HARVARD FOREST

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SPECIES DISTRIBUTION AND SOILS IN THE HARVARD FOREST

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INTRODUCTION AND ACKNOWLEDGMENTS

The Harvard Forest comprises an area of approximately 2300 acres in the northwestern part of Worcester County, Massachusetts. It lies within the upland plateau of Massachusetts between the Boston Basin on the east and the Connecticut Valley on the west. The area is characterized by long ridges running in a general northerly direction that rise to an elevation of 1383 feet at Prospect Hill, the highest point in the Forest. The lowest point is along the Swift River in the Slab City Block, at an elevation of 670 feet.

The ridges have long, rather gentle slopes that average from 2 to 10 degrees, and are broken in places by small terraces whose fronts may have slopes of 30 degrees. Boulders are frequently concentrated in "streams" varying in width from a few feet to more than 50 feet. On the south slope of Prospect Hill (see Fig. 1) is a boulder field that covers some two acres. In many cases the boulder streams occur in swales in the more poorly drained depressions and small valleys characteristic of this region.

The Forest is divided into three blocks as outlined in Figure 1. This map is made from parts of the Athol and Petersham seven-and-one-half minute quadrangles of the United States Geological Survey. The land was acquired by the University in 1907 and has been under continuous management since that date. A land use history of the area of the Forest from the time of early settlement to the present can be found in Raup and Carlson's *History of Land Use in the Harvard Forest* published in 1941. This study showed that during the height of agricultural development in the area some 75 percent of the land was cleared either for cultivation or for pasture. Following the opening of the West to settlement in the middle of the last century, there was a period of wholesale land abandonment. As the fields were abandoned, they seeded in to white pine in most cases. By the turn of the century these "old field" white pine stands were beginning to mature; and as they were harvested, it was hoped that they would reseed the land to pine. On the upland loam soils this was not the case, and the land was reclaimed by the species that made up what is believed to have been the major component of the pre-colonial forest — the hardwoods. The upland loam soils in the Harvard Forest support a forest cover that is now composed primarily of hardwood trees. Some of the stands are derived from old woodlots that persisted throughout the height of the agricultural period, while others have replaced the white pine stands that came up in abandoned fields. Together these hardwood stands now make a fairly continuous cover over large areas.

In composition they represent what have been called the "transition hardwoods" of central New England. Their principal constituents are red oak (*Quercus rubra*), white ash (*Fraxinus americana*), red maple (*Acer rubrum*), black birch (*Betula lenta*) and sugar maple (*Acer saccharum*). Other species that are widely distributed and locally abundant are white birch (*Betula papyrifera*), yellow birch (*Betula lutea*), white oak (*Quercus alba*), beech (*Fagus grandifolia*), and ironwood (*Ostrya virginiana*). Species that are of scattered occurrence or common in very small areas are linden (*Tilia americana*), shagbark hickory (*Carya ovata*), pignut hickory (*Carya glabra*), blue beech (*Carpinus caroliniana*), gray birch (*Betula populifolia*), black oak (*Quercus velutina*), sassafras (*Sassafras albidum*), black cherry (*Prunus serotina*), popple (*Populus grandidentata* and *P. tremuloides*), black ash (*Fraxinus nigra*), and elm (*Ulmus americana* and *U. rubra*). White pines (*Pinus strobus*) and hemlocks (*Tsuga canadensis*) are common. The former are now scattered as individual trees or in small groups throughout the upland transition hardwoods except where remnants of the old field stands remain, or where plantations have been maintained. The hemlocks are found in large concentrations on lower northerly slopes and in ravines.

Within the Forest the stands show a great variety of mixtures. Some are relatively simple, and contain only half a dozen species among which one or two are of primary significance. Others contain nearly all of the species noted above; but when this occurs the primary species are red oak, white ash, red maple, sugar maple, and black birch. Within the stands there is still further differentiation. A simple or complex stand may be designated on the type map as "RO-WA, 4–5," indicating that the primary species are red oak and white ash 35–55 feet tall. When such a stand is examined carefully on the ground, it is often found that within the area as a whole there are local concentrations of red oak and white ash rather than a random mixture.

During the years 1939–41 the United States Department of Agriculture made a soil survey of the Harvard Forest. Maps were constructed and descriptions written for the various soils designated (Simmons: 1939, 1940, 1941). Since that time much effort has been expended in attempts to relate the existing distribution of tree species and forest communities to the soil types as mapped. Within the areas of well-drained loam soils these attempts have not been successful. The species boundaries mentioned above, as well as those of the types, are found to cross the soil boundaries freely.

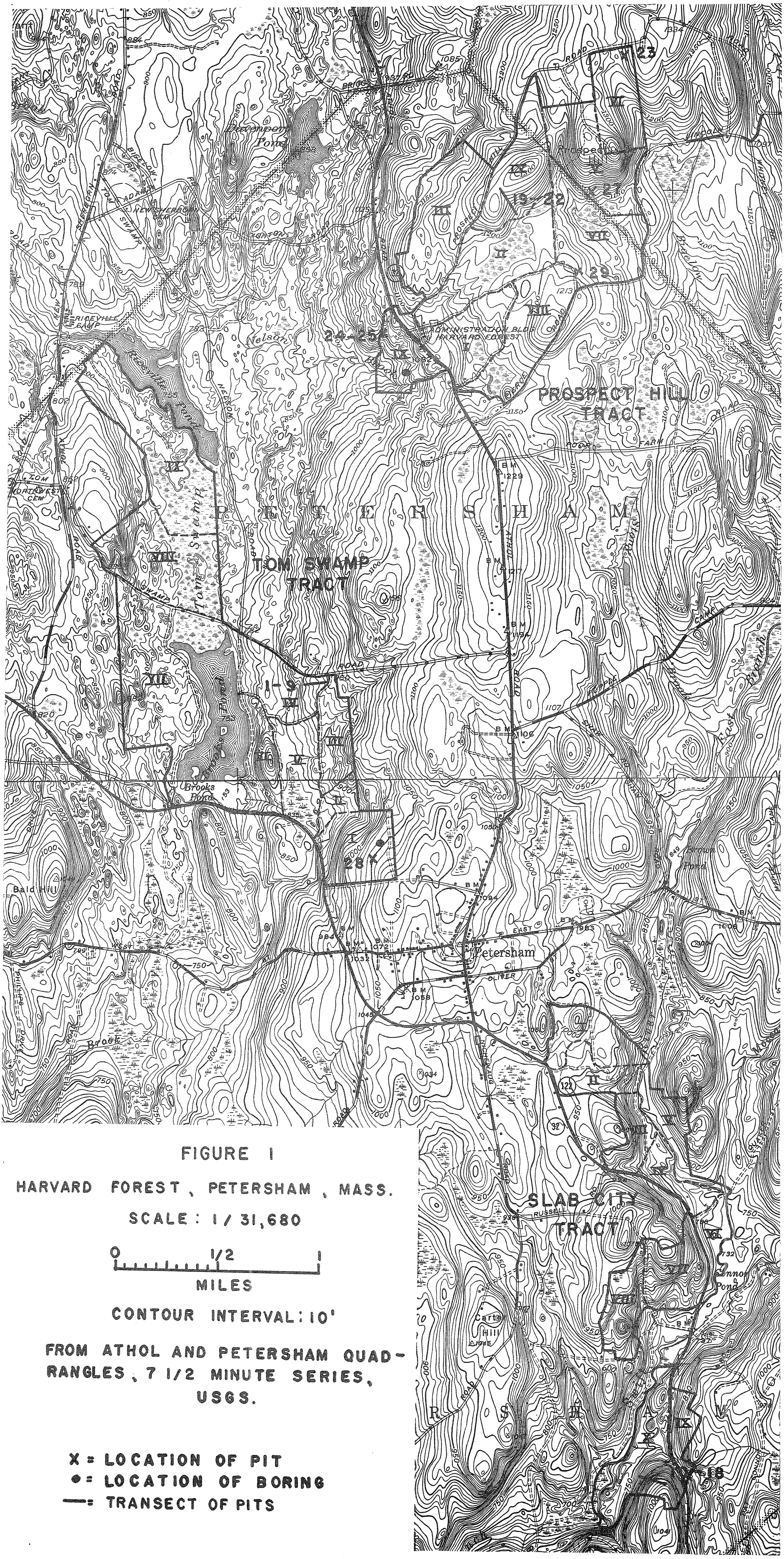


FIGURE I

HARVARD FOREST, PETERSHAM, MASS.

SCALE: 1/31,680

0 1/2 1
MILES

CONTOUR INTERVAL: 10'

FROM ATHOL AND PETERSHAM QUADRANGLES, 7 1/2 MINUTE SERIES, USGS.

X = LOCATION OF PIT
● = LOCATION OF BORING
— = TRANSECT OF PITS

SPECIES DISTRIBUTION AND SOILS

The local species concentrations show more coincidence with local topography and surface features than with the soils as mapped. This local topography is characterized by terrace flats and rises, depressions, and concentrations of boulders on the surface. The terrace rises vary from one or two feet to 20 or more feet in height. The terrace flats may be five or 10 feet wide, or they may be more than 100 feet from front to back.

The local concentrations of species are also related to the thickness of the upland loams and to the character of the underlying glacial tills. Some of these tills are of coarse material and are extremely permeable to water, while others are of sufficient fineness and compactness to perch temporarily a water table immediately beneath the loams[1] for a portion of the spring and early summer growing season. The loams are universally distributed over the Forest except in areas of glacio-fluvial deposits and rock outcrops. Where the thickness of the loam is about 20 inches or less over a till that perches the water table, the primary species in the forest canopy is white ash. Where the loam is more than 20 inches thick over such a till, the primary species is usually red oak. In all cases examined, the critical thickness is between 18 and 22 inches, but in most cases it is approximately 20 inches. In loams underlain by very permeable tills, white ash is rare or entirely absent, the stands are composed of relatively few species, and the areal distribution of species concentrations is more nearly related to the general topography.

The behavior of the water table under these varying conditions was clearly shown in the pits dug during the course of this study. The pits were examined immediately following a 2-inch rain. Those with compact, fine-textured till were filled to the top of this till by water flowing in from its surface.

The areal patterns of difference in the depth to the water table and the areal distribution of seasonal water table regimes coincide with the local distribution of species concentrations. The criteria used by the soil surveyors to differentiate the soil units do not bring out the water relation-

[1] The term "loam" as applied to Harvard Forest soils in this paper is somewhat anomalous. It here designates the rather loose and friable, fine-textured materials that overlie the glacial tills, outwash gravels and sands, and bedrock of the area. It ranges in texture from loamy coarse sand to fine sandy loam, and in color from light tan to reddish brown. It includes the humified "A" horizon, and, in the upland finer-textured soils, its light tan or reddish brown components are roughly coincident with the "B" horizon.

In nearly all sections that have been studied, it has been possible to describe the "loam" in this sense as a well-defined layer, separated rather sharply from the materials beneath it, whether they be compact tills or loose gravelly tills. Over compact tills the line of demarcation is a surface immediately recognizable by its compactness. Over gravelly tills the line is clearly defined on a textural basis. Loam, used in this sense, is absent or very thin over the outwash gravels and sands.

ships within a single unit in sufficient detail to show correlations with local type and species distribution.

The pits used in this study give more detailed data on the subsoil than were previously available. The interpretation of these data has led inevitably into problems of glacial geology. This paper is not concerned with glacial geology as such; nevertheless some understanding is desirable of the character and origin of the glacial deposits, and of the molding of the landscape under processes caused by intense periglacial frost and wind action — processes that were dominant during deglaciation but are no longer active. Such an understanding will afford an insight into the probable origin of what underlies the surface soils as mapped by the Department of Agriculture. Likewise, it should be of assistance in the development of materials and methods for the generalizations necessary to the construction of realistic management plans in this region.

This report will attempt to show, for parts of the Harvard Forest, how the surficial deposits that control the water table are arranged, vertically and horizontally, and how the forester might use the data presented here without digging as many deep pits as were required in the present instance. Further, it will suggest a sequence of glacial and post-glacial events and processes to account for the present arrangement of the surficial deposits.

The author's approach to the problems discussed in this paper was stimulated by the work of Dr. Hugh M. Raup and Dr. Charles S. Denny in the Black Rock Forest (Raup, 1938; Denny, 1938). They found correlation between forest types and soils that was not apparent when only the upper one to two feet of the soils were studied, but which began to develop as they delved into the underlying glacial deposits. The author expresses his appreciation of the direct assistance and stimulating suggestions given by fellow students, the staff of the Harvard Forest, and others during the course of the field work and the writing of this paper. Dr. H. M. Raup, Director of the Harvard Forest, has been a constant source of inspiration and assistance during all phases of the work. His suggestions have been invaluable. The late Dr. Kirk Bryan, Professor of Geology at Harvard University, visited the pits and offered valued suggestions. Dr. C. S. Denny of the U. S. Geological Survey has given freely of his time in aiding the interpretation and presentation of data. Mr. E. E. Smith and Dr. S. H. Spurr of the Harvard Forest kindly gave of their time to take much needed photographs. Mr. E. P. Stephens prepared the final draft of the figures that accompany the text. Dr. J. C. Goodlett provided the analysis presented in Table I.

THE PROBLEM

The Forest lies in the region of brown podzolic soils. (Simmons, op. cit.) Within this large unit the soils fall into two groups, i.e., the upland stony loams supposedly derived from granitic or schistose tills, and the sandy or gravelly loams on the outwash plains or glacio-fluvial deposits. It is with the former, the upland stony loams, that this paper is primarily concerned. The better drained stony loams are named "Charlton," "Gloucester," and "Brookfield." The more poorly drained are called "Acton," "Sutton," and "Whitman." The most common glacio-fluvial soil in the Forest is "Merrimac;" it is composed primarily of gravel and sand and is excessively drained.

The usual profile of the upland stony loams shows a dark brown surface horizon that ranges in thickness from one to eight inches. This in underlain by stony loam materials ranging in thickness up to 36 inches or more, and varying in color from light tan to reddish brown. The materials that underlie these two horizons vary greatly, depending upon several factors that will be pointed out in the following discussion.

That part of the Catena Key to Soil Series that applies to the Harvard Forest is here reproduced.

CATENA KEY TO SOIL SERIES

Parent material	*Well to excessively drained*	*Moderately well drained*	*Poorly drained*	*Very poorly drained*
Late Wisconsin till mainly from granite or granite gneiss 1. deep, friable to firm	Gloucester	Acton		Whitman
Late Wisconsin till mainly from gray mica schist 1. deep, friable to firm	Charlton	Sutton		Whitman
Late Wisconsin till mainly from brown rusty pyritiferous schist 1. deep, friable to firm	Brookfield	Sutton		Whitman
Glacio-fluvial sands and gravels from granite, or gray mica schist	Hinckley Merrimac			
Glacio-fluvial sands and gravels from granite, gray mica schist, and some rusty pyritiferous schist	Jaffrey			

The statement was made in the Introduction that little or no correlation has been found between existing forest cover types and the well-drained loam soils mapped by the Department of Agriculture. A fairly good correlation exists between forest types and the excessively drained soils on the one hand and very poorly drained soils on the other. The former (Merrimac, Hinckley and Jaffrey) are characteristic of glacial outwash sands and gravels. They support natural stands of hemlock and white pine. The latter, such as Whitman, have developed in swales that are normally wet and characterized by red maple, white ash, and yellow birch. However, the great majority of the land in the Harvard Forest falls between these two moisture extremes. It has, therefore, become desirable to find a basis for land classification that can be used in management plans for the upland hardwood forests that grow on these intermediate soils.

METHOD OF STUDY

Several series of pits were dug across the boundaries of the local species concentrations described above. These gave the data necessary for the construction of profiles that show the position and make-up of the materials underlying the ground surface. As each pit was completed, it was described, with notes on the thickness and character of each layer and the maximum depth of roots. Where more than one pit was used to determine the character of the deeper layers, the resulting series is shown in accompanying figures. The individual pits are described in the text.

For the description of the vegetation, the canopy in the immediate vicinity of the pits was examined. From this examination notes were made of what species dominated or were primary therein. The terms "dominant" and "primary" are used more or less interchangeably.

In conjunction with the series of pits in Tom Swamp IV a topographic map with a one-foot contour interval was constructed (Fig. 2). The terraces that are brought out clearly on this map are not evident on the 10-foot contour map of Figure 1.

DESCRIPTION OF PITS AND TRANSECTS

Tom Swamp, Compartment IV

In the area studied in Tom Swamp IV the distribution of red oak and white ash is shown above the profile in Figure 2, and the underlying strata are shown below. The first layer exposed in all the pits is a reddish brown loam darkened at the top by humus in the "A" horizon. It is from eight to 30 inches thick. The volume of stones, cobbles, and boulders[1] in this loam varies from pit to pit. The greatest concentration is in Pit 8, the least in Pit 1.

The next layer below the loam varies greatly. From Pit 3 through Pit 6 this layer is a reddish brown heterogeneous mass of sand, gravel, cobbles, and boulders; the rocks are both round and angular. Under this heterogeneous mass and under the reddish brown loam from Pit 7 east is a compact, gray till. The depth to this compact till varies from 16 inches in Pit 8 to 40 inches in Pit 5. In Pit 5 the layer of compact till is from 20 to 28 inches thick. Under the compact till in Pit 5 is a layer of stratified sand and silt that is from two to 12 inches thick. These variations in thickness are due to deformation of the layers of sand and silt (convolutions). Plates I and II show a part of this layer, in which some of the bands of sand and silt are at a 45-degree angle. Other bands are standing on edge, but are not visible in the photograph. Under this bed of stratified sand and silt is a mass of tight, clayey, gray till. It, too, is deformed or convoluted, and its thickness is inversely proportional to the thickness of the sand and silt. Under the clayey till is what may be bedrock or may be a large boulder. In three other pits of this series (1, 2, and 3) the tight, clayey, gray till found in the bottom of Pit 5 was encountered.

The soils that have been mapped here are Whitman stony silt loam in the flat at the west end of the area, and Gloucester stony fine sandy loam over most of the remainder of the transect. There is a small area of Sutton stony silt loam noted on Terrace 2. It covers only a small portion of the area in which the canopy is dominated by white ash.

In the area mapped there are concentrations of boulders visible on the

[1] In this paper rounded or subrounded rock particles from ⅛ to 3 inches in maximum diameter are called pebbles; those between 3 and 10 inches are called cobbles; those over 10 inches are called boulders. Where it is not deemed necessary to distinguish between sizes in the discussion, all rock particles over one inch in diameter will simply be called rocks.

surface. The greatest concentration is on the front of the first terrace. On a small area here the ground surface is made up entirely of boulders. On the flat of the first terrace there is an occasional boulder; approaching the second terrace front the concentration becomes greater; and at the foot of the second terrace front, there is a narrow band of closely spaced boulders. From this boulder band to a point on the flat of the second terrace, boulders are practically non-existent. The point on Terrace 2 where the boulders are again visible on the surface coincides with the point at which the white ash begins to be dominant, as is shown on the profile in Figure 2. The top of the second terrace merges with a fairly gentle slope and continues to a point near the eastern end of the map where there is a decided increase in slope. Over this area there is a fairly uniform distribution of boulders visible on the surface, with perhaps a greater number in the middle. At the easternmost end of the map area only an occasional boulder is visible. The small patch of Sutton stony silt loam previously mentioned is in the very bouldery portion of Terrace 2.

The tills under the layer of reddish brown loam in this area are capable of supporting a perched water table. The pits were dug during a very dry period, and at that time water was not present in any of them. However, examination following the period from November 25 to December 7, 1949, during which time 2.05 inches of rainfall were recorded at the Harvard Forest Headquarters weather station, showed that in every case the pits were being filled with water that was oozing in from the upper surface of the till. In Pits 1 and 2 the till in question is the tight, clayey, gray till. In Pits 3 to 9 it is the compact gray till. When the pits were filled to the top of the till, the water levels were maintained for several days following the rain.

Root penetration usually equals the depth to the compact till. Occasional roots are found in the compact till, but the number is very small (about 5 percent) in comparison to the number that terminate at the upper limits of the tight till.

As is the case with many other areas in the Harvard Forest, the woodlands along the transect in Tom Swamp IV have undergone a variety of treatments. Prior to 1918 the whole area except for the swale at the western end and a part of the flat of Terrace 2 was an old field white pine stand about 60 years of age. It was of varying quality and density, but had an abundance of advance growth hardwoods. Recorded operations before 1918 consisted of preliminary cuttings aimed primarily at the reproduction of the pine. Most of the area was finally clearcut in 1918, and the advance growth cut back to the ground. A small portion

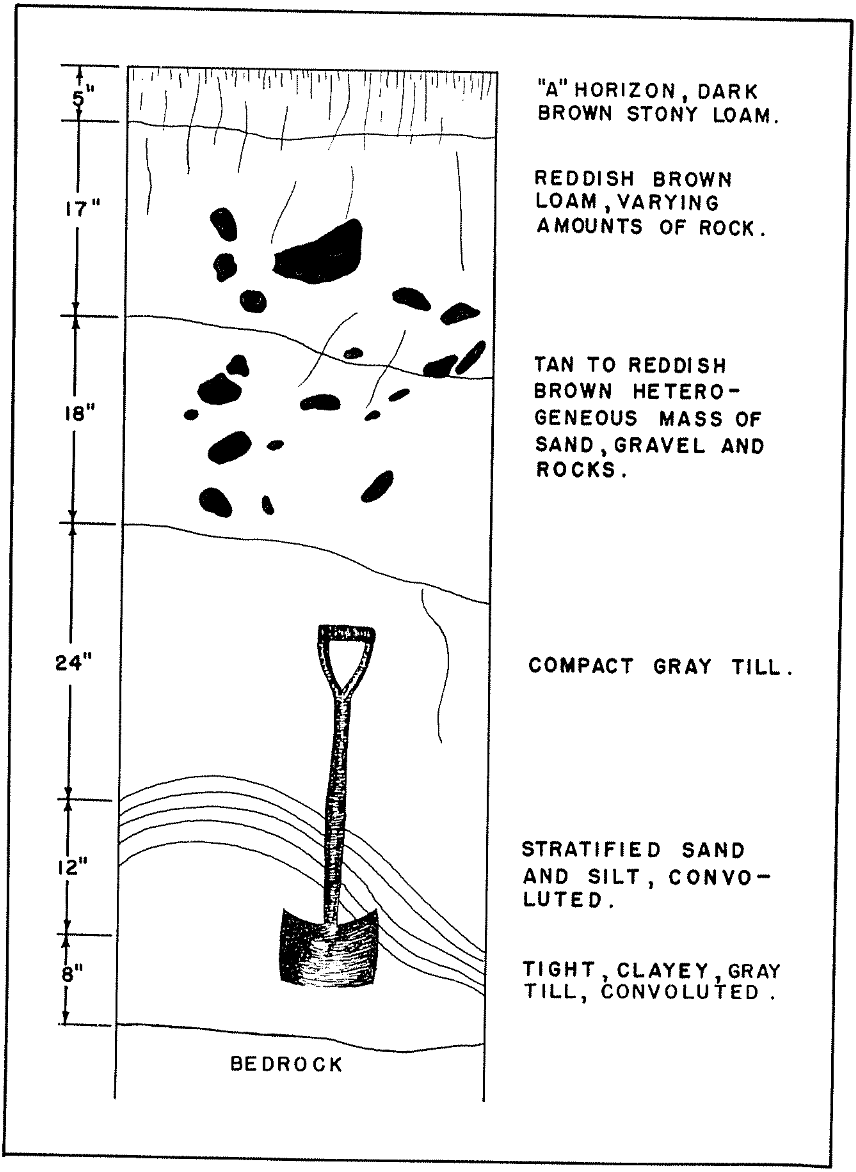

5"
17"
18"
24"
12"
8"
"A" HORIZON, DARK BROWN STONY LOAM.
REDDISH BROWN LOAM, VARYING AMOUNTS OF ROCK.
TAN TO REDDISH BROWN HETERO-GENEOUS MASS OF SAND, GRAVEL AND ROCKS.
COMPACT GRAY TILL.
STRATIFIED SAND AND SILT, CONVO-LUTED.
TIGHT, CLAYEY, GRAY TILL, CONVOLUTED.
BEDROCK

PLATE I. SOUTH SIDE OF PIT 5 IN TOM SWAMP IV

Note the pocket of fines to the left and below largest root at top; also, the bed of stratified sand and silt near the bottom. Pit 7 feet, 4 inches deep.

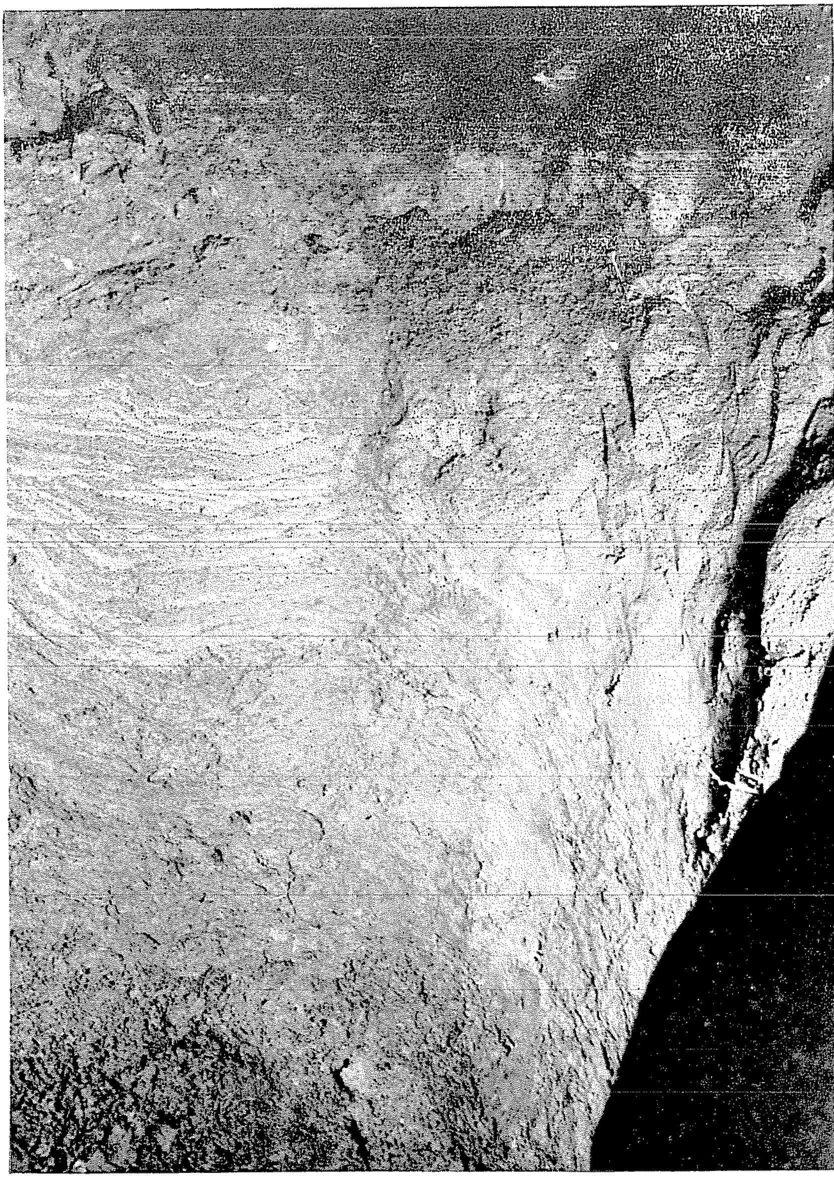


PLATE II. CLOSE-UP OF BED OF STRATIFIED SAND AND SILT IN PIT 5, TOM SWAMP IV

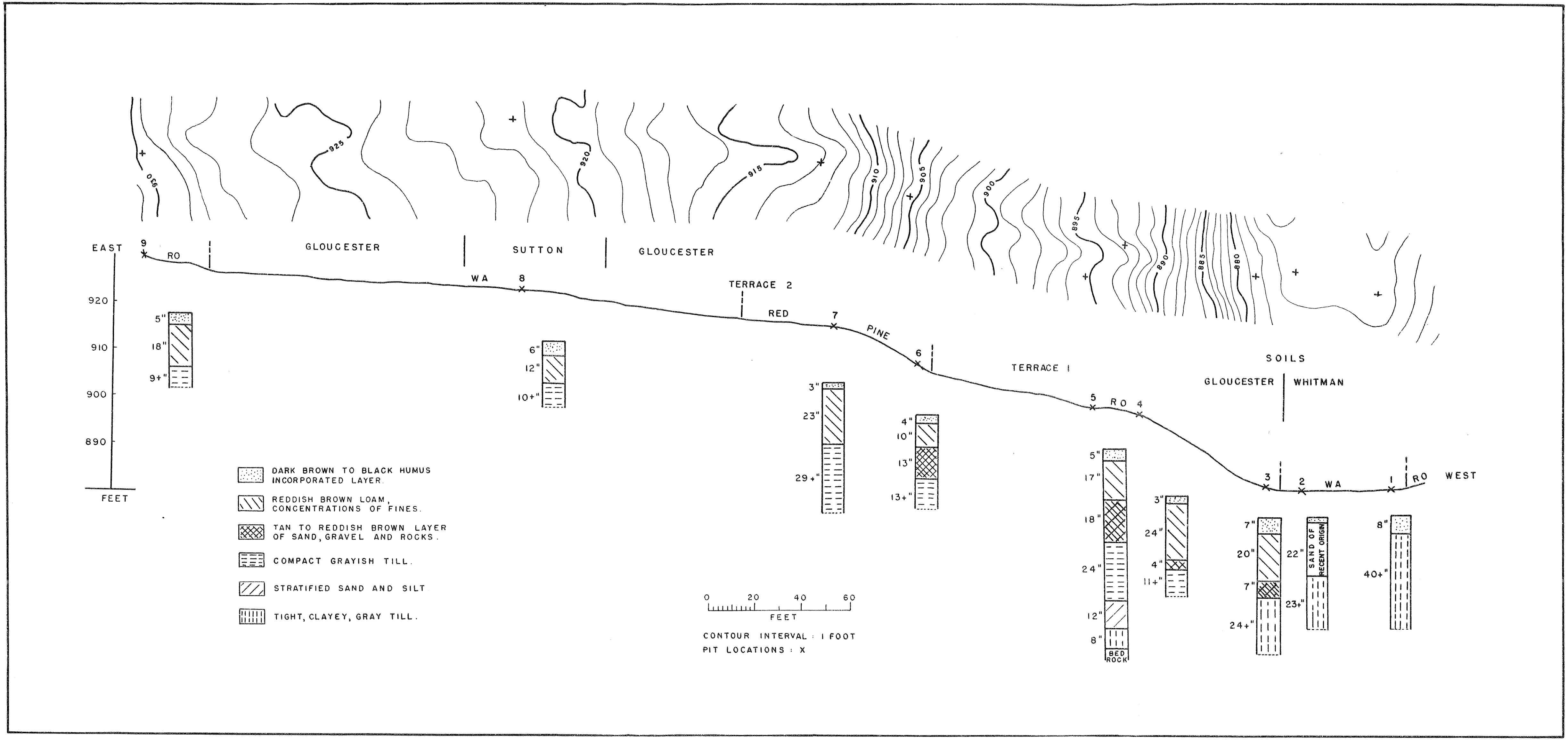


FIGURE 2. DETAILS OF PITS, TOPOGRAPHY AND PROFILE IN TOM SWAMP, COMPARTMENT IV.

at the eastern end of the transect was not cut until 1924. The area cut in 1918 was planted to red pine in 1919, and the small area cut in 1924 was planted in 1926.

The plantation of 1919 was weeded in 1920 and 1924, on both occasions to remove coarse red maple sprouts which were crowding the pine. By 1927 it was recognized that if any of the pines were to succeed, they would be in groups interspersed with the hardwoods. Treatment given in 1927 consisted of perfecting, by judicious weeding, the pine and hardwood groups. Most of the trees removed were red maple and black cherry. The only mention of selective cutting among the hardwoods that might indicate a favoring of either predominant red oak or white ash states that the crown-sensitive ash was favored in very narrow strips at the actual borders of the pine groups. The records also mention that in a few instances very large-crowned red oaks that threatened to become wolf trees were removed. The pine groups defined in 1927 were subsequently weeded to favor the pine, and there is no evidence of selection among the hardwood species in these groups. Weedings were made in 1929 and again in 1933.

In 1938 this area was made a part of a gypsy moth control experiment. A cutting was made to eliminate gray birch and poplar, and to reduce the proportion of red oak. It is clear from the records that before this operation was undertaken, well-defined areas of white ash dominance and red oak dominance were recognized, for the tallies are thus differentiated. In spite of the fact that an actual reduction in the proportion of red oak over the whole area was made, the report of an inspection in 1939 states that in the northern portion (the location of the transect here described), ". . . the distribution of species is more or less uniform but their distribution in numbers varies greatly in any given locality. Slight differences in elevation reflect major differences in the occurrence of species. In the lower areas ash is the dominant species and on most higher ground oak is the dominant species. . . ." This was the last operation carried out on the area of the transect.

From the above notes it can be assumed that although many cuttings have been made on this land, they have not materially altered the areal distribution of major patterns in hardwood stand composition. These patterns must have been formed first by natural seeding of advance growth under the old field white pine, and later by seedling sprouts from this advance growth as well as by subsequent natural seeding of hardwoods.

Because the water table commonly rises no higher than the top of the tight till and may be temporarily perched there, the depth to this till takes on considerable significance. As shown in Figure 2, at places in which the till is about 20 inches or less below the surface, white ash predominates in the forest canopy. Where it is over 20 inches down, red oak is the dominant species in the canopy. At localities such as those on the front and back edges of Terrace 2, where the depth to the tight till is close to 20 inches, a mixture of red oak and white ash occurs. Here the red oak grows on mounds six to 12 inches high with white ash in the intervening depressions. This suggests that in a transition zone a difference of six inches in the general surface level can be correlated with differences in the local distribution of red oak and white ash.

Over the length of the profile (Fig. 2) white ash is dominant where the water flowing through the reddish brown loam is forced to stay within about 20 inches of the surface. As is shown on this profile, white ash is found on the flat of Terrace 2, at the foot of Terrace 2, and in a major concentration on the flat at the west end of the profile.

Tom Swamp, Compartment I

The part of Tom Swamp Compartment I that supports a 30-year-old mixture of hardwoods is characterized by local concentrations of red oak and white ash. There are groups in which most of the canopy is of red oak and similar groups of white ash. Between the two extremes are transition zones where the two species are apparently mixed at random. That the mixture is not as random as it appears is shown below.

The history of the development of the present forest is well documented in the Harvard Forest records. In 1910 an old field white pine stand 60 years of age was growing on the area. There is evidence that the land was used for pasture or cropping from about 1750 until it was abandoned around 1850. In the winter of 1910–11 a thinning operation was conducted in an effort to secure pine reproduction. The thinning did not accomplish its aim, and in 1917 the area was clearcut. In 1919 the scattered distribution of both pine and hardwood made supplementary red and white pine planting advisable.

In 1921 the area was weeded, and again in 1923 and 1930. In each case an attempt was made to release the pine. By 1933, sixteen years after clearcutting, it was apparent that the hardwoods were going to control the area, and at that time a thinning of the hardwoods was made. Also at this time some small sample plots were established to study the control of the gypsy moth by silvicultural means. In these plots most of the oak was removed. Otherwise no further cutting was done until 1948 when the stand was thinned again.

The red and white pines planted in 1919 are represented in the present forest as individual trees or scattered groups except around the old sawmill site, where most of the advance hardwood growth had been destroyed. Most of the white pines are now suppressed, but a few scattered red pines have maintained places in the canopy.

At the time the old field pine was clearcut, the hardwood advance growth was mowed down to the ground. Weedings in subsequent years to favor the pine were indiscriminate with regard to hardwood species. When hardwoods became the expected crop trees in the early 1930's, the treatment given was in part a thinning to favor well-formed individuals, and in part a weeding to remove poorly-formed trees and short-lived species such as popple, gray birch, and pin cherry. In the thinning of 1948, the selection of trees to be removed was based entirely upon form and spacing, and a determined effort was made to keep intact the natural species composition of the stand. It can be assumed, therefore, that so far as red oak and white ash are concerned, the stand composition is essentially as it developed in the hardwood advance growth under the old field pine. The only exceptions are in the few small sample plots from which oak was removed for attempted control of the gypsy moth, and the location of these plots is known.

The area is underlain by a fine-textured, tight till. Pit 28 (Fig. 1) shows a layer of loam 22 inches thick, under which is tight gray till. The till becomes more compact to a depth of at least 73 inches. For other locations a soil auger was used to determine the thickness of the loam under the local concentrations of red oak and white ash.

In a pure stand of white ash, the layer of loam is invariably about 20 inches or less thick. In the areas that support stands of red oak, the loam is more than 20 inches thick. In Pit 28 it is 22 inches thick, and the trees in the immediate vicinity are red oaks. In the transition zones the same arrangement of individual trees with regard to minor elevations and depressions exists that was described in the discussion of white ash and red oak in Tom Swamp IV. Here again a very few inches of elevation up or down causes a small area to have its layer of loam either thicker or thinner than the critical 20 inches.

Time did not permit the mapping of the boulders in this area. However, rough estimates show that the greater the concentration of boulders on the surface, the greater the likelihood of finding a larger proportion of white ash. The thickness of the loam and the presence or absence of boulders on the surface are believed to be related in some way.

Prospect Hill, Compartment IX

In Prospect Hill IX all of the well-drained upland stony loams are represented, as well as some of the moderately well-drained and very poorly drained types. Likewise there are representatives of most of the hardwood mixtures found in the Forest.

Pits 24 and 25 suggest that the northern part of this compartment is underlain by a tight till similar to that in Tom Swamp IV. This till has the necessary characteristics for perching a water table.

In the northern part of the compartment there are short steep slopes, which are for the most part mapped as Gloucester stony loam. On these slopes are representatives of three definable associations. On the tops are found mixtures in which white oak predominates, on mid-slopes are mixtures in which red oak predominates, and at the bottoms red maple is primary.

The distribution of these mixtures seems to be coincident with the areal distribution of the depths to the tight till, and consequently with the position of the water table during a part of the year. It may also be determined in part by seepage of precipitation water down slope. There may also be some relation between the varying amounts of available moisture and the differences in thickness of the "A" horizon. Under the white oak, the latter is generally one inch or less thick; under the red maple, it varies from six to eight inches. Under the red oak growing on mid-slope, it varies between these two extremes, with the thicker portions at the lower elevations.

In the southern part of Compartment IX the surficial layer of loam is much thinner than in the northern part. As shown by small pits and borings with a 20-inch soil auger, a tight till is within 20 inches of the surface at every locality where white ash is growing. Under red oak the tight till could not be reached with the auger. The same relationships that were outlined for white ash in Tom Swamp IV exist here.

Prospect Hill, Compartment VII

The area studied in Prospect Hill VII is underlain by a tight till as shown in Pit 29 and scattered borings. The depth to the tight till is 22 inches or less in the pit and in all of the borings. From the topographic map, Figure 1, it can be seen that Pit 29 is located near the top of a hill on the upper reaches of an intermittent stream. This area has a relatively smaller water supply than areas farther down the slope.

The distribution of species from Pit 29 down the slope is as follows: white ash, to mixed white ash and red maple, to red maple. The distribution seems to be coincident with the relative amounts of available water as determined by slope; white ash (on the moist side of mesophytic) on the upper parts of the slope, and red maple on the mid- and lower slopes.

The soils as mapped along the line just described are Gloucester stony loam and Whitman very stony silt loam. The boundaries between these soils follow no pattern that relates to perched water table conditions. At one place a boundary line runs parallel to the contours, and at another it is perpendicular. Along the lines of probable water availability, however, we find species boundaries.

Prospect Hill, Compartment V

Pit 27, in Prospect Hill V, was dug in Charlton stony loam. It showed 27 inches of loam resting on a compact yellowish gray till. Up slope 100 feet from this pit a boring showed the layer of loam there to be less than 20 inches thick. The trees in the immediate vicinity of the pit were blown down by the hurricane of 1938, but the reproduction is of red oak and black birch. At the boring it is mostly red maple with an occasional white ash.

Prospect Hill, Compartment IV

The underlying strata of a part of the south slope of Little Prospect Hill, as determined by four pits, are presented in Figure 3. This sketch from field notes shows a loam which is underlain by a loose, gravelly, bouldery, reddish to yellowish till. The upper parts are reddish brown in color, while the lower parts are yellowish gray to gray.

White and black oaks are abundant on the top of the hill. Red oak is predominant from just below the crest of the hill to just above the terrace (Fig. 3) where it gives way to red maple. Red maple covers most of the terrace and in turn gives way to red oak on the outer edge and front of the terrace.

The distribution of species on this slope suggests a close relationship with probable amounts of available water. Precipitation water flows down through the reddish brown till to the yellowish gray to gray till and thence down slope as fast as it percolates through the loam. Farther down slope the amount of available water becomes greater. At the back of the terrace, near the bottom of the slope, the amount of available water is greatest. On the outer edge of the terrace and on its front the amount of available water is probably about equal to that on the mid-slope above the terrace.

The probable amounts of available water at different points on the transect coincide with the relative water requirements of the four species mentioned. White and black oaks (xerophytic species) are on the top of the hill, red oak (mesophytic) is on the mid-slope and on the front of the terrace, and red maple (a characteristic species of swales) is on the lower slope and the terrace where the water potential is greatest. No compact

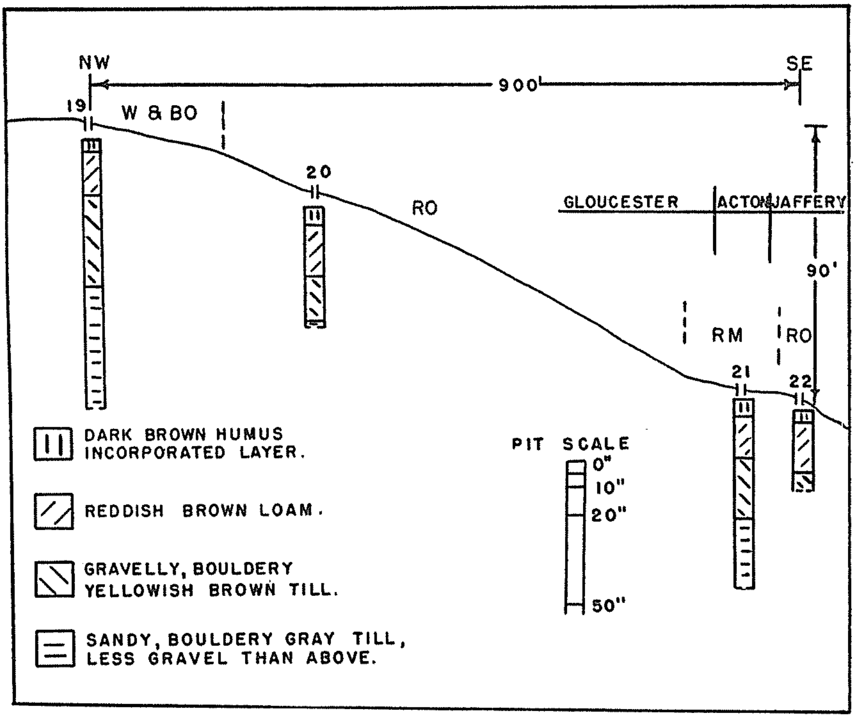


FIGURE 3. SECTION OF SOUTH SLOPE OF LITTLE PROSPECT HILL. SKETCH FROM FIELD NOTES.

till to support a parched water table is found here and therefore the 20-inch figure for the thickness of the loam has no significance.

Slab City, Compartment X

The series of pits in Slab City X is located on a long, fairly steep slope (Fig. 4) which is interrupted at about its midpoint by two small contiguous terraces. The pits (see Fig. 4) are located in that part of the slope from the outer edge of the terraces to the top of the hill to the eastward. At two points along the line of pits there are some white pines that are remnants of an old field succession. One group is on the higher of the two terraces; the other is near the top of the hill between Pits 17 and 18. At the outer edge of the lower terrace is a narrow band of white oak. The whole area has been mapped as Gloucester stony fine sandy loam.

The underlying strata are shown in Figure 4. The surficial layer over the transect is a loam which is reddish brown beneath the "A" horizon. The materials underlying this loam vary greatly. From a point between

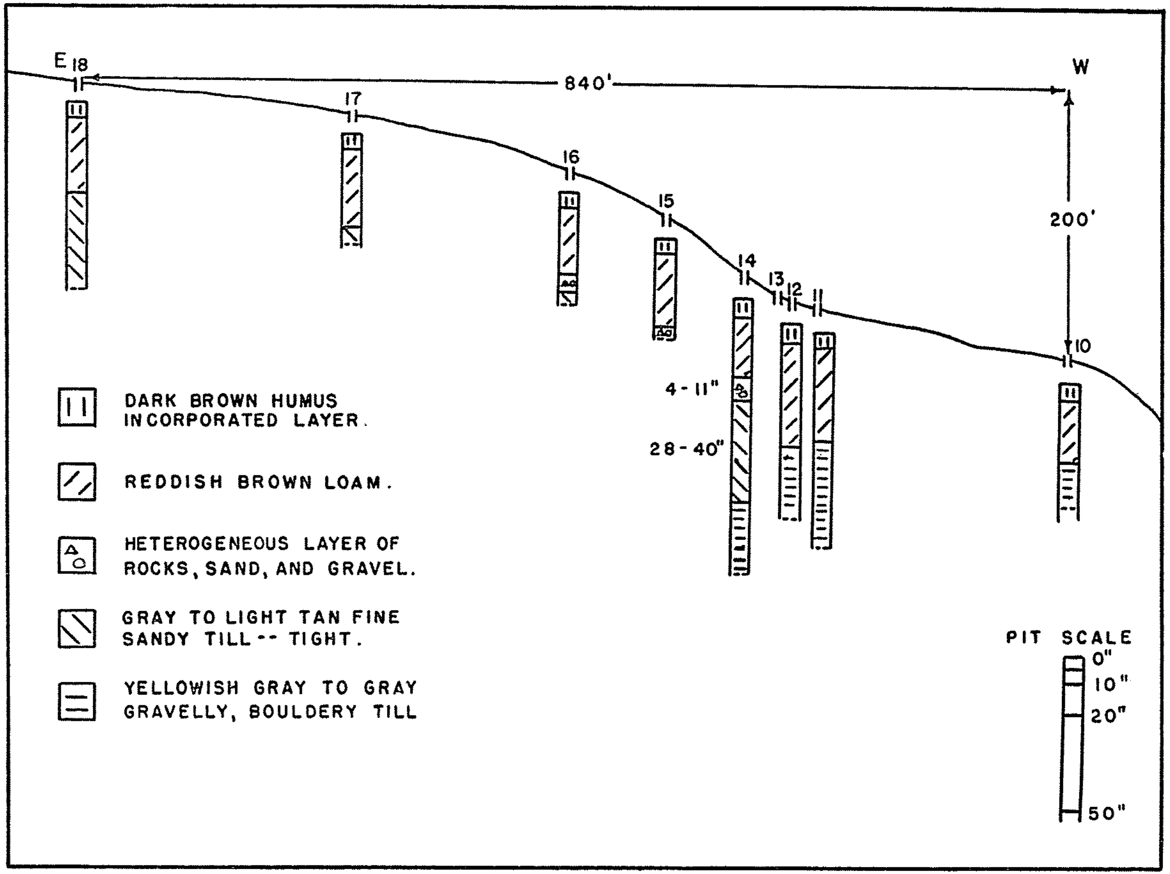
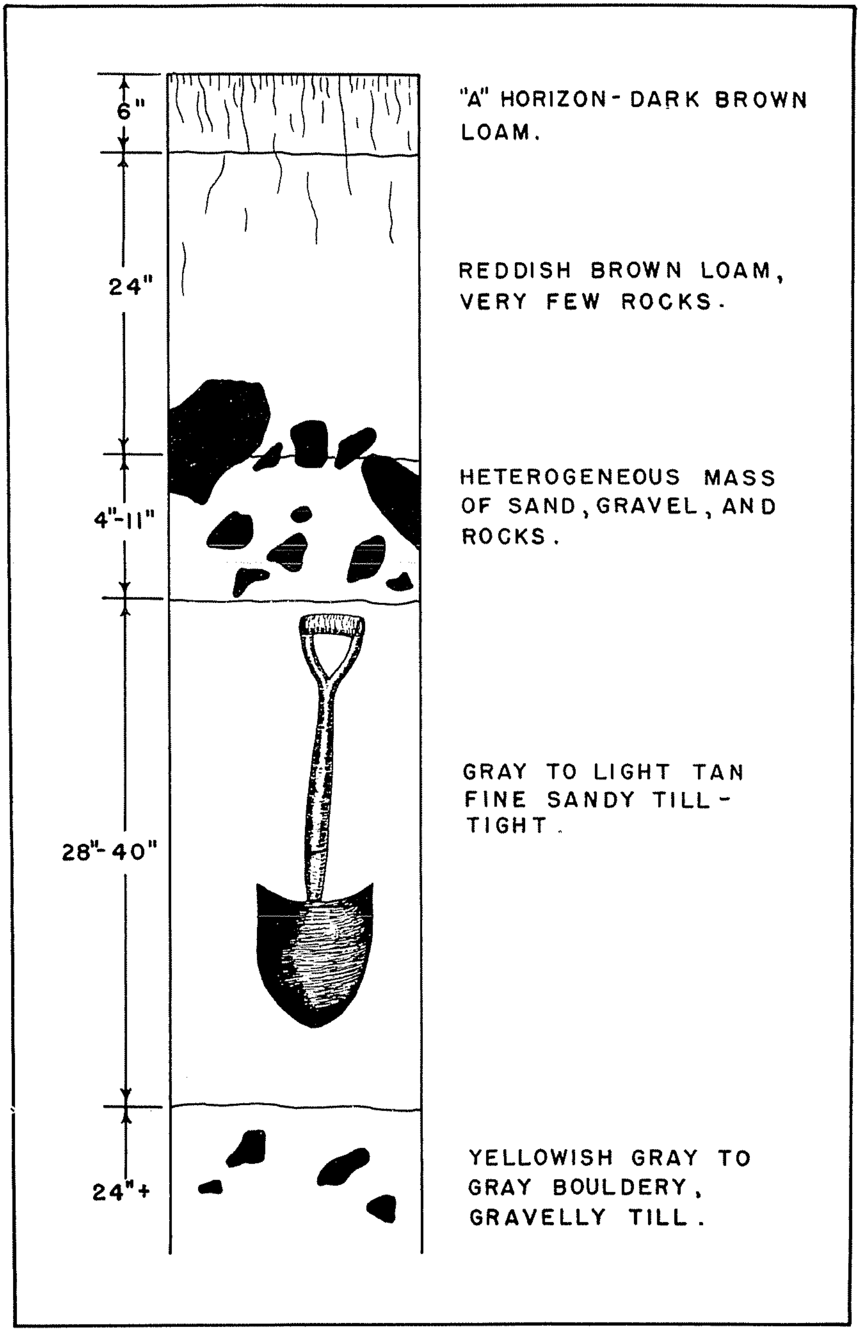


FIGURE 4. SECTION OF WEST-FACING SLOPE IN SLAB CITY TRACT, COMPARTMENT X.


6"
"A" HORIZON - DARK BROWN LOAM.
24"
REDDISH BROWN LOAM, VERY FEW ROCKS.
4"-11"
HETEROGENEOUS MASS OF SAND, GRAVEL, AND ROCKS.
28"-40"
GRAY TO LIGHT TAN FINE SANDY TILL - TIGHT.
24"+
YELLOWISH GRAY TO GRAY BOULDERY, GRAVELLY TILL.

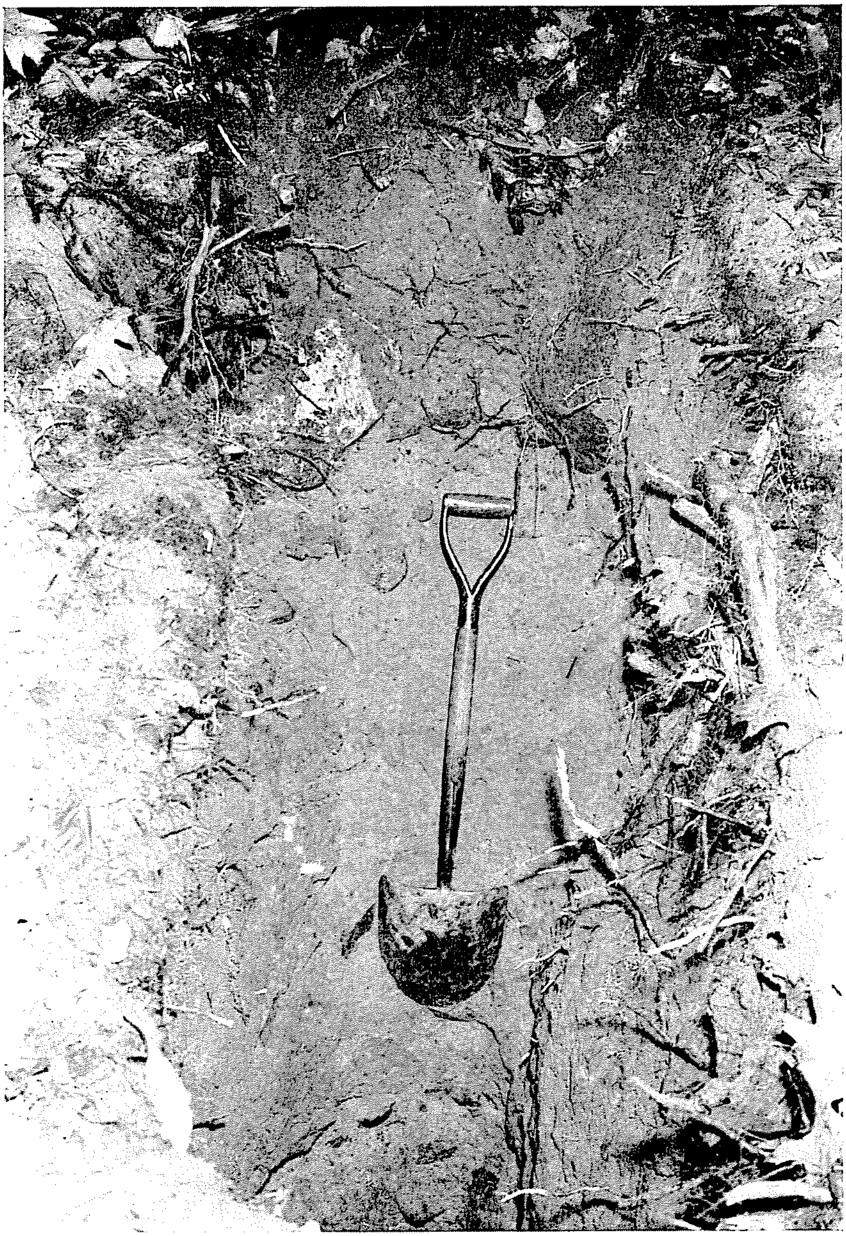


PLATE III. EAST SIDE OF PIT 14, SLAB CITY X

Note especially the layer of fine materials encompassed by the shovel and the layer of rock at the top of the shovel. Pit 7 feet, 10 inches deep.

PLATE IV. CLOSE-UP OF BOTTOM OF PIT SHOWN IN PLATE III

The coarse till here is directly beneath the upper layer of loess in pits 10, 11, 12 and 13, Slab City X.

Summary

The till that lies between the surficial layer of stony loam and the bedrock in the Harvard Forest falls roughly into two classes. The first of these is a tight compact till that is capable of holding up a perched water table. The second is a very coarse bouldery till that is highly permeable.

Areas underlain by coarse, permeable till are characterized by the more xerophytic trees of the native forests. In these areas on only the lower slopes of the hills where water accumulates from flowage down through the tills do the more mesophytic or swale species grow in abundance.

On the other hand, areas underlain by relatively fine textured, compact till harbor nearly all of the native tree species of the region. On such tills, however, there is wide variation in the specific content of the forest communities. These variations appear to be closely correlated with the depths to the compact tills, and hence to the perched water tables.

PROBABLE ORIGIN OF SOILS AND GROUND WATER REGIMES

The long smooth slopes that are interrupted in places by terraces and bouldery areas, and the almost universal surface layer of loam are prominent features of the landscape in the Harvard Forest. Such features are not forming at the present time. Terraces and bouldery areas similar to those in the Forest are now forming in parts of the Arctic and Subarctic, and are attributed to the downslope movement of surficial materials caused by intense frost action. By analogy the terraces, bouldery areas, and the loam of the Harvard Forest are thought to be the result of processes active under a subarctic or periglacial climate that characterized areas peripheral to the ice sheets (Bryan, 1928; Smith, 1949). At the Black Rock Forest in the Hudson Highlands of southern New York, Denny (1938) described bouldery areas and slopes that he attributes to processes active under periglacial climatic conditions during the retreat of the ice sheet.

The periglacial climate was characterized by cold periods during which the ground froze each year to depths of many feet. Whether or not there was perennially frozen ground in our area is not yet known. As the soil froze, it drew upon underground water and increased its bulk by the expansion of interstitial ice and the development of lenses and wedges of

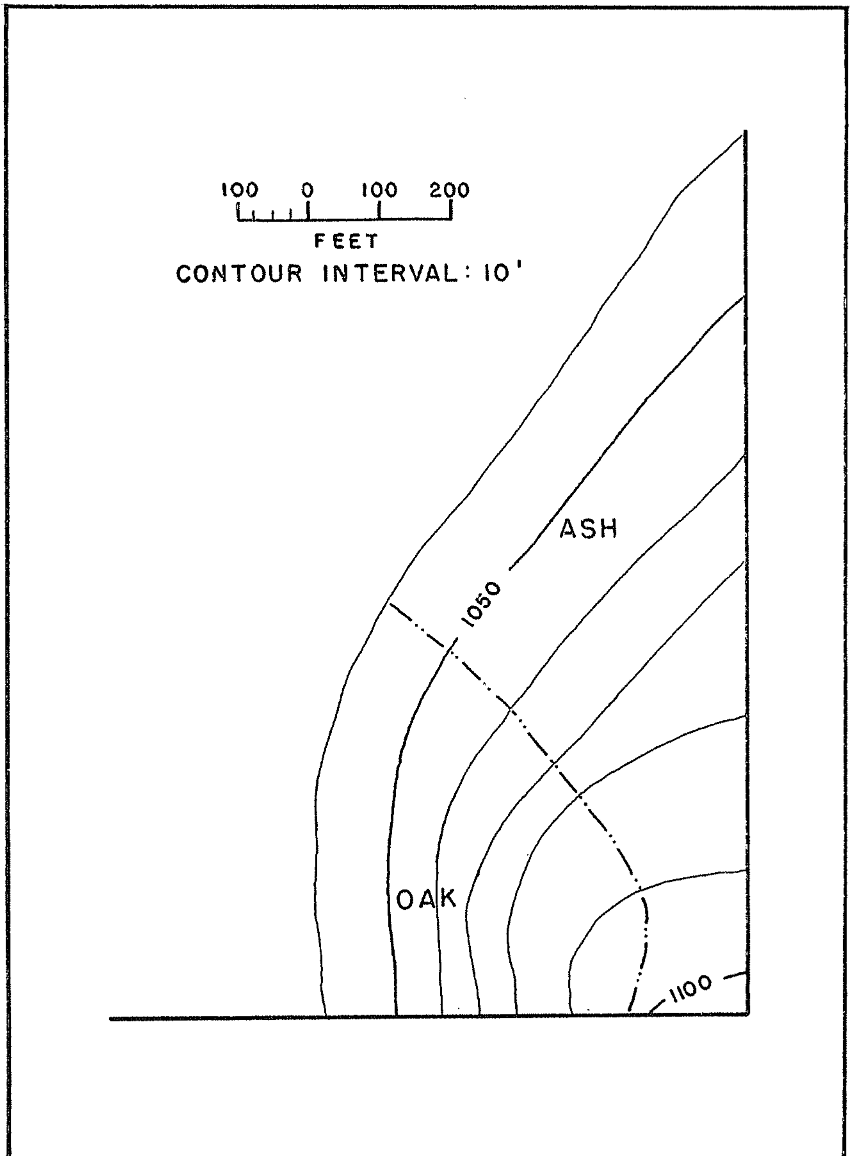


FIGURE 5. AN ENLARGEMENT OF THE TOPOGRAPHIC MAP OF A PART OF TOM SWAMP TRACT, COMPARTMENT I.

ice. The amount of water in the soil in the form of ice during periods of deep freezing was in excess of the water-holding capacity of the unfrozen ground. During periods of less severe weather, the ground would thaw, not from the bottom up but from the surface down. With this thawing the excess of water would be released, and masses of ground would become mobile even on gentle slopes. Such mobility, coupled with frost heaving which was proportionately greater than that which we know today, produced the micro-topography that is influencing present-day patterns of distribution in the vegetation. For a more detailed discussion of these phenomena, see Bryan (1946), and Smith (1949), in addition to Denny (op. cit.).

Figure 6 will serve to demonstrate the results of the mobility of soil masses and of the mixing and stirring which has resulted from frost heaving. These processes are known as "congeliturbation," and the prod-

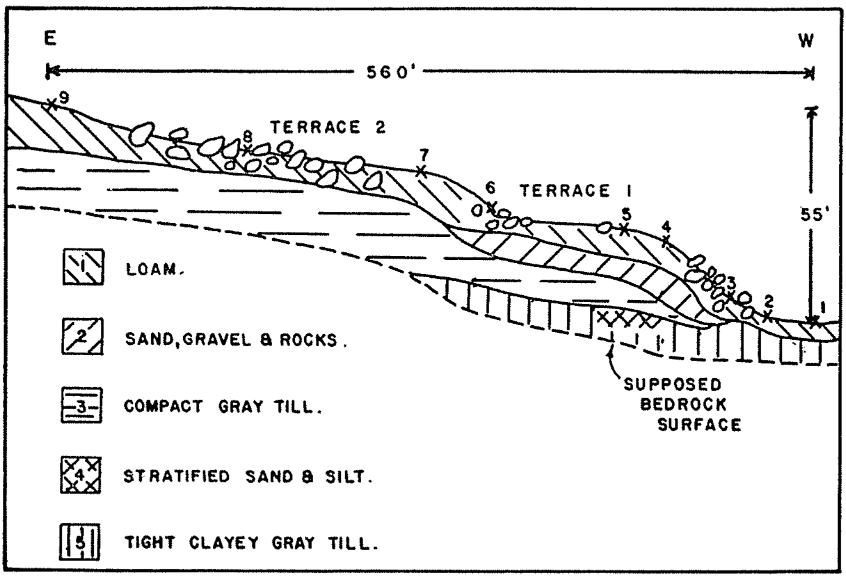


FIGURE 6. SCHEMATIC DRAWING (FROM FIG. 2) OF TRANSECT IN TOM SWAMP TRACT, COMPARTMENT IV.

ucts are "congeliturbates." The profile, derived from that shown in Figure 2, is located in Tom Swamp IV. The two terraces were formed by congeliturbation. The evidence for this conclusion comes from the shape of the terraces and from the position of the various layers that were exposed in the pits.

The shape of the terraces is similar to that of active congeliturbation terraces that have been described by geologists in the Arctic and Subarctic. They are lobate in form, and have a stair-step appearance on a slope such as this. In many cases boulders are concentrated on their fronts.

The pit that exposed the greatest number of layers was Pit 5. It shows that what is now in Layers 2 and 3 (the numbers refer to those in Figure 6) was probably a single layer that was subjected to frost heaving and mass movement. The bottom of the present Layer 3 undulates, and the materials of Layers 2 and 3 appear to have been pushed into folds as they moved as a mass down slope. At the same time a coarser fraction was being winnowed out to the surface and is now what we see as Layer 2. (Layer 1 is in part a later deposit. See below.) The coarsest fraction is of large boulders which are found on the front of the first terrace and on the flat of the second terrace. In the latter place the boulders were not dumped over the front of the terrace but, lacking the necessary gradient, were formed into a boulder stream that flowed around the side of the terrace. The majority of the boulders that are visible are resting on Layer 3.

In Pit 14, Slab City X, the evidence for sorting within the mass is even stronger than in Tom Swamp IV. In Plate III and its accompanying sketch, the top of the shovel handle is at the same level as a layer of rocks. The thickness of this layer varies, and the rocks are set in a very coarse matrix of sand and gravel. The rocks probably have been sorted out of the fine textured till which lies directly beneath. The latter rests on more till which is bouldery.

Other pits were made in surfaces that resemble frost forms. Pit 23 in Prospect Hill VI is in what had been interpreted as a bedrock terrace, but it exposed 10 feet of till. Pit 29 in Prospect Hill VII is in a boulder stream. Pit 28 and several borings in Tom Swamp I show that wide boulder streams are present. Low terraces scattered over the area probably were caused by the same processes that produced the boulder streams.

These studies indicate that the major portion of the surface of the Harvard Forest was modified by frost action under a periglacial climate, and that the local distribution of forest types is controlled to varying degrees by the resulting distribution and alteration of surficial materials.

Up to this point in the discussion the thin mantle of fine material which covers nearly all of the till in the Forest has been called loam. In 1935 Smith and Frazer, after careful study of the loams in eastern Massachusetts, found that this surficial layer of soil was primarily of eolian origin, and that it may have been modified by congeliturbation as it was deposited. The surficial layer of loam blankets the hills, and its character is not influenced to any marked degree by underlying deposits. The individual particles of soil are mostly of loess size 0.05 to 0.01 mm. (Russell, 1944). Similar analyses have been made recently by Colby, et al. (1952) near Amherst, Mass. Their results closely resemble those of Smith and Fraser.

The pits in the Harvard Forest appear to corroborate the findings of Smith and Frazer and to extend the known range of loess in New England. The most striking evidence in all the pits was the relative uniformity of the loam. It is hardly within the realm of possibility that the coarse till on the top of Little Prospect Hill and the tight, fine-grained till on the top of the hill in Slab City X could weather to the same type of loam. If the loam were produced *in situ*, the coarse materials that are now incorporated in it should have lost a little of their glacial character. They have not; the materials, ranging from large boulders through coarse sand, are still rounded, soled, and faceted, and many exhibit characteristic scratches. If the soils had developed by the weathering of the tills since glacial time, it would be expected that the outwash plains would also have developed a layer of fine textured loam similar to that on the uplands; but they have not done so. The outwash plains in many cases are made of finer textured materials than some of the tills exposed in the Forest.

In the one pit where the percentages of the different particle sizes were determined for different depths, the results strongly suggest some of those reported by Smith and Frazer (op. cit.). The analysis for Pit 23, Prospect Hill VI, is shown in Table I. The loam extended to a

TABLE I

PARTICLE SIZE AT DIFFERENT DEPTHS
Pit 23, Prospect Hill VI
by Percent

*Size ** *in mm.*	*In Loam* *6 to 9 in.* *Depth*	*In Till* *37 to 39 in.* *Depth*	*In Till* *78 to 81 in.* *Depth*
2.0–0.5	11.7%	27.7%	22.3%
0.5–0.25	15.7	24.1	22.7
0.25–0.1	21.5	23.4	25.0
0.1–0.05	11.7	8.6	11.0
less than 0.05	39.5	16.0	18.9

* Particles over 2 mm. in the samples are not included.

depth of 32 inches, below which there is a comparatively tight, grayish, sandy till.

Outwash plains to the east, north, and west of the Forest are possible sources for the loess (see Péwé, 1951). Another source was the surface of the frozen ground. While it was frozen, it had many of the qualities of dry earth, and consequently the finer particles would have been picked up by strong winds.

The loess appears to have been stirred by frost action. Evidences for this are, first, the fact that sand, gravel, and rocks are found throughout nearly all of it. The only source for these coarse materials is the till or congeliturbates, and it is difficult to conceive of their having got into the loess in such quantities by any process other than congeliturbation. Windthrow of trees has stirred the mixture of coarser materials and loess since the former were added by congeliturbation. Further evidence of frost action is the sorting of coarse and fine materials within the loam, where there are pockets of fines surrounded by stones. This is characteristic of a congeliturbate. The disposition of the loam on terraces, with the deepest deposits on the outer parts of the terrace flats, is suggestive of a certain amount of downslope movement while the coarser fractions were being incorporated.

The congeliturbation of the loess must have been less intense than that of the tills beneath. If the loess had been stirred at the same time as the till, and with the same intensity, there would not now be the clear-cut line that exists in many places between the loam and the till. The loess may have been stirred only for a short time, during and immediately after its deposit, when the glacial ice was disappearing farther northward and the periglacial climate was ameliorating.

A suggested sequence of events to produce the deposits as they are now seen at the Harvard Forest is as follows. The tills were laid down by the melting of the receding glacial ice. There is some evidence that these deposits represent two glacial episodes which may have been separated by an interstadial interval; or the second of which may have represented a readvance of the same ice sheet.[1] Both of these tills were heavily stirred by frost action to form terraces, boulder streams, and other surface features characteristic of this process. Finally there was deposited a layer of loess which covered most of the upland till surfaces. The loess, in turn,

[1] Upson (1938) believed that a small body of till located approximately two miles northeast of the Prospect Hill Tract is older than the other known drift of the region. This till, exposed at a depth of nine feet in a roadside bank along Massachusetts Route 2, possesses a dark brown color due largely to iron staining, is somewhat compact, and contains cemented rock fragments. The overlying material is light gray, less compact, and similar to the remainder of the till of the area.

was sufficiently stirred by frost action, along with the upper part of the congeliturbate beneath it, to bring stones and boulders into it and to alter its thickness in conformity to the terrace structure. However, it was not so intensely stirred as the original till, for it has not entirely lost its identity as a covering layer of finer textured material.

The dating of this suggested sequence in terms of the currently accepted divisions of the Wisconsin glacial period is beyond the scope of the present study. A question arises, however, as to whether the intense frost action shown by the terraces and boulder streams in this area could have been accomplished in a periglacial climate accompanying merely the recessional stages of a glacier. If not, it is necessary to postulate that the last great ice advance did not reach our area, but that the surface here underwent intensive frost action during all of this period of advance and retreat. Outwash plains from this glacier could then have produced the loess that formed part of the fine-textured matrix of the present loam soils.

SUMMARY AND SUGGESTED APPLICATIONS IN SILVICULTURAL PRACTICE

Throughout the course of this study an effort has been made to find evidence which the forester in the woods might use as a key to local forest-soil relationships — evidence that could be obtained without digging a great number of deep pits.

Glacial tills overlain by loams on the uplands in the Harvard Forest can be divided roughly into two groups: those which contain a considerable amount of fine sands and silt and are at the same time compact, and those composed of loose gravelly or coarse sandy materials.

The compact tills are capable of perching a water table during a part of the growing season in each year, and the loams above them support a rich mixture of hardwood species in which red oak, white ash, sugar maple, and black and white birch are predominant. The distribution of local concentrations among some of these species, such as oak and ash, appears to be related to micro-relief and to the relative thickness of the loam which overlies the till.

Loams that overlie coarse, loose, gravelly tills, on the other hand, support a group of hardwoods among which red, white, and black oaks predominate, and among which sugar maple and white ash are rare or non-existent. Here the till is incapable of perching a water table, and the site is more xerophytic.

Glacial outwash gravels and sands in the Forest are excessively drained;

and, for the most part, have little or no loam on them. The natural forest type for such sites appears to be a mixture of pine and hemlock.

For the areas that are underlain by a fine-textured compact till, a characteristic feature has been noticed. Where the over-all surface is slightly concave, a thin cover of loam is present; and where the surface is slightly convex, the loam is thick. The 10-foot contours in Figure 5 show the surface configuration of a part of Tom Swamp Compartment I. On this map where the contours are rounded, the loam is more than 20 inches thick and the predominant species in the canopy is red oak; where the contour lines are straight or slightly in-curving, the loam is less than 20 inches thick and the canopy is predominantly of white ash. For small areas, on-the-ground inspection (the best in any case) is the only way of determining whether the surface is concave or convex.

Boulder concentrations in areas that are underlain by tight till usually indicate a thin layer of loam. With few exceptions the individual boulders are resting on the underlying till and are protruding through the surficial loam.

In areas underlain by coarse loose till no indication of the thickness of the loam or of the character of the underlying materials is evident on the surface of the ground.

The investigations described in this paper strongly suggest that the distribution of the major forest types in the Harvard Forest is closely related to the behavior of a water table in the underlying glacial deposits. In general, these deposits are of relatively coarse or sandy materials, and contain relatively small fractions of silt and clay. Their capacity to support a water table, therefore, depends in part upon the proportion of fine sands or silt in them, and in part upon their compactness.

The coincidences described, suggesting a close relationship between mesophytic and xerophytic species complexes and the nature of the underlying glacial deposits, give rise to indicator values for these species complexes. At the Harvard Forest a preponderance of white, black and red oaks on land naturally seeded to these species gives presumptive evidence that the glacial tills underlying the loams are of relatively coarse, loose materials and are highly permeable. In contrast, a preponderance of ash, red oak, sugar maple, and the birches suggests a subsoil of compact, fine textured till.

The extent to which these findings can be applied beyond the limits of the Harvard Forest is as yet unknown. It will depend upon the extent to which the differences between glacial tills seen here can be defined elsewhere, and upon the extent to which analogous differences can be related to forest types on other till complexes. Likewise the usefulness of the relations between forest types and micro-relief will have to be determined by extensive field work. It is probable that the intensity of periglacial frost action in the glacial deposits was regionally variable, depending upon its geographic position with relation to the disappearing glacial ice, as well as upon the content and topography of the deposits themselves. Still other variables, which undoubtedly are regional in expression, are the fractions of eolian material in the loam, and the significance of the windthrow of trees upon the character of the soils and the forest communities.

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