Surficial Geology of the Athol Quadrangle Worcester and Franklin Counties, Massachusetts

By DONALD F. ESCHMAN

GEOLOGY OF SELECTED QUADRANGLES IN MASSACHUSETTS

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By Donald F. Eschman

ABSTRACT

The Athol quadrangle is in the eastern highlands of Massachusetts some 20 miles south of the New Hampshire border and an equal distance east of the Connecticut River. It is an area of considerable relief. Topography is largely controlled by the structure of the underlying high-grade (sillimanite zone) metamorphic schists and granitic gneisses. Drainage is to the Connecticut River by way of the Millers and Swift River systems.

The surficial material in general is thin and discontinuous glacial drift. Major north-south topographic trends provided sluiceways down which poured the glacial melt water and most of the sediment released from the melting ice. The glacial till is sandy and is generally rust colored owing to the abundance of limonite from rock weathering.

No well-marked ice terminus is evident in the area; apparently the drift was laid down by Cary(?) ice which extended much farther south at the time of its maximum advance. The general direction of retreat of this ice was from south-southeast toward the north and northwest, although the presence of a valley-train deposit along the Millers valley suggests that ice lingered in the Winchendon quadrangle, which is immediately to the northeast. The succeeding ice advance (the Valders Stade in the midcontinent region) did not reach the Athol area and, as is indicated by both the vegetational record and the sediments, had little effect on the area.

Sand and gravel are the only deposits of significant economic value within the quadrangle.

INTRODUCTION

The Athol quadrangle includes an area of about 55 square miles in the Worcester plateau of north-central Massachusetts approximately 60 miles west of Boston (fig. 1). It is almost entirely in Worcester County but includes about a quarter of a square mile of Franklin County. Glacial and postglacial deposits form a discontinuous mantle over igneous and metamorphic rocks in the area. The crests on the plateau represent a base-leveled surface that has been uplifted

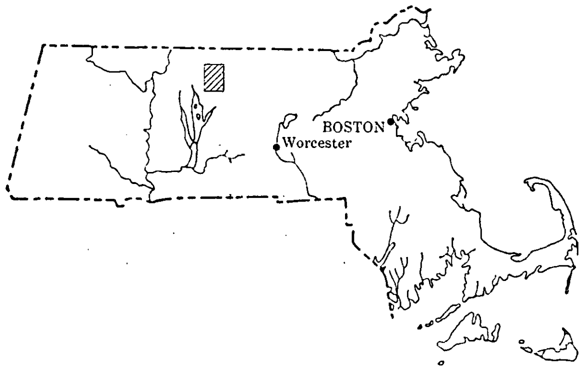

FIGURE 1.—Location of the Athol quadrangle (diagonally ruled).

and incised. The general altitude of the higher parts of the area is between 1,100 and 1,250 feet, although several hills reach 1,300 feet. The highest hill, Prospect Hill, has an altitude of 1,383 feet. The hilltops are generally slightly lower in the western third of the area. Maximum relief in the area is about 875, but local relief is generally less than 400 feet.

The main topographic features of the area, with the exception of part of the narrow valley of Millers River, are chiefly controlled by the lithology and structure of the underlying bedrock. This accounts for the rather pronounced north-south trend of the valleys and ridges in the area. The quadrangle is fairly well drained. Some local disarrangement of the drainage resulted from the deposition of glacial deposits, but no major drainage changes since preglacial time are evident. The through-going valley occupied by Brooks and Riceville Ponds and the outwash-filled valley of Tully River north of Athol are the two best examples of local changes of drainage as a result of glacial and glaciofluvial deposition.

The distribution of surficial deposits, as shown on plate 1, was determined from natural and artificial exposures, from several hundred hand-dug shovel and auger test holes, and from interpretations of origin based on morphological form. Bedrock formations are not individually distinguished on the map, but the distribution of principal bedrock exposures is indicated.

PRE-PLEISTOCENE HISTORY

Few details of pre-Pleistocene history are preserved in the quadrangle. No rocks of Precambrian age are exposed, and the Paleozoic Era is imperfectly represented. The events that occurred in this area between the Paleozoic Era and the Pleistocene Epoch must be inferred both from broad interpretations of the present topographic features and from the results of studies in the Connecticut Valley region. The area was subject to erosion during the long interval of Mesozoic and Tertiary time.

Tertiary drainage was at first generally independent of the structure and lithology of the underlying bedrock, but as erosion progressed the stream courses were increasingly adjusted to belts of hard and soft rocks. Uplift during the Tertiary Period aided in this adjustment of topography to rocks of different resistances.

By the end of the Tertiary Period, the long north-south valleys now occupied by the East Branch Swift River, Lake Ellis, Riceville and Brooks Ponds, and the Tully River were the sites of major drainageways. By this time, too, Millers River had taken its present course, skirting the edges of minor structural features and crossing the top of a low structural sag in the large intrusive body of Hardwick Granite that underlies the east half of the quadrangle. Millers River probably attained its present role as a master stream by headward migration during the late Tertiary. Subsequent piracy of south-flowing streams—such as those which occupied the Tully River valley, the valley of Lake Ellis and Davenport, Riceville, and Brooks Ponds, and the valleys of East Branch Swift River and Dunn and Beaver Brooks—aided in this growth. These valley systems are now cut into north and south draining segments, which are tributaries of Millers, Swift, and Ware Rivers.

PLEISTOCENE GEOLOGY AND HISTORY

The Pleistocene is distinguished as a time of glacial action by ice sheets that expanded southward from the Hudson Bay region. Nevertheless, during the greater part of the Pleistocene Epoch, central Massachusetts was free of glacial ice, and streams were the dominant erosive agent. Gross topographic features are thus largely the result of stream erosion with minor modification from the erosive action of overriding ice.

From evidence found in the Middle West, it is known that there were at least four major ice advances during the Pleistocene Epoch, but conclusive evidence for the three earlier advances is lacking in New England. With the recent recognition of post-Sangamon, pre-classical Wisconsin glacial advances in the Middle West, many if not all the weathered tills described from the islands off the New England shore may prove to be best correlated with the fourth major glaciation. For purposes of the present report it is best to consider that the area was affected by at least the latest of the four major glacial advances, the correlative of the Wisconsin ice sheet of the Middle West.

GLACIAL EROSION

The erosive power of the ice sheets that covered New England during the Pleistocene Epoch is shown directly by striae, grooves, and smoothed and polished surfaces on bedrock ledges, and indirectly by the abundance of materials deposited by the ice. Large-scale erosion included plucking and quarrying the bedrock and nearly complete removal of soil and weathered rock that mantled the area following the long period of weathering and erosion during the Tertiary. This weathered material must have been only a small part of the debris that was available for ice transportation and subsequent deposition. That the bulk of the material moved by the ice must have come from relatively unweathered bedrock is shown by the paucity of clays and other secondary minerals in the glacial drift. This scarcity of secondary minerals also suggests either that the residual soils developed during the Tertiary Period were thin, because the weathered material was removed as it was formed, or that the Tertiary soils were stripped from the New England area by stream or ice erosion prior to the advance of the last ice sheet.

No striations or grooves on bedrock were found within the quadrangle. This lack of small-scale erosive features is due to the fact that much of the bedrock of the area is so coarsely crystalline that such features could not be well developed on the surface by the abrasive action of ice-carried stones and boulders. In the areas of readily weathered mica schist, any striae produced have since been destroyed by weathering. Larger scale features at least modified by glacial erosion are well displayed by Round Top, Pratt, and Prospect Hills, as well as by many smaller hills and bedrock knobs. These display smoothed and rounded northern slopes and crests and oversteepened and plucked southern and southeastern slopes, indicating that the ice advanced across the area from a little west of north.

GLACIAL DEPOSITION

Nearly all the Athol quadrangle is covered with rock debris deposited by ice and glacial streams during the Pleistocene Epoch. The material deposited directly by the ice is till, and that deposited by melt water from the glacial ice forms kames, kame plains, kame terraces, ice-channel fillings, valley trains, and other undivided glaciofluvial deposits. The distribution of these various types is shown on the surficial map (pl. 1).

TILL

About 80 percent of the quadrangle is covered by till deposited as ground moraine and ablation moraine. Nowhere is there evidence that this till is more than a few tens of feet thick; in fact, most hills in the area are of bedrock.

The till is sandy and ranges from compact and blocky to loose. Wherever exposures more than 8 feet in depth were observed, the lower part of the till was compact. Size analyses of several till samples indicate that the material is less than 3 percent clay, about 13 percent silt, 40–60 percent sand, 10–30 percent pebbles, and about 15 percent cobbles and boulders. In most exposures the till is olive brown or gray, although it ranges from light bluish gray to dark yellowish red brown.

Within the Athol quadrangle no evidence was found that tills of more than one age are present, such as has been suggested for areas in northeastern Massachusetts. The color variation within the till, and a less pronounced variation in compactness and texture, seems instead to reflect the various source rocks from which the till was derived. The soils developed from the weathering of these tills are brown podzolic soils. In most places the soil profile developed on till comprises a dark-brown horizon several inches thick, a light-tan to reddish-brown B horizon typically 2–2½ feet thick, and a tight, clay-rich zone at the base. Beneath the B horizon the till only is slightly weathered. The deepest weathering noted, a little over 4 feet, is marked by a mottling of the till color.

Most of the light-gray to olive-gray fairly loose sandy till is in the southwestern and northwestern parts of the quadrangle. There the bedrock is Monson Gneiss, a moderately coarse grained rock containing much light-colored quartz and feldspar and rarely more than 10 percent dark minerals. A dull olive and olive-brown till is found in the east half of the quadrangle and, near the southwest corner of the quadrangle, in the valley occupied by Riceville and Brooks Ponds, areas underlain by biotite-rich Hardwick Granite. Dark-red, yellow-brown, and brown micaceous till is found chiefly in a narrow north-south zone underlain by rusty biotitic Brimfield Schist that extends through the west-central part of the quadrangle. This dark till is commonly more compact than that found to the east and west. Soils developed on this till are much darker in color than those developed on till derived from the Monson Gneiss or from the Hardwick Granite. Boundaries between the various types of till are nowhere sharp and distinct, largely because bedrock contacts are not sharply defined, and broad zones of rock are transitional in character. Till exposed on the south side of Main Street, Athol, about half a mile east of the main business intersection, displays nearly all the color variations found in unweathered till in the quadrangle.

The low content of silt and clay-sized particles in the tills is due chiefly to the fact that the tills were derived mainly from rather coarse grained bedrock which, on grinding, yields coarse sandy material. The low clay content suggests also that the area was not covered by a deep residual soil prior to the last ice advance, and it supports the idea that this part of Massachusetts was covered by glacial ice more than once during the Pleistocene.

GLACIOFLUVIAL DEPOSITS

Most glaciofluvial deposits in the area were laid down near or against blocks of stagnant ice in the valleys. Such ice-contact deposits are classified chiefly on the basis of topographic form and position within a valley. The various ice-contact deposits designated on the accompanying map (pl. 1) are kames, kame plains, kame terraces, and ice-channel fillings. Because of their common origin in juxtaposition with stagnant separated blocks of ice, all these ice-contact deposits may occur together. Valley-train deposits, though not laid down in direct contact with ice over much of their length, are, nevertheless, the result of deposition by glacial streams and are classified as glaciofluvial deposits.

Kames.—Kames occur as individual knobs or as irregular groups of knobs both within and on the sides of many of the broader outwash-filled valleys and in widely separated areas within the higher ground moraine in the central and eastern parts of the quadrangle. They are knobby conical hills of poorly to well-stratified sand and gravel. Groups of kames are found in several places, as near the head of the broad outwash-filled valley of Ice Company Brook south-southwest of the city of Athol; along Chase Road, Athol, just to the west; and just east of Davenport Pond in Petersham.

Kame plains.—In places the kame deposits are so broad that collapse resulting from removal of the confining ice walls after deposition did not destroy the flat tops which were the flood plains of the glaciofluvial streams. Such flat-topped roughly circular hills within a valley and detached from the valley wall are called kame plains. Five such deposits are shown on the map (pl. 1); (1) a short distance south-southwest of Sportsmans Pond, Athol; (2) along State Route 2 about half a mile east of Phillipston Four Corners, in Phillipston and Templeton; (3) along Baldwinsville Road a quarter of a mile south of Route 2, Phillipston; (4) in the middle of Thousand Acre Swamp, Phillipston; and (5) in the valley of East Branch Swift River half a mile north of Popple Camp Road, Petersham.

Kame terraces.—Kame terraces formed where sand and gravel were deposited in openings between ice blocks and the adjacent valley walls. Most of them are composed of coarse well-bedded sand and gravel, but some are of finer material; thus, the water which deposited them must have flowed, at least locally, at a rather low velocity. The surface of a kame terrace is generally irregular as a result of collapse during the melting of buried ice blocks or of erosion subsequent to deposition; some irregularities may be primary. Where the surface is marked by kettles, collapse due to melting of ice is clearly indicated. At an altitude of 770 feet on the west side of Millers River about half a mile downstream from its confluence with West Gulf Brook is a good example of a collapsed kame terrace. Other examples are at the south end of the terrace at an altitude of 850–900 feet around Doe Valley Road, and along Colony Road, Phillipston, near the northeast corner of the quadrangle. Most kame-terrace deposits are thin. The chief exceptions are those on the broad floor of the Tully River valley, where several terraces with rather high steep ice-contact slopes and broad flat tops are broken only by the large kettle holes occupied by Sportsmans Pond and Silver Lake.

Large-scale deltaic crossbedding was seen in an abandoned pit cut into the kame terrace in which Silver Lake is located, just north of the center of Athol. The small extent of this deltaic deposit, shown by the fact that no deltaic bedding can be seen in any of the other abandoned pits in this same surface, suggests that the pond into which this delta was built was of limited extent. The ice-contact slope on the north and northwest sides of this surface (altitude 590 ft), and the fact that the deltaic terrace on the east side of the valley is connected to a kame-terrace level along the east wall of Tully valley from the north, suggests that ice was present in the valley to the north at the time of delta formation.

Ice-channel fillings.—Included under the term "ice-channel fillings" are all ridges of glaciofluvial sand and gravel. Such deposits commonly bifurcate and join together, or branch in one or more directions. These ridges have a variety of origins. Some were deposited as eskers in drainage tunnels under and within the ice. Similar deposits are formed by surface melt-water streams as crack or crevasse fillings or are deposited on the surface of the ice and lowered to the ground by subsequent melting of the ice. In some places ridges of glaciofluvial sand and gravel result from nearly total collapse of a kame terrace deposited on a very irregular ice surface. Because it is almost impossible to determine accurately the mode of formation for each deposit, the noncommittal term "ice-channel filling" is used for all.

The ice-channel fillings on the ridge top just west of Millers River, three-quarters of a mile east of Silver Lake, and the long ice-channel filling just west of Tully River in the northwest corner of the quadrangle are composed of large pebbles and cobbles and are probably crevasse fillings. The deposit on the east side of Tully River about a quarter of a mile north of its confluence with Millers River at Athol is composed of finer grained material with a large sand component and is thought to be the result of irregular collapse of a kame-terrace deposit. The ice-channel fillings mapped at the south end of Lake Ellis valley and north and south of the intersection of Turnpike Road and Athol Road, Petersham, are probably eskers. They appear to have been deposited by melt-water streams flowing southward beneath the ice. Apparently the hydraulic head of these streams was sufficient to enable them to ascend the south wall of the valleys and emerge from the ice to drain southward through till and bedrock melt-water channels. At both places the streams emerged from the ice and deposited a kame terrace between the valley wall and the ice front. The kame terrace at the south end of Lake Ellis valley consists of 11 feet of lacustrine sand overlain by 5 feet of fluvial crossbedded sand and gravel, indicating that a short-lived pond occupied this site as the valley became ice free.

Valley trains.—For some time after the Millers River valley was freed of ice, melt water flowed down it from ice still occupying the broad lowland a short distance northeast of the area, in the Winchendon quadrangle. The melt-water streams deposited as much as 50 feet of fine-grained well-bedded sand and gravel in the Millers valley. Numerous remnants of this glaciofluvial deposit lie along the valley walls and are mapped as valley trains. These remnants are typically smooth, but many of them clearly show, in slip-off slopes, the effects of the migrating stream that later incised the valley train to produce the present terraces. The only valley-train remnant which has a very irregular top is the one just opposite West Gulf Brook. The closed depressions in this deposit may have resulted either from the melting of glacial ice buried in the valley train or from railroad construction many years ago.

Undivided glaciofluvial deposits.—Glaciofluvial deposits in five areas were mapped (pl. 1) as "undivided" because they are clearly of glaciofluvial origin but lack distinctive morphology. In most places the deposits are too thin to mask the till and bedrock topography beneath. In some places, however, such as along Buckman Brook, north of Newton Reservoir, postglacial stream erosion has extensively modified the shape of the deposit. The undivided glaciofluvial deposits mapped in the western part of the city of Athol also have been modified by postglacial deposition. During the 1938 hurricane the water level in Millers River rose to a point about 5 feet above the level of Main Street in the center of the business district. The flood covered the western part of the city and deposited a layer of mud and sand. Thus, much of the material mapped as "undivided glaciofluvial deposits" within the city probably is actually alluvium of recent origin.

One other area of sand and gravel is a large depression transected by the east boundary of the quadrangle along Royalston Road, Templeton. The depression is nearly rimmed by bedrock hills and is drained by Beaver Brook through a narrow opening in the low till ridge that closes the basin on the west. A 62-inch-deep hand-augered hole about midway between the west edge of the basin and the quadrangle boundary and 20 feet north of Royalston Road exposed 60 inches of fine to very fine sand overlying gravel. About 40 inches below the surface is a 3-inch-thick layer of limonite-stained coarse sand. Little or no bedding was evident in the upper 2 feet, the only part of the hole dug by shovel. The area south of the road is at a slightly higher altitude and is underlain by sandy till. The fine sand that underlies much of the basin may have been deposited in a small pond during the late stages of glaciation by melt-water streams draining ice in the valley of Beaver Brook to the north. However, much of the fine and medium sand found in this basin may have been deposited by subsequent slope wash and minor stream action.

DEGLACIATION

As the glacier in central Massachusetts melted, blocks of stagnant ice became detached from the main ice mass and were left behind in valleys and depressions, suggesting that much of the glacial retreat was by downwastage of the ice. In areas of such ice stagnation, glacial retreat is represented by a complex series of glaciofluvial sequences which, through detailed mapping, can be used to unravel the history of ice retreat, as was done by Jahns (1953) in the Ayer quadrangle. In the Athol quadrangle the topographic relief is greater and there are fewer low-level connections between valleys. As a result it is difficult to correlate sequences between different glaciofluvial drainages. The sequence map (pl. 2) shows the glaciofluvial sequences within the several valleys. These are definite correlations, for the most part based upon the uncollapsed graded upper surfaces of the deposits. In general the deposits in the southern and eastern parts of the quadrangle are older than those in the northern and western parts.

The oldest evidence of melt-water drainage in the quadrangle consists of the numerous isolated ice-contact deposits in the upland areas and very high on the walls of the major valleys. These deposits are so isolated from one another that age relations between them cannot be determined. With continued downwasting of the ice, the upland areas became ice free and the valleys only partly filled with ice. At this time glaciofluvial deposition began in the valleys. The sequences in each valley system are discussed separately.

DUNN BROOK AND EAST BRANCH SWIFT RIVER

The oldest glaciofluvial deposits in the quadrangle that can be grouped into sequences are in the south end of Beaver Brook valley, Dunn Brook valley, and the valley of the East Branch Swift

River. Proglacial drainage in these valleys was southward into the Petersham quadrangle. The earliest deposits are the ice-channel fillings north of Lincoln Road in Phillipston. These deposits, at altitudes of 1,080–1,060 feet, were laid down when both the Dunn Brook valley and the valley of the East Branch Swift River were filled with a considerable thickness of ice.

Thinning of the ice allowed the melt-water streams to drain across a divide at an altitude of approximately 1,030 feet and form the fine-grained ice-contact deposits at altitudes of 1,080–1,050 feet in the south end of Beaver Brook valley and 1,100–1,050 feet in Chickering and Dunn Brook valleys. These deposits are thought to be at least in part equivalent to the ice-contact deposits at altitudes of 1,000–950 feet in the valley of the East Branch Swift River.

The youngest glaciofluvial sequences in the Dunn Brook-East Branch Swift River drainageway are the low kame terrace and kame plain at altitudes of 950–940 feet in the valley of the East Branch Swift River; these kame deposits are composed of coarse and dirty gravel. Further melt-water drainage through this area was blocked by the high till and bedrock uplands to the north and by buried ice and the glaciofluvial deposits in Dunn Brook valley.

BEAVER BROOK–HOYT BROOK

After drainage into East Branch Swift River ceased owing to glacial wastage, the melt-water drainage of the northeastern part of the Athol quadrangle was to the east and southeast by way of Beaver Brook valley. The drainageway continued through a narrow divide at an altitude of approximately 1,010 feet along State Route 2 in the Templeton quadrangle one-half mile east of the Athol quadrangle boundary. Glaciofluvial deposits land down by this melt water are at altitudes of 1,060–1,010 feet in the south end of Beaver Brook valley and in the north end of Dunn Brook valley.

Later melt-water drainage in the Beaver Brook valley was northward and northeastward into the Otter River valley, in the Templeton and Winchendon quadrangles. The earliest sequence laid down by melt water draining northward through Hoyt Brook to Beaver Brook valley is made up of ice-contact deposits at an altitude of approximately 1,040 feet in Thousand Acre Swamp and the kame terraces at altitudes of from 1,000–920 feet in Beaver Brook and Hoyt Brook valleys. The youngest glaciofluvial sequence is made up of fine-grained kame and kame-terrace deposits at altitudes of 850–830 feet north of Royalston Road in Templeton. All later melt-water drainage from the northeastern part of the quadrangle was probably westward by way of the Millers River valley.

TOM SWAMP VALLEY

The earliest glaciofluvial deposit of any extent in Tom Swamp valley is a kame terrace just east of the intersection of Flat Rock Road and Turnpike Road, Petersham. This deposit, at an altitude of 850 feet, was laid down by a melt-water stream that drained southward and eastward into the valley through a narrow channel around the south end of the till and bedrock hill to the east. Correlated with this kame terrace are several ice-channel fillings to the north, which apparently were deposited by the same melt-water stream. This earliest sequence formed when Tom Swamp valley itself was deeply filled with ice.

As the ice in Tom Swamp valley thinned, melt water draining into the head of the valley laid down an extensive complex of ice-contact deposits. These deposits are at an altitude of approximately 810 feet at the north end of the valley and slope to 770 feet where Tom Swamp valley leaves the quadrangle. The youngest glaciofluvial sequence laid down by melt water draining southward through Tom Swamp valley is made up of undivided glaciofluvial deposits at a maximum altitude of approximately 770 feet along the walls of Riceville Brook valley. Continued northward retreat of the ice allowed melt water to drain southwestward into the Orange quadrangle by way of Thrower Brook valley.

LAKE ELLIS VALLEY

Lake Ellis valley contains only two glaciofluvial sequences. The older consists of a large kame terrace and ice-channel fillings at altitudes of 890–900 feet at the south end of the valley. These ice-contact deposits were formed, after the ice front had retreated a short distance up the valley, by melt-water streams that deposited sand and gravel between the ice and the south wall of the valley and then drained southward through several channels into Davenport Pond valley and from there into Tom Swamp valley. This sequence is thought to be approximately equivalent in age to the ice-contact deposits at an altitude of 800 feet in Tom Swamp valley.

The younger sequence was laid down by melt-water streams draining southward over and around ice blocks in Lake Ellis valley and then westward through Ellinwood Brook valley into Thrower Brook valley. The ice-contact deposits along the walls of Lake Ellis valley and the undivided glaciofluvial deposits in Ellinwood Brook valley were laid down at this time. A small temporary pond at an altitude of 850–860 feet occupied the area southwest of Doe Valley Cemetery at this time, as is indicated by 11 feet of finely laminated lacustrine sands underlying 5 feet of fluvial crossbedded sand and gravel.

THROWER BROOK VALLEY

Melt-water drainage in Thrower Brook valley was to the south and southwest into the Orange quadrangle and from there eventually into the Quabbin valley.

Ice-contact deposits with uncollapsed upper surfaces at altitudes of 750–730 feet make up the earliest sequence. These deposits were laid down by melt-water streams draining southwestward along the southeast wall of the valley. As the ice in Thrower Brook valley continued to thin, lower melt-water streams deposited the sequence at altitudes of 700–690 feet. Both sequences are thought to be equivalent in age to the younger deposits in Lake Ellis valley and to the undivided glaciofluvial deposits in Ellinwood Brook valley.

Southward, the large area of undivided glaciofluvial deposits having collapsed upper surfaces at an altitude of approximately 650 feet marks the ice-contact head of the next sequence. When this sequence was deposited, the ice had melted back to a position approximately marked by the present site of Thrower Brook.

Extensively collapsed undivided glaciofluvial deposits at altitudes up to 620 feet to the north make up the last sequence laid down in the valley. These were deposited by melt-water streams draining southward into the Quabbin valley. Minor amounts of melt water probably drained northward into the Millers River valley after the deposition of this sequence. Within the broad filled valley occupied by The Plains and Lake Rohunta in the Orange quadrangle are at least two outwash sequences. These were laid down by south-flowing drainage after the sequence at an altitude of 620 feet was formed around Ward Pond.

MILLERS RIVER AND TULLY RIVER VALLEYS

The oldest glaciofluvial deposits in the Millers River and Tully River valleys are small isolated kame terraces at altitudes of 1,040–840 feet. These deposits cannot be correlated with one another because of their small size and the large distances separating them.

The oldest glaciofluvial deposits that form a distinct sequence are the kames and kame terraces at altitudes of 800–720 feet along both walls of the Millers River valley. The next youngest glaciofluvial sequence is made up of kames and kame terraces at altitudes of 760–620 feet in the same valley. These early sequences were laid down when the Millers River valley and the Tully River valley were filled with a considerable thickness of ice. Correlation between individual ice-contact deposits in these early sequences is somewhat difficult because the deposits are separated by considerable distances and were deposited by melt-water streams that had abrupt changes in gradient.

The lower glaciofluvial sequences in the Millers River and Tully River valleys are in most places large features with extensive uncollapsed upper surfaces, and correlation between individual ice-contact deposits within a sequence can easily be made. These deposits were laid down by melt-water streams flowing over and around greatly thinned ice blocks in the Tully River valley and in the Millers River valley at and below its confluence with the Tully River. The older of the two lower sequences is made up of glaciofluvial deposits having uncollapsed upper surfaces at altitudes of 630–590 feet along the sides of the Millers River and Tully River valleys. Deltaic crossbedding in the westernmost part of the large kame terrace around Silver Lake indicates that when this sequence was laid down, a lake occupied at least a part of the broad valley near the confluence of Millers and Tully Rivers. If the altitude (about 575–580 ft) of the top of the forest beds is taken as a crude measure of the height of the water surface, all the low area to the southwest of the deposit could have been beneath lake water. The only place within this low area where possible lake-bottom deposits could be found was in a poor exposure (alt 520 ft) at the junction of South Main Street and North Orange Road just west of Athol. Here, nearly flat lying beds of sand and fine gravel are exposed. A 4-foot-thick sand layer about 2 feet below the surface may have been deposited in standing water. The sand and gravel above and below this sand layer, however, seems to be of fluvial origin. Emerson (1898, p. 572) mentioned a section of thin-bedded blue clay exposed in a pit at an abandoned brickyard north of Millers River near the Athol-Orange town line, Orange quadrangle, which might also have been deposited in such a lake. On the other hand, the flood plain south and southwest of the deltaic deposit is underlain by coarse sand and gravel. The valley fill here is probably thin, as the Millers River is flowing on bedrock only 0.8 mile below its confluence with Tully River. However, the presence of lower, and later, ice-contact deposits a short distance southwest of the area of deltaic bedding indicates that an ice block occupied at least part of the lowland area near the confluence and suggests that there was no body of standing water of any real significance at this point.

The younger sequence consists of the large ice-contact deposits at altitudes of 570–550 feet north and west of Sportsmans Pond and the small ice-contact deposits at altitudes of 560–550 feet in the bottom of Tully and Millers River valleys. Both this lower glaciofluvial sequence and the slightly higher one best developed around Silver Lake were laid down by melt-water streams that drained west down the present valley of Millers River and then southward toward the present site of Quabbin Reservoir through the valley occupied by Lake Rohunta, in the Orange quadrangle.

The glaciofluvial deposits mapped as valley train in the Millers River valley east of Tully River are not considered a sequence as their upper surfaces are in part modified by later stream erosion. These features are remnants of a valley train that was continuous at least to the site of the city of Athol. The relation of the valley train to the lower glaciofluvial sequences north and southwest of the city is not entirely clear, although the valley train seems to be as old or slightly older than the sequence at an altitude of 590 feet that borders Silver Lake.

The youngest glaciofluvial deposit in the Millers River and Tully River drainageway is the undivided material found in the western part of the city of Athol.

AGE OF THE GLACIAL DEPOSITS

The detailed chronology of the Pleistocene Epoch in New England is not yet established. Flint (1956) cited evidence that the Wisconsin ice sheet readvanced across much of southern New England to a point near Middletown, Conn., slightly more than 13,000 years ago; this would correlate well with the later phases of the Cary Stade in the Middle West. Although Flint (1953) originally felt that the Valders margin was best placed at St. Johnsbury, Vt., he later (1957, p. 360) pointed out that many parts of the St. Lawrence Lowland were free of ice during the Valders readvance. More recent work by MacClintock and Terasmae (1960) indicates that the last ice to advance across the St. Lawrence Lowland was pre-Valders in age. Their Fort Covington drift, probably the correlative of the Mankato drift in the Middle West, is traceable around the north edge of the Adirondack upland at the international boundary, and from there eastward toward St. Johnsbury. The drift blanketing the Athol quadrangle is, thus, probably of Cary age.

In the small high-level peat bog traversed by the relocation of State Route 2 two-tenths of a mile south of Batchelder Road and three-fourths of a mile west of Pleasant Street, Athol, a poplar log was found embedded in a fine-grained organic sediment 7 feet 8 inches below the bog surface and 18 inches above the underlying stratified sand. The radiocarbon date of this log as determined in the U.S. Geological Survey Laboratory is 10,800±250 years before present (W–361; Rubin and Alexander, 1958), and as determined by the Phoenix Project Laboratory of the University of Michigan is 10.700±800 years before present (M–413; Crane and Griffin, 1958). These two dates and the analysis of the pollen in the bog (Davis, 1958) support the general idea that the underlying drift is of pre-Valders age.

POSTGLACIAL GEOLOGY AND HISTORY

Most low-lying areas in the Athol quadrangle are underlain by alluvium or by swamp peat and muck. These deposits are largely the result of stream action and slope wash and the decay of vegetable material but are in part the result of wind action and mass wasting due to gravity. The age of some of these deposits is shown both by the fact that they frequently include coal particles and items of trash, as well as other evidence of human activity, and by the fact that many areas of such deposits have been subjected to flooding during historic time.

ALLUVIUM

Included in this unit are gravel, sand, silt, and clay found chiefly in the low-lying areas subjected to frequent flooding. In stream valleys the limits of the alluvium thus roughly bound the modern flood plain. The coarser fraction of the alluvium represents bedload of the stream deposited by lateral migration. The finer fraction, composed of silt and clay, was deposited by overbank flooding of the stream and by slope wash. These deposits consist chiefly of reworked glacial and glaciofluvial materials. The upper part of the alluvium just northeast of the confluence of Tully and Millers Rivers extends to a depth of more than 3 feet and is composed of fairly dark colored fine sand containing a few anthracite coal fragments. The lower part is largely composed of fine to medium sand with some gravel. Much of the floor of the Millers River valley was covered with several feet of water during and immediately following the 1938 hurricane, and much of the alluvium may be of very recent origin.

SWAMP DEPOSITS

The bogs and swamps in the valley bottoms and undrained depressions of several origins contain peat, muck, silt, and fine sand. Davis (1958) studied pollen taken from three bogs in the quadrangle: a large bog, Tom Swamp, lying in the valley occupied by Riceville and Brooks Ponds; and two smaller bogs, one (largely destroyed in the relocation of State Route 2) just south of Batchelder Road midway between Pleasant Street and South Athol Road, Athol, and the other traversed by a service road, about 0.3 mile southeast of the Administration Building of the Harvard Forest, Petersham. Borings by Davis in Tom Swamp showed that organic deposits reach a maximum thickness of nearly 38 feet; 24 feet of peat underlain by about 14 feet of gyttja, a black mud rich in determinable organic matter. The other two bogs were underlain by 10–15 feet of organic deposits. Wherever it could be observed at any of the three sites, the base of the organic deposits rests on relatively unweathered outwash sand and gravel.

WIND ACTION

In many parts of southeastern New England, ventifacts, a high proportion of fine-grained material in the upper zones of the soil, and stabilized and inactive sand dunes provide evidence of late-glacial and postglacial wind erosion and deposition. Many sand dunes are found in the Connecticut Valley about 20 miles west of Athol. However, despite a careful search, no positive evidence of extensive wind action, in the form of unquestionable ventifacts or definite windblown silts and sands, was found within the Athol quadrangle. This lack of evidence is probably due to the fact that the drift does not contain any rock type that could be readily cut and polished by windblown material, and to the fact that there are no extensive sand plains that would act as a source area for material of a size suitable to be picked up by the wind.

FROST ACTION

Southern New England was strongly affected by frost action (creep and solifluction) in late-glacial time. The lower slopes of many steep-sided bedrock hills are littered with coarse angular blocks of rock derived from the ledges and cliffs of bedrock by frost riving. The upper few feet of the soil seen in most exposures of glacial drift is loose and unstratified. This zone can best be explained as a result of mixing and stirring caused by alternate freezing and thawing. The present depth of frost penetration in the Athol area is generally 30–35 inches. At several places within the quadrangle and in the Petersham quadrangle just to the south, numerous terraces have been described and explained (Stout, 1952) as solifluction terraces formed during a period when frost action was much greater than at present.

One such terrace described by Stout within the Athol quadrangle is in a small high-level valley just south of Prospect Hill Road, Phillipston, half a mile N. 5° E. of the crest of Prospect Hill. This terrace, which is nearly 15 feet high and is 60 feet wide and about 120 feet long, is apparently composed solely of surficial deposits. A hand-dug hole 10 feet deep in the terrace tread was entirely in sandy till. The front of the terrace is littered with many angular boulders, and the back of the tread contains a shallow depression 2 feet deep and 30–40 feet in diameter. This rather prominent terrace, with the boulder concentration on the riser and the shallow depression at the rear of the tread, may be a good example of a solifluction terrace. However, there is no direct evidence, in the form of contorted layering or flow lines, that frost action played a major role in its formation; it could also be a primary feature of ice deposition.

A second terrace described by Stout is a short distance south of Tom Swamp Road about 1 mile west of its junction with Athol Road, Petersham. This terrace seems to be best explained as the result of accumulation of debris by glacial ice behind a low bedrock ridge. Stout based his idea of a solifluction origin for this and similar terraces along the wall of Tom Swamp valley on the fact that he found some evidence of soil flowage and creep and on the apparent lack of bedrock control of the steeper, frontal part of the terraces. Although it cannot be definitely stated that bedrock controls these risers, such control is strongly suggested for the majority of the terraces by the fact that the terrace fronts parallel the foliation of the bedrock in this area and the fact that along many of the terraces there are large masses of rock which do not rest on the ground surface and in which there is a strong parallelism of foliation to that of the outcrops of the valley.

TILTING DUE TO ISOSTATIC REBOUND

Much of New England was subjected to postglacial uplift as a result of rebound of the earth's crust due to the melting of the continental ice sheet. This is indicated by uplifted fossiliferous marine clay and marine shore features along the New England coast and by tilting of formerly flat water planes related to a moraine-dammed lake that occupied the Connecticut Valley during the retreat of the Wisconsin ice. J. W. Goldthwait (in Antevs, 1922) showed that uplift along the coastal region of Massachusetts north of Boston has amounted to about 2 feet per mile. Hyyppä (1955) found evidence for tilting of about 1 foot per mile in the coastal portion of Massachusetts south of Boston. Flint (1933, p. 974), extrapolating from the altitudes of remnants of lacustrine deposits around Hartford, Conn., and Amherst, Mass., computed a rate of postglacial uplift of 3.25 feet per mile in this 40-mile-long segment of the valley. Jahns and Willard (1942, p. 272–274), reporting on work in the Connecticut River Valley in Massachusetts and using altitudes of the lake surface as interpreted from delta remnants, obtained a rate of uplift of 4.2 feet per mile. On the other hand, Lougee (1953, p. 266), using questionable assumptions, said that the upper Millers River valley has been tilted "to the extreme of 24 feet per mile."

No means of determining the amount of uplift since deglaciation has been found within the Athol quadrangle. An initial horizontal surface, such as a lake shoreline, is ideal control, for its departure from the horizontal gives an exact measurement of the amount of tilt. In the absence of glacial lakes, evidence can only be derived from favorably situated glaciofluvial terrace deposits. Terrace remnants from streams that formerly discharged northward must now have a southward gradient on the restored surfaces or, at least, be horizontal. Thus a stream that had an original northward slope of about 4–5 feet per mile might now show a horizontal upper surface, the former northward gradient having been canceled by the southward postglacial tilt of the land. A stream that originally had a steeper northward gradient would merely have had its gradient reduced and, because the original stream gradient is unknown, would offer no evidence of tilt.

Most melt-water streams in the Athol quadrangle flowed south. The only extensive north-flowing drainage system that contains traceable kame terraces is that of Hoyt Brook, in the northeast corner of the quadrangle. Along Hoyt Brook the kame terraces slope to the north, in the present downstream direction; the fact that this was probably a relatively steep reach of the melt-water drainage system may account for the persistence of the general north slope of the surfaces despite the postglacial tilt of 4–5 feet per mile.

Postglacial tilt may have changed the slope of some of the extensive terrace and outwash-plain surfaces in south-trending valleys east and west of the Athol quadrangle. Horizontal flats underlain by fine-grained glaciofluvial deposits occur in the Otter River valley in the Templeton quadrangle and in the valley occupied by The Plains in the Orange quadrangle. Because it is impossible to retain horizontal surfaces on glaciofluvial deposits unless the deposits had a northward gradient approximately equal to the amount of postglacial tilt, these currently horizontal surfaces must have resulted from interaction of north-flowing streams and postglacial tilt. A northerly direction of drainage requires a main drainageway at the present site of the Millers River. However, geologists who have studied the deglaciation of central Massachusetts imply that the lower part of the Millers River valley was not ice free until after both these outwash deposits were laid down (Emerson, 1898, pl. XXXV, and 1917, p. 141; Alden, 1924, pl. VII and p. 102–103; Lougee, 1953, fig. 9).

VEGETATIONAL SEQUENCE

Detailed studies of pollen samples collected from three bogs in the Athol quadrangle (Davis, 1958) indicate that, on deglaciation, herbaceous vegetation was the first to take hold, succeeded by poplar forest, in turn succeeded by spruce. Following the period of spruce forest was a rather long period in which pine was predominant, succeeded by oak-hemlock forest and, in turn, by oak, pine, and hickory forest. The latest forest community represented in the pollen record studied by Davis is one of birch, oak, hemlock, and chestnut, which extended into pre-colonial times. Because, as Davis and Goodlett (1960) showed in their studies of modern pollen from a pond in northern Vermont, pollen rain does not give an accurate picture of the vegetation of the immediate area, this brief summary of the vegetational sequence is only an approximation of what happened. The Valders readvance is not strongly reflected in the pollen profile, even though it is well located within the sections by two radiocarbon dates on a poplar log taken from one of the bogs studied. This suggests that the Valders ice border was rather far from the Athol area.

ECONOMIC RESOURCES

Sand and gravel.—Sand and gravel were derived from the underlying igneous and metamorphic rocks and are generally suitable for use as concrete aggregate and for general construction. However, the rusty Brimfield Schist, which may locally constitute a fairly high proportion of the gravel, tends to break into slabs or plates with handling, a structural property of importance in some types of construction. The highly metamorphosed schist and gneiss associated with the Hardwick Granite are in many places rich in pyrite, a sulfide mineral which reacts with wet cement to form sulfuric acid and, thus, causes rapid breakdown of the concrete in which it is used.

In general, ice-contact deposits are the best source of coarse granular material. However, many of these deposits also contain a fairly large proportion of finer sand and gravel. The largest ice-contact features are in the broad valleys in and around Athol, particularly in the Tully River valley. Other extensive deposits of sand and gravel are along the west edge of the quadrangle some 3 miles south-southwest of Athol; these extend far into the adjacent Orange quadrangle. Still other deposits occur around Doe Valley Road and in the area between this road and Lake Ellis along the west side of Petersham Road. Relatively undeveloped deposits of coarse sand and gravel occur along Colony Road, Phillipston.

Till.—Much of the till is suitable for most types of fill. It is tough and compact, yet is sandy enough to hold its shape under heavy load conditions. Till has been obtained from many pits throughout the quadrangle for use as subgrade material for roads.

Peat and muck.—The many swamps and bogs contain much peat and muck. Although little or no use has been made of these deposits, they are a potential source of agricultural dressing.

Ground water.—The porosity and permeability of both the bedrock and the glacial till within the quadrangle are such that only moderate supplies of ground water are obtainable in much of the area. Water from either till or bedrock is typically rusty in color from the iron-rich minerals making up these materials. The greater permeability of the glaciofluvial deposits, as well as their position in the valley bottoms, makes them the greatest potential source of ground water, in terms of both quality and quantity.

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