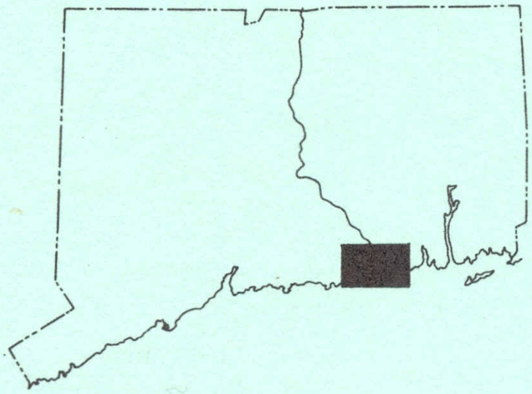
The Surficial Geology of the Essex and Old Lyme Quadrangles

WITH MAPS

Open Plate 1
Open Plate 2

Open Figure 3
Open Figure 4

RICHARD FOSTER FLINT



STATE GEOLOGICAL AND NATURAL HISTORY SURVEY
OF CONNECTICUT

DEPARTMENT OF ENVIRONMENTAL PROTECTION

1975

QUADRANGLE REPORT NO. 31

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WITH MAPS

RICHARD FOSTER FLINT
Yale University

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Douglas M. Costle, *Commissioner of the Department of Environmental Protection*

STATE GEOLOGIST
DIRECTOR, NATURAL RESOURCES CENTER
Hugo F. Thomas, Ph.D.
Hartford, Connecticut

EDITOR
Lou Williams Page, Ph.D.

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The Surficial Geology of the Essex and Old Lyme Quadrangles

by

Richard Foster Flint

ABSTRACT

The Essex and Old Lyme 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 to form irregular residual masses in the valleys.

While valley trains were being built up, winds removed material from them and deposited it as a thin covering of sand and silt over adjacent areas. In postglacial time the valley trains were dissected 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 Essex and Old Lyme quadrangles (fig. 1) lies along the coast of Connecticut and falls entirely within the Eastern Highland region (fig. 2). The aggregate area of the two quadrangles is about 110 sq mi, of which about one quarter lies beneath the waters of Long Island Sound and the Connecticut River estuary. The quadrangles include parts of Middlesex and New London counties; the boundary between these counties is the Connecticut River. Within the quadrangles are parts of the towns of Clinton, Deep River, East Lyme, Essex, Lyme, Old Lyme, Old Saybrook, and Westbrook. The chief centers of population are Essex and Old Saybrook.

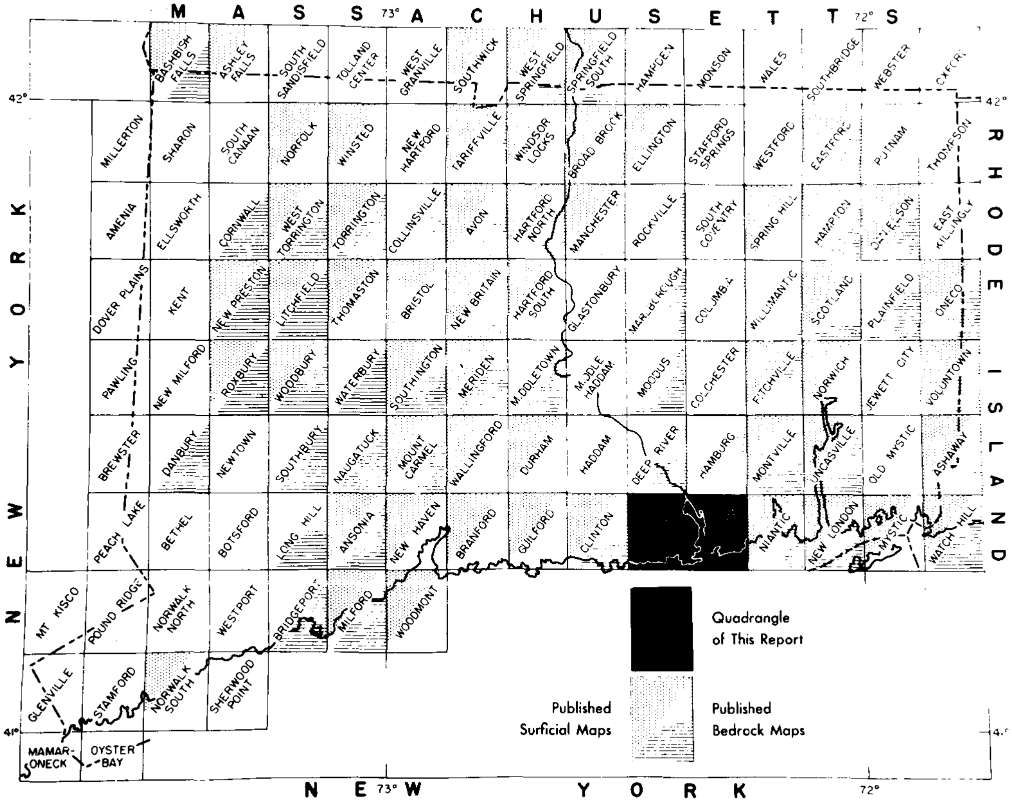

Fig. 1. Index map of Connecticut, showing locations of Essex and Old Lyme quadrangles and of other published quadrangle maps.

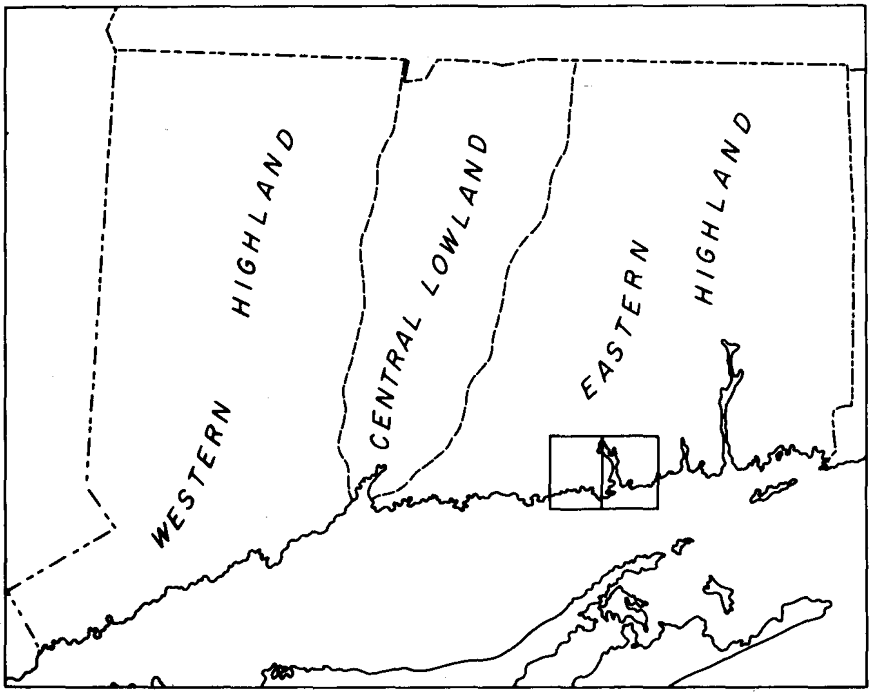

Fig. 2. Map of Connecticut, showing boundaries of the state's three natural regions and locations of Essex and Old Lyme quadrangles.

Mapping of the surficial geology, at the scale of 1:24,000, was done at various times in 1970, 1971, and 1972. 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 compilations, made by Richard G. Naylor, of data from the State Highway Department, the U.S. Geological Survey, and other sources. Helpful criticism of maps and text, by Fred Pessl, Jr., and Dennis O'Leary, is acknowledged.

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 Connecticut had been overrun by glacier ice was firmly established in the 19th Century by J. D. Dana. General discussion of the glacial features of Connecticut, although without special reference to the Essex/Old Lyme area, can be found in publications by Rice and Gregory (1906, p. 227-259) and Flint (1930, 1934).

BEDROCK GEOLOGY

The bedrock geology, described in detail by Lundgren (1964, 1967), may be summarized as follows: The area is underlain by very old metamorphic rocks, chiefly gneisses and schists, and by granite. These rocks were subjected to folding, which was followed by prolonged erosion. The erosion cut so deeply into the rocks that the folded structures are exposed at the present surface in an intricate pattern that delineates structural domes and structural basins. As indicated in a later section, many of these structural elements in the bedrock are reflected in the forms and trends of hills and valleys, mainly through varying erodibility of the many different kinds of rock. The more erodible rocks generally underlie valleys and comparatively low land, whereas the least erodible rocks underlie the higher groups of hills.

The physical and chemical characteristics of the various kinds of bedrock that underlie the quadrangles and the bedrock outcrop patterns influence to some extent the surficial geology of the Essex/Old Lyme area. The presence in the glacial drift of pieces of rock whose places of origin in bedrock can be identified 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 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—the patchy, loose material that commonly overlies it—is not shown separately. All bedrock exposures observed during field study were mapped; however, there are others, particularly toward the southern ends of groups of hills where glacial drift is comparatively thin.

TOPOGRAPHY

The surface of the area is irregular, rising northward from the shoreline to a maximum altitude of 390 ft near the northwestern corner of the Essex quadrangle, just northwest of Winthrop. Other high areas lie close to the northern boundary of that quadrangle. Many of the topographic elements in the area are elongated, N-S, NW-SE, or NE-SW, reflecting predominant trends of structures in the bedrock. The individual bedrock units differ somewhat in erodibility, as judged by the average altitude of each unit within the map area. A mechanical measurement of average altitude of each of seven units in the Guilford quadrangle (centered 13 mi west of the center of the Essex 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, great contrasts in topographic expression and altitude occur between adjacent facies of a single unit; these are visible on topographic maps. For example, the gneissic rocks of the Sterling Plutonic Group (Lundgren, 1967, pl. 1) in the Old Lyme quadrangle tend to be characterized by higher and more massive hills than are some of the rocks of the Plainfield Formation in the same quadrangle. The relationship is not entirely consistent, however, possibly because of other factors, such as variation in the proportions of different mineral species in the rocks and the spacing of joints and other structures, which likewise could 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, with abundant boulders scattered over the surface. It seems unlikely that this difference results wholly from local differences in thickness of the till mantle. Probably the difference antedates the till at least in part. Smoother pre-till topography is likely to have led to the deposition of an unbroken sheet of till, whereas knobby topography was conducive to 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 Essex/Old Lyme 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.

The relief of the bedrock surface of this belt is greater than it appears. The bedrock floor of the Connecticut River lies well below present sea level, as revealed by seismic profiles, and deep borings made mainly at the sites of bridges. One mile south of the Connecticut Turnpike bridge in the Old Lyme quadrangle, the bedrock floor, now covered with thick sediment, lies at −180 ft (fig. 6). Twenty miles upstream it is at least −155 ft, and at Middletown, 25 mi upstream, at least −150 ft (Haeni, 1971, fig. 14; Upson and Spencer, 1964, p. M9-M10). Comparable and even greater depths have been measured in other large valleys along the Connecticut coast. Although the valleys may have been deepened to some extent by glacial erosion, probably their present depths are mainly the result of change in the level of the sea relative to the land. The change seems to have been brought about partly by seaward downtilting of the New England coast and partly by lowering of sea level during glacial ages, when large volumes of seawater were evaporated, carried over the land, and precipitated as snow to build enormous glaciers. At these times Long Island Sound did not exist, and the coast lay seaward of what is now Long Island.

Where intersected by the sea, this hilly surface of Connecticut, with its deep valleys partly filled with sediment, forms an irregular shoreline consisting of points and headlands separated by coves. In the Essex and Old Lyme quadrangles three minor headlands—Point O'Woods, Hatchett Point, and the point east of White Sands Beach—consist of compact till, which resists erosion by waves more successfully than do the bodies of sand and gravel that are exposed in places along the shore, forming shallow coves. The three most conspicuous headlands, Saybrook Point, the point at Fenwick, and Cornfield Point, are formed by end moraines. Probably their boldness stems in large part from the very stony and, in places, bouldery character of the moraine material, which protects the moraines from rapid attack by the surf.

By far the most conspicuous indentation of the shoreline in this area is the estuary of the Connecticut River. The river is affected by tides far upstream from its mouth but, where it traverses the Essex and Old Saybrook quadrangles, its estuarine character is most obvious. The river is fringed in places by tidal marshes and, between Old Saybrook and Black Hall, attains a width, including the marshes, of more than 2 mi.

Other, much smaller, streams in the area are fringed by tidal marshes through varying distances upstream from their mouths. The presence of the marshes, the irregular shoreline, and a few small islands 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, which reveal a system of valleys that continue the principal valleys of Connecticut outward 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 21 mi west of the Essex 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 large valleys such as those of the Connecticut, Menunketesuck, and Black Hall rivers, relief has been reduced by the partial filling of the valleys with glacial drift. With such exceptions, the relief of the Essex/Old Saybrook area is attributable mainly to the irregular surface of the bedrock, the broader features of which were fashioned well before glaciation occurred.

DRAINAGE

The area of the Essex and Old Saybrook quadrangles is drained southward, chiefly by six rivers: Menunketesuck, Patchogue, Oyster, Connecticut, Black Hall, and Fourmile.

All these streams drained into the broad area that is now the floor of Long Island Sound, before the sound itself came into existence. Before submergence, Black Hall River joined the Connecticut a short distance south of the present Lynde Point.

The mouths of all six streams are submerged beneath seawater, upstream about as far as the extent of the nearly continuous fringing marshes shown in plates 1 and 2. As the outstanding river in the map area, the Connecticut shows the effect of submergence through the greatest distance; it is tidal as far upstream as Hartford, about 39 mi from Lynde Point.

The drainage has had 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 outcrop pattern 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 other factors.

Glaciation seems to have altered the pre-existing drainage pattern very little. Three obvious exceptions are: (1) On the Essex quadrangle, the Patchogue River flows SW for 1.5 mi downstream from the Connecticut Turnpike, occupying the swale between two parallel end moraines. (2) On the Old Lyme quadrangle, the Black Hall River turns, near the railroad bridge that spans it, and flows SW for more than a mile, following the proximal base of an end moraine. (3) Also deep borings show that the Connecticut River, where crossed by the Turnpike bridge, is not centered on its bedrock valley whose axis lies west of the existing river (Upson and Spencer, 1964, p. M9-M10; Haeni, 1971, fig. 11). The offset is probably of glacial origin. When the various glacial sediments were deposited and the sea surface stood far below its existing level, the bedrock valley became widely filled with sand and gravel washed from melting glacier ice and later, as sea level rose, with the fine sediment appropriate to an estuary. The existing course of the river at this place, therefore, has no contact with bedrock and was determined wholly by the surface of the sediment which fills the bedrock valley.

Apart from such deflections as these, the streams in the map area seem to be approximately where they were before glaciation.

The courses of small streams are interrupted in places by swamps and ponds, some of them occupying shallow basins created by the irregular deposition of glacial drift or by collapse of the drift during the melting of the masses of glacier ice that were buried beneath it. One example is along the drainage of Fishing Brook between Crystal Lake and Cedar Swamp in the Town of Old Saybrook, in the Essex quadrangle. Other examples, both in the Old Lyme quadrangle, are Black Hall River between Laysville and the Connecticut Turnpike, and Fourmile River, in places along its course. 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 such basins.

The named lakes and ponds within the area include water-supply reservoirs, present or former mill ponds, recreational ponds, and basins excavated in pits dug for sand and gravel. All were created or at least deepened by artificial dams. However, Rogers Lake, the largest, consists of two basins separated by a shoal only 6 ft beneath the present lake surface. The artificial dam at the southern end of the lake has raised the water level only 4 ft. The southern basin is 34 ft and the northern basin 66 ft below lake level. Hence the lake is largely of natural origin. Core borings have shown that the southern basin is underlain by at least 35 ft of sediment(all of it deposited in the lake), and the northern basin by 15 ft of soft lake sediment that overlies sand perhaps older than the lake (Davis, 1969, p. 410).

PREGLACIAL WEATHERING

Southwest of Connecticut, beyond the southern limit of the ice sheet that overran all of New England, the bedrock in most natural and artificial exposures displays to a varying extent the effect of long-continued weathering, chiefly by chemical decomposition. The weathered rock occupies a zone within which decomposition is most intense close to the surface, fading out downward into fresh rock at depths ranging from a few feet to tens of feet. In the glaciated region, however, exposed bedrock is generally undecomposed, implying that in most places the overriding ice sheet rubbed away the loose, weathered rock at the surface and bit down into the fresh, unaltered rock beneath.

Here and there in Connecticut, however, weathered bedrock is exposed under a covering of glacially deposited material. Most such places are the sites of deep artificial cuts. Within the Essex and Old Lyme quadrangles, a series of such exposures, seen in June 1968, were excavations made during construction of State Highway 9, exposing weathered rock here and there along what is now the highway, from a point just north of Kelsey Hill Road, in the town of Deep River, to at least the northern limit of the Essex quadrangle. Through this distance, altitudes of the exposures range from less than 100 ft to about 150 ft.

The weathered rock consists of schist, rich in quartz and biotite, most of it belonging to the Hebron Formation (Lundgren, 1964, pl. 1). The greatest exposed face is nearly 30 ft high. In this and other faces, the weathered zone extends downward nearly 20 ft. All or most of the biotite has been consumed, leaving the quartz grains as loose, fine sand, yet preserving the near-vertical foliated structure of the former bedrock. In the comparatively moist climate of New England, biotite decomposes very readily. The chemical reactions were hastened by the near-vertical "grain" of the rock. Furthermore, decomposition has penetrated most deeply along near-vertical joints, which clearly provided easy pathways for descending rainwater. In the areas between joints, chemical alteration was less thorough.

In one face bedrock is sharply overlain by a thick layer of glacial sediment, which, in contrast to the weathered schist beneath it, showed no apparent decomposition. The relationship shows that most or all of the decomposition of bedrock occurred before glaciation.

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 measured at 14 localities, 9 of them within the Essex quadrangle. All but one were measured during the current investigation. The exception, at a point 0.4 mi north of Lyme Station, was measured in July 1941, with a bearing of S 26° E; in 1972 it was no longer exposed. At the 14 localities (shown on pls. 1, 2) the compass bearings of the striations range between S 26° E and S 10° W, and average S 19° E. All but two of the recorded features are on broad, nearly horizontal bedrock surfaces. The two exceptions, with bearings of S 2° W and S 10° W, respectively, are on steeply sloping surfaces that parallel the trends of the valleys in which they occur. Yet these two aberrant bearings lie close to another exposure of bedrock that is nearly horizontal and on which striations, bearing S 20° E, have trends well within the range of all the others recorded within the two quadrangles. It is likely that the two variant features were made by ice whose local movement was controlled by local topography and does not reflect the average direction of movement throughout the map area. If the two variant readings are neglected, and only the remaining 11 considered, the average direction becomes S 23° E, probably a more accurate indication of the regional direction of movement of the former glacier. Not surprisingly, this average is similar to the directions of movement inferred from striations measured in the adjacent Guilford and Clinton quadrangles to the west (Flint, 1971, fig. 3). No feature of the striations contradicts the conclusion that all of them were made contemporaneously during a single glaciation.

Although the number of observed striation locations is similar to that of comparable localities in the adjacent Guilford and Clinton quadrangles, it is smaller than those in more distant areas to the west. For example, in the comparable area of the Ansonia and Milford quadrangles, 19 mi to 25 mi farther west, striations were observed at 75 localities (Flint, 1968, p. 8). The difference results chiefly from the types of bedrock present in the two pairs of quadrangles and their different degrees of industrial development.

Many of the striations exposed in the Ansonia and Milford quadrangles are on chlorite schist, a rock that is comparatively soft and fine grained, rather easily scratched, yet rather resistant to chemical decay. In contrast, most of the striations seen in the Essex and Old Lyme quadrangles are on coarse-grained crystalline rocks rich in quartz, which are more difficult to scratch. Furthermore, most of the striated surfaces seen in the Ansonia/Milford area are in artificial exposures that have resulted from a high degree of industrial activity. The Essex/Old Lyme 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 cliffiets controlled by joints in the rock. An example was well exposed in July 1971 during straightening of State Highway 153, 500 ft north of Rintoul Pond on the Essex quadrangle. The surficial sediments had been stripped off a knob of gneiss 30 ft high, immediately east of the highway, exposing the form of the bedrock. These features, known as stoss-and-lee forms, are good indicators of the direction of movement of former ice and, at the locality mentioned, that direction, S 25° E, is approximately the same as the average trend of striations in the Essex quadrangle.

Glacial erosion is involved not only in the creation of striations but also of local streamline hills. Smooth, oval in plan, and, in some cases, remarkably symmetrical, such hills are believed to reflect a process of glacial molding that is the work of both erosion and deposition. Here, as in other glaciated areas, streamline hills 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 the two materials.

An example is Cheney Hill, 1 mi south of the village of Essex. It is 0.8 mi long from base to base, 0.4 mi wide, and 150 ft high. Bedrock (Putnam Gneiss) is exposed or is very near the surface in a U-shaped belt that contours the southwestern, southern, and southeastern flanks of the hill but is not present close to the top nor in the northern slopes. At the northernmost point on the 150-ft contour line, a borehole for a well penetrated 47 ft of very compact till and then entered bedrock. These observations suggest that before glaciation, Cheney Hill was lower and consisted of bedrock, and that the ice that overrode it added to the bulk of the hill by plastering sediment thickly over at least its northern part. Other examples (for which, however, no borehole data are available) include the hill east of White Sands Beach in Old Lyme, Murdock Hill in Westbrook, and the unnamed hill 500 ft east of Stumpet Hill in the village of Essex.

When the forms of hills throughout the map area are compared with the pattern of rock types and structures shown on the bedrock maps of the two quadrangles (Lundgren, 1964, 1967), it is evident that many hills, even some having streamline form, parallel features in the bedrock. Several streamline hills, however, display no exposed bedrock and cross the general bedrock structure. The long axes of these hills trend NW-SE, broadly parallel with the average trend of striations; the forms of such hills were controlled primarily by glaciation.

STREAM-ABRADED BEDROCK

At a number of places, including some where exposures of bedrock are surrounded by outwash or ice-contact stratified drift (pls. 1, 2), bedrock has been abraded and smoothed by stream-borne sediment. Probably most such abrasion occurred during the melting of glacier ice and, less commonly, 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. A locality at which such surfaces can be seen conveniently is in the southern part of an abandoned gravel pit 500 ft west of State Highway 154, 3,600 ft northeast (along that road) from Cornfield Point in Old Saybrook.

TEMPORARY GLACIAL STREAM CHANNELS

Valleys that contain stratified drift indicate the former presence of temporary streams of meltwater. Apart from these, segments of some valleys that do not contain stratified drift appear to have carried temporary streams at times when melting glacier ice was so placed that it could provide the water. Most such channels cross minor divides, points from which today's runoff flows in opposite directions. Probably such places had been divides in preglacial time as well. Although most are now floored with colluvium or with swamp muck, during their occupation by streams bedrock probably was exposed in their floors.

Channels are indicated on plate 1 at four places:

1. Southwestern edge of Pond Meadow outwash body in Westbrook; crossed by telephone line.

2. Southwestern base of Mares Hill in Deep River.

3. Eastern base of Viney Hill, crossing the Essex/Old Saybrook Town Line.

4. Between Sunset Pond and South Cove in Essex.

Other channels include some that are far too small to be shown at the scale of the maps. Some are only a few tens of feet long and no more than 10 ft wide. They appear to follow joints in massive bedrock, and probably contained streams for only very brief periods.

GLACIAL SEDIMENTS

Sediments of glacial origin, collectively known as glacial drift, are of two general kinds: *till,* deposited directly from glacier ice, and *stratified drift,* deposited in streams or lakes created by the melting of glacier ice. Both kinds are present in the Essex and Old Saybrook quadrangles. Both are patchy and discontinuous in distribution and extremely variable in thickness. Specific measured thicknesses are given in the descriptions that follow.

Till

GENERAL CHARACTER

As a general type of sediment, till consists of a mixture of rock particles of many sizes, ranging from large boulders down to tiny particles of clay; however, at any one locality not all these sizes are necessarily present. Till forms a discontinuous mantle over the area. It covers much of the surface of the bedrock on hills and smaller valleys alike, and thereby shows that the bedrock had been sculptured, by weathering and by runoff of rainwater, essentially to its existing surface form before glaciation occurred. Because the major valleys are partly filled with sediment 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 sediment and, in turn, is underlain by bedrock. For example, the log of a well in the valley of Grassy Hill Brook, near the head of an arm of Rogers Lake (Old Lyme quadrangle), shows that sand and gravel were penetrated to a depth of 10 ft, followed in turn by 6 ft of till and by bedrock (unpublished data on file at U.S. Geological Survey, Hartford, Connecticut).

It is evident in plates 1 and 2 that in the majority of the areas where bedrock is at the surface or close to it, the slopes of hills are steeper than those elsewhere. The presence of steep slopes, in turn, depends to a considerable degree on minerals and structures, particularly foliation and jointing, in the bedrock. In places, vertical or very steeply dipping foliation and joints could have been quarried by the ice that flowed over the rock. 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 Essex and Old Lyme quadrangles the areas where bedrock is mapped as being at or close to the surface commonly display exposures of bedrock, many of them clifflike. Such areas also have many surface boulders, most of them consisting of the local bedrock and having 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 general appraisal of the thickness of till on north-facing slopes. However, the map area affords one measurement of thickness. The log of a well at altitude 200 ft on the northwestern slope of Cheney Hill, about 1 mi south of the Essex Post Office, shows 47 ft of till underlain by bedrock. The southeastern slope of the same hill is steeper, and boulders are abundant on its surface, suggesting that till is much thinner there.

Evidently many slopes that face "upstream" caused the flowing ice to deposit till over 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 surface, particularly on hillsides. Roadcuts, stream banks, and other surface exposures rarely show more than a few feet of till, as do most of the logs of borings, made principally for water wells, throughout the map area. However, 11 logs record till 30 ft or more thick, the greatest thickness being 80 ft (at a point about 1,100 ft north of the summit of Quarry Hill in Old Lyme). Probably the average thickness of till within the map area does not exceed 15 ft.

The surface of the till is smooth. It 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 it amounts to less than 5 percent. In the till within our map area, sand and silt are abundant relative to clay; hence the till is commonly rather friable. It is less so in areas underlain by micaceous, schistose rocks than in areas of quartz-rich, granitic rocks, where the fine fraction of till includes larger amounts of sand.

The pebbles, cobbles, and boulders in till are generally subangular, reflecting the joints and foliation surfaces in the bedrock from which they were derived. Most 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 (including big boulders) in the coarse fraction show that their surfaces are ragged fracture planes, modified little or not at all 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 commonly resembles the bedrock that immediately underlies it or that occurs within a short distance northward. Composition is reflected in the color of the sediment, which, when dried, ranges from yellows (hue 5Y) to yellowish grays and yellowish browns (hue 10YR) of the Munsell System (Goddard and others, 1948).

Although most of the till in the map area was derived from granitic, gneissic, and schistose rocks, a very small and variable proportion of it came from reddish and brownish sedimentary rocks and from basalt and diabase, all of Triassic age. Although such rocks do not occur within the map area, they are found northwest of a NE-SW line that passes within a distance of 15 mi (measured in the direction of the glacial striations) from the western edge of the Essex quadrangle. It is not remarkable, therefore, that Triassic elements are present in the till of this map area. They are present likewise in stratified drift, as stated in a later section.

Although most till is not stratified, at a few places within the area it 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 the structure is not known; it might have originated in at least two ways. Some 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.

STRATIGRAPHY AND CORRELATION

All the till seen exposed in the Essex/Old Lyme 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 layers of till are present and seem to be related to two distinct sets of striations (Flint, 1961). Elsewhere in Connecticut two different facies of till have been identified. They have been regarded by some geologists as having been deposited, respectively, beneath a flowing ice sheet, and on top of an ice sheet, near its margin, during the process of deglaciation. Others regard the two facies as deposits made by separate glaciations or, at least, as the result of significant change in the local direction of flow during a single glaciation. These differences of opinion are summarized by Pessl (1972). Probably the till of our map area is equivalent to one or the other of those tills or facies 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 time.

Erratic boulders

Erratic boulders, consisting by definition of boulders of any kind of rock that differ from the bedrock upon or above which they lie, are numerous in the map area. Some of them lie free on the surface of till or bedrock, 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). Forty-nine were observed, and many others were certainly missed in densely forested terrain. The largest seen, a pinkish gneiss on the southern side of Old Clinton Road in Westbrook near Turnpike Interchange 64, is set in till, which overlies quartz-schist bedrock across the road. The former dimensions of the boulder, now broken into several pieces, were about 15 x 15 x 15 ft.

Spacing of joints and foliation surfaces in the parent bedrock are the chief factors that determine the maximum diameter of a boulder. Both kinds of surface were instrumental in forming this large boulder.

In the Essex and Old Lyme quadrangles, the erratic boulders, both large and small, are distributed unevenly. Of the 49 large erratics plotted on plates 1 and 2, 24 are on or in very close proximity to end moraines. The cause of such concentration is discussed in the section on end moraines.

Stratified drift

KINDS OF STRATIFIED DRIFT

The sorted sediments, mostly stratified, that are 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 Essex/Old Lyme 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 margin of the glacier. The other end member is the drift deposited, miles or tens of miles from the glacier in which it originated, by streams that flowed away from the glacier. The sediments of both facies are much the same, although, like all stream-deposited sediments, they become finer grained and better sorted in the downstream direction. However, as long as ice, residual from the glacier, is present beside or beneath accumulating stratified drift, that drift will show characteristics that betray its peculiar place of deposition, and constitutes a facies labeled *ice-contact stratified drift.* Downstream the character of stratified drift changes, as residual ice beside or beneath it became gradually less abundant. Where the direct influence of ice has ceased to be evident, the sediment constitutes a facies labeled *outwash,* although it is essentially the same body of sediment.

We define ice-contact stratified drift, then, as sediment deposited in streams and other bodies of water against, upon, beneath, or otherwise in immediate contact with melting glacier ice. Such sediment includes sand, gravel, silt, and clay, and commonly possesses 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), and deformation of sedimentary layers 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 is characterized, in places at least, by constructional topography that includes basins (known as kettles), partial basins, irregular, knoll-like mounds (*kames*), and *kame terraces* gradually built up between the sides of a glacier and the sides of the valley it occupies. These features reflect the presence of irregular bodies of melting ice during accumulation of the drift.

In the map 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 oxidized bedrock. However, like the till mentioned earlier, a small portion of the stratified drift, in the form of scattered pebbles, and lenses of sand and silt, is derived from reddish sedimentary rock and dark-colored igneous rock of Triassic age, occurring north and west of the map area. The significance of this fact is mentioned in a later section.

In contrast with ice-contact sediment, outwash is defined as stratified drift deposited by streams beyond a 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 Essex and Old Lyme quadrangles are long bodies of stratified drift of one or both of the kinds 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, figure 3 (in pocket) is a map of the units, and figure 4 (in pocket) shows the long profiles of units in the largest valleys. Several of the drift bodies, elongate and confined to specific valleys, are referred to as *valley trains*, although that term is more commonly applied to bodies of drift that consist exclusively of outwash. Each of the valley trains consists, in an upstream part, of ice-contact sediment and, in a downstream part, of outwash sediment. The relationship between the two parts is gradational through a distance of a mile or more. Near the shore the outwash spreads laterally, so that some adjacent valley trains merge to form wide plains. The individual valley trains that participated in such mergers, however, were not necessarily built at precisely the same times. The communities of Grove Beach, Westbrook, and Old Saybrook are located on these plains. As the maps (pls. 1, 2) show, the plains have been dissected by streams during a postglacial period, and subsequently have been partly submerged in the sea. Therefore, they now consist of detached remnants separated from each other mainly by wetlands represented by tidal marshes.

The positions at which the valley trains change from ice-contact character to outwash character bear a significant relationship to the end moraines south of them. This matter is explained in the section that deals with end moraines. Meanwhile, six principal valley trains are described.

ORTNER'S—GROVE BEACH VALLEY TRAIN

This valley train (figs. 3, 4) lies in the southwestern part of the Essex quadrangle. It is named for Ortner's Pond near its northern end and Grove Beach near its southern end. Its northern part merges with the Menunketesuck River/Indian River Valley Train, in the adjacent Clinton quadrangle (Flint, 1971). In the north it is a narrow, irregular, thin body of sand and gravel, occurring as terracelike masses along the sides of Plane Brook and Menunketesuck River. Its undulating surface was created in part by collapse during melting of the residual ice upon which it had been built. South of Old Clinton Road the body broadens as it merges into outwash, a large part of which has been cut away by the Menunketesuck and other streams. The supply of sand and pebbles from the melting glacier was so abundant that the stream of meltwater, subdividing into a maze of small interlacing channels separated by sandbars, deposited it, building up the outwash plain to a height well above the surface of the Menunketesuck River of today. The rising plain was built up around both sides of the till-covered hill 0.5 mi northwest of Grove Beach, isolating it as a sort of island. The outwash sediment likewise enveloped segments of end moraine and left them isolated, as is clearly evident on plate 1. Probably the outwash sediment originally extended far southward through the area now occupied by Long Island Sound, which stood above sea level at the time the outwash was built.

In the few existing exposures and borehole records, sand predominates. Near the head of the valley train some of the gravel interbedded in the sand includes material of cobble size, whereas farther downstream it consists almost entirely of pebble sizes, and near the shore little if any gravel is present.

The thickness of the valley-train sediment varies. In a few places thicknesses of 7 ft to 14 ft, directly overlying bedrock, have been measured, and at the point where the Connecticut Turnpike crosses the channel of the Menunketesuck River, a boring passed through 44 ft of silt and sand that directly overlie bedrock.

PATCHOGUE RIVER VALLEY TRAIN

This valley train follows the course of Trout Brook and Patchogue River from the center of the Essex quadrangle to Long Island Sound. Its highest part, at an altitude of 60 ft, is at the Bowie Gravel Pit, on the western side of Highway 153 about 2 mi south of Centerbrook. From that point the valley train, of ice-contact character, slopes back northward through about a mile, as far as Tiffany Brook, where its altitude is only 30 ft and where it is inferred to be overlapped by the younger Centerbrook Valley Train. The backward slope is thought to be the result, not of deposition but of gentle subsidence (fig. 5). The sediment of the Patchogue River Valley Train appears to have been built up on top of a tonguelike lobe of the melting ice sheet. After deposition ceased, the ice beneath it melted from the top downward, gradually letting its covering of sediment down to the ground.

Just south of the Bowie Pit the valley train assumes the character of outwash and becomes very narrow, through a distance of a little more than a mile. South of Johnson Pond it spreads out to almost a mile in width, and again assumes an ice-contact character, having a very irregular surface with many small basins resulting from collapse of sediment over melting, buried ice. This seems to mean that thin residual ice was still present on the lower land before the deposition of sediment ceased. The alternative interpretation that (1) the ice-contact drift south of Johnson Pond is older than (2) the outwash north of it seems less probable, because no channel cuts straight through (1) from Johnson Pond southward. The existing drainage makes a hairpin turn as it passes through the northern part of (1), as though collapse of the stratified drift had occurred after, rather than before, the flow of meltwater through the area of the pond ceased.

Between the Connecticut Turnpike and the railroad the sediment once more assumes the character of outwash, merges with its Grove Beach neighbor, and passes southward beneath the present sound.

The valley train is at least 75 ft to 90 ft thick near its head, as shown by 11 test borings in and near the Bowie Pit and an additional boring 1,200 ft south of the pit. In the Rintoul Pond-Johnson Pond area three borings show the sand/gravel body to be 14, 20, and 28 ft thick.

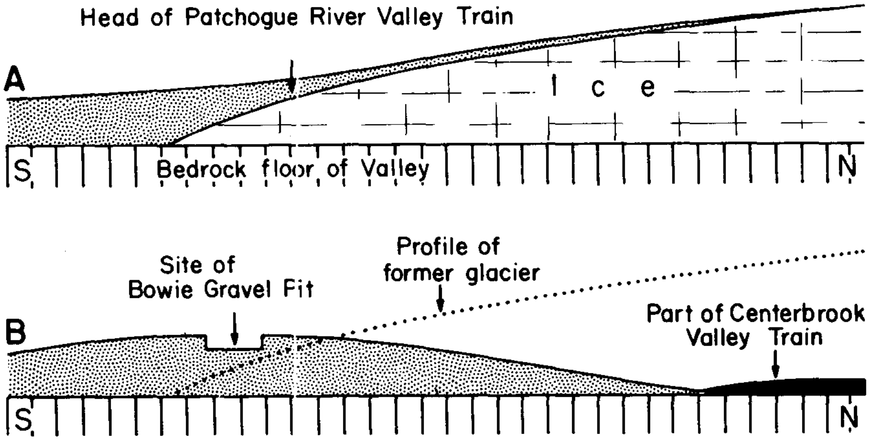

Fig. 5. Diagram showing the way in which the head of the Patchogue River Valley Train may have evolved, as explained in text.

CENTERBROOK VALLEY TRAIN

This valley train has two branches, each of which brought outwash sediment to the broad, flat area on which the village of Centerbrook stands. One branch is followed by the railroad from beyond the northern edge of the Essex quadrangle; the other occupies the valley of Deep River and passes via Ivoryton to Centerbrook. The southern edge of the wide plain overlaps the collapsed head of the Patchogue River Valley Train near the ponds along Tiffany Brook. Although most of this valley train consists of outwash, the more westerly branch, along Deep River and the tributary south of it, is of ice-contact character, well displayed in the Blakeslee pit and the Moskal Brothers pit south of it, both abutting State Highway 80.

The Blakeslee pit, more than 4,000 ft long, shows a wide range of sediment that includes silt, sand, pebbles, cobbles, and boulders as much as 10 ft in diameter. The sediment was deposited predominantly in streams and small temporary ponds; the many boulders were contributed by landsliding from adjacent ice and from the steep sideslopes of the valley. The whole assemblage suggests an alluvial fan, with a gradient of about 50 ft per mi, built partly over ice and partly between masses of ice. It grades rapidly into outwash near the eastern end of the pit. Borings in and near the pit indicate sediment thicknesses of 50 ft to 100 ft, overlying an irregular surface of till-covered bedrock. Farther east, near the intersection of Highway 80 with Warsaw Street, the outwash, as revealed by borings, is 50 ft to 60 ft thick and consists mainly of silt with some clay, suggesting that the meltwater there may have been ponded. Although shown on the map (pl. 1) as a single valley train, the sediment may represent two phases, the sand and gravel at altitudes as high as 160 ft along Warsaw Street and the silt at about 140 ft forming the flat at the northern end of Warsaw Street. If this is the case, the finer grained phase was deposited slightly later than the coarser sediment.

The Moskal pit, although large, exposes only 13 ft of sediment, mainly sand, which seems to have been deposited upon thin, residual ice that extended from the northern end of the site of Bushy Hill Pond eastward through nearly half a mile. Its deposition was contemporaneous with that of the sediment along Deep River.

The Centerbrook Valley Train can be traced eastward from Centerbrook to Sunset Pond, where it ends, at altitude about 30 ft, at a well-defined curving channel cut into till, leading down to sea level at South Cove. The downstream end of the channel appears to pass beneath a different and younger body of outwash derived from the North Cove area. It is possible, although not established, that before the channel at Sunset Pond began to function, the water that deposited the Centerbrook Valley Train escaped through the channel, at altitude 50 ft, now followed by the railroad, 2,000 ft southwest of the summit of Viney Hill. If it did, thin residual ice was then still present north of Ingham Ponds, downstream from the channel, because ice-contact drift there does not obviously indicate trenching by stream water.

OLD SAYBROOK VALLEY TRAIN

The next valley train to be described heads south and east of South Cove, passes along a network of routes, and reaches the line of the existing shore at two places: Westbrook and the vicinity of Chalker Beach. It is named for Old Saybrook because its greatest extension lies within that town. Like the Centerbrook Valley Train, it has two branches probably built in close succession within a short period. The older and more southerly branch heads adjacent, upstream, to the Turnpike bridge over the Connecticut River, and forms Ferry Point. An unknown portion of the ice-contact facies has been destroyed by erosion. The small part that remains merges immediately into an outwash facies that can still be followed southwestward along the turnpike and railroad to its junction, near where Fishing Brook joins Oyster River, with its more northerly counterpart. Very probably the outwash facies originally also spread southward down the line of the existing Connecticut River, cutting through the end moraines there and merging with outwash entering from the northeast at Old Lyme to form a Connecticut River valley train as much as 1.5 mi wide. The ice-contact facies exposes cobble gravel but the outwash part consists mainly of sand and pebble gravel.

The more northerly branch of the Old Saybrook Valley Train has an ice-contact facies that extends from the Connecticut River at Otter Cove Estates to the vicinity of Obed Heights, a distance of 2 mi. Merging into an outwash facies, the valley train continues southwestward surrounding many "islands" of till-covered bedrock and cutting through end moraine along the shore. Near the shore, later erosion has cut the outwash away through wide areas, forming shallow valleys that are now floored with tidal-marsh wetlands. The ice-contact facies is best displayed in the Appleby and Kutone sand pit. Here pit faces expose as much as 25 ft of sediment, 90 percent of it sand. In places, however, the sand wholly encloses very large boulders that probably slid off adjacent ice. The sediment includes fillings of shallow basins that probably had been created by collapse accompanying the melting of underlying ice. The outwash facies is composed primarily of sand, with varying proportions of gravel whose particles are progressively smaller and more thoroughly rounded in the downstream direction.

BLACK HALL RIVER VALLEY TRAIN

This valley train lies east of the Connecticut River, and is both comparatively long and little damaged by erosion. Although named for the longest of the streams that drain it, it extends north of the head of Black Hall River and also includes a large western member that is drained partly by Duck River and partly by Lieutenant River. The valley train includes an eastern unit followed by the course of Black Hall River, and a western unit that extends southward from the area south of Laysville past the site of the village of Old Lyme to the Connecticut River estuary.

The eastern unit, and its continuation northward as far as the northern edge of the Old Lyme quadrangle, consists almost wholly of ice-contact stratified drift. It was built when the southern margin of the continuous ice sheet stood just north of Rogers Lake. A large, detached mass of ice lay in the twin basins of the lake itself, while other, smaller masses lay dotted through the valley of Black Hall River at least as far as the end moraines near White Sands Beach. Gravel and sand from the glacier were deposited around and upon these ice masses, and after deposition ceased and the buried ice melted, the sediment collapsed to form the many basins in the surface of the valley train. On the broad plain at Cranberry Bottoms, west of Rogers Lake, the ice melted out before deposition ended, with the result that the plain contains no basins and the sediment there is mapped as outwash. Several borings around the southern half of Rogers Lake indicate that the valley train is thick there. Sand and gravel with minimum thickness as great as 94 ft is recorded.

The western unit of the Black Hall River Valley Train has a smooth surface marked by very few basins; also its altitude is slightly lower than that of the eastern unit. From this we infer that deposition of sediment along the western route continued until after most of the ice remnants had melted away. The western unit is therefore mapped as outwash. Probably the outwash merged with that on the western side of the present Connecticut River to form a wide plain extending southward through the wide gap in the end moraines between White Sands Beach on the east and Saybrook and Lynde Points on the west. The altitude of the combined plain, along a line running eastward from Lynde Point, would have been close to that of today's sea level.

FOURMILE RIVER VALLEY TRAIN

Named for Fourmile River, which flows along a line close to the eastern edge of the Old Lyme quadrangle, this valley train consists of ice-contact sediment in its northern half and of outwash in its southern half. The northern half is an undulating plain, 0.3 mi to 0.4 mi in width, pitted with basins and including coarse gravel mixed with its predominant composition of sand. North of the Connecticut Turnpike crossing, it merges into outwash consisting of sand and small pebbles, and also becomes narrow because the greater resistance to erosion of the bedrock there has resulted in a narrower bedrock valley. South of South Lyme the valley train has been much dissected by streams. Little is known about the thickness of the valley-train sediment. At a point about 300 ft east of Plants Dam a boring encountered at least 30 ft of sand and gravel. Between that point and the northern edge of the quadrangle the forms of kame terraces suggest that the valley train is at least as thick as near Plants Dam.

OTHER BODIES OF STRATIFIED DRIFT

Apart from the valley trains described above, few bodies of stratified drift were identified in the map area. Of these, three can be described as a group because their positions suggest they were formed close together in time. One is the small outwash plain at Pond Meadow, about a mile northwest of the center of the Essex quadrangle. An abundant content of cobble-size particles suggests the presence of glacier ice close by to the north. The meltwater that deposited the thin sand and gravel of this body may have drained away from the southwestern corner of the plain through an ill-defined channel, now dry, in bedrock hills, into the drainage basin of Spring Lot Brook. Today's drainage flows northward, but when the outwash was built, a northward route would have been blocked by the glacier.

One mile northeast of Pond Meadow, a small body of ice-contact stratified drift occupies the southern end of Ivoryton Park. It includes a form resembling a small esker, probably built in a tunnel or open channel in the margin of the glacier. The sediment suggests the presence of a small temporary lake ponded by the glacier against the base of Mares Hill. Very likely the meltwater escaped through a long channel, at about 100-ft altitude, leading southward into the Patchogue River drainage.

The third member of the group is an ice-contact body with the form of an inverted U, wrapped around the northern end of Viney Hill, about 1 mi southwest of Essex Post Office. Its internal character, with sediment built up in ponded water and other sediment deposited by streams, is displayed in the large Woollock pit. The meltwater escaped southward, through a short channel east of Viney Hill, into the area occupied by an arm of the Old Saybrook Valley Train. Drainage northward, the direction of today's drainage, was blocked by ice. The three small bodies of sediment just described lie in about the same latitude and therefore may have taken form at about the same time. The Patchogue River Valley Train, with its collapsed head, may likewise have been approximately contemporaneous.

Another small body forms the western shore of North Cove, just north of Essex. It consists of an ice-contact part and an outwash part. Its altitude is about 30 ft. Its building may have overlapped, in time, the latest part of the building of the Centerbrook Valley Train. The outwash remnants north and south of Middle Cove may have been contemporaneous with it.

The foregoing bodies lie within the Essex quadrangle. In the Old Lyme quadrangle a patch of ice-contact stratified drift abutting Uncas Pond and another patch half a mile west of that pond may be related to the Black Hall River Valley Train, but are disconnected and so small that their relationships are uncertain.

Another patch occupies an unnamed valley just west of South Lyme. Its northern part is typical ice-contact stratified drift, well displayed in an abandoned pit. This grades southward, with two discontinuities, into outwash that reaches the shore of Long Island Sound at Point O'Woods. The whole body could be regarded as a small valley train. Its head is significant in that it is aligned with two segments of what is probably a single end moraine. One segment lies 1,500 ft east, the other 1.8 mi west. Thus a single, contemporaneous former glacier margin through a distance of a little more than 2 mi may be indicated by features of two different kinds.

Still another isolated patch of stratified drift, in this case outwash, fringes Hamburg Cove in the northwestern corner of the quadrangle, and is exposed in a pit just north of Ely Ferry Road in Lyme. The sediment, predominantly sand with layers of silt and of pebbles, was built by south-flowing meltwater streams, and shows no indication of the presence of ice. It is typical outwash, with a surface altitude of 50 ft. The lower altitude of the ice-contact stratified drift at North Cove, 1 mi west across the Connecticut River, implies that ice was present there when the outwash at Hamburg Cove was deposited but so much subsequent erosion has occurred that it has not been possible to reconstruct the sequence of events. Small patches of outwash sand between Connecticut River and Lieutenant River, just north of the Turnpike, seem to be remnants of a formerly continuous body, but here also reconstruction is hardly possible. As indicated in a later section of this report, it is very likely that the valley of the Connecticut River was, at least once, filled with outwash sediment from side to side.

This possibility receives some support from two exposures, along the Connecticut River within the map area, that were examined in June 1941 but no longer exist. The first was in a sand pit on the eastern side of River Road in Essex, at the northern end of North Cove. It showed parallel-laminated gray to yellowish fine sand, interlayered with red silt derived from Triassic strata, the whole body at least 10 ft thick and overlain disconformably by 3 ft of stream-deposited sand and gravel, at an altitude of approximately 30 ft. A similar exposure of interlaminated, parallel layers of reddish and yellowish fine sand, 5 ft thick and underlain by till, was examined in that same year, in a cellar excavation at altitude 20 ft to 25 ft, on the western side of Ayres Road in Old Saybrook, about 0.8 mi northwest of Ferry Point. The sections described resemble those characteristic of the margins of valley trains active today. These valley trains act as dams across tributary re-entrants along the valley sides and create small lakes, into which fine-grained sediment from the valley train is washed. The presence, in such deposits, of sediment derived from Triassic strata implies a valley train that originated at least as far upstream as the nearest outcrop of Triassic rock. That outcrop is 25 mi upstream from the mouth of the river.

Other exposures of similar sediment were noted along the Connecticut River at places near Chester, Deep River, and Haddam. Furthermore, outwash sand at least 100 ft thick has been encountered in borings beneath the river at the site of the Baldwin Bridge, between Old Saybrook and Old Lyme, and has been inferred from a seismic-reflection survey farther downstream (fig. 6).

Taken together, these occurrences and the exposures described suggest that a long valley train once occupied the Connecticut River valley. The sea was then lower, relative to the land, than it is today. Hence the valley train would have extended far southward through the area now submerged beneath Long Island Sound, and would have met the ocean at some point on what is now the continental shelf. Evidently much of this large body of sediment was subsequently removed by erosion, and was carried southward to areas now submerged, leaving above sea level only small remnants in protected places. Study of the quadrangles upstream would probably throw more light on the sequence of events.

As a footnote to the description of minor bodies of stratified drift, a small ridge, along the western side of Mile Creek between the railroad and the southern toe of the end moraine 0.4 mi south of Tinker Pond in Old Lyme, might be mentioned. Eight hundred feet long, 100 ft wide from toe to toe, 10 ft high, and with pebble gravel at its surface, it resembles an esker deposited in an ice channel or an ice tunnel. From surface indications it appears to be overlapped at its northern end by the end moraine adjacent to it. It seems to antedate that moraine, which in turn antedates the Black Hall River Valley Train immediately north of it.

END MORAINES

In the coastal part of the map area are segments of end moraines. Such

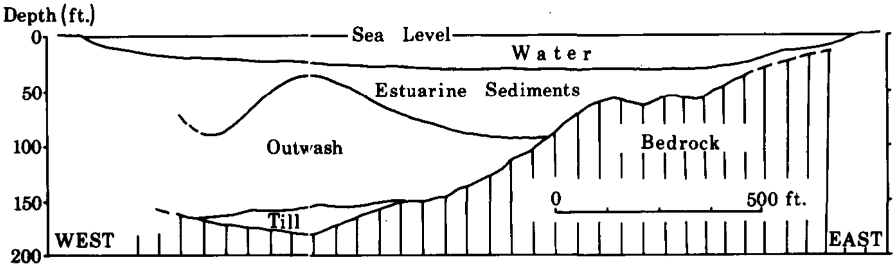

Fig. 6. Section across Connecticut River about 1 mi south of Baldwin Bridge in Saybrook and Old Lyme, based on seismic-reflection profiles (Haeni, 1971, fig. 10). Another section, at Baldwin Bridge, based on borings, is given by Upson and Spencer (1964, pl. 1D). The borings support the interpretation of the sedimentary units shown in this figure.

features are usually defined as ridgelike accumulations of drift built by a glacier along its margin. The position of the margin represents a balance between two processes--forward flow of ice and melting-back of ice. The longer the margin occupies a single position, the greater the volume of rock debris that is brought to that position by the flowing ice. The part of the debris that is not washed onward by meltwater accumulates there, forming a ridge, that varies in visible height. In these quadrangles, end moraines are 10 ft to 20 ft high and about 500 ft to nearly 1 mi wide.

As can be seen on plates 1 and 2, the areas of end moraine are densely populated and are occupied chiefly by houses and lawns. Hence exposures of the material underlying them are both few and very shallow. Apart from larger exposures examined in 1941, before most of the areas were built up, description of moraine materials is therefore based on small, surficial openings. At greater depth the materials may well be more compact than the loose, friable sediments exposed at the surface today. The drift consists of sandy 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, its crest rising and falling. In places the entire ridge disappears, leaving a gap not marked 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. The end moraines that traverse the Essex and Old Lyme quadrangles reflect these characteristics. The moraines are part of a discontinuous group of such ridges that have been identified in coastal eastern Connecticut and Rhode Island (Schafer and Hartshorn, 1965, p. 116).

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 small 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 19 moraine segments shown in plates 1 and 2 were identified on the basis of the following 7 characteristics. Few of the segments clearly possess all 7 but most have at least 3:

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, consisting of discontinuous ridges with irregular intervening basins, together creating relief of 5 ft to 10 ft and with very gentle slopes. The orientation of such features is random in many places, but in some it is generally E-W. Although a few of the basins are obvious kettles, most of them seem to have been caused by irregular deposition of drift.

4. Concentrations of boulders on crest and proximal (northern) slope, both at the surface and in exposed sections.

5. Composition consisting of till and stratified drift, the till exceptionally sandy owing to the sorting-out and removal of its finest constituents, clay and silt, by abundant meltwater at the margin of the glacier.

6. Alternations of (a) till and (b) stratified drift containing glacially shaped and striated stones, both in single exposures and between one part of a segment and another. Also local contortions in such drift. Both features probably were caused by slight fluctuations in the position of the glacier margin during the building of a moraine.

7. Absence of exposed bedrock within (although not beneath) the ridge.

The reason why the various end-moraine segments differ is that along different parts of the margin of an ice sheet different activities take place. At one place till is being plastered onto the ground from the base of flowing ice, whereas at another a fanlike body of sand and gravel is being piled up by streams of meltwater on thin marginal ice. Although minimum visible heights of the moraines range from less than 10 ft to more than 20 ft, true heights are not known because the bases of the segments are not exposed; indeed, some segments are partly buried by outwash.

With the possible exception of the triangular-shaped outwash body at Sound View and Hawks Nest Beach, outwash sediment 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. Evidently it was deposited when the margin of the ice sheet had melted back to positions north of the moraines. As meltwater streamed away from the ice, the outwash sediment built up by the streams wrapped around some of the segments of moraine, accentuating the isolation of one segment from another. Very likely, similar but earlier outwash was built contemporaneously with the end moraines but, if so, it has been partly eroded by streams, partly cut away by the postglacial sea, and partly buried by blankets of outwash of later date.

Erosion of moraines by streams is indicated at South Lyme, where an end moraine has been cut transversely by Fourmile River. The river washed away all the drift except the boulder sizes, which now litter the river bed. Similar erosion is evident where Mile Creek cuts a moraine 0.2 mi north of the railroad. Not only is the narrow valley of the creek choked with boulders residual from the moraine but the southern part of the moraine has lost all its substance except for boulder-size material, which constitutes a ridge, nearly 20 ft high, that preserves the moraine form. The more northerly part of the moraine still retains the smaller particles between its abundant boulders, some of which are as much as 20 ft in diameter.

It should be noted here that across the southern part of the Black Hall golf course immediately south of this moraine, much erosion has been accomplished by human activity. Between 1963 and 1972 an enormous number of large boulders was moved. Some were buried and many were pushed down the western side of Mile Creek valley just south of the railroad bridge over the creek. A longtime resident of the area remarked that before the removal one "could walk across the entire golf course, stepping only on boulders." Few boulders were removed from the eastern part of the course, the part that faces Mile Creek. The litter of large boulders there gives an idea of the appearance of the site before the removal of the boulders. The area is mapped as end moraine because of the linear form of the littered area and its continuity with the ridgelike moraine that extends northeastward from Mile Creek.

Another process that has affected end moraines is erosion by surf. Wherever a moraine has been cut along the shore, such erosion is evident. Boulders, being the least readily movable of the moraine materials, have accumulated along the beach and, by slowing erosion, are acting to protect the remnants of the moraine. The most obvious example is Cornfield Point in Old Saybrook, which is protected by an armor of residual boulders, in places augmented by artificially placed riprap. From that point a shoal, a ridge as much as 20 ft high, extends west southwest for nearly 2 mi, and includes both Hen and Chickens Reef and Crane Reef (pl. 1). It is a reasonable speculation that the entire shoal, probably now reduced to boulders, represents the westward continuation of the moraine between Cornfield and Lynde points. Farther east, a parallel though less well-marked shoal (pl. 2) extends from Hatchett Reef westward through 2.5 mi to a point opposite the mouth of the Connecticut River. This shoal, too, might represent what is left of a former moraine.

The local washing-out of the finer grained material of a moraine, leaving only residual boulders, suggests that local concentrations of boulders represent segments of former moraines. An example is an area 0.3 mi in length along and near Highway 156 just west of Mile Creek. This group of boulders, the largest one 15 ft in diameter, may well be related to the moraine at White Sands Beach. Another example consists of two concentrations of boulders, the largest also 15 ft in diameter, together stretching along the beach through a distance of 1,300 ft, immediately south of Point O'Woods. These, together with another concentration that extends 1,500 ft north from Hatchett Point, perhaps represent further eastward continuation of the end moraine at White Sands Beach.

The apparent concentration of boulders on the crests and northern slopes of moraines is evident generally, and is clearly indicated (pl. 2) between Knollwood and Fernwood in Old Saybrook, even though the boulders represented on the map consist only of those that are 10 ft or more in diameter. Such apparent concentration possibly has resulted from two causes: principally, (1) more abundant deposition in those places and, less importantly, (2) concealment of boulders in other places.

1. Once it has begun to accumulate, an end moraine constitutes a barrier, still further localizing the narrow zone within which additional debris can accumulate along the margin of the flowing ice that presses against the barrier. Many of the pebbles, sand, and smaller size particles are washed onward but the boulders tend to remain. 2. The deposition of pebbles and finer materials forms a discontinuous blanket over parts of the southern slope of the moraine, tending to bury and conceal any boulders already on that slope.

A feature that seems to be related to the non-uniform distribution of boulders is that the widths of moraines are greatest near the Connecticut River and decrease both east and west away from the river. Width is a rough measure of the bulk of a moraine, reflecting the volume of debris brought to the margin of the ice sheet in a unit of time. Volume, in turn, could be related to erodibility of the bedrock upstream or to rate of flow of the ice. As the bedrock that underlies a coastal belt 10 mi wide does not seem to be more erodible along the Connecticut River than elsewhere, greater rate of flow of ice through the Connecticut Valley seems a more likely cause. A few miles upstream, the bedrock valley extends from more than 100 ft below sea level to around 500 ft above it. In this trough, as much as a mile in width, the glacier was thicker than over the remainder of the coastal belt, and so would have flowed faster. Similar, faster flowing *ice streams* have been observed within the existing Greenland and Antarctic Ice Sheets, and are believed to be localized by bedrock valleys concealed beneath the ice. It is possible, then, that the Connecticut Valley localized an ice stream at the time when end moraines were built along the Connecticut coast.

Because the moraine segments shown on plates 1 and 2 are discontinuous and because the terrain is hilly, the segments have not been correlated with assurance. We can say, however, that a view in perspective suggests the segments may integrate into two parallel moraines or groups of moraines, each with a trend near N 80° E, slightly oblique to the general trend of the coastline. A southerly group includes the segments between Cornfield Point and those at White Sands Beach, north of Sound View, and near South Lyme. The last-named segment continues east of the map area and has been mapped on the adjacent Niantic quadrangle (Goldsmith, 1964). The northerly group includes the segments at Clinton Beach, Grove Beach, Quotonset Beach, Saybrook Manor, Old Saybrook, Saybrook Point, and possibly also the segment north of the Black Hall golf course.

Possible continuations of end moraines beneath present sea level are suggested by three long narrow ridges on the floor of Long Island Sound at three localities, as indicated by contours on plates 1 and 2. The first extends southeastward from Cornfield Point and is 2 mi long and as much as 20 ft high. The second, running southeastward from Saybrook Lighthouse, is 1 mi long and as much as 5 ft high. The third, extending southwestward from Hatchett Reef for 2.5 mi, is 5 ft or more in height. Because information on the composition of these ridges is lacking, the possibility that they are former shore features, such as beaches, spits, and beach dunes built of sand, and even the possibility that they are bedrock features, are not ruled out. However, the forms, trends, and positions of these ridges relative to moraines are compatible with the idea that they themselves are of morainic origin. If they are, probably they consist of boulders from which original finer material was washed away during the later submergence of the Connecticut coast. Probably also they are covered by the blanket of marine sediment that is spread over most of the floor of the sound.

Whether or not any or all of the submerged ridges are moraines, we can say that the southerly group of moraines mentioned above is the older of the two groups, built before the margin of the ice sheet had melted back to the position marked by the northerly moraines. The fact that each group is nearly straight, despite a pre-moraine relief of the general surface amounting to at least 150 ft, implies that when the moraines were built the wasting ice sheet was comparatively thick. Had it been thin enough to be strongly influenced by the relief, the margin should have been markedly lobate, a form that would have been reflected in the trends of the end moraines.

We have no means of measuring the thickness of the ice sheet in coastal Connecticut. However, if we assume reasonably that when the outer margin of the ice stood along the site of the present Long Island and built the Ronkonkoma Moraine there, the profile of the upper surface of the ice sheet approximated that of today's Antarctic Ice Sheet along the measured line that extends inland from Mirniy (Bentley and others, 1964, pl. 2), then at the site of Saybrook, some 23 mi north of the Ronkonkoma Moraine, the ice sheet would have been more than 3,600 ft thick. In a gradually warming climate, melting of such a thickness of ice could have been accomplished in considerably less than 1,000 years, as indicated by measurements made, over a 50-year period, on glaciers in Iceland (Ahlmann and Thorarinsson, 1937, p. 191).

Turning to the valley trains north of and, in places, surrounding the end moraines, we note again that in each valley train the arbitrary, generalized line (dashed on pls. 1 and 2) that separates the ice-contact part from the outwash part, represents the approximate position of the southern margin of the melting ice at the time when the valley train had been built up to its maximum thickness. Although they occur at different positions in each valley, these lines together occupy a belt of terrain, 3 mi to 4 mi wide, that trends slightly north of east, nearly parallel with the trend of the moraines. This arrangement suggests that the lines approximate the margin of the ice sheet at a single time, the differences in their individual positions resulting from differences in rate of melting in valleys that were unlike in size and shape. The lines suggest further that by this time the margin of the ice sheet had become slightly lobate as it thinned, while still maintaining its general ENE trend.

North of this belt of terrain no comparable rough alignment of the two facies of valley trains has yet been identified. Long valley trains become fewer and ice-contact stratified drift, marked particularly by kame terraces and kames, becomes more abundant relative to outwash. This change in character of the stratified drift suggests further thinning of the outer zone of the ice sheet, now fringed with lobes and separated masses of ice, upon which sand and gravel were being deposited by streams of meltwater. At the same time, north of that zone the glacier was nearly continuous, spreading over valleys and ridges alike but, in time, the thin marginal zone would migrate northward and gradually replace the continuous ice, and in turn would be replaced by the ice-free terrain south of it.

POSTGLACIAL SEDIMENTS

Alluvium and colluvium

In the Essex/Old Lyme 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 coastal Connecticut, as in the New Haven/Woodmont quadrangles (Flint, 1965), it is possible to identify and map (as *terrace alluvium*) the alluvium that veneers such terraces along large streams because it is coarser than the alluvium in the same areas. In the present map area, however, alluvium has not been identified on terraces.

Along some streams that have steep gradients, alluvium is replaced by a concentrate of boulders and large cobbles derived from underlying till, the smaller particles having been washed away. A conspicuous example is the floor of Deep River in an area about 0.5 mi north of Post Hill in the Essex quadrangle. Upstream, where the gradient is smaller, coarse alluvium is present.

Thickness of alluvium varies with size of the related stream. Exposed thicknesses of 2 ft to 3 ft are not uncommon; at a few points exposures of 4 ft to 5 ft were seen. The coarsest alluvium, mainly gravel, is found along small streams with steep slopes. Along large streams alluvium is mostly sand, silt, and clay in varying proportions, brown to yellowish brown, 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 wind, covers parts of many valley trains, and in places occurs on adjacent slopes underlain by till and bedrock. Although it generally overlies valley-train sediments, it does not overlie alluvium. Hence it must postdate the valley trains and must antedate the alluvium. Its observed thickness is generally less than 2 ft and in many areas is more than 6 in.; hence it is not included on the maps. Such sediment is primarily sand, with silt a minor constitutent. The sand grains are angular, and their angularity is not distinguishable from that of the sand grains in the local bodies of outwash. The similarity is compatible with the limited distribution of the wind-blown sand, which shows that the sand was derived from outwash and was blown only a short distance before being deposited.

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 long, narrow strips immediately landward of nine well-developed beaches. The strips of wind-blown sand are generally wider than the exposed parts of the beaches themselves. East and west of Hatchett Point their width reaches at least 400 ft and near Lynde Point nearly 1,000 ft. Viewed under a 10x hand lens, the sand is seen to be medium to fine grained and moderately angular, and is not distinguishable from the beach sand adjacent to it. Hence, on the maps it is identified separately only on the basis of the surfaces it forms as it accumulates in long strips. The form is undulating and, in places, hummocky where incipient dunes are present. Most of the dunes are 3 ft to 4 ft high but back of Clinton Beach and Plum Bank Beach they reach 6 ft. 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 truly modern. It is blown 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. However, the mouth of the Connecticut River, a fully tidal stream, is known to be floored with estuarine sediment, as revealed by core borings along the length of the Turnpike bridge (Upson and Spencer, 1964). This sediment, with a maximum thickness of more than 100 ft, consists of gray mud made up of silt, sand, clay, fine organic matter, bits of plants, and broken shells of clams, oysters, and other shallow-marine organisms. It has been found also in borings beneath tidal-marsh peat east of Clinton Harbor just west of the Essex quadrangle (Bloom and Ellis, 1963, fig. 5) where it is more than 20 ft thick and overlies outwash. 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 1, occur in various parts of the Essex and Old Lyme quadrangles. 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, but some of 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 Essex/Old Lyme area have not been studied from this point of view, but a marsh in New Haven (Deevey, 1943, p. 726) yielded a 28-ft core, 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.

Table 1.—Genetic classification of swamps and marshes in the Essex (E) and Old Lyme (OL) quadrangles.

Origin	Example
Basin in till	Swamp in Westbrook, 0.4 mi north of Toby Hill (E)
Basin created by dam of stratified drift	Mine Swamp, 0.7 mi southeast of Pond Meadow crossroads (E)
Kettle; basin in collapsed drift	Swamp in East Lyme, 0.7 mi north of Plants Dam (OL)
Valley floor without definite basin [1]	Swamp south of McVeagh Road in Westbrook, 0.5 mi north of Dee Pond (E); swamp 1.0 mi north of Turnpike Interchange 71 (OL)
Tidal marsh [2]	Marshes east and west of Connecticut River estuary and south of railroad

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

[2] Detailed in text.

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. The Connecticut River is fringed by tidal marshes upstream past the northern limit of the Essex and Old Lyme quadrangles. Stream channels within the marshes normally form 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 four 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 all beaches within the map area is about 13.9 mi, exclusive of all small beaches along the Connecticut River north of the railroad bridge. This length, however, includes the spit at Hawks Nest (point), which reaches out toward the opposing spit attached to Menunketesuck Island. This aggregate length equals more than half the length of the shoreline itself, exclusive of estuaries. The remainder of the shoreline consists of till, bedrock, end moraine, tidal marsh, and artificial fill, including concrete walls. The longest uninterrupted beach that lies wholly within the map area is Hawks Nest Beach (not Hawks Nest point at the mouth of the Menunketesuck River), 1.3 mi long.

The character of the beaches is related closely to the local materials available for beach building and maintenance by natural processes. Bedrock along the shore is represented by only a very few, very small exposures and so can be neglected. Where the coast consists of till, as east of Point O'Woods, at Hatchett Point, and east of White Sands Beach, promontories have formed and are fronted with boulder rubble that scarcely deserves the name *beach*. Where moderately erodible end moraine and very erodible outwash sediment form the shore, beaches are longer and generally wider, and consist mainly of sand with subordinate pebbles. Some segments of beach fringe tidal marshes, themselves not sources of sediment. Such segments are supplied by longshore drifting of sand from adjacent segments that fringe 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. The balance is 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.

Back of many of the beaches are low bluffs or cliffs cut by surf; some of these are blanketed by wind-blown sand derived from the beaches. The cliffs indicate that surf is eroding the land, and that the balance between erosion by surf and deposition of beach material is a moving balance in which, in the long run, erosion predominates. Groups and clusters of boulders offshore from end moraines indicate that net erosion is in progress today.

The rate of such erosion is comparatively rapid. A partly submerged 10-ft boulder, in 1972 lying 160 ft seaward of the cliff at White Sands Beach, in 1904 lay 15 ft landward of the cliff, partly embedded in end moraine, according to a lifetime inhabitant of the locality. This change implies that, during the intervening period, retreat of the cliff has occurred at an average rate of 2.5 ft per year.

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.

In densely populated areas much of the surface material that underlies streets, driveways, and lawns consists of fill. However, fill is mapped only where it is known or judged to be at least 5 ft thick and where its area is large enough 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 unweathered, 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 Essex/Old Lyme 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. Such 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 were discussed by Morgan (1930). Because the area 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 in the area 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 bedrock.

Evidence from outside the map area indicates that during the last million years or more, Connecticut was overrun by a sheet of glacier ice at least twice and possibly several times. In the Essex/Old Lyme area, however, 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 shape the hills and ridges into streamline form, 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 by ice 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 along a line in or south of what is now Long Island. At or near its limit, the glacier built the end moraines and outwash plains that are prominent features of the island. The outer margin of the ice sheet melted just rapidly enough so that, with the ice continually renewed by flow from the north, its margin remained in about the same position. Later, melting increased while flow was reduced, and the margin retreated northward across what is now Long Island Sound. During the retreat the ice sheet became thinner. Probably about 15,000 years ago, or somewhat later, the margin of the glacier had melted back to the line of the present Connecticut coast.

There ensued a period of several hundred years or more, when increase of flow or increase of melting or both caused the margin of the glacier to halt and to shift position slowly, forward and backward. The end moraines in the Essex/Old Lyme area and their correlatives eastward across Connecticut and Rhode Island were built at that time.

Thereafter, thinning affected an increasingly wide marginal belt of the ice sheet, through which the higher hilltops began to appear. At the same time the glacier began to flow more slowly. Eventually the ice became so thin that its outer or marginal part virtually ceased to flow and became nearly inert. Thinning progressively exposed the 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 derived from the active ice farther upstream. 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 to the south, then a zone of separated bodies of residual ice in the valleys, and finally a zone of continuous, thinning ice that extended far to the north.

In the valley trains in the Essex/Old Lyme area, 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 was deposited as thin coverings on stream-laid sediment and on the sideslopes of valleys.

As the ice sheet north of the map area continued to waste away, meltwater ceased to flow down the local valleys. Except for the Connecticut River, Fourmile River is the longest stream in the area, and its head is only 3 mi north of the northern edge of the Old Lyme quadrangle. By the time that point became free of ice, all the streams in the area had become dependent solely on local rainfall, and the abnormal deposition of valley-train gravel and sand had ceased. For a short time buried masses of ice continued to underlie those sediments, because the collapse features that are preserved today postdate the valley trains.

In contrast, the Connecticut River, with its headwaters far north in northern Vermont, continued to carry meltwater and to deposit outwash sediment until a later time. Although outwash is conspicuous along the river north of the Essex/Old Lyme area, it has not been identified with certainty within the area itself. Probably, with sea level much lower than it is today, the Connecticut was then flowing on a profile lower than today's sea level, so that near the present mouth of the river the outwash would be hidden from view. Deep borings for the Turnpike bridge across the river encountered a thick body of sand that very likely represents such outwash.

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

The sediment in Rogers Lake, mentioned earlier in this report as a deep natural lake only slightly deepened by an artificial dam, is at least 38 ft thick. Cores recovered from the full thickness of the sediment have been studied in detail. From the fossil pollen they contain, a continuous record of the local vegetation and climate during the last 14,000 years or so has been read (Davis, 1969), and has been dated by means of radiocarbon (Stuiver and others, 1963, p. 320; nos. Y-950, Y-951, 14,240 ± 240 B.P.) The record, confirmed by studies of pollen in cores elsewhere in coastal Connecticut, shows that during the deglaciation of the Old Lyme 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 –300ft. 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 coastal parts of the Essex and Old Lyme quadrangles are underlain by outwash sand and gravel, they produce little of these materials, despite strong demand, mainly because of dense population. Large- and medium-sized active sand-and-gravel pits are at present confined to ice-contact stratified drift of valley trains in areas of lesser population, north of the coastal belt, despite the fact that ice-contact stratified drift is generally a less desirable source of sand and gravel because it commonly contains cobbles and boulders, many of the latter very large and difficult to handle.

All the larger operating pits are located within the Essex quadrangle. Prominent among them are the Blakeslee pit and the Moskal Bros. pit, on opposite sides of Highway 80, 2 mi northwest of Ivoryton. Others are the Ed. Bowie pit, beside Highway 153, 2 mi southwest of Essex; the Appleby and Kutone pit, beside Highway 154, 2 mi southeast of Essex; and the Woollock pit, on Bokum Road at the western base of Viney Hill in Essex. A few smaller pits operate intermittently. Because the overall supply of reachable sand and gravel is dwindling, imports and substitutes are likely to find increasing favor.

The general distribution of sand and gravel in the two quadrangles, together with the locations of operating pits and estimates of the volumes of material probably available, will be found in a report by Vitali (undated).

Landfill

The material most commonly used as artificial fill is till. It is comparatively abundant; also it contains a variety of grain sizes, including silt and clay, a characteristic that 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 than farther south. Ice-contact stratified drift, also, is 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 their 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 permeable, and the water table is generally low (in many places 25 ft or more below the surface), as well as 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 Essex/Old Lyme area will be found in reports by J. S. Brown (1916, p. 14-45, 133-146; 1925).

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