LATE PLEISTOCENE AND RECENT DEPOSITS IN THE CONNECTICUT VALLEY, MASSACHUSETTS.
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PART I.

CONTENTS.

Abstract.
Introduction.
Acknowledgments.
Physiographic setting of the Connecticut Valley.
   General statement.
   Disappearance of the last ice sheet.
Classification of Quaternary deposits.
Discussion of individual areas.
   Leverett-Mount Toby area.
      General statement.
      Genesis of the deposits.
   Millers Falls-Turner Falls-Montague area.
      General statement.
      Pre-Lake features.
      Bottom deposits of "Lake Montague."
      Shore deposits of "Lake Montague."
      Post-glacial activity.

ABSTRACT. The Quaternary deposits of the Connecticut Valley in Massachusetts are classified according to a system based upon their morphology, structure, position, and relative ages. They are divided into five categories, which are listed in their general order of formation in any one area as follows:

1. Irregular deposits of till and local, intimately associated bodies of bedded silt, sand, and gravel laid down by glacial ice.
2. Kames, kame terraces, eskers, crevasse fillings, and other early-formed deposits of gravel, sand, and subordinate silt laid down along lines of through-going meltwater drainage.
3. Irregular accumulations of sand and gravel of essentially local derivation from wasting ice masses.
4. Terraces of clay, silt, sand, and gravel built on the bottom and along the margin of a single, large pro-glacial lake that occupied much of


11
the Connecticut Valley. These deposits are in part of ice-contact nature, but lie at levels lower than those of the forms in categories 2 and 3.

5. Fluvial terrace sediments and sand dunes deposited after the draining of the pro-glacial Connecticut Valley lake.

These five classes of deposits are discussed with particular reference to four selected areas that were mapped in detail. The distribution of ice-contact features, the probable nature of the late glacial Connecticut Valley lake, and the direction and magnitude of post-glacial tilt are also treated, and are evaluated in the light of evidence furnished by the Quaternary deposits. Localities of many exposures that may be considered critical are listed at the end of the paper.

INTRODUCTION.

OUTWASH features associated with the disappearance of the continental ice sheet from New England during late Wisconsin time have long been objects of extended discussion among geologists. For nearly a century such discussion has arisen in connection with the genesis and relative ages of the Pleistocene, as well as the Recent terraces in the Connecticut Valley. It was not until the latter part of the nineteenth century, however, that any attempt was made to survey, correlate, and establish the history of these terraces and related features over broad areas. Emerson's monograph on Old Hampshire County, Massachusetts, which appeared in 1898, contains the first significant result of such studies; its section on Quaternary geology stands today as the outstanding work on drift features in the Massachusetts part of the Connecticut Valley.

Emerson's work was soon followed by similar studies in adjacent regions, but his general interpretations and conclusions stood unquestioned for many years. More recently, however, some geologists have viewed the outwash deposits of the Connecticut Valley in the light of different theories of ice wastage, and accordingly have suggested revisions in earlier concepts of the origin and classification of these features. The conflict of opinions and attendant discussions that followed these suggestions appear to have been unsuccessful in settling definitely certain questions that bear on the status of many of the features, at least in the Massachusetts portion of the valley.

The chief purpose of this paper is to identify and classify as simply and as distinctly as possible the Quaternary deposits of the valley according to a system based upon morphology, positions, structure, and relative ages of the deposits themselves,

rather than upon a theory of ice wastage. Using such a classification, normal sequences of Quaternary sedimentation are outlined for selected parts of the valley, beginning with mechanical deposition of till, continuing with fluvial and lacustrine deposition of outwash material, and ending with post-glacial fluvial and aeolian activity. Although most of the outwash features here described furnish evidence bearing on the actual mode of ice wastage, a detailed discussion of such a controversial matter is beyond the scope of this paper.

The field work upon which this paper is based was done in the summer and fall of 1939 and in the spring and fall of 1940. Jahns is primarily responsible for the observations made in the Connecticut Valley proper and in some of the tributary valleys; Willard has confined his studies to tributary valleys, some adjacent to and others more distant from the Connecticut Valley. All work was done under a cooperative agreement between the Massachusetts Department of Public Works and the United States Geological Survey.

Acknowledgments.

The writers are greatly indebted to Professor Robert Balk of Mt. Holyoke College for information on important relations and localities in the Northfield and Bernardston quadrangles, and for his continued interest and helpful comments on the investigations as they progressed. They also had the advantage of working in the Lowell quadrangle for several months with L. W. Currier of the Geological Survey, U. S. Department of the Interior, thus gaining much information on similar glacial features in northeastern Massachusetts. Thanks are due G. R. Mansfield and L. W. Currier of the Geological Survey for their critical examination of the manuscript.

Physiographic Setting of the Connecticut Valley.

General statement.

The Connecticut Valley is sharply delineated in Massachusetts from the Berkshire Hills on the west and the central uplands, or Worcester County Plateau on the east. The Berkshire Hills actually represent a deeply dissected plateau, whose gently undulating upland surface slopes gradually southeastward in Massachusetts from a general altitude of 2,100 to one of 1,500 feet. The central uplands area is more maturely dis-
Fig. 1. Sketch map of Connecticut Valley in Massachusetts, showing distribution of post-glacial and late glacial deposits. Areas mapped in detail are outlined (See Text Fig. 9. Text Figs. 2, 3, 5 and 6.)
sected and much lower. The Connecticut Valley is a broad, triangular depression whose rather flat floor occupies an area of approximately 353 square miles. This floor, which in general lies at altitudes between 100 and 400 feet, is surmounted by several prominent hills and ridges, of which the most impressive are the Holyoke Range, the Deerfield Range, and Mount Toby (Text Fig. 1).

The Connecticut River flows dominantly south through the middle of the valley, and has four important tributaries in Massachusetts. The Deerfield and Westfield Rivers drain large areas in the Berkshire Hills, and join the Connecticut from the west near Turners Falls and Springfield, respectively. The Millers and Chicopee Rivers drain equally large areas in the central uplands, and empty into the Connecticut at French King Narrows and Chicopee. These and other noteworthy tributaries are shown in Text Fig. 1.

Disappearance of the last ice sheet.

Some generally accepted facts concerning the disappearance of the last ice sheet from the Connecticut Valley should be mentioned as an introduction to this discussion. Whatever the mode of ice retreat may have been, the general direction of deglaciation appears to have been from south to north, or more specifically from south-southeast to north-northwest. This conclusion is substantiated by Antevs' measurements and correlations of the late Pleistocene varved clays, and by the relative positions and ages of different outwash features adjacent to these clays. Although the validity of Antevs' conclusions was questioned and an opposing theory of southward disappearance of the ice was advanced in 1929, subsequent investigations have led to abandonment of most of these objections, as well as to acceptance of the concept of general northward recession.

In addition to the till laid down directly by the ice sheet, vast amounts of fluviatile and subordinate amounts of lacustrine sediments were deposited by meltwaters as the ice receded along valleys tributary to the Connecticut. In the Connecticut itself, however, most outwash deposition appears to have been

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associated with a large body of open water, which may be termed the Connecticut Valley lake. It is generally believed that this water body was pro-glacial, and it grew larger with the northward recession of the ice. According to Emerson, the “lake” consisted actually of a chain of water bodies possessing many features characteristic of a highly swollen river. An appreciable “thread of current” was thought to exist along the medial line of these bodies, carrying the waters to some indefinite outlet far to the south. Toward the end of its existence, the level of the swollen pro-glacial stream or “lake” subsided by gradual stages until the post-glacial Connecticut River was formed. Emerson divided the Massachusetts portion of the “lake” into three units, Lake Springfield, Lake Hadley, and Lake Montague. “Lake Springfield” occupied much of the valley south and east of the Holyoke Range, the much smaller “Lake Montague” lay north and east of the Mount Toby-Deerfield Range, and “Lake Hadley” spread over most of the remaining valley area.

Since the time of Emerson’s investigations, further study in Massachusetts and Connecticut has necessitated several changes in his concept of a swollen pro-glacial stream. It now seems probable that it was a single, ponded body of water. This is strongly suggested by drift features at Rocky Hill, Connecticut, that probably served as its dam, and by an abandoned rock-bounded channel near New Britain, Connecticut, that may well have served as its spillway-outlet. Flint favors the New Britain channel as the outlet because of its vertical and areal relations to the bottom sediments of the lake and because no other possible outlet appears to have been available. Further evidence in Massachusetts that supports this conclusion will be presented farther on. A spillway bottomed in bedrock and a drift dam in the present main valley probably caused the lake to maintain a rather constant level throughout its existence, but its final draining by the breaching of the easily eroded drift barrier at Rocky Hill must have been a relatively rapid process.

Classification of Quaternary Deposits.

Emerson classified the Quaternary deposits in the Massachusetts portion of the Connecticut Valley according to a scheme shown in Table 1. He indicated several levels of "lake shore" and "river bar-river flat" deposits, as well as a general lake-bottom deposit group. Although his statements are not entirely clear in all instances, his views on the relative ages of these sediments are probably those indicated in the table, possibly excepting some lake-bottom deposits formed prior to nearby "lake shore" deposits (deltas). In addition, he distinguished earlier "moraine terrace" deposits, which consisted of kettleed gravels "deposited in waters mostly banked on the west or north by ice."

Flint, in a summary of his most recent views, has divided the valley terrace deposits into three categories:

1. Deposits of gravel, sand, and silt, dominantly fluvial and subordinately lacustrine, built in contact with wasting ice, and now forming terraces chiefly of constructional origin.

2. Deposits of clay, silt, and (subordinate) sand, built in an open lake that filled part of the valley during or after disappearance of the ice, and later cut into terraces by post-lake fluvial dissection.

3. Deposits of gravel, sand, and silt, made by streams that trenched earlier deposits after the disappearance of the lake, lying as veneers on the surface of fluvial erosional terraces of contemporaneous origin.

From these and subsequent statements in Flint's summary, the writers have interpreted his three categories as shown in Table 1. An additional category of (deltas?) is added because he recognizes the possibility of such forms having been built into the open lake, although he does not include them in his classification. Most of these, however, he apparently prefers to consider as pre-lake features, namely, ice-contact deposits.

The classification proposed by the writers is shown in the right-hand column of Table 1. The four principal categories are defined in terms of depositional environment and, given in their general order of formation in any one area, are as follows:

1. Deposits from glacial ice and (to a limited extent) from local

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7 Emerson, B. K.: 1898, op. cit., pp. 533-721, pl. 35.
Table 1. Chronologic classification of Quaternary deposits in the Massachusetts part of the Connecticut Valley.

(Relative ages apply only to deposits along any one line normal to the direction of ice recession.)

<table>
<thead>
<tr>
<th>Age</th>
<th>Depositional Environment</th>
<th>Emerson 1898</th>
<th>Flint 1933</th>
<th>Jahns and Willard 1941</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent</td>
<td>Post-glacial rivers and adjacent land areas</td>
<td>Fluvial deposits capping terraces of contemporaneous fluvial erosion, local dunes, and swamp deposits</td>
<td>Lake-bottom deposits</td>
<td>Deltas and associated ice-contact deposits</td>
</tr>
<tr>
<td></td>
<td>Late glacial Connecticut Valley lake (Lakes Montague, Hadley, and Springfield)</td>
<td>Lower bars and river flats not built up to flood level</td>
<td>Lake-bottom deposits</td>
<td>Ice-contact deposits</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Upper bars and river flats nearly up to flood level</td>
<td>deposits graded to lake level</td>
<td>Lake-bottom deposits</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lake shore beds, normal high terrace of the flooded Connecticut River and its tributaries (Deltas?)</td>
<td></td>
<td>Ice-contact deposits</td>
</tr>
<tr>
<td>Pleistocene</td>
<td>Pro-glacial streams and lakes at levels higher than the Connecticut Valley lake</td>
<td>Moraine terrace deposits</td>
<td>Ice-contact deposits, dominantly fluvial and subordinately lacustrine</td>
<td>Ice-contact deposits of water drainage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>controlled by temporary spillways above lake level</td>
</tr>
<tr>
<td></td>
<td>Glacial ice and local meltwaters</td>
<td>Eskers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Till {Drumlins Ground moraine}</td>
<td></td>
<td>Till {Drumlins Ground moraine}</td>
</tr>
</tbody>
</table>
meltwaters: till and local bodies of bedded silt, sand, and gravel intimately associated with the till.

2. Ice-contact deposits from meltwater drainage held above the level of the Connecticut Valley lake by temporary spillways: gravel, sand, and subordinate silt.

3. Deposits, in part of ice-contact nature, built in and into the Connecticut Valley lake: clay, silt, sand, and gravel.

4. Recent deposits, fluvial and aeolian, laid down after the draining of the Connecticut Valley lake: sand, silt, and subordinate gravel.

To these must be added a fifth category of minor importance, although its deposits are widespread over certain areas. They are composed of gravel, sand, and subordinate silt contributed from adjacent wasting ice masses that were never associated genetically with any through system of meltwater drainage. Such sediments of essentially local origin were in process of formation in any area as long as ice blocks existed in that area; consequently, they show considerable overlap in time relations with the other outwash deposits (see Table 1). Parts of them were even laid down in some favorable places while sedimentation took place in the nearby Connecticut Valley lake.

In all areas investigated by them, the writers found Emerson’s mapping of lake-bottom and lake-shore boundaries strikingly accurate. But they also found that his four classes of valley-lake deposits, which correspond to category 3 in the classification above, should be reduced to two:

1. Deposits of clay, silt, and subordinate sand laid down on the lake bottom.

2. Deposits of gravel, sand, and local silt built over and around stagnant blocks of ice and into open water of the lake beyond the ice-block area; those portions of the deposits built into the lake are deltaic and overlie earlier-formed lake-bottom deposits.

Emerson’s mapping of several levels of lake-margin sediments was probably due in part to inaccuracies of vertical control as furnished by the topographic base maps then at hand, and perhaps also to identification of the gently dipping foreset portions of some of the large deltas as separate and distinct terrace levels. Doubtless his differentiation of several levels where only one appears to exist was further influenced by his conception of the gradually falling level of a “lake” whose outlet was being slowly lowered, and by his failure to realize fully the implications of late glacial and post-glacial crustal tilt.
Use of the classification suggested by Flint also presents certain difficulties. Not only are many of the lake-marginal features true deltas built out into open water over previously deposited bottom sediments, but most of them are directly traceable into ice-contact deposits of nearly simultaneous origin. Both types of sediments were originally graded to the level of the lake; on the other hand, some nearby ice-contact deposits at the same latitude commonly lie at higher altitudes and were formed by earlier meltwaters at levels temporarily controlled by bedrock thresholds or by more ephemeral spillways in ice or drift deposits. Thus a classification based on the levels to which the outwash deposits were graded over any one area, rather than one based upon the presence or absence of ice-contact features, seems more capable of consistent and successful use in the mapping of outwash features in the Connecticut Valley.

Flint did not include in his classification the deposits laid down directly by ice, but Emerson placed till (in ground moraine and in drumlins) as well as eskers in this category. No deposits definitely recognizable as terminal or recessional moraines appear to exist in the Connecticut Valley in Massachusetts. The grouping of eskers with till is of doubtful merit, inasmuch as eskers, crevasse fillings, or both occur in all classes of outwash deposits mentioned except those formed on the late glacial lake bottom. As to the classification of Recent deposits, Emerson, Flint, and the writers are in complete agreement.

Four representative areas that were mapped in detail (see Text Fig. 1) and several other areas that were visited but not mapped are described in this paper. The Quaternary deposits in these areas are discussed individually, according to the different categories distinguished by the writers.

Discussion of Individual Areas.

LEVERETT-MOUNT TOBY AREA.

General statement.

The glaciofluvial and glaciolacustrine deposits that occur along the valley of Long Plain Brook and in areas adjacent to Leverett and Cranberry Ponds illustrate the chronologic classification of Table 1. The Quaternary deposits of this area can be separated into three distinct groups: deposits graded to levels distinctly above the late glacial Connecticut Valley lake
and Recent Deposits in Connecticut Valley, Mass. 171

(in this area called "Lake Hadley"), deposits graded to the level of the lake, and bottom sediments of that lake.

The areal distribution of the outwash deposits in the area is shown in Text Fig. 9, B. The deposits between Cranberry Pond at the north and a point west of Joshua Hill on the south are in large part confined within the narrow valley. South of this part the chain of deposits is divided into two branches. The eastern branch follows a course around the southern flank of Joshua Hill above Leverett Pond. The other branch continues along the present course of Long Plain Brook, and at its southern end expands widely and passes abruptly into the low-lying, bottom sediments of "Lake Hadley." Besides the deposits in these main channels, gravels cover small outlying areas. The highlands are composed of till and bedrock. The most striking features of the drainage are the evident misfit condition of many of the present streams and the slight erosion accomplished by them.

Good exposures showing the structures of the outwash deposits are rare, but demonstrate that the deposits at the north and in the eastern branch are coarse and have good fluvial bedding, whereas those of the western branch are somewhat finer and are crudely deltaic.

Cranberry Pond, at the north end of the area, is surrounded by coarse gravel that forms steep, irregular or serrated slopes rising in places as much as 50 feet above the level of the water. To the northwest these gravels have produced a striking topography of rounded and flat-topped hillocks, and of reticulated serpentine ridges that have a maximum altitude of 420 feet. To the northeast the gravel forms a terrace against the foot of Stoddard Hill. Projecting from this terrace are narrow ridges that occur as an integral part of the terrace itself. In contrast with the somewhat similar forms to the west, the ridges are all flat-topped and have a maximum altitude of approximately 410 feet.

The deposits at the south end of the pond form a broad area of low hills that extends from the foot of Ingraham Hill on the east to Mount Toby on the west. The deposits on the Mount Toby side have been cut through by Roaring Brook along the lower part of its course. They can be followed to the south around the eastern side of a narrow bedrock ridge that separates them from Long Plain Brook. This chain of deposits forms the east branch previously mentioned and continues
through the valley south of Joshua Hill, where the gravel is thin or virtually absent, as, for example, at the divide north of Leverett Pond. The amount of material deposited differs locally. East of Long Plain Brook, at the southern end of the bedrock ridge that parallels the foot of Mount Toby, small areas of thin gravel are outlined by the steep, irregular slopes of adjacent, much thicker deposits. The upper surfaces of the thick deposits are commonly pitted, and their irregular marginal slopes show striking rectangular re-entrants; similar features can be seen also in the valley above Cranberry Pond.

Long Plain Brook heads in the narrow Mount Toby gorge, which is formed by the eastern slope of Mount Toby and the bedrock ridge previously mentioned (see Text Fig. 9, A and B). This gorge is approximately one mile long, and south of it the brook follows closely the base of the eastern slope of Mount Toby to a point where it swings south-southwest between till and bedrock hills before passing into a narrow, swampy strip of land between low gravel terraces (vertical-line pattern in Text Fig. 9, B). The marginal slopes of the terraces are not uniformly steep and their outlines are smoothly curved in plan. These matched terraces continue to a point opposite Leverett Station, where they widen and descend gradually to the level of Long Plain. The low land between the terraces passes without topographic break into Long Plain, which continues south approximately two miles before sloping abruptly to the bottom plain of the late glacial Connecticut Valley lake. In plan this terminal slope is smoothly curved (see Text Fig. 9, A).

The profiles in Text Fig. 9, C show the relative altitudes of the deposits that have been described, and thus illustrate the basis of their classification. The altitudes of the bedrock in the valley above Leverett Pond and in the valley of Long Plain Brook are also shown. These elevations have been corrected for post-glacial tilt of approximately four feet per mile, discussed farther on.

The profiles of bedrock are not meant to represent the detailed configuration of bedrock along the valley but indicate rather the general slope and locate places that are pertinent to the discussions that follow. The altitudes of the deposits of the northern end of the valley and in the eastern branch below Joshua Hill produce an irregular profile with little apparent general slope (profile A). All of the gravel deposits along the line of this profile have not been built up to the same level, but
they appear to have approached a maximum altitude of 420 feet. This is also the altitude of the divide above Leverett Pond. These gravel deposits are considered as a group because of the accordance between their maximum altitudes and the altitude of the divide, as well as their similarities in form, material, and stratification. One small deposit at the foot of Joshua Hill north of the divide reaches an altitude of 430 feet, and a gravel terrace south of the divide has the same altitude (profile B).

The profiles of Long Plain and its adjacent terraces (profiles D, E) are strikingly similar in slope but are separated from each other by a vertical difference of approximately ten feet. This is sufficient, however, to warrant the differentiation that has been made.

Local isolated occurrences of thin gravel south of Leverett Pond, at Ryans Hill, in the Mount Toby gorge, and elsewhere (points F, Text Fig. 9, C), cannot be considered as a part of any of the other units mapped. Because they are discordant in elevation and cannot be traced to spillways at their level, they are treated separately.

*Genesis of the deposits.*

The morphology, constituent materials, and structure of the deposits, together with their altitudes relative to adjacent divides or spillways have been discussed. The significance of these data as criteria bearing on the genesis of the deposits is next to be considered.

The description of the deposits makes it evident that they are of glacial origin, a fact first recognized by Emerson.\(^{10}\) The most important types are kames, kame terraces, kettled plains, eskers, and crevasse fillings. Some of the outwash features, however, do not show their glacial origin so clearly; Long Plain and the terraces adjacent to it are excellent examples.

The late Wisconsin ice sheet that covered the area is believed to have thinned until the highlands stood as nunataks above its surface. As wastage continued, small, isolated blocks of ice probably remained in local highland basins. A block of this kind is believed to have occupied the swampy area west of Ryans Hill (Text Fig. 9, A and B). The gravel here is thin and is thought to have formed from outwash material derived from

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Fig. 2. Successive stages in the development of outwash deposits in the Leverett-Mount Toby area.

A. Outwash deposition and meltwater drainage through Leverett Pond spillway.
B. Long Plain lobe considerably shrunken. Because Mount Toby spillway is still ice bound, meltwater drainage continues through the higher Leverett Pond spillway.
C. Mount Toby spillway and Leverett Pond spillway abandoned. Small remnant of Long Plain lobe holds "Long Plain Pond" at a level several feet higher than the nearby Connecticut Valley lake ("Lake Hadley").
D. Entire meltwater drainage empties directly into "Lake Hadley."

Heavy arrows indicate directions of meltwater drainage. Areas with no patterns represent ice masses. Patterns are the same as in Text Fig. 9. Water bodies are outlined with dashed boundaries.
the block as it melted. The water released by melting would be sufficient to account for the crude bedding and sorting of the material. This postulated genesis is supported by the discordance between the altitudes of these deposits and others mapped in the area, and by the lack of any apparent channels through which material could have entered the basin from outside sources. A similar origin is also suggested for the deposits west and south of Leverett Pond. The age of such local bodies of outwash relative to each other or to the glaciofluvial or glaciolacustrine deposits elsewhere in the area cannot be determined, but if formed in the manner suggested, they must represent in part the earliest outwash deposits of the area.

During this time the ice was assuming the form of a forked lobe in the valley of Long Plain Brook and its eastern tributary. Continued lowering of the surface of this lobe ultimately gave rise to an ice-choked drainage route, which, because of differential ice wastage, assumed a gently southward sloping profile. As a result, a large part of the meltwater released from areas farther north must have passed through this valley. It might be expected that, as the ice grew thinner, successively lower channels or spillways would be exposed, through which the meltwater could escape to points farther south in the valley or entirely outside the valley. The evidence suggests that the notch north of Leverett Pond was the first of these channels to become effective, although the deposits that occur at an altitude of 430 feet north and south of the Leverett Pond spillway must have been graded to a slightly earlier, higher level controlled by a bedrock spillway outside the area, or perhaps by a more temporary ice or drift barrier. It cannot be certainly established that the ice in the valley to the north was essentially continuous during this time. If, however, openings in it did occur, the deposits that formed in them were either not built up to meltwater grade or they have been subsequently regraded to a lower level. This follows because, as previously noted, no deposits in the eastern branch of the valley have altitudes greater than 420 feet.

Further surface ablation or melting exposed the Leverett Pond spillway, which then acted effectively as a channel to which many of the later deposits were graded (Text Fig. 2). As previously indicated, the altitudes of the ice-contact deposits in the valley north of the spillway approach the spillway altitude as a maximum. During the early stages of its melting,
the ice north of the spillway may have developed moulin's and crevasses, and its outer margins probably shrunk away from the valley sides. The theoretical reasons for such marginal shrinkage have been discussed by Flint.\textsuperscript{11} A large part of the meltwater that found its way into the valley may therefore have been concentrated in marginal streams or ponds, resulting in formation of the kame terraces on either side of the ice mass that are graded to the level of the spillway. The narrow gravel ridge that projects from the terrace north of Cranberry Pond (Text Fig. 2, B-D) was probably formed by the same marginal meltwater stream that built the terrace, because the two forms are comparable in altitude, material and stratification. The narrow ridge is undoubtedly a crevasse filling.\textsuperscript{12}

Another part of the meltwater, however, may have spread over the ice in small streams or as a single sheet. This would be particularly probable if the level of the ice approached closely the level of the spillway. At some places this meltwater might be expected to pour into open holes and crevasses, quickly dropping most of its sediments. If this is the manner in which many of the kames, segmented eskers, and crevasse fillings of the area formed, it is scarcely surprising that the altitude profile of their highest points is irregular. The altitude to which any particular member of this group may have been built would be determined primarily by the amount of material which entered the opening in the ice, and also by the level of the Leverett Pond spillway. If the amount of material left in any particular opening were equal to or in excess of the amount needed to fill the opening to the level of meltwater as controlled by the spillway, the resulting deposit would have an altitude equal to or only slightly greater than that of the spillway. On the other hand, if the quantity of material were not sufficient to fill the opening, the altitude of the resulting deposit would be determined solely by the amount of available material.

Throughout this early stage, drainage via the Mount Toby gorge (Text Fig. 9, A and B) is thought by the authors to have been effectively blocked, probably by ice. Emerson,\textsuperscript{13} on the other hand, has suggested that the valley south of Cranberry Pond was essentially free of ice during the accumulation of the


\textsuperscript{13} Emerson, B. K.: 1898, op. cit., pp. 585-586.
deposits just discussed. His conclusion regarding the origin of these deposits is illustrated by the following statement:

The waters running southward . . . found it (Mount Toby gorge) in flood time an insufficient outlet and turned eastward through the side valley into the Leverett Lake, clogging this with abundant sands.

If the deposits east of the gorge were formed in the manner outlined by Emerson, it becomes difficult to explain the numerous ice-contact features between Cranberry Pond and Leverett Pond, for these features indicate early-stage deposition. Further, it is impossible to account for the deposit north of the Leverett Pond spillway that has a higher altitude than the spillway. It also seems that if meltwater did flow east of the gorge, and that if the gorge itself were ice-free, the meltwater should have re-entered the main channel south of the central bedrock ridge that forms the east wall of Mount Toby gorge. This would preclude the formation of extensive outwash deposits above the 350-foot level, which is the altitude of the sag south of the gorge. It will be recalled, however, that most of the deposits of the eastern branch approach an altitude of 420 feet.

The form of the ice in the lower valley of Long Plain Brook cannot be determined, but it is suggested that a part of the mass remained there until the rest of the area was essentially ice-free. In the early stage it may have existed as a narrow tongue (see Text Fig. 2A). It cannot be definitely established that the shoreline of glacial "Lake Hadley" lay in the exact position shown in the figure, but the existence of the lake is demonstrated by the deltaic structure of Long Plain. How long the lake existed before the delta began to form is not known. At other places in the Connecticut Valley sufficient time elapsed between formation of the valley lake and the beginning of delta building to permit the accumulation of recognizable quantities of lake-bottom sediments. This suggests that ice was absent from at least some of the marginal parts of the Connecticut Valley before formation of the late, deltaic outwash deposits, a conclusion also reached by Emerson.\(^\text{14}\)

As shown in profile C, Text Fig. 9, the ice in the lower valley appears to have rested on bedrock whose surface sloped rather steeply to the south. This may have caused the ice

\(^{14}\) Emerson, B. K.: 1898, op. cit., p. 640.

_The American Journal of Science—Vol. 240, No. 3, March, 1942._
mass to disappear more rapidly at the north, so that by the
time meltwater drainage could be established along the route
of the Mount Toby gorge, the northern end of this tongue had
shrunk southward to a position now occupied by the narrow
part of Long Plain. If, as seems likely, "Lake Hadley"
existed in this part of the Connecticut Valley at this time, the
southern end of the tongue may well have been dissipated as
bergs in the lake. The remaining ice barrier, though small
(Text Fig. 2C), would have effectively dammed up the melt-
water that found its way into the valley from the north, and
causethe deposition of the introduced outwash material as
a delta. This is thought to have been the mode of deposition of
the material in the low terraces above Long Plain. The alti-
tude of the top of this deposit should then indicate in a general
way the water level in glacial Long Plain Pond. With disap-
pearance of the ice barrier, the level of the pond presumably
dropped to that of "Lake Hadley." As shown in Text Fig. 2D,
the outwash was then carried directly into "Lake Hadley" to
form the Long Plain delta. In flowing into the lake, the melt-
waters cut a channel through the earlier delta of Long Plain
Pond. The terraces above Long Plain, therefore, represent
erosional remnants of this early delta.

Somewhat similar depositional forms could have been caused
by a general lowering of the level of the Connecticut Valley lake,
in which case no ice barrier near the southern end of Long
Plain would have been required. However, little or no evidence
is available in other areas to support the concept of such
changes in level of the lake, and no forms comparable with the
terraces above Long Plain in other shore areas of "Lake
Hadley" have been noted. Although this subject is discussed
more fully farther on, it may be stated here that a local origin
(with a temporary ice barrier) for the terraces that flank
Long Plain seems to be the better interpretation.

Ice seems to have remained longest in the vicinity of Cran-
berry Pond, and probably existed there until Long Plain
had been completely built. This conclusion is supported
by the numerous, deep kettles and fresh ice-contact slopes
in that area. The upper surface of the terrace that flanks
Stoddard Hill lies in part at levels comparable to that of the
lip of the Mount Toby gorge (Text Fig. 9, B), which suggests
that it may have been partly regraded by meltwaters flowing
through the gorge into the Long Plain area.
MILLERS FALLS—TURNERS FALLS—MONTAGUE AREA.

General statement.

The Millers Falls—Turners Falls—Montague area (Text Fig. 1) is rectangular and occupies approximately 30 square miles. It was selected for mapping because it furnishes excellent and representative examples of outwash features associated with the late glacial "Lake Montague," which was a part of the Connecticut Valley lake. The area is shown in the accompanying map (Text Fig. 3), for which preliminary editions of the 7½ minute Greenfield and Millers Falls quadrangles have been used as bases; these quadrangle maps should be consulted for more detailed topographic information than that furnished by the altitudes at reference points in the figure.

The land forms of chief interest are broad terraces which lie at altitudes from 140 feet to nearly 370 feet above sea level. Irregular, considerably higher hills and ridges surround the terrace area almost completely, and in addition Wills Hill and Mineral Hill rise prominently within it (Text Fig. 3). The Connecticut River enters the mapped area from the northeast near French King Narrows, follows a westerly course from that place to Turners Falls, and thence flows in a general southerly direction. It is joined by the Millers River north of Millers Falls and by the Deerfield River immediately south of Montague City.

Pre-lake features.

The topographic features formed prior to the existence of "Lake Montague" are underlain by bedrock, till, and ice-contact deposits of pre-lake age. In general, this complex of glacial drift and bedrock (Text Fig. 3) consists of pre-Triassic crystalline rocks east of French King Narrows, Millers Falls, Great Pond, and Montague, and of Triassic sedimentary and volcanic rocks elsewhere. The bedrock is covered thinly and irregularly by a mantle of tough, incoherent, stony till, which is locally clayey. A few of the hills may be drumlins, but most of the till occurs as ground moraine.

Ice-contact features formed by meltwater drainage controlled in the Millers Falls—Turners Falls—Montague area by spillways above the level of "Lake Montague" are very uncommon. Where they do occur they are so irregular and so small that they have not been differentiated on the map, but instead are included in the glacial drift-bedrock complex.
Fig. 3. Quaternary geological map of the Millers Falls–Turners Falls–Montague area. Points marked with crosses are localities referred to in the text. Neither dunes of post-lake age nor small areas of post-glacial fluvial deposits between Millers Falls and Great Pond are shown on this map.
Bottom deposits of "Lake Montague."

With the gradual disappearance of glacial ice from the valley and the attendant northward expansion of "Lake Montague," a succession of fine-grained sediments was laid down on the lake bottom by inflowing meltwaters. These bottom sediments are in large measure the well-known annually-varved clays of the Connecticut Valley (Pl. 3B); their distribution clearly indicates the approximate extent of the pro-glacial lake and their correlation furnishes valuable data bearing on the chronology of important late Pleistocene events in the valley.

At several places where their base is exposed, the varved clays can be seen to lie directly upon bedrock or, less commonly in the medial parts of the valley, upon till. They accumulated locally to thicknesses of 200 feet or more in "Lake Montague," although their total thickness was considerably less in most places, either because of surface irregularities on the initial floor of the lake basin or encroachment of deltaic deposits before the lake was drained. Where the old lake bottom is preserved, the clays can be seen to grade upward into a 2- to 20-foot capping of silt and fine sand, a gradation especially well shown in clay pits east and southeast of Montague City (locality B, Text Fig. 3) and along a road cut north of the fish hatchery (locality C, Text Fig. 3—see also section given below).

Section of upper part of "Lake Montague" bottom deposits, from road cut 0.7 mile north-northwest of fish hatchery, 7½ minute Greenfield quadrangle. Measured in June 1939.

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Feet</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand, fine, gray, thinly bedded in manner suggesting varving; grades imperceptibly downward into gray to tan silt</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Silt, buff to tan, very fine and thinly bedded; grades into unit above</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>
| Clay, bluish, silty, similar to winter layers in varved clays below | 0 | 8%
| Silt, buff to tan, very fine | 1 | 3 |
| Clay, silty, bluish to buff, a typical winter layer | 0 | 8%
| Silt, fine, buff, and clay, silty, bluish, alternating 14 times; clay layers uniformly 8% inch to ½ inch thick, silt layers decrease in thickness uniformly downward from 7½ inch to 1 inch | 4 | 8½ |
| Varved clay, bluish to buff and pinkish, locally silty to sandy; winter layers thinner than summer layers | 2 | 7 |
| Covered | 10 | 8 |
| Triassic shale, to bottom of section | 50 | 0 |
| **Total** | **78** | **1½** |
This gradation of the varved clays upward into the silt-sand blanket that covers them everywhere on the old lake bottom is thus accomplished through gradual thickening of the summer layers and the disappearance of recognizable winter layers, a feature characteristic of nearly all such sections seen by the writers.

The distribution of exposed remnants of the old lake-bottom plain is shown in Text Fig. 3; they appear today on both sides of the Connecticut River southward from Turners Falls, and their gently undulating surfaces lie at altitudes from 215 to 270 feet. The varved clays are present not only in terraces cut in the lake-bottom, but they also directly underlie the more recent deposits laid down by rivers that trenched the old lake bottom in post-glacial time; in some areas they also underlie deltaic deposits built out into the lake before it was drained.

**Shore deposits of "Lake Montague"**

The shore deposits of "Lake Montague" are those that were built up to or slightly above lake level by meltwaters flowing directly into the lake. In most places these deposits are true deltas, whose foreset beds appear to merge downward into the lacustrine bottom sediments. Observed sections of lake-bottom sediments near delta fronts and the existence of varved clays beneath the deltas themselves confirm the interpretation that the varved clays are in part bottomset beds and are therefore the chronologic equivalents of certain higher-level parts of the deltas.

One of the finest examples of typical lake-shore deposits in the entire Connecticut Valley is that built into Lake Montague by the pro-glacial Millers River. Emerson\textsuperscript{15} presents an admirable description of this great sand plain, which fans out from the present mouth of the Millers River Canyon east of Millers Falls to a steep-faced, well-defined front extending from Turners Falls to Montague (Text Fig. 3). Profiles of its surface from apex (approx. 370 feet A. T.) to outer margin (305 to 328 feet A. T.) are gently concave upward, with a gradual flattening away from the apex. Although most of the surface is a smooth, featureless plain, of which Montague Plain is an excellent example, its eastern margin is strongly kettled from

Montague to Millers Falls. Great Pond and Green Pond occupy two of the largest kettles, and also mark the western edge of the ice-block area.

The materials that compose the apical portion of the plain are very coarse, cobbly to bouldery gravels. These attest the great transporting power of the pro-glacial Millers River. Further testimony is given by numerous potholes cut in granitic gneiss at an altitude of approximately 375 feet on the north side of the Mohawk Trail (state highway No. 2) half a mile east of the lower dam at Millers Falls (locality A, Text Fig. 3). Several are more than two feet in diameter. They were first pointed out to the writers by Professor Balk. The coarseness of the gravels decreases rapidly away from Millers Falls, so that coarse sand and pebble gravel compose the kettled part of the plain in the vicinity of Green Pond. All these deposits are commonly stream bedded, but in many places—particularly adjacent to kettles—they possess little or no regular stratification. Where their base is exposed, as in cuts of the Boston and Maine and the Central Vermont Railroads south of Millers Falls, they lie directly upon bedrock or till.

The surface of the deposits between kettles is continuous with the unkettled surface that extends to the west. The latter is underlain by clean, well-sorted foreset beds of sand and topset beds of pebbly gravel; both types of sediment become progressively finer toward the westward-facing outer margin of the plain. Although Emerson\(^{16}\) apparently considered the entire plain a delta, the kettled part shows no characteristic deltaic structure. In the more westerly, unkettled part of the plain, however, Emerson's statements concerning its deltaic structure were verified by the writers, who made fresh excavations along cuts of the Boston and Maine Railroad north and northeast of Montague (see 7½ minute Greenfield quadrangle) and along the south bank of the Connecticut River east of the Narrows (Text Fig. 3). Further and more critical evidence is afforded by occurrences of varved clay lake-bottom deposits beneath the delta in positions well back from its outer margin. One of the best of these is located in a small ravine immediately southwest of the Turners Falls Rod and Gun Club (locality D, Text Fig. 3), where a strong spring horizon marks the contact between the delta sands and at least 30 feet of underlying varved clays. This is only a few hundred feet from the locality at

\(^{16}\) Emerson, B. K.: 1898, op. cit., pp. 625-629.
Keith's Spring, described by Jefferson, who concluded that horizontally laminated clays abut against the sands of the high-level plain. He further concluded that the varved clays had been eroded before the sands were deposited. He pointed out, however, that the clays might pass continuously beneath the sands, because "the true surface may be masked by sand that has fallen down from above."

Jefferson's principal conclusion was incorrect and his suggestion that slump had obscured the true relations was well founded, as is proved by the features at locality D. Similar relations were observed in ravines along the south bank of the river to the east, where the presence of varved clays beneath the deltaic sands was verified by digging. Location of the upper contact of the clays usually presents little difficulty, because their relative imperviousness tends to create an horizon of springs in the sediments just above them. Further proof of lake-bottom deposits beneath the delta may be obtained north of Montague, where several long-abandoned pits were dug in varved clay once overlain by deltaic sands that were subsequently eroded away by post-glacial streams.

On the basis of its structure, as well as the presence of lake-bottom deposits beneath it, the writers are forced to conclude that most of the unkettled part of the pro-glacial Millers River deposits is a true delta. It is continuous and nearly contemporaneous with the ice-contact deposits of the kettled part, as indicated by continuity of materials and surface altitudes of the two parts. Emerson has described and figured bedding relations that demonstrate that completely buried ice blocks melted to form kettles after all deltaic deposition associated with the pro-glacial Millers River had ceased. Others, of course, melted sooner and their kettles were quickly filled with debris from the meltwaters that flowed across the plain.

The kettled part of the plain, therefore, is interpreted as the earliest deposited outwash material from the Millers River drainage system. Probably this material was deposited very rapidly in an environment of crevassed and broken-up ice blocks that were trapped and subsequently partly or completely buried by the debris. The height to which this kettled outwash plain was built was controlled in large part by the local meltwater

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7 Jefferson, M. S. W.: 1898, The postglacial Connecticut at Turners Falls, Massachusetts: Jour. Geol., Vol. 6, p. 464, Fig. 1 G., p. 468.

A. Remnant of bottom plain of late glacial "Lake Hadley," looking east from Dry Brook Hill; 1.3 miles northwest of South Hadley. Drift-covered bedrock hills in distance. This part of the old lake floor passes into the Pearl City delta in distance back of trees at extreme left.

B. Pebble foreset beds in Factory Hollow delta, north of Amherst. Gravel pit 0.6 mile east of North Amherst.
baselevel, namely the surface of the late glacial Connecticut Valley lake (termed "Lake Montague" in this part of the valley). The main body of the lake lay immediately west of the ice-block area—that is, west of Great and Green Ponds—and must have received fine-grained bottom sediments during at least the late stages of outwash plain construction. After the coarser outwash had been built out to the edge of the ice-block area, all additional material was laid down as a delta in the essentially ice-free part of the lake (see Text Fig. 8). Thus the great "delta-outwash plain" of the pro-glacial Millers River, though morphologically a unit, is actually a structural and genetic composite (Text Fig. 4). Its kettled part is not deltaic, and its deltaic part is not kettled. It is perhaps not unlike the so-called kettled deltas described from the Finger Lakes region in New York by Fairchild, who considered the kettles to be of ice-block origin rather than the results of capricious currents and deficient filling on the delta in the absence of glacial ice masses. Stone also has described many lacustrine deltas in Maine whose distal parts are strongly kettled and are traceable directly into kames, eskers, and other ice-contact features.

The structure of the delta-outwash plain of the pro-glacial Millers River, as interpreted from the field evidence cited in the foregoing pages, is indicated in Text Fig. 4. The vertical scale is greatly exaggerated to show the details of sedimentary relations. The deltaic sediments (dsg) shown in the section passed around the south end of Wills Hill (off the page toward the observer) in order to reach their most westerly position as indicated to the west of the hill. The relation between varved clays and slightly earlier-formed ice-contact outwash is inferred for this area on the basis of considerable known thicknesses of bottom sediments beneath the deltaic beds at rather short distances from the kettled part of the plain. Further, such relations actually have been observed at two places in other parts of the valley (see locality list at end of paper).

This interpretation of the Millers River outwash features necessitates some revision of earlier interpretations. Jefferson considered the Montague Plain to be the remnant of a

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Fig. 4. Cross-section of Millers Falls—Turners Falls—Montague area.

br—bedrock;
ti—till and local gravel;
ksg—kettled sand and gravel;
dsg—deltaic sand and gravel;

ve—varved clay;
du—dune;
rt—river terrace.
Vertical exaggeration approximately × 20.
much wider feature which at one time extended entirely across
the valley, but presumably was in part removed by some ero-
sional agent at a later date. This misconception probably
arose from his failure to recognize the deltaic nature of Mon-
tague Plain. Emerson, on the other hand, clearly recognized
this fact, but believed that the delta originally was built north-
ward and westward beyond Turners Falls into the basin-like
area west of Rocky Mountain, and that it was later cut through
by the Connecticut River. The writers consider the delta of
the Millers River meltwaters to have been much less extensive,
chiefly for these reasons:

1. The original front of the delta must have lain not far north
of its present, river-cut front immediately south of Turners Falls,
because the lake-bottom plain, with its typical fine-grained materials,
lies north of the river at a distinctly lower level than that of the
delta surface. This lake-bottom plain is just off the area shown in
Text Fig. 3.

2. The altitude of the delta surface near its outer, or lakeward
margin is almost 20 feet lower than the lake shore sediments north
and northwest of Turners Falls; this delta surface has not been
scoured.

3. The constituent materials of the outer part of the delta are
considerably finer grained than those that make up the lake-shore
features to the north.

Flint has mentioned ice-contact slopes on a terrace near
Turners Falls, and in a later publication he may have used
this interpretation as a partial basis for his statement that ice-
contact terraces occur at altitudes as low as 260 feet in the
latitude of Greenfield, Massachusetts. The “ice-contact
slopes” in question clearly are portions of the original front of
the Millers River delta, which has been cut by the post-glacial
Connecticut River for a short distance southwest of Turners
Falls (Text Fig. 3). The fact that this slope is the front of a
delta built out into an open valley lake precludes its interpre-
tation as an ice-contact feature; moreover, the phenomena nor-
ma:ly characteristic of ice-contact slopes are conspicuously

Emerson, B. K.: 1898, Geology of Old Hampshire County, Massachu-
Flint, R. F.: 1929, The stagnation and dissipation of the last ice sheet:
Flint, R. F.: 1933, Late Pleistocene sequence in the Connecticut Valley:
absent from it. The writers doubt the existence in the Connecticut Valley in or near the latitude of Greenfield (two and one half miles southwest of Turners Falls) of any ice-contact terraces below the level of the "Lake Montague" surface, or below an altitude of approximately 310 feet. Nearly all ice-contact forms found in the area lie at levels well above that altitude. The outer slopes of all the terraces below 310 feet are the results either of deposition in a standing body of water, or of fluvial erosion.

Finally, Jefferson\textsuperscript{25} proposed at least one readvance and a later retreat of the ice in the Turners Falls-Millers Falls area, whereas the writers can see no reason to assume anything other than a progressive northward disappearance of the ice. In brief, Jefferson's conclusion is predicated upon the assumptions that varved clays underlie the kettled area between Millers Falls and Montague and that an ice tongue filled the present river valley during the time in which the Montague Plain was under construction. The first assumption is known to be incorrect from field observations at several points, where the kettled gravels rest directly on till or bedrock with no intervening lake-bottom deposits. The second assumption seems unnecessary because it is founded largely upon erroneous interpretations at the Keith's Spring locality (D, Text Fig. 3) and at other localities of the same type. These have been discussed in connection with the presence of varved clays beneath the delta.

\textit{Post-glacial activity.}

Some time after the disappearance of the last unburied ice remnants and the cessation of the most active delta deposition by the Millers River in the area under consideration, the Connecticut Valley lake was rather rapidly drained, presumably through breaching of the drift barrier at Rocky Hill, Connecticut. This draining is said to have occurred at a time when the receding "ice front" stood at Lyme, New Hampshire, or approximately 80 miles to the north.\textsuperscript{26} As the lake waters shallowed, a thread of current must have formed, which grew into a well-defined zone of flow during the period of emergence of the lake-bottom areas. This zone of flow became the post-

\textsuperscript{25} Jefferson, M. S. W.: 1888, op. cit., pp. 470-471.

and Recent Deposits in Connecticut Valley, Mass. 189

glacial Connecticut River, an essentially consequent stream newly formed on sediments of late glacial age, and as such it followed the lowest portions of the deposits in "Lake Montague" and escaped through gaps in higher areas to the south.

Emerson and Jefferson27 recognized more than 40 years ago that the present Connecticut River flows far from its pre-glacial course in the Millers Falls—Turners Falls—Montague area. Concerning its probable pre-glacial course, Emerson stated:

The old bed of the Connecticut runs due south from Northfield past Millers Falls, and thence southwest to join its present bed at the mouth of the Sawmill River, in Montague. This course is marked by a line of kettle-holes . . . along the plain north of Millers River, by the sharp bend of the latter, and by the deep erosion basin that extends south from it. Farther on it is continued by the line of large kettle-holes of which Green Pond and Lake Pleasant* are the most important, and by the course of Pond Brook and Sawmill River.

These features, together with the distribution of bedrock outcrops in the area, leave little reason to doubt this position for such a course, which is indicated in the cross-section (Text Fig. 4).

The early Recent Connecticut River issued from French King Narrows, followed the relatively low northern margin of the pro-glacial Millers River delta where it abuts against the higher bedrock hills, and cut its circuitous course along this contact past the crossing of a sandstone reef near Turners Falls, and thence southward between the trap range (Rocky Mountain) and the bottom deposits of "Lake Montague." Subsequently, its bed was entirely superimposed on bedrock for long distances. The post-glacial Millers River, in order to join the Connecticut, made a great bend west of Millers Falls and then flowed northward toward French King Narrows.

East of Turners Falls lies a narrow but prominent ridge of Triassic sandstone and shale that forms the southern wall of Barton Cove. The scarps, plunge pools, and deep, short, recessional canyons of two large waterfalls are clearly preserved in this ridge (at localities G and H, Text Fig. 3), and have


*Great Pond.
been attributed to the early Recent Connecticut River,\textsuperscript{28} which must have flowed over the bedrock barrier for a considerable length of time. The waterfalls were successively abandoned, however, when the river succeeded in stripping the sands of the Millers River delta from a more westerly, lower-lying gap in the ridge, through which it flows at the present time; this gap is the Narrows.

A well-defined series of terrace remnants extends upstream from the lips of the abandoned waterfalls to points considerably north of the Massachusetts state line. This series represents the floodplain of the early Recent Connecticut, and consists of a veneer of fluvialite sediments lying on benches cut by the river in the older deposits of the glacial sequence. This is the Lily Pond terrace of Emerson\textsuperscript{29} (see Text Fig. 5), and presumably is the chronologic correlative of late glacial Lake Upham\textsuperscript{30} in New Hampshire. The terrace was deeply incised when the Connecticut found a new course through the Narrows and became controlled by the lower bedrock threshold at Turners Falls.

Although the Lily Pond terrace, with its height of 80 feet above the present river, is perhaps the most spectacular of the post-glacial features, several well-defined and commonly more extensive terrace groups flank the Connecticut at lower altitudes. Each was formed as a floodplain, and each is composed of fluvial sand, silt, and minor gravel overlying a surface cut by the river on Pleistocene or pre-Pleistocene materials (see Text Fig. 4). An excellent example of these relations may be seen on the east bank of the Connecticut northwest of Montague (locality E, Text Fig. 3), where at least 15 feet of varved clay is overlain unconformably by 22 feet of river silt and sand. Thus the lake-bottom clays originally extended over an area several times greater than that of the present lake-bottom terrace remnants (Text Fig. 3), because they are in part covered by late glacial delta deposits and in part by river sediments of Recent age.

The step-like post-glacial terraces and present floodplains

\textsuperscript{28} Emerson, B. K.: 1898, op. cit., pp. 724-725.


\textsuperscript{29} Emerson, B. K.: 1898, op. cit., p. 724. Named from a small pond at the base of the higher waterfall (G. Text Fig. 3): the pond has since coalesced with Barton Cove because of water storage behind the dam at Turners Falls.

\textsuperscript{30} Lougee, R. J.: 1939, op. cit., p. 139.
possess surfaces that are gently undulatory, commonly with very low slopes away from the river that created them. Such slopes are due to several features, most common among which are natural levees on the outer margins of the surfaces, abandoned and partly filled, meander channels on their inner margins, and similarly located, abandoned tributary channels. The junctions of different terrace or floodplain levels commonly form steep, sharply defined erosional scarp, the heights of which generally are ten feet or more. Many of these scarps are distinctly arcuate in plan, and doubtless are old meander scars. The most prominent irregularities on the floodplain and terrace surfaces are “scrolls,” or floodplain bars, and their associated swales, which usually are deepened by floodwater scour. For further and more detailed information concerning Recent river deposits in the area, the reader is referred to the descriptions of Emerson.31

In addition to deposits associated with rivers and streams, at least one other type of post-glacial deposit is prominent in the Millers Falls—Turners Falls—Montague area. Immediately following the disappearance of “Lake Montague,” broad plains of loose, easily removed sand and silt were exposed to the action of the wind, and dunes were formed in large numbers. As in other parts of the valley, most of these dunes lie east of the present Connecticut River; they occur on the surfaces of deltas, outwash plains, and lake-bottom terraces, and to a small extent on the highest river terraces. The finest examples are those north of Montague (locality F, Text Fig. 3), which rise to heights of 30 feet above the surrounding plain, and those immediately east of the airport at the northeast base of Wills Hill. Few of the dunes are active today; most of the wind deposition probably ceased when the cover of vegetation was established on the lake bottoms in early Recent time.


To be continued.