# Surficial Geology of the Canaan Area New Hampshire

*By* CHARLES S. DENNY

CONTRIBUTIONS TO GENERAL GEOLOGY

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[Plates in pocket]



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# SURFICIAL GEOLOGY OF THE CANAAN AREA, NEW HAMPSHIRE

By CHARLES S. DENNY


## ABSTRACT

Slightly weathered glacial drift of Wisconsin age, perhaps belonging to the Cary substage, covers most of the Canaan area, which includes parts of the Mascoma and Cardigan quadrangles in west-central New Hampshire. Largely concealed beneath the drift are igneous and metamorphic rocks of Paleozoic age. Two kinds of till are recognized: a loose, olive-gray to white upper till that includes both unsorted and stratified mixtures of boulders, cobbles, and pebbles in a matrix of sand and silt with little clay; and compact olive-gray to grayish-brown lower till that is a mixture of fine sand and silt with little clay containing a few fragments of rock. Compact till commonly has a platy structure down to a depth of 10 feet; below that depth it is structureless. Loose till rests in places on compact till. Both came from the same ice sheet. Compact till was probably deposited beneath the ice sheet Loose till accumulated beneath and on top of the ice as a result of wastage, both from above and from below, and was partly reworked by melt water. The till is overlain by sandy kame deposits that form terraces, in places associated with abandoned stream channels. A few ventifacts occur on top of some of the kame deposits. Colluvial deposits are scarce. Small areas of frost-disturbed patterned ground occur near the summit of Mount Cardigan, and some ancient effects of frost disturbance have been found on its western slope. Sandy and silty alluvium and swamp deposits have accumulated since the ice disappeared.


## INTRODUCTION

The Canaan area includes the eastern two-thirds of the Mascoma quadrangle and the western third of the Cardigan quadrangle, in west-central New Hampshire southeast of Hanover (fig. 13). The drift is of Wisconsin age and includes a loose bouldery upper till and a compact lower till, both probably deposited by the same ice sheet, and kame deposits of sand and gravel.

Field work was done in 1940 and 1941 under a grant from the Penrose Fund of the Geological Society of America. Two additional

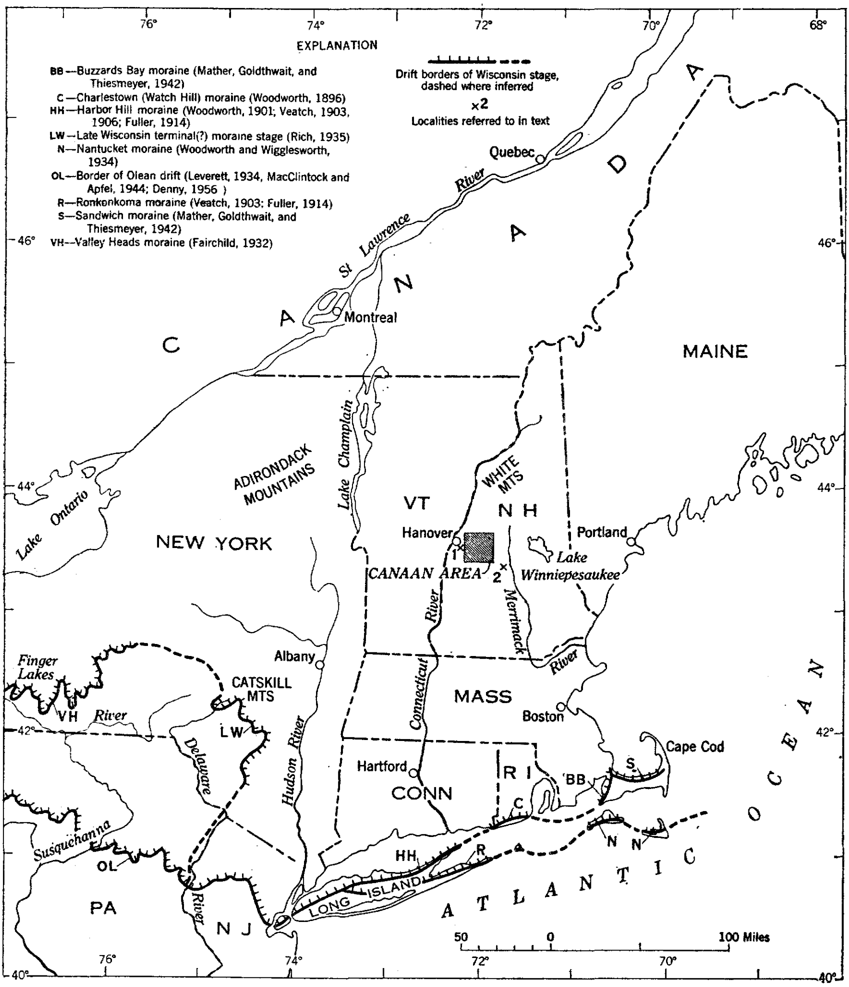


FIGURE 13.—Map of New England and vicinity showing some drift borders of the Wisconsin stage (Denny, 1956a, fig. 1C) and location of Canaan area.

weeks were spent in the area in 1954. The writer acknowledges with thanks the assistance of the society and their consent to publication outside their jurisdiction. W. H. Lyford, soil scientist in the Soil Conservation Service, U. S. Department of Agriculture, gave freely of his knowledge of the region. The work in 1940 and 1941 was carried on under the guidance of the late J. W. Goldthwait whose kindly assistance is gratefully remembered. The bedrock outcrops shown on plate 4 are based chiefly on unpublished data made available through the kindness of K. Fowler-Billings and C. A. Chapman. The author is also grateful for the assistance of S. E. White and D. C. Nutt.

## PHYSICAL GEOGRAPHY

The Canaan area is in the maturely dissected uplands of central New England. Low mountains rise 1,000 to 2,000 feet above rolling hills a few hundred feet high that separate narrow flood plains, swamps, and ponds. The lowest point in the area is Mascoma Lake, altitude 751 feet; the highest Mount Cardigan, altitude 3,121 feet. Melvin Hill, the divide between Indian River and Smith River just north of Tewksbury Pond, and Mount Cardigan are on the boundary between the Connecticut and Merrimack watersheds (fig. 13). The Mascoma and Indian Rivers flow westward across the regional trend of bedrock structure for part of their courses, but most streams flow northward or southward parallel to the structure.

The region has long cold winters with heavy snowfalls and short, comparatively cool summers. The climate varies widely with altitude (U. S. Dept. Agr., 1941, p. 989–1001). Podzolic soils characterize the area (Latimer and others, 1939).

## BEDROCK GEOLOGY

The Canaan area is underlain by igneous and metamorphic rocks of Paleozoic age that were deformed and metamorphosed during late Paleozoic time (pl. 5). Most of the rocks are foliated. The foliation strikes northward.

The bedrock influences the location of major topographic features. Quartz-rich rocks in the Clough quartzite (pl. 5) underlie highlands along the western edge of the area. To the east, foliated igneous rocks, including granite, quartz monzonite, and granodiorite, and the Bethlehem gneiss form lowlands and rolling hills. The divide between the Merrimack and Connecticut Rivers follows a highland where the Littleton formation is cut by many pegmatites close to its contact with Bethlehem gneiss. The summit of Mount Cardigan is composed of Kinsman quartz monzonite, but its western slope and much of the divide to the north is underlain by quartzite and sillimanite schist in the Littleton formation. In summary, the Clough quartzite and Littleton formation, rocks with abundant pegmatite, and the Kinsman quartz monzonite underlie highlands; foliated igneous rocks and the Bethlehem gneiss underlie lowlands.

## SURFICIAL GEOLOGY

The surficial mantle includes till and kame deposits of Wisconsin age and alluvium and swamp deposits of Recent age. The kame deposits are well exposed in numerous borrow pits, but the other surficial deposits are largely concealed beneath the vegetation. Contacts on plate 4 are drawn primarily on topographic evidence; rarely is a contact exposed. Contacts are dashed lines where topographic evidence is equivocal or where designation of a surficial map unit is queried.

## WISCONSIN DRIFT

### TILL

Two varieties of till are distinguished in the Canaan region. One is a loose, bouldery material with a coarse sandy matrix. The other is a compact till containing few boulders. Commonly the loose till rests on the compact till. This distinction between a loose upper till and a compact lower till was made originally in New Hampshire by Upham who later adopted Chamberlin's terms "englacial" and "subglacial" drift (Torell, 1877; Upham, 1878, p. 9–10; 1891; Crosby, 1890; Chamberlin, 1894; Flint, 1947; Lawrence Goldthwait, 1948). Both varieties of till are found throughout the area, but loose till is extensive at the surface where the bedrock is coarse grained and massive, and compact till is widespread where the bedrock is fine grained and schistose. On plate 4, the till is not divided into the two varieties. The loose, bouldery till was probably deposited in part directly by ice and in part by water. The compact till was deposited beneath moving ice. Some geologists have interpreted a loose till resting on compact till as the deposits of two glaciations (Currier, 1941; Moss, 1943; White, 1947; Judson, 1949). Some data on the physical properties of till in New Hampshire are given by Lawrence Goldthwait (1948).

#### COMPACT TILL

This till is olive-gray to grayish-brown and its matrix ranges in texture from fine sand to silt loam (Soil Survey Staff, 1951, p. 205–213). Most till with a silt loam matrix is found where the adjacent bedrock is the Littleton formation or the Ammonoosuc volcanics (pl. 5). Compact till contains from 5 to 10 percent pebbles, cobbles, and boulders. Many rock fragments are abraded and striated, especially those that are fine grained. Most compact till is a heterogeneous mass of material, but in some exposures, there are faint wavy laminae of fine sand. Compact till commonly has a platy structure, the plates being parallel to the ground surface. The plates increase in size from about 1 inch long near the surface to lengths of from 3 to 6 inches and thicknesses of from 1 to 2 inches at depths of 10 feet or more. In the few deep excavations studied, platy structure was not visible in compact till at depths of more than 10 or 15 feet (tables 1 and 2).

TABLE 1.—*Section of compact till in area of schistose bedrock. Exposure in east bank of Stony Brook about 1 mile south of State Route 14, or about 3 miles west of Enfield (loc. 1, fig. 13; outside of area shown in pl. 4)*

| | Approximate thickness (feet) |
|---|---|
| Top. | |
| 1. Sand; bouldery, yellowish-brown, noncalcareous, loose, unstratified | 3 |
| Contact sharp. | |
| 2. Till; silt loam matrix; dominantly dark brownish-gray; locally mottled with brown; noncalcareous; compact; platy structure; contains pebbles, cobbles, and a few boulders, all with a yellowish-brown silty coating. Some pebbles of gneiss are soft; others are hard | 9 |
| Contact gradational through about 6 inches. | |
| 3. Till; silt loam matrix; mottled olive-gray and grayish-brown; dominantly olive-gray near base; calcareous, firm; compact; structureless | 6 |
| 4. Till: similar to that above except transititional in color from that above to that below | 3 |
| 5. Till; silt loam matrix; olive-gray; calcareous; firm; compact; structureless; contains perhaps a maximum of 10 percent of pebbles, cobbles, and boulders, many striated. About half of the fragments are of relatively fine-grained schistose rock. In places contains a few layers of sand as much as a quarter of an inch thick | 48 |
| Base not exposed. | |

TABLE 2.—*Section of compact till exposed in borrow pit on north side of State Route 11 about 1 mile west of Webster Lake, Penacook quadrangle, New Hampshire (loc. 2, fig. 13; about 19 miles southeast of Canaan)* [1]

| | Approximate thickness (feet) |
|---|---|
| Top. | |
| 1. Outwash or till; boulders, cobbles, and pebbles in a coarse sandy matrix; yellowish-brown; loose; unstratified | 10 |
| Contact sharp, wavy. | |
| 2. Till; sandy loam matrix; dark grayish-brown (2.5*Y* 4/2); noncalcareous (pH 7.0–8.0); hard; compact; platy structure; contains about 5 percent of rock fragments, most less than a half inch in diameter. Plates are curved and near base of unit 2 are approximately 6 inches by 3 inches by 1 inch; plates are progressively smaller toward top. Surface of plates covered by single layer of sand grains. Some fragments of schistose rock can be crushed between the fingers | 10 |
| Contact gradational through about 4 inches. | |
| 3. Till; loam matrix; olive-gray to dark olive-gray (5*Y* 4/2–3/2); very slightly calcareous; hard; compact; structureless; contains a few percent of fragments of schistose and coarse-grained igneous rocks. A very few fragments are stained brown and can be crushed between the fingers | 40 |
| Base not exposed. | |

[1] Density, moisture content, and mechanical analyses of samples of till from this pit are given by Lawrence Goldthwait (1948). Locality listed as "Andover, on Rt. 11 'Borrow Area *A*' for Franklin Dam."

The compact till occurs in all topographic positions but is probably most extensive on lower slopes, especially on north-facing and northwest-facing hillsides. At or near summits the till is thin or bedrock is exposed. The maximum exposed thickness of compact till is about 30 feet, but thicknesses of more than 50 feet are readily inferred. For example, Gulf Brook flows northward from Spectacle Pond in Enfield in a gorge nearly 80 feet deep apparently cut in compact till (pl. 4).

Along the edge of valley floors compact till is overlain by younger deposits. Its extent or thickness beneath such deposits is unknown. On some slopes and on most hilltops compact till abuts against rock outcrops with no topographic break. In other places a gentle slope on compact till near a valley bottom extends uphill to a steep slope on bedrock thinly veneered with drift.

#### LOOSE TILL

The loose till is an olive-gray to white mixture of sand and silt with little clay (texture, coarse sand to loam). Boulders, cobbles, and pebbles are perhaps as much as 25 percent of the total mass. The rock fragments are angular and subangular; striated fragments are scarce. Most loose till is irregularly and discontinuously stratified, the beds lensing out within distances of a foot or two (figs. 14 and 15). A characteristic feature is small curving lenses of sand ranging from 2 inches to 1 foot long and from ¼ inch to 3 inches thick in an otherwise massive deposit. In places a pebble-free deposit consists of thin, curved layers of fine sand that resemble lake beds.

Two sketches illustrate the structure of loose till. In figure 14, unit 1 is a bouldery unsorted mixture of sand containing a few curved laminae of silt. The unit could have been deposited directly from melting ice. However, units 2 and 3 are more or less stratified and seem to require moving water for their deposition. The layers of unit 2 curve around the base of the overlying boulders and in unit 3 the stratification is discontinuous, curved, or inclined. The underlying compact till, unit 4, is firm and compact in comparison with the overlying material and contains relatively few fragments of rock.

In figure 15 none of the units are typical till. Unit 7 resembles lake beds and is intertongued with the coarse, almost structureless sand of unit 6. Unit 4 appears to be water-laid gravel and sand. Unit 3 is massive coarse sand containing fragments of laminated fine sand. Unit 2 is partly massive, partly stratified, and contains only a few pebbles.

Near South Grafton School and elsewhere a very sandy loose till containing relatively few fragments of rock forms knolls and ridges as much as 50 feet high. Many such knolls are covered with boulders and topographically resemble kame deposits (fig. 16). There is a gradation in lithologic character, in structure, and in topographic expression from loose till into kame deposits. On plate 4, kame deposits are restricted to well-sorted and well-stratified materials forming distinct knolls, ridges, or terraces.

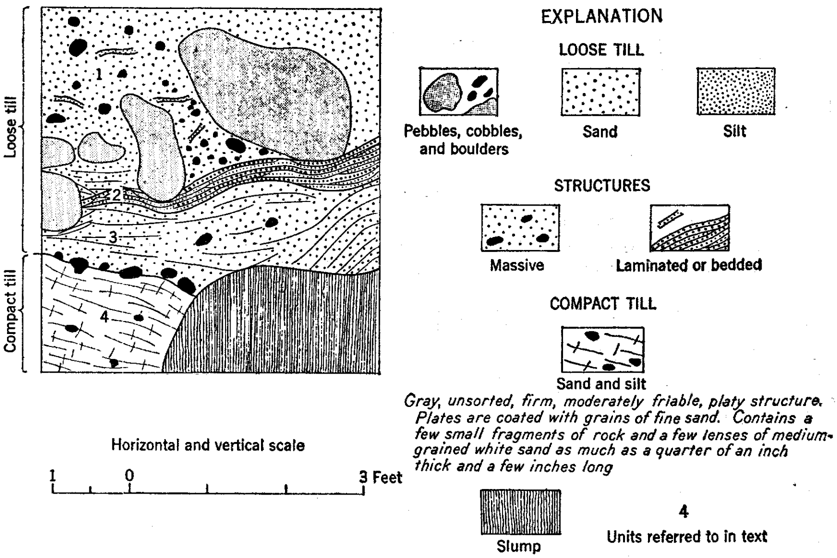


FIGURE 14.—Loose till. Unsorted mixture of pebbles, cobbles, boulders, and sand overlying laminated sand. Rests on compact till. Top of figure about 3 feet below ground surface. Exposure in road cut, altitude 1,020 feet, on west side of unsurfaced road about 1.2 miles south of Tuttle Hill in Orange (loc. 4, pl. 4).

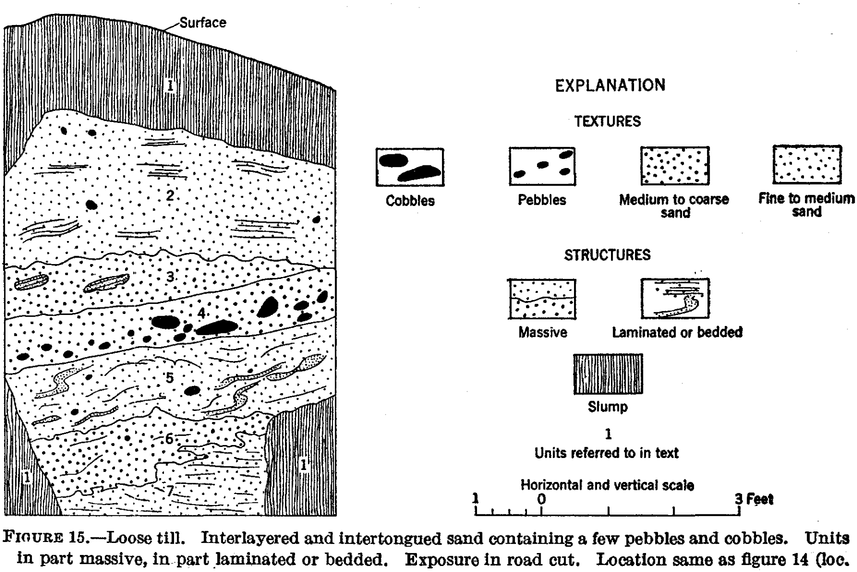


FIGURE 15.—Loose till. Interlayered and intertongued sand containing a few pebbles and cobbles. Units in part massive, in part laminated or bedded. Exposure in road cut. Location same as figure 14 (loc. 4, pl. 4).

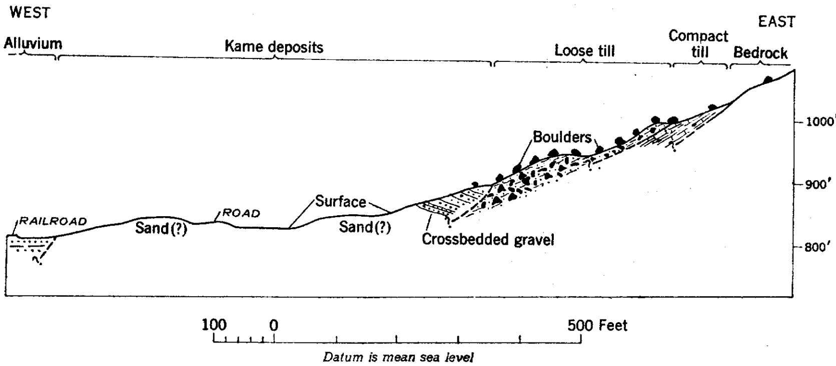


FIGURE 16.—Boulder-covered knolls of loose till on lower part of valley wall just above top of adjacent kame deposits. Locality is the southwest slope of Pine Hill on east side of Smith River in Danbury (loc. 7, pl. 4). Cross section based on a field sketch and plate 4.

Loose till is best exposed and probably most extensive on lower slopes just above the top of the kame deposits. Sections as much as 30 feet thick are exposed. Loose till appears to be absent from large areas on the uplands.

#### STRATIGRAPHIC RELATIONS

Loose bouldery till resting on compact till was seen at several exposures. In figure 17 a boulder-strewn knoll is underlain by about 8 feet of loose till that grades through a zone about 3 inches thick into firm, compact till with platy structure. Loose till was nowhere seen to overlie bedrock, but compact till has been seen to rest on bedrock at a number of places. No loose till has been found beneath compact till.

#### ORIGIN

The compact till and the loose till were deposited by one ice sheet but are unlike because of differences in manner of deposition. The field evidence demonstrates that loose till is bouldery and sandy, that compact till is loamy and includes fewer boulders than loose till, that loose till overlies compact till, that small masses of one variety of till occur within the other type, and that much loose till underlies knolls on lower valley walls. Loose till is less extensive on uplands and mountains.

These field relations are for the most part those observed by Upham (1878) but, in addition, he noted that most fragments of rock in the lower till were abraded to a considerable extent and some came from distant sources, whereas the fragments in the upper till were less abraded and locally derived, perhaps from adjacent hilltops. Upham concluded (1878) that the upper till was debris carried on top of or within the ice sheet, whereas the lower till was carried and deposited

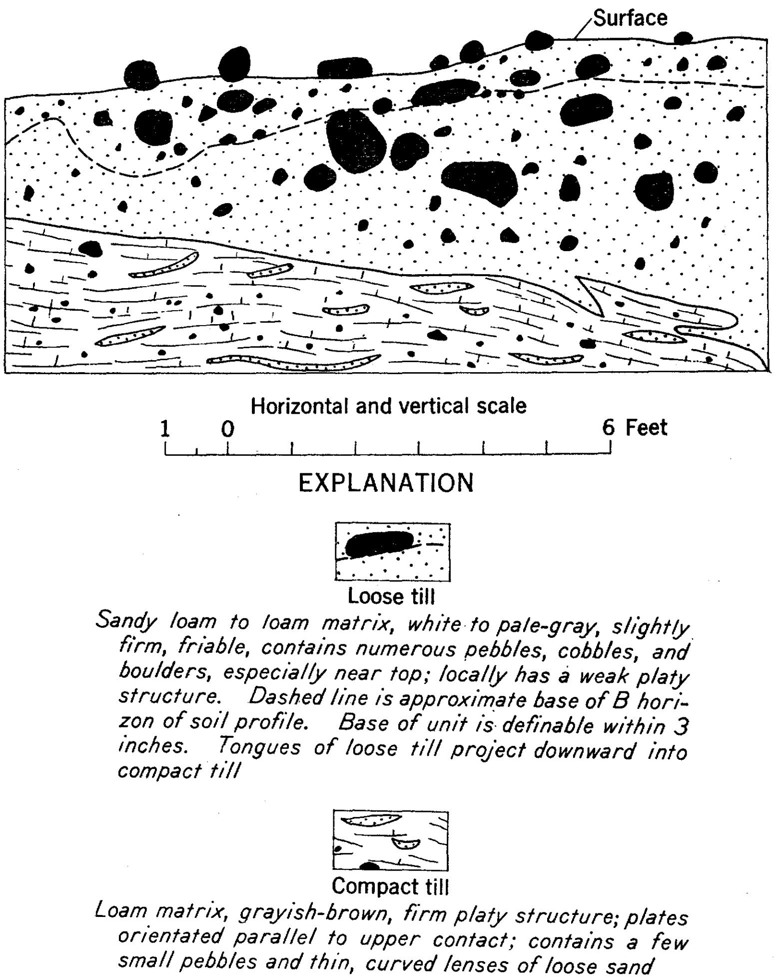


FIGURE 17.—Loose bouldery till resting on compact till. Exposure along dirt road at corner, altitude 1,220 feet, about half a mile west of Shepard Hill in Grafton (loc. 5, pl. 4).

under the ice. Upham's use of "upper till" and "lower till" does not entirely correspond to the writer's use of "compact till" and "loose till." Upham implied that the upper till formed an almost continuous surface mantle. He included in the upper till the soils developed on compact till.

The two varieties of till probably originated in the following way: Compact till was deposited beneath the glacier and doubtless owes its compactness partly to the weight of the overlying ice. Loose till, on the other hand, accumulated beneath, within, or on top of the ice, probably when it was melting upward from the bottom as well as downward from the top. Water-laid drift was deposited beneath or within the ice and subsequently was overlain by unsorted debris from within or on top of the ice sheet. The laminae of sand and slit wrapped around the lower part of the boulders (fig. 14) suggest that the boulders were let down from ice above after the laminae of sand and silt were deposited.

Boulder-strewn knolls of loose till resting on compact till and in turn overlain by kame deposits (fig. 16) suggest the following sequence of events: As the marginal zone of the glacier wasted downward, bouldery loose till was dropped on compact till, at first from beneath the ice with some water-laid material, later by sliding from the surface of the ice or from the adjacent valley wall. Streams flowing in channels between wasting ice and the valley wall laid down kame deposits on or against the loose till. Boulders were dropped or slid from the ice or from the valley wall on to both till and kame deposits. The relative scarcity of boulders within some loose till and most kame deposits compared with their abundance on the surface suggests that such bouldery accumulations result from surface sliding rather than as a lag concentrate.

The platyness of the compact till is commonly regarded as a structure resulting from compression of the till caused by the weight of the overlying ice (Flint, 1947, p. 106–107). However, this platyness may be primarily a result of weathering (p. 87).

### GLACIOFLUVIAL SEDIMENTS

The glaciofluvial deposits are chiefly sand, but about one-fifth are gravel. These materials were mapped as kame deposits and terrace sand (pl. 4). The sand is both coarse and fine grained, light gray to white, commonly includes scattered pebbles, and much of it is well sorted. The gravel consists chiefly of pebbles and a few cobbles in a coarse sandy matrix. Boulders are rare. The glaciofluvial deposits form horizontal strata ranging from 1 inch to 2 feet thick; a common thickness is 2 or 3 inches. Crossbedding (fig. 18) is a common feature of both the sand and the pebble gravel. Within one borrow pit the foresets may dip in several directions. The glaciofluvial deposits are known to rest on till or bedrock. The terrace sand is assumed on topographic evidence to rest on or against the adjacent kame deposits, but the contact was not exposed.

#### KAME DEPOSITS

The water-laid drift mapped as kame deposits forms terraces or ridges that extend northward along lower valley walls or valley floors. The deposits are more extensive in northward-draining valleys than in those that drain south and are a little more numerous on the east side of valleys than on their western slopes. Sandy kames contain less than about 40 percent gravel, commonly not more than 10 percent. They are more abundant than the gravelly kames. Kame deposits locally resemble loose till. On plate 4 kame deposits

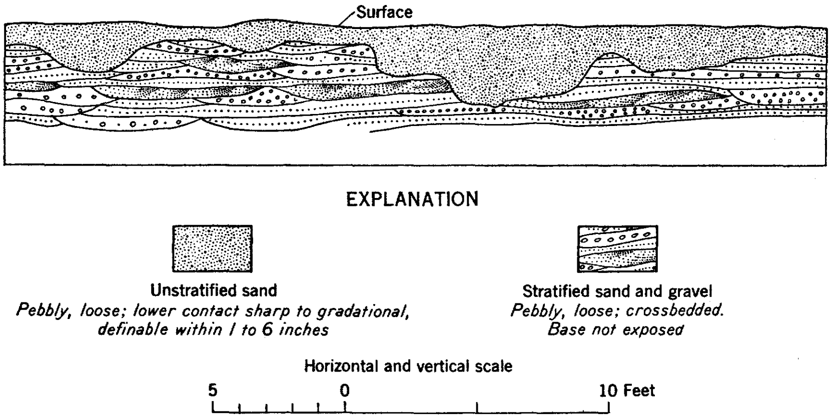


FIGURE 18.—Crossbedded kame deposits along Smith River in Danbury. Upper part of deposit is unstratified, the result of mechanical disturbance caused chiefly by roots of trees. Exposure in borrow pit on east side of U. S. Route 4, 1.4 miles northwest of Danbury (loc. 8, pl. 4).

are shown only where the materials are well sorted, well stratified, and form conspicuous knolls, ridges, or terraces. A few poorly exposed masses, apparently water-laid drift, are mapped as probable kames (Qk?).

Many sandy kames consist of 1 to 2 feet of crossbedded pebble gravel overlying stratified sand. The sand commonly contains lenses of crossbedded gravel and is probably a stream deposit; such kames are those in the valley of Little Brook south of George Pond and those that extend southeastward from Mirror Lake into and down the valley of Smith River to Danbury. In some sandy kames, the sand forms regular beds ranging from a fraction of an inch to about 2 inches in thickness and showing small-scale crossbedding or ripple marks. Such sand, probably of lacustrine origin, is exposed in borrow pits west of Mirror Lake and west of Melvin Hill (fig. 19). In the valley of Haines Brook south of Canaan, and in a small valley just west of Danbury, sandy kame deposits, at least in part of lacustrine origin, are covered with boulders as much as 10 feet in diameter, a few of which have been sand-blasted, especially those in the southern part of each valley. In places the sand is horizontally stratified; elsewhere foreset(?) beds dip southward.

The gravelly kames are small deposits of gravel that commonly form narrow ridges. A string of such ridges east of the junction of Indian River and Mascoma River was probably deposited in a channel in the ice. Exposures show southward-dipping beds.

Most kame deposits are at least 20 feet thick. The greatest thickness exposed or readily inferred is about 80 feet.

Near the margins of many kame deposits, the beds have been displaced along both normal and reverse faults with displacements of as much as several feet. Many of the fault planes strike parallel to

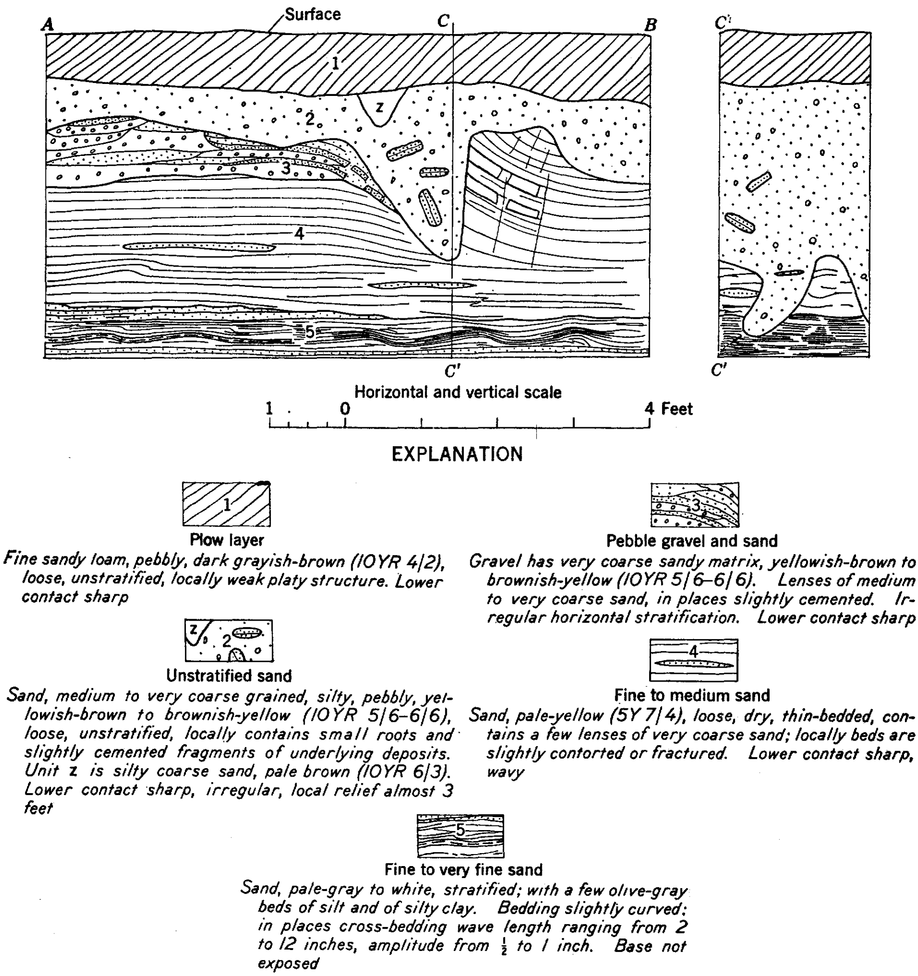


FIGURE 19.—Sandy kame deposits. Stream-laid pebble gravel and sand overlying horizontally bedded sand of lacustrine origin. The unstratified sand, probably disturbed by tree roots, forms a downward-projecting tongue that may be the cast of a large root. Section C—C' is at right angles to section A—C—B. Exposure in borrow pit on east side of road about 1.5 miles west of Melvin Hill in Springfield (loc. 9, pl. 4).

the edge of the deposit and dip steeply; most dip more than 60°. The deformation probably dates from a time when the water or ice content of these deposits was greater than at present because a Podzol soil cuts across the upper part of the deformed zone, and excavation of the deposits causes slumping, not faulting.

### TERRACE SAND

This unit is composed of coarse and fine sand, chiefly in horizontal beds. Lenses of gravel are scarce. The deposit is poorly exposed, forming low terraces along streams. Terrace sand is arbitrarily defined as a deposit that lacks the gravel cap or the topographic expression characteristic of kame deposits. It lies commonly not more than 10 feet above an adjacent flood plain. Locally the terrace may be cut into kame deposits. The thickness of the terrace sand presumably exceeds 10 feet, but the depth and extent of the sand beneath the valley floor is unknown. In headwater areas the terrace sand was probably deposited near wasting glacial ice, probably almost contemporaneously with adjacent kames. In broad valleys the terrace sand is less directly a product of wasting glacial ice, and part of it is somewhat younger than terrace sand in headwater areas.

### ORIGIN

The distribution and internal character of the kame deposits indicate that they were laid down in water in association with glacial ice, are younger than the adjacent bouldery loose till and older than the adjacent alluvium or swamp deposits, and have been dissected. The terrace sand is partly of similar origin and partly the result of postglacial alluviation or erosion.

During deglaciation the ice edge probably melted back in a northerly direction. The southern (and probably the higher) parts of the area were uncovered before the northern part, and melt water flowed in general southward; at present much of the drainage is westward down the Mascoma River. However, the proof of such northerly retreat and southward drainage is suggestive but not conclusive. The evidence is as follows: The abandoned stream channels on the valley sides commonly have a southerly gradient indicative of a southward streamflow. The bedrock divide about a mile north of Tewksbury Pond (Orange Summit) originally contained large potholes that were obliterated when the railroad was built. These potholes suggest melt water drainage across the divide but not necessarily southward. The downvalley gradient of the tops of the kames along the Smith River and the continuity in size and altitude of those across the Little Brook-Bog Brook divide south of George Pond suggest deposition by southward-flowing streams. The kames in the valley of Haines Brook south of Canaan and in the valley west of Danbury between Leeds Hill and Pond Ledges were apparently deposited in standing water held in by ice to the north. This melt water escaped eastward or southward through abandoned stream channels.

The fact that many kame deposits have a gravel cap resting on finer material is difficult to explain. Perhaps the gravel cap was deposited by a relatively large ice-marginal stream flowing partly across earlier water-laid deposits and partly across ice, in a channel formed both by erosion and by deposition. The deposits beneath the gravel cap were laid down in isolated pools or channels, not necessarily at the same time nor at the same level.

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Most of the kame deposits were laid down by streams flowing in channels at or near the edge of the ice sheet. Some of the kame-building streams flowed in channels in the ice sheet, as shown by the ridges of gravel and sand whose outer portions are faulted and deformed. Such deposits were built against a wall of ice. As the ice melted, they were faulted. The absence of deformed kame deposits, except locally near their margins, and the scarcity of exposures of till overlying water-laid drift indicate that when the kame deposits were formed, the adjacent ice was stagnant.

Most kame deposits in New England were once interpreted as deltas built into lakes ponded between a northward-retreating glacier margin and bedrock hills to the south (Goldthwait, 1938; Lougee, 1939, fig. 43). Few geologists have championed this view in recent years (Lougee, 1940). In a few places, however, the kame deposits may have been laid down in ponded water, for example, in the valley of Haines Brook and near Mirror Lake, although the ponds need not have been much more extensive than the deposits themselves. Lougee (1939, p. 142–143, fig. 43; Upham, 1878, p. 65) supposed that the sill at Orange Summit (the divide in the valley between Mirror Lake and Tewksbury Pond) controlled the level of a proglacial lake that widened northward and westward as the ice edge retreated until the lake covered a large part of the Canaan region and was finally drained by overflow westward down the Mascoma River valley into the Connecticut River. There is almost no evidence for such a large lake. Varved clays, which cover large areas in the Connecticut River valley to the west (Upham, 1878; Antevs, 1922), are exposed at only a few isolated places in the Canaan area, as in the Haines Brook valley, where a lake could have had a maximum area of only a few square miles.

The time of formation of one body of kame deposits in relation to others in the same valley or in other valleys is largely unknown. The evidence bearing on this question is meager. For example, the kame deposits along Little Brook south of George Pond in Enfield may have been laid down when melt water flowed from the vicinity of George Pond southward up Little Brook valley and across the existing divide into Bog Brook valley that drains southward into the Sunapee quadrangle. The topographic and lithologic character of these kames suggest that they were deposited almost contemporaneously by one southward-flowing stream. The adjacent areas now filled with alluvium and swamp deposits were then occupied by glacial ice. North of George Pond the kame deposits were probably formed partly in standing water and partly by northward-flowing streams.

In like manner the kames along Smith River from Tewksbury Pond to Grafton Center suggest contemporaneous deposition over a distance of at least 2½ miles. The deposits are generally bouldery near

Tewksbury Pond and are somewhat finer grained to the south near Grafton Center. Likewise the top of the deposits define a grade line that is roughly parallel to that of Smith River. In other south-trending valleys the topographic expression and internal character of the kames require contemporaniety of deposition over distances of not more than 2 miles.

Thus, while the ice sheet was leaving the Canaan region, it had a stagnant terminal zone at least a few miles wide measured in a northerly direction. But the characteristics of the ice sheet near its margin, such as its thickness and rates of movement or wastage, are conjectural (Goldthwait, 1938; Antevs, 1939; Lougee, 1940; Flint and Demorest, 1942; Rich, 1943). The abundance of water-laid drift in the Canaan region, as elsewhere in central and southern New England, requires a large volume of melt water and of rock debris. The water-laid drift could have accumulated by rapid melting over a wide stagnant zone (measured in many tens of miles), or by rapid melting along the narrow front of an ice sheet moving forward about as fast as it melted. Other explanations are also possible.

## WEATHERING OF DRIFT

The drift is slightly weathered to depths of at least 10 feet. The alteration of the drift by chemical processes is apparently slight, and the amount of clay developed by weathering is small. A few mechanical analyses of the surficial deposits, largely within the modern soil profile, are given by Latimer (Latimer and others, 1939, table 9).

The soils (Latimer and others, 1939; Simmons and others, 1949) range in thickness from about 18 to 30 inches; that is, the top of their C horizons are at such depths. The better drained soils developed in glacial drift are podzolized; they belong to the Podzol (table 3) or to the Brown Podzolic (table 4) great soil groups. The areal extent and the parent materials of these soils are given below.

*Areal extent and parent materials of podzolized soils on glacial drift*

| *Podzol soil* | *Brown Podzolic soil* |
|---|---|
| 1. Widespread occurrence above an altitude of about 1,200 feet; at lower altitudes occur where texture of parent material is loam or sandy loam. | 1. Found chiefly below an altitude of about 1,200 feet where the texture of the parent material is loam or heavier. |
| 2. Most extensive in areas underlain by glaciofluvial deposits or by loose bouldery till. | 2. Most extensive in areas underlain by compact till. |
| 3. Most extensive in areas underlain by coarse-grained, relatively massive bedrock. | 3. Most extensive in areas underlain by schistose bedrock. |

TABLE 3.—*Profile of a Podzol soil developed on loose bouldery till. (Soil is Hermon stony sandy loam; profile description generalized from Latimer and others, 1939, p. 67; and Simmons and others, 1949, p. 79)*

| Soil horizon | Description | Thickness (inches) | Range in depth (inches) |
|---|---|---|---|
| $A_0$ | Organic matter, black or nearly black; partly decomposed leaves and twigs; locally mixed with a little gray sand | 3 | 0–3 |
| $A_2$ | Sand or sandy loam, gray with a thin darkened layer one-fourth inch thick near the top and a corresponding brown layer near base; loose; locally with a weak platy structure; pH about 4.5 | 4 | 3–7 |
| $B_2$ | Sandy loam, rusty brown, slightly firm; tends to form lumps that are yellow on the inside and reddish-brown on the outside; pH about 5.5; transitional downward into underlying horizon | 5 | 7–12 |
| $B_3$ | Sandy loam, pale yellowish-brown; less coherent than horizon above; pH about 5.3; transitional downward into horizon below | 8 | 12–20 |
| $C_1$ | Light sandy loam or sand, yellowish-gray; loose; contains many small angular fragments of the unweathered parent rocks; pH about 5.3 | 10 | 20–30 |
| $C_2$ | Till, sandy, gritty, gray; slightly compact, friable; fragments of the parent rock are numerous; pH about 5.6 | 20 | 30–50 |
| | Base not exposed. | | |

TABLE 4.—*Profile of a Brown Podzolic soil developed on slightly compact till. Each horizon contains as much as 10 percent of small fragmenls of schist. In some places the profile includes a few boulders. (Soil is Charlton loam; profile description generalized from Latimer and others, 1939, p. 68)*

| Soil horizon | Description | Thickness (inches) | Range in depth (inches) |
|---|---|---|---|
| $A_0$ | Organic matter; loose leaf litter overlying dark-brown partly decomposed leaves and twigs | 2 | 0–2 |
| $A_1$ | Loam, dark-brown, loose; contains some finely divided organic matter; lower contact sharp | 2 | 2–4 |
| $A_2$ | Loam, brown, very friable; pH about 5.2; transitional downward into underlying horizon | 6 | 4–10 |
| $B_2$ | Loam, yellowish-brown, firm, friable; pH about 5.5; transitional downward into underlying horizon | 7 | 10–17 |
| $B_3$ | Loam, pale yellowish-brown, firm, friable; pH about 5.6; transitional downward into underlying horizon | 9 | 17–26 |
| C | Till; loam matrix; greenish-gray or olive-gray, slightly compact, friable; breaks into small irregular angular to platy fragments; pH about 5.6 | 24 | 26–50 |
| | Base not exposed. | | |

In the Canaan area the bedrock probably contains not more than a very small amount of free carbonates, and the drift is noncalcareous at least to a depth of 10 feet. A deep borrow pit about 19 miles southeast of Canaan (loc. 2, fig. 13) exposed very slightly calcareous drift below a depth of about 20 feet (table 2). The bedrock is the Littleton formation (Billings, 1955). Just west of the Canaan region the drift is calcareous below depths of about 10 feet (table 1). Thus the drift near Canaan may have been leached to depths of 10 or 20 feet, but the amount of free carbonates removed was small, probably not more than 1 percent by volume.

Compact till is slightly oxidized to depths of at least 10 feet. Below depths of from 10 to 15 feet it is unweathered and olive gray to dark olive gray (tables 1 and 2). Platy structure in the compact till (tables 1 and 2) is probably the result of weathering and not a fabric imparted to the till during deposition, because the structure is not visible in unweathered till. The plates are oriented parallel to the ground surface and decrease in size upward. Clay(?) has been deposited on the surface of the plates. Some exposures show narrow veins of yellowish-brown clay(?) that cut across the platy structure.

Most of the rock fragments in compact till are hard and unweathered; some have a yellowish-brown surface, especially those rich in ferromagnesian minerals; a very few fragments are soft. The sand fraction of the matrix consists of angular mineral grains most of which, viewed with a binocular microscope, look unweathered. A few grains are stained yellow.

The loose bouldery till and the glaciofluvial deposits are also little weathered. Their sandy matrix is essentially fresh, the color commonly white or gray. Most of the rock fragments in them are firm and unweathered except for a yellowish-brown stain on the outside of some, especially those from above a depth of about 5 feet. The sand fraction consists largely of angular mineral grains and rock fragments that are unweathered. Traces of a yellowish-brown stain are present in most samples.

The glaciofluvial deposits commonly are not regularly stratified within 1 or 2 feet of the ground surface. In some exposures the surface layer is massive or structureless (figs. 18 and 19); in others the strata and the soil horizons are contorted and broken (fig. 20). In some places the soil horizons appear to have been developed in a previously disturbed stratum, elsewhere "the thickness of each horizon varies greatly within a yard or less * * * (horizontally), and in many places fragments of the A horizon lie within the B horizon" (Simmons, 1949, p. 79). Such a disturbed layer overlies loose bouldery till in many places but is uncommon on compact till. These layers result from mechanical disturbances that are caused chiefly by the growth

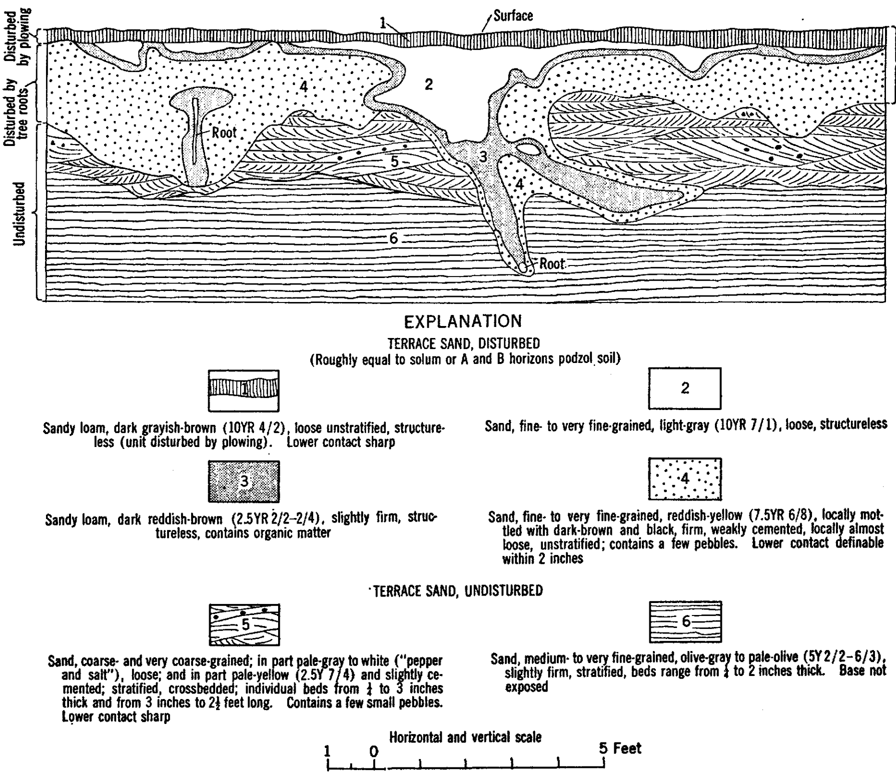



FIGURE 20. Terrace sand. Contorted upper layers, disturbed by tree roots and by plowing, overlie cross-bedded sand. Exposure in borrow pit in Enfield about 0.9 mile northwest of Banks Pinnacle near Grafton Pond (loc. 6, pl. 4).

and destruction of trees, principally by the roots (Shaler, 1892, p. 273–274; Lutz and Griswold, 1939; Lutz, 1940; Goodlett, 1954). Unquestionably, the growth of the base and the roots of a large tree distorts the adjacent sediments. When the tree dies and its roots decay, the resulting cavities are filled by loose unsorted material from above or from either side. For example, in figure 19, section *C—C′*, the tongues of unstratified sand projecting downward into the fine sands may be filled root cavities; and in figure 20, the tongue-shaped projections of unit 3 near the center of the figure may be of similar origin.

In addition to the growth of roots, the disturbances caused by the toppling of trees are probably an important cause of the lack of regular stratification near the top of the glaciofluvial deposits. This mechanical process was perhaps more effective in presettlement forests of large trees than in many of the second-growth forest stands of the present day. Such a disturbance probably has been going on since the region was reforested. Thus, the profile development of the modern soils must be comparatively recent, perhaps only a few hundred years old (Denny and Goodlett, *in* Denny, 1956b). In figure 20, unit 4 probably is the result of such disturbances that took place before the development of the existing soil profile.

The section shown in figure 20 is interpreted as follows: Horizontally bedded sand (unit 6) was deposited perhaps in standing water. After erosion, crossbedded sand (unit 5) was deposited up to approximately the present top of the section. This deposition probably took place during deglaciation. The terrace was forest-covered for thousands of years. Many generations of trees died or were toppled by wind, resulting in the gradual disruption of the stratification in the upper few feet of the crossbedded sand and the formation of a structureless surface layer (unit 4). A Podzol soil (table 3) was developed in this layer. In figure 20, units 2 and 3 are roughly the $A_2$ horizon of a Podzol soil, and unit 4 resembles the $B_2$ horizon of a Podzol soil. A large tree grew near the center of the section shown in figure 20. When this tree toppled or when its stump and roots decayed, the resulting cavities were filled by material from the $A_2$ horizon of the soil to form the thick mass of unit 2 and the fingers of unit 3 near the center of the figure. Any mound and pit produced by the toppling of this hypothetical tree were destroyed when the land was cleared and plowed. Such disturbance produced unit 1.

## AGE OF DRIFT

The drift in the Canaan area was deposited in Wisconsin time, probably in the latter part of that stage. It is within a region of probable Cary drift as interpreted by Flint (1953) and by MacClintock (1954), and is younger than the Valley Heads moraine (Fairchild, 1932) south of the Finger Lakes in New York State (Denny, 1956a, fig. 1*C*). The weathering and topographic expression of the drift are comparable to that north of Fairchild's Valley Heads moraine and are in general similar to that of the Wisconsin drift elsewhere in central and southern New England. Probably the drift in the Canaan region was deposited during the retreat of the ice sheet that built the Harbor Hill moraine on Long Island, the Charlestown moraine in Rhode Island, and the Buzzards Bay and Sandwich moraines in the Cape Cod region (fig. 13).

## ABANDONED STREAM CHANNELS

Elongate depressions on some valley walls are believed to be abandoned stream channels (pl. 4) that were cut by ice-marginal streams flowing along the edge of valley ice-tongues. These depressions commonly have steep side walls a few tens of feet high and flat floors a few tens to a hundred feet wide. They range from a few hundred feet to more than a thousand feet long. The floors of some depressions are covered with turf; others are strewn with boulders. The channels are commonly in drift, but locally one wall is of drift and the other bedrock. The ends of some channels are hanging, the channels being perched on the valley wall. The streams that carved them must have flowed in or on the ice sheet. The channel floor commonly slopes very gently southward, but the channels on uplands just south of Canaan slope northward (pl. 4). An abandoned stream channel just north of the Mascoma River and just west of Mascoma Lake (outside of area of pl. 4) has potholes in its bedrock floor (Goldthwait, 1925, p. 67).

Besides the abandoned stream channels shown on plate 4, many of the southward-trending cols on the uplands may have carried melt water during deglaciation. These cols are not shown as abandoned stream channels unless obviously deepened by stream erosion. Channels and cols similar to those in the Canaan area are widely scattered throughout the Connecticut River watershed in New Hampshire and are the chief evidence cited by Lougee (1939, fig. 43) for the many ice-dammed lakes that he believed were formed by the northwesterly recession of the ice front.

## ABRADED BEDROCK

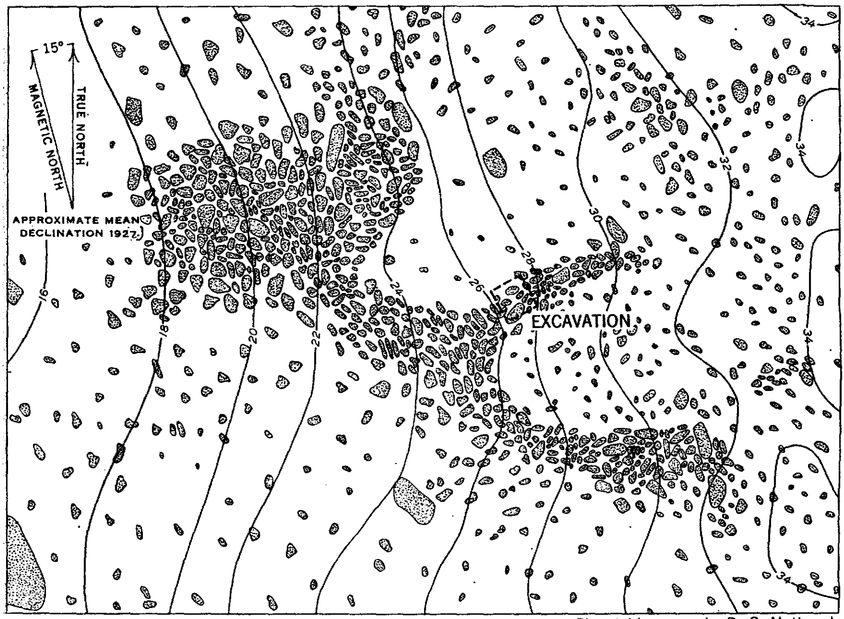
Rock outcrops commonly are abraded. Striae are found on all the formations. Polished surfaces are characteristic of outcrops of the Clough quartzite (pl. 5). The striae in the area trend south or southeast. On plate 4 only those striae noted by the writer are shown. Additional striae are recorded on maps by Goldthwait, Goldthwait, and Goldthwait (1951) and by Hitchcock (1878, p. 192, 219). In some pegmatites, large crystals of biotite or muscovite are striated on surfaces at right angles to the basal plane (Switzer, 1941).

## COLLUVIAL DEPOSITS AND PATTERNED GROUND

Colluvial deposits resulting from mass movements of the mantle are scarce in the Canaan area. On most slopes the surficial mantle is essentially stable at present and shows little evidence of downslope movement except that caused by tree throw (Denny and Goodlett, *in* Denny, 1956b). The few slopes where notable mass movements have occurred in recent years are in areas of fine-grained schistose bedrock. Slopes underlain by coarse-grained or massive igneous and metamorphic rocks are stable. Frost-produced patterned ground is now forming near the summit of Mount Cardigan (Denny, 1940).

A small area of patterned ground lies on the northwest slope of Mount Cardigan about 1.6 miles north northeast of Orange Basin (loc. 3, p. 4). The area is a pasture apparently underlain by compact till, at an altitude of about 1,800 feet, sloping westward at angles of 4° to 8°. This boulder-strewn pasture is covered by turf, moss-covered hillocks, and stumps of trees, probably spruce. The pasture contains many shallow, irregularly shaped depressions a few tens of feet across that sometimes contain water. Locally there are irregular terracelike features with risers that slope as much as 20°. Most boulders in the pasture range from 1 to 5 feet in diameter; 2 feet is a common size. Many more boulders lie on the surface of the ground than are apparent in the adjacent drift.

Two tongue-shaped areas of turf are outlined by lines of boulders that resemble boulder stripes or boulder garlands (fig. 21). An excavation in one of the boulder stripes exposed about 2 feet of bouldery




Planetable survey by D. C. Nutt and C. S. Denny, April 1941

EXPLANATION

Boulders shown by stipple. Areas left white are covered by turf and low shrubs. Boulders are chiefly coarse-grained sillimanite schist, but include other types of schist, gneiss, and quartzite

5 0 20 Feet

Contour interval 2 feet

*Datum assumed*

FIGURE 21.—Map of ancient(?) boulder stripes or boulder garlands on a west-facing slope underlain by compact till. Locality is on northwest slope of Mount Cardigan about 1.6 miles north northeast of Orange Basin at an altitude of about 1,800 feet (loc. 3, pl. 4).

material overlying compact till containing numerous pebbles and a few cobbles. The largest boulders were at the surface. Water sometimes flows in the boulder stripes. The vegetation-covered areas between the boulder stripes are slightly convex. The large mass of boulders northwest of the center of figure 21 is at the head of a shallow draw that extends downslope for perhaps 200 feet. Part of the floor of the draw is covered with boulders; the rest is covered with turf. The exposed boulders may be segments of a continuous deposit that is partly concealed beneath the turf.

Almost parallel bands of boulders trend downslope in other parts of the Canaan region, as the slope east of Indian River near Birch Corner School in Canaan, the hillsides about a half mile southwest of Gifford School in Grafton, and the slope west of George Pond in Enfield.

Some of the boulder bands, especially those near Orange Basin, are probably the result of both downslope and lateral movement of the mantle caused by repeated freeze and thaw. Such an origin is suggested by the close packing of the boulders with their longer axes in a vertical plane and by their abundance in comparison with those in the underlying compact till. The bands appear to be too large to be lag deposits, the result of present-day erosion by running water. The moss-covered hillocks on the slope near Orange Basin probably result from present-day frost heaving; but the continuous cover of vegetation that surrounds and locally crosses the boulder stripes indicates that the boulders have not moved for several years. The spruce(?) stumps suggest that the patterned ground was tree-covered and stable in the recent past. Thus these boulder stripes are probably at least 100 years old. Perhaps they are as old as the Pleistocene.

In other places, however, the boulder bands are relatively narrow, the boulders widely spaced, and the associated gully more pronounced than those shown in figure 21. Such bands are probably lag deposits left by running water.

Mountain slopes in the Canaan region are commonly strewn with boulders (fig. 22) most of which are covered with ferns and lichens; apparently they have not moved for a long time. Perhaps the boulders moved during a past interval of slope instability or were dropped in their present position by an ice sheet. In a few places on steep slopes or at the base of cliffs are bare boulders that may have moved in recent years.

Some gentle slopes on till are furrowed by broad, shallow gullies. One such gully is shown in figure 23. It has steep walls and is floored chiefly with boulders. This gully is one of several parallel gullies on a boulder-strewn slope. Absence of alluvial deposits at the mouth of the gully shows that it was not cut by modern stream erosion. The shape of the gully suggests formation by mass movements.

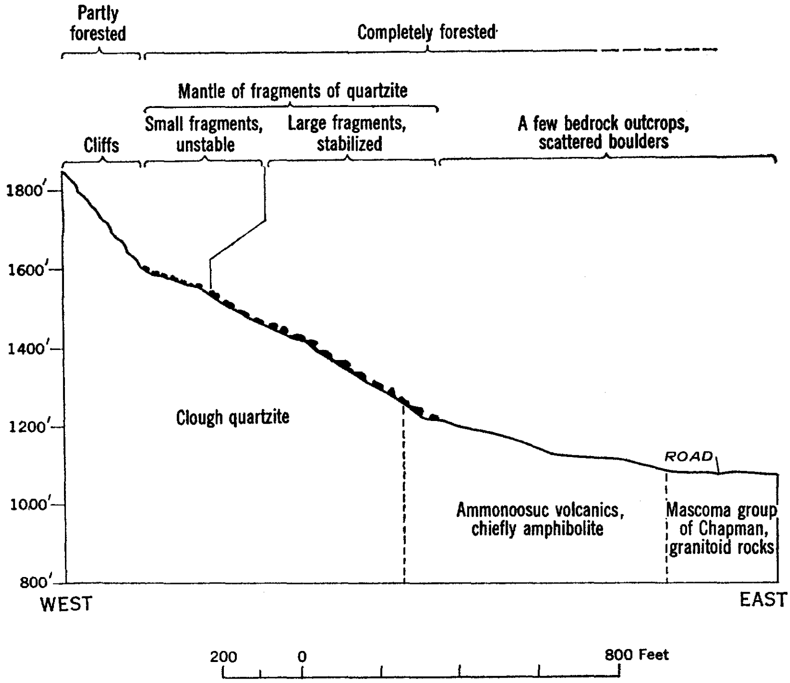



FIGURE 22.—Boulder-strewn east slope of Moose Mountain west of Enfield Reservoir (loc. 1, pl. 4). The slope is forest covered and mantled by quartzite boulders and smaller fragments. Next to the cliffs is an unstable mass of small rock fragments. Lower on the slope is a stabilized mass of boulders. The boulders form lobes pointing downslope. Bedrock data from Chapman (1939); structure not shown, bedding and foliation essentially vertical. Surficial deposits omitted except for fragments of rock on surface of ground.

## EOLIAN FEATURES

A few of the boulders on top of some kame deposits have been polished and slightly fluted by sand blasting. Such ventifacts are commonly coarse-grained granitic rocks or pegmatite. The quartz grains stand out because the adjacent feldspar and mica have been etched away. In some boulders of pegmatite, books of mica are polished on surfaces at right angles to the basal plane. The ventifacts are only slightly etched as compared to those from other glaciated regions such as Cape Cod (Mather, Goldthwait, and Thiesmeyer, 1942). Many of the ventifacts have been slightly weathered since they were abraded. Ventifacts are found chiefly on the kame deposits between Leeds Hill and Pond Ledges in Danbury, and in the Haines Brook valley south of Canaan. No ventifacts were found in areas where sand is moved today by the wind; hence the ventifacts are ancient. Probably they are contemporaneous with the kame deposits.

Sand is now being moved by the wind in a few areas of bare ground (included in the Windsor soils, Latimer and others, 1939; Simmons

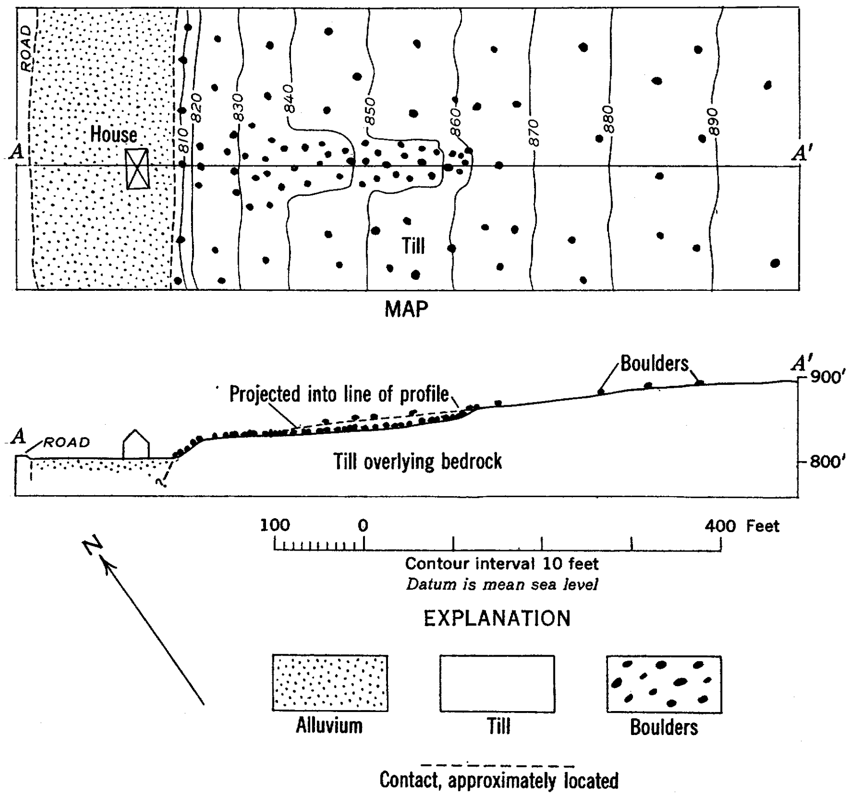



FIGURE 23.—Map and cross section of broad shallow gully, a common feature on some till slopes, and perhaps the result of ancient mass movements. Gully, on northwest-facing slope of Town Hill, is just southeast of Goose Pond Brook in Canaan (loc. 2, pl. 4).

and others, 1949). Such areas have probably been formed since the arrival of the first settlers.

## RECENT DEPOSITS

Alluvium and swamp deposits occupy the valley bottoms. The alluvium is chiefly sand and silt (textures range from sand to silt loam); the amount of gravel is small except near the base of mountains. The swamp deposits include peat and muck. The thickness of these deposits is unknown; their extent on plate 4 is based largely on soil maps (Latimer and others, 1939; Simmons and others, 1949). These deposits are assigned to the Recent epoch. Although paleontologic evidence of age of these deposits is lacking, they are younger than the drift.

## LATE QUATERNARY HISTORY

Before the advance of the last ice sheet, the Quaternary history of the Canaan area is obscure. Drift older than the last glaciation has not been identified. Goldthwait and Kruger (1938, loc. 23 and 33, table 1) described two localities in the area where weathered bedrock occurs beneath drift. Although the weathering probably antedates the last glaciation, its exact age is unknown. The last ice sheet that covered the Canaan area probably advanced as far south as Cape Cod, southern Rhode Island, and Long Island, where it built prominent moraines (Denny, 1956a). The polished and striated bedrock ledges record that the last movement of the ice sheet, just before its disappearance, was to the south and southeast.

The complete history of deglaciation is unknown. The surficial deposits on the floor and the sides of a typical northward-trending valley (fig. 16) probably record the following sequence of events. After compact till was deposited on an abraded bedrock surface by active glacial ice, the glacier became almost motionless (doubtless because it was being thinned from above and from below) and loose till was deposited beneath it, partly by running water, partly in ponded water, and partly directly from the ice. As the upper surface of the glacier was lowered, the loose till became mantled by boulders derived from the ice or from the adjacent valley wall. Continued wastage formed streams that flowed in open channels between the ice and the valley wall and built kame deposits to levels that were slightly below the top of adjacent loose till. In some places both sides of such channels were made of ice. Fine sands were deposited in standing water. Later, sand and a little gravel were deposited by streams. Finally the gravel that now caps many kame terraces was laid down. In some places the upper gravel may have been deposited during dissection of the kame deposits. During the close of gravel deposition, or immediately thereafter, sand was picked up, carried, and deposited by wind, producing a few slightly polished and etched boulders. Some of the material mapped as terrace sand was deposited at about the same time as the adjacent kame deposits. Meanwhile further north the melt water that laid down the kame deposits may have flowed in channels cut partly in ice and partly in bedrock—the abandoned stream channels of the present day. Dissection probably followed immediately. Little erosion or deposition has taken place since the ice disappeared. Some of the terrace sand may have been deposited in early postglacial time. Some of the larger streams have slightly widened their flood plains and deposited a covering of alluvium. Swamp deposits accumulated in depressions on the valley floor.

In the Smith River-Indian River lowland, there is a sequence of kame deposits. Assuming a northward retreat of the ice, the oldest kame deposits are those west of Danbury; between Pond Ledges and Leeds Hill, these deposits were built by melt water that flowed south and southeast through the abandoned stream channels (pl. 4). As the lowlands north and east along Smith River were uncovered by downwastage, the kame deposits in the valley of the Smith River accumulated. These kames, or at least their gravel cap, may have been deposited by a stream that flowed southward from the vicinity of Tewksbury Pond nearly to Danbury. It is possible that in the reach south of Grafton Center the stream deposited the terrace sand. After the rock sill at the divide between Tewksbury Pond and Mirror Lake was uncovered, melt water flowed across it and formed large potholes (Jackson, 1844, p. 113–114; Upham, 1878, p. 63). Perhaps an ice-dammed lake was formed north of this rock sill as indicated by the apparent delta structure of some of the kame deposits near Mirror Lake. But the Mirror Lake basin was probably occupied by a block of ice when the adjacent kames were built; thus any ice-dammed lake north of the divide must have been at least partly filled by glacier ice.

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