UNITED STATES DEPARTMENT OF THE INTERIOR
Ray Lyman Wilbur, Secretary

GEOLOGICAL SURVEY
W. C. Mendenhall, Director

Bulletin 839

GEOLOGY OF THE BOSTON AREA MASSACHUSETTS

BY

LAURENCE LAFORGE

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1932

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - Price 40 cents

CONTENTS

ILLUSTRATIONS

GEOLOGY OF THE BOSTON AREA, MASSACHUSETTS

By Laurence LaForge

INTRODUCTION[1]

POSITION AND GENERAL RELATIONS

The area herein described, which lies between parallels 42° 15′ and 42° 30′ and extends westward from the shore of Massachusetts Bay to meridian 71° 15′, comprises the Boston and Boston Bay quadrangles and has a land area, including marshes and islands, of 240 square miles. It is situated in eastern Massachusetts (see fig. 1) and includes nearly all of Suffolk County and parts of Middlesex, Essex, Norfolk, and Plymouth Counties. The city of Boston occupies the south-central part of the area.

In this bulletin, for convenience, the two quadrangles will be designated by the term Boston area. This is not the same as the Boston district, which comprises the Boston Basin and the adjacent territory in which the geology is closely related, so that it forms a sort of unit having distinctive geologic characters that differ in some respects from those of the surrounding areas. The limits of the Boston district are not well defined, but it extends several miles outside the Boston area on the north, southwest, and south and includes about twice as much territory.

GENERAL FEATURES OF SOUTHEASTERN NEW ENGLAND

The Boston area is part of a geologic and geomorphic province that comprises most of New England, southeastern Quebec, and the Maritime Provinces. The portion of this province within the United States is called the New England Province. A part of the southern margin of New England, however, including the Cape Cod Peninsula and the islands off the south coast, is within the limits of another province—the Atlantic Coastal Plain. The rest of southeastern New England, east of the Connecticut Valley and south of the White Mountains, lies in two of the sections of the New England province. On the east is a seaboard belt, 15 to 50 miles wide, most of which,

[1] See appendix, p. 101.

except a few bold hills, lies less than 400 feet above sea level and in which the surface features are largely due to glacial deposition. On the west is an upland, most of which, except the valleys by which it is dissected, stands more than 500 feet above sea level and in which the form of the surface is due largely to the relief of the underlying rock surface.

The two divisions are separated by an irregular slope, hardly marked enough to be called an escarpment, which extends from Point

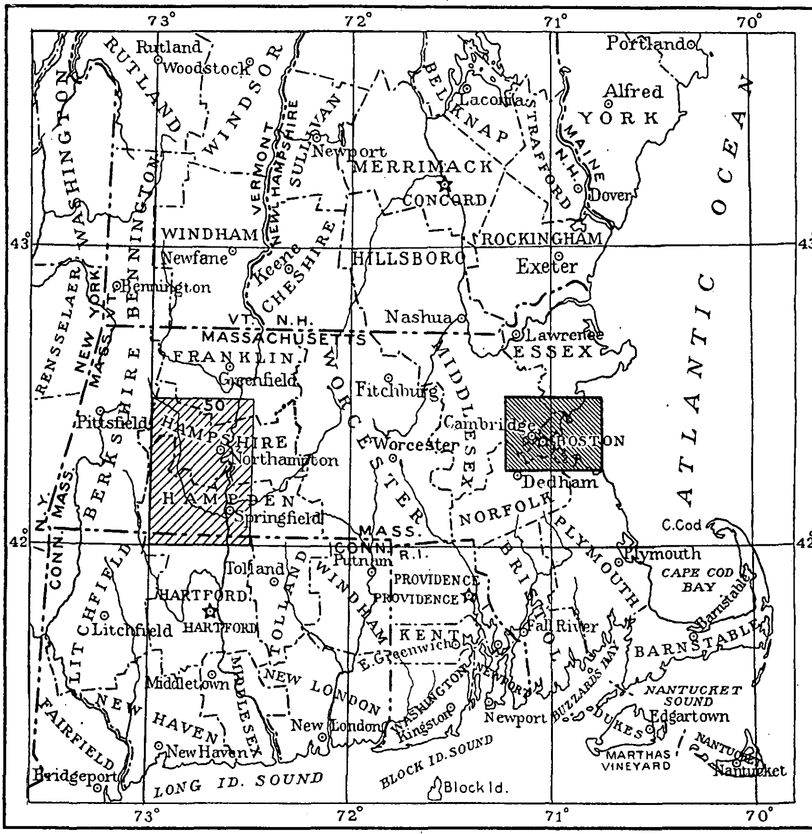


FIGURE 1.—Index map showing location of Boston area (dark shading). The area indicated by light shading is described in Folio 50 of the Geologic Atlas of the United States

Judith northward west of Narragansett Bay and past Providence, Marlboro, and Tyngsboro, across New Hampshire, and into Maine. The Boston area is situated in the seaboard belt, and its surface features are characteristic of that section.

Southeastern New England, east of the Connecticut Valley and excluding the Coastal Plain, is more or less a geologic unit. (See fig. 2.) Throughout the region as a whole the salient features of the geologic history have been much the same, the rocks are of the same general ages and sorts, and the same types of structure prevail.

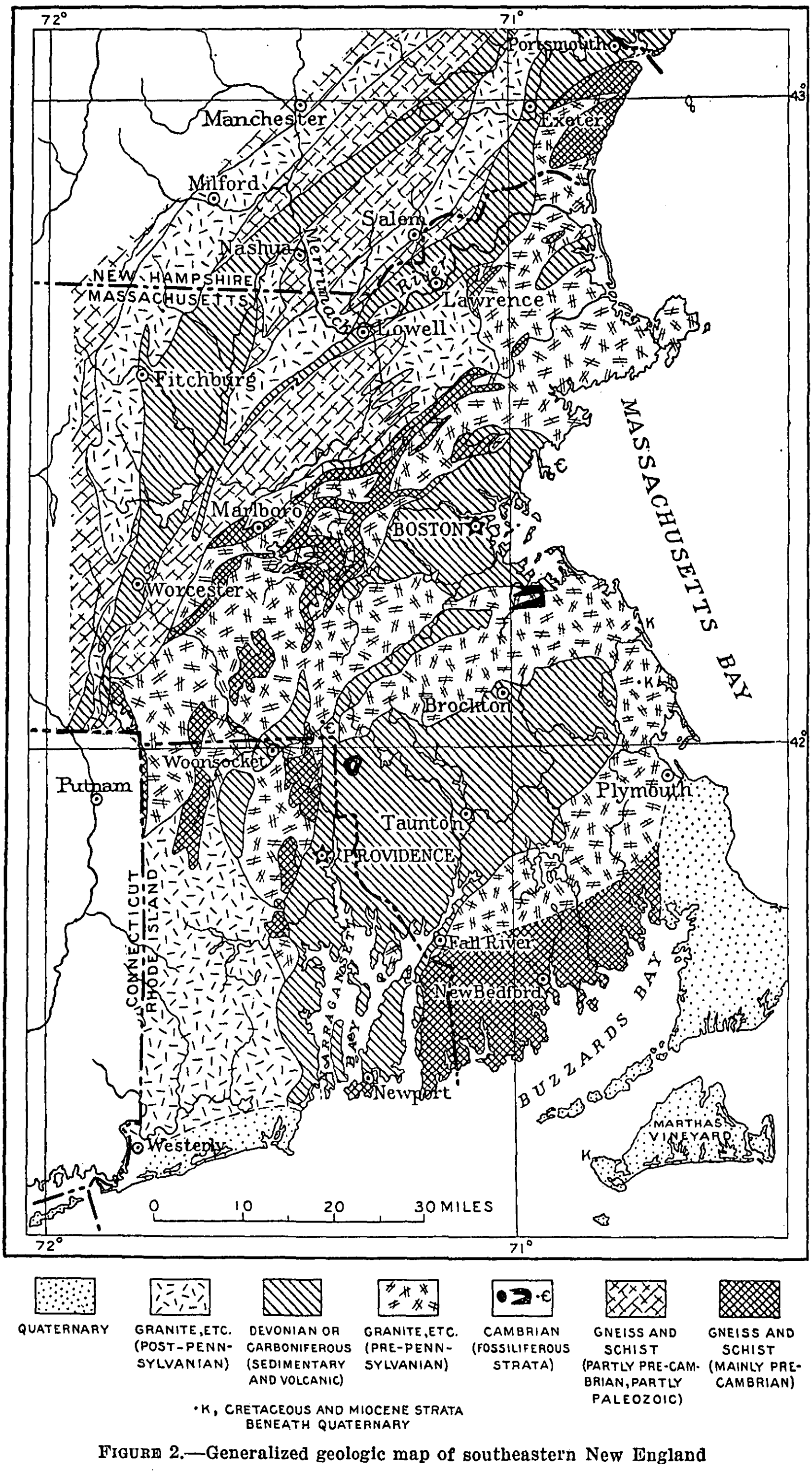


FIGURE 2.—Generalized geologic map of southeastern New England

There are, however, some differences that warrant a rough distinction between the northwestern and southeastern parts of the region, though the two are not sharply distinguished areally. A line drawn from Point Judith, R. I., to Webster, Mass., and thence northeastward past Marlboro, Bedford, and Amesbury to the sea at Portsmouth, N. H., serves fairly well as a boundary between them, although some rocks characteristic of each division are found on either side of such a line. The northwestern and larger division extends from eastern Connecticut across Massachusetts and New Hampshire into Maine; the southeastern division is confined to eastern Rhode Island and Massachusetts and a corner of New Hampshire, but a division that may be its counterpart extends from southeastern Maine into New Brunswick, and the two may be connected across the floor of the Gulf of Maine.

In general, post-Pennsylvanian igneous rocks are abundant and both sedimentary and igneous rocks of undisputed pre-Cambrian age are scarce in the northwestern division, whereas in the southeastern division post-Pennsylvanian plutonic rocks are almost unknown, but pre-Pennsylvanian plutonic rocks are abundant, as are metamorphic rocks, both sedimentary and igneous, of presumed pre-Cambrian age, and there are scattered remnants of Cambrian strata. The northwestern division was generally affected by post-Pennsylvanian regional metamorphism, but the southeastern division was little affected by such metamorphism, except in some rather small areas.

Both divisions contain basins of terrestrial Carboniferous strata. In the northwestern division the Carboniferous sedimentary rocks are dominantly fine grained, contain no true coal beds, have been much deformed and metamorphosed, and have been invaded by younger plutonic rocks but not by contemporaneous volcanic rocks. In the southeastern division the Carboniferous strata include thick beds of conglomerate and some beds of coal, are not as a rule so much deformed and metamorphosed, and have not been invaded by younger plutonic rocks but are associated in places with volcanic rocks.

The Boston area lies almost wholly in the southeastern division. About 2 square miles of its northwest corner, however, are occupied by rocks of types characteristic of the northwestern division and not found elsewhere in the Boston area.

HISTORICAL SKETCH

The geology of the Boston district attracted the attention of observers early in the nineteenth century (see pl. 3), and the district has ever since been a field of research, which has resulted in a considerable literature.[2] During the first 30 years little systematic work was done, and the literature of that period consists mainly of references to the occurrence of rocks and minerals at different localities in

[2] See Bibliography, pp. 93–100.

the area. The principal contributions of that period were made by William Maclure, Sylvain Godon, and J. F. and S. L. Dana. The fourth decade included the work of Edward Hitchcock in the first general survey of Massachusetts, which resulted in the geologic map published in 1844. The earliest papers on the glacial phenomena of the district also appeared about that time. In 1851 Louis Agassiz called attention to the fossils in the stratified rocks at East Point, Nahant, although their taxonomic character and geologic age were not established until many years later. The first determination of the age of any rocks of the district came in 1856, with the announcement by W. B. Rogers of the finding of trilobites, now regarded as of Middle Cambrian age, in the slate at Braintree. This discovery led to the belief that all the sedimentary rocks of the Boston Basin are of Cambrian age, a belief that persisted in some quarters for half a century.

In the seventies T. Sterry Hunt, a Canadian geologist, paid several visits to Boston, where he thought that he found in the geology of the district confirmation of his own theories of the origin, structural relations, and age of rocks of the sorts found therein. His visits stimulated the activities of the local geologists, especially N. S. Shaler and W. O. Crosby, and the decade was marked by a number of short papers on different aspects of Boston geology, most of them supporting Hunt's theories. This period culminated with the publication, in 1880, of Crosby's epoch-making book, "Contributions to the geology of eastern Massachusetts," which was accompanied by a large-scale map of the Boston district and a map on a smaller scale of the northeastern part of the State. Crosby's book has remained until the present time the only detailed and comprehensive treatment of the geology of the whole district, and his map is the only one so far published showing the geology in detail. The book was written while Crosby still adhered to Hunt's theories, which have since been abandoned, and while the stratified rocks of the Boston Basin were still believed to be Cambrian. Crosby later changed his stand on several points discussed in the book, much of which has now only a historical value. Other parts of it are still useful, as it contains information regarding exposures long since obliterated in the settlement of the area, and it still stands as the one monumental work on Boston geology.

The year 1880 marked not only the end of one era but the beginning of another, which may be called the golden age of Boston geology. While Crosby and Shaler still advocated views of the relations of the rocks based on Hunt's theories, those theories and their application to Boston geology were being overthrown by the work of J. S. Diller on the felsites north of the Boston Basin, by that of M. E. Wadsworth on the Quincy granite on the south, and by that of W. M. Davis and of E. R. Benton on the Brighton melaphyre in the basin. Based on modern ideas of geologic processes and structural relations, ideas still currently accepted by practically all geologists, the work of those men has stood the test of time, and the field work done since on the rocks that they studied has modified their results only in details. Professor Crosby soon accepted the greater part of the new views regarding the rocks, and his discovery, jointly with G. H. Barton, of plant fossils of Carboniferous age in the Pondville conglomerate of the Norfolk Basin, just south of and possibly adjoining the Boston Basin, gave the first impetus to the now generally accepted belief that the rocks of the Boston Basin are also Carboniferous.

From 1880 to 1900 much work was done by many men on all phases of the geology of the Boston district, and numerous papers were published. Interest in the glacial geology of the district was revived, and papers on the subject were published by Warren Upham, Shaler, Barton, Davis, Crosby, and others. The geomorphology of the region also attracted attention and was discussed to some extent by Davis and by Crosby. Among the outstanding events of this period were the announcement by A. F. Foerste in 1889 of the Lower Cambrian age of the fossils at Nahant, and the discovery by H. T. Burr in 1899 of a Lower Cambrian fauna in the slate at Mill Cove, in Weymouth, and by Burr and R. E. Burke, in the same year, of fossil tree trunks in the Roxbury conglomerate. The igneous rocks of Essex County were studied by Wadsworth, H. S. Washington, and J. H. Sears, and those of the region south of Boston by Wadsworth, Crosby, Florence Bascom, and T. G. White. The systematic geologic mapping of the Boston Basin on a large scale was begun by Crosby, who published descriptions and maps of the part of the basin in Hull, Cohasset, and Hingham. His work was extended through Weymouth and Quincy to the Blue Hills and the Neponset Valley, and he described the geology of those areas, but the projected maps of them were never issued. During this period, also, a wide difference of opinion existed regarding the structural relation of the Brighton melaphyre to the Roxbury conglomerate, whether intrusive or effusive, and J. E. Wolff, Benton, Crosby, and Burr published papers on the subject.

In 1900 the mapping of the Fells Upland was taken up by T. A. Jaggar and carried on by students working under his direction. The next year the United States Geological Survey took charge of the work, which was extended to cover the Boston and Boston Bay quadrangles, and the preparation of this report was begun, at first by Jaggar and later by the present author. The work has suffered from frequent interruptions and was wholly suspended for several years during and after the World War. It was also found needful to carry on geologic mapping or reconnaissance throughout northeastern Massachusetts and southeastern New Hampshire in order to obtain the data needed for working out some of the otherwise insoluble problems of the Boston district and to determine the age and correlation of some of the local formations. Much of the material so obtained by the author was used in the preparation of the geologic map of Massachusetts and Rhode Island, by B. K. Emerson, which was issued in 1916.

Meanwhile others were carrying on considerable work in the Boston district, notably G. R. Mansfield, on the Roxbury conglomerate; G. F. Loughlin, on the relations along the southern border of the Boston Basin; C. H. Warren, on the Quincy granite and associated igneous rocks; R. W. Sayles, on the tillite in the Roxbury conglomerate; and C. H. Clapp, on the igneous rocks of Essex County. Perhaps the most important event of the period was the determination by Sayles in 1909 and 1910 of the glacial origin of the tillite, a part of the Roxbury conglomerate. Two other events, although occurring outside the Boston area, had much to do with establishing the geologic age and sequence of some of the formations within the area. J. H. Perry had, in 1885, published the discovery, two years earlier, of a fragment of *Lepidodendron acuminatum* at the " coal mine " in Worcester and had announced the Carboniferous age of the " mica schist " (now called Worcester phyllite) at the same place, which Hitchcock had mapped as pre-Cambrian. Some geologists, however, thought that the fossil must have been transported to the locality in some manner and still maintained the pre-Cambrian age of the rocks. In 1911 David White, of the United States Geological Survey, found an undoubted Carboniferous flora in the rocks at the " mine " and confirmed Perry's opinion. This established the age of the Worcester phyllite, and of the igneous rocks intrusive into and deformed with it, as Carboniferous and aided in fixing the age of several other formations. The other important event was the discovery in 1915, by Arthur Keith at Rowley, Mass., of fossils of probable early Devonian age in the rocks of the Newbury volcanic complex. This established the age of those rocks, which had been supposed to be Carboniferous, as pre-Carboniferous, and threw doubt on the supposed Carboniferous age of the similar volcanic rocks of the Boston district.

Many other workers, not mentioned here by name, have each contributed something toward the great body of facts and conclusions whose accumulation has made possible the preparation of this report, and the author wishes to acknowledge his indebtedness to the labors of all those who have worked in the Boston field during more than a century. The photographs reproduced in this bulletin were loaned from the Gardner collection of Harvard University.

TOPOGRAPHY

FEATURES OF THE RELIEF

GENERAL CHARACTER AND DIVISIONS

Although the land surface of the two quadrangles has an area of only 240 square miles and a relief of only 380 feet it displays wide diversity in topographic form and surface character. Along the coast are rocky cliffs and headlands, long stretches of smooth, curving beach, reedy marshes and inlets, and many islands and reefs, some of sand, gravel, or boulders, others of bare, jagged rocks. Inland the low areas are partly occupied by broad alluvial plains and partly by

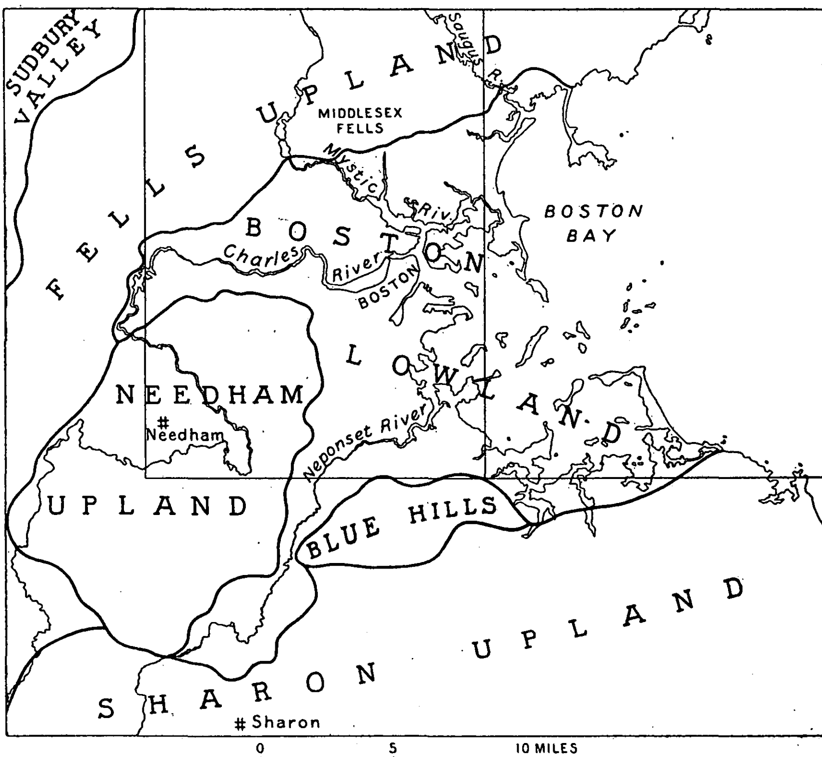


FIGURE 3.—Geomorphic subdivisions of Boston area. The Boston and Boston Bay quadrangles are indicated by the light ruling.

swamps and marshes, and the uplands comprise smoothly rounded hills and slopes of till, intricate areas having the kame and kettle topography of moraines, and rocky heights crowned by bare, wind-swept crags.

The area comprises portions of several geomorphic districts. (See fig. 3.) The central part, including much of the coast, is occupied by the Boston Lowland, northwest of which is the Fells Upland and southwest of which is the Needham Upland. Each of these districts has a rather characteristic surface form, and each extends into adjoining quadrangles. Besides these, the southern margin of the Boston quadrangle just touches some of the foothills of the Blue Hills, lying farther south, and part of the south side of the Boston Bay quadrangle lies on the low, rolling northern slope of the Sharon Upland.

The peninsulas of Winthrop and Hull and most of the islands are parts of the Boston Lowland, but because of their special features the coast line and the islands will be described under a separate heading.

BOSTON LOWLAND

The central part of the area is occupied by the Boston Lowland, which extends from Lynn, on the North Shore, to Weymouth, on the South Shore, and includes the islands in the harbor as well as most of Hull. It extends westward up the valley of the Charles River into the Framingham quadrangle and southwestward up the valley of the Neponset River into the Dedham quadrangle. The greater part of the lowland along the coast and in the main valleys is less than 50 feet above sea level and once consisted mainly of marshes and alluvial plains. The remainder, which is 50 to 140 feet above sea level, consists of rolling country, partly rocky but mainly glacial drift.

Among the most characteristic features of the lowland are the drumlins—smooth lenticular hills of till—which number more than 100, including those on the islands. The summits of some of them stand 160 feet above sea level, and in several parts of the lowland they are the dominating features of the landscape.

FELLS UPLAND

The northwestern part of the area is occupied by the Fells Upland, named from the Middlesex Fells, an area of characteristic upland topography. It is bounded on the southeast by a bold escarpment extending from Waltham to the coast in Swampscott. This rampart, from 100 to 300 feet high and so steep that in places its base is a cliff, is the most conspicuous feature of the landscape on the north side of the Boston Lowland, and its higher summits afford fine views of the lowland and the harbor. It is broken by several deep reentrants, two of which—the valleys of the Saugus and Mystic Rivers—extend through the upland and divide it into three sections. The eastern and middle sections, though mainly less than 250 feet above sea level, are rather rough and contain a greater proportion of bare rock surface than any other parts of the quadrangles. The western section is partly rough and rocky and partly smooth and drift covered and contains several high-lying broad swampy tracts. A number of hills stand more than 300 feet above sea level, and one in the eastern corner of the town of Lexington reaches 380 feet, the highest point in the two quadrangles.

NEEDHAM UPLAND

The southwestern fourth of the Boston quadrangle is occupied by the Needham Upland, named from the town of Needham, which is situated on it. It is lower than the Fells Upland and not so well defined, and a greater proportion of its area is occupied by plains of alluvium and of glacial outwash. Although its surface has considerable relief, a great part of the relief is due to the drumlins, of which there are about 40. Their size and height above their bases are about equal to those of the drumlins of the lowlands, but they stand on a rock platform considerably above the lowland, and the summits of several reach 300 feet or more above sea level.

COAST LINE AND ISLANDS

The coast line is irregular and has a length within the two quadrangles, excluding wharves, causeways, inlets, and islands, of more than 93 miles. Several oddly shaped peninsulas project from both the North Shore and the South Shore, which are also broken by a dozen estuaries and small bays. Much of the North Shore consists of beaches, two of which—Revere Beach and Lynn Beach—are each several miles long. The South Shore is more irregular and has but one notable beach—Nantasket Beach, which is more than 3 miles long. The peninsulas of Winthrop and Hull, with the chain of islands between their opposing ends, divide Boston Bay from Boston Harbor, a commodious and almost landlocked haven. These two peninsulas consist mainly of drumlins tied to one another and to the mainland by connecting beaches and marshes. The peninsulas of Marblehead Neck and Nahant, on the North Shore, and of Squantum and Houghs Neck, in the harbor, consist mainly of rocky knolls similarly joined to one another and to the mainland.

About the head of Boston Harbor are clustered the peninsulas of Boston, South Boston, and Charlestown, all originally joined to the mainland only by low necks that were submerged at the highest tides, but all now greatly changed artificially from their original form and extent, as have been also the shore lines of East Boston, Cambridge, and Somerville. Possibly nowhere else in the United States has the original extent and outline of a tidal harbor been so greatly modified artificially, chiefly through the filling in of tidal flats.

More than 100 islands, ranging in size from those many acres in area and 100 feet in height down to half-tide rocks and bars, dot Boston Harbor and Bay. Most of those in the bay are nearly bare rocks, but a few consist partly of glacial drift. Most of those in the harbor are glacial and consist of drumlins or groups of drumlins. Some of them have cliffs at places on their shores, where they have been partly cut away by the waves. Cliffs have been cut also on the headlands, formed by drumlins, on the outer or bay side of the peninsulas of Winthrop and Hull. Reefs of boulders, revealed at low tide, extend outward beneath the sea in front of the cliffs and show the original extent of the drumlins. (See fig. 5.)

DRAINAGE FEATURES

STREAMS

All the area is drained by streams flowing to Boston Bay except 11 square miles of the northwestern part, which is drained by tributaries of the Shawsheen River, which flows to the Merrimack, and the extreme northeast corner, which is drained to Salem Harbor. The principal streams are the Charles, Mystic, Neponset, and Saugus Rivers, the first three of which flow into Boston Harbor and the fourth into Lynn Harbor. All four rise outside the area and flow across it in devious courses. The Charles, which is notably winding, enters the southwest corner of the area and flows east and south to Dedham, where it is less than 3 miles from the Neponset. Thence it turns northwestward and leaves the area below Newton Upper Falls, to reenter at Waltham, whence it flows eastward to the harbor. At Dedham it is tapped by a power canal that leads to Mother Brook and the Neponset, and thus about one-third the flow of the Charles above Dedham reaches the harbor through the Neponset River.

All the larger streams have estuaries several miles long. Those of the Charles and Mystic were formerly bays of considerable size which have been greatly reduced by the filling in of the flats about their margins. The upper part of the former estuary of the Charles is no longer tidal, a dam at East Cambridge having converted it into a fresh-water basin.

PONDS AND SWAMPS

As the area has been heavily glaciated, much of it, at the time of its settlement by white men, was poorly drained, and ponds and swamps abounded in the hollows and on the plains. Settlement has changed these conditions greatly, and many swamps have been reclaimed, but the number of ponds has probably increased, as, although some have been drained or filled, a number of artificial ones have been made. Some of the natural ponds have been enlarged by damming at their outlets, and the greatly reduced remnant of the

111895—32——2

former Back Bay, in the estuary of the Charles, is now an inclosed basin. Large swampy areas still remain in the outlying districts, especially along the Charles below Dedham.

COASTAL MARSHES

A considerable part of the coast is bordered by extensive tidal marshes. About the head of Boston Harbor and along the shores of the estuaries entering it most of the marshes have been reclaimed, and the shore lines have been pushed out well beyond their former positions. In other areas extensive tracts of salt marsh still remain, especially the great Saugus Marsh, covering more than 1,800 acres between Revere and Lynn.

Where the marshes border the open water of the bay they are nearly everywhere protected by barrier beaches, and in such places the shore line is well defined. In some places along the estuaries and about the shores of Quincy and Hingham Bays, however, there is no beach separating the marsh from the open water, and the shore is rather poorly defined.

CHARACTERISTICS OF THE DRAINAGE

Certain characteristics of the drainage of the area have had an important influence on its settlement and its industrial and commercial development. First is the fact that the coast is a "drowned" coast, hence all the principal streams reaching the sea have estuaries into which the tide penetrates for several miles and which are navigable nearly to the head of tide. Second is the radial arrangement of the streams entering the head of Boston Harbor and the accompanying radial arrangement of the peninsulas between the estuaries. This arrangement of land and navigable water and the resultant spokelike routes of the main highways and railroads leading into Boston and the growth of settlement outward along the "spokes" have not only given Boston its name "The Hub" but have been factors of prime importance in the development of the Boston district as a commercial center and port. A third characteristic, common to most heavily glaciated regions, is that the drainage as a whole is unsystematic, many of the streams showing a lack of adjustment to the topography through which they have found their way and many being still obstructed by falls or rapids, which are a source of power. A fourth characteristic, of less commercial importance but of some scientific interest, is the asymmetric character of the drainage pattern. With hardly an exception the tributaries of the main streams from the north and northwest are larger and longer than those from the south and southeast, and the divides between the main drainage basins lie much nearer to the main streams north of them.

CULTURAL FEATURES

SETTLEMENT

All but the extreme southern corner of the city of Boston, in the former town of Hyde Park, is situated within the area here described. Besides Boston, 7 cities and 9 towns are wholly and 7 other cities and 17 other towns partly included in the area. An estimate based on the census of 1930 gives the population of the two quadrangles in that year as approximately 1,740,000. The average density of population of the whole area is about 7,250 per square mile, but by no means all the area is inhabited. The ponds, swamps, marshes, beaches, etc., cover at least 24 square miles, and the average density of population of the remainder is about 8,055 per square mile.

The greatest density of population is on the low-lying and fairly level land about the head of Boston Harbor and alongside the main estuaries. From Boston as a center the more densely settled areas extend outward along the lines of railroad that center in the " hub," especially along the main line of the Boston & Albany Railroad, where the belt of dense population extends westward into the Framingham quadrangle.

OCCUPATIONS

Not only is the Boston metropolitan district one of the principal centers of population in the United States, but it is also one of the principal manufacturing and commercial centers and one of the chief ports, both for foreign and for coastwise trade. It is likewise an important educational center, being the seat of two large universities and a number of colleges and technical institutions. In spite of being so largely occupied by urban and suburban communities, the quadrangles, especially along the shore, include several famous and popular summer resorts, which are patronized not only by people from the Boston area but by visitors from other parts of the country.

COMMUNICATIONS

A dozen lines of steam railroads, comprised in three systems, connect Boston with all parts of New England. Much of eastern Massachusetts is covered with a network of electric railways and motorbus lines, many of which radiate from Boston, and a system of fine State roads also binds together all parts of the State. From the port of Boston a number of steamship lines run to other points on the coast and to foreign ports, and there is still a considerable trade carried on by sailing vessels, especially those engaged in the fishing industry.

GEOLOGY

AREAL GEOLOGY AND STRATIGRAPHY

GENERAL CHARACTER, AGE, AND GROUPING OF ROCKS

The rocks of the Boston area are of many kinds: some of them are igneous and others sedimentary; some of them are greatly metamorphosed and others not at all; some of them are indurated and others incoherent. They range in age from pre-Cambrian to Recent but include no known rocks of Jurassic, Cretaceous, or Tertiary age. They are comprised in several groups, formed in epochs that were separated, for the most part, by considerable intervals of geologic time, and the several groups of stratified rocks are not found superposed in order of age. (See pls. 4 and 5.)

The oldest rocks are metamorphosed, are partly of igneous and partly of sedimentary origin, and are regarded as probably of pre-Cambrian age. There are some small masses of Cambrian strata, the only hard rocks of the district whose age is determined with certainty. The oldest well-defined group is a complex of plutonic igneous rocks of several varieties which is believed to be of early Paleozoic age, surely pre-Devonian. The next in order of age is another group of igneous rocks, not so diverse in composition as the group just mentioned but including both plutonic rocks and also effusive rocks and volcanic sediments. This group is of either Devonian or Carboniferous age but is believed to be mainly Devonian. It is partly overlain by and may be in part interstratified with the sedimentary rocks of the Boston Bay group, which is of considerable thickness but contains almost no fossils and which is also of either Devonian or Carboniferous age but is regarded as probably Carboniferous. The next younger group, consisting of plutonic intrusive rocks of late Carboniferous age, is only sparingly represented in the area. The youngest group of hard rocks is a set of diabase dikes that cut nearly all the other hard rocks of the area and are regarded as of Triassic age.

Spread indiscriminately over all the older formations and occupying the surface of a great part of the area is a blanket of incoherent glacial deposits and sediments of glacial origin. Finally, the youngest group comprises marine and alluvial deposits begun in Recent time and still in process of formation.

The central part of the area, comprising most of the Boston Lowland and part of the Needham Upland, includes the greater part of the Boston Basin, a basin of generally synclinal structure occupied by the stratified rocks of the Boston Bay group. A few small masses of Cambrian strata are exposed about the margins of the basin. The rocks of the two great igneous complexes occupy much of the Fells and Needham Uplands. The pre-Cambrian rocks appear to be confined to the Fells Upland, and the late Carboniferous igneous rocks are exposed only in the extreme northwest corner of the area.

PRE-CAMBRIAN ROCKS

GENERAL CHARACTER

Much of the Fells Upland is occupied by a complex of metamorphic rocks, partly of sedimentary and partly of igneous origin, which are among the most interesting rocks of the region. They are widely distributed in eastern Massachusetts, northern Rhode Island, and southeastern New Hampshire, as a rule in narrow belts and lenses ranging in width from a few feet to 3 miles and in length from a few yards to many miles. They are also found as inclusions of all sizes in the igneous rocks of the early Paleozoic eruptive complex.

The age of these rocks has not been finally determined. At one time those of sedimentary origin were rather generally regarded and described as Cambrian. For reasons given in the description of the Cambrian rocks it now seems best to treat these rocks as a separate group, and they are here classed as pre-Cambrian. In general character and degree of metamorphism the more schistose varieties agree fairly well with rocks elsewhere classed as Algonkian, but those varieties herein grouped under the formation name Waltham gneiss in several respects resemble more closely formations elsewhere classed as Archean.

There is some uncertainty as to whether the schistose rocks should be divided into two or three formations. The evidence that there are three is increasing, and that number of formations is here recognized. The oldest of the three, named by Emerson the Westboro quartzite, consists chiefly of quartzite. It is overlain by a formation, named by Emerson the Marlboro formation, comprising a variety of schists, some of which appear to be of volcanic origin. This seems to be overlain by a third formation, herein named the Woburn formation, composed chiefly of silicic volcanic rocks but containing some quartzite, by reason of which it has often been confused with the Westboro. These three formations are so intricately folded together and so extensively invaded by later intrusive rocks that it is wellnigh impossible to make out their relations in any one locality, but a general survey of their occurrence in eastern Massachusetts seems to warrant the establishment of the sequence herein adopted.

In the Boston area the larger lenses and belts of pre-Cambrian rocks have a general northeasterly strike and a vertical or steep northwesterly dip. There are many local variations of both strike and dip, and the longer strips of the formation are rather sinuous. It is noteworthy that even many of the comparatively small masses of the pre-Cambrian rocks, which are surrounded by and apparently are very large inclusions in younger igneous rocks, have the same general attitude as the larger belts and lenses. It is believed that this attitude was not acquired until the post-Pennsylvanian deformation of the region, long after the intrusion of the igneous rocks.

WALTHAM GNEISS

The Waltham gneiss is here named from the city of Waltham, in the northeastern part of which it is well displayed. It is a complex of gneisses of several sorts and is probably mainly igneous.

The formation occupies much of northern Waltham, southeastern Lexington and Burlington, and northwestern Woburn. It extends northeastward into the Lawrence quadrangle and southwestward into the Framingham and Franklin quadrangles. It is fairly resistant and forms rather rough hills, and its outcrops are abundant.

The formation comprises several varieties of biotite gneiss and hornblende gneiss, some aplitic gneiss, and a few porphyroid gneisses containing conspicuous crystals of feldspar in a matrix that is largely biotite. In some of the coarser-grained biotite gneisses the layering is irregular, and these varieties appear to be of igneous origin and were probably granites and diorites that have been strongly sheared. The aplitic varieties appear to be intrusive into the rest of the complex and may be part of a much younger intrusive group. Some of the porphyroid gneisses have the appearance of volcanic rocks, as if they were originally amygdaloidal lavas, but they have been so much altered as to make this inference uncertain. Besides these varieties there are fine-grained biotite gneisses, more siliceous than the other sorts, in which the layering is so regular and so much like stratification as to raise the question whether they are not recrystallized micaceous sandstones.

Although there are local irregularities the foliation of the gneiss has a general northeasterly strike and stands vertically or dips steeply northwestward. The outcrops are scattered so at random that no one variety can be traced more than a short distance along the strike, and the internal structure of the formation is unknown; hence no estimate of its thickness can be made. Its structural relations to other formations are also uncertain, except that it has been invaded in places by some of the rocks of the early Paleozoic igneous complex. On the one hand it seems to be intricately infolded with the other pre-Cambrian rocks, and conglomerates in those rocks contain pebbles of gneiss not unlike varieties of the Waltham gneiss; but on the other hand some of the pre-Cambrian schists have been invaded by gneissic rocks hardly to be distinguished from the Waltham gneiss.

The Waltham gneiss seems to have been contorted since it acquired its gneissic structure; hence, unless that structure is original, it must have been through two periods of marked deformation.

The age of the formation is indeterminate, but it is regarded as probably pre-Cambrian because it seems to have been affected by an earlier deformation and metamorphism of which the younger rocks of the area show no signs. Its general lithologic character and the degree of its metamorphism are much the same as those of known Archean rocks in the northeastern United States, and it may, quite possibly, be of Archean age.

WESTBORO QUARTZITE

The Westboro quartzite, named by Emerson from the town of Westboro, consists almost wholly of quartzite.

In the Boston area the formation occurs in several small lenses and narrow strips, chiefly in Waltham, Belmont, Arlington, Melrose, and Saugus. Probably the best as well as the most extensive development is that in Melrose and Saugus, where it crops out in many places. It is not a particularly resistant formation, and much of the area occupied by it is low ground, although it is found here and there on hills.

The formation consists almost wholly of white, light-yellow, cream-colored, or light-gray quartzite, in some places containing feldspathic material, in others considerable muscovite, and in still others some biotite or other dark mineral. It is as a rule thin bedded and differs slightly in composition and weathering from bed to bed, so that many outcrops have fluted surfaces parallel to the bedding. Its thickness is unknown but may be 500 feet or more. The structural relations and age of the formation are discussed in the general section on the pre-Cambrian rocks.

MARLBORO FORMATION

The Marlboro formation was named by Emerson from the town of Marlboro, where it is well displayed. It is a complex of gray, green, and brown schists of several sorts.

In the Boston area the formation occurs mainly in two interrupted belts, one extending across the northwest corner of the Boston quadrangle in Lexington and Burlington, the other extending in a sinuous course across Waltham, Belmont, Arlington, Winchester, and Stoneham. There are also a few small masses in Lynn and Marblehead. It is more resistant than the Westboro quartzite and generally occupies the slopes of hills.

A considerable part of the formation consists of dark-green, dark-gray, or black schist and slate, in some places almost a hornstone, composed chiefly of biotite, chlorite, and epidote, with some quartz and hornblende. From its association with rocks that appear to be sheared and altered basaltic lavas this rock is believed to be largely of volcanic origin and to have consisted originally in the main of fine basaltic tuff. That it is not wholly volcanic and is in part perhaps a marine sediment is attested by the not uncommon occurrence in it of thin beds of limestone, quartzite, and pebbly sandstone or even conglomerate. South of Arlington Heights the formation contains extensive bodies of volcanic rocks of several varieties, and the much altered basaltic masses in Woburn, Stoneham, and Melrose may be associated with this formation.

The thickness of the formation has not been determined, as the top has nowhere been definitely located, but, to judge from the width of outcrop, it may be as much as 3,000 feet. The age and structural relations of the formation are discussed in the general treatment of the pre-Cambrian rocks.

WOBURN FORMATION

The Woburn formation is named from the city of Woburn, in the southwestern part of which it is well displayed. It is a complex of silicic igneous rocks and interbedded siliceous sediments.

The formation occurs in the Boston area mainly in the ravine known as Shaker Glen, in southwestern Woburn. Smaller masses of it are found in central and eastern Woburn and in Waltham, Arlington, and Burlington. It is more resistant than the Westboro quartzite and generally occupies higher and rougher ground.

The formation is composed largely of felsic igneous rocks, probably mainly volcanic. Rhyolite and dacite are the predominating types, although there are some sparsely porphyritic varieties that are probably andesitic. Most of the igneous rocks are highly siliceous and well laminated and have frequently been taken for quartzite and so mapped. On Emerson's geologic map of Massachusetts and Rhode Island the Woburn is included in either the Westboro quartzite or the Marlboro formation, but the suspicion had already arisen that it might be a separate formation, and a statement to that effect was inserted in the text of the bulletin containing the map.

The thickness of the formation is uncertain, as it is so extensively involved with other rocks. As it seems to be largely volcanic, its thickness probably differs from place to place, but the average thickness is probably not far from 500 feet. The age and structural relations of the formation are discussed in the general treatment of the pre-Cambrian rocks.

CAMBRIAN SYSTEM

GENERAL FEATURES

The Cambrian system is represented in this area by several small masses of somewhat metamorphosed strata. Cambrian fossils have been found at only one locality within the two quadrangles, but they have been found in several localities just south of the area.

Both the Lower and Middle Cambrian series are represented in the fossiliferous beds, and they are the only pre-Quaternary rocks in the Boston district whose age can be determined with certainty and on internal evidence. They are, however, of little use in fixing the age of neighboring formations, because they occur in such small and isolated masses, and all that can be ascertained with regard to their external structural relations is that they have been invaded by igneous rocks which are known from other evidence to be much younger.

Lower Cambrian fossils have also been found at several localities in the Narragansett Basin and in boulders on the beach at Cohasset, but no Middle Cambrian fossils have been found elsewhere in eastern Massachusetts. There are pebbles of quartzite containing Upper Cambrian fossils in a conglomerate of Carboniferous age in the Narragansett Basin, but the parent ledges from which they were derived have not been discovered. No other Cambrian rocks are known in southern New England east of the Connecticut River. (See appendix.)

Much of the quartzite and schist now regarded as pre-Cambrian has in the past been included in the Cambrian; hence the statements in geologic literature that Cambrian strata have been found widely distributed over eastern Massachusetts. Sears mapped as Cambrian nearly all the metamorphic sedimentary rocks of Essex County and reported the discovery of fossils at several localities. Except at Nahant his reported discoveries have not been confirmed by later geologists, and some of the rocks stated by him to contain fragments of Cambrian fossils are now known to be much younger, Devonian fossils having been found at one place. Furthermore, the rocks formerly supposed to be Cambrian differ lithologically from the fossiliferous Cambrian rocks, and most of them are much more metamorphosed. It seems best, therefore, to exclude them and confine the Cambrian to the fossiliferous rocks and to other beds of the same type in their immediate vicinity.

The scattered remnants of Cambrian strata indicate that Cambrian rocks formerly covered much of southeastern Massachusetts. All the certainly Cambrian rocks are now found immediately at the borders of the Boston and Narragansett Basins. Presumably they owe their preservation to having been covered by the rocks of those basins until a comparatively late geologic time, whereas other Cambrian beds, not so covered, were long ago removed in the profound degradation that southeastern New England has suffered since the Paleozoic era.

LOWER CAMBRIAN SERIES

WEYMOUTH FORMATION

The Weymouth formation was named by the author from the town of Weymouth, where the formation is most abundantly fossiliferous. It consists mainly of siliceous slate and slaty quartzite.

The type locality of the formation is at Mill Cove, in Weymouth, in the Abington quadrangle. In the Boston area it is found only at Nahant, where it is exposed in the cliff southwest of East Point. Several small masses of the formation are exposed at low tide on the west side of Nahant, but identifiable fossils have been found only in the cliff at East Point. (See pl. 6, *A*.)

At Nahant the formation is chiefly gray slaty quartzite and cherty greenish slate, with some thin beds of white limestone. It has been baked by intrusive igneous rocks but otherwise has not been much metamorphosed.

In the cliff at East Point possibly 100 feet of beds are exposed above low-tide level, but the formation evidently extends below that level, and its whole thickness can not be determined. The exposures at Weymouth indicate that the thickness must be at least several hundred feet.

At Nahant the formation is in contact only with intrusive igneous rocks. At Weymouth it is probably overlain by Middle Cambrian beds, but the floor on which it was deposited is nowhere exposed.

About 30 species of fossils have been identified from the formation, chiefly from the Weymouth locality. They include brachiopods, gastropods, pteropods, and crustaceans; at Nahant the pteropods predominate. The paleontology of the formation has been fully described by Grabau, who gives lists of fossils.

The fossils belong to the *Olenellus* fauna and fix the age of the formation as Lower Cambrian. It is nearly equivalent to the Hoppin slate of the Attleboro district, in the Narragansett Basin, and to the Lower Cambrian formations of Western New England.

MIDDLE CAMBRIAN SERIES

BRAINTREE SLATE

The Braintree slate was named from the town of Braintree, in the Dedham and Abington quadrangles, where the formation is fossiliferous. It is typically a rather massive dark-gray slate.

In the Boston area the formation occurs only in small masses along the border of or included in the Quincy granite in Quincy and Milton, in the southeast corner of the Boston quadrangle. Outside the area it is found in the northwest corner of the Abington quadrangle, in Quincy, Braintree, and Weymouth, where it has yielded fossils in several places. (See pl. 7.) A small area of similar rocks lies at the northern base of the Blue Hills, in the Dedham quadrangle. No fossils have been found at this locality, but the rocks are believed to be part of the Braintree slate. No fossils have been found in the formation in the Boston area, but it is easily identified lithologically, and the outcrops are nearly continuous with those of the type area at Hayward Creek. The formation is not known except along the southern margin of the Boston Basin.

The formation consists of noncalcareous green to dark-gray or black, rather massive slate. In the Boston quadrangle it has been altered by the contact of the intrusive Quincy granite, with induration and the development of considerable mica and garnet and some tourmaline in almost microscopic crystals.

The thickness of the formation is unknown but is probably at least 1,000 feet. In Weymouth it probably overlies the Weymouth formation, but the contact is nowhere exposed. It has been intruded by the Dedham granodiorite and the Quincy granite, and it is bordered on the north by the Roxbury conglomerate, from which it is separated by a fault.

The formation has yielded seven species of fossils, mainly trilobites and pteropods. The chief fossil locality was the former Hayward Creek quarry in the Abington quadrangle, a classic locality of New England geology, where fine specimens of *Paradoxides harlani* were obtained. The fauna is a characteristic *Paradoxides* fauna and fixes the age of the formation as Middle Cambrian, but there are no other formations in eastern New England with which it can be correlated.

EARLY PALEOZOIC IGNEOUS ROCKS

GENERAL CHARACTER

Igneous rocks believed to be of early Paleozoic age occupy about half the territory extending from Buzzards Bay northward to Hampton, N. H., and from the coast westward to Marlboro and Grafton. They also form most of the floor on which the younger sedimentary and volcanic rocks were deposited. In the Boston area they occupy much of the Fells and Needham Uplands and of the South Shore east of Hingham Harbor, and they must underlie most of the Boston Basin, beneath the younger rocks. They were exposed by erosion and deeply weathered and disintegrated before the eruption of the volcanic rocks here assigned to the Devonian or Carboniferous, and they must have formed the greater part of the surface upon which those rocks were deposited.

The rocks of this group belong to several types, ranging from aplite and pegmatite to gabbro and camptonite, but all have certain mineral and chemical characters in common. These are, briefly, as follows: The dominant feldspars, commonly yellowish or pinkish, are microcline and andesine, and orthoclase is scarce; quartz, where present, is generally sea-green and is more resistant to weathering than the other minerals; titanite is an almost universal though not abundant accessory mineral; and in the granites and syenites the dark minerals have been very largely altered to chlorite and limonite. Chemically the rocks tend to be rich in calcium, iron, and magnesium, although the Dedham granodiorite, one of the types richer in silica and alumina, probably equals or exceeds in bulk all the others combined.

The rocks of the group also have a general likeness in textural and structural characters, in their slight amount of regional metamorphism and their considerable chemical alteration, and in their relations to the neighboring rocks. They are also all younger than the pre-Cambrian rocks and older than the Devonian (?) rocks. The less silicic types have been everywhere invaded by the more silicic types, and their mutual contact relations show a progression in age from the least silicic, which are the oldest, to the most silicic, which are the youngest. Their eruption must necessarily have lasted for a considerable time. Nevertheless there is also complete intergradation between types of related composition, and in some places two contrasted types appear to have solidified side by side and simultaneously. There seems, therefore, to be ample justification for including all the rocks in a single group of the same general geologic age.

The age of the group has not been determined further than that it is probably early Paleozoic. The Dedham granodiorite is almost surely younger than the Cambrian rocks of the region, and the gabbro or norite of Nahant, which is here included in the group, is certainly post-Cambrian. The rocks of the group are also older than the Devonian (?) volcanic rocks—probably considerably older, as they had been deeply eroded and weathered before the eruption of the volcanic rocks. The convergence of different lines of evidence seems, therefore, to fix the probable age of the group as Ordovician or possibly early Silurian.

The rocks of this group have invaded the pre-Cambrian rocks and include numerous masses of them, especially of the schistose varieties. They have been in turn invaded by the Devonian or Carboniferous igneous rocks, which contain included masses of them, and they have furnished much of the material in the conglomerates of the Boston Bay group. They were considerably folded and faulted, together with nearly all the other rocks of the region, at the end of Carboniferous time, but they were little metamorphosed.

Most of the sorts of rock constituting the group occur in the Boston area, but they are so intricately mixed, by both intrusion and intergradation, that it is impossible to map them separately except on a very large scale. For convenience in mapping and description the numerous types are here combined into the three general subgroups adopted by Emerson, which comprise respectively the gabbroic and dioritic, the tonalitic, and the granitic varieties. No sharp lines can be drawn on the ground or in the laboratory between the rocks of these subgroups, and the inclusion of a mass of rock in one or another of them is often a matter of personal choice. Hence the three formations shown on the map—the Salem gabbro-diorite, Newburyport quartz diorite, and Dedham granodiorite—are not lithologic units, like most formations, but cartographic units adopted mainly for convenience. Furthermore, because of the intricate mixing of the different sorts, none of the three as mapped is made up wholly of types characteristic of that formation, but each includes many small areas of rocks of types characteristic of the other formations.

SALEM GABBRO-DIORITE

Under the formation name Salem gabbro-diorite are included the gabbros, diabases, amphibolites, camptonites, norites, and diorites belonging in the group—types characterized by the scarcity of quartz and the dominance of ferromagnesian minerals over feldspars. The formation as mapped includes small masses of rocks of the other two formations of the group, and small masses of this formation are mapped with the other two formations.

The best development of the formation is in the Salem quadrangle, outside the Boston area. Within the area it occupies most of Swampscott, Marblehead, and Salem. There are other small areas in the northwestern part of the Boston quadrangle and in Dedham, Westwood, and Cohasset. The gabbro or norite of Nahant is here included in the formation, though some authors have assigned it otherwise. In very few areas occupied by the formation is it the only one to be found there, as in almost every outcrop the rocks that constitute the formation have been invaded by tonalite, granite, or aplite. The norite of Nahant is an exception to this rule, the only rocks which invade it being dikes, chiefly diabasic, belonging in much younger igneous groups.

The formation as mapped includes at least eight varieties of rocks, some of which, however, are of only minor importance. The most abundant and widely distributed type, which gives the name to the formation, is typically developed in Salem. It is a medium-grained dark-gray granular rock, ranging to light gray with increase of feldspar, and it has a rather wide range in composition, grain, and color in different localities. It consists essentially of andesine, labradorite, quartz, pyroxene, hornblende, and biotite, with accessory apatite, magnetite, pyrite, and ilmenite or titanite. In a few places it is porphyritic, containing large phenocrysts of microcline, and in a few places it is foliated or gneissic. It grades on the one hand into quartz diorite and on the other into hornblende diorite.

Another widely distributed type, especially abundant in Waltham, is a fine-grained gabbro which has the composition, color, texture, and weathering of diabase but which forms small rounded stocks and irregular masses of all sizes and shapes, like ordinary plutonic rocks, instead of dikes, like ordinary diabase.

A third common type, found mainly in Marblehead and Woburn, is a dense, fine-grained, almost aphanitic dark-gray to black rock composed essentially of labradorite and hornblende, with accessory pyrite, magnetite, ilmenite or titanite, and not uncommonly augite. It grades into amphibolite on the one hand and into camptonite on the other.

A fourth type, found only sparingly in the Boston area, is a medium-grained to fine-grained felsitic-looking rock of olive-brown or tan-brown color, composed essentially of andesine and labradorite, with subordinate hornblende, pyroxene, and biotite, the dark minerals having been largely altered to chlorite. This type, on account of its dominant feldspar, seems to be an intermediate variety between a diorite and an anorthosite.

The rock which forms nearly all of Nahant, Little Nahant, and Egg Rock is herein assigned to this formation, although some geologists have put it elsewhere. It has been called diabase, hypersthene diabase, norite, and gabbro by different authors, who have also stated its composition differently. It differs considerably from place to place in texture and color and probably to some extent in composition, but it is typically a dark-gray, coarsely granular rock composed essentially of labradorite, augite, and titaniferous magnetite, with or without hypersthene. It is certainly post-Cambrian and probably pre-Carboniferous, but because of its isolation and lack of contacts with other formations its age has not been more closely determined. It is herein assigned to the Salem gabbro-diorite because of its general magmatic character and because it is cut by some dikes that appear to belong to the Lynn volcanic complex.

The different types of the Salem gabbro-diorite grade into one another in the field, so that it is the exception rather than the rule to find two types separated by a sharp contact. They also grade into the different types of the Newburyport quartz diorite, although in places dikes of quartz diorite cut the gabbro-diorite. Nearly every outcrop of the formation is cut by dikes of the granite and aplite of the Dedham granodiorite. The gabbro-diorite of considerable areas, especially in Woburn, Arlington, and Swampscott, is really a plutonic breccia on a huge scale, grading from diorite with scattered granite dikes to granite with scattered diorite inclusions, and no sharp formation boundary can be drawn anywhere in such areas. (See pl. 8.) Again, at some localities in Winchester, Arlington, and Lexington, granite and diorite are intricately mixed, some of the contacts between the two phases being sharp and others being completely gradational, all in the same outcrop. In such places it seems as if the magma must already have separated into two partly immiscible phases that were intruded together in a complex fashion and solidified simultaneously and side by side, as no theory of magmatic differentiation in place seems competent to explain the phenomena displayed.

NEWBURYPORT QUARTZ DIORITE

The formation named by Emerson the Newburyport quartz diorite comprises those rocks of the early Paleozoic igneous complex which are composed of dominant calcic plagioclase and subordinate quartz and ferromagnesian minerals. These are among the most characteristic rocks of eastern Massachusetts, but they are also some of the hardest to map, because ordinarily they are not sharply defined but grade into the other types of rock in the complex.

In the Boston area the formation occupies several areas, some of considerable size, in the Fells and Needham Uplands. It also forms dikes in the Salem gabbro-diorite and gradation phases of both the Salem gabbro-diorite and the Dedham granodiorite. It is a rather resistant formation and occupies many of the higher hills in the uplands.

The formation includes several varieties of quartz diorite, the variety depending on the dark minerals contained, but all are so similar that a single lithologic description will serve. The rock is typically medium grained, granular, and light gray to greenish and contains dominant andesine and labradorite in about equal amounts, subordinate quartz and either hornblende or biotite or both, and accessory pyrite, magnetite, and titanite. Some phases contain a little augite or hypersthene or both. Where the rock contains considerable biotite it tends to be foliated and in some places has acquired a distinctly gneissic structure. There appears to be no uniform composition of the rock, as it differs from place to place, and all possible gradations are found between it and the granodiorites, syenites, diorites, norites, and gabbros of the group. In many places it has a markedly fresh look, especially on newly fractured surfaces, and the biotite-rich phases, in particular, look fresher and younger than any other igneous rocks in the area. However, what are apparently even the freshest types, when examined in thin section, show considerable kaolin and chlorite, and the degree of alteration as a whole is about the same as in the other formations of the group.

Dikes of the formation cut the Salem gabbro-diorite, and the larger masses of it are cut by dikes of the Dedham granodiorite. It is therefore intermediate in age as well as in composition between the other formations of the group.

DEDHAM GRANODIORITE

The formation mapped as the Dedham granodiorite occupies a greater area in eastern Massachusetts than any other formation, and it is more widely distributed than any other rock in the State except the Triassic diabase. It comprises the pegmatites, aplites, granites, granodiorites, and syenites of supposed early Paleozoic age—rocks containing considerable alkalic feldspar and only subordinate amounts of ferromagnesian minerals.

The formation occupies a number of areas, some of them rather large, in all parts of the Boston area except the Boston Lowland. It also occurs in dikes and small stocks cutting the other two formations of the group.

It includes several types and minor phases, but the most abundant is the granodiorite, a rather coarse-grained granular rock composed essentially of microcline, andesine, quartz, and chlorite, commonly with considerable epidote and kaolin. The quartz is vitreous and generally greenish white or pale sea-green and is peculiarly resistant to weathering, so that grains of it stand out on weathered surfaces of the rock, giving them an appearance somewhat like the sole of a hobnailed boot. The microcline is generally reddish or pinkish and the andesine greenish. The feldspars are more or less kaolinized, and the chlorite and epidote are alteration products of biotite and hornblende, which are now rarely found in the rock. The granodiorite differs more or less in composition and texture and especially in color in the different stocks and intrusive bodies, and the color inclines to yellowish white, pinkish, or red where the microcline is dominant and to greenish white or light or dark greenish gray where the andesine is dominant. In a few localities it is dark red and porphyritic, with conspicuous phenocrysts of red microcline as much as 2 inches in length. In a few other localities, as in the Oaklandvale part of Saugus, it is somewhat gneissic, the structure probably being secondary.

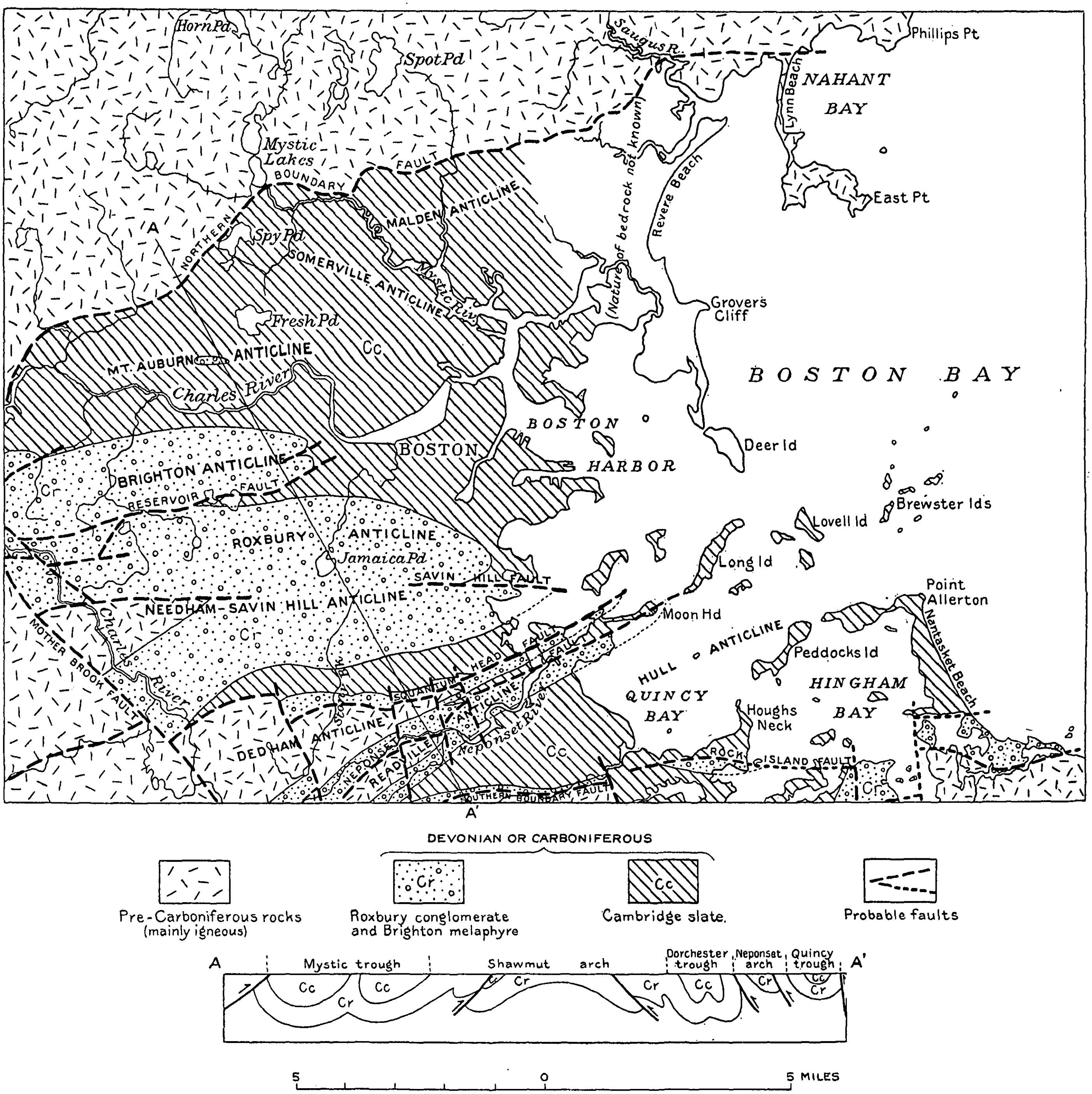
Another prominent type of the granite is a pink to bright-red medium-grained to fine-grained or almost aphanitic rock composed almost wholly of dominant red feldspar, mainly microcline, and subordinate quartz, with a few little spots of chlorite or epidote that once were biotite or hornblende. Rock of this type forms several small elongated stocks in Winchester, Woburn, and Stoneham and numerous dikes cutting the other rocks in that part of the area. In western Lexington there are a few small lenses of red granite containing some slightly altered hornblende.

A syenitic phase, which, except that it contains no quartz, seems to be intermediate in composition between the red granite and the Salem gabbro-diorite, forms the summit of Arlington Heights and is found in a few small dikes in the neighboring diorites. It is a

EARLIEST GEOLOGIC MAP OF THE BOSTON DISTRICT

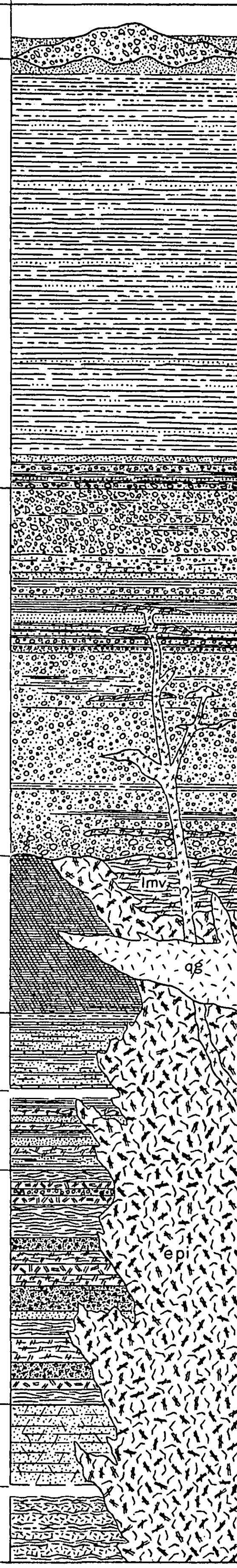
After Dana, J. F. and S. L., Outlines of the mineralogy and geology of Boston and its vicinity, with a geological map, Boston, Cummings & Hilliard, 1818. Also in Am. Acad. Arts and Sci. Mem., vol. 4, 1818.

111895—32. (Face p. 26.)



GENERALIZED GEOLOGIC MAP AND SECTION OF BOSTON BASIN

SYSTEM	SERIES	FORMATION	SYMBOL	COLUMNAR SECTION	THICKNESS
QUATERNARY	Recent Pleistocene	Surficial deposits			Feet 0-200+
		UNCONFORMITY			
DEVONIAN OR CARBONIFEROUS		Boston Bay group: Cambridge slate	Cc		(40?) 2000 to 3500
		Boston Bay group: Roxbury conglomerate	Cr		1500 to 3000
		UNCONFORMITY			
CAMBRIAN	Middle Cambrian	Braintree slate	Єb		1000±
	Lower Camb.	Weymouth formation	Єw		300-600
		RELATION UNKNOWN			
PRE-CAMBRIAN		Woburn formation	wb		500±
		Marlboro formation	mb		1500±
		Westboro quartzite	wt		500±
		RELATION UNKNOWN			
		Waltham gneiss	wh		?



COLUMNAR SECTION FOR THE BOSTON AREA

111895—32. (Face p. 26.)

medium-grained reddish-gray rock composed essentially of microcline, andesine, hornblende, biotite, and perhaps augite, with the usual accessory minerals. It grades into a phase hardly distinguishable from the red granite. A somewhat different rock, seemingly intermediate in composition between syenite or monzonite and gabbro, forms the summit of Turkey Hill in Arlington and extends into southwestern Winchester. It is a medium-grained reddish-gray porphyritic granular rock, composed essentially of the same minerals as the syenite on Arlington Heights but in other proportions, as the dark minerals equal or exceed the feldspars in amount, and the rock contains abundant phenocrysts of andesine.

The pegmatitic and aplitic phases of the formation occur only in dikes and veins cutting practically all the older rocks of the district, including the larger masses of the granodiorite itself. They are yellowish white, cream-colored, or light gray and range in grain from nearly aphanitic aplites to moderately coarse pegmatites. They are composed almost wholly of microcline and quartz, with the microcline generally somewhat in excess, but some of the thicker dikes of aplite of medium grain contain a few sparsely distributed crystals of biotite.

The rocks mapped as Dedham granodiorite have invaded practically all the older formations of the district and are themselves invaded by the felsites associated with the Quincy granite. They are overlain in places by the Devonian or Carboniferous volcanic rocks and by the stratified rocks of the Boston Bay group, to the conglomerates of which they have furnished much material.

GENERAL RELATIONS

All the known rocks of the complex are plutonic and therefore intrusive. Their textures and relations indicate that they solidified at considerable depths and beneath a cover of other rocks. They are intrusive into the pre-Cambrian rocks, which must originally have occupied most of southeastern New England. The scattered remnants of Cambrian rocks and the pebbles of Upper Cambrian quartzite in the Dighton conglomerate of the Narragansett Basin show that Cambrian strata at one time covered much of southeastern Massachusetts, but the remnants owe their present positions to profound faulting, and it is quite possible that, except perhaps at Nahant, the older igneous rocks nowhere invaded Cambrian strata.

The rocks of the group nearly everywhere form the floor beneath the Devonian or Carboniferous volcanic and sedimentary rocks, and it is worthy of note that in almost every place where the basal contact is exposed the underlying rock is the Dedham granodiorite or a tonalite into which the granodiorite grades. It commonly shows evidence of deep weathering and disintegration before its burial,

111895—32——3

and where the overlying rock is tuff, volcanic breccia, or arkose it is almost impossible to differentiate the two formations.

The consanguinity of the rocks of the group, as shown by their common mineral and chemical characters, is strong evidence of their contemporaneity, at least in the larger sense. This conclusion is supported by their common relation to the adjacent formations, their common areal distribution, and their intricate mixture and intergradations, and there seems little reason to doubt that they were derived from a common parent magma. On the other hand, they comprise a wide range of lithologic types which display a progression in age from the least to the most silicic. The group as a whole, therefore, affords an example of magmatic differentiation on a large scale and in a complex fashion, and the cause and manner of its differentiation are problems which have attracted much attention from a number of geologists. Several explanations have been offered, but most of them assume that the differentiation occurred in place and after intrusion. All are presumably partly correct, and each is applicable to some of the observed phenomena, but none is satisfactory when applied to all the phenomena displayed by the group as a whole and throughout its geographic range. From a study of the group as a whole and in all its relations the author has arrived at a somewhat different explanation, involving differentiation before movement to the place of final solidification. This subject, together with the intrusion, denudation, weathering and alteration, and deformation of the rocks of the group, is discussed further under the heading "Geologic history."

DEVONIAN OR CARBONIFEROUS ROCKS

GENERAL CHARACTER, GROUPING, AND AGE

The whole of the Boston Lowland, about half of the Fells Upland east of the valley of Mystic River, and much of the Needham Upland are occupied by rocks that are much younger than those already described but are older than the deformation at the end of the Carboniferous period. Part of these rocks are sedimentary, and part of them are igneous; and of the igneous rocks part are intrusive and part are effusive. The sedimentary and effusive rocks lie on a floor formed of the pre-Devonian rocks of the region, through which the intrusive rocks have forced their way.

The igneous rocks may be divided into two general groups—an older group, composed chiefly of volcanic rocks, forming the Lynn and Mattapan volcanic complexes, and a younger group of intrusive rocks, comprising the Quincy granite and associated rocks. The sedimentary rocks, which with some contemporaneous volcanic rocks constitute the Boston Bay group, are in part terrestrial and in part lacustrine deposits and contain virtually no fossils.

The age of these rocks is not definitely known, as some or all of them may be Devonian or part of them may be Carboniferous. At one time all were supposed to be Carboniferous, but the discovery that part may be Devonian has thrown doubt on the Carboniferous age of the rest. The question of their age is discussed more in detail in the descriptions of the several groups.

The volcanic rocks include not only effusive lavas but also dike rocks and thick beds of tuff, agglomerate, volcanic breccia, and conglomerate. These rocks are found only in or adjacent to the basins of late Paleozoic strata in eastern Massachusetts. In the Newbury and Framingham Basins they are the only rocks exposed, and in the Boston Basin they form much of the floor and margins of the basin, beneath the sedimentary rocks, with the lower part of which they may be interstratified to some extent. In the Boston area they occupy much of the Fells Upland from Medford to Lynn, half of Marblehead Neck, a large part of the Needham Upland, several large areas in the Neponset Valley, and smaller areas in Hingham and Hull.

The subdivision of the volcanic rocks is a difficult problem, which has not yet been satisfactorily solved. The division into two formations—the Lynn and Mattapan volcanic complexes—herein adopted is based partly on lithologic character and partly on structural relations, but there is considerable probability that the two are contemporaneous, and their separation may therefore be invalid. Hence the formation names must be regarded as adopted only tentatively, chiefly as the most convenient way of expressing facts whose relations are not yet fully understood.

The age of the rocks of the volcanic complex forming the Newbury Basin, in Essex County (Newbury volcanic complex), was determined as probably Lower Devonian through the discovery by Keith, in 1915, of marine fossils regarded by Ulrich as probably of that age, in a calcareous shale that is an essential part of the complex. The rocks of the Lynn complex are essentially identical lithologically with those of the Newbury Basin and are believed to be of the same age. That the rocks of the Mattapan complex are also of that age seems fairly certain for similar reasons. So far there is no difficulty in thus correlating the volcanic rocks, but an argument of the same sort fails when applied to the volcanic rocks of the Attleboro district, in the Narragansett Basin. Those rocks, which are of the same lithologic types as part of those of the Mattapan complex and hence might be supposed to be of the same age, are interstratified with sedimentary rocks that are undoubtedly Pennsylvanian. At what point in the chain of reasoning there is a flaw has not been determined, hence it seems best in this report to state the age of the Lynn and Mattapan complexes and the rocks associated with them as

Devonian or Carboniferous. This assignment leaves the age of the rocks of the Boston Bay group still undetermined but is as far as it is safe to go at the present time.

LYNN VOLCANIC COMPLEX

The Lynn volcanic complex comprises the volcanic rocks of late Paleozoic age, commonly known as felsites, in the Fells Upland and on Marblehead Neck. It is equivalent to the Lynn volcanics of Clapp, except that the norite of Nahant, which he included in his Lynn volcanics, is here grouped with the early Paleozoic igneous rocks. On Emerson's geologic map of Massachusetts and Rhode Island the Lynn was included in the Mattapan volcanic complex, and the two were regarded as of a different age from the rocks of the Newbury Basin.

In the Boston area, to which they are almost wholly confined, the rocks of the complex occur mainly in two principal tracts—a northern one extending from eastern Winchester into northern Saugus and a southern and larger one extending from West Medford into Lynn. A smaller tract occupies the northern half of Marblehead Neck. The rocks are rather resistant to erosion and are abundantly exposed, forming rugged hills that exhibit many cliffs and are crowned by bare crags.

The formation includes a number of sorts of rock, nearly all of volcanic origin but partly effusive and partly sedimentary. It also includes dikes penetrating the adjacent older formations. Several strongly contrasted and easily distinguishable types are included in the formation, but its structure is so complicated that they can not well be mapped separately except on a very large scale.

The effusive rocks are dominantly silicic and consist mainly of types formerly grouped under the general name felsite, but they also include some ferromagnesian rocks, which are largely andesitic. They range in texture from glassy or flinty through cryptocrystalline to fine-grained granular, though most varieties are rather conspicuously porphyritic, and in structure from thoroughly massive to strikingly and rather finely banded. Spherulitic and taxitic phases and fairly well developed lithophysae are found in a few places, but they are not characteristic of the rocks in general. The rocks present a considerable variety of colors, including white, light gray, yellowish gray, pink or red, purplish gray, purplish brown, greenish gray, and slate-green. Some are mottled, but in most the groundmass is of rather uniform shade.

The groundmass of the more silicic varieties which are mainly aphanitic, consists, where the minerals can be recognized, of albite and quartz and perhaps a potassic feldspar and accessory biotite, pyrite, apatite, and zircon in small amounts. The phenocrysts are chiefly albite or oligoclase, and some varieties of rock contain also phenocrysts of quartz. The alteration of the rocks is not marked, but many outcrops have a thin whitish weathered crust of kaolin.

Chemically these rocks are high in silica and low in lime and magnesia and are distinctly sodic. They were formerly classed under the general name felsites, and later they were called rhyolites. In recent years the tendency has been to call them quartz keratophyres because of their sodic character.

The formation includes also basaltic varieties of effusive rocks, some of which are amygdaloidal, but none have yet been mapped as melaphyre, as have similar rocks of the Mattapan complex. The basaltic varieties are rather more coarsely crystalline than the felsites and are generally darker and more altered. Their groundmass, which now consists mainly of sericite, kaolin, chlorite, epidote, calcite, and limonite, originally consisted probably of feldspars of intermediate composition, hornblende, and biotite, with quartz in some varieties, and accessory magnetite. The phenocrysts are different in the different types—albite and hornblende in the trachytes, oligoclase and quartz in the dacites, and andesine in the andesites. Some of the andesites contain amygdules of quartz and epidote. These rocks also were originally included under the name felsite, but in recent years the fact has been recognized that they are more closely allied to basalts.

The sedimentary rocks—tuffs, breccias, agglomerates, and a little slate and conglomerate—are mainly of explosive origin and consist chiefly of volcanic material, although the coarser deposits contain pebbles and even boulders of foreign material, especially quartzite and granite. All are probably terrestrial, and only a few are waterlaid. Because some of the lavas are flow breccias that have incorporated waterworn detritus from the surface over which they flowed, the volcanic sediments can not everywhere be distinguished from the effusive rocks. A basal agglomerate or breccia is found in some places where the rocks were deposited on a deeply weathered surface of the Dedham granodiorite. At the "ball" quarry on the Saugus branch of the Boston & Maine Railroad between Cliftondale and Saugus the lava seems to have been erupted into or through a granite saprolite that ranged in coarseness from fine arkose to disintegrated boulders several feet in diameter. The resulting breccia is a mixture of granite boulders and fragments, arkose, tuff, and an interpenetrating matrix that was probably a very fluid lava.

In West Medford the arkose overlying the granodiorite and tonalite grades upward through a material so much altered that its original nature, whether arkose or tuff, is indeterminate, into poorly bedded conglomerate with lenses of slate and sandstone. This conglomerate in turn grades upward into a rock that was long called feldspathic quartzite but is now regarded as a siliceous tuff. No lava flows have been certainly identified in the West Medford section, but its uppermost part, which has been so shattered by faulting and shearing that its original nature has been obscured, may consist of a brecciated flow of rhyolite.

In northwestern Saugus and on Vinegar Hill in eastern Saugus are coarse agglomerates that contain much foreign material, granite boulders several yards in diameter being found in the rock on Vinegar Hill. These deposits were probably formed near volcanic vents. Breccia of another type, which is of explosive origin but contains almost no foreign material, is formed in southeastern Melrose and in the eastern part of the Lynn Woods. It is dull red or purplish gray, is rudely stratified, and ranges in different beds from fine material to fragments several inches across. The fine layers seem to be volcanic ash. The fragments in the coarse layers are mostly angular, but they consist of volcanic rocks, mainly coarse tuff, ejected scoriae, and small bombs. Such rocks are not flow breccias but seem to be volcanic muds, the material in them consisting chiefly of tuff that had been deposited elsewhere and washed away and redeposited in these beds. These breccias are more homogeneous than the felsite breccias, as they consist almost wholly of andesitic material, and they probably originated in an explosive eruption of andesitic type.

Breccia of still another type, that may be intrusive, is found in Melrose Highlands, in the Oakgrove district of Malden, on Marblehead Neck, and elsewhere. The matrix is generally dacitic and either bright red or light slate-green; in some places, as on Marblehead Neck, it is yellowish gray, roughly banded, and probably a keratophyre of some sort. On Marblehead Neck it contains few fragments of other than related volcanic rocks, but elsewhere it contains much foreign material from underlying formations.

Besides the effusive and sedimentary rocks the Lynn complex includes many dikes too small to be mapped. They may be either the last irruptions of volcanic magma or the first irruptions of the plutonic magma of the Quincy granite type, as the magmas of the two groups of rocks are chemically closely related. Texturally, however, these dikes are more closely akin to the volcanic rocks than to the dikes of intrusive felsite associated with the Quincy granite. They cut the volcanic rocks in many places and also the Dedham granodiorite but are almost unknown in the other older rocks. They include most of the types of rock in the flows, although the silicic types predominate. Some of these dikes consist of intrusive breccia like that described in the preceding paragraph, and, like some of the inclusion-bearing diabase dikes described farther on, they contain inclusions of rocks and minerals not known elsewhere in eastern Massachusetts.

Perhaps the most interesting dike of the complex is the bostonite dike on Marblehead Neck, the type locality for that rock, from which many museum specimens have been obtained. It is exposed on the west shore of the neck only at low tide, and its relations are nowhere displayed. Most geologists have regarded the mass as a flow, but Clapp has presented good reasons for believing it a dike, with which the present author concurs.

The effusive rocks of the Lynn complex were erupted upon a surface formed chiefly of the early Paleozoic igneous rocks, and the intrusive rocks of the complex cut the volcanic rocks as well as the underlying older rocks. The complex is cut in turn by intrusive stocks of the Quincy granite type and by several sets of diabase dikes. It is separated from the Boston Basin by a fault, and its relation to the rocks in that basin is unknown, but it is almost certainly older than they. Its age and correlation are discussed in the general treatment of the Devonian or Carboniferous rocks.

MATTAPAN VOLCANIC COMPLEX

The Mattapan volcanic complex comprises the late Paleozoic volcanic rocks in and adjoining the southern part of the Boston Basin. The Brighton melaphyre, part of which is interbedded with the lower strata of the Boston Bay group, may represent the final eruptions of Mattapan time and hence may be a part of the Mattapan complex. This has not been finally determined, however, and the Brighton melaphyre is here treated as younger than the Mattapan.

The Mattapan complex is of greater areal extent than the Lynn complex and is found in several areas from the Framingham Basin on the west to Nantasket on the east. In the Boston area it occupies about half of the Needham Upland in Newton, Needham, and Brookline, and two areas extending from Hyde Park into Dorchester and Milton. Similar masses in Hingham and Nantasket are assigned to the formation. The rocks of the formation are rather resistant to erosion, but the area which they occupy is heavily blanketed with drift, and they are not exposed so abundantly as those of the Lynn complex.

Most of the rocks of the formation are of the same types as those of the Lynn complex, and the description of one formation will apply fairly well to the other. The two differ in some details but not more than would be expected in areas of volcanic rocks of the same general age a few miles apart. Thick beds of volcanic ash and of coarse tuff, mud flows, and water-laid sediments composed of reworked tuff with some extraneous pebbles are perhaps more abundant in the Mattapan complex, and its structural and age relations to the rocks of the Boston Bay group are better displayed than those of the Lynn complex.

It is unnecessary to repeat here the descriptions of those types of rock that occur in both formations. Some of the silicic varieties that are abundant in the Lynn complex are rare or lacking in the Mattapan, which contains some silicic types not found in the Lynn. The most striking is a rock in the southwestern part of Needham that may be intrusive, though its relation to the surrounding rocks is nowhere displayed. It is light yellowish gray, ranges in grain from aphanophyric to granophyric, and contains abundant phenocrysts of quartz in a groundmass of fine crystals of quartz and albite. In most places this rock is cut by several sets of closely spaced, nearly vertical joints, which gives some ledges a structure closely simulating columnar jointing. (See pl. 6, *B*.) Another silicic type, common about Mattapan, is a semivitreous rhyolite which in some outcrops is so evenly and closely laminated that it has been mistaken for quartzite. The commonest melaphyre is an andesite containing amygdules of epidote and quartz. Porphyritic types, largely trachytes and dacites, are also abundant. Although there was plainly some alternation in the eruption of more and less silicic lavas, the earliest flows were felsites and the latest were melaphyres, and most of the melaphyres are younger than most of the felsites.

The sedimentary rocks of the complex are chiefly tuffs, tuff breccias, and mud flows, composed largely of andesitic material. Near the top are some interbedded lenses of conglomerate, sandstone, and slate. The breccias and mud flows, some of which are many feet thick, are among the characteristic rocks of the complex and are found throughout its extent, from Framingham to Nantasket. In places they are associated with agglomerates, some of which contain olivine bombs as much as a foot in length. The sandstone and slate are mainly composed of reworked tuff, and the conglomerate of pebbles of volcanic rocks, but the conglomerate contains also some pebbles of other sorts of rocks.

The conglomerate and sandstone lenses have been confused with the lower part of the Roxbury conglomerate, which, however, is commonly much coarser and only obscurely stratified. Furthermore, they have no great lateral extent and give place to ordinary volcanic rocks, whereas the base of the Roxbury is nearly everywhere traceable as a continuous horizon. The failure, heretofore, to recognize these stratified rocks as volcanic sediments and essential parts of the volcanic complex has led to much confusion in the interpretation of the stratigraphy and structure of the Boston Basin. The fine-grained, well-bedded tuffs simulate the Cambridge slate, parts of which have much the same composition as the tuffs; the mud flows are easily mistaken for thick-bedded, brecciated parts of the slate; and the volcanic conglomerates are not easily distinguished from some parts of the Roxbury conglomerate. Careful study of the composition, texture, and relations of the rocks, however, shows that they are interbedded in a volcanic complex, are composed of volcanic material, and are stratigraphically below the recognized base of the Roxbury.

The Mattapan complex contains some dikes and larger intrusive masses of the same types as those of the Lynn complex, and the description of those rocks will serve for both. The neighboring Dedham granodiorite is also cut by "felsite" dikes that may be Mattapan.

Not only are the Mattapan and Lynn complexes composed mainly of rocks of the same general lithologic types, but they have the same general structural relations to adjacent formations. They are probably also of the same age and should presumably be mapped as one formation, but this is not yet certain, hence they have been mapped separately here.

QUINCY GRANITE AND ASSOCIATED ROCKS

GENERAL RELATIONS

The plutonic rocks of a considerable group in southeastern New England are characterized by abundant amphibole and pyroxene and little or no mica, and by their sodic composition. They occupy large areas in Essex and Norfolk Counties in Massachusetts and in Providence and Kent Counties in Rhode Island. They are regarded as being in general the plutonic equivalents of the volcanic rocks just described, to which they seem to be related chemically, and their irruption is regarded as being the final stage of the Devonian igneous cycle, of which the volcanic eruptions were the initial stage.

The age of these rocks is fairly well fixed by their structural relations to the other rocks and is either Devonian or early Carboniferous. Stocks and dikes of Quincy granite in Essex County cut the rocks of the Lynn volcanic complex, which is regarded as probably of early Devonian age. On the other hand rocks associated in age with the Quincy granite have furnished pebbles to the Carboniferous conglomerates of the Narragansett Basin, whose basal strata are at least as old as earliest Pennsylvanian and are possibly somewhat older.

In the Boston and adjacent areas the sodic rocks include not only the Quincy granite, which is strictly plutonic, but also some felsite dikes cutting older rocks, and the Blue Hill granite porphyry, which is regarded as the suddenly chilled shell or peripheral zone of the Quincy granite batholith.

QUINCY GRANITE

The Quincy granite is a hornblende granite that appears to be chemically akin to the volcanic rocks of the Lynn and Mattapan complexes. Although of considerable extent in quadrangles adjacent to the Boston area, it occupies but a small part of that area at the northern and southern sides. The northern edge of the type area of the formation, in Quincy and Milton, just enters the southeast corner of the Boston quadrangle, and the southern edge of the Peabody area of the granite just enters the northern side of the Boston Bay quadrangle, in Lynn. Several small stocks of the granite are intrusive into the older rocks in Lynn, Marblehead, and Swampscott, and the Salem gabbro-diorite in Swampscott is cut by many dikes of the granite. (See pl. 8.)

The typical Quincy granite is a moderately coarse-grained bluish-gray rock composed essentially of dominant quartz, feldspar, and hornblende, subordinate aegirite, and accessory zircon, titanite, and magnetite. The feldspar is almost all microperthite, composed of intergrown microline and albite, and the hornblende is mainly riebeckite, but some phases of the rock contain cataphorite also. These minerals, with the aegirite, make the rock notably sodic as compared with the other granites of the district.

There is little variety in the small masses of the granite in the Boston area. A fine-grained contact phase is developed in Quincy, where the rock is in contact with Braintree slate, and another contact phase is shown in the stock in East Lynn, which lies between the Salem gabbro-diorite and the volcanic rocks. This rock is somewhat foliated and apparently has been sheared during faulting along the contact. It is composed almost wholly of quartz and microperthitic feldspar and is more altered than most other phases of the granite. The rock of some of the small stocks in Marblehead is poor or lacking in quartz and is allied to nordmarkite. In the Boston area there are no nephelite-bearing sodic rocks, such as are found in Salem and Beverly, which are interpreted as formed by assimilation of Salem diorite into the granite.

The Quincy granite is intrusive into or against all the other rocks with which it is in contact except the Roxbury conglomerate, from which it is separated by a fault. The relative age of the two formations is uncertain, as no pebbles of the granite have been surely identified in the conglomerate and no dikes of the granite cut the conglomerate, but the granite is supposed to be the older.

The Quincy granite forms the eastern and lower part of the range of the Blue Hills, just south of the Boston area, the western and higher part of the range being formed by the Blue Hill granite porphyry. The latter formation does not enter the area here mapped but is important in connection with the geology of the area because of the age relations shown by it.

It is bluish gray, porphyritic, and of nearly the same mineral and chemical composition as the Quincy granite, and it is regarded as a quickly chilled phase formed at the top of the granite batholith as the magma came to rest after intrusion. It is overlain, along the southern base of the Blue Hills, by the Pondville conglomerate of the Narragansett Basin, the base of which is a "giant" conglomerate formed of boulders and cobbles of the porphyry in a matrix of finer material derived from the same rock. This relation fixes the age of the porphyry, and hence of the Quincy granite and associated rocks, as certainly pre-Pennsylvanian and probably Mississippian.

INTRUSIVE FELSITES

Near the Quincy granite some of the older rocks are cut by scattered dikes of light-gray or yellowish-gray porphyritic rock, composed chiefly of quartz and a kaolinized feldspar that probably was albite. These rocks have generally been called felsites. In the Fells Upland they cut both the early Paleozoic igneous rocks and the rocks of the Lynn volcanic complex, but they are found only near stocks of Quincy granite, with which they are probably genetically connected. In the Needham Upland and on the South Shore they cut the Dedham granodiorite and the associated diorite, but some of them are several miles from any recognized stocks of Quincy granite. As a rule they can be distinguished from the dikes associated with the volcanic rocks, and they are with little hesitation assigned to the rocks associated with the Quincy granite.

In the areas of both the Lynn and the Mattapan volcanic complexes are small stocks of medium-grained hornblende-bearing or biotite-bearing granite porphyry. These may be plutonic equivalents of some of the coarser volcanic porphyries, or they may be small outlying stocks of Quincy granite. As they are in the midst of the volcanic complexes they are in this report mapped with those formations.

BOSTON BAY GROUP

GENERAL RELATIONS

The Boston Bay group comprises the late Paleozoic stratified rocks which, with the interbedded Brighton melaphyre, occupy the Boston Basin, including most of the Boston Lowland, a part of the Needham Upland, and a strip along the South Shore. These rocks are not found except in the Boston Basin, which, however, extends southward a little beyond the area here described into the Dedham and Abington quadrangles and southwestward across the corner of the Framingham quadrangle into the Franklin quadrangle. In East Boston, Chelsea, Winthrop, Revere, and the Saugus Marsh bedrock is not exposed on the surface and has not been encountered in excavations. The rock beneath East Boston, Chelsea, and Winthrop is probably the Cambridge slate, but that beneath the Saugus Marsh, Lynn Beach, and most of Revere is quite unknown, as indicated on the areal-geology map.

The rocks of the group consist of conglomerate, tillite, arkose, sandstone, quartzite, slate, and melaphyre. The sedimentary rocks seem to be wholly nonmarine and largely terrestrial. The tillite was probably deposited on land, but it includes some fluviatile beds, and the slate is probably lacustrine, though part of it may be fluviatile. The rocks are almost wholly devoid of fossils, either plants or animals, and seem to have been deposited under conditions that precluded the existence of life in their vicinity.

The group comprises three formations—the Roxbury conglomerate, Brighton melaphyre, and Cambridge slate. The Brighton melaphyre does not lie between the other two formations but is intruded into and interbedded with the lower part of the Roxbury. Owing to the conditions under which the beds were deposited few definitely recognizable horizons can be traced throughout any considerable part of the basin, and sections in different parts differ much not only in details but in general make-up. The thickness of the Roxbury conglomerate differs widely in different places, and, partly for this reason and partly because of thrust faulting, no close estimate of its thickness can be made. On account of the irregular thickness and the lack of persistent key horizons the structure of the Boston Basin is difficult to interpret and never has been satisfactorily worked out. Even the sequence of the formations was long in doubt.

The Roxbury conglomerate overlies the Dedham granodiorite and part of the rocks of the Mattapan volcanic complex and contains pebbles of those rocks as well as of the older rocks of the region. All the rocks of the group are cut by two sets of diabase dikes, but they are nowhere invaded by plutonic rocks. The rocks of the group, in common with all the older rocks of the region, were folded and faulted in the great Appalachian deformation at the end of the Carboniferous period, and they are not overlain by any younger rocks except the Quaternary deposits.

The age of the rocks of the group is one of the greatest puzzles in the geology of the region, and it remains unsolved after a century of work. Except a few short pieces of tree trunks, of which not even the genus can be certainly determined and which may be of either Devonian or Carboniferous age, no fossils have been found in these rocks. In the absence of direct, internal evidence of age, indirect or external evidence, such as the structure of the Boston Basin and the relations of the rocks of the group to the adjacent formations, must be used. On such external evidence the age of the group is known to be not older than Devonian and not younger than Carboniferous, and at present its age can not be more definitely stated.

The Boston Bay group can not be positively correlated with any other rocks in southeastern New England. When it was regarded as Carboniferous it was correlated with the rocks of the Narragansett, Woonsocket, Worcester, and Merrimack Basins, and some geologists hold that the rocks of all five basins are remnants of a cover of Carboniferous strata that formerly extended over the whole region. The nonmarine character of the rocks, the differences in sections a few miles apart, and the lack of persistent beds are not in accord with such a view, however, and it now seems hardly tenable. The close juxtaposition and possible connection of the Boston and Norfolk Basins, on the other hand, make it seem not improbable that their rocks may be of the same age, and there is therefore a slight balance of probability in favor of regarding the rocks of the Boston Bay group as Carboniferous.

ROXBURY CONGLOMERATE

The Roxbury conglomerate is the basal formation of the Boston Bay group. Except at one locality in Watertown it is not exposed on the surface or in excavations north of the Charles River. The main area of the formation occupies nearly all of Roxbury and large parts of Dorchester, West Roxbury, Brookline, Brighton, and Newton. There are other large areas in Hyde Park, Milton, and Hingham and small ones in Quincy and Hull. As a rule the rock is resistant and forms bold hills with many ledges and cliffs.

In Emerson's bulletin on the geology of Massachusetts and Rhode Island the Roxbury is described as comprising three members—the Brookline conglomerate member at the base, the Dorchester slate member in the middle, and the Squantum tillite member at the top. Later knowledge gained from recent excavations has shown that this threefold division does not persist throughout the area occupied by the formation with sufficient definiteness to warrant the mapping of the members separately. Furthermore, the Dorchester slate member does not everywhere have a well-defined lower limit, and in some areas beds characteristic of it are intercalated in most of the formation below the tillite. The threefold division is herein retained for convenience in description, but no attempt is made to represent the members on the map or in the sections, and they are not regarded as clearly distinguishable stratigraphic subdivisions throughout the area.

The thickness of the formation differs greatly in different parts of the Boston Basin, but it is probably nowhere less than 1,500 feet in any section where the full thickness is preserved, and in some areas it may be as much as 3,000 feet or more.

The Brookline conglomerate member consists mainly of massive conglomerate, which may attain a thickness in some areas of 1,200 feet. In a few places it is well stratified, but in much of its outcrop area it shows no bedding. (See pl. 9, *A*.) Its base, where exposed, is generally coarse and heterogeneous, containing cobbles and small boulders, many of which are of the same rock as the underlying formation, which in a few places is the Dedham granodiorite but elsewhere is some part of the Mattapan volcanic complex. Hence, although they are for the most part rather well rounded, they apparently have not been transported far. In Quincy, Hingham, and Hull the basal zone is interbedded with flows of Brighton melaphyre, and the same association may occur also in some areas in Newton.

The Dorchester slate member is characterized by beds of red and purple sandy slate, purplish sandstone and grit, and small-pebble conglomerate. Much of the slate is composed of rather coarse material, apparently reworked basaltic or andesitic tuff. The rocks of this member are well stratified, and the sandstone and slate commonly show a characteristic cross-bedding. The Dorchester member is best shown and apparently is best developed in Dorchester and Hingham, where its position in the formation is clear. The sandy slate and interbedded sandstone of Allston Heights, in Brighton, were long believed to be part of the Cambridge slate, but it now seems more probable that they should be assigned to the Dorchester slate member of the Roxbury. This may be true also of the beds exposed in the long railway cut east of West Newton station. The slate and sandstone in Allston Heights are cut by dikes and sills of Brighton melaphyre and are interbedded with flows of the same rock, but neither of these conditions is found in any beds that are certainly part of the Cambridge.

The Dorchester slate member ranges in thickness from 300 to possibly 2,000 feet or more. Its limits can not be defined with precision, and in Allston, where it is apparently very thick, its seemingly great thickness may be due to duplication by strike faults. Some of the beds or lenses of slate in Dorchester and Allston are at least 150 feet thick, but such considerable thicknesses of continuous slate are not common in this zone.

The Squantum tillite member, which forms the upper part of the Roxbury conglomerate, is exposed at many places in the southern part of the Boston Basin, but north of the Charles River it was seen only at the former quarry in East Watertown. The peculiar conglomerate on North Beacon Street in Allston, which contains many angular fragments of slate and was once thought to be a local bed in the Cambridge slate, may possibly be Squantum. A similar rock was formerly exposed in eastern Allston and in Auburndale, and a few boulders of it were found near Bemis, hence a narrow belt of tillite may underlie that part of the basin, but it is so largely conjectural that it has not been mapped.

The Squantum member consists mainly of a peculiar breccia now regarded as tillite or glacial conglomerate, interbedded with a few thin layers that are regarded as water-laid drift. (See pl. 10.) The tillite contains striated and faceted pebbles and other indications of its glacial origin, including angular boulders of granite and other rocks 3 to 4 feet long. Its base is nowhere certainly exposed, but it probably merges downward into the underlying conglomerate, a part of which, while yet gravel, presumably was incorporated into the base of the till. The thickness of the tillite is probably at least 600 feet in some places in the southern part of the basin, but it may be and probably is much less in the Brighton-Watertown-Newton area. At its top, where that is exposed, it ordinarily grades into the Cambridge slate through transition beds which are similar in composition to those found in the Dorchester slate member but which include also some beds of tillite a few feet thick.

No fossils have been found in the Roxbury conglomerate except a few short pieces of tree trunks that were collected near Forest Hills, probably in the Brookline conglomerate member. The pieces are casts of trunks from which the bark had fallen, and the genus to which they belong is uncertain but is probably either *Cordaites* or *Lepidodendron*. Their age, therefore, can not be determined more closely than that they are either Devonian or Carboniferous.

The interpretation of the Roxbury formation has always been difficult. It contains waterworn material derived from most of the older rocks of the district, and most of the pebbles are rather well rounded, yet wherever the base of the formation is exposed it consists largely of pebbles of the underlying rocks. Hence it was once regarded as marine and as mainly a shore deposit. It is devoid of evidence of marine action, however, and its general structure and largely unsorted character indicate that it was deposited mainly on land and by torrential streams. The discovery that the upper part of the formation is tillite has shed much light on the problem, and it is now regarded as mainly of glacial origin and as consisting chiefly of outwash deposits that were later overridden by the ice and covered with a deposit of till.

BRIGHTON MELAPHYRE

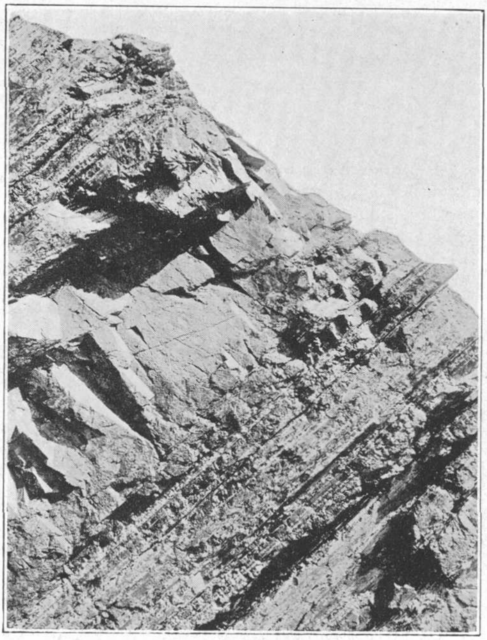
The formation mapped as Brighton melaphyre comprises dikes, flows, and probably sills, chiefly of basalt, intruded into and interbedded with the Roxbury conglomerate in Newton, Brighton, Brookline, Quincy, Hingham, and Hull. A few irregular dikes that are intrusive in the rocks of the Mattapan volcanic complex in Needham, Dorchester, and Milton are presumed to belong in the formation, and there is a single small mass of rock of the same sort near Saugus Center. These small masses are not mapped.

The rock is greenish, brownish, or purplish amygdaloidal melaphyre of basaltic character, composed of augite, labradorite, and olivine with accessory pyrite, magnetite, and hornblende, though the hornblende may be secondary. The rock is now much altered to chlorite, epidote, limonite, and calcite. Some masses of it contain small kaolinized phenocrysts of calcic feldspar. The amygdules are mostly small and well rounded and are composed of calcite, though some contain quartz and epidote. In some masses of the rock amygdules are notably abundant, but other masses contain very few.

Some bodies of the melaphyre contain angular fragments of rock of the same sort and seem to be flow breccias or mud flows, as fragments of rock of other sorts are scarce. As there are a few beds of tuff and explosive breccia, some of which contain olivine bombs, the effusive character of at least part of the formation and the occurrence of explosive eruptions during its extrusion seem well established.

The interbedded masses range in thickness from a few feet to several hundred feet and in length from 100 feet or less to more than a mile. The thicker ones are probably not single sheets, but lack of continuity in outcrops and the possibility of concealed faults make this inference uncertain. Some of the smaller intrusive masses are clearly dikes or pipes that fed flows or sills.

There has been much discussion regarding the structural relations of the melaphyre, especially in Quincy, Brighton, and Newton, some geologists holding that it is nearly all effusive and contemporaneous with the conglomerate, others that it is intrusive and later than the conglomerate. Those on both sides seem to have been overinfluenced by the relations shown in some areas and to have given insufficient attention to those shown elsewhere, and no one on either side seems to have discriminated between the Brighton melaphyre, which is associated with the Roxbury conglomerate, and the melaphyre that is part of the Mattapan complex and is older than the Roxbury. The author has reached the conclusion that some of the interbedded sheets of Brighton melaphyre are certainly flows and that others

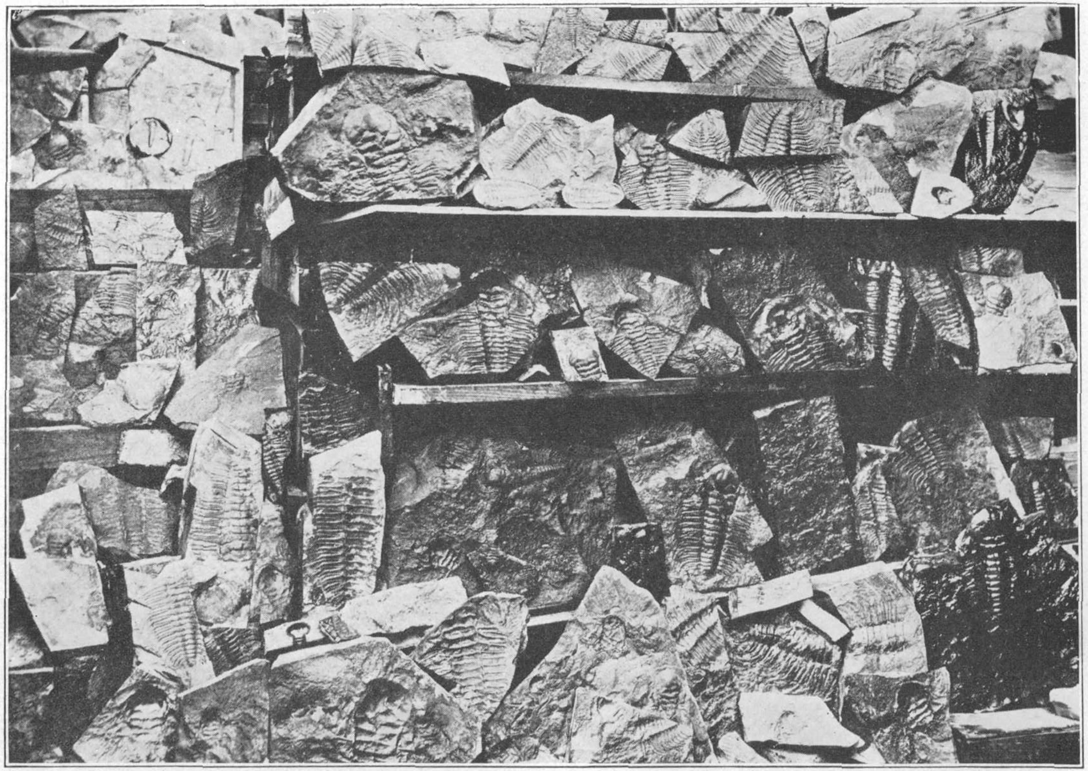


A. WEYMOUTH FORMATION (LOWER CAMBRIAN) IN THE CLIFF AT EAST POINT, NAHANT

The formation here consists of thin-bedded quartzite, calcareous slate, and cherty limestone, cut by sills of gabbro. The best preserved Lower Cambrian fossils were found at this locality, where the strata, though somewhat metamorphosed, are little sheared. Photograph by F. H. Lahee, 1914.

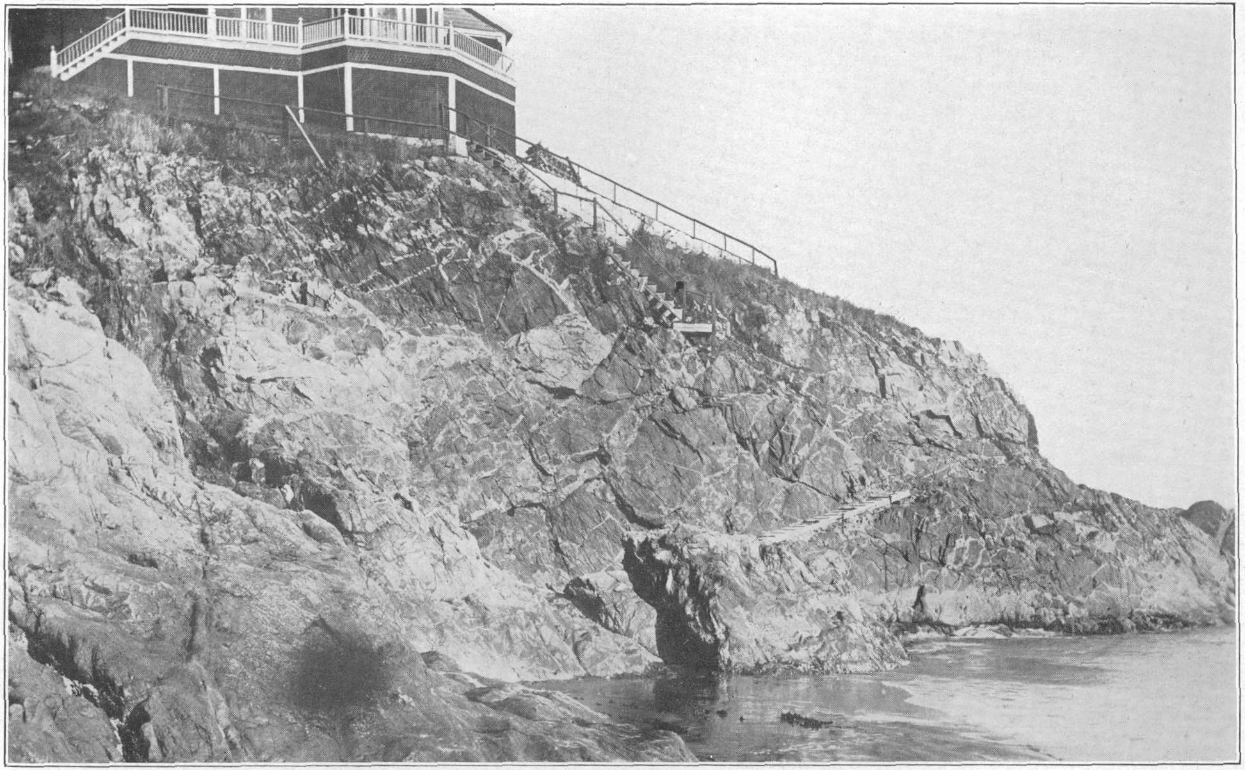
B. COLUMNAR JOINTING IN RHYOLITE PORPHYRY

Note the irregularity in form, size, and development of the columns, the absence of "cup-and-ball" structures, and the absence of polygonal jointing on the upper surface of the block. Photograph by J. L. Gardner, jr., 1901.



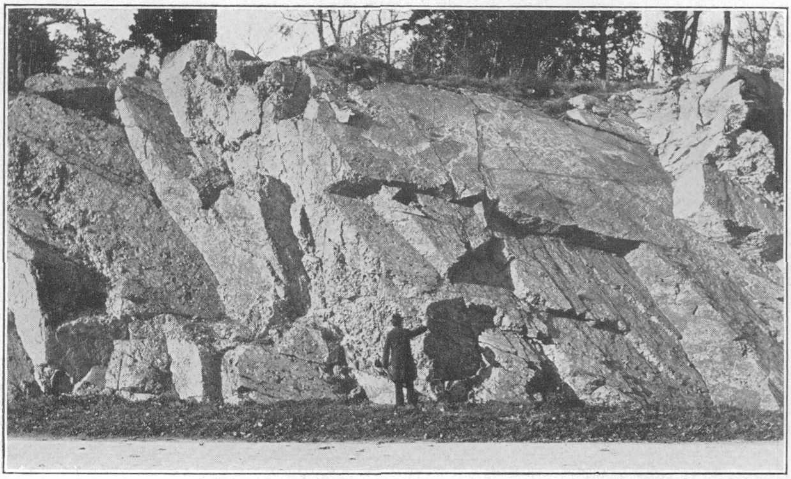
FOSSILS OF MIDDLE CAMBRIAN AGE FROM THE BRAINTREE SLATE

The specimens, which are of the trilobite *Paradoxides harlani*, came from the former quarries at Hayward Creek, East Braintree, where practically all the good specimens of Middle Cambrian trilobites were found. Photograph by W. C. Ryder, 1910 (?).



PLUTONIC BRECCIA IN CLIFF AT CLIFTON, MARBLEHEAD

The darker rock is Salem diorite, which has been invaded and brecciated by dikes of granite and tonalite. This locality is typical of the breccia that occupies practically all of Swampscott, with adjacent parts of Marblehead, Salem, and Lynn. Photograph by N. L. Stebbins.

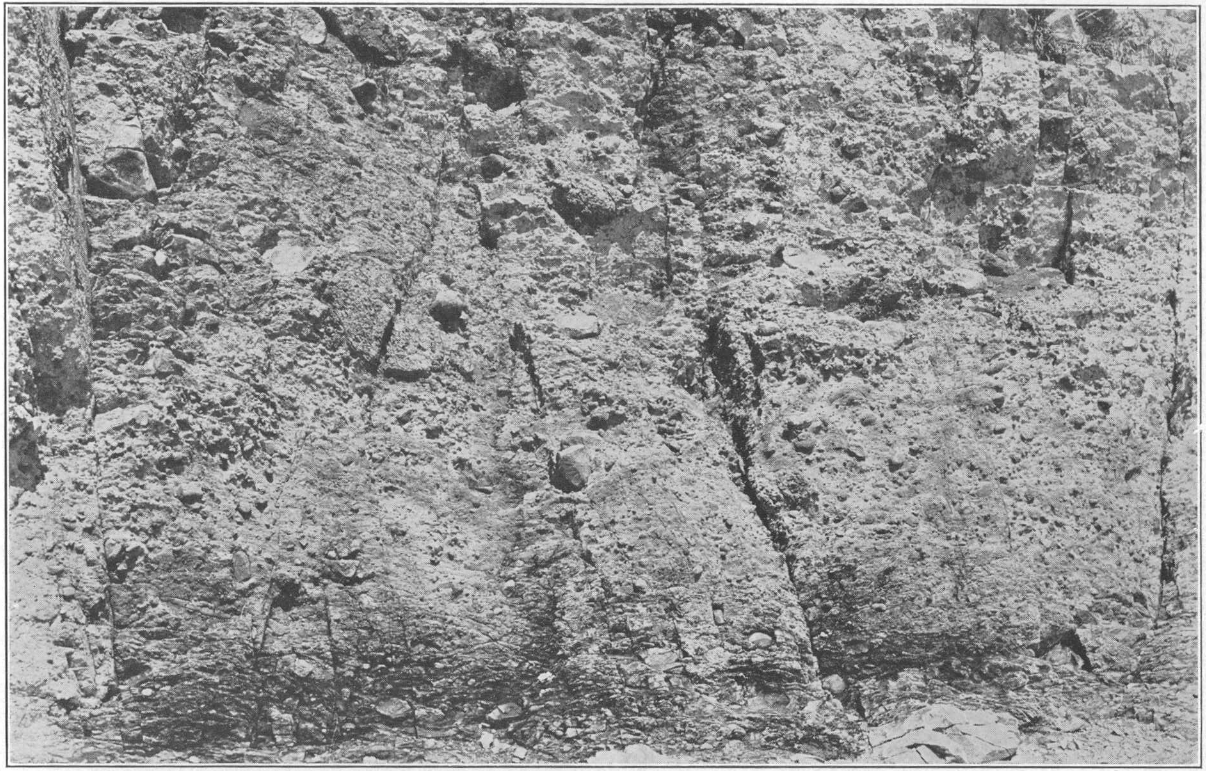


A. CLIFF OF ROXBURY CONGLOMERATE ON COMMONWEALTH AVENUE IN WASHINGTON HEIGHTS, BRIGHTON DISTRICT, BOSTON

This cliff, now removed, was a typical exposure of the lower, true conglomerate part (Brookline member) of the Roxbury. The view also shows well the perfection of the torsion joints in such coarse and heterogeneous rock. Many pebbles are sliced cleanly through, and many square feet of the joint plane surfaces are as smooth as if in fine-grained sandstone.

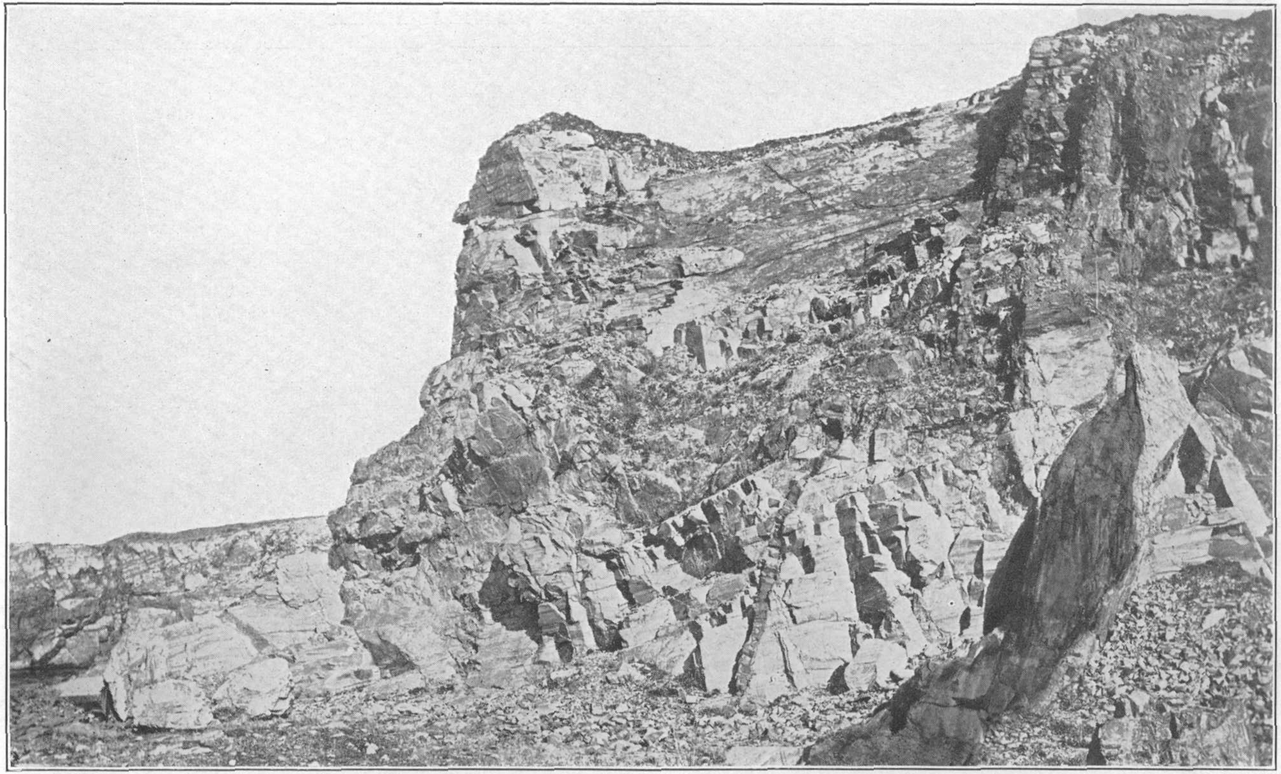
B. DISINTEGRATING DIABASE OF THE GREAT MEDFORD DIKE, IN THE FORMER QUARRY AT PINE HILL, MEDFORD

A close view, showing well two boulders of disintegration, partly surrounded by series of exfoliation shells and embedded in completely disintegrated saprolite, still in place but easily removable. Photograph by F. H. Lahee, 1914.



SQUANTUM TILLITE IN CLIFF AT SQUANTUM HEAD, QUINCY

A typical exposure of the tillite of the Squantum area, where the matrix is sandier than in Hyde Park and Roslindale. The view shows the wide range in size and shape of the pebbles and boulders, their heterogeneous lithologic character, the absence of sorting or stratification, and the low ratio of fragments to matrix. Photograph by F. H. Lahee (?), about 1914.



CAMBRIDGE SLATE IN THE FORMER MYSTIC QUARRY, SOMERVILLE

This cliff, now quarried away, showed fairly well the characteristic features of the formation in the area where it was best exposed. At the right of the view the slate is cut by the "twin dikes," two diabase dikes of the later north-south set that were of interest because of the contained inclusions of rocks and minerals brought up from considerable depth. Photograph by N. L. Stebbins.

are probably crosscutting sills, but that all are contemporaneous with the Roxbury conglomerate.

The correlation of the melaphyre is nevertheless still rather uncertain. For years it was not distinguished from the closely similar rocks of the Mattapan complex, and it may possibly be part of that complex and represent eruptions that continued after the deposition of the Roxbury conglomerate had begun. On the other hand, it may represent entirely distinct eruptions that occurred in a later igneous cycle than the Mattapan epoch.

CAMBRIDGE SLATE

The Cambridge slate is the upper formation of the Boston Bay group. It occupies all the northern part of the Boston Basin, except one small area in Watertown, and several long belts in the southern part. It underlies most of Boston Harbor and forms part of the small rocky islands in Boston Bay off the mouth of the harbor. It is only moderately resistant and occupies low land or forms low hills, except where it is held up by the underlying Roxbury conglomerate.

The formation consists chiefly of rock of generally fine-grained argillaceous character that has been called pelite, shale, argillite, and slate, though none of those names is wholly satisfactory. As "slate" is generally used locally and has been longest in use, it has been adopted for use in this report. The typical Cambridge slate is dark bluish gray or brownish gray, rather fine grained, and composed chiefly of argillaceous material. Some parts of it are well stratified and thin bedded; other parts are rather massive. Most of it splits easily parallel to the bedding, and nearly everywhere it has developed a fissility across the bedding, but only rarely is this secondary structure dominant, and practically nowhere in the basin is the rock a true slate. (See pl. 11.)

The formation contains no conglomerate, unless the peculiar conglomerate in Allston and Auburndale, already mentioned, is part of it. Coarse-grained beds, some of them sandy but most of them composed mainly of reworked tuff, are scattered through the formation, mainly in its lower part. Near its top it contains some red and green shale, and what is probably its uppermost part has been named the Tufts quartzite member. This member, consisting of 30 feet or so of greenish and white quartzite, is exposed in only three places—on the south slope of College Hill, Somerville, in the large quarry in East Everett, and on a half-tide island in the Mystic River. These three localities are situated respectively at the apex and on the north and south limbs of a syncline pitching eastward, but there are no exposures within the V thus formed, and nothing is known of the rock therein, hence it is uncertain whether the Tufts member is the top of the formation or whether there is more slate above it. (See appendix.)

The thickness of the formation is in doubt. It may not be so great as it appears to be, as concealed faults are highly probable, but it must be at least 2,000 feet and it may be 3,500 feet or more. The Tufts quartzite member is probably less than 40 feet thick. The slate is cut by several sets of diabase dikes but is not overlain by any younger rocks except Quaternary deposits. No fossils have been found in it, and its age can not be determined directly.

CARBONIFEROUS ROCKS

ANDOVER GRANITE

The Andover granite is the muscovite granite of late Carboniferous age in eastern Massachusetts. In the Boston area it occupies only a small part of the northwest corner.

The normal granite is medium grained to moderately coarse grained, light gray to nearly white, and is composed of quartz, albite, microcline, and muscovite, with or without biotite, orthoclase, and microperthite. The grain is rather irregular, and the normal phase grades into porphyritic and pegmatitic phases. The rock is also generally foliated and in many places is rather strongly gneissic.

A striking feature of the granite is its diversity, even in a single ledge. This is well shown at the falls on the Shawsheen River in Bedford, in the southeast corner of the Lowell quadrangle, a few hundred yards outside the Boston area, where not only the normal granite but also coarsely porphyritic, coarsely pegmatitic, and strongly gneissic phases are displayed in one large outcrop. The porphyry contains large phenocrysts of microcline in a matrix of the normal granite; the pegmatite contains crystals of quartz, feldspar, and muscovite several inches across; and the gneiss, composed of the same minerals, is fine grained and so evenly foliated that it resembles a well-stratified arkose. These phases are sharply separated in parts of the outcrop but intergrade in other parts, and all are manifestly phases of the one granite.

Elsewhere the granite displays also a greisen phase, composed almost wholly of rather fine grained quartz and muscovite, and pegmatitic phases that contain large plates of biotite as well as of muscovite and nearly perfect icositetrahedral crystals of garnet, some of them nearly an inch in diameter.

The relation of the granite to the other rocks of the Boston area is unknown, and it may be separated from them by a fault. It is intrusive into the Carboniferous strata of the Merrimack Basin but has been deformed along with them. It is therefore regarded as of late Carboniferous age.

DIABASE DIKES OF DIVERSE AGES

GENERAL RELATIONS

All the hard-rock formations of the Boston district are cut by dikes of the sort generally called, for convenience, trap dikes. The rock of most of the dikes is diabase, and that of most of the rest has a diabasic texture but is considerably altered in composition. The rock of still other dikes has neither the composition nor the texture of diabase, but their general character and structural relations are such as to indicate that they also were originally diabase or some closely related rock.

The diabase dikes display a great variety of size, form, relations, structure, and weathering. They range in thickness from a fraction of an inch to more than 500 feet, in length from a few feet to more than 4 miles, and in form from straight, almost even-sided dikes filling what are obviously joint fissures to masses of such irregular shape that they can hardly be called dikes. Sills, also, are not uncommon in the Cambridge slate. By far the greater number of dikes cutting the stratified rocks are nearly perpendicular to the stratification, and dikes that are markedly oblique to the beds, although not unknown, are scarce. Faulted and offset dikes are common, and many of those that were intruded before the deformation of the inclosing rocks were tilted and warped with the rocks.

It is difficult to estimate the number of dikes in the Boston area, but there must be many hundreds, as there is no reason to suppose that they are less abundant in the areas covered with Quaternary deposits than in areas where outcrops are numerous. They are very abundant in the Cambridge slate areas, especially in the northern half of the Boston Basin. They are also abundant along the rocky shores in Cohasset, Hull, Nahant, Swampscott, and Marblehead and among the rocky hills in Stoneham, southern Wakefield, and eastern Winchester. In some areas of rocks of little resistance to erosion almost the only outcrops consist of diabase.

Diabase dikes are notably scarce in the areas occupied by the Quincy and Andover granites and are especially abundant in those occupied by the Cambridge slate. Otherwise there seems to be no relation between the abundance of the dikes and the formation which they cut. In some areas, such as the southeastern part of the Middlesex Fells, diabase dikes are surprisingly few, but in other areas of rock of the same sort they are abundant.

Most of the dikes can be grouped according to their trends into four sets. Some, especially in Nahant and Marblehead, can not at present be assigned to any of the sets, and possibly some of them belong to sets not recognized elsewhere. The relative age of the sets is shown by their intersections, and their geologic age is fairly well known from their relations to other rocks. The sets are (1) the older east-west set, (2) the northwest-southeast set, (3) the younger east-west set, and (4) the north-south set. Dikes of sets 1 and 2 are found only in certain areas of pre-Carboniferous rocks, but those of sets 3 and 4 are found throughout the district.

Some trap dikes in the Middlesex Fells cut the Dedham granodiorite but are cut off by the rocks of the Lynn volcanic complex. These dikes have the composition and texture of minette and are not included among the diabase dikes, although they have a common north-south trend and apparently form another set.

Although many of the dikes are large enough to be mapped, only one is shown on the maps in this report. The others are not shown because to do so would complicate the maps unnecessarily and because they could be shown only where outcrops are abundant, thus giving a misleading idea of their distribution.

OLDER EAST-WEST DIKES

The older east-west dikes are extremely scarce, and none have been definitely recognized within the Boston area. The best-known ones are a mile or so outside of this area, in the vicinity of Pine Tree Brook, southeast of Milton Center. They are mentioned here because of their possible connection with some of the rocks of the early Paleozoic igneous group and their possible importance as a link in the geologic history of the region.

Several dikes that trend almost east cut the Braintree slate, which strikes east and stands about vertical, so that the supposed dikes may be upturned sills. The dikes consist of dark-gray or nearly black rock, ranging in grain from fine to rather coarse and composed essentially of hornblende and a calcic feldspar. They have evidently been considerably altered, and they may never have been diabase. The mass of Braintree slate which they cut appears to be a large inclusion, possibly a roof pendant, in the Quincy granite, and the dikes do not extend into the granite but probably are cut off by it. If so they are of post-Cambrian and pre-Carboniferous age and prove the occurrence of a period of intrusion of trap dikes in pre-Carboniferous time. Furthermore, the possibility of their genetic relationship to the early Paleozoic igneous rocks is a little additional indication of the post-Cambrian age of those rocks.

NORTHWEST-SOUTHEAST DIKES

There is considerable doubt whether the northwest-southeast dikes constitute a set by themselves or whether they are offshoots of the younger east-west dikes. In the western part of the Middlesex Fells, where these dikes are abundant, the evidence from intersections is indeterminate, as the northwest-southeast dikes appear to be cut by the east-west dikes in some places and to be branches of them in other places. If there are really two separate sets, probably they are not greatly different in age and belong together in one eruptive cycle.

The rock of the northwest-southeast dikes is typically light greenish gray, fine grained to almost aphanitic and obscurely porphyritic, and is nearly all altered to chlorite, epidote, calcite, and limonite, though the texture indicates that it was originally diabase. The rock is almost identical in composition, texture, and degree of alteration with that of some of the sills of the younger east-west set, and, as the northwest-southeast dikes are everywhere associated with east-west dikes, it seems probable that they, like the sills, are branches of those dikes.

YOUNGER EAST-WEST DIKES AND SILLS

The younger east-west dikes occur throughout the Boston area and cut all the hard-rock formations, but they are scarce in the Quincy and Andover granites. They include the largest diabase dikes of the region, some of them being traceable for several miles and reaching a maximum thickness of 400 to 500 feet. Dikes 100 feet thick are fairly common, and those less than 5 feet thick are rather scarce, although not unknown. A number of sills, ranging in thickness from a few inches to 30 feet, cut the Cambridge slate, and several of them are plainly offshoots of the east-west dikes.

The trend of the dikes of this set ranges from N. 60° W. to S. 75° W., and their hade ranges from 0° to 30°, its direction depending on the attitude of the inclosing rocks, as the dikes were tilted and warped in the general deformation of the region. Some of them are fairly straight, but most are rather irregular, and many are branched or are split about horses.

The rock of these dikes is typical medium-grained diabase, tan-brown to olive-brown on weathered surfaces and dark greenish gray on fresh surfaces, and composed of labradorite, augite, and subordinate magnetite, with accessory pyrite and, in some dikes, olivine. Some also contain a little probably secondary hornblende. Many of the thinner dikes have a layer of basaltic glass at the contact. The dikes are more or less altered, and most long-exposed surfaces have a thin weathered crust of limonite and kaolin. Spheroidal weathering is rare, and the ultimate product of disintegration is a moderately coarse limonitic sand. Many of the dikes are porphyritic, and their petrography is an interesting study by itself.

The rock of the thicker sills is not particularly different from that of the dikes. That of some of the thinner sills is much like that of the northwest-southeast dikes, but that of other thin sills is very different and contains conspicuous small rhomb-shaped phenocrysts of calcic feldspar in a nearly aphanitic groundmass, the whole rock being altered to a mixture of kaolin, calcite, limonite, and other minerals. Nearly all the dikes of the set and all the sills except the porphyritic ones display an imperfect columnar jointing, at least across their central portions.

As dikes of this set cut the Andover granite they must be at least as young as late Carboniferous, but as they plainly were affected by the deformation at the end of the Carboniferous period they can not be any younger. Their age is therefore more definitely known than that of most other rocks of the region.

MEDFORD DIABASE DIKE

The great Medford diabase dike is the best-known diabase dike in the district and one of the largest. As it can not certainly be classed with any of the sets it is described by itself and is shown on the geologic map. The main dike extends from Powderhouse Hill, in West Somerville, northward almost to Spot Pond, a distance of 3 miles, and attains a maximum thickness of 560 feet. Rock of the same sort is or was once exposed in Allston, Brookline, and West Roxbury, at localities almost on the line of the main dike prolonged southward. The northernmost and southernmost exposures on this line, which trends N. 19° E., about the average trend of the north-south dikes, are 11 miles apart. All the outcrops on this line are thought to be the higher portions of a single dike with an irregular top, the rest of which has not yet been exposed by erosion. Diabase of the same type is or was exposed also at the Granite Street quarry in Somerville, on Galen Street in Watertown, and a little east of Main Street in South Medford. These exposures are presumed to be outcrops of branches of the great dike.

The rock of the dike is dark gray, is medium to coarse grained, and in many places contains some biotite and hornblende in addition to the ordinary minerals of diabase. Its most notable characteristics are its spheroidal weathering and its relatively rapid disintegration into fine angular gravel and coarse residual sand. (See pl. 9, *B*.) The rock at the Granite Street quarry in Somerville is also noted for an extraordinary pegmatitic phase, which is perhaps secondary and due to pneumatolytic action.

The south end of the main mass, where it tapers to a point just south of Powderhouse Hill, is a breccia made up almost wholly of angular fragments of other rocks, the interstices between which are filled with fine-grained, almost glassy diabase. Among the inclusions are blocks of Tufts quartzite and of a pegmatite thought to be a phase of the Dedham granodiorite and smaller pieces of rocks and minerals not found elsewhere. Seemingly the ascending diabase magma tore loose and bore along fragments of the walls and packed them into the tapering end of the fissure.

Although having about the same trend as the north-south dikes, the Medford dike differs from them in lithologic and structural character, and it is cut in one place in Medford by a north-south dike that seems to be a member of that set; hence it is not included with the north-south dikes. It can not be much older than those dikes, however, as it is clearly later than the younger east-west dikes and than the fault bounding the Boston Basin on the north. It is therefore regarded as of Triassic age.

NORTH-SOUTH DIKES

The north-south dikes, which occur throughout the area and cut all the other hard rocks, are the most interesting diabase dikes in the region. It is problematical whether they or the younger east-west dikes are more numerous, but none of them attain as great thickness or length as the larger east-west dikes.

The north-south dikes range in thickness from less than an inch to 40 feet and in length from a few feet to half a mile. Although many are faulted or offset, nearly all occupy preexisting joint fissures; hence they are, as a rule, nearly straight, with smooth walls that are approximately parallel. Their trend ranges from about due north to N. 25° E., and nearly all hade to the west, ordinarily less than 15°. This hade appears to be due to tilting after their intrusion, accompanied by faulting along the joint fissures, so that many of the dikes have been torn loose from one of their walls, and some have been split lengthwise, by the faulting. A few thin sills are associated with the dikes of this sort.

The rock of these dikes is the youngest and least altered hard rock in the region. It is typical olivine diabase, dark gray to almost black, fine grained to almost aphanitic, and rarely porphyritic. Except for a thin rusty, weathered crust on long exposed surfaces it is very little altered. It weathers spheroidally, although not so strikingly as the Medford diabase, and disintegrates into a rusty-brown powder.

Some of the most interesting dikes of this set are the inclusion-bearing dikes, now nearly all obliterated by quarrying, some of which contain fragments of Dedham granodiorite and of volcanic rocks of the Lynn complex. As several of these dikes were irrupted through the Cambridge slate the existence of the granodiorite and of the volcanic rocks beneath the Boston Basin and hence the fact that those rocks are older than the Boston Bay group seems established. Among the inclusions are also pieces of rocks and minerals not found at the surface in the Boston district. (See pl. 11.)

The north-south dikes are clearly post-Carboniferous, as they were not affected by the great post-Pennsylvanian deformation and they occupy joint fissures that were formed since the strata cut by them were folded. The rock of which they were composed is like that of dikes throughout the State and elsewhere that are commonly regarded as late Triassic, and the movement by which they were tilted and faulted was probably the block faulting that occured at the end of the Triassic period. Their age is thus determined fairly closely.

QUATERNARY SYSTEM

GENERAL RELATIONS

Nearly the whole land surface of the two quadrangles is occupied by surficial deposits of Quaternary age, part of them Pleistocene and part Recent. Those of Pleistocene are mainly glacial, and those of Recent age comprise the ordinary alluvial and marine deposits found in any area of the sort.

The Quaternary deposits are distributed throughout the area but attain their greatest thickness and extent in the Boston Lowland and the broader valleys. On the uplands their thickness ranges from a few inches to at least 60 feet and possibly more. In the lowlands their maximum thickness is unknown but is certainly several hundred feet. This blanket of Quaternary deposits lies upon and to a certain extent masks the inequalities in a bedrock surface of greater relief than the present land surface and fills old valleys that extend well below present sea level. In parts of the Boston Lowland the pre-Quaternary topography is too deeply buried to affect the present surface, but elsewhere the major features of the two correspond fairly well, except for such prominent glacial features as drumlins.

PLEISTOCENE SERIES

GENERAL CHARACTER AND DIVISIONS

All the known Pleistocene deposits of the Boston area are of late Pleistocene age, presumably post-Illinoian, and nearly all are of glacial derivation. They consist chiefly of glacial and associated deposits of Wisconsin age, but they include also marine deposits, some of which are of pre-Wisconsin and some of late Wisconsin age. Although it is possible that the area was invaded by one or more of the earlier ice sheets, no pre-Wisconsin drift has been recognized in it.

The Pleistocene deposits as mapped and described in this report comprise three groups—the pre-Wisconsin (?) deposits, the Wisconsin drift sheet, and the late Wisconsin marine deposits.

PRE-WISCONSIN (?) DEPOSITS

Much of the Boston Lowland is underlain by moderately hard blue clay. When the district was first settled by white men the clay was probably not exposed anywhere except in the channels of a few streams and tidal creeks, but throughout large areas it was covered only by a thin layer of alluvial soil, and thus it was encountered in many shallow excavations and scores of clay pits have been opened in it. In other large areas it is overlain by Wisconsin drift, and in much of the lowland it must form the floor on which that drift lies.

The formation consists of laminated blue clay of the sort commonly associated with the glacial deposits in the northeastern United States. In a few places it contains thin beds of sand and silt, but generally it is homogeneous. It is a still-water deposit, but so far as known bears no evidence whether it is marine or lacustrine. Its thickness ranges from a few feet to an unknown maximum, but it is probably not less than 200 feet thick in some places.

The clay ranges in altitude from 40 feet above sea level to an unknown distance below and forms the floor, beneath the silts of Recent age, of much of Boston Harbor and the tributary estuaries. It must constitute a large part of the material filling the hollows in the bedrock surface that are now below sea level, but whether it everywhere lies on bedrock or whether older Pleistocene deposits intervene in places is unknown. Its upper surface is also irregular and has a relief of at least 100 feet, but much of the irregularity is due to subsequent erosion.

No fossils have been found in the clay, although it may have been the source of the fragmentary marine fossils in the till of some of the drumlins in Boston Harbor. Its age has been variously fixed, but the preponderance of evidence indicates a pre-Wisconsin or early Wisconsin age. Very little is known regarding pre-Wisconsin Pleistocene deposits in eastern New England, and it is unwise at present to attempt to fix the age of the clay more closely or to correlate it with deposits elsewhere.

WISCONSIN DRIFT

General relations.—The material deposited by the Labrador ice sheet of the Wisconsin stage forms a blanket over the surface of much of the area. In the more rugged uplands, where the bedrock surface is very rough, the drift blanket is thin and is interrupted by large areas of bare rock, and this is true of much of the coast also. In parts of the Boston Lowland the Wisconsin drift is thin or lacking, except for the drumlins, and the Recent deposits overlie the blue clay or the bedrock with little or no intervening material.

The Wisconsin drift consists of ice-borne material ranging in coarseness from rock flour to boulders weighing many tons and in shape from angular blocks torn from the parent ledges to smoothly rounded pebbles. Most of the larger boulders are of local origin, many of them having been moved only a few yards and few of them having been carried more than 2 or 3 miles, but many smaller ones were brought from northern New England. Much of the finer outwash was also brought a long way, as the sand characteristic of it has been observed at Concord, N. H., and evidently came from some locality farther north. (See fig. 4.)

The drift comprises the usual assemblage of ice-laid deposits or till, glaciofluvial outwash, and glaciolacustrine deposits, all occurring in the forms characteristic of glacial topography, some of which have received names. The several sorts of deposits and their characteristic topographic forms are not everywhere well separated but in many places merge into those adjoining. Hence they are difficult to map, because of their intricate relations and the impossibility of drawing definite boundaries between them. The surficial-geology map in this report is therefore much generalized, and deposits of similar character, not clearly separated, are shown in patterns of the same color, without boundary lines between them.

Because of the complex morainal topography it is not feasible, on a map of the scale here used, to differentiate the several recessional moraines, and the outwash and lacustrine deposits associated with each, according to their relative age, or to show the positions of the retreating ice front at its successive halts. Furthermore, in much of the area the glacial geology has been greatly obscured by human occupation, and it is not possible in such tracts to map the recessional moraines. Therefore no attempt has been made on the accompanying surficial geology map to indicate the order in which the moraines were formed.

General till sheet.—Much of the surface is occupied by a heterogeneous deposit of till, or ground moraine, either poorly or not at all stratified, containing many boulders and cobbles in a matrix of so-called boulder clay, although the boulder clay is in general notably sandy. This material was chiefly deposited directly on the surface by the melting of the stagnant ice of the waning ice sheet. It is rarely more than a few feet thick, but it merges, by increase in thickness and some change in character, into till moraines on the one hand and into drumlins on the other. Ordinarily it constitutes merely a blanket on the underlying bedrock, the configuration of whose surface is the controlling factor in the topography, but in some places it attains thickness enough to form low, irregular knolls and hillocks that are independent of the bedrock relief.

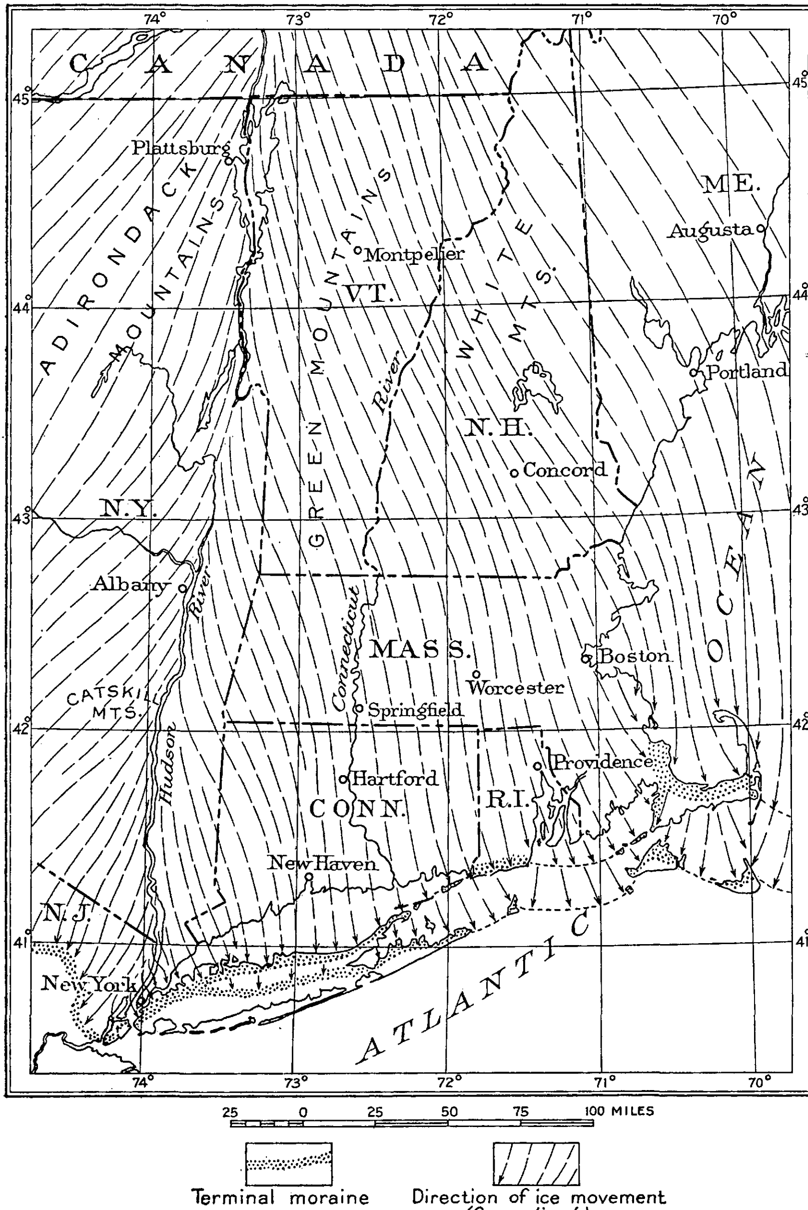


FIGURE 4.—Map of parts of New England, New York, and New Jersey, showing directions of movement and terminal moraines of the last great ice sheet. (Compiled by W. C. Alden.)

The till sheet occupies the areas between the morainal belts. Nearly everywhere it lies directly on the bedrock, and each belt of it is overlapped by the outwash and lacustrine deposits associated with the next younger moraine.

Drumlins.—The drumlins are smooth oval hills of ground moraine or subglacial till, as a rule more clayey and more stony than the general drift sheet. About 180 such hills have been recognized in the Boston area, and nearly all are situated in the Boston Basin or on its southern and southwestern margins. (See pl. 12, *A*, and fig. 5.) In some parts of the basin they form irregular, more or less coalescent groups; in other parts they stand in ill-defined rows a few miles long; and elsewhere single drumlins are scattered at random. There are very few in the large areas of outwash and alluvial deposits or in the tidal marshes.

Their length, which may be as much as three times their width, ranges from a few hundred feet to nearly a mile, and they stand 10 to 150 feet above the surrounding territory. The highest point in Boston—330 feet above sea level—is the summit of Bellevue Hill, a drumlin in West Roxbury, and the highest point in the Boston Basin—340 feet—is the summit of Lyman Hill, in Brookline. The average trend of the longer axes of the drumlins is about S. 55° E., approximately the direction of the latest movement of the ice, and in the Boston area only a few have trends differing notably from the average. Where they form chains or rows the trend of the row is about the same as that of the drumlins.

The drumlins are composed of rather compact stony till with little evidence of stratification, although in some the finer material is somewhat obscurely stratified. Some geologists have regarded the drumlins as made up of a core of pre-Wisconsin till and a coating of Wisconsin till, but so far as the author has observed there seems to be no warrant for this conclusion, the till of the drumlins being of essentially the same composition and condition throughout and showing no indication of having been deposited during two widely separated glacial stages. Some of the drumlins in the harbor contain fragments of marine fossils that probably were originally deposited in an older marine clay that was gouged out and transported by the Wisconsin ice and redeposited in the till of the drumlins.

Some drumlins were manifestly formed upon or against elevations in the bedrock surface, as rock is exposed about their bases or even high on their slopes; in others, some of which have been partly cut away, either artificially or by wave erosion, no bedrock is exposed. Furthermore, by no means all those drumlins that lie upon or against rock knobs are situated in the lee (southeast) of those knobs; in some of them rock is exposed along one or both sides of the hill, and in others it crops out at the southeast end. There is therefore no systematic relation of the drumlins to bedrock in the Boston area.

Till moraines and boulder belts.—The general till sheet is not everywhere a thin veneer but in many places forms knolls and hillocks whose surface form is their own. Many of these till hillocks are arranged in groups or belts which are closely associated with the kame and kettle belts that mark the halts of the receding ice front and which are, in fact, parts of the recessional moraines. The till in the hillocks does not differ especially from that of the till sheet and

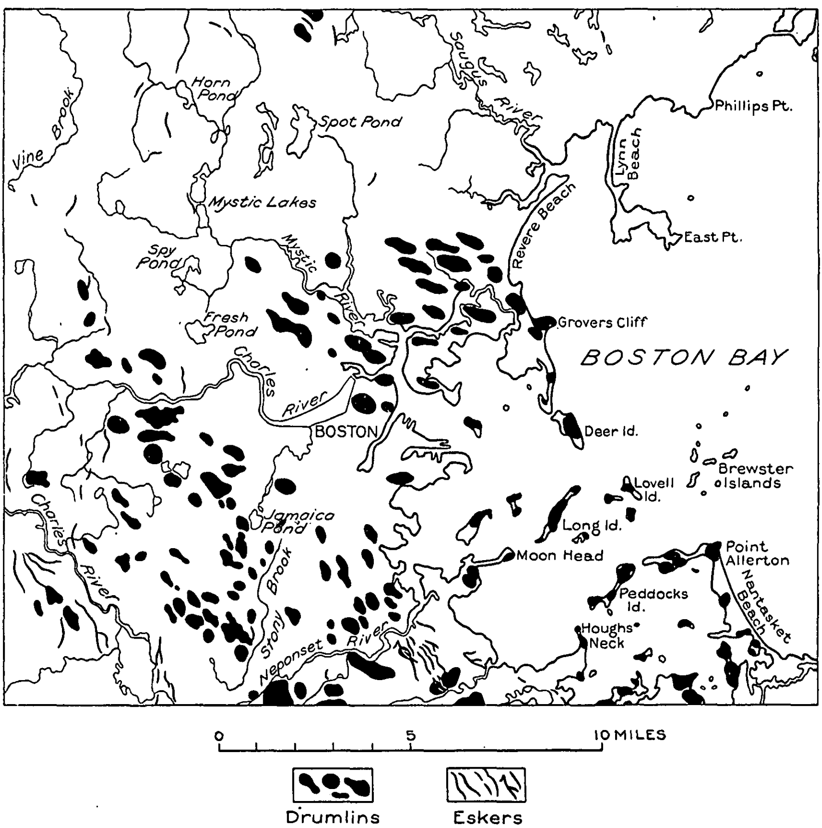


FIGURE 5.—Distribution of drumlins and eskers in the Boston area

consists of material deposited in place, with little or no transportation by water, from the lower part of and beneath the stagnant ice. Belts of large boulders, which are associated with the till moraines in some places, are also among the features which, collectively, make up the recessional moraines of the district.

Because of the relief of the surface on which the melting ice lay and the probably considerable irregularity in the form and thickness of the stagnant ice itself, the till moraines and the kame moraines are closely associated and grade into each other. In many places stratified and unstratified materials are so mixed that the deposit as a whole is neither the one nor the other, and whether it should be classed as till or outwash is largely a matter of judgment.

Kame and kettle moraines.—The till moraines are associated with and grade into outwash deposits of irregular thickness and surface form that have the characteristic "knob and kettle" topography which is perhaps the most distinctive feature of the Wisconsin drift. These belts of kames and kettles are the most characteristic and persistent components of the recessional moraines of the district. They are formed of gravel and moderately coarse sand and are as a rule well but irregularly stratified, cross-bedding and lenses being abundant. In general small boulders are not uncommon, both in the beds and on the surface, although notably large boulders are scarce. Much of the kame material was deposited upon or about masses of stagnant ice and slumped as the ice melted, hence both the surface form and the internal structure of the kame moraines are more irregular than when the material was deposited.

The kame and kettle moraines grade into till moraines on the one hand and into kame terraces and outwash plains on the other hand. They are partly overlain by late Pleistocene lacustrine deposits and Recent alluvial deposits, and the kettle holes and other low places contain many small irregular patches of such deposits, most of which have been omitted from the map.

Eskers.—Eskers are fairly numerous in the Boston area, being commonly associated with the moraines, of which they are striking features, although they add little to the bulk of the deposits. They are abundant in a belt along the west side of the Boston quadrangle and in an area in the southeastern part of the quadrangle, in Milton and Quincy. They are rare in the higher parts of the uplands, as they tend to follow lower ground. They are also rare in the broad alluvial areas and tidal marshes of the Boston lowland, although some partly buried eskers are found in those areas, and not improbably others are wholly buried by the later deposits. Undoubtedly some have been obliterated in the settlement of the district, as they are a convenient source of road material and are easily removed.

The eskers of the Boston area range in size from low, hardly noticeable ridges a few hundred feet long to bold "horsebacks" nearly 100 feet high and a mile or more long. The best known and probably the largest is the Auburndale esker, which lies across the western margin of the Boston quadrangle. It originates in a group of kames in Auburndale, runs southwestward and then southeastward about a mile, and merges with the sand plain on which most of Waban is built. (See pl. 13.)

Most of the eskers begin rather abruptly and fully developed, but some begin in groups of kames, and a few emerge from beneath the margins of later sand plains. Most of them wind through kame fields, and some lose themselves among the kames, without definite terminations. Some end abruptly or die out against hillsides covered with till, the further courses of the depositing streams probably having been across ice and having such steep grades that no material was deposited. Still others disappear beneath later lacustrine or alluvial deposits. Many eskers, however, merge with small deltas or large sand plains, and the points of escape from the ice of the streams that formed the eskers are fairly obvious. None of the typical eskers of the district show any evidence of having been modified by marine submergence during the disappearance of the ice, and none are overlain by marine deposits, except those that are partly buried by the Recent tidal marshes.

A number of eskers are shown on the surficial-geology map, but probably by no means all the eskers in the area have been mapped. Most of them traverse kame fields, where small or poorly developed eskers are not easily distinguished from other types of gravel ridges. Furthermore, because of the steep slopes and the coarse gravelly soil most of the kame and kettle areas are not cultivated and are largely covered with thickets of scrub oak, sumac, and other small trees, and in such a thicket a small esker might easily escape recognition.

Outwash plains.—A large part of the area covered by Wisconsin drift, especially in the lowlands and the valleys, is occupied by deposits of outwash sand and gravel, some of which cover several square miles. Some of these deposits were laid down close against the ice and are associated with and in a way form part of the recessional moraines; others are valley trains—the flood plains of streams that flowed from the melting ice and deposited material for long distances from the ice front. The plains formed in contact with the ice are also of two sorts—those of the general nature of deltas, where the material was deposited in glacial lakes, and those of the general nature of alluvial fans, where it was deposited on land. Where they are typically developed and their relation to the ice can be determined the plains of the different sorts can generally be distinguished, but they merge into one another, both laterally and vertically, in many places where no definite lines can be drawn between them. On the surficial-geology map in this report all the outwash plains are indicated by the same color and symbol.

The deposits of the outwash plains consist of fine gravel, sand, and fine silt, but nowhere of true clay. The delta plains are in general regularly stratified but display some cross-bedding. The apron plains and valley trains are less regularly stratified and contain abundant cross-laminated and lenticular beds. Boulders are scarce in the bedded deposits but are not uncommon on the surface of the delta plains.

The typical delta plains have rather steep lobate margins, breaking down in places into groups of kames which probably mark the former positions of buried ice masses. Both the top-set and the fore-set beds are well developed, and in certain plains whose surface has not been artificially modified some distributary channels can still be seen. There has been some slumping of very steep ice-contact slopes, but true back-set beds are rather rare, and most of the contact slopes where the plains were built against steep faces of ice are well preserved. Where a delta deposit lapped on a sloping ice foot its margin is now a kame and kettle belt, and pitted plains are common. The pitted plains are not confined to the areas close to ice contacts, as the shallow, saucerlike kettle holes that are interpreted as marking the former positions of small buried ice lumps may occur anywhere in the delta plains and are found even in the valley trains.

Lacustrine deposits.—During the melting of the ice sheet lacustrine deposits were formed wherever the topographic conditions permitted. Some of them were soon covered by outwash, and their existence is revealed only by chance in stream cuts and artificial excavations. Those not so buried are nearly everywhere overlain by Recent alluvium, but the Recent deposits are generally thin, and the lacustrine deposits beneath are revealed in shallow excavations and in some places merely by plowing. They consist of fine sand, silt, clay, and a few thin layers of peaty material. In many places they grade upward into the Recent alluvium.

Practically all the Pleistocene lacustrine deposits that can be identified as such are lake-bottom beds, and in only a few places have beach deposits been suspected. Probably beaches were formed about the larger glacial lakes, but most of them have since been buried by wash from the surrounding slopes. A notable feature of the lake beds, where they consist of clay, is their relative imperviousness, to which is due the continued existence of many ponds and wet bogs in undrained or poorly drained kettles and ice-block holes among porous outwash deposits.

LATE WISCONSIN MARINE DEPOSITS

General relations.—Some parts of the area northeast of the Saugus River are occupied by marine deposits of late Wisconsin age, consisting partly of till and outwash reworked by the waves into beaches and spits and partly of clay carried out by glacial streams and deposited in coves and inlets. These materials are generally overlain by thin deposits of Recent age, into which they grade in places, and are exposed only in stream cuts and artificial excavations. As the reworked material also grades downward into undisturbed glacial deposits its mapping is largely a matter of judgment. For these reasons the marine deposits are mapped only in areas where they are practically the surface formations.

Beaches and spits.—Only one beach of Pleistocene age has been identified in the Boston area. This extends northward from the rocky headland of Phillips Point to the eastern foot of the upland that occupies the central part of Swampscott and thence swings northeastward in a sweeping curve to Beach Bluff. It is a broad, low swell whose crest is now 25 to 35 feet above sea level. The part extending northward from Phillips Point has a nearly symmetrical cross section and appears to have been a wave-built beach that joined the former island of Phillips Point to the mainland. On both sides it slopes down gently to marshy areas, now partly reclaimed. The ridge curving northeastward to Beach Bluff is higher and unsymmetrical in cross section. On the seaward side it slopes gently down to the marsh and present beach, but its back or landward slope is steeper and more irregular. This part of the old beach extends along a till ridge that probably was a recessional moraine, deposited when the ice front stood in the sea and submerged and reworked on the surface when uncovered by the melting of the ice. The same moraine extends northeastward through Clifton but is there higher and was not submerged and reworked.

Marine clay.—Several small areas in Lynn, Swampscott, Marblehead, and Salem, lying below the 20-foot contour, are underlain by marine clay that extends below the present sea level. This clay is nearly identical in general character with the clay of the Boston Lowland, and the two have sometimes been regarded as the same. It is, however, fossiliferous and is regarded by the author as part of the "Leda clay," which is extensively developed along the coast of Maine, New Hampshire, and northeastern Massachusetts and is definitely determined to be of late Wisconsin age. The clay in the brick pits along Revere Brook in West Lynn, which contains late Pleistocene fossils, seems to be the southwesternmost area of "Leda clay" still remaining above sea level, but not enough is yet known about the extent and relations of the Pleistocene marine clay in southern Essex County to permit stating its age and correlation with full assurance.

RECENT SERIES

ALLUVIAL DEPOSITS

Alluvial deposits of Recent age, ranging in thickness from a few inches to 6 feet or more and in area from patches of less than an acre in extent to those covering several square miles, abound in all parts of the Boston area above the present reach of high tide and in many places extend outward beneath the tide marshes to an unknown distance and depth. They lie both in the lowlands and in the uplands but are more abundant and larger along the courses of the

111895—32——5

main streams, particularly where the streams have been forced to find their way through or among the morainic deposits.

The alluvial deposits are of two sorts—(*a*) flood-plain deposits of sand and silt and (*b*) swamp and marsh deposits of silt, muck, and peat. The flood-plain deposits, which are of minor extent in the Boston area, occur in narrow strips along some of the streams and along the bases of the slopes surrounding some of the swampy tracts. The fresh-water swamp and marsh deposits are much more extensive and are more important in relation to human activities. At present they occupy a total area in the two quadrangles of not less than 7 square miles, and they were originally of greater extent, but large tracts, especially in the Boston Lowland, have been reclaimed. The alluvial deposits of the two sorts grade into each other and are interbedded in many places, and both grade downward into similar deposits of late Pleistocene age.

MARINE DEPOSITS

Recent marine deposits occupy a large part of the shore and extend inland to the limit of the areas invaded by the highest tides. They also are of two sorts—(*a*) wave-formed beach and spit deposits of sand and gravel and (*b*) tide-marsh deposits of silt, muck, and peat. Deposits of both sorts are still in process of formation, although the areas of both have been somewhat reduced in the last century by artificial changes of coast line. The beaches consist mainly of sand, with some fine gravel here and there, but a few "pocket beaches" are built almost wholly of gravel or shingle. The sand on the higher parts of the beaches and behind them has been more or less shifted about by wind, but true sand dunes are almost wholly lacking and the few that exist are small and inconspicuous. Spits of gravel or sand, laid bare at low tide, extend outward from some of the points and from some of the islands in Boston Harbor, and reefs of boulders, too large to be removed by the waves, lie at the bases of the cliffs where drumlins have been partly destroyed by the waves and the finer material of the till has been washed away.

Marine marsh deposits at present occupy a total area in the two quadrangles of about 8 square miles, and they were formerly much more extensive, large areas about the head of Boston Harbor and the estuaries of the Charles and Mystic Rivers having been converted into "made land." The marsh deposits consist mainly of peat and vegetal detritus but contain considerable mud and silt in the interstices of the peaty matter. Throughout a large part of the marshes the deposit is thin, and it feathers out along their landward margins, but a thickness of 14 feet of marine peat has been found by boring in a small marsh at Nahant.

In a few places tide-marsh deposits are overlain by sand blown back from barrier beaches, and in a very few places where all the conditions are favorable they are overlain along their landward margins by rain-washed alluvium from steep bordering slopes. Nearly everywhere, however, marine deposits form the surface of the marshes at the present time and are being added to at nearly every high tide. The marine deposits are underlain in some places by fresh-water marsh deposits, in some places by Pleistocene clay beds, and in some places by till and glacial outwash of Wisconsin age. The surface on which they were deposited is irregular, and islands of rock or of glacial deposits project through some of the marshes and break the evenness of their surfaces.

STRUCTURE

GENERAL CONDITIONS

The hard rocks of the Boston area are not in their original attitude and relative positions but have been greatly deformed and displaced. Hence the geologic structure is complicated and difficult to interpret, especially as so much of the bedrock is covered by surficial deposits. The principal structural features are folds and faults, and the minor features include joints, fissility, and schistosity, although evidence of dynamic metamorphism is not generally conspicuous except in those rocks regarded as pre-Cambrian.

Probably all the hard rocks, except some of the diabase dikes, are more or less folded. Outside the Boston Basin, as the formations are largely igneous and are of irregular and discontinuous distribution, the character of the folding and main structural features, aside from trend, can not well be determined. Within the basin, where the rocks are mainly sedimentary, the major features have been worked out, but owing to complicated faulting in some areas and the scarcity of outcrops where surficial deposits occupy most of the surface the details of the structure defy interpretation. This is particularly true in the southern half of Newton and in parts of Brighton, Quincy, Weymouth, and Hingham, where the strata have been fractured and tilted in different directions to form a patchwork of blocks without determinable structural relations to one another.

FOLDS

In the Fells Upland the formations have a general northeasterly structural trend. Bedded rocks that presumably were originally level are now tilted, in places considerably, and as their strike conforms in general to the regional trend, they are presumably folded, even though the folds can not be traced. The dip is generally northwest, and the beds are supposed to be folded and overturned southeastward toward the Boston Basin.

In the Needham Upland the general structure is anticlinal, but little can be learned regarding its detail.

The Boston Basin is a synclinorium having a rude fan structure much complicated by faults. The general trend of the folds, as of the basin itself, is northeasterly, ranging to easterly and even a little southeasterly in some places. The folds pitch eastward and carry the Roxbury conglomerate below sea level, and the basin is therefore deeper beneath Boston Bay than on the land and may extend far eastward beneath the Gulf of Maine.

The central part of the basin is a broad, flat-topped anticline—the Roxbury anticline—of Roxbury conglomerate, with minor folds on its flanks, overturned on both sides toward the main axis. The Roxbury anticline pitches eastward, and the conglomerate passes beneath sea level near Savin Hill in Dorchester. The northern flanking fold—the Brighton anticline—is lost beneath the Quaternary cover in Brookline, and the southern one—the Needham-Savin Hill anticline—extends into the harbor, the conglomerate passing beneath sea level just east of Savin Hill. These three anticlines together form a central upfolded belt called the Shawmut arch.

The northern part of the basin is a generally synclinal area of Cambridge slate—the Mystic trough—which widens rapidly and probably also deepens eastward. The underlying conglomerate is exposed in only one of the folds—the Mount Auburn anticline—and at only one place, in East Watertown, but the lithologic character of the slate north of College Hill, in Medford, indicates that its base is there not far below the surface. The Roxbury conglomerate is not exposed along the northern margin of the basin, and that part of the trough is probably cut off by a thrust fault.

The southern part of the basin is also mainly a down-folded belt of Cambridge slate, which also widens and deepens eastward but is more closely folded and more complex than the Mystic trough. The underlying conglomerate is brought up along several minor folds, as well as along part of the southern margin of the basin, where most of it is cut off by a fault and only the uppermost part remains.

FAULTS

Faults are among the most abundant and characteristic structural features of the area and have had a marked influence on its structural development. Altogether there must be hundreds of faults in the rocks of the area, but most of them are small and are concealed by surficial deposits. Some small faults can be seen in outcrops, and in a few places short stretches of some of the main faults are exposed.

The main faults are, however, chiefly hypothetical, although they are necessary postulates in the interpretation of the structure.

The faults of the Boston area are of two general sorts—thrust or compression faults, which have the same general trend as the main structural features of the region, and normal or tension faults, which have a general trend approximately perpendicular to the main structural trend. The normal faults are nearly everywhere clearly younger than the others, and some are certainly much younger, though it is not certain that all are.

The Boston Basin is bounded along its northwest side by a profound fault, which is believed, from the general relation of the formations, to be a thrust fault. Several other thrust faults probably traverse the rocks of the Fells Upland, and a number of them add to the complexities of structure in the Roxbury conglomerate anticlines. North of the axis of the central anticline the direction of overthrust, both within and without the basin, appears to have been from the northwest, and the faults are probably not very steeply inclined. South of that axis the upthrow is on the south instead of on the north, but the main faults, including those that bound the basin along part of its south side, are highly inclined, if not vertical, and may possibly be interpreted either as steep overthrusts or as normal faults. Here, as in other parts of the Appalachian region, the structure of so small an area as two quadrangles can be only tentatively explained until that of a considerable surrounding region has been studied, and as yet very little is known of the geologic structure of the quadrangles next south of the Boston area.

Most of the normal faults of the younger set that are exposed are small, having throws of a few feet at most, along north-south joints or along the walls of Triassic diabase dikes. The areal and structural relations of the rocks in the Boston Basin make the existence of large faults of nearly north-south trend and of major importance as structural features highly probable. Several such faults are mapped in the western part of the Boston quadrangle and others are believed to exist in the southern part of the Boston Bay quadrangle.

JOINTS

The most conspicuous structural features of the rocks of the Boston area are the joints, which cut all the hard-rock formations except the Triassic dikes and which are so abundant that outcrops in which the rock is not cut by joints are very scarce. At least three principal sets of joints and generally one or two incipient or partly developed minor sets can be observed in almost every formation, and five or six sets are well developed in the Cambridge slate, the norite of Nahant, and some of the rhyolites. Throughout the area the master joints have an approximately north-south trend, and joints of this set are found nearly everywhere. The number of other sets that are developed, the particular sets that are developed, and the angles at which they intersect one another depend partly on the formation and partly on the geologic structure.

The universality of the jointing and the fact that many joints pass from one sort of rock to another without change in direction or character show that the joint system as a whole is regional rather than pertaining to individual formations. The perfection of development of the joints regardless of the kind of rocks in which they occur is also a striking characteristic. Even the Roxbury conglomerate, a rock of conspicuously heterogeneous composition and texture, is traversed by numbers of clean-cut, smooth joints that intersect the hardest pebbles, which remain firmly embedded in the matrix. (See pl. 9, *A*.) The joints are therefore plainly the result of the deformation of the rocks and not of their shrinkage while cooling or hardening. They are believed to be due to torsional stresses produced by slight but comparatively rapid crustal warping.

In some of the more massive igneous rocks the average distance between parallel joints is several feet, but in some of the rhyolites and in parts of the Cambridge slate the joints of at least one set are closely spaced, on the average not more than an inch apart. The fine-grained portions of such rocks, if three or more sets of joints are about equally well developed, are cut into small smooth-sided polyhedral blocks resembling large crystals. Measurements of the interfacial angles show, however, that the faces have no systematic mutual relations and that apparently parallel faces really diverge from parallelism by several degrees. Furthermore, although the faces of the small blocks appear to be planes, practically all the joints, when traced for more than a foot or so in the outcrops, prove to be curved surfaces rather than planes.

METAMORPHIC CHARACTERS

All the hard rocks of the Boston area except some of the diabase dikes show the effects of regional metamorphism to a slight degree, but, except in the pre-Cambrian rocks and aside from the fissility that is developed nearly everywhere, metamorphic characters are rarely conspicuous. The pre-Cambrian rocks are nearly all gneissic or schistose and were probably considerably metamorphosed before the other rocks of the region had been formed. The Paleozoic rocks are nearly everywhere slightly metamorphosed but rarely more than slightly.

The most conspicuous metamorphic character of the rocks is a fissility, akin to slaty cleavage but different from it in some respects, which is developed to a greater or less extent in almost all the Paleozoic rocks of the district but is most pronounced in the formations that occupy the Boston Basin, especially where those formations have been closely folded or strongly faulted. Although there are some local variations, nearly everywhere in the area this fissility strikes northeast and dips rather steeply northwest, no matter what may be the attitude of the rock in which it is developed. Like the joint systems, it is, therefore, the result of regional deformation and not peculiar to certain rocks. True slaty cleavage has not been noted in the area but is fairly well developed in portions of the Braintree slate just outside the area, in the Abington quadrangle, and in the Cambridge slate in the Framingham quadrangle.

STRUCTURE SECTIONS

The locations of the structure sections shown on Plate 1 were chosen to illustrate the geologic structure of the Boston quadrangle and, as far as possible, the manner in which that structure was developed. As there is relatively little land in the Boston Bay quadrangle and the exposures of stratified rock are separated by wide stretches of water, structure sections in that quadrangle would be mainly hypothetical, hence none have been prepared.

The sections show the rocks roughly as they would appear in the sides of deep trenches cut across the country. The lines A–A′, B–B′, etc., on the map show the positions of the sections. The vertical and horizontal scales are the same, so that the sections show the relief and slope of the land surface, as well as the attitude of the rocks, in true scale. The sections represent the structure as it is inferred from surface observations of dip, strike, and other features, except that the scale of the map does not permit the minute details of structure to be shown. Each section is generalized from data plotted in a belt of some width and projected into the plane of the section. Where the strike of a tilted bed or structure is oblique to the plane of the section the projected dip, as shown, is less than the true dip. A fault is shown on the map by a heavy solid or dashed line and in a section by a heavy line whose inclination shows the probable hade of the fault, the arrow indicating the direction in which the displaced block moved.

Sections B–B′, C–C′, and F–F′, extend from the Fells Upland into or across the Boston Basin. These show not only the differences in the kind and attitude of the rocks but also the differences in attitude and relief of the two geomorphic divisions. However, owing to the relatively small relief of the whole area, the last-named differences are not well brought out on profiles drawn on the scale of the map and without vertical exaggeration. These sections show the supposed overthrusting of the rocks of the upland onto those of the basin, so that the Roxbury conglomerate does not reach the surface anywhere along the northern margin of the basin within the quadrangle. Sections F–F′ and G–G′ extend from the basin into the area of Quincy granite on the south and show the cutting out of the basal part of the Roxbury conglomerate by the southern boundary fault. Sections B–B′ and C–C′ cross the anticline of pre-Carboniferous rocks forming the floor of the basin in the Hyde Park region and show its present structural relation to the rocks of the basin. The scale of the sections does not permit the showing of details of folding or the intricate relation to the Roxbury conglomerate of some of the bodies of Brighton melaphyre. Sections B–B′, C–C′, and E–E′ indicate something of the structural relations of the rocks of the Fells Upland, but in view of the large areas of rocks without outcrops and the very few exposures of actual contacts between formations the relations shown in these sections are largely conjectural.

GEOLOGIC HISTORY

PRE-CAMBRIAN TIME

The history recorded in the rocks of the Boston area begins with the formation of the pre-Cambrian rocks. The stratified rocks of pre-Cambrian age must have been deposited on a floor of older rocks, of which nothing certain is known. Within the area so little is left of the pre-Cambrian rocks and their relations are so obscure that not much can be learned regarding their history, which, however, can be partly reconstructed from evidence gathered in adjacent districts. Stratified rocks of pre-Cambrian age are found in most parts of eastern North America where the floor beneath the Paleozoic strata is exposed, and they are believed to have been deposited over a large area. Because of the rather widespread occurrence of beds of limestone among them they are usually regarded as having been deposited in the sea. In New England, as in some other areas, deposition was accompanied by the eruption of lava flows and the formation of beds of tuff.

The Boston area was probably entirely covered by pre-Cambrian rocks, largely of volcanic origin, although the location of the volcanic vents is unknown. As the relative age of the Waltham gneiss and the other pre-Cambrian rocks has not been determined, the gneiss may be a part of the floor upon which the other rocks were deposited, or it may consist of plutonic rocks whose intrusion followed the volcanic eruptions and ended the eruptive period.

The formation of the pre-Cambrian rocks was evidently followed by a period of great deformation, probably accompanied by mountain building, during which the rocks were much sheared and metamorphosed. Although there is no evidence to that effect in the Boston area, it is believed that the deformation was followed by a long period of erosion during which the region was reduced to a surface of comparatively slight relief.

CAMBRIAN PERIOD

Early in the Paleozoic era the worn-down pre-Cambrian land surface had been submerged and was receiving marine deposits. The outline of the sea of that time can not be determined, but the distribution of the Cambrian strata now remaining in eastern Massachusetts indicates that it probably covered much if not all of southeastern New England, at least during Lower Cambrian time. The deposits were at first chiefly sand or sandy mud, but they contained lenses of clay and of calcareous ooze, and the remains of several species of marine animals, especially mollusks and crustaceans, were buried in them.

In Middle Cambrian time the deposits became almost wholly clay, containing only a little sand and calcareous material, and the animals whose remains have been found preserved were mainly trilobites. As Middle Cambrian strata are now found only in the Boston district the sea of that time may have become restricted, in southeastern New England, to a rather narrow bay or strait.

In Upper Cambrian time the character of the deposits again changed, this time to quartz sand, and the remains of only a single species of brachiopod have been found preserved. The Upper Cambrian sea may not have covered the Boston area, but that it lay not far to the southeast seems fairly certain. (See appendix.)

ORDOVICIAN AND SILURIAN PERIODS

The history of the Boston area throughout most if not all of the Ordovician period is unknown, and no light is thrown on it by observations in other areas, as there are no positively identified Ordovician rocks in New England east of the Appalachian Valley. How great a thickness of Cambrian strata was deposited in eastern Massachusetts, whether deposition continued in Ordovician time or was terminated by uplift, and whether the uplift, when it did occur, was merely crustal warping or was a great deformation are equally unknown. All that is certain is that by the beginning of Devonian time the region had long been dry land and had undergone long-continued and profound degradation.

During some part of this interval the rocks of the early Paleozoic igneous complex were formed. They are all of plutonic or hypabyssal types and according to the commonly accepted idea must have been intruded beneath a thick cover of rocks of some sort. The available evidence indicates that nearly everywhere this cover consisted of the metamorphic rocks of pre-Cambrian age, which, although highly deformed, presumably still occupied most, if not all, of the region. There is no evidence that the igneous rocks reached the surface and no certainty that they invaded Cambrian strata, though such invasion is suspected.

Many masses of rock of different size and composition were irrupted, but there was a general progression in composition from less to more silicic types. The reasons have already been given for regarding all these rocks as parts of a single eruptive group and hence as having a common magmatic origin. The problem of the magmatic differentiation of these rocks has been studied by several geologists, most of whom have regarded it as having occurred in place or nearly so. Attempts have been made to explain it as having been caused by cooling against the wall rocks, by assimilation of part of the wall rocks, by zonal fractionation in laccolithic masses, and by gravitative fractionation in batholithic masses of great depth. Probably some differentiation did occur on a small scale and locally in each of these ways, but none of them is sufficient to account for the differentiation of the whole group throughout its geographic range. Again and again the overlying rocks and even the first-formed rocks of the group itself were invaded by intrusive masses. The older rocks of the group had long been solidified when they were invaded by later rocks of the same group, and the irruption of the whole group must have occupied a large part of a geologic period, or perhaps even longer.

Clearly, therefore, no theory of differentiation in place based primarily on the supposed structural relations of the different types of rock will suffice to explain the phenomena. From a study of the geographic distribution of the types of rock in the group throughout its range, as well as their structural relations, the author is of the opinion that the differentiation must necessarily have taken place in a primary magmatic chamber that probably underlay the whole region. Gravitative fractionation may have been a considerable factor, but the differentiation was probably also due partly to assimilation of the invaded rock. Both processes would tend to cause a progressive change in the composition of the parent magma, which was basaltic at first, toward the silicic end of the scale, until at length, when the final solidification occurred at the end of the eruptive period, the irrupted masses had the composition of aplite.

The invasion of the overlying rock by the parent magma did not take place in a single great engulfment. Many dikes, plugs, and small batholiths successively invaded the overlying rocks and solidified, some of them to be themselves invaded in turn. As the composition of the magma grew more silicic the lithologic character of the intrusive masses changed accordingly, and as the later masses not only invaded the early ones but penetrated farther into the overlying rocks, the granite is now the most abundant and widely distributed rock of the group.

Whether the irruption of the plutonic rocks was accompanied by either volcanic outbreaks or mountain-building deformation can not be determined, as degradation has removed the evidence, if any ever existed. It was, however, followed by a long period of quiescence, during which the land was profoundly degraded, much of the cover which the plutonic rocks invaded was removed, and the plutonic rocks themselves were exposed and deeply eroded. Upon the land surface thus produced the volcanic rocks of probable early Devonian age were deposited. Hence the degradation of the surface must have been going on during the Silurian period and, inasmuch as it probably amounted to several thousand feet, it must have occupied most of the period. The irruption of the plutonic rocks presumably occurred in early Silurian time or even still earlier, in the Ordovician period.

DEVONIAN PERIOD

At the beginning of the Devonian period the surface of the region was land that had long been subjected to weathering and erosion. Its surface was occupied largely, but not wholly, by the Dedham granodiorite, which was deeply weathered and partly disintegrated. Upon this surface the volcanic rocks of probable early Devonian age were deposited. Whether the surface was low and flat or had considerable relief and whether the volcanic rocks were deposited over the whole of a wide area or were accumulated only about centers of eruption can not now be determined. There are some indications, however, that the surface had some relief and that the deposition of the volcanic rocks was rather localized.

There is, indeed, some reason to believe that early in the Devonian period minor crustal warping had already begun, the forerunner of the great deformation that culminated at the end of the Carboniferous period. The surface was probably broadly warped into troughs and swells, which, in Carboniferous time, became respectively the basins and the uplands separating them. This warping probably became more marked and more sharply localized throughout Devonian time, so that by the end of the period the future basins were fairly well defined. Even at first the areas in which the volcanic eruptions occurred and in which the volcanic rocks were deposited were probably controlled largely by the warping. In the Newbury Basin, in Essex County, the land was depressed so that the surface was beneath the sea for a time early in the period, but there is no indication that the whole region was so submerged.

The eruption of the volcanic rocks was followed and perhaps overlapped by the irruption of the plutonic rocks of the hornblende granite group (Quincy granite). The cover of older rocks thus invaded must have been rather thin, and there is some reason to believe that the main stock of Quincy granite nearly or quite reached the surface before solidification, hence the formation of the quickly chilled shell now constituting the Blue Hill granite porphyry. During the irruption of the plutonic rocks the degradation of the surface, including the newly formed volcanic rocks, was still going on, and with this series of events in progress the Devonian period came to an end.

CARBONIFEROUS PERIOD

In eastern Massachusetts Devonian time merged into Carboniferous time without sudden or marked change in the condition or attitude of the rocks and the surface. A change of some sort occurred, however, as in Devonian time erosion dominated and the transported material was mainly deposited elsewhere, but in Carboniferous time deposition was dominant and a great thickness of sedimentary material was laid down over much of the surface. Opinion is divided as to whether the Carboniferous beds were deposited in a continuous sheet that covered the whole region and extended indefinitely northeastward and southwestward or in several basins that were nearly or quite separate. Everywhere there was a general progression in the character of the strata from siliceous and rather coarse to argillaceous and rather fine, and when the belief prevailed that the strata are marine, belief in their original extension over the whole region also prevailed. No marine fossils are found in any Carboniferous rocks in the region, however, and it is now believed that the deposits are lacustrine and terrestrial. It is also now recognized that, although there is a general similarity in the sequence of the strata in the several basins, such similarity is to be expected whether the sediments were marine or terrestrial, and that the basins differ greatly in the detailed character and succession of the beds and in the abundance or rarity of fossils. In the Boston Basin fossils are so scarce that it is not certain whether the strata are Carboniferous.

The deformation that seems to have begun in early Devonian time presumably continued through the Devonian period, so that by the beginning of Carboniferous time the surface of the region had considerable relief and variety of form. In the Boston area the relief must have been fairly strong, as the basal strata appear to be torrential deposits of material of local origin. Although the Roxbury conglomerate contains pebbles of nearly every sort of rock in the district except Quincy granite and the later diabases, it contains none that need have been transported more than a dozen miles, although some may have come much farther. In many places the base of the conglomerate is composed largely of pebbles of the sort of rock constituting the underlying formation. As most of the pebbles are well rounded these facts used to be regarded as evidence that the deposit is of marine origin, and it was interpreted as being largely a shore formation. In the absence of other indications of marine origin that hypothesis has been abandoned, and the formation is now regarded as terrestrial and perhaps in part lacustrine. The discovery that part of the conglomerate is tillite has thrown new light on the problem, and the formation is now regarded as being mainly of glacial origin. Much of the formation is believed to have been outwash gravel laid down in front of an advancing glacier which overrode the gravel for several miles and on melting deposited the till that now forms a part of the conglomerate. The intercalated beds and lenses of slate and conglomerate are probably mainly lacustrine strata deposited in temporary lakes in front of the ice.

So little tillite is left and it is so greatly disturbed by folding and faulting and cut by erosion into separate masses that it is unsafe to do more than conjecture regarding the position and the direction of movement of the glacier by which the till was deposited. There are some indications that the ice came from the east or southeast into what is now the Boston Basin but that it did not occupy the entire area of the basin. No tillite has been found in the southwestern part of the basin, and all the conglomerate in that part appears to be of the ordinary sort. The rock types represented in the pebbles and boulders in the tillite can all be found within a few miles. Quite possibly much of it may have been picked up by the ice from the gravel now forming the lower part of the Roxbury conglomerate, over which the glacier advanced across the basin.

The suggestion that the glacier may have come from the southeast is partly supported by the peculiar character of the Dighton conglomerate, the uppermost formation in the Narragansett Basin in southeastern Massachusetts. That formation contains pebbles and small boulders of muscovite granite and of quartzite, and the quartzite contains fossils of Upper Cambrian age. The source of both sorts of rock is unknown, but the pebbles of both are larger and more abundant toward the southeast side of the basin, seemingly indicating a source in that direction. The suggestion has been made that the Dighton conglomerate is also of glacial origin, but no unmistakably glacial characters have been found in it. Such data as are available seem, therefore, to indicate that there was then a mountainous region southeast of the Boston and Narragansett Basins, from which the streams brought detritus derived from formations not now exposed in Massachusetts and from which a piedmont glacier descended to and spread some distance over the lower country and deposited the till that now forms a part of the Roxbury conglomerate. During the melting of the glacier the Boston Basin appears to have been occupied by a lake in which was deposited a great thickness of glacial clay, containing a few thin beds of sand, which now constitutes the Cambridge slate.

LATE CARBONIFEROUS DEFORMATION

The Carboniferous period ended with a great mountain-building movement that affected most of eastern North America. The rocks of the Boston district, in common with those of the rest of New England, were closely folded and compressed, and some of them were much metamorphosed. Some folds were overturned, and others were broken by strike faults that developed into overthrusts miles in length. The basins in which the Carboniferous strata had been deposited were deepened into synclinoria of complex structure, which, because most of the area is now covered by Pleistocene glacial deposits, can not be fully unraveled. The structure of the floor of older rocks upon which the Carboniferous strata had been deposited, already complex because of its previous deformation and the extensive igneous intrusion in early Paleozoic time, was made much more complex by the further folding and compression of the rocks. There was presumably considerable overthrusting in these rocks also, but it is almost impossible to determine such features in areas where the structure is so complex and exposures are so few.

The history of the Boston area during the deformation is a part of the history of the region in general and can not be interpreted without some knowledge of the regional history. However, as the Boston Basin borders the sea and is adjoined on the land side by areas of crystalline rocks of whose deformational history only the salient points can be determined, the story of the development of the structure of the basin must be read almost entirely from the rocks of the basin itself. The dominant stress during the deformation was clearly compressional and acted mainly along northwest-southeast lines. The general northwesterly dip of the bedded rocks of the Fells Upland and of the fissility or incipient cleavage that was extensively developed in the rocks of the Boston Basin and the greater overthrusting from the north than from the south indicate that the displacement was southeastward in the Boston district and immediately surrounding the area. As this is not true everywhere in New England, the course of events in the Boston area would appear to have been influenced largely by factors localized in eastern Massachusetts. Furthermore, the Boston Basin plunges eastward and may extend many miles beneath the sea. Possibly, therefore, the part of the basin now above sea level is only the west end of a large geosyncline and the structure of the part now exposed may not be typical of that now submerged. Hence it is somewhat hazardous to base conclusions regarding the deformational history of the basin on the only part that can be studied.

The compression first produced folding and buckling of the strata of the Boston Basin as the synclinorium developed. The number and position of the folds were probably influenced largely by local differences in the thickness and composition of the formations. Increasing compression resulted in further deepening and wrinkling of the synclinorium and in the development of an inverted fan structure, with several prominent subordinate anticlines. This compound character of the synclinorium is so marked in the part of the basin now above sea level that this part might almost be described as comprising two synclinal basins separated by an anticlinal arch. As the deformation continued the areas of crystalline rocks on each side of the basin were forced upward and inward in relation to the basin, so that the sides of the basin were crowded toward each other. This resulted in faulting along the margins of the basin, and the rocks on both sides were overthrust upon those of the basin. The greater displacement was toward the southeast, hence on the northwest side of the basin the dips of the faults are less and the crystalline rocks are overthrust farther than on the south side. One result of this difference is that the Roxbury conglomerate is not exposed anywhere along the northwestern margin of the basin within the Boston quadrangle. Another is that the strata are more closely appressed and vertical or steep dips are more common in the southern part of the basin than in the northern part.

There is no reason to suppose that the Carboniferous strata occupying the Boston and other basins were covered by younger strata before the deformation began, and they may not have been fully indurated. The Roxbury conglomerate seems to have behaved as a competent layer, and where it was thrust upon other rocks it overrode them without itself being much broken or crumpled. On the other hand, the marked scarcity of present indications of bedding in the Roxbury throughout considerable areas indicates that it may have undergone considerable internal rearrangement and resulting obliteration of bedding. The dikes of the younger east-west set, which are of Carboniferous age, were formed just before the folding, as they cut all the rocks of the basin, including the highest known beds of the Cambridge slate, but they were deformed with the strata and they are broken in many places by small thrust faults that were developed during the later stages of the deformation.

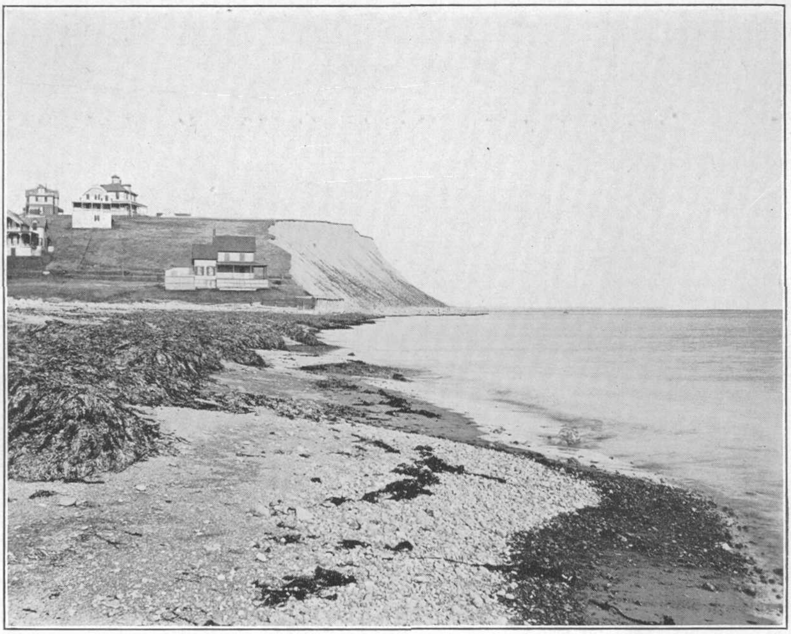
The further continuation of the compression resulted in the thrust faulting that is a marked feature of the present structure of the basin. (See pl. 14.) Such faulting occurred not only on the large scale that is shown in the areal maps and the structure sections but also on a small scale, as shown by the small thrust faults seen in all outcrops of any considerable size throughout the basin. That the compression continued and was pronounced after the folding and faulting had ceased is shown by the characteristic fissility or cleavage of the rocks, which affects all the formations to about the same degree and which has nearly the same trend and dip throughout the basin, largely without regard to the attitude of the rocks.

The intrusion of the Andover granite probably occurred early in the epoch of deformation. That granite occupies only a small part of the Boston area, and its relation to the other rocks is not shown therein. However, the Andover and other granites of similar age are intrusive in the Carboniferous strata of the Worcester and Merrimack troughs and are deformed with them, hence the relation in time of the granitic intrusion to the deformation is rather closely fixed. Those granites are also cut by a few scattered diabase dikes that appear to belong to the younger east-west set.

TRIASSIC PERIOD

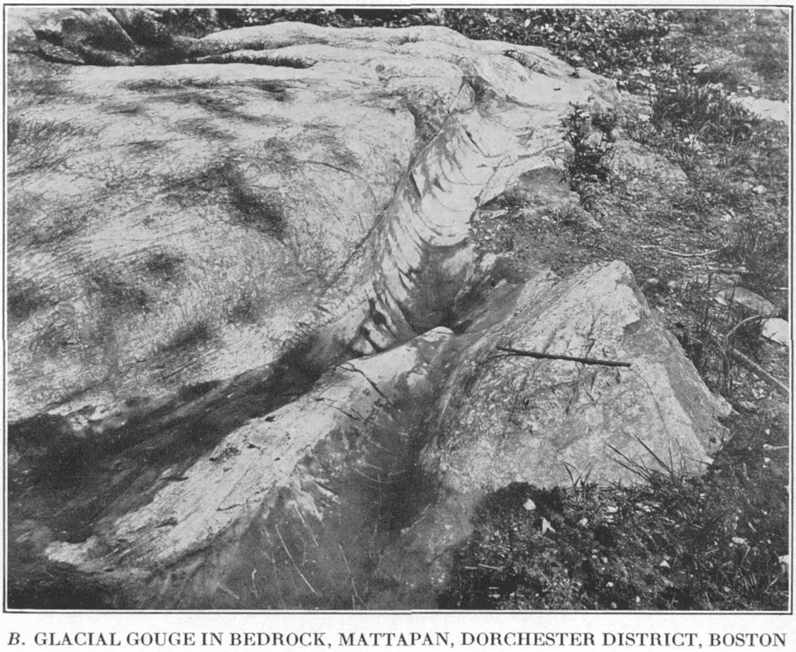
The fairly continuous story of geologic events in the Boston area, as recorded in the rocks, is concluded with the deformation at the end of the Carboniferous period. The record since then is interrupted by gaps that represent more time than the rocks and structural features of later date. Presumably such gaps correspond to long periods of weathering and degradation of the land. There is no reason to suppose that there was, except in Pleistocene time, any considerable deposition of sedimentary rocks or, except at the end of the Triassic period, any marked deformation or eruption. From time to time some warping, tilting, and uplift or subsidence of the land surface occurred, but such movements were of the gentler sort and left no record in the rock structure.

There are no Triassic strata in eastern Massachusetts and no igneous rocks of assuredly Triassic age. Situated as it is between the Acadian trough on the northeast and the Connecticut trough on the southwest, the region could hardly have escaped being affected by the diastrophic movements recorded in the Triassic strata in these basins. Furthermore, the intrusion of diabase dikes and sills was not



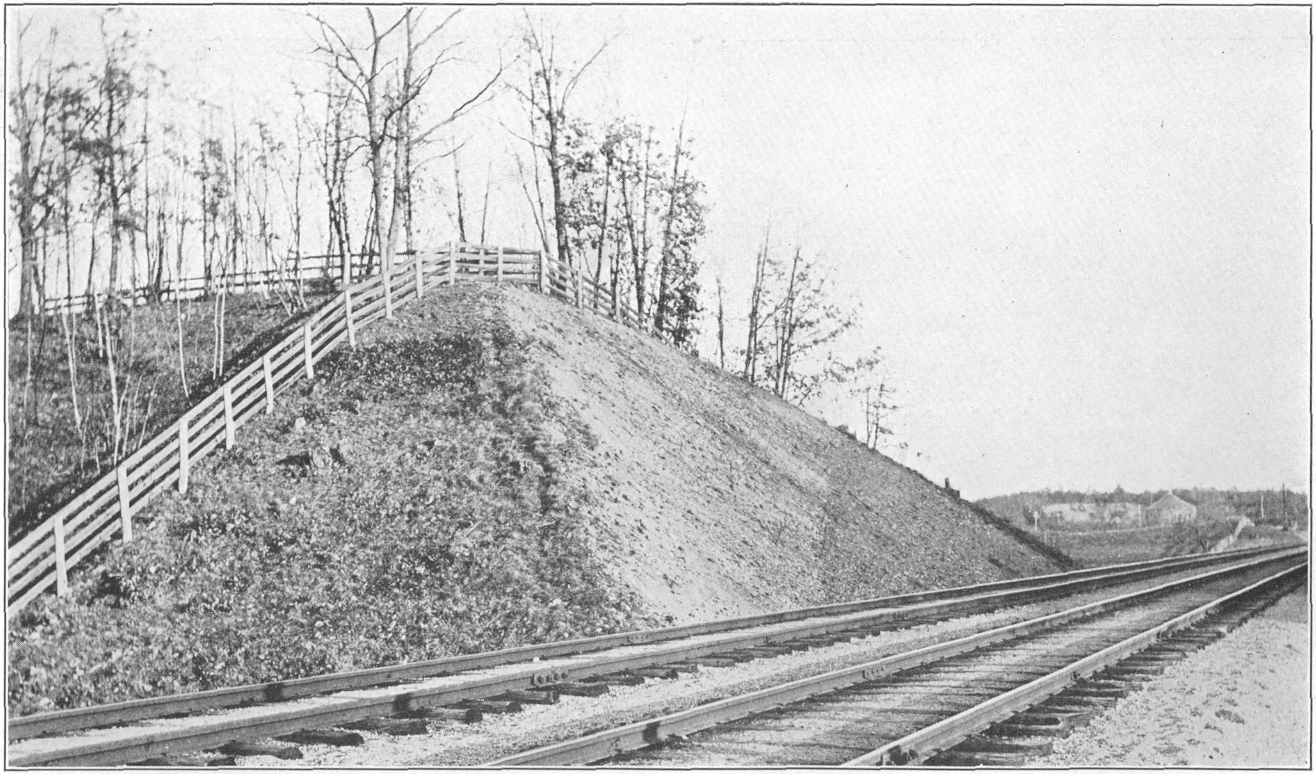
A. GREAT HILL OR WINTHROP HEAD, WINTHROP

Looking north from Shirley Beach, with Grovers Cliff in the distance. Great Hill is a typical drumlin, which has been half cut away by the waves. The photograph was made before 1900, and the cliff has receded several feet since. The slope is now covered with cottages, and the Winthrop standpipe is on the summit. The base of the cliff is now protected by a sea wall and riprap, and erosion there has been stopped, but the top is still receding through frost action and rain wash, and the edge is now perilously near the base of the standpipe.



B. GLACIAL GOUGE IN BEDROCK, MATTAPAN, DORCHESTER DISTRICT, BOSTON

The view shows a gouge carved in the rock by a small boulder frozen in the bottom of the glacial ice.



THE AUBURNDALE ESKER, NEWTON

Cut on Highland branch of Boston & Albany Railroad, looking east. The view shows the triangular section characteristic of most well-developed eskers, and the steepness of the side slopes. In the middle distance is a shallow cut through a lobe of the Woodland outwash plain, and in the background is an old gravel pit in the southwestern margin of the Brae Burn outwash plain. The point where the picture was taken is a little outside the western margin of the Boston quadrangle.

CLIFF ON THE NORTH SIDE OF BEACON STREET, EAST OF NEWTON CENTER

Showing the Roxbury conglomerate overthrust on the Cambridge slate. The author, as well as most other geologists familiar with the locality, regards this contact as a fault and as part of a great structural overthrust several miles in length. A few geologists, on the other hand, regard it as an angular unconformity of the conglomerate on an interbedded lens of slate of purely local extent.

THE "CHURN" OR "SPOUTING HORN," MARBLEHEAD NECK

The fissure has been formed by the weathering out of part of a diabase dike cutting the rhyolite breccia of the cliff. When the tide is rising the surf rushing into the chasm strikes its inner end with great violence, and spray is thrown high in the air. The view is deceptive as regards the height of the cliff; the surface of the rocks in the foreground is more than 30 feet above the level of the water. Photograph by M. H. Graves.

confined to the Triassic basins but occurred over a far greater area. The diabase dikes of the north-south set in the Boston area are lithologically akin to those that cut the strata in the Triassic basins and are clearly younger than the structure imposed on the Carboniferous rocks in the great deformation. Hence geologists have little hesitation in referring such intrusive bodies, in the Boston area as elsewhere, to the Triassic eruptive period. This reference aids greatly in fixing the geologic date of some of the events recorded in the rocks of the Boston area.

The history of much of Triassic time in the Boston area is a blank. To judge from what is known of it in other parts of the Appalachian region it must have been a time of prolonged degradation of the surface, in which the land was probably reduced well toward base level. The subsidence by which the Triassic basins were formed probably began fairly early in the period, and the evidence afforded by the beds of conglomerate intercalated with the other strata suggests that it continued throughout the time of deposition. No record of this warping is preserved in the Boston area except in the great system of joints that cut all the rocks other than the diabase dikes of the north-south set. At one time the joints were supposed to have been produced during the great deformation at the end of Carboniferous time, but they are independent of the deformed structure of the rocks and evidently were formed after the rocks had acquired their present attitude. Furthermore, they are torsional joints, developed under a tensile stress presumably imposed by mild regional warping and not under compressive stress such as characterized the Carboniferous deformation. They do not cut the dikes of the north-south set, many of which were formed in joint fissures, hence it seems probable that the joints were developed at some time during the Triassic period but prior to the intrusion of the diabase dikes.

At the end of the Triassic or the beginning of the Jurassic period the diabase dikes of the north-south set were erupted into fissures of the master set of joints of the system just developed. The great Medford dike and other intrusions of coarse diabase of similar type may or may not have been erupted previously; there is no definite evidence on this point. Indications are lacking that any of the Triassic diabase reached the surface and formed flows in the Boston area, and as all the dikes are relatively small there is no reason to suppose that such extrusion occurred.

The intrusion of the dikes was accompanied and followed by renewed warping of the surface, and as the rocks were then jointed the warping caused considerable tilting of large blocks or slices of rock and faulting along the master joints. The diabase dikes of the east-west set were offset in numerous places by the faults, and many dikes of the north-south set were split or were torn loose from one or both walls. The cross faults that are conspicuous features of the Boston Basin and that offset the formations considerably must also have been developed at this time.

The faulting that ended or immediately followed the Triassic period was the latest marked structural deformation that has affected the rocks of the Boston area. Since that time they have remained in substantially the same attitude that they then assumed, although their position with regard to sea level has presumably differed considerably from time to time.

JURASSIC TO TERTIARY TIME

The geologic history of the area from the end of the Triassic period until the Pleistocene epoch is another blank except in so far as it can be interpreted from the topography of the area. The interval was dominantly one of land conditions and was characterized by profound degradation of the surface, which presumably was several times reduced well toward base level. It was repeatedly uplifted, with revival of dissection and the beginning of degradation toward a new base level. It is possible, also, that the district may have been once or twice submerged by the sea and that it may have been covered by Cretaceous or Tertiary strata, but there is no definite evidence on this point.

It is generally believed that southern New England was reduced to a peneplain toward the end of the Jurassic period and that the peneplain was then uplifted and tilted so that it stood well above sea level in western Massachusetts but was submerged by the sea on the southeast. The basal Cretaceous strata were probably deposited on the submerged part of the peneplain and extended for an unknown distance northwest of the present coast line. The northernmost known remnants of Cretaceous strata are in Scituate, some miles southeast of the Boston area, and no other Cretaceous rocks are known in Massachusetts except on Marthas Vineyard. The Cretaceous beds may formerly have extended northwestward and covered the Boston area, but there is nothing at present to indicate that they did.

Seemingly no remnants of the Jurassic peneplain are preserved in southern New England, though some parts of the upland may have been but little modified from it. The belief has long been held that large tracts of the upland are parts of the peneplain, which is described as descending southeastward from the plateau at the base of the Green Mountains to pass beneath sea level at the coast. The extended field work of the author on the geomorphology of southern New England has led him to a different interpretation, which is supported by the observations of Arthur Keith and of Joseph Barrell, though the conclusions reached by each of these investigators differ from those of the author in some details.

The general upland surface of the region, aside from the residual mountains and the glacial drumlins, is not a single, nearly uniformly sloping surface that descends gently to sea level at the coast but is a complex surface, made up of several distinct platforms that stand at altitudes ranging from 140 to 2,200 feet above sea level. The higher platforms have gentle slopes to the southeast, south, or southwest, but the lower ones are nearly level throughout many square miles. Furthermore, the several platforms are intricately intermingled, as tongues of lower ones extend far up the valleys into the plateaus and lobes of higher ones extend out along divides between lowland areas. Near the coast outlying areas of higher platforms are surrounded by lower ones. Finally, along the coast the surface does not everywhere descend gradually to and beneath the sea, but in places one or another of the lower platforms extends to the shore and is cut off abruptly or is beveled by a relatively steep slope. In other words, the surface of southern New England, if smoothed by obliteration of its minor irregularities, would be found to be quite different from its usually accepted form. Moreover, it is so complex that it can not be assumed to have been modified from an uplifted and tilted peneplain by any conceivable warping. It can have been developed only by repeated degradation in several partly completed cycles, separated by small uplifts. The erosion may have been in part marine, as claimed by Barrell, especially in southern Connecticut and Rhode Island, but the present form of the surface, aside from the effects of glaciation, has clearly resulted mainly from the work of streams.

The erosional history of the Boston area in Cretaceous and Tertiary time is but partly known and never can be worked out in more than outline. In fact, nothing is known of the events of the Cretaceous period except that the surface must have been undergoing prolonged degradation. Parts of only the lowest three of the platforms mentioned in the preceding paragraph are found in the area, and all three were probably developed late in the Tertiary period. Presumably the surface was previously reduced to some of the higher platforms, but they have long since been removed by the continued degradation, and a quite different topography has been developed in their stead.

Early in Tertiary time there must have been subsidence, followed by invasion by the sea, as remnants of Miocene strata also are preserved in the cliffs at Scituate. The sea may have covered the Boston area, and Miocene beds may have been deposited in it, but no traces of such beds remain, and their former existence in the area is merely a hypothetical possibility. Any submergence must have been brief, as during the Pliocene epoch the land stood higher than now, and the district may then have been more than 100 miles inland.

The present relief of the area, aside from the effects of Pleistocene glaciation, was developed mainly late in the Tertiary period, probably in Pliocene time. The land may not have stood high at the beginning of the Pliocene, but it was uplifted twice or thrice during the epoch, and at the end it must have stood much higher than now. The work of the streams in reducing the surface and broadening the reduced areas to platforms went on as before, and the surface soon acquired a relief that was not greatly different from that of the present, except that it was more accentuated.

There are several reasons for believing that at the end of the Pliocene epoch the land stood higher than now. The larger valleys of the Boston Lowland are deeply filled with drift, and the bedrock surface beneath is well below sea level. Complete data are lacking, but enough is known of the form of the bedrock surface to warrant the conclusion that it was developed by stream erosion, hence the land must have stood higher than now by an amount at least as great as the depth of the drift-filled valleys. The maximum depth below sea level of the bedrock surface is not known, but it is more than 200 feet and may be considerably more. Several lines of evidence lead to the conclusion that at the end of the Pliocene epoch the Atlantic coast was far southeast of its present position and probably near the margin of the continental shelf and that the present sea bottom near the Massachusetts coast was land. The streams that carved the buried valleys must have had some fall between the Boston area and the points where they reached the sea, hence the difference between the altitude of the land then and now is greater than the maximum depth below sea level of the bedrock surface within the area.

Very little is known of the drainage pattern of Pliocene time, although there has been considerable speculation regarding it. The master streams of southern New England in the Cretaceous period and possibly in early Tertiary time probably flowed southeastward in courses determined by the warping and tilting of the Jurassic peneplain. Some writers have concluded that the southeasterly course of the main streams persisted throughout Tertiary time, and this conclusion seems rather probable as regards the streams from the Blackstone River westward. In eastern Massachusetts, however, there are reasons for believing that a subsequent drainage had been developed along the trend of the geologic structure and that the master streams of Pliocene time flowed northeastward. The drainage of the greater part of the Boston area appears to have been tributary to a master stream that had nearly the present course of the Neponset River and flowed on northeastward toward the deeper part of the present Gulf of Maine, where it may have debouched into an arm of the sea.

A deeply buried valley extends southward from Winchester through the Mystic Lakes, across eastern Arlington and western Cambridge, thence between Brighton and Cambridgeport, and across eastern Roxbury and Dorchester Neck to the Old Harbor, and there is little doubt that it is the valley of the Pliocene predecessor of the Mystic River. On account of its considerable depth, more than 200 feet in Dorchester, some have assumed that it could not have been made by a stream with so small a drainage basin as the present Mystic and have asserted that it is the valley of the Pliocene Merrimack. The author knows of no facts in support of this conclusion. Evidence is lacking of a buried valley extending through to the present course of the Merrimack, and such a valley, if it ever existed, must have crossed the present valley of the Shawsheen River, which apparently is also a preglacial valley. There is also reason to believe that the Pliocene course of the Merrimack below Lowell was not greatly different from the present course past Lawrence, Groveland, and Newburyport, and that if the ancestral stream ever flowed southeastward from Lowell to Boston it must have been far back in Tertiary or even in Cretaceous time and long before the present topography of eastern Massachusetts was developed.

QUATERNARY PERIOD

PLEISTOCENE EPOCH

PRE-WISCONSIN TIME

Little is known of the Pleistocene history of the Boston area before the Wisconsin glaciation. According to some authors, at least two deposits of till that are older than the Wisconsin and are supposed to correspond to the Kansan and Illinoian drift sheets of the central United States, as well as some glacial deposits that may be as old as the first or Jerseyan drift, are found on the islands off the southern coast of New England, separated from each other and from the Wisconsin drift by interglacial deposits, some of which are marine. If this is true the Pleistocene history of southern New England was as varied as that of the Central West, with the added complication of marine submergences.

There is no evidence in the Boston area of invasions by pre-Wisconsin ice sheets. The deposits encountered in deep borings on islands in Boston Harbor have been interpreted by some geologists as showing the existence, beneath the Wisconsin till, of both pre-Wisconsin till and interglacial deposits. This explanation may be correct, but it can not be accepted until more detailed information is at hand.

The blue clay that underlies much of the Boston Lowland may be of pre-Wisconsin age and of marine origin. Its thickness, the altitude of its upper surface, and the form of the underlying surface, so far as that is known, indicate that it was deposited on a surface of moderate relief, probably due to stream erosion, which had been submerged about 40 feet more than at present, and that later the land rose again until it stood considerably higher than now, and the surface of the clay was more or less dissected before it was overridden by the Wisconsin ice.

Southern New England seems to have stood several hundred feet higher when it was invaded by the Wisconsin ice sheet than it does now. In the Boston area drift of Wisconsin age was deposited on a surface much of which is now below sea level, but there is nothing in the form of the deposits to indicate that they were laid down on other than a land surface. The conclusion seems warranted that Boston Harbor and Bay were not then in existence and that the margin of the ice sheet was far to the east, in what is now the Gulf of Maine but may then have been chiefly land. Nothing is known of the drainage pattern of the area at the time just preceding the invasion by the Wisconsin ice sheet. It may have followed the same general lines as that of Pliocene time, but if the area had already been covered by at least two earlier ice sheets and had been partly submerged since the supposed Illinoian glaciation, presumably a new, youthful drainage had developed on the modified surface. The subsequent modification of the topography by the Wisconsin glaciation has probably destroyed all traces of an earlier Pleistocene drainage pattern.

WISCONSIN GLACIATION

The drift left by the Wisconsin ice sheet during its occupation of and disappearance from the area covers so much of the surface and is nearly everywhere so thick that most traces of events during the advance of the ice have been obliterated. Presumably most of the erosive work of the ice was done then, but in the absence of more than an approximate idea of the topography in pre-Wisconsin time the extent to which it was modified by glacial erosion must remain conjectural. It is clear, from the form of many of the ledges now exposed and from the number of huge angular blocks that were not carried far from the parent ledges, that plucking was a very important factor. In parts of the area where the bedrock is abundantly exposed there are many canal-like ravines, some of them more than 100 feet wide and 1,000 feet long, between parallel walls of rock, which look like down-faulted troughs or grabens. They are, however, probably due to glacial plucking of the blocks between parallel joints. In other places small knolls of rock were shattered by the ice as it moved over them, and the blocks of rock were tilted about and left in a confused heap, although many were moved but a few feet.

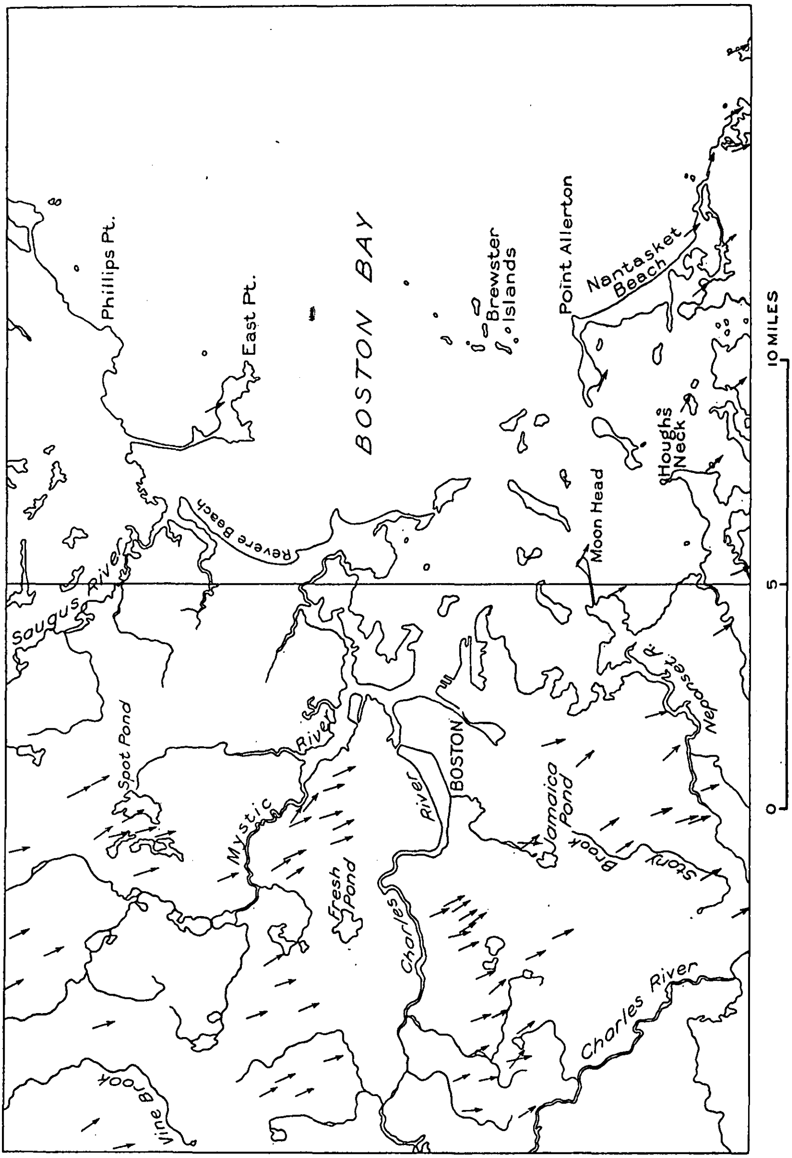


FIGURE 6.—Direction of local striations in Boston area

The Wisconsin ice sheet approached from the northwest and moved over the area in a southeasterly direction. Glacial striations and small grooves are abundant on the ledges (see pl. 12, *B*, and fig. 6) and show that the general direction of movement was about S. 15° E., although locally controlled to some extent by the topography. Striations with a more easterly trend are preserved on many ledges, and in some places they seem to indicate that, late in the stage of ice formation, the movement was more easterly than at first. Furthermore, the trend of the longer axes of most of the drumlins is considerably more easterly than the average trend of the striations, and the same is true of the trend of the chains of drumlins.

As the ice sheet at its maximum extended nearly 100 miles south of Boston its thickness in the Boston area must have been considerable. It covered the highest hills in the area, possibly to a depth of hundreds of feet. An ice sheet of so great thickness, heavily loaded with débris in its lower part, must have been an effective grinding agent. It rounded, smoothed, and polished the ledges beneath it, although it may not have greatly modified the larger features of the relief. In its work it was unsparing of its tools, and the large blocks of rock that it plucked from the ledges were rapidly reduced to rounded boulders and then to fine material. As a result the greater part of the coarse material in the drift, including nearly all the large boulders, has been transported only a few miles at the most, although some cobbles and boulders can be identified as having come from formations many miles away. Another result is that boulders, although the most conspicuous element of the drift, are really but a small part of it compared to the far greater bulk of gravel, sand, and clay, much of which was brought from far to the north and was ground ever finer as it was borne along.

The greater part of the record of Wisconsin time that is preserved in the drift relates to the disappearance of the ice from the region. During its advance and while the climate was probably growing more frigid, the ice came on more rapidly than its margin was wasted by melting, and it steadily invaded the country south of it. When it reached its maximum extent the rate of advance and that of melting were probably rather closely balanced for some time, as a large terminal moraine was accumulated along the ice margin and a great quantity of outwash was discharged from the melting ice while its margin was almost stationary.

Eventually, as the local climate again became more genial and as the conditions at the center of ice dispersion became unfavorable to continued growth of the glacier, its forward movement slackened and at times ceased, although frequently renewed spasmodically. When the renewed forward movement was vigorous it sometimes exceeded the rate of melting back of the ice margin, which advanced again for a short distance. Commonly, however, the rate of advance and that of melting back were nearly balanced, and the margin remained stationary for a time. In the intervals when the advance slackened greatly or ceased the ice near the margin was stagnant and melted away in place and the ice margin retreated rapidly for some distance.

When the ice margin was readvancing new material was continually brought forward and was dropped at the melting edge or was washed out in front of the ice by streams flowing from it. When the advance ceased and the stagnant ice melted where it lay, the outwash was spread over the land already bared or was deposited in hollows in the surface of the ice. Thus a series of recessional moraines, each marking a line where the ice front was nearly stationary for a time, was built across eastern Massachusetts. Each moraine is made up largely of kame fields and outwash deposits, is associated with eskers and deltas, and is fronted by outwash plains. The intermediate belts of country are occupied largely by ground moraine deposited from the stagnant ice as it melted, but they also contain many ice-block holes surrounded by outwash plains. As the region has a relief of 600 feet and as some of the readvances of the ice were rather narrowly localized the recessional moraines are not parallel and regularly spaced but merge, interlock, and overlap in a bewildering network, and completely to disentangle the successive stages of the ice margin during the stage of retreat is hardly possible.

When the ice was stagnant or nearly so and was melting in place it melted off the hills first and occupied the valleys for some time afterward. Outwash from the melting ice was deposited along its margins against the hill slopes in kame terraces, small deltas, and local sand plains. Streams ran along the margin, in some places over beds of ice, cut channels across spurs, and deposited material in lower spots. Small lakes formed in hollows between the ice and the hills, and thin lacustrine beds were deposited on their bottoms or about their shores. As the ice melted down and cleared more and more of the lower ground such ice-margin features were developed repeatedly, at all altitudes from the hilltops down to and below present sea level. Deposits were formed in this manner throughout eastern New England, under local conditions and in no regular relation either to the position of the ice front as a whole or to the sea level at the time. Nevertheless they have been interpreted by some geologists as marine and as showing that when the ice was melting from the Boston area the land stood several hundred feet lower than now and was submerged up to the margin of the ice, so that the outwash was deposited in the sea. Some of the local deltas and terraces have been correlated by other geologists into southward descending series that are interpreted as showing that the land has since been tilted in that direction at a slope of several feet to the mile. They have reached different conclusions, however, regarding the degree of tilting, depending on their individual modes of correlation of the former local water levels. It must be said, moreover, that considerable pertinent evidence of several sorts seems to be opposed to the idea of a general regional tilt.

During the retreat of the ice margin across the Boston area parts of the area were occupied by a series of ice-margin lakes of considerable size, into which deltas and sand plains were built from the ice that formed parts of the shores. The outlines and outlets of some of these lakes are fairly well defined, and the levels of many of them can be determined, and if the Boston area had not been settled the history of its glacial lakes might perhaps have been worked out. As it is, so much of the evidence has been obscured or destroyed by the settlement of the area that the task is nearly hopeless, and no attempt has been made to do it. Enough evidence remains, hewever, to warrant a general outline of the course of events.

Just as the ice melted from the hills while it still lay in the valleys, so it left the higher country west of Boston before it did the lower ground along the coast and it still occupied what is now Boston Bay after it had disappeared from most of the Boston quadrangle. One result was that, during the melting of the ice from the Boston area, its margin had for some time a general northwest-southeast trend. Its actual outline was usually rather complex, with tongues extending southward in the valleys and reentrants extending northward on the higher ground, and different parts of it faced in different directions. Another result was that for a long time the ice abutted against the Blue Hills, south of the eastern part of the Boston quadrangle, and its drainage was shut off from flowing eastward to the lower ground now in Boston Bay. Series of lakes were formed at different but generally successively lower levels as the ice retreated from those parts of the valleys of the Charles and Neponset Rivers southwest of a line drawn through Hyde Park and Waltham. At first the overflow of the lakes was discharged somewhere south of the Blue Hills. After the ice had melted from the northern slope of the Blue Hills an outlet, now abandoned, was opened up to the east, south of Brush Hill. Still later the present course of the Neponset River through Hyde Park was freed of ice and the lake was drained. The small lakes that still remained in the valley of the Charles above Waltham were eventually drained, but the process was more complex, as the retreat of the ice margin successively opened up several outlets across Newton and Brighton.

At least part of Boston Harbor was then free of ice, and the eastward discharge of the Neponset and Charles Rivers had become fixed. Much of this part of the record can not now be read, because the area involved is either closely built over or is beneath the harbor.

The story of the retreat of the ice margin northward from the Charles River is similar, except that, as the general slope of that part of the area is southward, there was less opportunity for the formation of ice-margin lakes, except locally between the higher hills. The northwestern part of the area, however, now a part of the drainage basin of the Shawsheen River, slopes toward the Merrimack, and there another series of ice-margin lakes was formed. At first they discharged southward or southeastward to the Charles and Mystic Rivers, but later they were gradually drained as successive outlets to the northeast were opened. Probably no other part of the region about Boston affords a better chance than this one for the working out of the glacial-lake history, as it is rather sparsely settled, and the topography has been but little modified by human action.

LATE WISCONSIN TIME

The Wisconsin ice sheet disappeared from Massachusetts long before the end of the Pleistocene epoch. During the remainder of Wisconsin time the geologic conditions in the region must have been similar to those of the present day. The Pleistocene epoch merged into the Recent epoch without marked changes, and the features of late Wisconsin time and those of the Recent epoch are indistinguishable except by their geomorphic relations.

At some time during its occupation by the Wisconsin ice sheet the region about the Gulf of Maine became depressed and much of it was eventually carried below sea level. According to the generally accepted hypothesis the depression was due to the weight of the ice sheet, affected all of eastern North America north of New Jersey, and amounted to 600 feet or more in the St. Lawrence Valley, and as has already been stated, some geologists believe that the Boston area was submerged several hundred feet when the ice left it. The author knows of no established facts that support either the above-mentioned hypothesis as a whole or several of its major features, except the undisputed fact that some parts of eastern North America were below sea level for a time after the disappearance of the Wisconsin ice sheet and have since been reelevated. He prefers, therefore, in outlining the geologic history of the district in late Wisconsin time, to mention only those episodes that are well established.

The subsidence about the shores of the Gulf of Maine carried the coast of Maine, New Hampshire, and northeastern Massachusetts below sea level, and marine sediments were deposited over much of the submerged area. In Maine the submergence amounted to several hundred feet, but it was progressively less southwestward, being a little more than 100 feet about Newburyport and dying out at Boston. No evidence has been found that the coast of Massachusetts south of Boston has ever, at any time since the disappearance of the Wisconsin ice sheet, stood lower than at present. The southernmost formerly submerged areas are in Lynn and Swampscott, and the only marine deposits formed at that time in the Boston area are in that part of the area. The submergence in Swampscott was approximately 20 feet, and the area now occupied by Marblehead and eastern Swampscott was then a group of rocky islands like those off Salem. A crescentic beach was thrown up by the waves back of the present site of Phillips Beach and tied two islands, now Phillips Point and Beach Bluff, to the mainland. From Salem northeastward considerable marine clay was deposited during the submergence, but none has been found in the Boston area except in the western part of Lynn and along the Forest River in Salem.

The submergence was rather brief, and the land soon rose again to a position somewhat higher than at present. Much of the newly formed marine sediment was brought above sea level and exposed to dissection, especially about the heads of the tidal inlets. The conditions in the area since then have been essentially those of the present time.

RECENT EPOCH

The geologic conditions in the Boston area in Recent time have been throughout essentially the same as at present, and the natural changes that have taken place have been of the same sort as those now going on. Some loose material has been washed from the higher ground and steeper slopes and spread out on the lower and flatter areas, forming flood plains, level meadows, and swampy tracts. Changes, probably extensive, have been wrought in the shore line by the waves and the currents: on the one hand headlands have been cut back and cliffs formed generally along the steeper shores, and small islands have been reduced to mere half-tide shoals; on the other hand beaches have been built across bays and inlets, forelands have been built out in places, and tidal marshes have grown behind some of the beaches and along the estuaries.

The whole New England coast has manifestly stood higher than now at some time since the Wisconsin glaciation and since the deposition of the marine clay described above and has subsequently been depressed so that it is now "drowned." The depth of the submergence is not definitely known, but the form and relief of the adjacent sea bottom lead to the tentative estimate of a submergence of possibly 400 feet off the coast of southeastern Massachusetts. Until the beginning of the twentieth century it was generally believed that the subsidence is still going on. At present there is a difference of opinion on the matter, some writers maintaining that the movement ceased a few thousand years ago and that the land has since stood still. Nevertheless, the author believes that a slow subsidence is still in progress, so slow that its rate has been only approximately determined but is of the order of 1 or 2 feet in a century. So much convergent evidence of different sorts, some of which can not be explained in any other way, agrees in support of this conclusion that, with all deference to the eminence of those who have taken the contrary view, it is here stated with confidence.

As usual in areas that have become great centers of population, the activities of man in the last three centuries have been an important factor in modifying topographic conditions in the Boston area. Many small hills, not only of glacial materials but of solid rock, have been removed, large areas of wet ground have been drained or filled, thousands of acres of new land have been made by filling in former marshes, tidal flats, and estuarine waters, and the harbors and channels have been deepened by dredging. Some ponds have been drained, but the number of water bodies has been increased by the creation of numerous artificial ponds. Former islands have been converted into peninsulas by the construction of causeways, small streams traversing the cities have been confined to covered conduits, and other small changes in topographic conditions have accompanied the settlement of the area. These changes are still going on.

NATURAL RESOURCES

MINERAL RESOURCES

GENERAL NATURE

The mineral resources of the Boston area that are of commercial importance are chiefly nonmetallic and consist of stone, gravel, sand, and clay, which are extensively used for building material and for road construction. They are abundant and are of considerable value. Commercial deposits of useful metallic minerals are virtually lacking. Besides the resources of commercial importance there are extensive deposits of peat, which at present is only a potential resource.

The mineral production of the area is decreasing in amount and probably in total value from year to year. Several causes, such as the increases in the cost of labor, fuel, and carriage, the increasing use of concrete for construction, and competition from outside, have contributed to this result. By far the most influential factor, however, has been the rapid growth of the cities and towns. This results in a decrease in mineral production, because the land occupied by quarries, gravel pits, and brickyards becomes more valuable for building sites and is so used. Furthermore, as the quarries and pits become surrounded by densely settled areas their continuance becomes a nuisance or even a danger to those living near by and they are forced to cease operating.

In the nineteenth century the clay industry was one of the most important in the area, and scores of small brickyards and a number of large ones were in operation throughout the Boston lowland in areas underlain by clay. By 1900 most of the small pits had been closed, but some of the larger ones were still in operation. One by one these have been shut down, until the manufacture of brick has almost ceased. Most of the yards have been dismantled, the pits have been filled in, and the areas once occupied by them have been covered with streets and buildings.

The stone industry has passed through a similar decline. Formerly large quantities of rock for building and, at a later date, for road construction, were taken from numerous small quarries in Roxbury, Dorchester, Brookline, Brighton, Newton, Somerville, Medford, Malden, and Everett. Some of these quarries are still being worked, but most of them have been closed for years, and many have entirely disappeared, the ledges having been removed and the areas built over.

From time to time in the quarrying operations small veins of metallic sulphides have been found, which have given rise to reports of gold, copper, and lead deposits. So far as can be ascertained nothing of real value was ever recovered at any of these places. There was at one time, however, a small mine among the hills in the northern part of Medford from which silver ore was taken in paying quantities for a few years.

BUILDING MATERIALS

The building materials obtained in the area include sand, gravel, clay, and several varieties of building stone. Sand for use in building operations is dug at many places, the chief sources of supply being the outwash plains and the kame moraines. The sand is of satisfactory quality, and much of it can be used without screening. The supply is practically inexhaustible, and as fast as one pit is closed for some reason another is opened somewhere else. In many places on the outwash plains no sand need be brought to the spot for building a house, as a sufficient supply will be obtained in digging the cellar.

What has been said of sand is equally true of gravel, except that drumlins, eskers, and till moraines are additional sources of supply. The demand for sand and gravel for use in concrete has resulted in the opening of several large plants on outwash plains in outlying districts, and possibly the annual production of sand and gravel is increasing. No close estimate of the production of such materials can be made, because of the number of small pits and quarries that are operated intermittently and in response to purely local demand.

The glacial clays of the area have in the past been extensively used in the manufacture of brick, draintile, sewer pipe, flower pots, and similar rough pottery. The manufacture of brick has almost ceased, but the other products are still being manufactured at a plant in West Cambridge.

Most of the kinds of rock that occur in the area in considerable quantity have been used locally to some extent as building stone, but only a few have had any extensive or general use. The Roxbury conglomerate, the Quincy granite, and the Cambridge slate have been used most. Other varieties that have had a considerable local use are the Dedham granodiorite, the Medford diabase, some of the quartz diorites, and some of the lighter-colored and more massive felsites.

The Roxbury conglomerate has been extensively used in all sorts of construction, even as dimension stone, because, in spite of its heterogeneous texture, the pebbles are generally so firmly embedded in the matrix that blocks can be trimmed to any desired shape and can even be polished, although the rock is rarely used in polished slabs. The color, which is pleasing, especially for exterior trim, ranges from bluish gray to yellow-drab. Because of its massiveness, the readiness with which it can be quarried, and the ease with which it can be trimmed without impairing its strength, the conglomerate has been used more than other sorts of rock in the area for such structures as retaining walls, bridge abutments, and stone arches. In recent years it has also been extensively used, crushed, in making concrete rubble.

The Quincy granite is the most valuable building stone in eastern Massachusetts. The principal quarries are, however, outside the Boston area, within which the granite takes minor rank in volume of production. Like the conglomerate, it is used in all sorts of construction, but it is in particular demand for such buildings as churches, college buildings, and public buildings generally. It is also extensively used in monumental work. Its normal color is bluish gray or pearl-gray, but it ranges to reddish or brownish gray in some areas. The slightly weathered rock known as "sap," which is light yellowish brown, is in considerable demand for buildings and for exterior trim. The granite quarries easily, as a rule, is adapted for architectural carving, and takes a good polish; hence it is in some demand for use as ornamental stone.

The Cambridge slate was also formerly used in all kinds of construction. When the large slate quarries were in operation and some of the rock in places where the joints were not too closely spaced could be quarried in fairly large blocks, a number of buildings, especially churches, were constructed of it. Later its use became chiefly confined to retaining walls, bridge abutments, house foundations, and the like, and now it is seldom, if ever, used in any sort of construction. Although rather dark, its color is not displeasing in buildings of a style of architecture to which it is adapted.

The Medford diabase was at one time used for all sorts of construction, as well as in monumental work, but it went out of fashion long ago, and it is now seldom quarried for any purpose. Its color, which is a dark, somber gray, and the small amount available have been the main reasons for its going out of use, as in other respects it is satisfactory as a building stone.

In much of the Boston area the Dedham granodiorite is too much shattered by jointing and fissility or too variant in color and texture to be a satisfactory building stone. It has been quarried to some extent to supply local demands for stone for rough construction but has been used very little in the superstructures of buildings. The same is true of the more massive and uniform varieties of the quartz diorites and some of the lighter-colored felsites.

ROAD MATERIALS

The road materials of the Boston area consist of gravel and stone, both being employed directly in the construction of roads and also in the concrete and other fabricated materials now so much used in pavements and sidewalks. The gravel is obtained from the same sources as those used for building material. When cobblestone pavements were in use the glacial drift provided the cobbles, which nowadays are crushed and used in macadam pavements and in concrete rubble. Boulders of most of the sorts of rock in the drift are also used for crushing.

The crushed-stone industry is now probably the most extensive industry in the Boston area that is based upon the use of natural materials found in the area. Nearly all the sorts of rock that are found in the area in considerable quantity are crushed, in one locality or another, for use in constructing roads and sidewalks, but the most extensively used sorts are diabase, melaphyre, conglomerate, and felsite. The crushed rock is screened into graded sizes, all of which are used in some part of the work, even the smallest being used as surfacing for bituminous macadam, for gravel sidewalks, and as a filler in granite-block pavements.

The coarsely granular residual material from the weathering of the Medford diabase (see pl. 9, *B*) is used, under the name "Medford gravel," for surfacing drives and paths in parks and cemeteries. Some of the granites of the area, especially the Quincy granite and the Dedham granodiorite, have been used for paving blocks, curbing, and the like, but not to any great extent.

PEAT

Great quantities of peat underlie the marshes, both fresh and salt, and reach a thickness of 15 feet in places. A number of attempts have been made to use the peat as fuel, either in dried blocks or in briquets, but no commercially successful method has been put into operation, and at present there is little encouragement to regard the peat deposits as a possibly important source of fuel in the future. The peat has been used a little as a fertilizer, and at present the main value of the peat lands seems to be for agricultural purposes. When properly drained and cultivated the fresh-water marshes become very fertile soil, and where the land is not more valuable as building sites they are already being extensively converted into truck farms.

WATER RESOURCES

GROUND WATER

The municipal water supply of most of the cities and towns in the Boston area is obtained outside the area, and local ground water is used in only a few of the towns as a municipal supply, in some manufacturing plants, and on farms. The availability, abundance, and quality of the ground water in different parts of the area differ with the geologic conditions, the density of settlement, and the diversion of rain water into sewers. Where the drift is thin and outcrops are numerous the ground-water supply is generally scant, but on the broad plains of the Boston Lowland and in the drift-filled valleys the supply is generally plentiful, though not everywhere of suitable quality, especially in the densely settled areas.

Ground water obtained from springs and shallow wells is now used for a domestic supply only on farms and in outlying houses, but the water of some large springs in outlying districts is bottled and sold extensively in the cities. Ground water from shallow or deep wells is used as a partial or complete municipal supply in Newton, Brookline, Woburn, Dedham, Needham, and Wellesley and as a private supply on some large outlying estates. A number of manufacturing plants in the large cities of the Boston Lowland also draw supplies from deep wells, several of which pass through the drift and enter the bedrock, generally the Cambridge slate.

SURFACE WATER

Some municipalities in the Boston area obtain their water from lakes and ponds within the area. Lynn, in particular, draws its water supply from a chain of ponds in the Lynn Woods in the northwestern part of the city and from other ponds farther northwest, outside the Boston area. Before the establishment of the metropolitan water board, whose system furnishes water, brought from outside the area, to most of the cities and towns, a number of lakes and ponds were used as local sources of supply. Several of these are still used as distributing reservoirs for the metropolitan system, and Fresh Pond, in Cambridge, formerly the source of the Cambridge water supply, is similarly used as the distributing reservoir for the Cambridge water system, which is separate from the metropolitan system. Others, like Jamaica Pond and the Mystic Lakes, are not now used as reservoirs but have become essential features of the park system of the area.

The larger estuaries are still commercial waters, lined with wharves and utilized by coasting vessels carrying coal, lumber, ice, and such commodities, but the fresh-water portions of the rivers are now used only by pleasure craft, chiefly canoes. The larger bodies of surface water in the district, other than the distributing reservoirs, will in the future be valuable mainly for their scenic beauty and their use in recreation, as parts of the park system.

WATER POWER

Considerable water power is developed on the Charles River at Newton Upper Falls and in Waltham and Watertown and on Mother Brook and the Neponset River in Hyde Park and at Lower Mills. On the whole, water power is not, at least at present, an especially important or valuable resource of the area, and its use is decreasing. It is capable of considerably greater development as a resource, but, partly on account of climatic conditions and partly because the present tendency is strongly toward the development of the streams and their banks as parts of the park system and toward the removal of manufacturing plants to other sites, there is no immediate prospect of a considerable increase in developed water power.

SOILS, FORESTS, AND SCENERY

As the Boston area is so largely urban and suburban, and as agriculture is a minor industry in it, the soils, which on the whole are not particularly fertile, do not constitute an especially important natural resource. Parts of the uplands however, are well adapted for grazing, and the areas of fresh-water peat, when properly drained and cultivated, make good truck ground, hence considerable tracts in the outlying parts of the area are occupied by dairy farms and truck farms, and the soils of such tracts are of value as a resource.

A surprisingly large part of the area is covered with woods or brush, in view of the fact that it is a metropolitan district and contains so large a population. A considerable supply of firewood is obtained from the wooded lands, but practically no land in the area is otherwise valuable as timber land. Much of the brush-covered area is worthless for almost any purpose except as possible future building sites, and most of it, on account of the fire hazard, is at present not only not a resource but is a positive detriment to the surrounding territory. The chief future use of the wooded areas as natural resources, like that of the surface water bodies, will arise from their potential scenic and recreational values as parts of the general park system.

Scenery has not ordinarily been regarded, at least in the neighborhood of large cities, as an important or valuable natural resource. Many large cities, however, of which Boston is one, are fortunate in having much attractive scenery in their immediate neighborhood, and the appreciation of this resource and the disposition to preserve and utilize it for the public good are increasing. In the Boston area there is an abundance of natural scenery of great beauty and variety (see pl. 15), much of which has been preserved in its natural state in the parks and other public reservations. It thus becomes doubly valuable as a resource, first for its own sake and next because in laying out the parks, much of the desired scenery is already available and does not have to be created artificially at great expense.

SELECTED BIBLIOGRAPHY OF PAPERS PERTAINING TO THE GEOLOGY OF THE BOSTON DISTRICT AND RELATED AREAS

Agassiz, Louis, On two kinds of drift in Cambridge, Mass.: Boston Soc. Nat. Hist. Proc., vol. 3, p. 183, 1850.

Barrande, Joachim, Trilobiten der Primordial-Fauna in Massachusetts: Neues Jahrb., 1860, pp. 429–431.

Barrell, Joseph, Factors in movements of the strand line and their results in the Pleistocene and post-Pleistocene: Am. Jour. Sci., 4th ser., vol. 40, pp. 1–22, 1915.

——— The Piedmont terraces of the northern Appalachians (edited by H. H. Robinson): Am. Jour. Sci., 4th ser., vol. 49, pp. 227–258, 327–362, 407–428, 1920.

Barton, G. H., Glacial origin of channels on drumlins: Geol. Soc. America Bull., vol. 6, pp. 8–13, 1894.

Bascom, Florence, Volcanics of Neponset Valley, Mass.: Geol. Soc. America Bull., vol. 11, pp. 115–126, 1900.

——— The petrographic province of Neponset Valley, Mass.: Acad. Nat. Sci. Philadelphia Jour., 2d ser., vol. 15, pp. 129–161, 1912.

Benton, E. R., The amygdaloidal melaphyre of Brighton, Mass.: Boston Soc. Nat. Hist. Proc., vol. 20, pp. 416–426, 1880.

Billings, M. P., On the mechanics of dike intrusion: Jour. Geology, vol. 33, pp. 140–150, 1925.

——— Structural geology of the eastern part of the Boston Basin: Am. Jour. Sci., 5th ser., vol. 18, pp. 97–137, 1929.

Bouvé, T. T., The genesis of the Boston Basin and its rock formation: Boston Soc. Nat. Hist. Proc., vol. 23, pp. 29–36, 1884.

BOWMAN, ISAIAH, Pre-Pleistocene deposits at Third Cliff, Mass.: Science, new ser., vol. 21, pp. 993–994, 1905.

——— Northward extension of the Atlantic preglacial deposits: Am. Jour. Sci., 4th ser., vol. 22, pp. 313–325, 1906.

BROWN, R. M., The clays of the Boston Basin: Am. Jour. Sci., 3d ser., vol. 14, pp. 445–450, 1902.

BURR, H. T., A new lower Cambrian fauna from eastern Massachusetts: Am. Geologist, vol. 25, pp. 41–50, 1900.

——— The structural relations of the amygdaloidal melaphyr in Brookline, Newton, and Brighton, Mass.: Harvard Coll. Mus. Comp. Zoology Bull., vol. 38 (geol. ser. 5), pp. 53–69, 1901.

——— and BURKE, R. E., The occurrence of fossils in the Roxbury conglomerate: Boston Soc. Nat. Hist. Proc., vol. 29, pp. 179–184, 1900.

CABOT, E. C., Glacial scratches in Brookline, Mass.: Boston Soc. Nat. Hist. Proc., vol. 3, p. 28, 1848.

CLAPP, C. H., Geology of the igneous rocks of Essex County, Mass.: U. S. Geol. Survey Bull. 704, 132 pp., 1921.

CLAPP, F. G., Geological history of the Charles River in Massachusetts: Tech. Quart., vol. 14, pp. 171–201, 255–269, 1901.

——— Clay of probable Cretaceous age at Boston, Mass.: Am. Jour. Sci., 4th ser., vol. 23, pp. 183–186, 1907.

——— Complexity of the glacial period in northeastern New England: Geol. Soc. America Bull., vol. 18, pp. 505–556, 1908.

CLAPP, W. F., A new fossil *Vitrinella* from Boston, Mass.: Nautilus, vol. 26, pp. 38–40, 1914.

CROSBY, I. B., The earthquake risk in Boston: Boston Soc. Civil Eng. Jour., vol. 10, pp. 421–430, 1923.

CROSBY, W. O., Report on the geological map of Massachusetts, 42 pp., Massachusetts Comm. Centennial Exposition, 1876.

——— Notes on the surface geology of eastern Massachusetts: Am. Naturalist, vol. 11, pp. 577–587, 1877.

——— Contributions to the geology of eastern Massachusetts: Boston Soc. Nat. Hist. Occasional Papers, No. 3, 286 pp., 1880.

——— On the relations of the conglomerate and slate in the Boston Basin: Boston Soc. Nat. Hist. Proc., vol. 23, pp. 7–27, 1884.

——— Geology of the outer islands of Boston Harbor: Boston Soc. Nat. Hist. Proc., vol. 23, pp. 450–457, 1888.

——— Physical history of the Boston Basin: Boston Soc. Nat. Hist., Teachers' School of Science, Lowell Free Courses, 1889–90, 22 pp., 1889.

——— Geological history of the Boston Basin, Mass.: Boston Soc. Nat. Hist. Proc., vol. 25, pp. 10–17, 1890.

——— Composition of the till or boulder clay: Boston Soc. Nat. Hist. Proc., vol. 25, pp. 115–140, 1891.

——— Geology of the Boston Basin; Nantasket and Cohasset: Boston Soc. Nat. Hist. Occasional Papers, No. 4, vol. 1, pt. 1, pp. 1–177, 1893.

——— Geology of the Boston Basin; Hingham: Boston Soc. Nat. Hist. Occasional Papers, No. 4, vol. 1, pt. 2, pp. 179–288, 1894.

——— Geology of the Boston Basin; the Blue Hills complex: Boston Soc. Nat. Hist. Occasional Papers, No. 4, vol. 1, pt. 3, pp. 289–563, 1900.

——— Are the amygdaloidal melaphyrs of the Boston Basin intrusive or contemporaneous?: Am. Geologist, vol. 27, pp. 324–327, 1901.

——— Origin of eskers: Boston Soc. Nat. Hist. Proc., vol. 30, pp. 375–411, 1902.

——— A study of the geology of the Charles River estuary and Boston Harbor: Tech. Quart., vol. 16, pp. 64–92, 1903.

CROSBY, W. O., Genetic and structural relations of the igneous rocks of the lower Neponset Valley, Mass.: Am. Geologist, vol. 36, pp. 34–47, 69–83, 1905.

——— and BALLARD, H. O., Distribution and probable age of the fossil shells in the drumlins of the Boston Basin: Am. Jour. Sci., 3d ser., vol. 48, pp. 486–496, 1894.

——— and BARTON, G. H., Extension of the Carboniferous formation in Massachusetts: Am. Jour. Sci., 3d ser., vol. 20, pp. 416–420, 1880.

——— and LOUGHLIN, G. F., A descriptive catalog of the building stones of Boston and vicinity: Tech. Quart., vol. 17, pp. 165–185, 1904.

CURTIS, G. C., Evidence of recent differential movement along the New England coast [abstract]: Science, new ser., vol. 19, pp. 522–523, 1904.

——— Destruction of the drumlins in Boston Harbor [abstract]: Science, new ser., vol. 32, p. 127, 1910.

——— Observations on changes of level on the Atlantic coast line from Cape Cod to Cape Race, Newfoundland [abstract]: Science, new ser., vol. 33, p. 468, 1911.

DALE, T. N., The commercial granites of New England: U. S. Geol. Survey Bull. 738, 488 pp., 1923.

DANA, J. F. and S. L., Outlines of the mineralogy and geology of Boston and its vicinity, with map, 108 pp., Boston, 1818. Also in Am. Acad. Arts and Sci. Mem., vol. 4, pp. 129–223, 1818.

DAVIS, C. A., Salt-marsh formation near Boston and its geologic significance: Econ. Geology, vol. 5, pp. 623–639, 1910.

——— Some evidences of recent subsidence on the New England coast [abstract]: Science, new ser., vol. 32, p. 63, 1910.

——— Some historical evidence of coastal subsidence in New England [abstract]: Geol. Soc. America Bull., vol. 25, pp. 61–63, 1914.

DAVIS, W. M., Banded amygdules of the Brighton amygdaloid: Boston Soc. Nat. Hist. Proc., vol. 20, pp. 426–428, 1880.

——— The distribution and origin of drumlins: Am. Jour. Sci., 3d ser., vol. 28, pp. 407–416, 1884.

——— Structure and origin of glacial sand plains: Geol. Soc. America Bull., vol. 1, pp. 195–202, 1890.

——— The subglacial origin of certain eskers: Boston Soc. Nat. Hist. Proc., vol. 20, pp. 477–499, 1892.

——— The physical geography of southern New England: Nat. Geog. Soc. Mon. 1, No. 9, pp. 269–304, 1895.

DESOR, ÉDOUARD, On the phenomena of drift and glacial action in New England: Am. Jour. Agriculture, vol. 6, pp. 213–214, 1847.

DILLER, J. S., The felsites and their associated rocks north of Boston: Boston Soc. Nat. Hist. Proc., vol. 20, pp. 355–368, 1880.

DODGE, R. E., Additional species of Pleistocene fossils from Winthrop, Mass.: Am. Jour. Sci., 3d ser., vol. 47, pp. 100–104, 1894.

DODGE, W. W., Notes on the geology of eastern Massachusetts: Boston Soc. Nat. Hist. Proc., vol. 17, pp. 388–419, 1875.

——— Notes on the geology of eastern Massachusetts: Boston Soc. Nat. Hist. Proc., vol. 21, pp. 197–216, 1882.

——— On the relations of the Menevian argillites and associated rocks at Braintree and vicinity, in Massachusetts: Am. Jour. Sci., 3d ser., vol. 25, pp. 65–71, 1883.

——— Some localities of post-Tertiary and Tertiary fossils in Massachusetts: Am. Jour. Sci., 3d ser., vol. 36, pp. 56–57, 1888.

EARLE, R. B., Mineral veins of the Mystic quarries, Somerville, Mass. [abstract]: Science, new ser., vol. 9, p. 752, 1899.

EDWARDS, A. M., On some sub-peat deposits of Diatomaceae: Boston Soc. Nat. Hist. Proc., vol. 7, pp. 283–287, 1860.

EMERSON, B. K., Distribution of diabase in Massachusetts: Science, new ser., vol. 28, pp. 318–319, 1908.

——— Geology of Massachusetts and Rhode Island: U. S. Geol. Survey Bull. 597, 289 pp., 1917.

——— and PERRY, J. H., The geology of Worcester, Mass., 166 pp., Worcester Nat. Hist. Soc., 1903.

——— ——— The green schists and associated granites and porphyries of Rhode Island: U. S. Geol. Survey Bull. 311, 74 pp., 1907.

FAIRCHILD, H. L., Postglacial marine submergence of Long Island: Geol. Soc. America Bull., vol. 28, pp. 279–308, 1917.

——— Postglacial uplift of northeastern America: Geol. Soc. America Bull., vol. 29, pp. 187–238, 1918.

——— Postglacial uplift of southern New England: Geol. Soc. America Bull., vol. 30, pp. 597–636, 1919.

FOERSTE, A. F., The paleontological horizon of the limestone at Nahant, Mass.: Boston Soc. Nat. Hist. Proc., vol. 24, pp. 261–263, 1889.

FULLER, M. L., A new occurrence of Carboniferous fossils in the Narragansett Basin: Boston Soc. Nat. Hist. Proc., vol. 27, pp. 195–199, 1896.

——— Probable representatives of pre-Wisconsin till in southeastern Massachusetts: Jour. Geology, vol. 9, pp. 311–329, 1901.

——— Ice retreat in glacial Lake Neponset and in southeastern Massachusetts: Jour. Geology, vol. 12, pp. 181–197, 1904.

——— Glacial stages in southeastern New England and vicinity: Science, new ser., vol. 24, pp. 467–469, 1906.

——— The geology of Long Island, New York: U. S. Geol. Survey Prof. Paper 82, 231 pp., 1914.

GODON, SYLVAIN, Mineralogical observations made in the environs of Boston in the years 1807 and 1808: Am. Acad. Arts and Sci. Mem., vol. 3, pp. 127–154, 1809.

GRABAU, A. W., Paleontology of the Cambrian terranes of the Boston Basin: Boston Soc. Nat. Hist. Occasional Papers, No. 4, vol. 1, pt. 3, pp. 601–694, 1900.

——— and others, Guide to localities illustrating the geology of the vicinity of Boston, 100 pp., Am. Assoc. Adv. Sci., 50th anniversary meeting, Boston, 1898.

GULLIVER, F. P., The Newtonville, Mass., sand plain: Jour. Geology, vol. 1, pp. 803–812, 1893.

HITCHCOCK, C. H., Geological description of Massachusetts, with map: Official topographical atlas of Massachusetts, pp. 17–22, Walling & Gray, 1871.

——— Lenticular hills of glacial drift: Boston Soc. Nat. Hist. Proc., vol. 19, pp. 63–67, 1877.

HITCHCOCK, EDWARD, Final report on the geology of Massachusetts, 2 vols., 831 pp., 1841.

——— Geological map of Massachusetts, 1844.

HOBBS, W. E., Some new fossils from eastern Massachusetts: Am. Geologist, vol. 23, pp. 109–115, 1899.

HOBBS, W. H., On the petrographical characters of a dike of diabase in the Boston Basin: Harvard Coll. Mus. Comp. Zoology Bull., vol. 16 (geol. ser. 2), pp. 1–12, 1888.

HUNT, T. S., On Laurentian rocks in eastern Massachusetts: Am. Jour. Sci., 2d ser., vol. 49, pp. 75–78, 1870.

HUNT, T. S., On the geology of the vicinity of Boston: Boston Soc. Nat. Hist. Proc., vol. 14, pp. 45–49, 1871.

HYATT, ALPHEUS, On a raised beach at Marblehead, Mass.: Essex Inst. Bull. 2, p. 111, 1870.

——— On the porphyries of Marblehead, Mass.: Boston Soc. Nat. Hist. Proc., vol. 18, pp. 220–224, 1876.

JACKSON, C. T., Sur les conglomérates de Roxbourg (Boston) et les dykes qu'il contiennent: Soc. géol. France Bull. 7, p. 27, 1835.

——— Direction of drift scratches and cleavage planes of the Roxbury, Mass., greywacke: Boston Soc. Nat. Hist. Proc., vol. 3, p. 28, 1848.

——— On Tertiary fossils from Marshfield, Mass.: Boston Soc. Nat. Hist. Proc., vol. 3, pp. 323–324, 329, 1850.

——— The syenite of Nahant, Mass., not a metamorphic rock: Boston Soc. Nat. Hist. Proc., vol. 4, p. 170, 1852.

——— On the Braintree, Mass., argillite and its trilobites: Boston Soc. Nat. Hist. Proc., vol. 6, pp. 42–44, 1856.

JAGGAR, T. A., jr., An occurrence of acid pegmatite in diabase: Am. Geologist, vol. 21, pp. 203–213, 1898.

JOHNSON, D. W., The supposed recent subsidence of the Massachusetts and New Jersey coasts: Science, new ser., vol. 32, pp. 721–723, 1910.

——— Botanical evidence of coastal subsidence: Science, new ser., vol. 33, pp. 300–302, 1911.

——— Fixité de la côte atlantique de l'Amérique du Nord: Annales de géographie, vol. 31, pp. 193–212, 1912.

——— Botanical phenomena and the problem of recent coastal subsidence: Bot. Gaz., vol. 56, pp. 449–468, 1913.

——— Is the Atlantic coast sinking?: Geog. Rev., vol. 3, pp. 135–139, 1917.

——— and REED, W. G., jr., The form of Nantasket Beach, Mass.: Jour. Geology, vol. 18, pp. 162–189, 1910.

KEITH, ARTHUR, Topography of Massachusetts: U. S. Geol. Survey Water-Supply Paper 415, pp. 8–23, 1916.

LAHEE, F. H., Late Paleozoic glaciation in the Boston Basin: Am. Jour. Sci., 4th ser., vol. 37, pp. 316–318, 1914.

LANE, A. C., The geology of Nahant: Boston Soc. Nat. Hist. Proc., vol. 24, pp. 91–95, 1889.

LOUGHLIN, G. F., Contribution to the geology of the Boston and Norfolk Basins; I, The structural relations between the Quincy granite and the adjacent sedimentary formation: Am. Jour. Sci., 4th ser., vol. 32, pp. 17–32, 1911.

MACLURE, WILLIAM, Observations on the geology of the United States: Am. Philos. Soc. Trans., vol. 6, pp. 411–428, 1809.

MANSFIELD, G. R., The origin and structure of the Roxbury conglomerate: Harvard Coll. Mus. Comp. Zoology Bull., vol. 49 (geol. ser. 8), pp. 91–271, 1906.

MARCOU, JULES, On the Braintree, Mass., slate and formations of like age elsewhere: Boston Soc. Nat. Hist. Proc., vol. 7, pp. 357–358, 1860.

MERRILL, G. P., The newer eruptive rocks of the Nantasket area, Mass.: Boston Soc. Nat. Hist. Occasional Papers, No. 4, vol. 1, pp. 31–44, 1893.

——— Disintegration and decomposition of diabase at Medford, Mass.: Geol. Soc. America Bull., vol. 7, pp. 349–362, 1896.

MORSE, E. S., On certain fossil shells in the boulder clay of Boston Basin: Am. Jour. Sci., 4th ser., vol. 49, pp. 157–165, 1920.

MUDGE, B. F., The salt marsh formations of Lynn, Mass.: Essex Inst. Proc., vol. 2, pp. 117–119, 1862.

NILES, W. H., On the occurrence of shells of existing species in a boring at Fort Warren, Boston Harbor: Boston Soc. Nat. Hist. Proc., vol. 12, pp. 244, 364, 1869.

ORDWAY, ALBERT, On the occurrence of other fossil forms at Braintree, Mass.: Boston Soc. Nat. Hist. Proc., vol. 8, pp. 5–6, 1861.

PERRY, J. H., Note on a fossil coal plant found at the graphite deposit in mica schist, at Worcester, Mass.: Am. Jour. Sci., 3d ser., vol. 29, pp. 157–158, 1885.

POWERS, SIDNEY, The origin of the inclusions in dikes: Jour. Geology, vol. 23, pp. 1–10, 166–182, 1915.

PRESCOTT, WILLIAM, A sketch of the geology and mineralogy of the southern part of Essex County, in Massachusetts: Essex County Nat. Hist. Soc. Jour., vol. 1, pp. 78–91, 1839.

RAYMOND, P. E., Notes on the ontogeny of *Paradoxides*, with the description of a new species from Braintree, Mass.: Harvard Coll. Mus. Comp. Zoology Bull., vol. 58, pp. 225–244, 1914.

ROGERS, W. B., On trilobites from Braintree, Mass., and on the geologic relations of the district: Boston Soc. Nat. Hist. Proc., vol. 6, pp. 27–29, 40–41, 1856.

——— Proofs of the Protozoic age of some of the altered rocks of eastern Massachusetts from fossils recently discovered: Am. Acad. Arts and Sci. Proc., vol. 3, pp. 315–318, 1857.

ROORBACH, G. B., Shore line changes in the Winthrop area, Mass.: Geog. Soc. Philadelphia Bull., vol. 8, pp. 46–64, 1910.

SAYLES, R. W., The Squantum tillite: Harvard Coll. Mus. Comp. Zoology Bull., vol. 66 (geol. ser. 10), pp. 141–175, 1914.

——— Banded glacial slates of Permo-Carboniferous age, showing possible seasonal variations in deposition: Nat. Acad. Sci. Proc., vol. 2, pp. 167–170. 1916.

——— and LAFORGE, LAURENCE, The glacial origin of the Roxbury conglomerate: Science, new ser., vol. 32, pp. 723–724, 1910.

SEARS, J. H., The stratified rocks of Essex County, Mass.: Essex Inst. Bull., vol. 22, pp. 31–47, 1890.

——— On keratophyre from Marblehead Neck, Mass.: Harvard Coll. Mus. Comp. Zoology Bull., vol. 16 (geol. ser. 2), pp. 167–172, 1890.

——— Evidences of subsidence and elevation in Essex County in recent geologic time, as shown by field work at the seashore: Essex Inst. Bull., vol. 26, pp. 64–73, 1894.

——— Report on the geology of Essex County, Mass.: Essex Inst. Bull., vol. 26, pp. 118–139, 1894.

——— The physical geography, geology, mineralogy, and paleontology of Essex County, 418 pp., 1905.

SHALER, N. S., On the relations of the rocks in the vicinity of Boston: Boston Soc. Nat. Hist. Proc., vol. 13, pp. 172–177, 1869.

——— On the parallel ridges of glacial drift in eastern Massachusetts: Boston Soc. Nat. Hist. Proc., vol. 13, pp. 196–204, 1870.

——— Outline of the geology of Boston and its environs, in Winsor, Justin, The memorial history of Boston, pp. 1–8, 1880.

——— Seacoast swamps of the eastern United States: U. S. Geol. Survey Sixth Ann. Rept., pp. 353–398, 1885.

——— The geological history of harbors: U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, pp. 93–209, 1893.

SHIMER, H. W., A lower-middle Cambrian transition fauna from Braintree, Mass.: Am. Jour. Sci., 4th ser., vol. 24, pp. 176–178, 1907.

SHIMER, H. W., Postglacial history of Boston: Am. Jour. Sci., 4th ser., vol. 40, pp. 437–442, 1915.

——— Postglacial history of Boston: Am. Acad. Arts and Sci. Proc., vol. 53, pp. 441–463, 1918.

STIMPSON, WILLIAM, A list of fossils found in the post-Pliocene deposit in Chelsea, Mass.: Boston Soc. Nat. Hist. Proc., vol. 4, pp. 9–10, 1851.

STODDER, CHARLES, On drift in a ridge at South Boston, Mass.: Boston Soc. Nat. Hist. Proc., vol. 2, pp. 131–132, 1846.

——— On drift-filled cracks in clay at East Boston: Boston Soc. Nat. Hist. Proc., vol. 4, p. 286, 1853.

TARR, R. S., The origin of drumlins: Am. Geologist, vol. 13, pp. 393–407, 1894.

——— Postglacial and interglacial (?) changes of level at Cape Ann, Mass.: Harvard Coll. Mus. Comp. Zoology Bull., vol. 42 (geol. ser. 6), pp. 181–191, 1903.

TILTON, J. L., On the southwestern part of the Boston Basin: Boston Soc. Nat. Hist. Proc., vol. 26, pp. 500–505, 1895.

——— Notes on the geology of the Boston Basin: Iowa Acad. Sci. Proc., vol. 3, pp. 72–74, 1896.

TOWNSEND, C. W., Coastal subsidence in Massachusetts: Science, new ser., vol. 33, p. 64, 1911.

UPHAM, WARREN, Glacial drift in Boston and its vicinity: Boston Soc. Nat. Hist. Proc., vol. 20, pp. 220–234, 1879.

——— The till in New England: Geol. Mag., 2d ser., vol. 6, pp. 283–284, 1879.

——— The succession of glacial deposits in New England: Am. Assoc. Adv. Sci. Proc., vol. 28, pp. 299–310, 1880.

——— Marine shells and fragments of shells in the till near Boston: Am. Jour. Sci., 3d ser., vol. 37, pp. 359–372, 1889.

——— The structure of drumlins: Boston Soc. Nat. Hist. Proc., vol. 24, pp. 228–242, 1889.

——— Recent fossils of the Harbor and Back Bay, Boston: Am. Jour. Sci., 3d ser., vol. 43, pp. 201–209, 1892.

——— The origin of drumlins: Boston Soc. Nat. Hist. Proc., vol. 26, pp. 2–25, 1893.

——— Deflected glacial striae in Somerville, Mass.: Boston Soc. Nat. Hist. Proc., vol. 26, pp. 33–42, 1893.

——— The fishing banks between Cape Cod and Newfoundland: Boston Soc. Nat. Hist. Proc., vol. 26, pp. 42–48, 1893.

——— Marine shell fragments in drumlins near Boston: Am. Jour. Sci., 3d ser., vol. 47, pp. 238–239, 1894.

VERRILL, A. E., Occurrence of fossiliferous Tertiary rocks on the Grand Bank and George's Bank: Am. Jour. Sci., 3d ser., vol. 16, pp. 323–324, 1878.

WADSWORTH, M. E., Notes on the petrography of Quincy and Rockport: Boston Soc. Nat. Hist. Proc., vol. 19, pp. 309–316, 1878.

——— Notes in geology and lithology: Harvard Univ. Bull. 22, pp. 359–360; Bull. 23, pp. 431–432, 1882.

——— On the relation of the Quincy granite to the Primordial argillite of Braintree, Mass.: Boston Soc. Nat. Hist. Proc., vol. 21, pp. 274–277, 1882.

——— On the trachyte of Marblehead Neck, Mass.: Boston Soc. Nat. Hist. Proc., vol. 21, pp. 288–294, 1882.

——— The argillite and conglomerate of the Boston Basin: Boston Soc. Nat. Hist. Proc., vol. 22, pp. 130–133, 1883.

WALCOTT, C. D., Cambrian faunas of North America: U. S. Geol. Survey Bull. 30, 369 pp., 1886.

WALCOTT, C. D., Fauna of the Lower Cambrian or *Olenellus* zone: U. S. Geol. Survey Tenth Ann. Rept., pt. 1, pp. 509–760, 1890.

——— Correlation papers; Cambrian: U. S. Geol. Survey Bull. 81, 477 pp., 1891.

——— The North American continent during Cambrian time: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, pp. 523–568, 1891.

——— Note on Lower Cambrian fossils from Cohasset, Mass.: Biol. Soc. Washington Proc., vol. 7, p. 155, 1892.

WARREN, C. H., Petrology of the alkali granites and porphyries of Quincy and the Blue Hills, Mass., U. S. A.: Am. Acad. Arts and Sci. Proc., vol. 49, pp. 203–331, 1913.

——— and PALACHE, CHARLES, The pegmatites of the riebeckite-aegirite granite of Quincy, Mass., U. S. A.: their structure, minerals, and origin: Am. Acad. Arts and Sci. Proc., vol. 47, pp. 125–168, 1911.

——— and POWERS, SIDNEY, Geology of the Diamond Hill-Cumberland district in Rhode Island-Massachusetts: Geol. Soc. America Bull., vol. 25, pp. 435–476, 1914.

WEBSTER, J. W., Remarks on the geology of Boston and its vicinity: Boston Jour. Philosophy, vol. 2, pp. 277–292, 1824; vol. 3, pp. 486–489, 1826.

WENTWORTH, C. K., The shapes of beach pebbles: U. S. Geol. Survey Prof. Paper 131, pp. 75–83, 1922.

WENTWORTH, R. P., Preglacial Wisconsin drift in the Boston Basin: Science, new ser., vol. 42, p. 58, 1915.

WHITE, DAVID, Age of the Worcester phyllite: Washington Acad. Sci. Jour., vol. 2, pp. 114–118, 1912.

WHITE, T. G., A contribution to the petrography of the Boston Basin: Boston Soc. Nat. Hist. Proc., vol. 28, pp. 117–156, 1897.

WILSON, A. W. G., The Medford dike area: Boston Soc. Nat. Hist. Proc., vol. 30, pp. 353–374, 1901.

WOLFF, J. E., The great dike at Hough's Neck, Quincy, Mass.: Harvard Coll. Mus. Comp. Zoology Bull., vol. 7 (geol. ser. 1), pp. 231–242, 1884.

WOODWORTH, J. B., On traces of a fauna in the Cambridge slates: Boston Soc. Nat. Hist. Proc., vol. 26, pp. 125–126, 1893.

——— Carboniferous fossils in the Norfolk County Basin, Mass.: Am. Jour. Sci., 3d ser., vol. 48, pp. 145–148, 1894.

——— Some typical eskers of southern New England: Boston Soc. Nat. Hist. Proc., vol. 26, pp. 197–220, 1894.

——— On the fracture system of joints, with remarks on certain great fractures: Boston Soc. Nat. Hist. Proc., vol. 27, pp. 163–184, 1896.

——— Note on the elevated beaches of Cape Ann, Mass.: Harvard Coll. Mus. Comp. Zoology Bull., vol. 42 (geol. ser. 6), pp. 191–194, 1903.

APPENDIX

It was originally intended that the results of the study of the Boston area would be published as one of the folios of the Geologic Atlas of the United States, and the material was prepared and submitted in a form suited to that style of publication. It was later decided to publish the report as a bulletin, and the material has been utilized in that manner without expansion, although it is recognized that the condensed style, with omission of all minor details, and the small-scale maps, both necessitated by the folio form of publication, leave much to be desired that should be found in a bulletin on so complicated and so important an area.

Furthermore, the field work was finished in 1925 and the material was submitted for publication early in 1926, hence the report does not embody the results of more recent investigations, some of which have an important bearing on the interpretation of the geology of the district. Excavations now in progress (December, 1931) are bringing to light facts that may result in a new interpretation of the structure of a part of the Boston Basin. Boston geology is never at a standstill and will never be final as long as excavations are being made.

For the reasons just stated, it has been thought desirable to make a brief supplementary statement, embodying the most significant new data and pointing out the changes that may be involved. No change has been made in the maps and sections, which are to be viewed as representing the state of knowledge in 1925 and the most reasonable interpretations that could then be made.

The most outstanding addition to geologic knowledge in the past six years was the discovery, by Messrs. Rhodes, Graves, and Chase, students in the Massachusetts Institute of Technology, of Upper Cambrian fossils in the quartzite and slate at Green Lodge, several miles south of the Boston area. The locality is outside the Boston Basin, and the discovery has no immediate bearing on the problems of the basin, but it is of importance as showing that Upper Cambrian strata must originally have been rather widely distributed over southeastern Massachusetts. (See pp. 19, 67.) It is also important as showing that the strata at Green Lodge are not of Carboniferous age and hence do not form part of a hypothetical connection between the Boston and Norfolk Basins, as has been sometimes suggested. Full details of this discovery are given in a paper by the discoverers.[1]

Test borings for foundation exploration made in West Everett encountered quartzite when they reached the bedrock, which was

[1]Rhodes, E. J., and Graves, W. H., jr., A new Cambrian locality in Massachusetts: Am. Jour. Sci., 5th ser., vol. 22, pp. 364–372, 1931.

undoubtedly the Tufts quartzite member of the Cambridge slate. This discovery serves to confirm the existence of the syncline of quartzite mentioned on page 44, and apparently, surprising as it may seem, it indicates that the quartzite is actually the highest rock, stratigraphically, in the Boston group and that it is not overlain by anything but Pleistocene deposits.

Many excavations made during the construction of streets and houses in the area between West Newton and Waban have encountered bedrock, and it seems probable that the great mass of melaphyre on West Newton Hill extends farther south and west than is shown on the areal-geology map. More data are needed in that area, but there are already indications that the structure there may be rather different from that represented on the map. The same thing is true of the area in the western corner of Brookline and the southeastern part of Newton, where new facts are coming to light frequently.

Excavations in other smaller areas in the basin are throwing new light on the structural problems and have thrown doubt on some of the interpretations in the foregoing report. It now seems rather certain that the Hyde Park cross fault extends from Hazelwood almost directly northward close to the line of the railroad at least as far as Forest Hills, beyond which it has not yet been traced. It is also clear that the boundary between the slate and conglomerate in the area between Forest Hills and Roslindale does not swing in a great reversed curve, as mapped, but is offset to the north about half a mile on the west side of the Hyde Park fault, so as to pass under the northern slope of Peters Hill. The map has not been altered in these areas, because more information is needed before definite changes can be made. Similarly, in other parts of the basin, new light from recent excavations indicates that changes in interpretation may eventually have to be made, but the data are as yet insufficient for doing so. This is true, for example, of the great fault shown on the maps in this report as extending from Savin Hill westward through Jamaica Plain to the Charles River south of Upper Falls. This fault has been mapped on very slender evidence, and the author is by no means sure of its existence.

So far as the Pleistocene geology is concerned, there has been nothing of importance added to the knowledge of it since 1925, and there is no reason to alter the statements in the text. On the other hand, considerable new evidence has been found bearing on the problem of present-day coastal subsidence, and it all points in the same direction and serves to support the conclusion confidently stated in the foregoing text.

This supplementary statement is written December 18, 1931.

INDEX