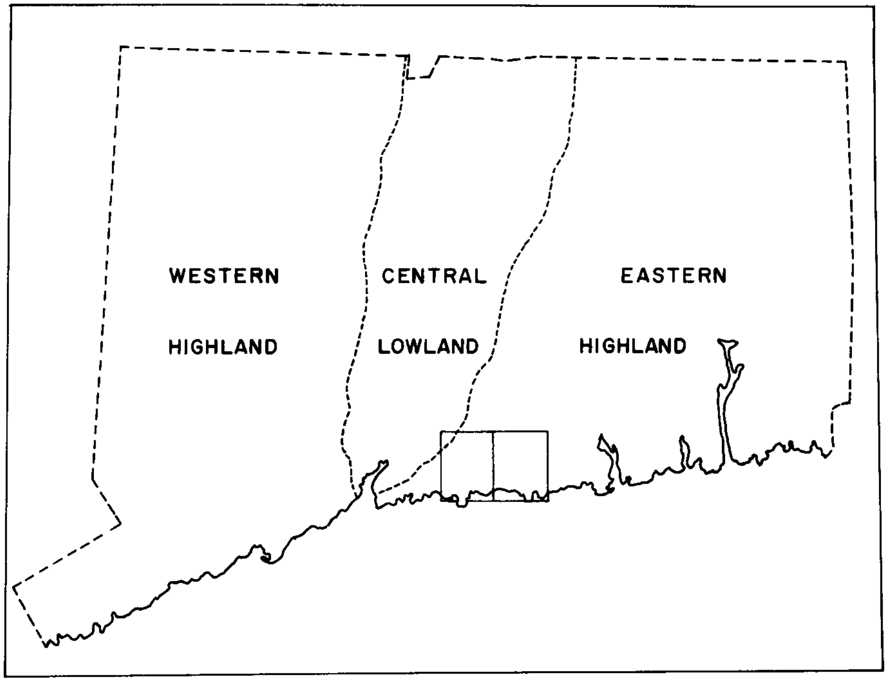

Fig. 2. Map of Connecticut showing boundaries of its three natural regions and locations of the Guilford (left) and Clinton (right) quadrangles.

corner of the Guilford quadrangle extends into the Central Lowland region. The total area of the two quadrangles is about 110 sq. mi., of which nearly 10 percent lies beneath the waters of Long Island Sound. The quadrangles include parts of New Haven and Middlesex counties; the boundary between these counties is the Hammonasset River. Within the quadrangles are parts of the towns of Branford, North Branford, Guilford, Madison, Clinton, Killingworth, Deep River, and Westbrook. The chief centers of population are Guilford and Clinton.

Mapping of the surficial geology, on the scale of 1:24,000, was done at various times in 1967, 1968, and 1969. Data for the maps were obtained chiefly from observations of natural and artificial exposures, test holes made with hand tools, and analysis of land forms. Subsurface information was obtained mainly from the State Highway Department and the U.S. Geological Survey.

In Connecticut the surficial materials (the unconsolidated sediments that overlie the bedrock) are chiefly of glacial origin; here surficial geology and glacial geology are nearly synonymous. That Southern Connecticut had been overrun by glacier ice was firmly established by J. D. Dana (1870, 1871). General discussion of the glacial features of Connecticut, although without special reference to the Guilford/Clinton area, can be found in publications by Rice and Gregory (1906, p. 227-259) and Flint (1930, 1934). J. S. Brown (1928, pl. 5) published a map that included the area of the Guilford and Clinton quadrangles, on which the distribution of till and stratified drift was shown on the scale of 1:62,500.

BEDROCK GEOLOGY

The bedrock geology of the two quadrangles as part of a considerably larger area was described by Mikami and Digman (1957), who also presented a geologic sketch map on the scale of 1:62,500. Subsequently, Bernold (1962) restudied the area of the Guilford quadrangle and mapped its bedrock geology in greater detail. Briefly, the area is underlain by parts of three domelike massifs, the Killingworth, Branford/Stony Creek, and Clinton domes. The cores of the domes consist of granitic rocks, which are generally coarse grained and commonly foliated. The cores are surrounded and separated by metasedimentary and metamorphic rocks, represented in the Guilford and Clinton quadrangles mainly by the Bolton and Middletown formations, in which schists are a conspicuous constituent.

This region of granitic and metamorphic terrane is cut off abruptly on the west by the Triassic Border Fault, a deep, major structure that trends NE, traversing the northwestern corner of the Guilford quadrangle. West of the fault the rocks are of Triassic age; within the map area these consist of reddish and brownish arkosic sandstone and fanglomerate, and ancient basaltic lava flows, all cut by faults. In addition, a single diabase dike of Triassic age, trending NE through the northwestern part of the Guilford quadrangle, roughly parallels the Border Fault and lies about 0.5 mi. southeast of it. In some places this dike forms a continuous ridge; in others it is not noticeable topographically.

The physical and chemical characteristics of the various kinds of bedrock that underlie the quadrangles and the pattern in which they crop out at the surface influence to some extent the surficial geology of the Guilford/Clinton area. The presence, in the glacial drift, of rock particles having identifiable areas of bedrock origin helps to determine directions of movement of former glacier ice in southern Connecticut.

Because glacial drift is thin over most parts of the area, bedrock is exposed at the surface in many places and is close to the surface rather generally. In areas that are covered nearly continuously with glacial drift, exposures of bedrock are shown individually on the maps (pls. 1, 2). Most such exposures are small. In many hill areas, however, the blanket of drift is so thin and discontinuous that exposures of bedrock are numerous and closely spaced. Such areas are mapped as bedrock and the thin overlying regolith is not shown separately. All bedrock exposures observed during field work were mapped; however, there are others, particularly toward the southern ends of groups of hills.

TOPOGRAPHY

The surface of the area is irregular, rising northward from the shoreline to a maximum altitude of 480 ft at the northern boundary of the Clinton quadrangle, about 1.25 mi. north of Killingworth. Other high areas lie close to the northern boundaries of both quadrangles. Many of the topographic elements in the area are elongated NW-SE, reflecting predominant trends of structures in the bedrock. The individual bedrock units differ somewhat as to erodibility, as judged by the average altitude of each unit within the map area. A mechanical measurement of average altitude of each of the seven units defined by Bernold (1962) in the Guilford quadrangle. followed by statistical comparison, showed (Flint, 1963, p. 688) that the units with greatest altitude are generally rich in quartz and K-feldspar, and in some of them joints are spaced very widely. In contrast, units with relatively low altitude tend to be rich in such minerals as amphiboles, micas, and calcic plagioclase. Evidently, therefore, mineral content affects erodibility.

Locally, there are greater contrasts in topographic expression, and in altitude as well, between adjacent facies of a single unit; these are visible on topographic maps. For example, the belts of mixed rocks mapped by Mikami and Digman (1957, pl. 1) tend to be marked by more irregular topography, more conspicuous linearity of hills, and in places lower altitudes of hills than are the granitic rocks in the central areas of the three domes. This relationship is not entirely consistent, possibly because of other factors, such as spacing of joints, which were not mapped but which probably influence local topography.

Still another influence on local topography is thickness of the mantle of till that overlies most of the upland areas. This is discussed in connection with the description and distribution of till. We note here, however, that uplands having smooth topography generally expose till in roadcuts and other artificial excavations, whereas those marked by very irregular topography more commonly expose bedrock, in many instances with abundant boulders scattered over the surface. It seems unlikely that this difference results wholly from local differences in thickness of the mantle of till. Probably the difference antedates the till at least in part. Smoother pretill topography is likely to have led to the deposition of an unbroken sheet of till, whereas knobby topography was conducive to the discontinuous deposition of till and to glacial quarrying of boulders from the lee slopes of rock hills, creating numerous boulders. Some of the knobby areas are made up of knobs of pegmatite enclosed in the schist that underlies the low areas between the knobs.

The Guilford/Clinton area forms part of a coastal belt of dissected hilly country that extends across Connecticut (Flint, 1963). Within that belt hilltop altitudes decline southward at an average rate of about 50 ft per mi., and the whole surface passes beneath Long Island Sound. Where intersected by the sea, this surface forms an irregular shoreline, with points and headlands separated by coves. The most conspicuous indentation of the shoreline in this area is Clinton Harbor. This water body consists of the submerged mouths of the Hammonasset and Indian Rivers. The river mouths have been modified by the building of end moraines, beaches, and tidal marshes. Another, lesser indentation is Guilford Harbor, in part the submerged mouth of West River.

These and other, smaller streams enter the sea through areas that are fringed with tidal marshes. The irregular shoreline and the many small islands immediately offshore suggest that this part of the coast has been submerged beneath the sea since the valleys and hills were fashioned by erosion. The suggestion is confirmed by geophysical surveys of the floor of Long Island Sound beneath its mantle of surficial sediments, both terrestrial and marine. The results show a system of valleys that continue the principal valleys of Connecticut beneath the Sound (Grim and others, 1970, p. 661). It is apparent also that the submergence, or at least the most recent submergence, postdates glaciation, for terrestrial sediments, including freshwater-swamp deposits, underlie tidal-marsh peat at positions well below the level of low tide in the valley of the Quinnipiac River in New Haven, about 8 mi. west of the Guilford quadrangle.

Except in the larger valleys and in places along the coast, the cover of glacial drift that overlies the bedrock is generally so thin that it does not conceal bedrock hills. In many places it masks only the small details of relief, and some hills have almost no covering of drift. However, the details of the relation between thickness of drift and topography are little known because the records of borings, on which such knowledge depends, are scanty. It is evident that in comparatively large valleys such as that of the Hammonasset River, relief has been reduced by the partial filling of such valleys with glacial drift. With such exceptions the relief of the Guilford/Clinton area is attributable mainly to the irregular surface of the bedrock, the broader features of which were created well before glaciation occurred.

DRAINAGE

The area of the Guilford and Clinton quadrangles is drained southward, chiefly by six rivers: West, East, Neck, Hammonasset, Indian, and Menunketesuck. All these streams once drained into the broad lowland that is now the floor of Long Island Sound, before the Sound itself came into existence. Before submergence West River joined East River a short distance south of Guilford Harbor, and Indian River flowed into Hammonasset River at some point south of Clinton Harbor.

The drainage has existed in its present general pattern for many millions of years, since long before glaciation of the region, but the controls under which the pattern took shape are not known. When the positions of the larger streams are compared with the pattern of outcrop of the bedrock units, it appears that some stream segments follow belts of weak rock or are parallel with foliation or other bedrock structures. Nevertheless, other segments cut across structures at various angles and therefore must have been localized by factors other than those structures.

Glaciation seems to have altered the pre-existing drainage pattern very little. Apart from local instances, such as Neck River east of Clinton Harbor, which appears to occupy swales along the proximal bases of segments of end moraine, streams seem to be approximately where they were before glaciation. A possible exception is suggested by the relation between Menunketesuck and Indian Rivers. About a mile east of Kelseytown the Menunketesuck turns abruptly northeastward and flows out of the map area, but then bends south again and reaches the sea about 2 mi. east of Clinton Harbor. However, a lowland occupied by Indian River leads directly seaward from the turn near Kelseytown. It is floored with outwash sand and gravel, the surface of which is only 10 to 20 ft higher than the Menunketesuck at the turn. One could speculate that the Menunketesuck formerly flowed southward, but was deflected to a northeasterly course during deposition of the outwash sediment. The northeast-trending segment, however, seems to be an old one because it parallels the strike of foliation in the local bedrock and because it lacks the characteristics of extreme youth. The speculation therefore is not compelling and the possibility of glacial diversion remains unresolved.

The courses of some streams are interrupted in places by swamps and ponds, some of which occupy shallow basins created by the irregular deposition of glacial drift or by the collapse of drift during melting of masses of glacier ice. Examples are seen along Iron Stream and Dowd Hollow in Madison, near Podunk Great Plain in Madison, and along the Menunketesuck River near Bushy Pond in Clinton. The presence of such basins results from the recency of glaciation; the time since that event has been too short to permit the re-establishment of stream flow uninterrupted by basins.

None of the named lakes and ponds within the area is known to occupy a wholly natural basin. All were created or at least deepened by artificial dams. The lakes include water-supply reservoirs, present or former mill ponds, recreational ponds, and basins excavated in pits dug for sand and gravel.

PREGLACIAL WEATHERING

At one locality in the map area was found evidence, at least indirect, of weathering of bedrock that took place before the glaciation described in this report. The locality is a borrow pit 200 ft east of State Highway 69, on the northern side of Hog Pond Brook about 1,100 ft east of Madison Lakes (Clinton quadrangle). The pit, opened in 1968, exposes a thickness of about 11 ft of weathered material through a distance of about 70 ft.

The material is unlike anything else seen in the map area. It consists mainly of till-like sediment, with silt, clay, and sand (in order of estimated decreasing abundance) as a matrix in which pebble- and cobble-size stones are set. Most of the stones are firm, little-weathered, chunky pieces of gneiss, a few are disintegrated gneiss and amphibolite, and a few are rocks of other kinds. In all of these, glaciated shapes are present but rare. The matrix is a soft earthy mass ranging in color from moderate yellowish brown to dusky yellow and olive gray. In much of the mass, structures are not apparent, but in places small, lenticular bodies of silt suggest the activity of trickles of meltwater in the base of a glacier. At the south end of the face, stones are lacking and the earthy mass has the structure of deeply weathered, mixed foliated rock and may represent bedrock in place. No soil profile could be discerned; the matrix material seems about equally decomposed from top to base of the exposure.

Most of the exposed material (but not quite all of the stones) sufficiently resembles the amphibolite of the Monson Formation of Bernold (1962), which underlies this part of the map area, to support the suggestion that the exposure described represents weathered Monson bedrock and locally derived till that includes both amphibolite and gneiss of the same bedrock. It seems possible that the till (if till it is) is of the same age as the till exposed elsewhere in the map area, although the possibility that it is older cannot be excluded on a basis of the facts noted.

Similar exposures have not been seen in the area; perhaps such material is present elsewhere but not exposed. This locality is immediately south of the base of a highland, 100 ft to 200 ft higher than it, underlain by gneiss of the Monson Formation. It is thus in the lee of the highland in terms of direction of movement of the ice sheet, and so is a place rather well situated to have been protected from intense glacial erosion.

GLACIAL-EROSIONAL FEATURES

Striations and grooves etched into the surface of bedrock by particles of rock imbedded in the base of flowing glacier ice are exposed within the map area. Their lengths range from a few inches to a few feet. They were seen at eight localities, four on each quadrangle. At those places, shown on plates 1 and 2 and in figure 3, the compass bearings of striations range between S55°E and S10°E, indicating that the former glacier moved across these quadrangles from NW to SE. No feature of the striations suggests that all were not made contemporaneously during a single glaciation. The number of localities at which striations were seen is small compared with the numbers in other nearby areas. For example, in the Ansonia and Milford quadrangles, 12 to 18 mi. farther west and with a comparable area, striations were observed at 75 localities (Flint, 1968, p. 8). The difference results partly from differences in the kinds of bedrock present and partly from differences in degree of industrial development within the two pairs of quadrangles.

Many of the striations exposed in the Ansonia and Milford quadrangles are on chlorite schist, a rock that is comparatively soft and fine grained, accepting scratches rather easily, yet is rather resistant to chemical decay. In contrast, most of the striations seen in the Guilford and Clinton quadrangles are on coarse-grained crystalline rocks rich in quartz, which are difficult to scratch. Furthermore, most of the striated surfaces seen in the Ansonia/Milford area occur in artificial exposures that have resulted from a high degree of industrial activity. The Guilford/Clinton area is little industrialized and, in consequence, artificial exposures are few. The surfaces of natural bedrock outcrops have been exposed for a far longer time and are less likely to retain striations because of the ease with which weathering destroys such markings. These surfaces are roughened and granulated by weathering.

At a few places within the map area small rock knobs are smoothed to whaleback form at their northerly ends, whereas their southerly ends are steep cliffets controlled by joints in the rock. A good example is visible on the western side of a granite quarry, 800 ft south of the Connecticut Turnpike and 0.7 mi. east of the western limit of the Guilford quadrangle. Such stoss-and-lee forms are good indicators of the direction of movement of former ice and, at the locality mentioned, that direction, N10°W, is the same as that indicated by local striations.

The best-preserved glaciated surface seen in the map area is at the southern shoulder of Highway 80, 0.35 mi. east of the North Madison road intersection. It consists of pegmatite that is grooved, striated, and in places polished, and includes a body of quartz marked with fine microstriations. Some of the other exposures in the area show striations only on pods of quartz, the remainder of the exposed surface being free of glacial markings.

Glacial erosion is involved in the creation of local streamline hills, believed to reflect a glacial molding process that is the work of both erosion and deposition. Here, as in other glaciated areas, such hills can consist almost entirely of bedrock or of glacial sediments, or of any proportion of the two. In the absence of exposures of bedrock or of records of drilled wells, it is difficult to distinguish between them. Figure 3 shows the positions of 27 hills in which bedrock is not obviously

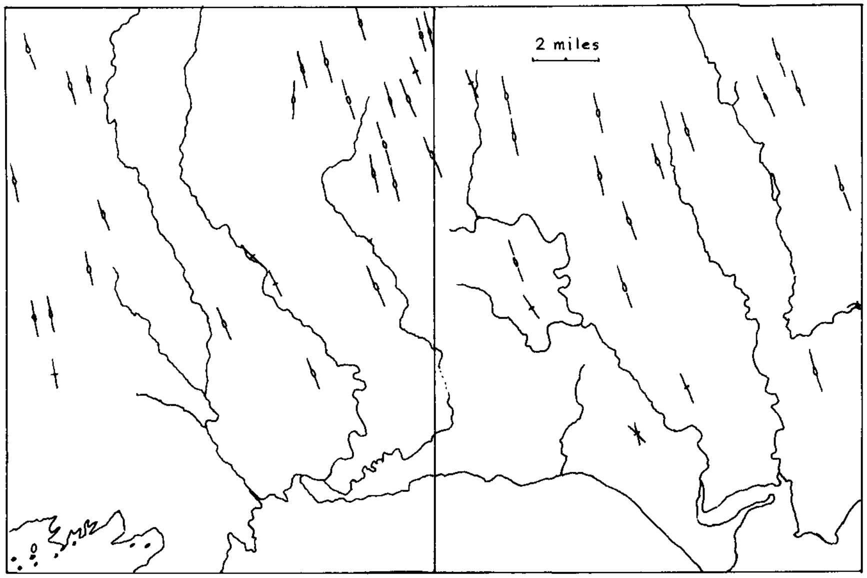

Fig. 3. Sketch map of the Guilford (left) and Clinton (right) quadrangles showing locations and trends of streamline hills (open ellipses) and striations (crossbars).

exposed. The hills are reasonably symmetrical and therefore are believed to consist of glacial drift, at least in their upper parts. They are ovate in plan, 500 ft to about 3,000 ft in length, and 10 ft to 50 ft or more in height. Nearly ideal examples are Cranberry Hill and Walnut Hill near North Madison and Chestnut Hill, Buell Hill, and Tower Hill in Killingworth.

A well in the top of Walnut Hill penetrated glacial drift and encountered bedrock at a depth of 28 ft. As the hill is 50 ft high, about half its height is the result of upbuilding of glacial sediment over a former hill of bedrock. A well close to the top of the unnamed hill at 400 ft, 1.35 mi. southeast of Walnut Hill, encountered bedrock at a depth of 125 ft, a depth equal to the height of the hill. Another well, just east of Route 79 and 1,500 ft south of this well, reached bedrock at a depth of 90 ft. A well near the intersection of Cow Hill Road with Gold Mine Road in Killingworth reached bedrock at 38 ft. Such great thicknesses of glacial drift are thought to be rare in upland areas where streamline hills are not present.

Other streamline hills are nearly free of glacial sediments. An example is the ovate hill that centers 900 ft northwest of the Connecticut Turnpike overpass at Moose Hill Road in Guilford. Although its form is indistinguishable from that of hills of glacial drift, it exposes bedrock in the cut made for the Turnpike, through the full width of 500 ft to 600 ft. We conclude that molding by the glacier was effective, whether the glacier was eroding bedrock or plastering sediment onto the surface,

The trend of the long axes in the map area is NW-SE, nearly parallel with that of striations, as can be seen in figure 3. It is parallel also with the local trends of the chief stream valleys and therefore of the interfluves between the valleys. In short, in this area the "grain" of the topography as a whole is NW-SE. The fact that the direction of flow of the former glacier parallels the "grain" of the bedrock surface here seems to be mainly coincidence, because in some other parts of the state, where the chief valleys and interfluves have a differently oriented "grain," striations and the axes of streamline hills are still generally NW-SE. The trend of streamline hills and striations therefore was not controlled primarily by the preglacial valleys and interfluves.

STREAM-ABRADED BEDROCK

At a number of places, including some of those where exposures of bedrock are surrounded by outwash or ice-contact stratified drift (pls. 1, 2), the bedrock has been abraded and smoothed by stream-borne sediment. Probably most such abrasion occurred during the melting of glacier ice, and less probably during the later dissection of stratified drift. The stream-abraded surfaces are smoothed without being scratched and consist of bosses and basins with rather small diameters, in contrast to the broader, less irregular surfaces made by glacial abrasion.

GLACIAL SEDIMENTS

Sediments of glacial origin, collectively known as glacial drift, are of two general kinds: those deposited directly from glacier ice and those deposited in streams or lakes created by the melting of glacier ice. Both kinds are present in the Guilford and Clinton qualrangles.

Till

GENERAL CHARACTER

Till, a nonsorted, mostly nonstratified glacial sediment consisting of rock particles of all sizes, forms a discontinuous mantle over the area. It covers much of the bedrock surface on hills and smaller valleys alike and thereby shows that the bedrock had been sculptured essentially to its existing surface form before glaciation. Because the major valleys are partly filled with sediments younger than the till, the till itself is exposed in them only rarely. However, borings made in the floors of valleys show that till generally underlies the younger sediments and, in turn, is underlain by bedrock. For example, the log of a well drilled on the property of the Guilford Chester Water Company in the valley of the West River, about 500 ft west of the Town Mill Pond, shows that sand and gravel (probably mostly outwash) were penetrated to a depth of 85 ft, followed by 6 ft of till, underlain by bedrock (unpublished data on file at U.S. Geological Survey, Hartford, Connecticut).

It is evident in plates 1 and 2 that the slopes in the majority of the areas where bedrock is at the surface or close to it are steeper than those elsewhere. The presence of steep slopes, in turn, depends to a considerable degree on the bedrock minerals and structures, particularly foliation and jointing. In places, vertical or very steeply dipping foliation and joints could have been quarried by the ice that flowed over the rocks. Large and small pieces of rock would have been split away from a hill and carried southeastward, leaving behind a steep clifflike slope. As long as it remained steep, no amount of quarrying would change the angle of the slope created in this way by the ice that flowed past it. For such cliffs to form, the structures need not have been at right angles to the direction of ice movement. Their trend needed only a component transverse to the "downstream" direction. An analogy is a carpenter's plane passing across the end of a board. Even if the plane meets the trailing edge of the board obliquely, bits of the wood will be chipped and split off.

In the Guilford and Clinton quadrangles the areas where bedrock is mapped as being at or close to the surface commonly display exposures of bedrock, many of them clifflike. They also have many boulders, mostly of the local bedrock and with joint-controlled faces.

In contrast, most slopes that faced the oncoming ice are sufficiently mantled with till to conceal the bedrock. Records of wells that penetrate both till and underlying bedrock are too few to permit any appraisal of the thickness of till on north-facing slopes. Clearly, however, many such slopes caused the flowing ice to deposit till upon them. Similarly, the broad tops of many interfluves received a mantle of till sufficiently thick to conceal the bedrock except for sporadic exposures. The till mantle has smoothed topographic detail by filling small valleys and pockets in the bedrock surface, particularly on hillsides. Roadcuts, stream banks, and other surface exposures rarely show more than a few feet of till. The thickest section of till seen exposed within the map area is 18 ft; it is in a pit on the eastern side of River Road in Clinton, 2,000 ft northeast of Whedon's Pond. This is its minimum thickness; till extended below the floor of the pit.

Data on thickness of glacial drift in the four towns that constitute most of the map area are shown in table 1. These data consist of the depth to bedrock in wells, drilled or dug in those towns, for which records are on file. They are not entirely accurate because, although most of the drift reported is till, stratified drift is present in some of the borings. One of the till-thickness values in Guilford is twice as large as the other. This results, at least partly, from the fact that the WRC data represent groups of private houses, sited on tracts in the less rocky parts of the town, whereas the WPA data represent mainly farm-houses scattered through all parts of the town. Probably the WPA data are the more realistic of the two groups. On the basis of them it could be suggested that average thickness of till in the two quadrangles is between 7 ft and 15 ft.

Table 1.—Depths to bedrock in borings in four towns.

Town	Guilford		Madison		Clinton	Killingworth
Source of information[1]	WPA	WRC	WPA	WRC	WPA	WPA
No. of wells	88	124	38	112	17	18
Av. depth to bedrock (ft)	6.5	13	24	21	11	16

[1] WPA—Works Progress Administration records on file at U.S. Geological Survey, Hartford, Connecticut. Borings antedate 1936.
WRC—unpublished drillers' logs on file at State Water Resources Commission, Hartford, Connecticut. Borings postdate 1965.

Throughout the map area the till mantle generally has little relief that results from local variations in its own thickness, independent of the relief of the underlying bedrock surface. The glacier appears to have smeared till over the bedrock in a blanketlike manner.

The till includes a coarse fraction consisting of pebbles, cobbles, and boulders and a fine fraction consisting of sand, silt, and clay. As is general throughout much of Connecticut, the coarse fraction is conspicuous in surface exposures but, when measured, is found in most samples not to exceed 20 percent of the total. In some samples it amounts to less than 5 percent. In our map area, sand and silt are abundant relative to clay; hence the till is commonly rather friable. Till is less friable in areas underlain by micaceous, schistose rocks than it is in areas of quartz-rich granitic rocks, where the fine fraction of till includes relatively large amounts of sand.

The pebbles, cobbles, and boulders in till are generally subangular in shape, reflecting the positions of the joints and foliation surfaces in the bedrock from which they were derived. Most of them show some degree of smoothing and abrasion acquired during their travel in the glacier. Corners and edges between facets are rounded, and the surfaces of a few (generally fewer than 5 percent) are scored with striations. A very few are well rounded; very likely these had been transported in streams before being last picked up by the glacier. The sand-size particles are mainly very angular, implying crushing while in glacial transport.

In some exposures the shapes of many particles in the coarse fraction (including big boulders) reflect the fact that their surfaces are ragged fracture planes with little or no evidence of modification by glacial abrasion. These fragments may have been torn from bedrock by the glacier and transported without coming into frequent contact with other pieces of rock, or they may have resulted from crushing.

In composition the till resembles the bedrock that immediately underlies it or that occurs within a short distance upstream. Composition is reflected in the color of the sediment, which, when dried, ranges from yellowish browns (hue 10YR) to yellowish grays and yellows (hue 5Y) of the Munsell system (Goddard and others, 1948).

As mentioned in a foregoing section, the northwestern corner of the Guilford quadrangle is underlain by reddish and brownish sedimentary rocks and by basalt and diabase, all of Triassic age, in sharp contrast with the granitic, gneissic, and schistose rocks that underlie the remainder of the two quadrangles. In this northwestern corner of the mapped area the glacial drift is derived from Triassic rocks. It is distinctive (Flint, 1965) and can be seen in exposures along and near Route 80 in the vicinity of the Guilford-North Branford Town Line. Southeast of the Triassic area, Triassic elements in the till diminish rapidly but do occur, although rarely, in the vicinity of the shore, 6 mi. or so downstream.

An exposure near the intersection of Route 80 with Roast Meat Hill in Killingworth yielded, in a count of pebble-size particles, 2 percent of Triassic elements. The locality is 10 mi. downstream from Triassic bedrock north of our quadrangles, as measured along a line parallel with the trend of the directional features shown in figure 3. Triassic elements are found also in the stratified drift of the valley trains described in a later section. The particles, like those exposed in the sand pits 1 mi. north of Woods crossroads in Madison, are rounded; they were carried by the glacial Hammonasset River after having been released from the glacier. In stratified drift exposed in the valley of East River at Nut Plains, 30 percent of the pebble-size particles are of Triassic rock. Minimum transport (partly by streams) of 2.5 mi. from bedrock sources is implied.

Although most till is not stratified, at a few places within the area the till possesses distinct fissility. This structure consists of closely spaced subparallel partings that in most exposures are also approximately parallel with the ground surface. The origin of this structure is not known; there are at least two ways in which it might have originated. Some till fissility may have resulted from the plastering by moving ice of successive layers of wet, plastic sediment onto the ground. In places it may have been formed by repeated wetting and drying, or other physical changes, after deposition and even after deglaciation. Fissile till was well exposed in 1969 in the pit on the eastern side of River Road in Clinton, 2,000 ft northeast of Whedon's Pond but only in parts of the thick section exposed there.

STRATIGRAPHY AND CORRELATION

All the till seen exposed in the Guilford/Clinton area appears to be part of a single layer, deposited during a single glaciation. In the Mount Carmel quadrangle, northwest of our map area, two distinct till layers are present and seem to be related to two distinct sets of striations (Flint, 1961). Probably the till of our map area is equivalent to one or the other of those tills, but information is insufficient to support a determination, which must await wider study. In any case, our till probably was deposited during the Wisconsin Glacial Age of geologic stratigraphy.

Erratic boulders

Erratic boulders, consisting by definition of rock that differs from the bedrock underlying them, are numerous in the area. Some lie free on the surface whereas others are partly embedded in drift. Many of the boulders exceed 5 ft in longest diameter but only those with a diameter of 10 ft or more were plotted on the maps (pls. 1, 2). Twenty-five of these were observed; many others were certainly missed in densely forested country. The largest, a quartzose schist beside Iron Works Road in Clinton, 1,500 ft south of the telephone line, has broken into several pieces; its former dimensions were about 51 x 23 x 12 ft. The next largest measures 24 x 15 x 12 ft.

Spacing of joints and foliation surfaces in the parent bedrock are the chief factors determining the maximum diameter of a boulder. Both were operative in forming this largest boulder found.

Stratified drift

KINDS OF STRATIFIED DRIFT

The sorted sediments, mostly stratified, deposited in streams and lakes derived from melting glaciers are collectively known as stratified drift. Some of this material was derived directly from rock particles in glacier ice, and some consists of reworked and redeposited till. Most of the stratified drift in the Guilford/Clinton area was deposited by streams. In it two facies can be discerned, each an end member of a gradational series. One facies is the drift deposited in contact with melting ice near the glacier margin. The other end member is the drift deposited by streams flowing away from the glacier, miles or tens of miles from the glacier in which it originated. The sediments of both facies are much the same, although, like all stream-deposited sediments, they become finer grained and otherwise better sorted in downstream direction. But as long as ice, residual from the glacier, is present beside or beneath the accumulating stratified drift, the drift will have characteristics that betray its peculiar place of deposition, and constitutes a facies labeled *ice-contact stratified drift*. Downstream from the point where the meltwater stream has passed over the last identifiable remnant of buried ice, the sediment will have different characteristics, and constitutes a facies labeled *outwash,* although it is essentially the same body of sediment.

We define ice-contact stratified drift, then, as sediments deposited in streams and other bodies of water against, upon, beneath, or otherwise in immediate contact with melting glacier ice. Such sediments include sand, gravel, silt, and clay, and commonly possess one or more of these characteristics: great internal variability, poor sorting, large and abrupt changes in grain size both vertically and horizontally, inclusion of small bodies of till, erratic boulders, or flowtill (till-like sediment deposited by landsliding off adjacent ice), deformation of sedimentary laminae by subsidence or other displacement activated by melting of underlying or adjacent glacier ice.

Rounding of individual particles, although highly variable, is commonly slight or only partial. In addition, ice-contact stratified drift has, in places at least, constructional topography that includes basins (known as kettles), partial basins, and knoll-like mounds. These features reflect the presence of irregular bodies of melting ice during accumulation of the drift.

In this area virtually all the stratified drift ranges in color from grayish and dark yellowish orange (hue 10YR) to dusky yellow (hue 5Y) on the Munsell scale (Goddard and others, 1948), reflecting the color of comminuted local bedrock. The only exception is the small area of Triassic bedrock, where the drift approaches moderate brown (hue 5YR). As we have noted, some drift of Triassic derivation is present throughout both quadrangles, but is so thoroughly diluted with material derived from the local rocks that it does not appreciably affect the color of the drift.

In contrast with ice-contact sediments, outwash is defined as stratified drift, deposited by streams beyond the glacier, and free of any influence of buried ice. It is commonly characterized by lenticular beds, each consisting of parallel laminae inclined in the downstream direction. Range of grain size is relatively small (most outwash consists of sand and pebble sizes), and stratification is more regular and systematic than in ice-contact sediments.

In the Guilford and Clinton quadrangles are long bodies of stratified drift of one or both of the types described. In the following sections the principal bodies are discussed as physical units, beginning at the west and proceeding eastward. Plates 1 and 2 show the extent of each unit and figure 4 shows the long profiles of units in the largest valleys. Four of the drift bodies, elongate and confined to specific valleys, are referred to as valley trains, although that term is more commonly applied by geologists to bodies of drift consisting exclusively of outwash. Each of these valley trains consists, in its upstream and middle parts, of ice-contact sediments. In its downstream part the ice-contact sediments grade into outwash. Near the shore the outwash sediments spread laterally, so that those in each valley merge to form a continuous outwash plain that is common to the four valley trains. The communities of Guilford, East River, Madison, and Clinton are located on this outwash plain, which, as the geologic maps (pls. 1, 2) show, has been dissected by postglacial streams, so that today broad remnants of the plain are separated from each other mainly by tidal marshes.

An historical inference can be drawn from these four valley trains, in each of which ice-contact sediments grade southward into outwash sediments at about the same latitude. At the time when the valley trains had been built to maximum thickness, the ice sheet had already disappeared from the shore region, south of the line that separates outwash from ice-contact sediments. That line is 2 to 3 mi. from the shoreline. North of the line the principal valleys still contained lobes and separated masses of ice, upon which ice-contact sand and gravel were being deposited by streams of meltwater. Still farther north, north of the heads of the valley trains, the glacier was nearly continuous, spreading over valleys and interfluves alike, and still covering the state except for a narrow coastal belt. This general picture should help to make clear the following descriptions of the principal valley trains, which should be read in connection with plates 1 and 2 and figure 4 (in pocket).

WEST RIVER VALLEY TRAIN

This body of stratified drift is named for West River, which traverses the Guilford quadrangle from end to end and empties into Guilford Harbor. The northern end of the valley train lies in the vicinity of Quonnipaug Lake in the Durham quadrangle (Simpson, 1968). In the extreme northern part of the Guilford quadrangle it forms an irregular and apparently thin body of sand and gravel. Its undulating surface was created in part by collapse of the body during melting of the ice upon which it had been built. Its areal pattern and its altitude suggest that in addition to the meltwater that flowed down West River, some water may have escaped for a time past the site of Our Lady of Grace Monastery, down the valley of Hall Brook, and so into the drainage of East River. After collapse that route would no longer have been possible.

The discontinuities in the West River valley train shown on the map were caused partly by nondeposition in places where ice was especially thick and partly by erosion by the postglacial West River and its tributaries. In many places, as in the first mile downstream from Route 80, the valley train consists of a constructional terrace (a kame terrace) built up by streams flowing along one margin or both margins of a tongue of glacier ice. The faces of such terraces are irregular, in contrast with the more sharply defined scarps cut by the postglacial river and well displayed upstream from Hungry Hill.

The thickness of the valley-train sediments is unknown. A well on the western bank of West River at the telephone line crossing, northwest of Hungry Hill, is said to have penetrated sand and gravel through a distance of 200 ft, ending in the same material. In the absence of abundant subsurface records it cannot be determined whether such a depth is normal or unusual.

A short distance north of the Connecticut Turnpike the transition to outwash occurs. The surface becomes smooth and continuous, and the outwash spreads eastward and westward as it becomes free from the valley that farther upstream confines the valley train to a narrow width. Thus it forms the wide coastal outwash plain that extends from west of Guilford to the eastern edge of the Clinton quadrangle, a distance of 10 mi. The explanation of the plain lies in the geometry (fig. 5) of the two surfaces that slope seaward at different rates. The general slope of hilltops on the bedrock surface is about 50 ft per mi., while that of the valley trains is around 15 ft per mi. The outwash sediments continue southward beneath the floor of Long Island Sound, because they were deposited at a time when the sea level was far lower than it is today and the area now occupied by the Sound was land. The outwash plain is dissected by modern streams to a depth of 10 to 20 ft.

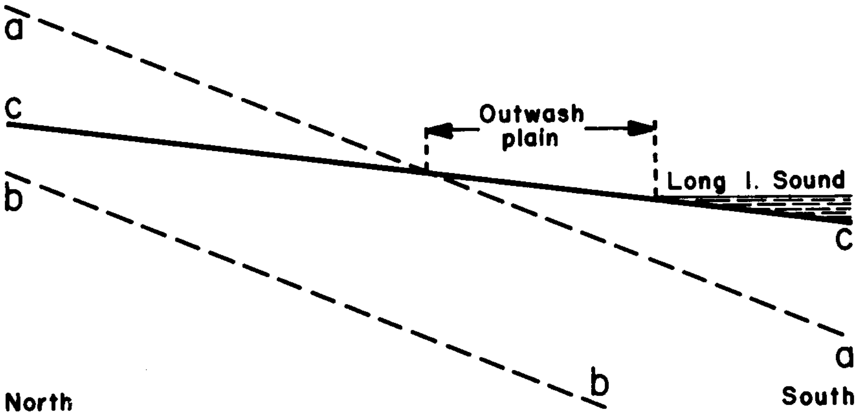

Fig 5. Profiles showing relation of valley trains and bedrock hilltops to sea level. Explanation: a-General slope of hilltops of the bedrock surface. b-Assumed slope of valleys in bedrock. c-Slope of valley trains. The coastal outwash plain forms where the bedrock hilltops pass beneath the valley trains.

EAST RIVER VALLEY TRAIN

The East River valley train is shorter than its western neighbor. Its upstream end is at Malley's Pond, just south of Route 80. There it subdivides into as many as three narrow units separated by hills of bedrock. South of the Guilford Lakes these reunite to form a single, wider body. Both the surface form and the internal character of the sediments exposed in pits south of Nut Plains indicate that the valley train has subsided irregularly; this occurred as underlying remnants of ice melted away. Probably when the valley train was active its entire profile was rather smooth. Hence if one projects the smooth, concave profile of the outwash near the mouth of East River (fig. 4, profile B) northward past the Guilford Lakes, it is apparent that the central and northern parts of the valley have subsided through some 20 to 40 ft.

North of the Connecticut Turnpike the valley train changes character from ice-contact stratified drift to outwash. The transitional zone through which the change takes place is about a mile long and within it the change occurs a little farther north on the eastern side of the valley than on the western side.

Between East River and Guilford the outwash facies merges with that of the West River valley train. Although the connection between the merged units is interrupted at the surface as a result of erosion by the postglacial East River and by subsequent deposition of tidal-marsh sediments, probably beneath the surface the units are continuous. East of East River the outwash facies projects northward up the valley of Neck River through a distance of about one mile, but farther north there is no related ice-contact facies. Evidently the part of the ice sheet that lay in the Neck River valley, which is narrower and probably less deep than the valley of the East River, discharged outwash from its terminus but was not fringed with detached, separate masses of ice upon which stratified drift could be deposited. The East River/Neck River outwash body in turn merges eastward with the Hammonasset River valley train, constituting a coastal outwash plain near the center of which Madison is located. The existing East River has cut into this plain to a depth of 10 to 30 ft; the cut is floored with tidal marsh.

HAMMONASSET RIVER VALLEY TRAIN

The next valley train to the east is shaped roughly like a Y, with the two nearly parallel arms represented, respectively, by the valley of the Hammonasset River and that of its chief tributary, which contains Chatfield Hollow, Foster's Pond, and Deer Lake. Of the two arms the latter is the longer, probably because upstream from their junction the valley of the Hammonasset is very narrow and steep sided and therefore is likely not to have retained residual masses of ice for long; also, its shape facilitated the removal of drift by erosion both during and after deglaciation.

In the vicinity of Deer Lake and Foster's Pond ice-contact stratified drift has the form of crude terraces and broader bodies of gravel and sand. Along the upper Hammonasset and its small tributary, Hog Pond Brook, are similar bodies of sediment with collapsed surfaces and a few kettles. The largest of these is a broad spread of sand and pebble gravel extending SE along Route 79 from Madison Lakes for about a mile. It is collapsed and therefore slopes NE toward the axis of the valley.

Downstream from the junction of the two arms of the Y the valley train is continuous. Its most conspicuous and unusual feature is a massive ice-contact delta about 0.5 mi. wide, extending downvalley for about 0.5 mi. from the stream junction. It has been commercially excavated and is exposed in five pits, the deepest of them nearly 50 ft deep. Its original upper surface, not much of which remains, is flat, sloping from an altitude of about 80 ft at its upstream end to about 70 ft at its downstream end. Except for the northern flank, which abuts on a hill of bedrock, the sides of the delta are erosional, having been cut by postglacial streams.

The delta character of this body, which consists of sand with minor amounts of gravel, is evident in the excellent pit exposures. The foreset beds, almost wholly sand, are at least 17 ft thick, with their basal parts concealed. They dip generally SE at an angle of 20° to 25°, but with NE dips in the northeastern part, suggesting a former lobe at the mouth of a stream channel. In one area possible local collapse is suggested. The overlying topset beds are separated from the foresets by a clean-cut surface of erosion, generally flat but locally having 6 ft of relief owing to channeling. The topsets themselves, 10 ft to 20 ft thick, consist of sand with subordinate pebble gravel and cobble gravel, gently cross stratified. Some beds contain small-scale foreset laminae inclined SE. In the south-central part of the topset unit, near the surface, a lentil 8 ft thick, consisting of parallel-laminated horizontal fine sand, suggests a former interlobe area. In other places very local crumpling of topset layers suggests under-water sliding of sediment before the building of the delta ended. In the southern part of a small knob of till projects through the delta but is not exposed in section. Probably bedrock lies close below it.

Because there is little evidence of collapse in the pit sections, it is unlikely that the delta was constructed on top of residual ice, nor is there evidence that the exposed part of the foreset beds was built against ice. Nevertheless, beginning about 0.5 mi. downstream from the delta, the valley contains a mile-long body of ice-contact sand and gravel that reaches an altitude of 60 ft along the valley sides but only 10 ft to 20 ft in places on the valley floor. On the evidence of its surface form, then, this mass subsided through some 50 ft, as residual ice beneath it melted away. It is reasonable to suppose that the implied former mass of sediment-covered ice formed a dam that temporarily retained an ice-contact lake, in which the delta was built. The sediment for building the delta was contributed by streams of melt-water, perhaps flowing in part over ice, in both arms of the Y formed by the Hammonasset River drainage in this area. When the lake drained away, probably through subsidence of the temporary dam downstream, the river detoured the delta, following the lowest line available, namely the contact between the southern margin of the delta and the sloping surface of till adjacent to it. This is the line it follows today.

Another group of pits in the mass of ice-contact sediment north and west of Whedon's Pond and Schumann's Pond exposes similar deltaic features. There a broad surface at altitude a little more than 60 ft consists of 3 ft to 4 ft of topset sand and pebble gravel overlying 12 ft to 14 ft of foreset sand, the beds dipping S and SE. Nearly the full thickness of this delta is exposed, because the lower parts of the foreset beds are concave, approaching a horizontal position at the bases of exposures, at an altitude of about 40 ft. The mass contains kettles, indicating the presence of ice during delta building, but is not collapsed as a whole. Probably this delta is nearly contemporaneous with the one first described, although it may well have started to be built slightly earlier. During the building of both bodies the water seems to have escaped over sediment-covered ice along the valley of the Hammonasset —in other words, along the Hammonasset valley train.

In the valley train the transition from ice-contact stratified drift to outwash occurs within the first 1,000 ft north of the Connecticut Turnpike. The outwash facies spreads in the downstream direction and merges with the adjacent East River and Menunketesuck River/Indian River valley trains. This gently sloping segment of the coastal outwash plain is closely similar to segments farther west, already described.

MENUNKETESUCK RIVER/INDIAN RIVER VALLEY TRAIN

The most easterly of the major vally trains is somewhat shorter than the others, and its ice-contact facies is less pronounced. That facies is developed along and south of the Kelseytown Reservoir and along Indian River from the telephone line south past Bushy Pond. It merges imperceptibly into outwash through the zone between Bushy Pond and Kelseytown. At Clinton the outwash area spreads laterally, and on the west coalesces with outwash of the Hammonasset valley train. The fanlike form of the outwash plain at Clinton is emphasized by three parallel swales, floored with tidal marsh, that drain into the Hammonasset River estuary. Probably these are radial drainage channels that formed part of the postglacial dissection pattern on the fan. The fact that fewer hills of till and bedrock project through the outwash plain at Clinton than elsewhere, suggests that the deep bedrock valleys of the Hammonasset and Indian Rivers underlie the outwash in this area.

OTHER BODIES OF ICE-CONTACT STRATIFIED DRIFT

Apart from the valley trains described above, only four considerable bodies of ice-contact stratified drift were identified in the map area. The first of these lies just north of Clear Lake in the Guilford quadrangle, at altitude about 150 ft. It constitutes the head of a long valley train, the Branford River valley train, the remainder of which traverses the Branford quadrangle and has been fully described (Flint, 1964, p. 17, figs. 4, 6).

The second body, also in the Guilford quadrangle, occupies the vicinity of Dream Lake and Shelley Lakes. Lying at about 100 ft altitude along the course of Iron Stream, a tributary to East River, it could be treated almost as well as part of the East River valley train. It is thin, with an undulatory surface that has gently collapsed; no extensive exposures have been seen in it.

The third body, labeled Podunk Great Plain, lies 1.5 mi. southeast of the second, at altitude about 150 ft. Judged from poor exposures, it consists of sand and pebble gravel with a generally smooth surface locally pitted with kettles. The fourth body, on the Clinton quadrangle, likewise is thin. It spreads irregularly over a broad interfluve at more than 300 ft elevation, immediately east of Killingworth, and extends northward along the headward part of the Menunketesuck River. A large pit adjacent to Reservoir Road shows poorly sorted sediment, including boulders. This is matched in pit exposures on the Reginald Frye farm southwest of Union Cemetery. An excavation just west of the intersection of Route 80 with Roast Meat Hill Road shows finer grain sizes, including a considerable proportion of fine sand. Some erosion during the accumulation of the sediment is indicated by a low stream-cut scarp in the drift 700 ft to 1,000 ft east of Reservoir Road. The scarp appears to be the work of a glacial rather than a postglacial stream.

No firmly based explanation of the localization of these bodies of drift seems possible. Topographic factors visible today do not appear to have been paramount. Possibly the explanation lies in the localization of drainage lines in or on the ice sheet when and where these sediments accumulated.

END MORAINES

In the coastal part of the map area are segments of end moraines. Such features are usually defined as ridgelike accumulations of drift built by a glacier along its margin. The drift may consist of till, stratified drift, or any combination of the two, and is likely to vary from place to place along the length of a moraine. The ridgelike form of the moraine also varies, with its crestline rising and falling; in places the entire ridge disappears, leaving a short or long gap unmarked by end moraine. Likewise two or more successive end moraines built at different times may merge into a single ridge, and elsewhere spread apart again.

These characteristics are reflected in the end moraines that traverse the Guilford and Clinton quadrangles. They are part of a discontinuous group of such ridges that have been identified in coastal eastern Connecticut and Rhode Island (Schafer and Hartshorn, p. 116, *in* Wright and Frey, 1965). Those in our map area are hardly more than bits and pieces. Some of the discontinuities have been caused by erosion by glacial and postglacial streams and by the sea; others seem to have resulted simply from nondeposition at the margin of the ice sheet. The presence of hills of bedrock and till that antedate the moraines adds to the difficulty of identifying segments of the moraines themselves, particularly where there are no clear exposures. The twelve moraine segments shown in plates 1 and 2 were identified on the basis of the following seven characteristics. Few of the segments clearly possess all seven but most have at least three:

1. Linear form with E-W long axis.
2. Unsymmetric cross profile, with steeper northern slope and gentler southern slope.
3. Constructional topography in detail, including closed basins.
4. Concentrations of boulders on crest and proximal (northern) slope, both at the surface and in exposed sections.
5. Till exceptionally sandy owing to sorting-out of particles of clay and silt sizes.

6. Alternations of till and stratified drift in single exposures and between one part of a segment and another. Local contortions in such drift.
7. Absence of exposed bedrock within (although not beneath) the ridge.

The reason that all segments are not alike is that different activities took place along different parts of the margin of the ice sheet. For example, at one place till was being plastered onto the ground from the base of flowing ice while at another a fanlike body of sand and gravel was being piled up by streams of meltwater on thin marginal ice. Thus, no two parts of such a moraine are exactly alike. Minimum visible heights of the moraines range from 10 ft to about 30 ft. True heights are not known because the bases of the segments are not exposed.

Most of the outwash adjacent to the end moraines was not deposited contemporaneously with the moraines. On the contrary, it seems to be younger; it belongs to the valley trains already described and was deposited when the margin of the ice sheet lay 1 mi. to 2 mi. north of the moraines. As meltwater streamed away from that margin, building up the coastal outwash plain, the outwash sediments wrapped around some of the moraine segments, accentuating the isolation of one segment from another.

It is likely that a similar outwash plain was built contemporaneously with the end moraines, but if it was, it has been partly eroded by streams, partly cut away by the postglacial sea, and partly buried by the blanket of outwash of later date.

For example, erosion, probably postglacial, by the Hammonasset River immediately downstream from the railroad bridge has flushed the finer particles out of the adjacent end-moraine segment, leaving a concentration of large boulders on the river bed. Again, erosion by surf along the shore has narrowed the two segments at Hammonasset Point to a fraction of their probable original width. Boulders, being the least readily movable of the moraine sediments, have accumulated along the beach, and are acting to protect the remnants of the moraine, slowing the rate of erosion. Similar boulders are concentrated in a narrow belt that extends northeastward into the water through nearly 0.5 mi., continuing the trend of the moraine. Probably this marks the site of the moraine. One-half mile farther northeast, Hammock Point marks the beginning of another segment of moraine, probably correlative with the ones at Hammonasset Point. Possibly the small E-W-trending body of till southeast of Willard Island and the elongate sandy point labeled Cedar Island are likewise segments of end moraine, at least in part. They are mapped respectively as till and beach sediments because no other sediments are exposed in them, and linearity alone seems an insufficient basis for classifying them as end moraine.

These uncertainties emphasize the difficulty involved in correlation of segments of moraine in hilly terrain. A view in perspective suggests that the segments in our map area may integrate into two parallel moraines or groups of moraines, each with a trend near N80°E, slightly oblique to the general trend of the coastline. The more southerly group includes the segments between Hammonasset Point and Clinton Beach, as well as those at Harbor View and near Route U.S. 1 nearby. The northerly group extends from the railroad bridge over the Hammonasset River southwestward through Madison to Hogshead Point in the Guilford quadrangle. A possible further continuation is the Indian Neck/Pine Orchard segment in the adjacent Branford quadrangle, mapped (Flint, 1964) as till because its linear form is the only feature by which it could be differentiated from part of a general blanket of till.

The southerly element is the older of the two groups. The fact that each group is nearly straight, despite a premoraine relief of the general surface amounting to at least 150 ft, implies that at the time when the moraines were built the wasting ice sheet was comparatively thick. Had it been thin enough to be influenced by the relief, the margin should have been somewhat lobate, a form that would have been reflected in the trends of the end moraines.

POSTGLACIAL SEDIMENTS

Alluvium and colluvium

In the Guilford/Clinton map area, alluvium is the sediment deposited by postglacial streams of various sizes, and colluvium is the sediment postglacially moved down hillslopes by creep, slump, and related processes of mass-wasting. Colluvium is difficult to identify except in clean exposures, and where identified in the area it is very thin. Hence it is included, on the maps, with alluvium, till, or bedrock.

Alluvium ranges in texture from cobble gravel down to silty sand and in places into clayey silt. It occurs on valley floors and in stream channels and small alluvial fans. Nearly all the sediment mapped as alluvium lies at the surfaces of floodplains, most of which are no more than 5 ft above the streams at low water but which are inundated at times of high water. Some alluvium, however, may overlie very low terraces that possibly are not inundated under existing stream regimens. Elsewhere in the region, as in the New Haven/Woodmont quadrangles (Flint, 1965), it was possible to identify and map (as *terrace alluvium*) the alluvium that veneers such terraces along large streams, because it is distinctive. In the present map area, however, terrace alluvium could not be distinguished from alluvium, possibly because of the relatively small size of even the larger local streams.

In places, however, a stream planed off its bed in till, and later became incised, leaving part of its former bed as a terrace consisting of till. The best example in the area is a terrace, more than 3,000 ft long and 300 ft wide, mapped as till, along the western side of West River about 1.5 mi. downstream from Route 80. Shallow test holes did not reveal any alluvium overlying the till. Evidently the stream, which was then undercutting ice-contact stratified drift exposed in a higher terrace, was competent to carry its bed load past this area.

The thickness of alluvium varies with size of the related stream. Exposures of alluvium along the Hammonasset River locally show thicknesses of more than 4 ft. In other streams thicknesses are commonly less than 3 ft. The coarsest alluvium, mainly gravel, is found along small streams having steep slopes. Along large streams alluvium is mostly sand, silt, and clay in varying proportions, brown to yellowish brown in color, and with irregular to indistinct stratification.

Wind-blown sand and silt

A thin, patchy cover of sand and silt, believed to have been deposited by the wind, covers most parts of the valley trains, although it has not been identified on adjacent slopes underlain by till and bedrock. Though generally present overlying valley-train sediments, it does not overlie alluvium. Hence it postdates the valley trains and antedates the alluvium. Its observed thickness is generally less than 2 ft and in many areas is no more than 6 in.; hence it is not included on the maps. Such sediment is primarily sand, with silt a minor constituent. Being at the surface wherever it occurs, it has lost whatever lamination it may have possessed originally, probably in large part through the growth of roots of trees and other plants. Its color approximates that of the valley-train material that underlies it. It is believed to date from the time of valley-train deposition, when valley-floor sediments were being built up so rapidly by meltwater streams that they were not yet carpeted with vegetation. Therefore, winds were able to pick up the finer material, much of which was redeposited in the immediate vicinity. The distribution of this sediment, however, tells nothing significant about wind directions at the time or times when the sediment accumulated.

Wind-blown sand occurs also as a long narrow strip adjacent to Hammonasset Beach and Clinton Beach, two long and much exposed beaches. The strips of wind-blown sand are about as wide as are the exposed parts of the beaches. The surface form of the sand strips is undulating on a small scale and, in places, sand hummocks, essentially very small dunes, as much as 3 or 4 ft high, have developed. The sand thins out rapidly on the landward side of each strip. In most places this sand is still actively moving, and so is not only postglacial but modern. It is fed landward from the adjacent beaches.

Estuarine sediments

Because industrial development is slight along this part of the Connecticut coast there is a dearth of information about surficial sediments offshore and beneath the surface on coastal land. Judging from borings and other excavations near New Haven and farther west, near Stratford, we can say that it is likely that the Hammonasset River (which is affected by tides even at some distance north of the Connecticut Turnpike bridge) is floored with estuarine sediment toward its mouth. Such sediment elsewhere in this region is gray mud, including silt, sand, clay, fine organic matter, bits of plants, and broken shells of clams, oysters, and other shallow-marine organisms. It has been encountered in borings beneath tidal-marsh peat east of Clinton Harbor (Bloom and Ellis, 1963, fig. 5) where it is more than 20 ft thick, overlying outwash, and there is little reason to doubt that it is present elsewhere in our map area. The stratigraphic relations of this sediment are discussed in the following section.

Swamp and marsh sediments

Swamps (wooded) and marshes (nonwooded), as described in table 2, occur in various parts of the Guilford and Clinton quadrangles.

Table 2..—Genetic classification of swamps and marshes in the Guilford (G) and Clinton (C) quadrangles.

Genetic origin	Example
Basin in till	Swamp, in Guilford, midway between Malley's Pond and Dream Lake (G)
Basin created by dam of stratified drift	Swamp 0.5 mi. NE of Killingworth (C)
Kettle; basin in collapsed drift	Swamp 0.5 mi. NW of Turnpike Interchange 62 (C)
Valley floor without definite basin [1]	Small swamp in Podunk Great Plain (G); swamp 0.4 mi. SE of Bushy Pond (C)
Tidal marsh [2]	Marshes NE and NW of Guilford Harbor (G)

[1] Such swamps and marshes occur where drainage is impeded by variations in permeability of floor material, which possibly includes plant matter.

[2] Detailed in text.

Their sediments, which underlie the living vegetation, consist mainly of muck, an olive-gray to dark-gray or brownish mixture of silt, clay, and fine sand with a high percentage of comminuted decayed plant matter. They also include peat, which is nearly pure organic matter. In small swamps such deposits are seldom more than 10 ft thick; however, the artificial pond at Star Meadow Day Camp, 0.8 mi. north of Nut Plains, was excavated from a swamp in which the peat was at least 15 ft thick.

The thicker swamp deposits preserve a fossil record of changes in vegetation and climate since the time when the ice sheet melted off the area. Swamps and marshes in the Guilford/Clinton area have not been studied from this point of view, but a marsh in New Haven (Deevey, 1943, p. 726) yielded a core, 28 ft long, containing a record of fossil pollen that shows the kinds of trees and other plants that lived in the vicinity during approximately the last 15,000 years. The succession of vegetation shows, in general, progressive warming of the climate with intermediate fluctuation.

Among the swamps and marshes in the two quadrangles, tidal marshes constitute a special category. They do not occupy basins but lie at and upstream from the mouths of streams, and hence are open to the sea. They have resulted from submergence or "drowning" of the lower parts of valleys. The tides move in and out, creating an environment for the growth of specialized plants, mostly grasses. Within the area every valley or lowland that extends to the coast is floored wholly or partly with tidal marsh. Stream channels within the marshes normally have an intricate pattern of meanders. In most marshes the natural channels are supplemented by artificial drainage ditches and are filling with vegetation.

The vegetation of the marshes grades upstream from grasses adapted to tolerate salt water into reeds, cattails, and bulrushes characteristic of water with low salinity. Because this gradation is irregular, it is not feasible to separate true tidal marsh from freshwater marsh by a line on the map. Consequently all swamps and marshes within the quadrangle are indicated by a single convention.

The sediments of the tidal marshes consist of muddy peat and peaty mud, and form crudely wedge-shaped bodies that thicken seaward. Their seaward parts are underlain generally by estuarine mud, their landward parts generally by valley-train sediments or till. These relations indicate that the Connecticut coast has been undergoing gradual submergence by rise of sea level, subsidence of the land, or both. Rate of accumulation of tidal-marsh sediment along Hammock River was measured over a period of 4 years, and was found to average around 10 mm per year (Bloom, 1967, p. 24-26). Other data on Connecticut marshes are summarized by Hill and Shearin (1970).

Beach sand and gravel

The aggregate length of beaches within the map area is about 9 mi., about half the length of the entire shoreline exclusive of estuaries. The remainder consists of till, bedrock, and artificial fill, including concrete walls. The longest uninterrupted beach is Hammonasset Beach, with a length of nearly 2 mi. from Webster Point to Hammonasset Point. The character of the beaches is related closely to the local materials available for beach building and maintenance by natural processes. Where the coast consists of bedrock, beaches are few and are both narrow and short; examples are the three beaches near Vineyard Point in Guilford. Where the coast consists mainly of erodible stratified drift, as in Madison, beaches are broader and much longer.

The grain size of beach sediments likewise reflects the character of the materials exposed locally to the surf. Thus the beach at and east of Hammonasset Point, which fringes a bluff of bouldery till, consists of gravel with many boulders, whereas northwest of that point the beach fringes sandy outwash and consists almost entirely of sand. Some beach segments fringe tidal marshes, themselves not sources of sediment. Such segments are supplied by longshore drifting of sand from an adjacent segment that fringes erodible material.

The beach sediments rarely exceed a very few feet in thickness. They are maintained by a precarious balance between local erosion and deposition by surf and longshore currents, and the easily altered by the building of seawalls and other structures on the beaches themselves or on the points and headlands between them. This fact is being taken into account increasingly in the planning of construction programs, so as to protect what has become a recreational asset of great value. Efforts to counteract local erosion of beaches and to widen them for recreational use have included importation of sand for spreading on existing beaches and even for the creation of new beaches.

Although the surf has cut low bluffs or cliffs in both stratified drift and till, no cliffs have been cut in the bedrock exposed along the shore. The local bedrock is very resistant to erosion and the time since the sea has risen to approximately its present level has been too short to permit significant erosion of bedrock.

Artificial fill

Artificial fill consists of deposits made by human activity; these include roads, railroads, shore protection, and building-construction fills as well as the large accumulations of trash called "dumps." Much of the fill material mapped was obtained from sources close to the fill bodies, but part of it was brought from more distant sources, some of which are the borrow pits shown on the maps. The largest bodies of fill in this area are along the Connecticut Turnpike, the railroad, and stretches of the shore of Clinton Harbor, as well as in Hammonasset State Park.

In densely populated areas much of the surface material that underlies streets, driveways, and lawns is fill. However, fill is mapped only where it is known or judged to be at least 5 ft thick and where it is large enough in area to be shown at the scale of the map. Areas of conspicuous artificial cutting that are continuous with areas of fill are mapped as fill. Such areas include large sand and gravel pits.

WEATHERING AND SOILS

Where the contact between bedrock and overlying till is exposed, the surface of the bedrock is fresh and unweathred, just as it was left after glacial abrasion. However, in places where no till was deposited or where overlying till has been stripped away by erosion, the surface of the bedrock is slightly but noticeably weathered. Weathering takes the form of slight roughening, slight bleaching, or oxidation. Along joints such weathering changes extend downward well below the surface. This is the extent of local postglacial weathering in bedrock.

In glacial drift and wind-blown sediments the most obvious effect of weathering is oxidation, which in most places is limited to a depth of 2 or 3 ft. Oxidation imparts a yellowish or brownish hue to the fine-grained particles in the drift and also forms rinds of limonite on the surfaces of stones and boulders of amphibolite and other rocks rich in iron-bearing minerals.

Within the thin zone of weathering, soils are developed. The Guilford/Clinton area lies within the region of Brown Podzolic soils of northeastern United States. Brown Podzolic soils are imperfectly developed Podzols characterized, in forested areas, by a thin gray leached zone beneath a thin mat of partly decomposed organic matter. These soils, having weakly developed profiles, are normally less than 30 in. thick.

Within the map area there are a number of soil types, some of which have been discussed in a publication by Morgan (1930). As the quadrangle lies within a single zone of climate and vegetation, local differences among its soils must result mainly from differences in parent material, relief, and drainage. Of these factors parent material is believed to be the most important.

Weathering that probably occurred before glaciation is represented at a locality southeast of Easter Lake and is described in a foregoing section.

GLACIAL AND POSTGLACIAL HISTORY

Before glaciation of the region began, the principal valleys, ridges, and hills had already been shaped by long-continued erosion and, except in detail, were similar to those of today. The surface was mantled with a regolith, perhaps thick, developed by weathering of the underlying rocks.

Evidence from outside the area indicates that Connecticut was overrun by a sheet of glacier ice at least twice and possibly several times, during the last million years or more, but in the Guilford/Clinton area evidence of only one glaciation has been found thus far. In that glaciation the ice sheet flowed across the area from NW to SE. Because evidence of glaciation is present on the highest hills as well as in the valleys, it is clear that when the glacier reached its maximum extent the area was completely buried beneath ice. The cumulative effect of this and earlier glaciations was to smooth, round off, and generally streamline the hills and ridges, to smooth and widen some of the valleys, and to remove most of the pre-existing regolith.

In the Great Lakes region the combined evidence of till layers and radiocarbon dates indicates that a group of related glaciations occurred within the last 70,000 years or so and that the last major invasion culminated around 18,000 years ago. It is thought that at about the latter time the part of the ice sheet that covered New England reached its outer limit at what is now Long Island, and built end moraines and outwash there. Its terminus melted just rapidly enough so that with the ice renewed by flow from the north, the terminus remained in about the same position. Later, melting increased while flow was reduced, and the terminus retreated northward across what is now Long Island Sound. During the retreat the ice sheet became thinner, and hilltops in southern Connecticut began to reappear. Probably before 15,000 years ago the ice-sheet terminus had melted back to the line of the Connecticut coast.

There ensued a time, several hundred years or more, when increase of flow or increase of melting or both caused the terminus of the ice sheet to halt and to shift positions slowly, forward and backward. The end moraines in the Guilford/Clinton area and their correlatives eastward across Connecticut and Rhode Island were built at that time.

Thereafter, thinning affected a wide area of the ice sheet, more and more hilltops reappeared, and rates of flow of the ice decreased.

The terminus of the glacier melted back from the moraines, and the ice became so thin that the outer or marginal part of the glacier virtually ceased to flow and became practically inert. Thinning progressively exposed the lower hills, while tongues and detached masses of ice remained in the larger valleys. Streams of meltwater flowed between the margins of such masses and the adjacent valley sides and built up thick embankments of sand and gravel. In many places stratified drift completely buried residual masses of ice. In this way the ice-contact facies of the valley trains were built up, with the sand and gravel merging southward into outwash in the zone that had by then become free of ice. Thus during deglaciation there was an ice-free zone, then a zone (thought to have been at least 6 mi. wide) of separated bodies of residual ice in the valleys, and finally a zone of continuous thinning ice that extended far to the north.

All the valley trains in the Guilford/Clinton area were built up at very nearly the same time, as shown by the fact that in all of them the zone of transition between the ice-contact parts and the outwash parts occur at comparable positions. To the south, the outwash was built up between and around segments of end moraine, eroding the sides of the segments and partially burying them. Throughout the valley-train episode, fine sediment was blown from valley floors and deposited on the stream-laid coarser sediments as thin coverings.

As the ice sheet north of the map area continued to waste away, meltwater ceased to flow down the local valleys. The head of the Hammonasset, the longest stream in the area, is only 6 mi. north of the northern boundary of the Clinton quadrangle. When that point became deglaciated, all the streams in the map area were dependent solely on local rainfall for their water supply, and the abnormal deposition of valley-train sediments ceased. Buried masses of ice continued to underlie the sediments, however; the collapse features that are preserved today postdate the valley-trains.

The postglacial streams generated by rainfall trenched and reworked the sediments of the former valley trains, creating thin swaths of alluvium. Probably they also drained the kettles left in valley floors or filled them with sediment.

Analogy with comparable parts of the coastal region where paleobotanic studies have been made of the drift indicates that during the deglaciation of the area the vegetation consisted mainly of treeless, tundralike grassland; after deglaciation it changed to spruce forest and later to other conifers. Still later, a warmer climate induced the gradual development of the deciduous forest we see today.

At the time of maximum extent of the ice sheets in North America and Europe, sea level was very low, possibly as low as –300 ft. As meltwater returned through streams to the ocean, sea level gradually rose. By about 5,900 years ago it had risen, relative to the land, to about 26 ft below the present mean sea level, as shown by a series of radiocarbon dates on wood and peat from beneath estuarine mud at several places along the Connecticut coast (Bloom and Stuiver, 1963).

Throughout postglacial time the existing soils were forming beneath a cover of largely forest vegetation. The youngest soils are those on postglacial terraces and alluvium. The accumulation of peat in swamps and the postglacial return of forests have altered the landscape appreciably, but the deforestation, cultivation of the soil, and construction of roads and buildings that are the work of man are changes that are far more conspicuous. When settlement of coastal Connecticut by European people began in the 17th century, all the land within the quadrangles, except tidal marshes, a few other marshes, and patches of bare rock was clothed with forest. Today about 70 percent of the land area consists of woodland. The podzolic character of the local soils reflects the influence of the forest cover.

ECONOMIC GEOLOGY

Sand and gravel

Although the coastal part of the two quadrangles is underlain by outwash sand and gravel, it produces little of these materials, which are in great demand, mainly because it is fairly densely populated. Large- and medium-sized active sand and gravel pits are at present confined to the ice-contact stratified drift of valley trains in areas of lesser population, north of the coastal belt, depite the fact that ice-contact stratified drift is a less desirable source of sand and gravel because it commonly contains cobbles and boulders, many of the boulders very large ones.

Prominent among the operating pits are those of the Shore Line Washed Sand & Stone Co., on the Killingworth side of the Hammonasset River, 0.5 mi. north of the telephone line, and of the Seashore Construction Co., in Madison just south of Woods crossroads. Another is on the northeastern side of East River in Guilford, 1 mi. south of Nut Plains. A few small pits operate intermittently. The overall supply of reachable sand and gravel is dwindling rapidly, and imports and substitutes are likely to find increasing favor.

Landfill

The material most commonly used as artificial fill is till. It is relatively abundant and contains a variety of grain sizes, including silt and clay, which promotes compaction. Ordinarily pits are created as fill is needed, at localities close to the areas to be filled, and are abandoned as filling is completed. The supply of till is still extensive, particularly in the northern part of the area where the till cover is thicker. Ice-contact stratified drift also can be used as fill for many purposes.

Swamp and marsh deposits

The organic deposits in swamps and non-tidal marshes within the map area are potential sources of garden humus. However, as most of the bodies are small in area and probably also in thickness, it is doubtful whether economic development is feasible.

Ground water

Various bodies of stratified drift within the area are potential sources of ground water for domestic use or for small industrial plants. However, because they consist of sand and gravel they are very permeable, and the water table is generally low (in many places 25 ft or more below the surface) and rather closely adjusted to the level of tidewater or to that of the nearest surface stream. In consequence, the development of a reliable water supply from such material depends on thickness of the sediment in the zone below the water table. This is a matter for local investigation in each case.

Till is generally too thin and in some places too impermeable to be a source of water other than for shallow wells of low yield. Most users of water within the map area prefer to derive their supplies either from surface reservoirs or from wells drilled into bedrock.

Discussion of ground-water problems pertinent to the Guilford/Clinton area will be found in reports by J. S. Brown (1925; 1928, p. 53-81).

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