GEOLGY OF THE BOSTON METROPOLITAN AREA

by

KENNETH GRENVILLE BELL

S.B., Massachusetts Institute Of Technology
(1939)

S.M., Massachusetts Institute Of Technology
(1940)

SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
(1948)

Signature of Author

Department of Geology: May 11, 1948

Certified by

Thesis Supervisor

Thesis Supervisor

Chairman, Departmental Committee on
Graduate Students
ABSTRACT
ABSTRACT

The formations of the Boston Metropolitan Area can be divided into five groups on the basis of nearly identical ages and similar lithologic characteristics. The first group consists of the oldest rocks of the area which are the remains of five stratified formations, all presumably of early Cambrian age, that are found as inclusions and pendants in younger large intrusive igneous bodies. The rocks of the second group form the sub-alkaline batholiths of the area. The third group is made up of numerous small alkaline batholiths and minor intrusive bodies and contemporaneous volcanic flows. The stratified formations of the Boston Basin belong in the fourth group. The fifth group consists of a multitude of dikes and sills of diabasic rock that have invaded all of the formations of the area.

Among the rocks of the first group are remains of the non-fossiliferous quartzites of the Westboro Formation, basaltic volcanic flows of the Marlboro Formation and a variety of volcanic flows of the Woburn Formation. The age of these rocks is not definitely known but is probably Lower Cambrian. The remainder of the group consists of argillites and limestones of the Weymouth Formation with a Lower Cambrian fauna and shales of the Braintree Formation with a Middle Cambrian fauna. The rocks of this group are unmetamorphosed or exhibit a very slight degree of meta-
morphism except in the immediate vicinity of contacts with igneous intrusive bodies where they have been reconstituted by a moderate degree of thermal metamorphism.

Two assemblages of igneous rocks comprise the sub-alkaline batholiths. The older and more basic assemblage includes the Nahant Gabbro and the Salem Gabbro-diorite. These igneous formations appear to have been emplaced as masses of molten magma. The younger and more alkaline assemblage comprises the Dedham Granodiorite batholith and its numerous apophysal offshoots. The main body of the granodiorite batholith appears to have emplaced as a mass of molten magma while a considerable portion of the roof phases have been developed by the metasomatic replacement of pre-existing rocks. The interval between the times of emplacement of the two assemblages of igneous rocks was probably short. The younger more alkaline types are intrusive into the older basic types. There is not any evidence to support the hypothesis of some earlier geologists that the rocks of the sub-alkaline group represent the differentiation in place under gravitative control of a single magma.

The alkaline group includes the Quincy Granite batholith, the Peabody Granite stock and minor intrusive bodies of granite, syenite and nordmarkite. These igneous bodies were emplaced as masses of molten magma. While these intrusive bodies were being emplaced the enclosing rocks of the sub-alkaline batholiths were hybridized by heat and solutions
derived from the granitic magmas. The flows of the Lynn Volcanics and the Mattapan Volcanic Complex appear to be associated with the emplacement of the alkaline intrusive bodies.

The stratified rocks of the Boston Basin are composed of sediments of glacial origin and flows of the Brighton Volcanic Complex. The sediments were produced by a mountain type glacier which, during the greater part of its existence, formed a terminal moraine at a high altitude. The outwash deposited the coarse sediments on the foothills and at the edge of the basin to form the Roxbury Conglomerate and carried the fine grained sediments into a lake in the main part of the basin to form the Cambridge Siltstone. During the late stages of the glaciation a maximum advance of the ice deposited a stratum of till in the basin, this now being the Squantum Tillite. The flows of the Brighton Volcanic Complex, which are interstratified with the Roxbury Conglomerate, appear to be the late phases of a period of volcanism that commenced with the eruption of the flows of the Mattapan Volcanic Complex.

The early Cambrian sedimentary formations were accumulated in a marine environment. During Upper Cambrian time the seas retreated from the area and thereafter the land was subjected to a long period of erosion. The sub-alkaline batholiths were probably emplaced during the Taconic orogeny. By Late Silurian or Early Devonian time erosion had stripped much of
the cover from the Dedham Granodiorite batholith. It is probable that the alkaline batholiths were emplaced during the Acadian orogeny and at the same time the flows of the Lynn Volcanics and the Mattapan Volcanic Complex were erupted upon the erosional surface of the Dedham batholith. By the close of the Acadian orogeny in Middle Devonian time high mountains had come into existence to the southward of the Boston Basin. During Upper Devonian time the summits of these mountains were glaciated and the sediments produced were deposited in the Boston Basin. There may have been some deposition of terrestrial sediments in the area during Carboniferous time, but if so, these sediments have been removed by subsequent erosion. During the Appalachian orogeny the formations of the area were folded and ruptured by numerous faults. The post-Paleozoic history of the area appears to have been one of continuous slow erosion. A large number of diabasic dikes and sills were injected into all of the formations of the area, presumably during Triassic time. The area was subjected to continental glaciation during the Pleistocene and much of the terrain was blanketed with various kinds of glacial deposits.
TABLE OF CONTENTS
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>1</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td></td>
</tr>
<tr>
<td>Location of the Area</td>
<td>1</td>
</tr>
<tr>
<td>Purpose of the Investigation</td>
<td>2</td>
</tr>
<tr>
<td>Regional Features</td>
<td>4</td>
</tr>
<tr>
<td>Formations of the Boston Metropolitan Area</td>
<td>6</td>
</tr>
<tr>
<td>EARLY PALEOZOIC STRATIFIED FORMATIONS</td>
<td>8</td>
</tr>
<tr>
<td>Westboro Quartzite - Marlboro Formation - Woburn Formation</td>
<td>9</td>
</tr>
<tr>
<td>Westboro Quartzite</td>
<td>13</td>
</tr>
<tr>
<td>Marlboro Formation</td>
<td>21</td>
</tr>
<tr>
<td>Woburn Formation</td>
<td>32</td>
</tr>
<tr>
<td>Weymouth Formation</td>
<td>39</td>
</tr>
<tr>
<td>INTRUSIVE IGNEOUS ROCKS</td>
<td></td>
</tr>
<tr>
<td>General Statement</td>
<td>44</td>
</tr>
<tr>
<td>Salem Gabbro-diorite</td>
<td>47</td>
</tr>
<tr>
<td>Nahant Gabbro</td>
<td>64</td>
</tr>
<tr>
<td>Dedham Granodiorite</td>
<td>76</td>
</tr>
<tr>
<td>Normal Variety</td>
<td>80</td>
</tr>
<tr>
<td>Stony Brook Variety</td>
<td>84</td>
</tr>
<tr>
<td>Newburyport Quartz-diorite Variety</td>
<td>87</td>
</tr>
<tr>
<td>Porphyritic Micrographic Granodiorite</td>
<td>90</td>
</tr>
<tr>
<td>Micrographic Granodiorite</td>
<td>95</td>
</tr>
<tr>
<td>Stoneham Red Granite Stock</td>
<td>97</td>
</tr>
</tbody>
</table>
Syenodiorite ........................................ 99
Aplitc Dikes ........................................ 101
Pegmatites ........................................... 103
Rocks Provisionally Assigned to the
Dedham Granodiorite ............................... 104
Diorite Stock in Lexington ....................... 104
Quartz - Biotite - Diorite ......................... 107
ROCKS OF THE ALKALINE GROUP .................... 112
Peabody Granite ..................................... 114
Nordmarkite of Marblehead ....................... 126
Quincy Granite ....................................... 131
Apophysal Phases of Quincy Granite ............ 132
Andover Granite ................................. 137

Origin of the Dedham Granodiorite and its
Relation to the Salem Gabbro-diorite ............ 139
Hybridization of the Salem Gabbro-diorite .... 186
Hybrid Rock of Little Nahant ..................... 196
Discussion of Rocks Called Waltham Gneiss .... 202
MIDDLE PALEOZOIC VOLCANIC ROCKS ................. 210
Lynn Volcanics ..................................... 211
Mattapan Volcanic Complex ....................... 231
STRATIFIED ROCKS OF THE BOSTON BAY GROUP .... 242
Roxbury Conglomerate ............................. 244
Squantum Tillite ................................... 254
Cambridge Siltstone ............................... 258
Brighton Volcanic Complex ....................... 262
Origin of the Sedimentary Rocks of the Boston Bay Group .................................. 267
Age of the Rocks of the Boston Bay Group ...... 285
DIKE ROCKS ................................................. 307
STRUCTURAL GEOLOGY OF THE BOSTON METROPOLITAN AREA
Topography and General Structural Features ... 309
Northern Boundary Fault of the Boston Basin .. 312
The Fells Upland
Divisions of the Fells Upland .............. 317
The Seaboard Unit .............................. 318
The Marblehead Fault .......................... 320
The Lynn Fault ................................. 321
Marblehead-Swampscott-Peabody Fault Block. 323
Saugus-Melrose Anticline ...................... 326
Western Upland .................................. 330
Nahant ........................................... 332
The Boston Basin
Principal Divisions ............................ 334
Northern Synclinorium ......................... 335
Tufts Syncline .................................. 335
Somerville Monocline .......................... 336
Watertown Area ................................ 336
Charles River Syncline ....................... 339
Central Anticline ................................ 340
Southern Shingle-block Zone .................. 345
Franklin Field Faulted Syncline .......... 346
Mt. Hope Thrust ............................... 350
## MAP SECTION

### Structure Sections

#### OUTCROP MAPS:

<table>
<thead>
<tr>
<th>Location</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marblehead South Quadrangle</td>
<td>No. 1</td>
</tr>
<tr>
<td>Lynn</td>
<td>No. 2</td>
</tr>
<tr>
<td>Boston North</td>
<td>No. 3</td>
</tr>
<tr>
<td>Lexington</td>
<td>No. 4</td>
</tr>
<tr>
<td>Nantasket</td>
<td>No. 5</td>
</tr>
<tr>
<td>Hull</td>
<td>No. 6</td>
</tr>
<tr>
<td>Boston South</td>
<td>No. 7</td>
</tr>
<tr>
<td>Newton</td>
<td>No. 8</td>
</tr>
<tr>
<td>Natick</td>
<td>No. 9</td>
</tr>
<tr>
<td>Norwood</td>
<td>No. 10</td>
</tr>
</tbody>
</table>

#### GEOLOGIC MAPS:

<table>
<thead>
<tr>
<th>Location</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marblehead South Quadrangle</td>
<td>No. 11</td>
</tr>
<tr>
<td>Lynn</td>
<td>No. 12</td>
</tr>
<tr>
<td>Boston North</td>
<td>No. 13</td>
</tr>
<tr>
<td>Lexington</td>
<td>No. 14</td>
</tr>
<tr>
<td>Nantasket</td>
<td>No. 15</td>
</tr>
<tr>
<td>Hull</td>
<td>No. 16</td>
</tr>
<tr>
<td>Boston South</td>
<td>No. 17</td>
</tr>
<tr>
<td>Newton</td>
<td>No. 18</td>
</tr>
<tr>
<td>Natick</td>
<td>No. 19</td>
</tr>
<tr>
<td>Norwood</td>
<td>No. 20</td>
</tr>
</tbody>
</table>
INTRODUCTION
INTRODUCTION
LOCATION OF THE AREA

The area described in this report is bounded approximately by parallels 42° 15' and 42° 30', the shore of Massachusetts Bay and meridian 71° 15'. The southern boundary is irregular and locally extends to the northward and southward of parallel 42° 15'. This area is located in Eastern Massachusetts and includes nearly all of Suffolk County and parts of Essex, Middlesex, Norfolk and Plymouth Counties. The city of Boston occupies much of the south-central portion of the area. The total land area described comprises approximately 240 square miles.

The maps used during the course of field investigations and also upon which the areal geology of the area has been plotted are the seven and one-half minute series topographic sheets of the United States Geological Survey. The report covers the Marblehead South, Lynn, Boston North and Lexington Quadrangles in their entirety and practically all of the Newton, Boston South, Hull and Nantesket Quadrangles and a small portion of the Norwood and Natick Quadrangles.
PURPOSE OF THE INVESTIGATION

The study of the Boston Metropolitan Area was undertaken with the purpose of obtaining data to make possible a better understanding of the origin and relations of the many types of rocks found within this area. The igneous and sedimentary formations of this area have been studied for more than a century and have been the subject of a considerable amount of literature. These rocks pose many problems that have never been satisfactorily answered because of several circumstances such as the complex relationships existing between some of the formations, a lack of suitable exposures, the absence of fossiliferous strata that would indicate ages, lack of knowledge concerning the physical chemistry of silicate magmas and lack of knowledge concerning the changes that take place in rocks during metamorphism. During recent years knowledge in the fields of metamorphism of rocks and the physical chemistry of silicate melts has been increased greatly and important contributions have been made in the field of sedimentation. The writer undertook the task of making a thorough field study of the rocks of the area in order to find features which, in the light of more recent knowledge, would furnish more satisfactory answers to some of the problems. The rocks of the area have been mapped in considerable detail and petrographic studies made of them. A large portion of the investigation was devoted to a study of the relationships exist-
ing between the various intrusive igneous rocks and their possible method of origin. Much time was also devoted to a study of the Late Paleozoic sedimentary formations of the Boston Bay Group with the object of determining the stratigraphic sequence and the source of the sedimentary material. The field investigations were conducted with the view of obtaining data that would permit a more thorough understanding of the structural features of the area.

The geological study of the Boston Metropolitan Area was carried on as a thesis project by the writer at intervals during the period of November 1946 to May 1948. The project was under the supervision of Prof. W. L. Whitehead and Prof. R. R. Shrock. The writer is indebted to Prof. Whitehead and Prof. Shrock for many helpful suggestions and discussions during the course of the investigation. A portion of the field work was done in the company of Prof. Whitehead who furnished automobile transportation to some of the more inaccessible parts of the area. Several suggestions by Prof. H. W. Fairbairn greatly facilitated the study of the igneous rocks.
The Boston Metropolitan Area is a small part of a geological and geomorphological province comprising the greater part of the New England States, the Maritime Provinces of Canada and Southeastern Quebec including the Gaspe Peninsula. That portion of this province lying within the United States is called the New England Province. The Cape Cod Peninsula and the islands lying to the southward are parts of another province called the Atlantic Coastal Plain. The southeastern portion of the New England Province can be separated into two divisions. The eastern-most division is a comparatively low lying belt some 15 to 50 miles in width extending from the southern part of Rhode Island northward along the Massachusetts - New Hampshire coast and into Maine. With the exception of a few prominent hills the elevations of this belt are less than 400 feet above sea level. The topography largely has been produced by glacial deposition. The western division of the New England Province is an upland area in which the topographic features tend to reflect the relief of the underlying rock surface. The elevations, except in the valleys of numerous streams, are generally in excess of 500 feet above sea level. There is not any prominent topographic feature separating the seaboard and western divisions, in fact, the passage from one to the other is almost imperceptible.
The Boston Metropolitan Area lies within the seaboard division of the New England Province. The greater portion of the rocks of this division consist of early Paleozoic igneous intrusive and extrusive formations and small remnants of Cambrian stratified formations. Small areas of late Paleozoic sedimentary and volcanic formations that were deposited upon an erosional surface of the early Paleozoic igneous formations have been preserved by virtue of occupying down-faulted or down-folded troughs that are called "basins". The Boston Basin is one of several such structural features of the seaboard division. The metropolitan area described in this report includes most of the Boston Basin with its stratified formations and portions of the uplands to the northward and southward that are composed mainly of igneous formations.
FORMATIONS OF THE BOSTON METROPOLITAN AREA

Pleistocene:

Glacial deposits (Ground moraine, outwash deposits, lake deposits, drumlins, eskers)

Triassic:

Diabase dikes and sills

Carboniferous:

Andover Granite (?)

Devonian:

Upper Devonian:

Boston Bay Group:

Cambridge Siltstone
Squantum Tillite
Roxbury Conglomerate
Brighton Volcanic Complex

Lower Devonian:

Eruptive Igneous Rocks
Mattapan Volcanic Complex
Lynn Volcanics
Intrusive Igneous Rocks (Alkaline Batholiths):

Quincy Granite
Peabody Granite
Marblehead Nordmarkite

ORDOVICIAN:

Sub-Alkaline Batholiths:
Dedham Granodiorite
Salem Gabbro-diorite
Nahant Gabbro

CAMBRIAN:

Middle Cambrian:
Braintree Formation

Lower Cambrian:
Weymouth Formation
Woburn Formation (?)
Marlboro Formation (?)
Westboro Formation (?)
EARLY PALEOZOIC STRATIFIED FORMATIONS
EARLY PALEOZOIC STRATIFIED FORMATIONS

The oldest rocks found in the vicinity of Boston are remnants of sedimentary and volcanic formations. Some of these remnants have been preserved in the form of pendants and inclusions in large batholithic masses of igneous rocks while others appear to be the remains of the roofs that covered these intrusions. The remnants which are probably the oldest consist of non-fossiliferous sedimentary rocks and volcanic flows that outcrop rather extensively in a narrow belt extending from northeastern Massachusetts to northwestern Rhode Island. These rocks cannot be dated accurately on the basis of present knowledge but because of the low degree of metamorphism exhibited, the writer groups them with rocks of known Early Paleozoic Age. The only remnants of the early formations that are dated by fossils are found as small pendants in the igneous rocks surrounding Boston Bay. One group of these rocks contains a Lower Cambrian fauna, another a Middle Cambrian fauna. Outcrops of the Middle Cambrian formation were not found within the area covered by this report.
A rather narrow belt of stratified and slightly metamorphosed rocks consisting of quartzites, quartz-mica schists, green and black schists of several varieties, conglomerates, limestones and volcanics extends intermittently across most of the eastern part of Massachusetts and into the northern part of Rhode Island. The trend is from the northeast, beginning in the vicinity of Salem and Peabody in Essex County, Massachusetts, to the southwest ending in the northwestern portion of Rhode Island. The lack of continuity is mainly due to intrusions of large masses of younger igneous rocks which have either displaced or absorbed the older stratified rocks. These formations are believed to contain the oldest strata of originally sedimentary origin preserved in this area. They are now found with the igneous rocks as innumerable inclusions and roof pendants varying in size from tiny remnants which can be seen in a hand specimen up to masses exposed over several acres of ground and as narrow outcropping areas several miles in length which appear to have been preserved by being the lower portions of folds which escaped assimilation by igneous intrusions and erosion by surface agencies.
At least two and possibly three formations are represented. The individual members of these formations are not present throughout the entire extent of the area in which outcrops are found, partly because of the relatively small and scattered distribution of these outcrops and partly because of lenticular shapes and omission of members from one section to another. For instance, limestone strata are present in the Marlboro Formation of Rhode Island and the southern portion of Massachusetts but not in sections represented in Middlesex and Essex Counties of Massachusetts and strata of conglomerate are found intermittently throughout the entire area. The formation which is considered to be the oldest consists mainly of light colored quartzites and is called the Westboro Quartzite. Overlying this is a thick series of predominately dark colored strata consisting of various kinds of schists, conglomerates, limestones and volcanics. These dark colored rocks have been named the Marlboro Formation. The uncertain relationship between these two formations and a third series of rocks which are predominately or wholly of volcanic origin indicates the possibility of a third formation. This is called the Woburn Formation. All three are named from the location of typical exposures.
The attitude of the strata in all the formations show a general northeast-southwest strike and a steep north westward dip with minor localized variations throughout the Massachusetts section. In Rhode Island pronounced variations from this general trend are reported by Emerson and Perry. These writers consider the structure to consist of tightly compressed isoclinal folds cut by numerous intrusions and dikes of igneous rocks and broken by faults.

The age of these formations is uncertain and has been placed in both the Pre-Cambrian and the Cambrian by various writers, the basis for such choices being the degree of metamorphism and comparisons with similar stratified rocks found elsewhere. None of the formations contain any fossiliferous members. They do not show contacts with any other rocks of definitely known age. The exposed contacts are with igneous intrusives and extrusives of much younger age. There are no exposures which furnish information regarding the nature of the floor upon which the basal members were deposited. The rocks of the area are intrusive into these formations or are

volcanic rocks which overlie them unconformably. These relations indicate that the Westboro, Marlboro and Woburn Formations are older in age than any other rocks with which they make contact. A rather low degree of metamorphism is exhibited which has not been intense enough to destroy the original stratification and generally has reached only the stage of formation of chlorite or biotite. There are some similarities with formations of known Cambrian age found farther to the westward. Because of these similarities and the low degree of metamorphism a Cambrian age seems most probable to the writer. Remnants of slightly metamorphosed fossiliferous Middle Cambrian strata are found in the area, therefore the three formations under consideration are probably of Lower Cambrian Age.
WESTBORO QUARTZITE

The formation of this group which is presumed to be the oldest consists of massive quartzites, feldspathic sandstones, quartz-mica schists and localized conglomerate strata. It was first named the Grafton Quartzite by Emerson¹ who tentatively correlated it with the Pelham Quartzite and Cheshire White Quartzite of the western part of the state and assigned a Cambrian age. It is also the formation designated as the Cumberland Quartzite of Rhode Island by Woodworth.² Descriptions in these publications are very meager. A brief description of outcrops in several localities is given by Emerson in U.S.G.S. Bulletin 597 where he uses the name Westboro Quartzite.

The most extensive exposures of the Westboro Quartzite in the area covered by this report are found in a belt approximately one mile wide extending south westward from the north central part of Saugus through the central portion of Melrose, crossing the Middlesex Fells Reservation and ending in West Medford and Winchester. The continuity of this belt is broken

to some extent by intrusions of igneous rock and cappings of volcanic flows belonging to the Lynn Volcanic Series. Small isolated outcroppings are found in Woburn east of Woodbrook Cemetery and on the east side of Garfield Avenue north of Green Street, also in Arlington as large inclusions or roof pendants in the Salem Gabbro-diorite of the hilly area between Summer Street and Mystic Street - Hutchinson Road of Winchester. Remnants of this formation constitute many of the quartzite inclusions in the Salem Gabbro-diorite of Waltham and Belmont, likewise the quartzite and micaceous quartzite inclusions in the Salem Gabbro-diorite and Dedham Granodiorite of Lynn and Marblehead.

The predominant phase is a light gray, fine grained, saccharoidal textured quartzite of rather high purity. Micaceous strata, some containing muscovite, others chlorite or biotite are fairly common but do not show any great thickness, ordinarily only a few inches and at most only a few feet, and are usually interbedded with more quartzose strata thereby showing a tendency towards thinly bedded stratification. The more pure saccharoidal textured quartzite forms thick massive strata with only slight micaceous seams. This type makes up the basal or the stratigraphically lowest portion of the formation exposed along the southeast side of the belt described above. Fresh specimens show a very even grained texture and a very uniform light gray color. The rock is dense and brittle. Very little change is caused by weathering,
the most noticeable being a general softening as if beginning to disintegrate into a fine sand. Micaceous strata become more numerous towards the upper portion of the formation and there is an indication that there may be a gradual transition into the overlying dark colored Marlboro schists. This character is most evident in the northwest part of Saugus where an almost continuous outcropping section along the hydroelectric power line passing over the hill lying to the east and northeast of Griswold Pond shows a gradual transition from light gray quartzite at the south to dark colored schists at the north.

All specimens examined microscopically contained feldspars, usually with orthoclase predominating but also some plagioclase. These feldspars are frequently altered, sometimes to the extent that optical properties cannot be determined. Specimens from large outcrops of massive quartzite show only a few percent of feldspar grains which are quite evidently detrital material deposited with the original sediment. Specimens collected from outcrops found as inclusions or roof pendants in granitic rocks show a very marked increase in the percentage of feldspar grains, both potash types and plagioclase, presumably caused by feldspathization during the emplacement of the Dedham Granodiorite batholith. In the same specimens the mica flakes become larger and begin to show a definite common orientation with biotite being the most common type. A wide variety of quartzite specimens
was collected from inclusions and pendants in the Salem Gabbro-diorite. These all contain varying amounts of feldspars, those with a small amount having chlorite as the micaceous constituent and those with a larger amount showing biotite. The original sedimentary material was quite evidently somewhat feldspathic since the degree of metamorphism reached in specimens containing the lower amount of feldspars will not account for the presence of these minerals. Increases of feldspars in the immediate vicinity of igneous intrusions are interpreted to be the result of metasomatic changes during the period of the intrusion.

A moderate degree of metamorphism is exhibited. Grains for the most part are sub-rounded to angular showing a tendency to form an interlocking mosaic. Original shapes have been partially destroyed by means of some recrystallization consisting of incooperating siliceous cementing material into the adjoining grains and through a slight brecciation which has broken off smaller interstitial grains from the larger. Strain shadows, undulatory extinction and cracked grains are quite common. The lower portion of formation was deposited as well graded material. The upper portion contained considerable amounts of fine grained detrital material mixed with the quartz. This fine grained detritus is now altered to micaceous minerals, normally a fine flaky chlorite but less commonly coarser grained and changing to biotite.
in the immediate vicinity of igneous intrusions.

Generally in the area studied the bedding of the Westboro Quartzite is not well preserved with many outcrops not exhibiting any recognizable features of stratification. Others show poorly defined bedding, usually preserved as micaceous strata which are frequently displaced by small scale faulting or considerably broken up by localized brecciation. Outcrops with good bedding are rare. Individual strata very rarely can be traced from one outcrop to another and often cannot be followed across a single outcrop. Sufficient dips and strikes can be obtained in the area to indicate that the stratification follows a slightly sinuous course having a general northeast-southwest strike and vertical to steep northwestward dips. A few measurements showed an east-west strike, most of which were found in the west part of Melrose. In the eastern portion of the Middlesex Fells Reservation at the northeast of Spot Pond a few very steep southeastward dips were found, probably caused by a slight local overturning. Indicators of top and bottom of strata such as cross bedding and graded bedding are scarce and not distinct enough to be reliable but it is believed that topside lies to the northwest. Most of the formation is therefore in an upright position, the main structure being the southeast flank of a long synclinal fold. This attitude of the stratification is consistent with
the general trend even in small inclusions and pendants in the younger igneous rocks.

Relationships of the Westboro Quartzite to the older rocks of the area are obscure. There is not at any place an exposure where the character of the floor upon which it was deposited can be observed. Actually in the area studied there is not any certainty that the basal strata of the formation are preserved. Folding, faulting, erosion and igneous intrusions have either completely destroyed the floor and the basal strata or have removed the remnants from the surface. Its relation to the overlying Marlboro Formation also is uncertain. In the northwestern part of Saugus it appears to grade upward into the dark colored schists in a conformable sequence. Elsewhere the two formations are usually separated by considerable thicknesses of igneous intrusives which have absorbed or displaced portions of the stratified sequence. Boulders of whitish quartzite similar in appearance to the Westboro are found in volcanic flows of the Marlboro Formation exposed to the north and northwest of the hill known as High Rock which lies on the Melrose-Wakefield town line. There is not any evidence in the vicinity as to the manner in which these boulders reached their present position. Other types of rock are also found in these flows so it is probable that the lavas flowed over terrain on which these types were exposed at the surface and carried along some
of the loose fragments. This condition suggests an unconformity. The best field evidence seems to indicate a gradual conformable transition from nearly pure quartzite through micaceous chloritic quartzite into dark colored schists, the dark colored portion being considered the basal strata of the Marlboro, and either a disconformable or unconformable relationship between the volcanic flows and the underlying schists. The plutonic igneous rocks of the area are intrusive into the quartzite and therefore are younger. The Salem Gabbro-diorite contains inclusions and pendants of the quartzite which are quite numerous in the hilly area between Summer Street, Arlington and Mystic Street - Hutchinson Road of Winchester. The quartzite inclusions in the gabbro-diorite of the north portion of Waltham and other parts of Winchester are probably remnants of the Westboro. Dedham Granodiorite intrusive into the quartzite can be seen in the south part of the Breakheart Reservation at North Saugus, in the Middlesex Fells Reservation and on the small island in the South Reservoir of the Winchester Water Works. Inclusions of quartzite in the granodiorite are common in all exposures of the latter lying along the south edge of the belt of stratified rocks. Flows of the Lynn Volcanic Series form cappings on the quartzite in a few places among which are the south part of the Breakheart Reservation and the northeastern part of the Middlesex Fells Reservation.
Boulders and pebbles of quartzite presumably derived from this formation are numerous in the conglomerate of West Medford.

The exact age of the formation is not known. It does not carry any fossils or make contact with other rocks that are fossiliferous. It is older than all other rocks with which it makes contact. As already explained in the general section a Lower Cambrian age seems most probable.

The deposition is considered to have taken place in a marine environment. Wherever stratification is preserved undisturbed by faulting and brecciation an evenness and regularity consistent with this type of origin is found. The lower beds show an uniformity of grain size and absence of argillaceous material characteristic of thoroughly washed arenaceous sediment which could very well be the result of wave action. The upper beds still maintain the same regularity of stratification but contain a large amount of fine material indicating a more rapid deposition with less wave action or deposition in deeper water farther from shore. The total thickness of the formation is uncertain due to numerous intrusions of igneous rocks and the fact that the basal portion probably is not exposed. In the North Saugus and Middlesex Fells Reservation sections of at least one thousand feet of strata are exposed. The original thickness was likely somewhat greater.
MARLBORO FORMATION

The series of predominately dark colored stratified rocks which are associated with and apparently overlie the Westboro Quartzite were named the Marlboro Formation by Emerson because of prominent outcrops in this town. Descriptions in the literature are very brief with the exception of some of the older reports on the Rhode Island area. Various types of chloritic, biotitic and amphibolite schists together with volcanics, quartzites and limestones are reported as belonging to parts of this series. It would appear that all the dark colored stratified and metamorphic rocks of uncertain age in the area together with some interbedded light colored members have been grouped under this name regardless of type or mode of origin. This practice has probably been for convenience because some types are difficult to distinguish without microscopic study and the origin in many cases is obscure. Much of this group is undoubtedly sedimentary as indicated by the presence of thick limestone beds, especially in the Rhode Island and southern Massachusetts sections. In other localities the group appears to consist mainly of basaltic lavas. It is possible that a thorough detailed study of the entire sequence will reveal a sedimentary series and a volcanic series, the two not necessarily being conformable or even closely related in age.
In the area covered by this report the dark colored rocks of this group lie in two northeast-southwest trending belts. The one having the greatest exposures lies parallel with and roughly adjacent to the northwest side of the Westboro Quartzite just described. It was first noticed at the north edge of the Lynn Quadrangle where large pendants are found in the edges of the Peabody Granite stock. From there it can be traced southwestward along a belt about two miles in width passing through North Saugus, Wakefield, Stoneham, the north half of the Middlesex Fells Reservation, Winchester and ending against the north boundary fault of the Boston basin in Arlington and Belmont. Long continuous exposures begin in Wakefield and end in Winchester. Elsewhere outcroppings consist of pendants and inclusions in intrusive igneous rocks. Contacts with the quartzite are scarce, the two usually being separated by masses of igneous intrusives. Several rock types are represented. The second belt lies farther to the northwest and consists of widely scattered inclusions and pendants in igneous rocks. These are found along a belt beginning at the north edge of the Lexington Quadrangle in Woburn and passing southwestward through Burlington, Lexington and Waltham. The rock types here are somewhat different from those of the first belt, the differences being interpreted as changes caused by thermal metamorphism. Scattered remnants of quartzite are found along the southeast side suggesting a repetition of the sequence.
There is some evidence that the Westboro Quartzite grades upwards into dark colored chloritic quartz schists with the percentage of chlorite steadily increasing stratigraphically upwards. Such a transition is noticeable in the North Saugus section already mentioned under the Westboro Quartzite and to a lesser extent in the Middlesex Fells Reservation at the west side of the South Reservoir of the Winchester Water Works. The dark colored chloritic quartz schists are assumed to be of sedimentary origin. There is not any true boundary between these schists and the real quartzites. On the map accompanying this report a boundary is arbitrarily fixed at the approximate point where chlorite reaches a sufficient concentration to make the rock gray in color and the colored portion is called Marlboro Formation. This is a questionable procedure since these chloritic strata may properly be considered merely to be the uppermost strata of the Westboro Formation and to be entirely distinct from the rocks described below. A thorough study along the entire extent of the formations would be necessary in order to obtain data by which the two could be separated.

With the exception of the two localities noted above the large southeastward belt mapped as Marlboro Formation is believed to consist entirely of basaltic lavas. Several variations are represented, some of which have similar macroscopic appearances to one another and also closely resemble
the highly chloritic schists. This feature makes field identification of weathered outcrops somewhat risky, but since several representative specimens collected for microscopic study were all volcanic types it is reasonably certain that any sedimentary strata that may exist must be quite thin.

A type characteristic of some of the small isolated outcrops in Lynn, North Saugus and along the southeast edge of the main belt in Wakefield is a very fine grained, even textured, even colored, dark gray rock. The grain is so fine that it is almost impossible to detect crystalline texture, even with a hand lens. Microscopic examination shows a pliotaxitic texture with a mineralogical composition consisting almost wholly of closely packed minute plagioclase laths and needles. Some specimens have minute lath-shaped plagioclase phenocrysts. The mineral is usually labradorite but in some cases is andesine. The small amount of interstitial/when it can be identified under the microscope consists of the alteration minerals chlorite, calcite and epidote accompanied by an abundant extremely fine grained opaque mineral assumed to be magnetite. Frequently the interstitial material is dark colored and too fine grained to permit identification of constituents. The magnetite forms from two to five percent of the total rock volume. Tiny veinlets of secondary epidote and quartz are quite numerous.
Porphyritic and amygdaloidal varieties are characteristic of the outcrops in Wakefield, Stoneham and the Middlesex Fells Reservation. If the very poor indications of a northwestward dip and assumed upright position are correct, then these flows are younger and lie above the pilotaxitic lavas. While the latter are most frequently found along the southeasterly side of the belt some are occasionally found interstratified with the porphyritic flows. Specimens taken from the porphyritic and amygdaloidal flows are usually quite thoroughly altered to chlorite, epidote, uralite and calcite. Mafic constituents form approximately half of the rock volume. Originally a colorless pyroxene formed abundant phenocrysts but these have been almost completely altered to uralite which in turn has often been partly changed to chlorite. The remnants are too small or are too much clouded with alteration products to permit a positive identification but extinction angles indicate a monoclinic variety. Hornblende appears to be a primary constituent of some specimens. The plagioclase is labradorite forming in long blades without any preferred orientation. It is almost completely clouded by alteration products. Magnetite is always present, frequently up to five percent by volume. Alteration minerals now form a very large portion of the mass. In addition to uralite and chlorite formed at the expense of mafites, calcite and a powdery material probably consisting of kaolin, iron oxide
stain and micas is formed from plagioclase. Epidote or the colorless clinozoisite fills veinlets and tiny cavities. The original texture can usually be seen even though the first formed minerals are largely replaced.

Amygdaloidal texture is most often found in flows that are otherwise pilotaxitic. A variety of secondary minerals now form the amygdules. Good exposures of these flows are found on the north slope of the hill called High Rock near Wakefield-Melrose town line.

The sequence contains a few lenticular masses of boulder agglomerates. Besides numerous fragments of basaltic lavas these masses contain boulders of quartzites and of other rocks that cannot be correlated with known outcrops. The quartzite of the boulders is similar in appearance, both macroscopically and microscopically, to the Westboro. It is probable that the lavas flowed over a terrain on which the quartzites and other rocks outcropped and in their movement picked up considerable loose surface material. This condition is very suggestive of an unconformity between the volcanics and the sedimentary strata of the Westboro Formation. The best exposures of the boulder agglomerates are on the north slope of High Rock and on the hill a short distance to the northwest. Others are in the thickly wooded area of the Middlesex Fells Reservation at the west side of the Middle Reservoir of the Winchester Water Works.
La Forge states that south of Arlington Heights the Marlboro Formation contains extensive bodies of volcanic rocks of several varieties. Although separated by a large mass of igneous intrusives these outcrops are believed to be a continuation of the above described flows. Field observations verified La Forge's conclusion but specimens for microscopic study were not collected from these outcrops.

The second or northwestward belt considered to be part of the Marlboro Formation is made up of still different types of rock. The exposures are all relatively small inclusions or pendants in the Salem Gabbro-diorite. Stratification is frequently better preserved here than in the southeastward belt. The rock may be quite uniformly gray in color or finely laminated black and white. In most cases the composition is very simple, consisting mainly of green hornblende and plagioclase. The two minerals usually form grains of about the same size so that the texture is equigranular. Hornblende frequently shows numerous euhedral crystals while plagioclase tends to be more irregular. Segregation of the two minerals into alternating bands produces the fine black and white lineation seen on some outcrops.

The plagioclase varies in composition from oligoclase to andesine. Magnetite is always present, ranging up to five percent of the rock by volume, and is closely associated with the hornblende. Both plagioclase and hornblende are finely crystalline but still coarse enough to be easily identified with a hand lens. Magnetite is much finer. The proportion of hornblende to plagioclase varies from one specimen to another, lying between sixty-percent hornblende - thirty-five percent plagioclase and thirty-five percent hornblende - sixty percent plagioclase. These rocks can be classified as plagioclase-amphibolites and have reached their present condition through thermal metamorphism. The original material was undoubtedly basaltic lava. It can be assumed that alteration, apparently of a hydrothermal type, produced in it as secondary minerals uralite, chlorite, calcite and epidote such as are abundant in the lavas of the main south-easterly belt. The original pyroxenes and labradorite were quite thoroughly altered as is the case with the flows in the southeast belt. The emplacement of the Salem Gabbrodiorite batholith caused remnants of the weathered flows to be left as roof pendants and inclusions. Heat furnished by the intrusive mass brought about a recrystallization resulting in complete mineralogical reconstitution. The original plagioclase having lost a considerable portion of its calcium content in the formation of secondary calcite re-crystallized as oligoclase or andesine. Formation of the
green hornblende proceeded from two directions. Chlorite, calcite, uralite and epidote combined to produce the higher temperature hornblende while any remnants of pyroxene were reduced to the same mineral, the temperature being such that the hornblende and plagioclase thus formed satisfied the requirements for equilibrium. Any iron required for the formation of hornblende was drawn from magnetite, the surplus being gathered into grains somewhat larger than ordinarily found in the basaltic flows.

Along the extreme northwest edge of this belt a few small inclusions of a thermally metamorphosed rock having a still different composition are found in the gabbro-diorite. Quartz forms fifty percent or more of the volume with feldspars, biotite and very minor hornblende and magnetite making up the rest. These rocks could be produced by the same process of thermal metamorphism outlined above provided the original material was a chloritic feldspathic quartzite similar to the dark colored schists at the top of the Westboro Quartzite. The metamorphism would be towards higher temperature minerals. There is not sufficient field data available to indicate whether or not the Westboro Quartzite should outcrop in this vicinity.

Other exposures of the plagioclase amphibolites are found outcropping near the edges of the Peabody Granite stock in Wakefield and North Saugus and as pendants within it in Peabody. These exposures are identical in appearance and
composition to those of Woburn, Lexington and Waltham. They lie along the line of strike of the basaltic flows of Wakefield and Stoneham and therefore it is quite reasonably certain that they represent the contact phases abutting against the granite. This granite is considered to have been emplaced as a mass of molten magma and would therefore have been able to furnish the heat required for metamorphism.

Indications of flow structure or other stratification in the Marlboro Formation are generally poorly preserved or non-existent in most outcrops. The porphyritic and amygdaloidal basalts are almost completely devoid of such features. The scattered stratified remnants show an universal northeast-southwest strike and a steep northwestward dip except in a very few instances where faulting has disturbed the strata. This condition applies to both belts. The only structural set-up that very satisfactorily satisfies this condition is that the outcrops are remnants of long isoclinal folds.

The thickness of the formation cannot be positively determined because it is not certain that either the top or the bottom is anywhere exposed. This situation is a result of both being cut off by younger igneous intrusions. At least three thousand and possibly as much as five thousand feet of thickness is exposed.

Since there are not any fossiliferous members within
the formation and it does not make contact with other formations containing fossils the age is also uncertain. It is presumed to be younger than the Westboro Quartzite because it appears to overlie that formation and because of contained quartzite boulders similar to portions of the Westboro. It has been intruded by the Salem Gabbro-diorite and the sub-alkaline batholiths and the Peabody Granite Stock and is therefore older than these igneous bodies. It would seem reasonable to assign to the Marlboro Formation a Lower Cambrian age younger than that of the Westboro Quartzite.
In several areas of Massachusetts and New Hampshire are found interbedded quartzites and volcanic rocks, chiefly rhyolitic types, which appear to overlie the Marlboro Formation. The quartzites are reported to be of somewhat different lithologic character than the typical Westboro Quartzite which is not interbedded with volcanics and there is some evidence that the series constitutes a later formation overlying the Marlboro.\(^1\) La Forge very briefly describes some exposures believed to be of this series and gives to them the name Woburn Formation because the largest exposures are located within this town.\(^2\) The outcroppings described below are those mentioned by La Forge. There is given a somewhat different and more detailed description than that published by La Forge.

The largest exposures of the type grouped under the name Woburn Formation to be found in the area studied are located in the western part of the town of Woburn where they are to be seen outcropping along the northwest or the southeastward facing slope of a deep, steep sided ravine.

---

known as Shaker Glenn. Much smaller remnants are found to
the northeast and southwest. Some of the inclusions in the
Salem Gabbro-diorite of Waltham and Belmont are also labeled
Woburn Formation on the map accompanying La Forge's bulletin.
These latter rocks will be discussed at the end of this
section.

The rocks found on the northwest side of Shaker Glenn
are believed to be entirely of volcanic origin since the
numerous outcrops examined and several specimens collected
for microscopic study are all definitely igneous types.
They are stratified, or layered, showing an uniform northeast-
southwest strike and a steep northwestward dip. The total
thickness cannot be determined since there is no indication
that the base of the series is exposed in the bottom of the
ravine and the uppermost flows at the top of the slope are
hidden by a covering of glacial drift. A thickness of at
least five hundred feet is exposed and the total is assumed
to be somewhat greater. Light colored whitish or pinkish
phases seem to be predominant in the lower flows exposed and
grey, greenish or black phases in the uppermost. Some out-
crops show alternating light and dark colored strata varying
from a foot to several feet in thickness. Each color appar-
ently represents a different flow although disconformities
and erosion surfaces between them are not easily distinguished.
The main outcrops lie within an area about one mile in length
and one quarter to one half mile in width, comprising a large roof pendant in Salem Gabbro-diorite. There are not any actual contacts with formations other than the gabbro-diorite exposed. The southeast side is most likely bounded by a fault which determines the position of the ravine. This fault cannot be seen as the bottom of the ravine is the course of a fairly large brook, is devoid of outcrops and is more or less covered with talus from the slopes. The southeast or northwestward facing slope is composed of Salem Gabbro-diorite with small intrusive plugs of Dedham Grano-diorite; it shows no trace of the stratified volcanics. Much smaller remnants of the volcanic rocks found nearby are definitely inclusions or pendants in the gabbro-diorite therefore the same relation is considered to hold for the Shaker Glenn exposure.

All of the Woburn Formation in the Shaker Glenn locality is believed to be volcanic since strata of definite sedimentary origin were not observed. Two distinct phases are represented. The lower flows exposed consist mainly of light-colored, whitish to pinkish porphyries with good flow structure. The mineral composition varies somewhat from one flow to another. The phenocrysts consist for the most part of orthoclase and microcline, the two usually appearing in the same section, and a lesser amount of plagioclase having the composition of calcic albite or oligoclase. The groundmass is
very finely crystalline showing a mixture of feldspars and extremely fine interstitial quartz. There are not any minerals of the pyroxene-amphibole-biotite groups. Secondary minerals are quartz in tiny microscopic veinlets, epidote in veinlets and scattered grains and powdery incipient alteration products of feldspars, probably calcite and kaolin. Flow lines are well developed, being regular and uniform in some strata and extremely irregular in others. Trains of tiny crystals in the flow lines bend and wrap around the phenocrysts. Evidence that the rock has been subjected to considerable stress is furnished by numerous fractured and bent phenocrysts, strain shadows and undulatory extinction. These light colored phases have a mineral assemblage normal for rhyolites and since dark colored constituents are absent they can be classified as leucorhyolites.

The dark colored flows which are most abundant in the upper portion of the exposed section differ considerably in composition from the light colored members even though to some extent the two types are rather thinly interbedded. The color varies from greenish to dark gray and black. These rocks are also porphyritic and have well developed flow structure. Phenocrysts consist of both dark and light colored minerals. In some flows plagioclase having the composition of calcic albite or oligoclase forms the greatest numbers with a lesser amount of finer orthoclase. Some flows show
numerous remnants of a colorless pyroxene identified as enstatite which formed large phenocrysts now almost completely altered to uralite and chlorite. Other flows show numerous large grains and aggregates of a green hornblende which are in many cases alteration products of a mineral that has entirely disappeared. Magnetite is a prominent constituent in all cases, usually forming about five percent of the volume. It can be seen as small grains and long thin ribbons following flow lines. Secondary minerals are epidote and chlorite in rather large amount as alteration of original ferro-magnesium constituents and calcite as alteration of plagioclase. Some specimens show a large amount of dark colored devitrified glass that is too fine grained to permit identification of minerals. The groundmass is generally dark colored and composed of fine grained material that cannot be identified definitely. Dark colored constituents are usually slightly less in volume than the light colored. Quartz, when present as a primary constituent, is found as very fine interstitial material in the groundmass. These dark colored flows are very similar in structural and textural features to the light colored members. They differ in mineralogical composition by being low in quartz and potash feldspars, by having an abundance of mafic constituents and by having sufficient magnetite so that it may be classified as an essential constituent. These flows can be classified as rhyodacites.
Beyond the fact that remnants of the Woburn Formation are found as inclusions and pendants in the Salem Gabbro-diorite and is therefore older than that rock in age there is nothing in the area to indicate its relations to other formations. As stated above previous reports by other geologists imply that it overlies the Marlboro Formation but outcrops which would verify this conclusion are not available in this area. Small remnants, some of which are completely surrounded by outcropping Salem Gabbro-diorite are found both to the northeast and southwest along the line of strike of the Shaker Glenn exposure and extend for a distance of some two or three miles in each direction.

Some of the inclusions in the gabbro-diorite of Waltham and Belmont have been mapped as Woburn Formation by LaForge.\(^1\) These inclusions are usually small remnants of stratified rocks with quartzites and feldspathic quartzites being most abundant. Stratification can frequently be traced from one small isolated remnant to another thus indicating a continuity of structure. Some of the felspathic quartzites have numerous fine bands or layers of pink orthoclase and microcline giving an appearance similar to that of some of the leucorhyolites of Shaker Glenn. Microscopically these rocks resemble

---

sediments more closely than volcanic flows but they do not resemble any portion of the Westboro Quartzite seen elsewhere in this area. In this same vicinity and closely associated with the quartzites are found remnants of dark colored volcanic flows. Their present composition is green hornblende, a plagioclase having the composition of oligoclase or andesine and a rather large amount of magnetite. These rocks can be classified as plagioclase amphibolites. They could have been formed by the thermal metamorphism of weathered volcanic flows of either the Marlboro or Woburn Formations. The source of these inclusions is obscure and a very thorough investigation would be necessary in order to definitely determine the correct formation name to be applied to them.
WEYMOUTH FORMATION

The cliffs at East Point, Nahant contain the only fossiliferous rocks found within the area covered by this report. The rocks exposed at this locality consist of dense grayish and greenish colored argillites with a few interbedded thin strata of white limestone. These stratified rocks have been invaded by some dikes and large sills that appear to be related to the Nahant Gabbro and also by a variety of younger dikes. The argillaceous strata have been hardened and slightly metamorphosed, apparently by heat from nearby igneous intrusions. They have a cryptocrystalline texture in which the only recognizable minerals are scattered minute grains of quartz, epidote and calcite. The limestone strata do not show any readily noticeable effects of metamorphism. A characteristic feature of some of the argillaceous strata consists of small greenish and brownish nodules or concretions that are found in layers paralleling the stratification. Epidote and a brownish iron oxide are principal constituents of these nodules. They appear to have passed through the same metamorphism as the containing rock and therefore probably were formed while the sediments were in an unconsolidated state. The minerals in these nodules have been reconstituted by metamorphism.
The fossils contained in the limestone strata were identified as being Lower Cambrian forms and were first described in the literature by Foerste\(^1\) who correlated these rocks with fossiliferous shales and limestones found near Mill Cove in Weymouth. The fossils from the latter locality have been identified as being of Lower Cambrian age and have been described by Burr\(^2\) and by Grabau\(^3\). The initial correlation of the sedimentary rocks of Nahant with those of Weymouth appears to have been on the basis of lithologic similarities rather than on paleontological evidence. The most abundant fossils at Nahant consist of several species of Hyolithes and Orthotheca and at Mill Cove in Weymouth consist of several species of Orthotheca, Olenellus, Agraulus and other less common forms. Complete lists and descriptions of the fauna of these localities are given in the reports of Foerste, Burr and Grabau. On the

basis of the correlation and because the rocks of the Mill Cove locality are the most abundantly fossiliferous LaForge applied the name Weymouth Formation to the Lower Cambrian sedimentary rocks of Weymouth and Nahant.¹

The small remnants of sedimentary rocks found as inclusions or roof pendants in the igneous rock along the north shore of Nahant and at Little Nahant have been considered to be parts of the Weymouth Formation by some geologists. The writer did not find any features in these remnants that would either prove or disprove this relationship. Several inclusions and pendants of a dense gray argillite are found in the Salem Gabbro-diorite in the vicinity of Glenmere Pond in the eastern part of Lynn. The writer believes these remnants can be correlated with the argillite at East Point, Nahant. The rocks from the two localities have similar lithologic characteristics and contain layers of greenish nodules or concretions. The nodules are abundant in the low lying outcrop at the northwest edge of Glenmere Pond. These nodules appear to be a characteristic feature of the rocks assigned to the Weymouth Formation. The writer did not examine the locality at Mill Cove in Weymouth but Emerson describes it thusly: "At Weymouth the formation consists of reddish, brownish, and greenish cherty

¹ LaForge, Laurence, Science, n.s., Vol. 29, Pages 945-946, 1909.
slate, with greenish epidotic and calcareous lenses and thin beds of white limestone. ¹

The exposure of the Weymouth Formation at East Point, Nahant is separated from the Nahant Gabbro at the west by a fault with the igneous rock forming the relatively upthrown block. In all other directions the formation passes under the water of Massachusetts Bay. The sedimentary rocks contain some large dikes and sills of basic rock that apparently are related to the gabbro and do not exhibit any features or have any contacts that show their relationship to other formations of the area. The strata have a northeast-southwest strike and a northwestward dip. A maximum thickness of seventy-five feet of strata is exposed above sea level but the total thickness is greater by whatever amount extends below sea level. The sedimentary strata of East Point most likely form a large roof pendant in younger igneous rocks. If the correlation of the igneous rock of some of the dikes and sills with the Nahant Gabbro is correct then the gabbro is obviously the younger rock. The sedimentary remnants found in the vicinity of Glenmere Pond in Lynn are older than the Salem Gabbro-diorite and if these are properly correlated with the Weymouth Formation then the gabbro-diorite is of post Lower Cambrian Age. Crosby has given a detailed description of the Mill Cove locality and

is of the opinion that even though contacts between the sedimentary strata and the surrounding granite are not exposed the granite is the younger rock. It appears that the Weymouth Formation is everywhere older than the rocks with which it is associated.

INTRUSIVE IGNEOUS ROCKS
INTRUSIVE IGNEOUS ROCKS

GENERAL STATEMENT

The greater portion of Eastern Massachusetts is made up of a complex of igneous intrusive rocks believed to be of Early to Late Middle Paleozoic Age. Many types are represented, ranging from gabbros to seyenites and granites, with the more basic generally being the older. Many of these rocks were intruded into the stratified formations of Early Cambrian age apparently after the latter had been crumpled into folds. Following a period of erosion during which large areas were stripped of whatever cover may have existed, some of these intrusive rocks became the floor upon which were accumulated Late Paleozoic sediments and volcanic flows. There is some evidence that intrusions of plutonic igneous rocks continued even after the outpouring of the Late Paleozoic volcanic flows.

Previous investigators have divided the plutonic rocks into two main groups, each of which supposedly represents a distinct period of igneous activity. These divisions are, first, a sub-alkaline group of older rocks including gabbros, diorites, quartz-diorites, granodiorites and similar types, and secondly, an alkaline group of younger rocks including normarkites, seyenites and granites. The various rocks are not always segregated into outcropping areas in which but one type can be found. Frequently two or more types of these
igneous rocks are found to be complexly involved within a small area or even a single outcrop. Only the youngest granites form outcropping areas in which but one rock type is found. The oldest rocks have been successively invaded by each of the younger intrusions which have partially absorbed, altered or reconstituted their minerals. Because of these circumstances only a small portion of the older igneous intrusive rocks are preserved in their original form and mineral composition.

This complexity has resulted in several theories and explanations for the origin of these rocks. To date most investigators have considered the various rock types of the sub-alkaline group to have been formed by differentiation from a single parent magma, some having the differentiation take place in essentially the position now occupied by the rocks and others having it take place at considerable depth with several differentiated fractions being forced upwards towards the surface of the earth. But few geologists have conceded that assimilation of earlier existing rocks may have played some part in arriving at the present compositions. Those who have advocated differentiation from a single magma in essentially the present position consider the entire group to have been emplaced by a single large batholithic intrusion. Those who advocate differentiation at depth postulate two or three batholithic intrusions following one another at short
intervals. Field relations pose many problems that cannot be explained satisfactorily by either of these theories. A discussion of the various theories and an explanation believed to be more satisfactory than the older hypotheses for the origin of these rocks will follow the descriptions of the various types.

The area covered by the following descriptions is but a small portion of the total extent of outcroppings of intrusive igneous rocks in Eastern Massachusetts. Descriptions are limited to outcrops in the area actually examined by the writer, therefore it is probable that some minor variations can be found farther afield. The writer believes that the area studied is sufficiently large and has enough outcroppings so that the principal observations and conclusions reached will be found to be characteristic of the entire igneous intrusive complex of Eastern Massachusetts.
SALEM GABBRO-DIORITE

The rocks of the Salem Gabbro-diorite group are the oldest members of the igneous intrusive complex as is made evident by the fact that they have been invaded by all the other types found in the area. Previous geological reports covering this area list several widely differing varieties and types under this name with about the only feature common to all being a dark gray color. LaForge remarks "The formation as mapped includes at least eight varieties of rocks, some of which, however, are of only minor importance". Clapp describes several varieties in U.S.G.S. Bulletin 704 as also does Emerson in U.S.G.S. Bulletin 597. It is the opinion of this writer that some varieties of rocks have been mistakenly included under this name. For instance, rocks have been mapped as Salem Gabbro-diorite and described as being composed of plagioclase and hornblende with the descriptions being nearly identical with that of the plagioclase-amphibolites formed by thermal metamorphism of the basaltic lavas of the Marlboro Formation. Some younger gabbro intrusions have also been included in this group. Quite often field identification of the various types

of dark colored rocks found in this area is difficult and uncertain thus making a microscopic study necessary for a proper identification, a factor which has probably led to a general grouping of these dark colored rocks under the single name of Salem Gabbro-diorite.

On the map accompanying this report two large areas are indicated as being Salem Gabbro-diorite. One area lies in the towns of Marblehead, Salem, Swampscott and Lynn at the northeast part of the Lynn Quadrangle. The other forms a belt about four miles in width striking diagonally across the Lexington Quadrangle from Woburn at the northeast to Waltham at the southwest. Numerous small remnants of older stratified rocks and invasions of younger igneous intrusive types are common to both areas.

Actually but little of the areas so mapped consist of original unaltered gabbro or diorite. Outcrops that have not been invaded and have not had the original mineralogical composition more or less altered by either material or heat from younger intrusive magmas are rare. These younger intrusions are represented by innumerable veinlets, dikes and plugs and zones of "hybridized" rocks. A large portion of the areas are neither gabbro, diorite nor members of any of the younger more siliceous types but rather a complex intermingling of basic and siliceous rocks or else "hybrid" types produced by incomplete assimilation of the basic rocks in
later magmas or magmatic solutions. All variations from gabbro with a few small veins of granite or aplite to a mass predominately granite with rounded or angular xenoliths of the gabbro can be found. As the amount of material introduced into a locality by later intrusions increases, the gabbro or diorite, as the case may be, rapidly becomes converted to "hybrid" rock types, losing both its original mineralogical composition and texture but not attaining those of the younger rock types. Considerable areas of originally basic rock have been rather thoroughly permeated by solutions that, to a greater or less degree, have altered the original minerals and introduced new material thereby producing mineral assemblages that are not consistent with any normal rock type. These altered rocks are the so-called "hybrids". All mixtures of the basic and younger intrusive rocks plus the hybrids have been mapped with the Salem Gabbro-diorite as a matter of convenience and also because the younger intrusions form outcropping areas possessing greater uniformity of a single rock type, a condition that has not been retained by the older basic rocks.

Areas in which the gabbros and diorites have been preserved in their original form are of very limited extent. The best unaltered exposures are found at the west side of Marblehead Village, in the south part of Salem, in the extreme eastern part of Woburn and a few scattered localities in Lexington. All other areas mapped as Salem Gabbro-diorite
consist of basic rocks intruded by the younger more siliceous types with the latter sometimes forming so much of the volume that their formation names could just as properly be used, or, in other cases a hybridized rock is the prevailing type. Such areas indicated as being Salem Gabbro-diorite on the map are in Swampscott, along the shoreline of Marblehead and most of the Woburn, Winchester, Arlington and Waltham outcrops. The manner in which the younger igneous components were introduced and the changes which took place during hybridization will be discussed in another section.

The descriptions given below are those of the remains of the basic rocks, that is, the types which in their original unaltered form occupied all of the area now mapped as Salem Gabbro-diorite. Minor differences in mineral composition and texture are found. These variations are assumed by the writer to be the result of magmatic differentiation taking place during the emplacement of the batholith. The rocks vary from gabbros to diorites thus accounting for the use of a double name.

The more basic phase of this group will be described first because normally it would be expected to have solidified first and because most of its constituent minerals persist into the less basic diorite. These more basic or gabroïdic types are dark colored rocks varying from a dark gray to almost black depending upon the relative quantities
of light and dark colored constituents. Different specimens show a considerable variation of average grain sizes ranging from coarse crystals three or four millimeters in diameter to fine crystals one or two millimeters in diameter. In most specimens the grain size is quite uniform but rock from some areas tends to be slightly porphyritic with plagioclase forming the phenocrysts. This feature is characteristic of the gabbro outcropping between Loring Avenue and the Boston and Main Railroad tracks in the south part of Salem. Feldspars usually show well developed crystal shapes in the form of long laths or tabular grains so that the texture is distinctly ophitic in many cases where phenocrysts have not been developed. The original texture is very quickly destroyed in the vicinity of later igneous intrusions. Outcrops weather to a reddish brown color with the intensity of the red increasing in the more basic phases. Such outcrops are usually characterized by a mottled appearance due to numerous small reddish brown spots.

Plagioclase forms approximately fifty percent of the volume of the more basic phases of these rocks. This figure is an average obtained by the examination of several specimens which varied between forty and sixty percent of this constituent. The majority of the plagioclase grains have long lath shaped or tabular outlines giving an ophitic texture to many specimens. A few zoned crystals having a calcic core and a
more acid mantle are sometimes found. The composition is that of calcic labradorite in the most basic specimens and grades towards sodic labradorite or calcic andesine in the least basic ones. The crystals are usually clear and colorless in thin sections but a few were found containing minute dark colored inclusions. This plagioclase shows a greenish color in hand specimens. Most of the crystals have albite twinning but an occasional untwinned grain can be found.

Olivine may or may not be present. When this mineral is present in a specimen it is a minor constituent not exceeding five percent of the volume. The grains are small and are always fractured. The fractures are frequently filled with minute secondary grains of magnetite while the olivine is stained somewhat yellowish in such cases. Only the most basic specimens of the gabbro contain olivine.

A pyroxene may form any portion between fifteen and thirty percent of the total volume of the rock. The grains of this mineral are large and irregular in shape. A reaction rim of green hornblende around the periphery is common but is not present with all grains. This pyroxene is not uniform in composition and optical properties but varies progressively from the core to the circumference of the crystals. The cores, or those portions of the grains which were the first to crystallize, have a light pinkish brown color and a characteristic feature is the presence of clouds of minute.
orientated needles of a black, opaque mineral. As a rule these inclusions rather uniformly fill an area within the grain but sometimes they tend to concentrate in curling, feathery wisps, always with the individual needles maintaining the same common orientation. The composition of the needles is not definitely known but may be titaniferous magnetite as is suggested by the pink color of the surrounding pyroxene. This pyroxene grades from a central pinkish core outward into a clear colorless phase, the transition being gradual with the two phases showing complete continuity of cleavage and extinction angles. The pinkish phase is faintly pleochroic, the colorless phase is non-pleochroic. The colorless phase is either entirely free from inclusions or contains small irregularly distributed black grains which are indicated by observation of many pyroxene crystals to be a clotting together of the minute black needles. Both phases are optically positive with a small optic angle which decreases slightly in passing from the colorless to colored mineral. The birefringence is very low for the colorless outer rims but gradually increases towards the central core so that the distinctly pink portion of the mineral becomes highly birefringent. The maximum extinction angles in sections normal to the principal cleavage are about 37 degrees. Scattered grains of the colorless phase without the central pinkish core are always present, being
more numerous in some specimens than in others. On the basis of its optical properties this pyroxene is considered to be a pigeonite.

Hornblende was found in all the specimens examined, varying in amount from five to twenty percent of the volume of the rock. A small portion of this mineral was formed as reaction rims around pyroxene while the remainder crystallized as discreet grains throughout the rock mass. All of this hornblende appears to be primary constituent which crystallized during the solidification of the magma since there is no evidence of any of it having been produced as a result of later metamorphic changes. It is greenish brown in color, moderately pleochroic from pale brownish to distinctly green shades and optically negative. Its grains vary considerably in size with the larger ones being poikilitic and containing numerous small inclusions of feldspar. Well formed crystal faces have not been developed frequently by this hornblende.

Magnetite or titaniferous magnetite varying in amount from two to five percent of the total rock volume was observed in all specimens examined. The grains of this minor constituent are irregular in shape and vary in size from minute inclusions in pyroxene and hornblende up to particles at least one millimeter in diameter. Most of this magnetite has crystallized as an original constituent, the relatively
insignificant remainder being of secondary derivation from the decomposition of olivine. Practically all of the magnetite grains are closely associated with the mafites with but few being interstitial to feldspar crystals.

Minor constituents are apatite and zircon. Some specimens of the rock show large numbers of small apatite prisms with none having a total absence of this mineral. Zircon is very sparingly distributed.

A small amount of a dark reddish brown, strongly pleochroic biotite was found in some specimens. The flakes of this mica are small and are always found surrounding or in the immediate vicinity of magnetite grains. This biotite appears to be a primary minor constituent.

Alteration minerals in fresh specimens are insignificant in quantity. A minute amount of magnetite has been derived from olivine. An incipient fringe of a chlorite-like mineral is occasionally found around hornblende grains. Traces of an alteration product from plagioclase that is too fine grained to give optical properties but shows a high relief are suggestive of calcite.

An average composition of the most basic phases of the Salem Gabbro-diorite based upon visual estimates of the quantities of the various constituents present in thin
sections from several specimens would be approximately as follows:

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plagioclase (Labradorite)</td>
<td>50%</td>
</tr>
<tr>
<td>Olivine</td>
<td>3</td>
</tr>
<tr>
<td>Pyroxene (Pigeonite)</td>
<td>25</td>
</tr>
<tr>
<td>Amphibole (Hornblende)</td>
<td>15</td>
</tr>
<tr>
<td>Biotite</td>
<td>2</td>
</tr>
<tr>
<td>Magnetite</td>
<td>3</td>
</tr>
<tr>
<td>Apatite</td>
<td>1</td>
</tr>
<tr>
<td>Other Constituents</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Rocks of this composition having labradorite as the plagioclase constituent correspond with the classification and description of gabbro as given by Johannsen. A satisfactory alternate name would be olivine-gabbro.

The above description indicates that the most basic phase of the unaltered rocks forming the Salem Gabbro-diorite batholith is rather coarse grained olivine-gabbro having an ophitic texture. Outcrops of this rock are not common, partly because relatively small portions of the batholith solidified as the more basic phase and partly because some of such portions have been invaded and altered by later igneous intrusions. The best outcrops are found in Marblehead on the small hills lying to the northwest of Devereaux Station.

and in Salem in the rough hilly area between Swampscott Road and the municipal Golf Course. Field observations indicate that the latter area is to a large extent composed of unaltered olivine-gabbro but this conclusion must be checked by detailed sampling and study of numerous thin sections. The few specimens collected from widely scattered points within this area by the writer were olivine-gabbro. The rock found outcropping on the north side of Horn Pond Mountain in Woburn is likewise a basic gabbro. This area has been invaded by younger igneous intrusions and although slightly altered the rock retains most of its original mineralogical composition and texture.

The less basic phases of the Salem Gabbro-diorite will be described briefly because the constituent minerals differ but little from those of the olivine-gabbro phase. There is a moderate transition in composition from that of the gabbro described above towards a more acidic type of rock. The principal changes are in the composition of the plagioclase and the elimination of olivine. Zoned plagioclase crystals having a central core of labradorite or andesine and an outer mantle of oligoclase become quite numerous. Very small interstitial grains of quartz and potash feldspar begin to appear in the most acidic specimens. With the exception of olivine, the same suite of minerals comprise the mafic constituents as are found in the olivine-gabbro phase with
hornblende and biotite increasing slightly and pyroxenes decreasing slightly as the overall composition grades towards the less basic phases of this rock. The total amount of mafites is ordinarily less than fifty percent of the rock volume. The plagioclase constituents generally amount to more than fifty percent of the rock volume. Rocks of this general composition fall within the classification and description of diorite as given by Johannsen. These dioritic phases tend to be finer grained and do not turn as brown on weathered surfaces as the gabbroidic phases of the batholith. Good exposures of the diorite are found in the hilly area at the extreme northwest corner of the Marblehead South Quadrangle, also in the vicinity of Clifton Village where scattered remnants unaffected by younger intrusions can be found and a few isolated outcroppings in the central and eastern portions of Lexington.

The writer believes that the Salem Gabbro-diorite formation was emplaced as a mass of molten magma at some considerable depth below the earth's crust. The formation may represent a single large batholithic invasion or may consist of several apophysal offshoots from a deep seated magma reservoir.

Numerous areas having dimensions of several miles each lying within a region some sixty miles in diameter have been mapped as being parts of this formation. The writer is not familiar with the rock from all of these various areas but will accept the descriptions as being substantially correct. Since these areas of Salem Gabbro-diorite are separated from one another by belts of older stratified rocks and younger igneous intrusives containing remnants of the stratified rocks it is reasonable to suggest that the gabbro-diorite represents several protuberances from a deep seated magma chamber rather than the remains of a single large invasion covering hundreds of square miles. This hypothesis is further borne out by the fact that the olivine-gabbro phase described above occupies a central position in respect to the dioritic phase in the two areas examined in the course of this investigation. Such separation could result by differentiation in separate apophyses. Remnants of the older stratified rocks of the Westboro and Marlboro Formations that are closely associated with the gabbro-diorite show the effects of thermal metamorphism. But little mineralogical change has taken place in the quartzites of the Westboro Formation because of their simple composition. The basaltic lavas of the Marlboro Formation have been thoroughly reconstituted to form plagioclase-amphibolites, a change that requires the contribution of a considerable amount of heat. The surrounding or adjacent igneous intrusion would be the
logical source of this heat and further indicate a magmatic origin for the gabbro-diorite.

Additional proof of the magmatic origin in batholithic intrusions for this formation is found in its varying composition. Descriptions of two phases, an olivine-gabbro and a diorite have been given. These two rock types represent the end members of a differentiation series developed by the cooling and solidification of the magma involved in the intrusions. In the field all variations between the two types can be found, these showing complete transitions in the composition of the plagioclase from labradorite to sodic andesine or calcic oligoclase, a less noticeable decrease in the ratio of pyroxene to amphibole and the disappearance of olivine. In a rough way these transitions progress outward from a central area of the more basic olivine-gabbro. A study of the several specimens collected by the writer indicates that if it were possible to get numerous samples of rock unaltered by younger igneous intrusions from closely spaced intervals over the entire outcropping areas of the Salem Gabbro-diorite and on a map plot the content of some variable constituent such as the albite molecule of the plagioclase an irregular series of contours around the olivine-gabbro areas would probably be the result. Such a condition can originate through differentiation in a cooling and crystallizing magma. The olivine-gabbro phase with its higher content of calcium, iron and magnesium would have crystallized first and at the higher temperature.
Because the minerals comprising this phase have a specific gravity slightly higher than that possessed by the magma a concentration into the central or deeper portion of the fluid mass resulted thereby initiating the process of differentiation. This formation should not be considered as a heterogenous collection of various rock types or a waste basket into which all dark colored rocks difficult to identify or explain can be dumped as has been done by some geologists in the past but as an intrusive body of magmatic material that solidified in an orderly manner producing a sequence of gradually changing rocks of allied mineralogical and chemical characteristics. Such rocks as plagioclase amphibolites do not belong here and must be eliminated leaving only those rocks which could have been produced by the solidification of a single magma.

The use of the term "gabbro-diorite" in naming this formation deserves some explanation. The term was defined by Kemp as follows: "Gabbro with hornblende which may, in fact be secondary after augite. Intermediate rocks between true gabbros and diorites".¹

¹ Kemp, James Furman, A Handbook of Rocks for use without the Microscope, 1896.
A definition by Johannsen is, "A poorly chosen term for hornblendite-gabbro or augite-diorite".\(^1\) Common usage of the names of gabbro and of diorite is to designate two primary rock families separated on the basis of the plagioclase constituents, rocks being primarily composed of a pyroxene and plagioclase more calcic than Ab\(_1\) An\(_1\) being called gabbro and rocks composed primarily of an amphibole and plagioclase more sodic than Ab\(_1\) An\(_1\) being called diorites. The term "gabbro-diorite" was first applied to this formation by Clapp with the explanation, "In whatever manner the term gabbro-diorite is defined it at least always connotes a rock intermediate between a gabbro and diorite and has been used in this sense, although not widely. With this meaning, which seems the most logical and convenient, the term has been employed in this report".\(^2\) In his description of the formation Clapp describes as the normal rock a phase intermediate between the olivine-gabbro and the more acidic diorite and considers the other varieties to be variations from this phase, such a rock would fit into the explanation which he gives to the term "gabbro-diorite". The writer would prefer to use the term in a somewhat different sense. The writer's interpretation of the field relations of the various phases is

---

that solidification of the magma began with an olivine-gabbro phase and ended with a diorite, both types fitting into the classification and composition as given by Johannsen, and that a continuous intermediate sequence between these two types exists. The use of the term "gabbro-diorite" as applied to this formation should signify a single igneous mass which by differentiation during the course of its cooling produced a continuous rock sequence beginning with the composition of a gabbro and ending with the composition of a diorite.
The main portion of Nahant is composed of a basic plutonic igneous rock which Clapp recognized to be different from other rocks of the area and to which he gave the name Nahant Gabbro. He correlates this rock with the so-called alkaline batholith, that is, the Quincy Granite. LaForge has a different opinion and in describing the Salem Gabbro-diorite says "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". Field investigation and microscopic study of several specimens by the writer indicate that some points of similarity exist between the most basic phases of the Salem Gabbro-diorite and the plutonic igneous rock of Nahant. The rocks of Little Nahant are hybridized gabbros and will be described in another section of this report. The basic rocks of Nahant do possess characteristics setting them somewhat apart from the typical phases of the Salem Gabbro-diorite, therefore, a detailed

description of them is thought to be desirable.

The plutonic igneous mass composing most of Nahant has been described differently by several investigators and the rock classified as either a gabbro or a norite. These inconsistent descriptions are probably the result of insufficient field work on rock exposures having varying characteristics and study of too few randomly selected specimens.

The basic rock under consideration forms all of the outcrops at Nahant with the exception of the Cambrian sedimentary strata at East Point, some small inclusions or roof pendants along the west end of the north shore, some small areas of a younger intrusive granite or syenite at the east end of this shore and a variety of younger dikes. This basic rock has an uniformly even, medium grained granitic texture over the entire area except for a few small pegmatitic textured veinlets. Its color varies from a medium greenish gray to almost black depending upon the mineralogical composition and degree of alteration. Surface weathering causes it to turn brownish. Some of the outcrops show a crude banding or segregation of dark and light colored constituents into wide layers, a condition probably produced by differentiation and flowage while the magma was crystallizing. Other exposures are composed almost entirely of a dark colored phase, the rock being nearly black in color, while still others are light greenish gray.
This rock disintegrates readily under the influence of surface weathering breaking down into particles composed of individual mineral grains and thus producing a coarse angular sand. Outcrops along the shore are scoured to smooth surfaces by wave action so do not show this feature.

The mineral assemblage found in these rocks resembles that of the most basic phases of the Salem Gabbro-diorite more closely than that of any other igneous rock type found in the surrounding region. The most abundant mineral constituent is plagioclase, which in all but the darkest colored phases forms more than half the volume of the rock. Specimens taken from outcrops that have not been altered in any manner show that this plagioclase has a greenish color. In thin sections it is seen to be euhedral with rather short, tabular, overlapping crystals a characteristic feature, but occasionally the plagioclase has the form of long slender laths. Its composition as indicated by extinction angles is that of calcic labradorite. Zoned crystals of plagioclase were not observed in any of the thin sections examined.

The principal mafic constituent is a pyroxene of variable composition considered by the writer to be pigeonite. This mineral has usually crystallized in large irregularly shaped grains tending to be interstitial to plagioclase and varying in amount from twenty to forty percent of the volume of the rock. It is similar to the pigeonite of the Salem Gabbro-
diorite, having pinkish to greenish or colorless variations but not showing as clearly complete transitions from the colored to colorless phases. Clouds of minute orientated black needles are seen in almost all of the pinkish portions but are missing from the colorless phases of this pyroxene. The optic angle and birefringence varies considerably from one grain to another and frequently even within the same grain. The pyroxene component of this rock apparently varies through a rather wide range of composition with the last crystallizing phases varying towards the composition of augite. Some writers have reported the presence of hypersthene and used this as a basis for classifying the rock as a norite. Grains of pyroxene having the optically negative character and the pleochroism of hypersthene were not found in any of several thin sections examined by the writer. Washington makes the statement, "In my specimens I could find none of the hypersthene mentioned by Sears". These observations would seem to indicate that some of the monoclinic pyroxene having a variable composition has been mistakenly identified as hypersthene.

A strongly pleochroic, dark reddish brown biotite is a minor primary constituent of this rock. Some grains of this

mineral have an unusual orange to brownish pleochroism probably caused by a small content of titanium. Biotite has formed only in the immediate vicinity of magnetite grains. All specimens examined contained magnetite which varied in amount from three to eight percent of the rock volume. The grains of this mineral are usually quite large and irregular in shape but accumulations of tiny granules evidently formed by decomposition of some pre-existing mineral are common in some of the darker colored specimens. This magnetite is a titaniferous variety and is sometimes surrounded by leucoxene.

The darker colored specimens contain a mineral that was probably olivine but which is now sufficiently altered to magnetite and a fibrous green amphibole or chlorite so that identification is uncertain. The alteration prevents the use of optical properties in identifying this mineral but other characteristics seem to be identical with those of olivine. This constituent was originally present in quantities up to five percent of the volume of the rock.

Other minor constituents are pyrite existing in the form of tiny irregular grains and zircon as minute prisms. Thin sections of some specimens contain small shreds of a dark greenish brown mineral that cannot be identified because of partial alteration. This mineral may be an amphibole.

Alteration or secondary minerals are calcite, epidote, chlorite, leucoxene and reddish iron oxide. All of these
minerals are found in small amounts in most specimens.

Microscopic examination of several thin sections from representative specimens of this rock indicate that an approximate average mineralogical composition on a volume basis would be fifty-five percent labradorite, thirty percent monoclinic pyroxene, five percent magnetite and minor amounts of biotite, olivine, pyrite and zircon. This rock is therefore a gabbro.

This gabbro of Nahant differs from the gabbro phase of the Salem Gabbro-diorite by containing a slightly more calcic plagioclase, very little if any amphibole, a noticeable titanium content and absence of minute apatite grains. These differences in mineralogical composition as determined by microscopic study of thin sections are verified by chemical analyses of the two rocks as given by Washington.\(^1\) These analyses show that the Nahant rock contains higher percentages of lime and titanium and less phosphorus. The most striking similarity is the presence of a large amount of an unusual type of pyroxene in both rocks.

The Nahant Gabbro and the Salem Gabbro-diorite are probably closely related in age and origin. The similar

---

assemblages of minerals found in the two rocks and chemical compositions that do not differ greatly indicate a possible origin from a single parent magma. If this is true the Nahant Gabbro represents the earliest differentiate of the magma since it is the more basic of the two rocks or it might possibly be a portion of the same magma that crystallized at greater depth and therefore contains a slightly larger proportion of the heavier basic constituents.

Contacts and structural relations of the Nahant Gabbro with other rocks are so meager that but little information concerning relative ages or stratigraphic positions can be obtained. This condition is to a large extent a consequence of Nahant being a virtual island which does not have enough area to include all the gabbro and portions of its contact neighbors. The only sizable outcrop of a different formation in close proximity to the gabbro is the exposure of the sedimentary Lower Cambrian Weymouth Formation at East Point. The two formations are separated by a fault. A large sill and some smaller dikes of diabasic rock have been injected into these sediments producing a feature that has caused some geologists to suggest that offshoots of the main gabbroidic magma extended upward and penetrated the overlying sedimentary formation. LaForge says, "The diabase contains olivine and is virtually identical in composi-
tion with the normal gabbro but is finer grained and has an ophitic texture". The writer examined thin sections of two specimens taken from the thick diabasic sill at East Point and agrees with the textural description but could not find either olivine or aggregations of alteration minerals that would suggest its former presence. Instead, the rock is slightly more acidic than the gabbro which is exactly the change in composition to be expected in the case of an offshoot extending upwards from the main magma mass. There is not any serious objection to the proposal that the sedimentary Weymouth Formation was invaded by offshoots from the main gabbro mass. Sometime after this invasion the area was faulted with the main portion of Nahant being a relatively upthrown block. Subsequent erosion removed the sedimentary rocks covering the gabbro. If the intrusive igneous sill within the sedimentary Weymouth Formation is properly correlated with the Nahant Gabbro then the intrusion of these gabbroidic rocks took place sometime after the Lower Cambrian. The only other stratified rocks associated with this gabbro are a few small inclusions or roof pendants exposed in the cliffs at the point called John's Peril on the west end of north shore of Nahant. Some of the remnants are quartzites

while others are too much altered to permit satisfactory identification but seem to be of volcanic origin. These inclusions or roof pendants cannot be positively correlated with any definite formation.

With the exception of numerous dikes of several varieties the only igneous rocks associated with the Nahant Gabbro are a few small areas of a reddish syenite exposed along the north shore in the vicinity of the cliffs called Spouting Horn. This rock is intrusive into the gabbro and may be the outer fringe of a large plug as is indicated by the fact that the exposures extend below the low tide level. The surrounding gabbro has been altered by this intrusion, rather intensely adjacent to the granitic rocks, and to a noticeable extent in practically all outcrops within a distance of one-half mile. The first constituent to be affected seems to be the plagioclase which loses its greenish color and begins to show an incipient alteration producing calcite. The bleaching of the plagioclase causes the greater portion of the outcrops of gabbro along the north shore of Nahant to be a lighter color than those found elsewhere. Close to the granitic intrusions the plagioclase becomes thoroughly clouded by alteration and the original mafites are altered to biotite, chlorite or epidote. Calcite becomes a prominent secondary constituent and a small amount of potash feldspar and quartz has been introduced into the gabbro. These
changes are characteristic of hydrothermal alteration and the volume of rock affected indicates the presence of a sizable mass of granite, either a short distance below the surface or more likely extending to the northward under Nahant Bay.

The intrusive syenitic rock is reddish in color with a medium grained granitic texture. Thin sections show that it consists of about seventy-five percent of anhedral microcline-microperthite grains, five percent plagioclase having the composition of oligoclase, minor amounts of fine grained interstitial quartz and magnetite and the remainder being secondary chlorite, epidote and calcite. Because of the small quantity of quartz a proper classification for this rock would be quartz-syenite. It is nearly identical with the rock of some of the small granitic plugs penetrating the Salem Gabbro-diroite in Lynn and Swampscott. In commenting upon this rock Clapp remarks, "Along the north shore of Big Nahant a felsic differentiate is intrusive into the normal gabbro. It is composed chiefly of microperthite in large euhedral grains and of a small amount of quartz in clear interstitial grains". ¹

This remark seemingly implies that the syenitic rock is a late differentiate from the magma that produced the gabbro. If this is a correct interpretation of the meaning intended by Clapp, it cannot be accepted by the writer. The syenite differs from the gabbro far too much in mineralogical composition and there is no evidence of intermediate phases being present in the immediate area. It is more likely a border phase of the Quincy Granite with which it is closely allied in mineralogical composition.

If the writer's interpretation of field relations is correct with offshoots of the Nahant Gabbro being intrusive into the Lower Cambrian Weymouth Formation and the main body in turn being invaded by border phases or early differentiates of the Quincy Granite, then the latter two formations serve to limit the period during which the gabbro could have been emplaced. Unfortunately the Quincy Granite is probably of Middle or Late Carboniferous Age therefore the time period indicated becomes somewhat long. A close estimate of the age of this gabbro cannot be based on field relations and must be determined by other means. An approximation can be reached by a correct correlation with other rocks of the area and will properly place this gabbro in the sequence of formations.

In attempting to correlate the Nahant Gabbro with other formations Clapp says, "On account of the syenitic and micro-
perthitic differentiate, the occurrence of basaltic hornblende and of the peculiar orange-brown biotite, the gabbro at Nahant is correlated in a general way with the alkaline batholiths. The writer cannot agree with any of this reasoning. As is evident from the descriptions, the syenitic rock intrusive into the gabbro has a totally different assemblage of mineral constituents with the exception of minor accessory minerals found in almost all igneous rocks. The two types would represent phases close to the opposite ends of a differentiation series. That two such radically different phases of a single differentiation series could exist together without some evidence of intermediate phases is unlikely. It is much more reasonable to accept the field evidence showing extensive alteration of the gabbro by heat and solutions contributed by the invading syenite and postulate that two different periods of igneous intrusion are represented with the gabbro having been emplaced first and becoming completely solidified before being invaded by a much later syenite. The syenite can very well be correlated with the alkaline batholiths and therefore would be of approximate Middle or Late Carboniferous Age. The gabbro is best correlated with the Salem Gabbro-diorite and is indicated to be of Early Paleozoic Age.

DEDHAM GRANODIORITE

The igneous rock formation known by the name of Dedham Granodiorite forms locally a large portion of the outcrops within an area extending in a north-south direction from the northern boundary of Massachusetts to the shores of Buzzards Bay at the south, and in a westerly direction about twenty-five miles from the Atlantic Coast. In the area to the south and southwest of Boston this granodiorite is the only kind of rock outcropping over large segments of the country. North of Boston the granodiorite is usually found outcropping in rather small northeast-southwest trending belts or as small plugs protruding through the older igneous and stratified rocks. The first description of the Dedham Granodiorite seems to have been given by Crosby. In this report he describes all of the granitic rocks of Eastern Massachusetts under the title of "Granite" and does not attempt to divide these rocks into more than one formation. The rock now known as the Dedham Granodiorite is his granite containing pink feldspar. The

name Dedham Granite was used by Loughlin and Hechinger\(^1\) in 1914 and Dedham Granodiorite by Emerson\(^2\) in 1917. The name is derived from the location of typical exposures of this rock in the town of Dedham. Several phases or varieties of rocks make up this formation, some of which have been incorrectly identified and mapped in previous reports on the geology of the area. The writer includes the Newburyport quartz-diorite Formation of Emerson\(^3\), Clapp\(^4\), and LaForge\(^5\) among the varieties of the Dedham Granodiorite for reasons that will be explained later. The Dedham Granodiorite was

emplaced as a large batholithic intrusion. Various phases of it are intrusive into the Cambrian stratified formations and the basic rocks of the Salem Gabbro-diorite. Sometime after the emplacement of the batholith the region was subjected to a long period of erosion during which large areas of the granodiorite were laid bare and it is upon this erosional surface that younger volcanic and sedimentary formations of presumably Devonian and Carboniferous Age were accumulated.

Numerous outcroppings of the Dedham Granodiorite are found within the area investigated for this report. It forms Phillip's Point in Swampscott and the south half of Marblehead Neck. A belt about one mile in width containing alternate areas of granodiorite and glacial drift extends from Birch Pond in Saugus southwestward through Melrose, the Middlesex Fells Reservation and Medford to the north boundary fault of the Boston Basin. Another mass outcrops in the Maplewood section of Malden. A large stock outcrops in Stoneham and small plugs are found in Arlington, Belmont, Waltham, Woburn and Lexington. The Newburyport Quartz-Diorite variety is exposed in a belt one to two miles in width extending from Sluice Pond in Lynn westward through Lynn Woods, North Saugus, Wakefield, Stoneham, the Middlesex Fells Reservation and ending in Winchester. To the south of Boston outcrops of the granodiorite in Hull, Cohasset and Hingham were examined, these being on the north fringe of a large mass extending a consid-
able distance southward. Another area of the same rock extends southwestward from West Roxbury into Dedham, this likewise being a part of a much larger mass.

Several phases or varieties of rocks ranging from quartz-diorite through granodiorite to granites make up the Dedham Granodiorite Formation. The distribution of outcroppings of the various phases combined with the types of older rocks closely associated with each strongly suggests that structural conditions and stratigraphic positions of the older rocks had some effect on the composition and texture of the rocks solidifying from the invading igneous materials. Although varying somewhat in composition, all varieties of rocks included within the Dedham Granodiorite formation by the writer possess characteristics indicating similar methods of emplacement and history. An intense crushing or fracturing of the component mineral grains is found in most varieties of these rocks. This feature is most readily seen in large quartz grains and to a lesser extent in large feldspar grains. Large plagioclase grains frequently exhibit bent and twisted twinning laminae. Strain shadows and undulatory extinction is strongly developed in quartz grains and to a lesser degree in feldspar grains. In extreme cases the crushing and fracturing of the mineral grains has led to the development of a cataclastic texture, examples of which can be found in all varieties of the rocks comprising this formation. Quartz
and sometimes potash bearing feldspars show two generations of crystallization, one prior to and the other following the development of cataclastic texture. Ordinarily the original mafic constituents have been quite thoroughly altered. The potash bearing feldspars tend to become red under the influence of surface weathering. A description of the various phases of the Dedham Granodiorite Formation will be given in the following paragraphs.

NORMAL VARIETY OF THE DEDHAM GRANODIORITE

The rock commonly called the normal variety of the Dedham Granodiorite is light colored, coarse grained and has a subhedral granitic texture. In some cases it is somewhat gneissic, in others porphyritic, but as a rule is quite evenly granular in character. The color varies from greenish to whitish or pinkish depending upon the mineralogical composition and degree of alteration and weathering. Typical outcrops have an extremely rough uneven surface caused by protruding quartz grains which have resisted weathering and erosion more than the other constituents. This characteristic surface of the outcrops frequently has been described as a "hob-nailed boot texture". Almost invariably the normal phase of the granodiorite shows an intense fracturing or crushing of the component mineral grains that easily can be seen in hand specimens without the aid of a magnifying glass.
The essential mineral constituents of the normal phase are plagioclase, quartz, a potash bearing feldspar and a mafite. Minor accessory constituents are magnetite and apatite. The plagioclase is usually calcic andesine having a whitish or pale greenish color which becomes either strongly white or stained a deeper green where slight alteration has taken place. The andesine crystals are large, frequently have euhedral shapes and are likely to be fractured. Those crystals which are not fractured often show bent and twisted twinning laminae indicating that they have been subjected to great stress. Zoned plagioclase crystals are rare in this phase of the granodiorite. The few such crystals observed varied from calcic andesine to sodic andesine in composition. Quartz is usually in the form of large anhedral grains that are almost universally fractured, show strain shadows and undulatory extinction and frequently have a distinctly biaxial optical character. The grains usually contain numerous trains or clouds of minute inclusions. The quartz is most often colorless or pale green in color but may be slightly milky in some specimens. The type of potash feldspar varies, even in specimens taken from a single outcrop. Microcline is the most common type with orthoclase and microcline-microperthite following in order. When orthoclase is the potash feldspar constituent it usually contains some intergrown albite but hardly enough to permit the mineral to be called microperthite.
The potash feldspars are generally formed as large anhedral grains but in a few instances where these minerals are only minor constituents the grains are small and interstitial. The potash feldspars of this granodiorite have a whitish color in fresh specimens. Under the influence of surface weathering the color becomes strongly pinkish. The mafic constituent of the normal phase of the granodiorite has usually been altered to green chlorite and only rarely can remnants of the original mineral be found. The most common remnant is a dark reddish brown biotite. A few of the thin sections examined contained a partially altered mineral suggestive of green hornblende. All of the specimens examined contained calcite, chlorite and epidote as secondary or alteration minerals, these constituents sometimes totalling ten percent of the rock volume. The plagioclase, almost always having the composition of calcic andesine, is the most abundant mineral constituent, usually forming about fifty percent of the rock volume. Quartz customarily forms about twenty-five percent of the volume, potash bearing feldspars ten percent, altered mafites ten percent and the accessory and secondary minerals five percent of the rock volume. These figures will vary slightly for specimens taken from different outcrops or even from different parts of a single outcrop. Sometimes irregular streaks in which either the potash feldspar or the altered mafic mineral is the most abundant constituent can be found in otherwise normal type outcrops. Rocks having
the approximate mineralogical composition given above fall within the description and composition of granodiorites as given by Johannsen. ¹

The so-called normal variety of the Dedham Granodiorite is the most abundantly outcropping variation of this formation. It forms Phillip's Point in Swampscott, the rock here in large part having a greenish color because of abundant fine grained chlorite and epidote. The normal variety outcrops on the south half of Marblehead Neck and within a belt about one mile wide extending from Birch Pond in Saugus southwestward through the Middlesex Fells Reservation to Medford. Much of the rock in these areas tends to be whitish because of small amounts of potash feldspars and mafic constituents and has a slightly gneissic texture. Another smaller belt of the same variety shows outcrops in the central portion of the Breakheart Reservation in Saugus, at the south east side of Griswold Pond in Saugus and on the hill called High Rock lying on the Melrose-Wakefield town line. Also, small plugs outcrop in Arlington at the northwest side of Spy Pond, in Waltham in the area surrounding the Fernald State School and at the north side of Lyman Pond, in Woburn at the south side of Shaker Glenn and on the Lexington-Burlington town line one-half mile

northwest of Wheeler Road. The granodiorite outcropping in Hull, Cohasset and Hingham is considered to be the normal variety although some is slightly porphyritic with large pink orthoclase phenocrysts. The coarse grained granodiorite extending southwestward from West Roxbury is of this variety. Much of that in the area surrounding East Dedham has an odd purplish color caused by minutely disseminated hematite grains.

STONY BROOK VARIETY OF THE DEDHAM GRANODIORITE

A variety of rock considered to be a border phase of the Dedham Granodiorite batholith by the writer is well displayed in the Stony Brook Reservation located in the West Roxbury and Hyde Park sections of Boston. Other places where this same variety of rock is found are, a large area lying to the east and southeast of the town of Needham and some small areas along the south edge of the Middlesex Fells highland in Medford. That portion of this variety of the Dedham Granodiorite outcropping in the vicinity of the Stony Brook Reservation and in Needham has been mistakenly mapped as a part of the Mattapan Volcanic Series by both Emerson¹ and LaForge². The small

outcroppings in Medford apparently have not been recognized by previous investigators.

**Megascope**c examination of typical specimens of this rock from the Stony Brook Reservation show it to have a faint pinkish color and a fine grained even texture. The component mineral grains appear rounded and to a large extent glassy to the naked eye thereby causing this rock to have the appearance of a well graded arkosic quartzite. The grains of mafic constituents are minute in size when present. Disseminated very minute particles of hematite cause this rock to become locally reddish or purplish in color.

Microscopic examination of thin sections of specimens from the Stony Brook Reservation shows an evenly sized granitic texture made up of anhedral grains. Fractured grains, strain shadows and undulatory extinction are characteristic features of the minerals. The rock is composed of nearly equal proportions of plagioclase, potash bearing feldspar and quartz. Most of the grains of plagioclase are clear and colorless and the few exceptions are clouded by a slight incipient alteration. The grains of this mineral usually show albite twinning with the extinction angles indicating a composition of andesine. The potash bearing feldspar is microperthite which occasionally shows Carlsbad twinning. The quartz is clear, colorless and often is free from the trains of minute inclusions characteristic of most of this mineral in the Dedham Granodiorite Formation. The original mafic constituents have been completely altered to chlorite. Magnetite, hematite and pyrite are minor accessory constituents. Pyrite is not
ordinarily found in specimens containing the iron oxides. A few tiny grains of epidote are found in most specimens. Plagioclase, microperthite and quartz in about equal quantities constitute more than ninety-five percent of the volume of typical specimens of this variety of the Dedham Granodiorite.

In the field this rock always appears to show a gradual transition into the normal variety of the granodiorite. This trend is made evident by a gradual increase in the grain sizes of all constituents, especially plagioclase which increases in size more noticeably than the other constituents, and by decrease in the amounts of quartz and potash bearing feldspar. This phase of the granodiorite lies adjacent to the normal variety of the Dedham Granodiorite in some of the quarries in the Stony Brook Reservation but with the two always separated by a minor fault.

The rock under consideration is a granodiorite that grades towards the composition of a leucogranite. It contains more quartz and less plagioclase and mafites than the normal variety of the Dedham Granodiorite. In further discussions in this report it will be called the Stony Brook variety of the Dedham Granodiorite.

The Stony Brook variety of the granodiorite outcrops over some rather extensive areas. That portion of this variety found in Needham is generally a little closer to the composition of the normal variety of the granodiorite than the rock described above. In all of the outcropping areas there has been local development of cataclastic textures. The position of outcrops of the Stony Brook variety of the granodiorite indicate that it is a border phase of the Dedham Granodiorite batholith and that it grades into the normal variety of the granodiorite at a relatively slight depth.

NEWBURYPORT QUARTZ-DIORITE VARIETY

Within the area covered by this report are large exposures of rock mapped as Newburyport quartz-diorite by earlier investigators but which are considered to be a phase of the Dedham Granodiorite Formation by the writer. The type locality of the Newburyport Quartz-diorite Formation is near the city of that name and was not examined by the writer so no comparisons will be made between it and the rock of the area actually investigated. The outcrops of the so-called Newburyport Quartz-diorite lie within a belt one to two miles in width extending from the south side of Sluice Pond in Lynn through Lynn Woods, North Saugus, Wakefield, Stoneham and the north end of the Middlesex Fells Reservation and also in a small area on Dedham Island near the town of Dedham. This
rock ordinarily has an even, medium grained, granitic texture that is much finer than that of the normal variety of the Ded- ham Granodiorite. Its color is most often grayish or greenish but occasionally may be whitish or pinkish depending upon the type and amount of feldspar constituents present. The assem- blage of minerals is essentially the same as that of the normal variety of the granodiorite. The percentage of volume of the various minerals can be found varying through a wide range so that locally true quartz-diorites and true granites can be found. With the exception of the rare granite vari- ation the most abundant constituent of this so-called quartz diorite is plagioclase. This mineral usually appears as large euhedral crystals having the composition of calcic an- desine. Zoned crystals having a calcic andesine core and an oligoclase mantle were observed in thin sections of some specimens but this feature is rare among the rocks under con- sideration. Ordinarily the plagioclase grains are almost completely clouded by incipient alteration. Quartz is al- ways the second most abundant constituent, being present in anhedral grains of greatly varying size that tend to be smaller than and interstitial to the plagioclase. The quartz grains are almost universally fractured and show strain shadows and undulatory extinction. Trains of minute inclusions are characteristic feature of the quartz of these rocks. A potash bearing feldspar is always present. Some specimens contain
orthoclase in anhedral grains of widely varying sizes, others contain microperthite that frequently shows large grains with Carlsbad twinning. As a rule the mafic constituents have been completely altered so that the original minerals cannot be identified but an occasional specimen is found to contain a small amount of unaltered green hornblende. Pyroxenes were not found in any of the specimens examined. Magnetite and biotite are minor accessory constituents of these rocks. The original mafic constituents have usually been altered to aggregates of chlorite, epidote and calcite although in some cases biotite is found instead of chlorite. All of the thin sections examined contained secondary calcite and epidote as scattered grains or as fillings of tiny veinlets and fractures. Although wide variations in composition can be found the greater portion of this so-called quartz-diorite contains on a volume basis approximately fifty percent plagioclase (andesine), twenty percent quartz, ten percent potash bearing feldspar, fifteen percent altered mafites and five percent of accessory constituents, secondary minerals and alteration products not directly replacing mafites. Rocks having this approximate composition do not fall within the normal modes of quartz-diorites (tonalites) as given by Johannsen. There is too much potash-bearing feldspar and not enough plagioclase. Instead they fall within the modes of granodiorites as given

by the same author\textsuperscript{1}. It is partly on account of this composition that the writer considers these rocks to be a part of the Dedham Granodiorite Formation. In the field the so-called quartz diorite is not ordinarily closely associated with the normal variety of the Dedham granodiorite. In the few local areas where the two varieties of rock are found together or actually make contact with one another the position of each seems to have been determined by the attitude and composition of pre-existing stratified rocks. This feature is discussed in a later section of this report. The normal variety of the Dedham Granodiorite occasionally shows a gradual transition from a coarse grained to a fine grained texture without any apparent change in its mineralogical composition or the type of pre-existing rocks replaced. In some such cases the fine grained portion has been mapped as quartz-diorite by previous investigators, a circumstance that leads the writer to believe that much of the field identification of these two varieties of rocks has been on a textural basis.

\textbf{PORPHYRITIC MICROGRAPHIC GRANODIORITE}

An unusual rock quite different in appearance from other varieties of the Dedham Granodiorite outcrops along a belt approximately one-half mile in width extending from the south

\begin{flushright}
\end{flushright}
side of Mt. Hood Memorial Park in Melrose southwestward through Malden and Medford to the south edge of the Middlesex Fells Reservation. The field relations of this rock and its assemblage of minerals indicate that it is a part of the Dedham Granodiorite Formation. Megascopically the rock is medium to rather coarse grained with numerous large subhedral to euhedral grains of a white or pale greenish plagioclase and a finer grained crystalline matrix. The matrix is composed of quartz, pink feldspar, long needles of a mafic constituent and occasional small plagioclase grains. This assemblage of minerals and grain sizes gives the rock an uneven texture and a mottled appearance caused by large white grains being enclosed in a rather finely crystalline stippled pink, gray and white groundmass. Microscopic examination shows that specimens taken from different outcrops vary slightly in mineralogical composition. Most of the plagioclase phenocrysts have slightly elongate subhedral to euhedral shapes. The majority of these grains vary between two to three millimeters in width and four to five millimeters in length. In some specimens the plagioclase phenocrysts are so clouded by alteration products that it is impossible in most cases to determine the original composition of this mineral. Unaltered portions of a few grains in which albite twinning is preserved indicate that this plagioclase is at least as calcic as sodic andesine. The outer edges of the phenocrysts frequently show the effects of corrosion and
alteration, apparently of a metasomatic character. The boundaries of crystals altered in this manner often have embayments and irregular contacts with the finer grained crystalline matrix. The outer rim of the crystal is frequently clear, untwinned and unaltered while the core is clouded by a mass of incipient alteration products. The extinction angle in the rim as measured from the 010 crystal face is not uniform but gradually increases towards the center of the grain. This feature combined with the evidence of corrosion and absence of twinning indicates a probable extraction of calcium from the outer edges of the phenocrysts. The constituents of the matrix are much finer grained than the plagioclase phenocrysts. Here a pale greenish hornblende is the only mineral showing euhedral forms. Quartz and orthoclase are present as small anhedral grains. These two minerals are to a considerable extent combined in a fine grained micrographic intergrowth. In some specimens the intergrown quartz and orthoclase constitute the greater portion of the matrix while in others the two minerals are almost wholly separated into discreet grains. Occasionally a small grain of a colorless pyroxene having a small optic angle is found. This mineral is presumed to be a pigeonite. Magnetite and apatite are present as minor accessory constituents. A few small, scattered grains of calcite and epidote are also present. The alteration material forming from the plagioclase phenocrysts is too fine grained to permit positive identification. In some
cases it is flaky like sericite and in some phenocrysts it is minute granules having a faintly greenish color. With the exception of the large plagioclase phenocrysts the minerals of this variety of the granodiorite show but little alteration as compared to those of the normal variety. Fractured grains and strain shadows are characteristic of the quartz but are not numerous among the other minerals. There have been two distinct stages of crystallization in this rock. The plagioclase phenocrysts belong to the first and the micrographic groundmass to the second stage.

The outcrops of this rock contain numerous small, grayish, fine grained inclusions. Microscopic examination shows these inclusions to have a slightly porphyritic texture. The ground mass is composed principally of randomly orientated, long plagioclase laths. These laths have corroded boundaries and have lost most of the original albite twinning. The extinction angles are rather obscure but seem to indicate that the original composition of this plagioclase was that of labradorite. The interstitial material between the plagioclase laths consists of fine grained anhedral quartz and still finer grained magnetite. The phenocrysts are anhedral grains of untwinned plagioclase that have developed within solid rock. They have enveloped all grains of magnetite that lay in their path and also occasional plagioclase laths. Minute needles of euhedral greenish hornblende penetrate both types of feldspar. Alteration minerals consist of minute grains of calcite,
epidote and extremely fine grained material forming from
the original plagioclase. The inclusions examined by the
writer did not contain any potash feldspars. These
remnants apparently represent the assimilation of an older
more basic rock by the granodiorite magma. The abundance
of plagioclase laths suggests that this rock may have been
a pilotaxitic textured basaltic lava.

The variety of the granodiorite being described is in-
dicated by field relations in respect to the abundance and
character of its inclusions and the regional trend of the
belt it occupies to be a roof phase of the granodiorite batho-
lith. It seems to have been formed in two stages of meta-
somatic replacement. The first stage produced a porphyritic
textured rock. The second stage, during which a considerable
amount of potash and silica was introduced and the plagioclase
was still further altered, produced the micrographic inter-
growth of quartz and orthoclase forming the groundmass. It
is not known whether the late silica and potash was contri-
buted by the last stages of the granodiorite intrusion or by
the younger Quincy Granite but an origin from the granodiorite
magma seems most likely.
An approximate mineralogical composition on a volume basis for a typical specimen of this rock is as follows:

- Plagioclase 65%
- Quartz 15
- Orthoclase 10
- Hornblende 5
- Pyroxene 1
- Other constituents 4

This composition does not differ greatly from that of the normal variety of the granodiorite.

In order to distinguish this variety of the granodiorite from others it will be called porphyritic micrographic granodiorite in further discussions. Although this rock outcrops along a belt about four miles in length most of it is covered by younger rocks of the Lynn Volcanic Series and by areas of glacial drift, therefore exposures are scarce. The best outcrops are found in the south part of Mt. Hood Memorial Park in Welrose, on the hills lying along the southeast side of Forest Street in Malden and in an area surrounding the Fulton School in Medford.

MICROGRAPHIC GRANODIORITE

A medium grained, reddish variety of the granodiorite outcrops in the Maplewood section of Malden and along the south edge of the Middlesex Feilis Highland in Medford. These
outcrops are within a belt lying between that of the porphyritic micrographic granodiorite described above and the north boundary fault of the Boston Basin. This rock has the characteristics of a transitional phase between the normal variety and the porphyritic micrographic variety of the granodiorite but continuous outcrops to prove this relationship are not available. The mineralogical composition and texture of this rock varies slightly from one outcrop to another. Ordinarily it has a medium grained granitic texture but may become locally porphyritic. The color is a mottled pink, white and gray. The plagioclase constituent of this variety of the granodiorite tends to have the form of rather large euhedral grains but in many cases these have been broken into small fragments. Its composition varies from andesine to calcic oligoclase. This plagioclase is only slightly clouded by incipient alteration and has not been altered around the edges of the grains. The albite twinning is sharp and clear. Quartz and orthoclase are finer grained and interstitial to the plagioclase. A portion of these minerals always appear in small grains with micrographic intergrowths. In different specimens such fine grained intergrowths may form any portion up to sixty percent of the entire rock volume. The original mafic constituents have been altered beyond recognition. Alteration minerals present are chlorite and
epidote formed from the mafites and a small amount of calcite. There is a local variation in the amounts of the different constituents, with plagioclase ranging between thirty-five and sixty-five percent, quartz and orthoclase combined ranging between thirty and sixty percent and altered mafites amounting to less than five percent of the rock on a volume basis. Good exposures of this variety of the granodiorite are found in some abandoned quarries on the west side of Broadway in Malden and in an abandoned quarry on the north side of the Fellsway in Medford. A specimen consisting of about sixty percent of a micrographic intergrowth of quartz and orthoclase was taken from the latter quarry. This phase of the Dedham Granodiorite Formation will be called micrographic granodiorite in further discussions.

**STONEHAM RED GRANITE STOCK**

An elongate stock of granitic rock lies along the north-west side of the village of Stoneham. The outcrops of this rock are small and widely scattered because of thick deposits of glacial debris covering the countryside. Megascopically this rock is reddish in color, is medium-grained and has a granitic texture. Microscopic examination shows it to have a cataclastic texture with almost all of the original grains having been broken into small fragments that have strong strain shadows and undulatory extinction. The mineralogical
composition of this rock is much different than that of the normal variety of the granodiorite. Plagioclase having the composition of andesine is a minor constituent forming not more than five percent of the volume of the rock. The grains of this mineral have either been broken into small fragments or show bent and twisted twinning laminae. The amount of quartz varies from five to twenty-five percent of the rock volume. The large quartz grains are always fractured and show strong strain shadows and undulatory extinction. The original mafic minerals were minor constituents forming between five and ten percent of the rock volume. In the specimens examined these minerals were completely altered to chlorite and epidote. The principal mineral constituents of this rock are microcline and microperthite which are found in about equal quantities accounting for sixty to eighty percent of the rock volume. The correct classification of this rock is granite. The writer considers it to be a part of the Dedham Granodiorite Formation because of its cataclastic texture, complete alteration of the original mafic constituents, pink weathering potash feldspars, bent twinning laminae of the plagioclase feldspars and strong strain shadows and undulatory extinction of the larger mineral grains. These features are not characteristic of the granites of the Peabody and Quincy batholiths but are found to some degree in all varieties of rocks making up the Dedham Granodiorite Formation.
SYENODIORITE OF ARLINGTON HEIGHTS

A coarse grained rock having a granitic texture and a buff or cream color forms a plug or small stock outcropping on the Arlington-Belmont town line near the summit of Arlington Heights. This rock is the syenitic phase of the Dedham Granodiorite mentioned by LaForge and Emerson. Megascopic examination shows that this rock consists almost entirely of feldspars which are accompanied by only minor amounts of an amphibole and brownish biotite. It exhibits a peculiar microscopic appearance. Feldspar minerals constitute approximately ninety-five percent of the rock volume. These minerals are plagioclase having the composition of andesine, microperthite and microcline, all of which are present in anhedral grains of widely varying sizes and seemingly mixed together in a state of complete disorder and confusion. The plagioclase tends to be present as large grains having ragged outlines, bent twinning laminae and occasionally undulatory extinction. Some grains of this mineral have been

broken into small fragments. The microperthite and microcline grains show a great diversity of sizes and shapes, are intimately mixed with one another and are both interstitial to and penetrating large grains of plagioclase. The mafic constituents are green hornblende and a brownish biotite, both of which are almost unaltered. A slight incipient alteration of the hornblende has produced some chlorite. Magnetite and apatite are minor accessory constituents. The manner in which the feldspar minerals are mixed together makes estimation of the amounts of each present in the rock difficult if this is done by visual observation of thin sections, therefore a polished specimen of this rock was etched with hydrofluoric acid fumes and stained with an acetic acid solution of sodium cobaltinitrite. The results indicated a total potash bearing feldspar content of approximately twenty-five percent on a volume basis. There is not any quartz in this rock. It has a cataclastic texture with the fragmental material consisting of plagioclase and microperthite cemented together by a later crystallization of potash feldspars. The approximate mineralogical composition of this rock on a volume basis is:

- Plagioclase (Andesine) 70%
- Total Potash Feldspars 25%
- Hornblende 3%
- Biotite 2%
The accessory and alteration minerals are of such small quantity that these have been ignored in arriving at the above estimation. A rock of this character falls within the descriptions and compositions of syenodiorite as given by Johannsen. It differs from the normal variety of the Dedham Granodiorite by the total absence of quartz and the unaltered condition of the mafites. The field relations indicate that it exists as a small plug intrusive into Salem Gabbro-diorite. Small dikes and veins of this syenodiorite are found cutting the gabbro-diorite in the area immediately surrounding the plug. The area in which this syenodiorite outcrops is a thickly settled residential section in which the terrain has been smoothed and graded for streets and lawns thereby almost eliminating outcrops.

**APLITE DIKES**

Aplite dikes are intrusive into the normal variety of the Dedham Granodiorite in the vicinity of the Stony Brook Reservation and at Phillip's Point, Swampscott. In the Stony Brook Reservation and in the immediately surrounding area dense, fine grained, pinkish or cream colored aplite dikes and veins

---

are quite numerous in the outcrops of the coarse grained normal variety of the granodiorite. The form of these minor intrusions varies from small irregular veinlets a few inches in width and sometimes less than ten feet in length up to well defined dikes five or six feet in width and extending entirely across large outcrops. The mineral assemblage consists of plagioclase, microperthite and quartz as essential constituents and minute quantities of iron oxides and altered mafites as accessory constituents. The plagioclase is clear, colorless, unaltered and has the composition of calcic oligoclase or sodic andesine. These aplites contain slightly more quartz and microperthite and a lesser amount of a more sodic plagioclase than the normal variety of the Dedham Granodiorite which surrounds them. The writer considers these aplites to have formed by crystallization from a late differentiate of the granodiorite magma that accumulated in shrinkage cracks of the cooling batholith.

Some large dikes of a medium grained granitic rock cutting the normal variety of the Dedham Granodiorite at the Galloupe's Point section of Phillip's Point, Swampscott are likewise considered to be an aplitic phase of the granodiorite by the writer. This rock also contains slightly more quartz and potash bearing feldspars, in this case microcline and microperthite, than the surrounding normal variety of the granodiorite. The plagioclase constituent is clouded by incipient
alteration but appears to have the composition of andesine. The quartz grains are sometimes fractured and show strong strain shadows and undulatory extinction.

**PEGMATITES**

The writer did not observe any pegmatites cutting the rocks of the Dedham Granodiorite Formation. Numerous veins and dikes of a pegmatitic character are found cutting the Salem Gabbro-diorite Formation, especially those portions that have been hybridized by younger igneous intrusions. In some areas the materials forming these dikes must have been derived from the Dedham Granodiorite magma. For example, in Arlington and Woburn the gabbro-diorite has been invaded by small plugs of the granodiorite and locally cut by numerous pegmatitic dikes. The absence of granites in these localities leads to the conclusion that the pegmatites were probably derived from the granodiorite magma. The minerals represented in the pegmatites are pink microcline and a milky white quartz, both of which have crystallized in large grains. Quite frequently the two minerals are segregated with microcline forming the outside portions of dikes or veins and quartz forming the central core.
ROCKS PROVISIONALLY ASSIGNED TO THE DEDHAM GRANODIORITE

Two kinds of igneous rock which have a more basic composition than the common varieties of the Dedham Granodiorite and which do not appear to be phases of the Salem Gabbrodiorite were found during the course of field investigations by the writer. One of these rocks is a diorite forming a small stock that is intrusive into the Salem Gabbro-diorite in Lexington. The other rock is also a diorite and appears to be a roof phase of the Dedham batholith. Its composition has to a large extent been determined by the assimilation of pre-existing more basic rocks. This diorite outcrops in a belt extending through parts of Belmont and Waltham at the northwest side of the north boundary fault of the Boston basin. The writer provisionally assigns these rocks to the Dedham Granodiorite Formation on the basis of mineralogical and textural features that are more characteristic of the rocks of this formation than of the rocks of any other formation within the general area.

DIORITE STOCK IN LEXINGTON

A dark greenish gray, coarse grained diorite outcrops at the intersection of the Concord Turnpike and Waltham Street in the town of Lexington and also on the tops of the hills lying immediately to the northeast of this intersection. Small dikes of this rock are found cutting the Salem Gabbro-
diorite outcropping a short distance to the south of this area. This diorite appears to form a small stock about three-quarters of a mile in diameter that is intrusive into the Salem Gabbro-diorite.

Microscopic examination of a thin section of this rock showed it to have a subhedral texture with the component mineral grains being fractured and in most cases showing strong undulatory extinction. The most abundant mineral constituent is a plagioclase having the composition of highly calcic andesine. The grains of this mineral originally had subhedral outlines but are now fractured and have bent and twisted twinning laminae with undulatory extinction. This plagioclase is to a large extent clouded by incipient alteration. Rather large euhedral grains of apatite are distributed throughout the specimen. The only unaltered remnants of the original mafic constituents are some small shreds of a greenish hornblende that has been fractured and shows undulatory extinction. Magnetite appears in two forms, first as scattered large grains apparently representing a primary crystallization, and secondly as aggregates of tiny granules closely associated with chlorite and which probably have been formed by the decomposition of an original mafic constituent. Small grains of pyrite are also found in this rock. The original mafic constituents have been almost completely eliminated by the production of abundant chlorite. The appearance and close association of some of this chlorite
with magnetite granules suggests the possibility of a mafic mineral other than hornblende as having been an original constituent of the rock. Epidote is distributed throughout the rock as small grains, as fillings in tiny veinlets and as minute granules enclosed within plagioclase grains suggesting partial saussuritization of some of the latter mineral.

The approximate mineralogical composition of this rock on a volume basis is as follows:

- Plagioclase (Calcic Andesine) 60%
- Hornblende 5%
- Apatite 5%
- Magnetite 2%
- Chlorite 20%
- Epidote 4%
- Pyrite and unidentified alteration minerals 4%

If it is assumed that most of the chlorite represents hornblende as a primary constituent then this rock is properly classified as a diorite.

This diorite possesses some features which strongly suggest that it is an abnormally basic phase of the Edham Granodiorite batholith. The fractured grains, undulatory extinction of individual grains, bent twinning laminae of the plagioclase and almost total alteration of the original mafites are features generally characteristic of all varieties of the Edham Granodiorite and are not characteristic of the
Salem-Gabbro-diorite. In the field this diorite is intrusive into Salem Gabbro-diorite and in turn is not intruded by and does not show signs of hybridization by more acidic intrusive igneous rocks. It differs from most varieties of the Dedham Granodiorite by containing a greater amount of mafic constituents, by having a slightly more calcic plagioclase and by the appearance of apatite in a quantity sufficient to make this mineral an essential constituent. The writer is inclined to believe that this diorite is a phase of the Dedham Granodiorite batholith but prefers to map it as a separate unit because of its more basic composition.

Dikes and masses of a rock having the megascopic characteristics of this diorite are intrusive into Salem Gabbro-diorite in the hills along the east side of Lincoln Street in Waltham. The writer did not collect any specimens of this rock for microscopic examination therefore cannot state whether or not it is identical with the diorite of the Lexington stock.

QUARTZ-BIOTITE-DIORITE IN BELMONT AND WAITHAM

Scattered outcrops of a rather dark colored medium to coarse grained rock having a granitic texture and containing quartz and biotite as minor essential constituents are found within an area about one-half mile wide extending from Concord Avenue in Belmont to Chester Brook in Waltham and lying along
the north side of the north boundary fault of the Boston Basin. The rocks of this area are indicated to be a portion of the Newburyport Quartz-diorite Formation on the map accompanying LaForge's bulletin. Actually, a variety of rocks including remnants of the Cambrian quartzite and volcanic formations, the Salem Gabbro-diorite, the normal variety of the Dedham Granodiorite, hybrid types and a quartz-diotite diorite outcrop within this area with the latter variety being the most abundant. Similar biotitic rocks have not been found elsewhere in the area investigated for this report.

Specimens of this rock taken from different outcrops vary slightly in mineralogical composition and appearance. The light colored mineral constituents are most abundant but a rather uniform distribution of dark colored minerals tends to give the rock a gray or mottled appearance. The texture is ordinarily granitic, but occasionally becomes slightly gneissic. Some outcrops contain numerous small dark colored inclusions.

Examination under the microscope shows that this rock has a subhedral to anhedral texture. The principal mineral constituent is a plagioclase having the composition of sodic labradorite. The grains of this mineral are subhedral to

---

euhedral in outline, frequently have bent and twisted twinning laminae and in some specimens are slightly corroded and altered around the edges. Scattered spots of incipient alteration producing a minutely granular product that cannot be identified cloud some of the grains of plagioclase. Quartz in the form of rather small interstitial grains having fractures, strain shadows and undulatory extinction is evenly distributed throughout these rocks. The most abundant mafic constituent is a greenish hornblende. This mineral appears as large poikilitic grains with anhedral outlines or as aggregates of small grains. Many of the larger grains have become separated along the principal cleavage planes. The biotite is present in several forms. Some specimens contain large well-developed flakes of this mineral which seem to have been formed as a primary constituent. Other specimens definitely indicate that biotite crystallized later than the hornblende. In these cases small biotite flakes tend to form a rim around hornblende grains and also fill the fractures in the latter mineral. Hornblende has not been converted to biotite by alteration. Biotite may also appear as large aggregates of randomly orientated small flakes. This mineral was brown colored in all of the specimens examined. Small grains of magnetite and pyrite are closely associated with the mafic constituents. Small euhedral grains of apatite were found in all of the specimens examined. Secondary and alteration minerals consist of small scattered
grains of calcite, epidote and chlorite. Discreet grains of potash bearing feldspars could not be identified under the microscope. Staining tests showed the presence of potash in the altered rims of plagioclase grains and also with extremely fine grained interstitial quartz. The approximate average mineralogical composition of these rocks on a volume basis is as follows:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plagioclase (Sodic Labradorite)</td>
<td>60%</td>
</tr>
<tr>
<td>Quartz</td>
<td>15</td>
</tr>
<tr>
<td>Hornblende</td>
<td>15</td>
</tr>
<tr>
<td>Biotite</td>
<td>7</td>
</tr>
<tr>
<td>Magnetite and Pyrite</td>
<td>1</td>
</tr>
<tr>
<td>Calcite and Epidote</td>
<td>1</td>
</tr>
<tr>
<td>Other constituents</td>
<td>1</td>
</tr>
</tbody>
</table>

A thin section made from one of the dark colored inclusions found in these rocks showed that these remnants are plagioclase amphibolites. The area in which these rocks outcrop lies on the line of strike of the basaltic lava flows of the Marlboro Formation of Arlington, Winchester and Stoneham therefore the inclusions are presumably thermally metamorphosed remnants of the basaltic lavas.

The classification system of Johannsen indicates the rocks being described to be quartz-gabbros. Such a classification would seem to place these rocks with the Salem Gabbro-diorite Formation. The writer is of the opinion that they are more
likely a phase of the Dedham Granodiorite Formation. In the Waltham end of the outcropping area these rocks are apparently intrusive into the gabbro-diorite but exposures that would definitely verify this relationship were not found. The bent and twisted twinning laminae of the plagioclase grains and the abundance of fractured quartz grains having strain shadows and undulatory extinction are characteristics of the rocks of the Dedham Granodiorite Formation. These rocks are most likely roof phases of the Dedham Granodiorite Formation that have absorbed basic material from invaded basaltic lavas. The abundance and composition of the inclusions would seem to verify this conclusion. The writer would therefore prefer to call this rock a quartz-biotite-diorite rather than a gabbro because of this probable origin. Gabbros are generally considered to have as essential constituents labradorite feldspar and a pyroxene while diorites have andesine feldspar and an amphibole with biotite being a possible constituent of both types of rock. Quartz is not an essential constituent of either gabbros or diorites. The assemblage of labradorite, amphibole, quartz and biotite forming the rock just described makes it one that does not fit into the normal classification of igneous rocks.
ROCKS OF THE ALKALINE GROUP

The rocks of the alkaline group consist of nordmarkites, granites and syenites that are younger in age and intrusive into the rocks of the sub-alkaline group. The alkaline group is divided into two sub-groups. One sub-group includes the granites and related nordmarkites and syenites outcropping within a few miles of the Massachusetts coast from Quincy to Cape Ann. The granite bodies which form the major portion of this sub-group appear to be contemporaneous and generally have been considered to be separate intrusive bodies of a single magmatic activity. The name Quincy Granite has been applied to all of the granites of this sub-group although in some cases the name of a particular locality is also used to designate the rock found within it. The second sub-group includes the granites and related pegmatites outcropping within a northeast-southwest trending belt extending from Andover to Marlboro. These rocks have been named Andover Granite. The granites of the two sub-groups are probably nearly contemporaneous but differ slightly in composition.

The greater portion of the rocks of the alkaline group are exposed outside of the area covered by this report. The only large masses of these alkaline rocks outcropping within the area are a portion of the granite stock of Peabody, a nordmarkite stock in Marblehead and a part of the Andover Granite exposed in Lexington. The main features and relations
of most of the bodies of the alkaline rocks are not exhibited by exposures within the area studied and therefore the descriptions will be brief.
The Peabody Granite is the youngest of the plutonic igneous intrusive rocks to be found in the area immediately to the north of the Boston Basin. It is intrusive into all other plutonic igneous rocks and in turn is intruded only by minor aplites and pegmatites representing late differentiates from its own magma. With very minor differences it is identical in mineralogical composition with the granites of Cape Ann and Quincy which are of the same approximate age. These granites form several stocks and small batholiths close to the northeastern shore of Massachusetts which geologists have ordinarily grouped under the single name of Quincy Granite. The Peabody Granite of this group forms a roughly elliptical stock or small batholith about five and one-half miles long by three and one-half miles wide, mostly within the town of Peabody, but also extending into Lynn and Saugus. Another elongate stock of the same rock about one mile long by one-quarter mile wide outcrops along the western side of Eastern Avenue in Lynn. Several very small plugs or dike-like intrusions of it are found in the Salem Gabbro-diorite at the northeast side of Flax Pond in Lynn. A syenitic rock that is apparently a silica poor phase of this granite forms a stock to the east of Clifton Village in Marblehead and also the prominence called Skinner Head on the west side of Marblehead Harbor. These two outcroppings are described in the following
section. In addition to these well defined outcroppings, scattered dikes and veins in the older igneous rocks are found in Marblehead and Lynn.

Only the south edge of the Peabody stock is included in the area mapped for this report. Here, large bald hills have great expanses of outcrops left bare by glaciation. The rock is remarkably uniform in texture and composition over the entire area examined. A few widely scattered dikes of aplite and pegmatite are seen in the edges of the stock, otherwise the mass is pure granite. Diabasic dikes such as those which in great numbers intrude all other igneous rocks of the area, including the Lynn Volcanic Series, are not to be found in the granite. Joints in the granite are widely spaced and tend to follow a cubic system. This feature has permitted the ice of the Pleistocene continental glacier to pluck great cubic blocks from the south slopes of hills, these blocks often having dimensions of as much as fifty feet along the edges. Many of these blocks were carried southeastward for varying distances to form a prominent boulder train. Quite frequently these erratics are found disintegrated to a coarse, granular gravel and in this case are called saprolites. The granite outcrops weather to a light pinkish buff color that is very conspicuous. A few inclusions or roof pendants of the Marlboro Formation are found along the edges of the stock. These pendants have been thermally metamorphosed to plagioclase-amphibolites or quartz-plagioclase-amphibolites depending upon
their original composition, the necessary heat having been derived from the granitic magma.

Freshly broken, unweathered specimens of the granite have a light greenish gray color with a pronounced greasy luster. After a short exposure to the atmosphere the color changes to a darker shade of green, still retaining the greasy luster. The color is due to the feldspars which are most abundant mineral constituents. Specimens collected from small abandoned quarries show that surface weathering affects the color to a depth of some four or five feet causing the feldspars to be more nearly white or pale gray but retaining some indication of the greenish color and showing some interstitial iron staining. The color changes are probably caused by the presence of minute traces of iron in the feldspars.

The mineral composition and texture is very uniform in all of the granite of the areas examined. The essential minerals are microperthite, quartz, a plagioclase, and dark green hornblende. Minor constituents are a colorless pyroxene, a green pyroxene, magnetite, zircon and apatite, any of which may or may not be present in a specimen. Alteration minerals are riebeckite, biotite and kaolin. Feldspars and quartz generally form ninety-five percent or more of the volume and mafites five percent or less. The texture is subhedral. The largest and most abundant mineral grains are microperthite which frequently exhibits well defined crystal boundaries.
Other minerals are interstitial and anhedral. Quite frequently the large grains of microperthite are separated from one another and from the coarser interstitial grains by narrow zones of finely brecciated material, which was most likely broken from the larger crystals by movements in the last residual magma just prior to the final crystallization. Microperthite grains generally average about three millimeters in diameter and quartz grains one to two millimeters. The minute brecciated interstitial grains are a very small fraction of a millimeter in diameter.

Microperthite very consistently forms about seventy percent of the volume of the rock. Its grains are subhedral to euhedral, quite frequently showing some regular crystal boundaries but rarely entire crystal shapes. Carlsbad twinning is very common. This microperthite is an intergrowth of a potash bearing feldspar and albite, the two being present in very close to equal proportions. The potash feldspar is probably microcline since occasional indications of triclinic twinning are found. The plagioclase constituent is albite or slightly calcic albite as indicated by extinction angles on occasional small areas of albite twinning. Triclinic and albite twinning in the intergrown material are rare. In thin sections the potash feldspar is clear, unaltered, and shows a gray interference color. Albite may be slightly clouded by incipient alteration, especially in specimens that are
slightly weathered, and shows a white interference color. Its slightly higher indices of refraction also permit it to be determined by movement of the Becke line. Clapp states "The potash and soda feldspar are present in the microperthite in about equal amounts. The calculated average percentage by volume is 52 percent orthoclase to 48 percent albite - that is, 51 parts by weight of orthoclase to 49 parts of albite". He does not explain the method used in arriving at these figures. Examination of several thin sections indicates these figures are reasonable. All indications point to this microperthite as having been formed by crystallization from a liquid of eutectic composition.

Plagioclase is present in some specimens in very small amounts. Two generations appear to be present. The first is found as occasional remnants in the interior of microperthite grains. Such remnants are not sharply defined, grading off indistinctly into the surrounding microperthite and are clouded by incipient alteration. The composition is probably somewhat calcic albite, but cannot be determined exactly since twinning is not well preserved. The second generation is found as small grains in the interstitial material and as small areas showing albite twinning on the outer edges of some

---

microperthite grains. Maximum extinction angles on the albite twinning are from 15 to 18 degrees, therefore it is probably nearly pure albite. The amount of plagioclase in the specimens examined does not exceed one percent of the volume of the rock. Clapp reports a few higher figures, probably from areas not examined in this investigation.

Quartz very consistently constitutes about twenty-five percent of the volume of the rock. The larger grains are smaller than those of the microperthite and tend to be interstitial. The quartz is slightly smoky or grayish in color. Thin sections show that it contains numerous irregular trains and scattered clouds of minute liquid inclusions but otherwise the mineral appears clear and colorless. The grains are very irregular in shape. Fractured grains are numerous but extinction is almost always sharp and clear in contrast to that of the quartz in the older igneous rocks of the area. The finely brecciated interstitial crystalline material separating many large grains is usually coated with a thin film of quartz indicating a final crystallization of this constituent.

The principal mafic constituent of this granite is a dark green hornblende forming small grains interstitial to microperthite and quartz. This mineral is optically negative, strongly pleochroic with \( X = \) light brown, \( Y = \) brownish green and \( Z = \) dark green but with slight variations in tints from one specimen to another. It has an extinction angle on
the 010 face of 30 degrees. This is presumed to be the mineral which Clapp\(^1\) doubtfully calls katophorite but neither the color or optical properties check. It is considered to be a hornblende rich in soda and ferrous iron and low in magnesium.

Two varieties of pyroxene are found. Some specimens show a colorless pyroxene with a small optic angle and low birefringence, the interference color being first order white. This mineral is optically positive and has an extinction angle on the 010 face of 35 degrees. It is assumed to be a pigeonite. The other pyroxene is a light green variety with weak pleochroism, is optically positive and has an extinction angle greater than 40 degrees. Some grains show a strong blue interference color. This mineral is probably aegirine-augite or hedenbergite. The two pyroxenes are found side by side in some thin sections. The greenish variety shows some indication of surrounding the colorless pigeonite and would therefore represent a later crystallization. Both varieties occasionally have fragments of the green hornblende around the outer edges. The total amount of pyroxenes present in the granite is only a fraction of one percent of its total volume. These minerals exist as very small grains, many of which are

partially altered, therefore identification is difficult.

Magnetite is occasionally found associated with the mafites in some specimens of the granite as very small grains which are occasionally altered to a red oxide.

A fibrous blue amphibole occasionally forms a thin fringe around grains of the greenish pyroxene and hornblende. It has nearly parallel extinction, is faintly pleochroic but too fine grained to give other optical properties. This mineral is an alteration product considered to be riebeckite.

Biotite is found as a rare alteration product, usually having been derived from hornblende in the vicinity of magnetite grains. The flakes are minute in size and have a deep reddish brown color.

Other minor alteration products are kaolin forming at the expense of albite and a yellowish to brownish substance found as small radiating aggregates and coating joint surfaces. The latter material is likely a mixture of iron oxides and kaolin. A few tiny grains too small to identify but having the appearance of clinozoisite are closely associated with the mafites.

Zircon and apatite are found as very minor primary constituents in some specimens of the granite.

Aplitic dikes cutting the edges of the main Peabody stock differ in mineral composition from the coarse granite by showing a considerable increase in the amount of quartz and by
having a small amount of primary biotite as a mafic constituent. In the aplite specimens collected mafites other than biotite were altered by weathering but seem to have originally crystallized as green hornblende. The mafic constituents form a very minor portion of the volume of the aplites. Microperthite is sparingly developed. An untwinned potash feldspar is the principal feldspathic constituent while albite, partly intergrown in microperthite and partly as distinct grains, is present in considerably less amount in these aplites.

The only pegmatite dikes known to be cutting the Peabody Granite lie outside the area mapped for this report, therefore they will not be described.

The various stocks of the Peabody Granite are believed by the writer to have been emplaced as masses of molten magma. Field relations and microscopic characteristics of the granite indicate this mode of origin. In the field the very persistent uniformity of texture and composition of the granite combined with a total absence of inclusions, xenoliths or other remnants of pre-existing rocks in the area examined are factors favorable to this hypothesis. The few aplitic dikes of the Peabody stock are explained as having crystallized from a late differentiate of the granitic magma which accumulated in shrinkage cracks as the mass solidified and cooled. The scattered roof pendants of pre-existing rocks are found near the periphery of the stock. The material composing the rocks of these
pendants has been completely recrystallized and the mineral composition reconstituted in a manner that can only be explained by thermal metamorphism. The heat given off by the surrounding granitic magma was apparently sufficient to accomplish this result.

Microscopic examination shows that the granite consists mainly of microperthite in large subhedral to euhedral grains. Normally this mineral can be expected to crystallize from a liquid of eutectic composition, the liquid prior to crystallization being of necessity a magma. The quartz is always smaller in size and interstitial to the microperthite thereby demonstrating its slightly later crystallization, a normal sequence in the solidification of this type of magma. Another argument for magmatic origin is the presence of finely brecciated interstitial material. Fractures are numerous in the large microperthite and quartz grains and the small interstitial material clearly has been chipped from the corners and edges of these large grains. Such a result could be obtained by movement of a crystal "mush" shortly before crystallization of the last remaining liquid. It is quite probable that this magma was under considerable pressure from orogenic sources and in an effort to attain relief was moving in a direction towards a lower pressure. Flowage or movement of a mass predominately crystalline with a minor liquid component would result in considerable abrasion and crushing of the solids. The fact
that strain shadows and undulatory extinction in the minerals of this granite are uncommon shows that the crystals were in an environment such that simple fracturing relieved stresses, therefore they must have had some degree of freedom in a liquid medium. The thin film of quartz which coats many of the tiny brecciated fragments and is the agent cementing the mass together represents the final crystallization from the residual interstitial liquid. All of the specimens studied were taken from small plugs or from near the edges of the Peabody stock where the effects of movement might be expected to be somewhat greater because of friction or drag developed along the nearby walls. The above described features strongly favor a magmatic origin for the Peabody Granite.

The age of the Peabody Granite cannot be stated with any great degree of exactness. With the exception of a few dikes believed to be of Triassic age, it is the youngest of the intrusive igneous rocks found in its general vicinity. It penetrates all of the other plutonic types. The writer believes it to be contemporaneous with the Lynn Volcanics. The basal volcanic flows frequently contain many boulders and fragments of the older igneous rocks which represent loose surface material picked up by the flowing lavas while moving across terrain on
which these rocks outcropped. Fragments of the granite are not found in the lavas. Dikes believed to be associated with the Lynn Volcanics are found cutting all of the formations of the area except the granite and related syenites and nordmarkites. It is quite possible that the granite may be the intrusive phase and the volcanic flows may be the extrusive phase of a single period of magmatic activity. This hypothesis will be discussed in detail in the section of this report that presents the writer's views on the age relations of the rocks of the Boston Bay Group.
A quartz poor, coarse grained, granitic rock that is probably an earlier magmatic differentiate from the source that produced the Peabody Granite forms a stock about one-half mile in diameter lying to the east of Clifton village in Marblehead. The same type of rock also forms the cliffs of the prominence called Skinner Head on the west side of Marblehead Harbor. This second exposure is only some seventy or eighty yards in diameter. The outcrops form prominent knobs projecting above the surrounding terrain. They weather to a distinctive greenish brown color and all are quite thoroughly disintegrated to a considerable depth. This disintegration is intergranular with hardly any chemical decomposition of the constituent minerals. The only rocks closely associated with these coarse grained granitic intrusions are a few small aplite dikes in the Clifton stock, a partially altered outcrop of the Salem Gabbro-diorite exposed near the west side of this stock and a peculiar porphyritic dike with microperthite phenocrysts in a finely crystalline groundmass of quartz and feldspar exposed along the northwest edge of the small stock at Skinner Head.

The texture of this granitic rock is anhedral to subhedral with but few well developed crystal shapes. Mafic minerals constitute from five to twenty percent of the volume of different specimens. It is impossible to obtain specimens
that do not crumble to small particles from surface outcrops because of the deep intergranular disintegration. A fairly compact specimen was taken from a small abandoned quarry near the northeast edge of Clifton village. The quarry face showed that disintegrated rock extends to depths of at least ten feet below the surface of the ground. The freshest sample obtained had a greenish gray color with a greasy luster. Surface weathering turns the outcrops slightly brownish by the accumulation of a small amount of iron oxide. Grain sizes of the constituent minerals mostly vary from two to four millimeters in diameter with only a small amount of fine interstitial material being present.

The mineral composition of this rock is very similar to that of the Peabody Granite. Coarse grained microperthite is the principal constituent, accounting for seventy-five to eighty percent of the volume. It is an intergrowth of albite and presumably microcline since occasional indications of triclinic twinning are seen. The grains are generally anhedral with few regular crystal boundaries. Carlsbad twinning is uncommon as contrasted to the microperthite of the Peabody Granite which shows frequent twinning of this kind. The two feldspars are present in nearly equal proportions. Plagioclase is slightly more abundant than in the Peabody Granite with remnants of large grains having indistinct boundaries that grade into microperthite being a characteristic feature.
The thin sections examined did not contain properly orientated grains that would permit an exact determination of the plagioclase mineral but it is probably a sodic oligoclase. The mafic constituents are more abundant than in the Peabody Granite and consist of the same minerals, that is, a colorless pigeonite with small optic angle, a faintly colored pyroxene occasionally showing strong blue interference colors, greenish brown hornblende, a nearly opaque dark reddish brown mica and magnetite. Quartz is a very minor constituent, being found only as rare, small interstitial grains accounting for less than five percent of the volume. Although the rock is deeply disintegrated and crumbles readily, actual decomposition of the various minerals in most cases is in the incipient stage. Hornblende and magnetite show a somewhat greater degree of alteration than the same minerals in the Peabody Granite, otherwise the two rocks are decomposed to about the same degree.

The larger grains, which are usually microperthite, are almost always broken, some showing several fractures. Fine grained interstitial fragments are present but not as abundantly as in the Peabody Granite. The cementing medium is not quartz but a dark greenish brown, nearly opaque material that cannot be identified and which weathers rather easily producing some red iron oxide, thus accounting for the brownish surface alteration and the deep intergranular disintegration.
Rare instances of quartz and calcite filling minute fractures are found, both minerals being secondary and introduced.

These intrusive plugs at Clifton and Skinner Head can be classified as quartz-syenites, or more exactly as nordmarkites. The mineralogical composition and texture checks very closely with the description of typical nordmarkites in which microperthite is the principal constituent as given by Johannsen. The small aplite dikes or veins are more acidic late differentiates from the magma that formed the main enclosing nordmarkite mass. Two specimens from different aplitic veins in the Clifton stock were examined microscopically. One specimen was found to consist on a volume basis of about seventy percent microperthite, twenty-five percent quartz and a small amount of green hornblende, a mineral composition practically identical with that of the Peabody Granite. The other specimen is more siliceous, consisting of about forty percent quartz, fifty-five percent of feldspar clouded by incipient alteration and a small amount of decomposed mafites. At Skinner Head a dark, reddish-gray porphyritic rock outcrops on the beach at the northwest edge of the nordmarkite.

The outcrop is quite thoroughly brecciated and does not satisfactorily indicate whether this is a large dike or a volcanic flow. The phenocrysts are mostly composed of microperthite but with a minor amount of plagioclase also being present and the groundmass is finely crystalline consisting of tiny grains of potash feldspar and quartz showing well developed flow structure. This mineral composition is essentially the same as that of the Peabody Granite.

The writer believes these nordmarkites were formed by the crystallization of a magmatic differentiate which separated from the same parent source as that which produced the magma forming the Peabody Granite with the separation occurring shortly before that of the more granitic type. Evidence supporting this hypothesis is found in the common rocks mineral assemblage of the two, with the nordmarkite being slightly richer in calcium bearing plagioclase and mafites and poorer in quartz. The aplites representing crystallization of the last residual liquids of the nordmarkite magma very closely approach the composition of the granite, thus furnishing additional proof of the earlier separation of the nordmarkite magma from a common parent magma. The age of the nordmarkites should be slightly older than that of the Peabody Granite.
QUINCY GRANITE

A few outcroppings of the Quincy Granite batholith are located at the extreme south edge of the area covered by this report. The rock of this igneous plutonic intrusive mass is a microperthite-quartz-hornblende-granite having several textural variations. Its mineralogical composition is nearly identical with that of the Peabody Granite described in this report. Most geologists consider the Peabody and Quincy Granites to be two intrusive masses of the same magmatic material. The writer does not know of any field relations of these rocks that would contradict this hypothesis. The relations between the Quincy Granite and other formations were not indicated by any exposures in the area investigated therefore it will not be described in detail by the writer. The Quincy Granite has been adequately described by several geologists. An exceptionally fine report on it has been written by Warren.¹

APOPHYsal PHASES OF THE QUINCY GRANITE

IN LYNN, SWAMPSCOTT AND MARBLEHEAD

Several small stocks, plugs and dikes of a reddish granite are intrusive into the Salem Gabbro-diorite Formation in Lynn, Swampscott and Marblehead. This granite weathers to a reddish brown color thereby causing its outcrops to have a distinctive appearance that permits easy field identification. The basic rocks of the gabbro-diorite formation surrounding these granitic intrusions have been more or less altered and converted to hybrid types.

Megascopic examination shows that most specimens of the granitic rocks being described have a medium to fairly coarse grained granitic texture. A pinkish to reddish feldspar is always the most abundant mineral constituent while varying amounts of dark colored mafites, white plagioclase and quartz give some specimens a mottled appearance. The component mineral grains tend to be evenly sized.

Microscopic examination of several specimens of these granites taken from different stocks or plugs showed that in all cases microperthite forms from seventy-five to eighty percent of the rock volume. The grains of this mineral are usually large, anhedral and slightly clouded by incipient alteration. The relative amounts of the other constituents vary for specimens taken from different exposures, that is, quartz may be more abundant than hornblende in one specimen.
and the proportions be reversed in another. The amount of quartz varies from five to fifteen percent of rock volume. Its grains tend to be small and interstitial with rather large grains being found only in the specimens containing the greatest amounts of this mineral. The quartz grains are occasionally fractured but ordinarily show sharp, clear extinctions with the few exceptions showing faint strain shadows. This mineral contains numerous minute inclusions. It has always been the last constituent to crystallize. In hand specimens of these granites the quartz grains show a faint smoky color. The amount of plagioclase varies from about five to eight percent of the rock volume and in different specimens has the composition of sodic andesine or calcic oligoclase. Large grains of plagioclase are scarce and are not found in most specimens. The principal mafic constituent of these granites is a greenish hornblende accounting for from two to seven percent of the total volume of various specimens. This mineral frequently shows some degree of alteration, having been partially changed to either a dark reddish brown biotite or chlorite. It is often poikilitic and always encloses or is closely associated with small magnetite grains. Some specimens of the granite contain minute grains of a colorless mineral suggestive of a pyroxene. This mineral is always enclosed in or closely associated with hornblende. Its grains are usually partially stained brownish, a condition which in combination with the small sizes makes identification of this
mineral uncertain. Small grains of epidote were found in all of the specimens examined. These rocks are properly classified as granites and will be considered as such by the writer even though specimens from some of the minor intrusions approach the mineralogical composition of quartz-seyenites.

Some of these granites show cataclastic textures in varying degrees of intensity. This feature is most strongly developed in the rock of the small plugs located in the south part of Swampscott. Here the granite is finer grained, weathers to a darker red color and shows more complete alteration of the hornblende than the rock from outcrops in which the cataclastic texture has not been developed. The fractured and brecciated grains are cemented by a late crystallization of quartz.

The writer considers these granites to be apophysal phases of the Quincy Granite. Although pink weathering potash feldspars are characteristic of the Dedham Granodiorite of the surrounding region and are not characteristic of either the Quincy or the Peabody Granites the mineralogical composition and macroscopic appearance of the rocks under consideration are more closely allied to the granite formations than to the granodiorite. The mineralogical composition of these rocks is nearly the same as that of the granite found in the small stocks of the Peabody Granite in Lynn. With the exception of
some of the smaller plugs in the south part of Swampscott the
degree of cataclastic brecciation exhibited is about of the
same intensity as that of the Peabody Granite. The quartz
of these rocks has a faint smoky color characteristic of that
of the granite formations and differing from the glassy or
milky quartz of the granodiorite. Since Quincy Granite is a
term generally applied to all the granites of Quincy, Peabody
and Cape Ann and because these granites have essentially
identical mineralogical compositions and are believed by
most geologists to be of about the same age the writer con-
siders the rocks just described to be apophysal varieties
of the granite formation. Field relations do not indicate
whether the apophyses are offshoots of the main Peabody stock
or of the Quincy batholith of the granite formation. The only
other type of rock associated with these apophysal granites
is the Salem Gabbro-diorite which they have invaded.

The quartz-syenite intrusive into the gabbro along the
north shore of Nahant is closely related to these apophysal
granites in both mineralogical composition and megascopic
appearance. It is quite probable that the intrusions of
granitic rock at Nahant are the same as those just described.

Some of the outcrops of the apophysal granites are lo-
cated on the golf course of the Tedesco Country Club in
Swampscott and Marblehead, at the east end of Commercial Street
in Marblehead, on the knob about one-quarter of a mile north-
east of the intersection of Paradise Road and Burril Street
in Swampscott and on a knob in the east corner of the intersection of Eastern Avenue and Essex Street in Lynn. Specimens taken from the two last named outcrops showed a well developed cataclastic texture.
ANDOVER GRANITE

Within the area covered by this report the Andover Granite outcrops only in the extreme northwest corner of the Lexington Quadrangle. The few exposures in this locality represent only a small portion of the total extent of this granite formation and therefore it will be dealt with briefly by the writer.

In the area investigated by the writer the outcrops of this granite are small and widely scattered. The rock is whitish or light grayish in color, medium grained, micaceous and has a distinct foliation. The essential mineral constituents in order of abundance are quartz, microcline, albite and muscovite. Biotite is a minor accessory constituent. Thin sections show the component mineral grains to be somewhat shattered and to have strain shadows and undulatory extinction. These features are not as highly developed as in the Dedham Granodiorite. Pegmatite dikes composed of coarse grained quartz, microcline, albite, muscovite and biotite cut almost every outcrop of the granite found in the area. A few outcrops of the granite contain inclusions or small pendants of a dark colored micaceous rock containing conspicuous amounts of biotite and hornblende. These inclusions are probably remnants of some portion of the Cambrian stratified rocks, possibly a part of the Marlboro Formation.
Outcrops showing the Andover Granite in contact with rocks of other formations were not found. Dikes or minor intrusions that might be associated with this granite were not observed in the surrounding terrain.

Descriptions in earlier geological reports correlate this granite with the Quincy Granite. Clapp\(^1\) reports that apophyseal phases of it invade the Salem Gabbro-diorite, Newburyport Quartz-diorite and the Dedham Granodiorite at locations to the north of the area covered by this report. In writing of this granite LaForgé\(^2\) says, "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".

---

THE ORIGIN AND EMEPLACEMENT OF THE DEDHAM GRANODIORITE
AND ITS RELATION TO THE SALEM GABBRO-DIORITE

The several varieties of rocks differing somewhat in mineralogical composition and texture, but still so closely related that they must be considered as the resultant phases of a single igneous activity, which comprise the Dedham Granodiorite Formation pose several problems that must be answered before a satisfactory explanation of the origin and method of emplacement of this formation can be postulated. Among the features which must be considered are the slightly varying mineralogical and textural compositions of the different varieties of the granodiorite and the obvious segregation of some of these varieties into outcropping belts suggestive of stratified formations. The relative abundance of inclusions, xenoliths and roof pendants and the types of rocks represented in these remnants appears to be closely related to the particular variety of the granodiorite in which they are found. The fact that some varieties of the granodiorite are associated with the remnants of a single kind of stratified rock has great significance. The universal fracturing of the component mineral grains, bent twinning laminae of the plagioclase feldspars and strong strain shadows and undulatory extinction found in specimens of all of the varieties of the formation examined by the writer must have an explanation unique to this formation since these features are not generally
characteristic of the rocks of any other igneous formation outcropping in the general region. The fairly common development of cataclastic textures is presumably closely related to the above listed features. The explanation of the origin of the formation must account for the presence of border phases, apophysal varieties and aplites connected with the granodiorite. The almost complete alteration of the mafic constituents in some of the varieties may be significant. Finally, the intrusive relationship between the granodiorite and the older rocks of the area, including the Salem Gabbro-diorite, must be satisfied by the proposed origin and method of emplacement. A satisfactory hypothesis for the origin of the Dedham Granodiorite Formation in its entirety must furnish a solution to all of these problems. The writer will comment upon the explanations for the origin of the Dedham Granodiorite given in previous geological reports and then will present his own hypothesis which it is believed more satisfactorily answers the problems posed.

Most geologists who have studied the igneous rocks of Eastern Massachusetts have advocated an origin by differentiation from a single magma for the Salem Gabbro-diorite, Newburyport Quartz-diorite and the Dedham Granodiorite Formations with these rocks constituting a single so-called sub-alkaline batholith. There has been divided opinion as to the
place where differentiation of the magma into the three principal rock types occurred. One group has postulated differentiation in essentially the position now occupied by these rocks. LaForge has proposed differentiation at considerable depth below the earth's surface followed by successive invasions of magmatic fractions of increasing acidity. A few geologists have considered the possibility of the character of the Dedham Granodiorite having been determined by the rocks displaced but have not thoroughly investigated the idea.

The most recent and also most thorough discussion of the hypotheses that the rocks of the sub-alkaline batholith were formed by differentiation in place is given by Clapp. The following quotations have been extracted from his descriptions and conclusions. "Nowhere throughout Essex County, although the different varieties of the sub-alkaline rocks are in many places in close contact, is one type distinctly intrusive into any other. ----- In most places a zone or belt of quartz-diorite lies between the gabbro-diorite and the granodiorite. ----- All this evidence supports most strongly the conclusion that the original sub-alkaline magma has been differentiated, giving rise to the various phases. The phases have been arranged according to their density the granodiorite on top and the gabbro-diorite below, with a transition zone of quartz-diorite. ----- It appears, therefore, as
if the sub-alkaline batholith of Essex County is almost an ideal example of the differentiation in place of an original basaltic magma through fractional crystallization under gravitative control. The Salem Gabbro-diorite greatly pre-dominated and underlies the Dedham Granodiorite, which has in places, near the top of the batholith, a facies that is still further differentiated - a biotite calci-alkali granite; and between the gabbro-diorite and the granodiorite is the transitional Newburyport quartz-diorite. Even though Clapp's report covers a much larger area of the igneous rocks than that of the writer several criticisms of the above conclusions are possible.

Within the area in which Clapp worked the gabbro-diorite outcrops more extensively than the granodiorite but a glance at a geological map of Eastern Massachusetts will show that the reverse is true when the entire extent of the igneous rocks of this group are considered, in fact, at the surface of the earth the total extent of areas that have been mapped as granodiorite is several times greater than that of the gabbro-diorite, furthermore, these formations pass under the ocean with the granodiorite occupying several times the length of

the shoreline that is occupied by the gabbro-diorite. Separation of an originally basaltic magma into different rock types by differentiation and fractionation results in the basic phases such as gabbros and diorites being greatly predominant in volume over acidic types such as granodiorites and granites.

The writer cannot agree with the statement that in most places a zone or belt of quartz-diorite lies between the granodiorite and the gabbro-diorite. In those areas in which Clapp was not able to find the so-called quartz-diorite occupying an intermediate position he resorted to faulting as the means of separating the end members of his differentiation series. In some cases the field evidence for such faults is very obscure. The so-called quartz-diorite of the area covered by this report is considered by the writer to be one of the more basic phases of the Dedham Granodiorite Formation, the composition and location of which have been determined by basaltic lava flows that it replaced. The so-called quartz-diorite phase may or may not occupy an intermediate position between the gabbro-diorite and the granodiorite. In those areas in which it does outcrop between the gabbro-diorite and the granodiorite its situation is purely coincidental.

In attempting to prove the existence of a continuous transition from gabbro-diorite to granodiorite and granite Clapp says "The rocks are also transitional in part. On
account of the faults that separate the various types and that bring contracted (apparently a misprint and should be "contrasted") types in contact with each other no one continual section could be taken along which a gradual transition could be shown. It would be possible, however, to collect specimens - and this has been done by the writer - which show a gradual, almost perfect transition between the end members. --- The transition of the granodiorite is downward into quartz-diorite; but upward it is into true granite, which contains alkaline feldspar in excess of calc-alkaline feldspar. - The transition between the quartz-diorite and the gabbro-diorite is of less perfect demonstration, partly on account of the poor exposures in North Saugus and Wakefield and also because it is probable that the two types are separated by a fault, which has not been recognized in mapping. To the northwest of Birch Pond the transition is best shown. Immediately north of the Lynn fault at the west end of the pond is gabbro-diorite; north of this quartz enters and the rock passes through a quartz-bearing diorite into a quartz diorite. --- This feature is best shown in the Parker River syncline in which the granodiorite that forms the center gives way on the flanks to quartz-diorite and the quartz-diorite in turn to gabbro-diorite." ¹ These remarks would seem to

indicate that Clapp himself was not too certain of the transition from gabbro-diorite to granodiorite. The writer carefully examined both the Birch Pond and Parker River syncline areas and could not find any field evidence to substantiate Clapp's conclusions.

The Birch Pond area lies within the area mapped in detail for this report by the writer. In commenting upon it more thoroughly Clapp says, "The quartz-diorite is transitional into gabbro-diorite on the north and also on the south, just west of Birch Pond, Lynn, where the Gabbro-diorite lies immediately north of the Lynn Fault". On the geological map accompanying his bulletin he shows a long fault extending from the Wyoma section of Lynn westward past the north end of Birch Pond to the vicinity of Wakefield. On the south side of this fault he shows volcanic flows of the Lynn Series that unconformably overlie Dedham Granodiorite (normal variety). Along the greater portion of the north side of this fault he shows Newburyport Quartz-diorite Formation. At the west end of Birch Pond a small area in which quartz-diorite is supposedly transitional into gabbro-diorite is indicated. The writer could not find any field evidence that would justify mapping Clapp's Lynn Fault. The volcanic flows of the area

unconformably overlie granodiorite at the south and the
so-called quartz-diorite at the north with the basal flows
locally containing fragmental material from both rocks. The
writer could not find any Salem Gabbro-diorite at the west
end of Birch Pond. In the south portion of this locality
flows of the Lynn Volcanic Series unconformably overlie the
so-called quartz-diorite. Outcrops of the latter rock are
found within an area extending northward from the west end
of Birch Pond for a distance of about one-half mile to the
south edge of a marsh at the west end of Walden Pond. The
rock called quartz-diorite by Clapp contains some inclusions
or roof pendants of the Marlboro Formation and is cut by
some large diabasic dikes which also intrude the overlying
volcanic flows to the southward. Instead of a zone showing
a complete transition from quartz-diorite to gabbro diorite
and separated from the volcanic flows by a fault as claimed
by Clapp this area actually shows the so-called quartz-diorite
containing remnants of the Marlboro Formation being overlain
unconformably by the volcanic flows and all of these rocks
being cut by diabasic dikes. It is possible that Clapp may
have mistakenly identified some of the remnants of the Marl-
boro Formation or the large diabasic dikes as gabbro-diorite
but even in this case it would not be possible to show a
complete transition from one type of rock into another.
The Parker River syncline is outside the area mapped for this report but the writer made a special field trip to this locality in order to further check the relations between the gabbro-diorite, quartz-diorite and granodiorite. The field work was limited mainly to observing the character and relations of the igneous rocks forming the borders of this basin. A prominent feature of this area is the great amount of glacial debris covering the terrain and almost completely mantling the bed rock. Outcrops for the most part are small and widely scattered, frequently being separated by distances of a mile or more. Most of the outcrops in the area immediately surrounding the basin were found to be a rather basic granodiorite identical in megascopic characteristics to the rock outcropping in the Lynn-Saugus-Wakefield-Stoneham belt that is called Newburyport Quartz-diorite in previous geological reports. This granitic rock contains rather numerous inclusions of an older basic volcanic rock which also forms a few widely scattered outcrops. Field observations indicate that most of the granitic rock outcropping around the border of the Parker River Syncline was formed by the metasomatic replacement of an older basic volcanic rock in the same manner as the so-called quartz-diorite of the southern area was formed. An outcrop of a fine grained, light colored rock similar to the Stony Brook variety of the Dedham Granodiorite lies on the north side of the road from the Newburyport Turnpike to the village of
Linebrook. The writer did not find any rocks that positively could be identified as Salem Gabbro-diorite. A small outcrop of a fine grained, dark colored, hybridized rock is located on the east side of Newbury Street near the Rowley-Ipswich town line. Microscopic examination of a thin section of this rock showed it to have been completely reconstituted by thermal metamorphism and partially altered by metasomatic replacement. Its original character is uncertain. The only other dark colored rocks observed by the writer were found in the central part of Ipswich village at a distance of about four miles from the border of the basin. The only outcrop found in this four mile interval is composed of a basic volcanic rock. The dark colored rocks in Ipswich village have been metamorphosed and hybridized by an invasion of granitic magma and a thorough study of the surrounding area would be necessary in order to obtain the data from which the original character of these rocks could be determined. The inspection of the borders of the Parker River syncline led to the conclusion that outcrops in this area are far too few in number and too widely scattered to indicate the relations existing between the rocks of the sub-alkaline group. There is not any evidence of successive belts of the normal variety of the Dedham Granodiorite, of the Newburyport Quartz-diorite and of the Salem Gabbro-diorite surrounding this basin with complete transitional phases between each type as has been inferred by Clapp in his description and so indicated on his map.
It is the writer's opinion that there is not any field evidence to justify a conclusion that there exists a continuous transition from gabbro-diorite to rocks having the composition of quartz-diorites. The most acidic phases of the Salem Gabbro-diorite are rocks having an ophitic texture, abundant mafic constituents and no original quartz or potash bearing feldspars. The so-called quartz-diorites on the other hand have a granitic texture, abundant quartz and some potash bearing feldspars. There is a substantial compositional gap between the two types of rocks.

The writer is willing to concede that to some extent transitional phases between the so-called quartz-diorite and the normal variety of the granodiorite can be found. The several specimens of the so-called quartz-diorite examined under the microscope by the writer had a mineralogical composition indicating that for the most part this rock is actually a granodiorite. The relatively slight difference in composition of the two varieties may be attributed to assimilation of pre-existing rocks from the roof of the batholith, the normal variety of the granodiorite having assimilated quartzites or siliceous rocks and the so-called quartz-diorites having assimilated basaltic lavas with the result that the latter contain a more abundant amount of mafic constituents. The transitional phases are found along what was the line of contact between the Cambrian quartzites and the
basaltic lavas and may possibly represent replacement of the chloritic strata of the quartzite formation. In the south part of Stoneham and in the Middlesex Fells Reservation there is some interfingering of the two varieties of the granodiorite and also some rocks that show transitional features between the normal and the "quartz-diorite" varieties of the granodiorite. The writer does not consider these transitional features to be the result of differentiation in the original magma.

In further support of his differentiation hypothesis Clapp says "In the central part of the main Saugus Anticline—that is in the lowest part of the granodiorite—there is a distinct basification of the normal granodiorite. The change is gradual, almost imperceptible, until one notices that the granodiorite is almost lacking in potash feldspar, which can be recognized megascopically. The grain and quartz content, however have varied but little from those of the normal granodiorite."¹ The rock which he is describing outcrops in the wide belt of the normal variety of the granodiorite between Birch Pond and the Saugus-Melrose town line.

From the Newburyport Turnpike westward the granodiorite assumes a whitish color. The potash bearing feldspars have not been turned pink by weathering but are white and are not easily recognized by megascopic examination. These minerals are more easily detected by optical methods under the microscope. Specimens stained with sodium cobaltinitrite solution showed that potash bearing feldspars constitute approximately ten percent of the volume of this particular rock, an amount that is consistent with the composition of the normal variety of the granodiorite as a whole. The writer cannot agree with the statement that the rock under consideration is the lowest part of the granodiorite. Its outcrops show exceptionally numerous inclusions and probably also small pendants of micaceous quartzite. The ledges exposed in road cuts along the Newburyport Turnpike contain only scattered small inclusions but large outcrops surrounding Stevens Pond and also lying to the north of this pond frequently have as much as fifty percent of their surface area represented as these remnants of older rocks. The stratification preserved in the inclusions quite persistently shows a northeast-southwest strike and a steep northwestward to vertical dip, an attitude which is the characteristic regional trend. Lesser numbers of inclusions are found in the granodiorite outcropping on the east side of the Newburyport Turnpike. The granodiorite of this locality has a slightly
gneissic texture which may be a feature inherited from replaced micaceous quartzites. On the basis of the numerous orientated inclusions and the slightly gneissic texture the writer considers the granodiorite of this Saugus locality much more likely to be a roof phase of the batholith and furthermore could not find evidence of basification by microscopic determination of the mineralogical composition. It is the writer's conclusion that this particular rock does not represent differentiation within the granodiorite as implied by Clapp. A nearly similar whitish granodiorite outcrops on the south part of Marblehead Neck and in this locality inclusions of micaceous quartzites are also exceptionally abundant.

There is some evidence of transitions between the normal variety of the granodiorite and felsic or granitic phases. In the Stony Brook Reservation in the south part of Boston the normal variety of the granodiorite appears to be transitional into the slightly more acidic "Stony Brook" variety. In this same locality the normal variety is cut by aplitic dikes representing a more acidic differentiate of the magma. Elsewhere the acidic phases of the granodiorite appear to be apophysal offshoots from the larger magma masses, as for example, the red granite stock in Stoneham.

The writer disagrees with the statement that one type of rock of the sub-alkaline group is not distinctly intrusive into another. Since, in the writer's opinion, the granodiorite
and the so-called quartz-diorite are phases of a single igneous invasion, intrusions of one into the other naturally would not exist. Intrusions of different varieties of the granodiorite formation into the gabbro-diorite are fairly numerous and are distributed throughout the greater extent of the outcropping areas of the latter formation. The syenodiorite variety is intrusive into the gabbro-diorite at the summit of Arlington Heights. The normal variety of the granodiorite is intrusive into the gabbro-diorite along the south-east side of Spring Street in Lexington, also in the area between Lexington Street and Shaker Glenn in Woburn and in an area about one-half mile north of Wheeler Road in Lexington and Burlington. All of these intrusions have the form of small stocks or plugs and in some cases dikes or veinlets can be found extending from the main bodies into the surrounding gabbro-diorite.

The field observations of the writer seem to contradict most emphatically the conclusion that the group of igneous rocks under consideration represent the differentiation in place of an originally basaltic magma with three main types of rock being segregated into distinct layers under gravitational control. The extent of the outcropping areas of the granodiorites is several times greater than that of the gabbro-diorites, a circumstance seemingly indicating that the volume of the granodiorites is greater than that of the more basic rocks. This result is not characteristic of the
differentiation of a single mass of magma. The principal areas of the Salem Gabbro-diorite containing practically all of the outcrops mapped as belonging to this formation lie to the north of Boston while the bulk of the granodiorite rock is found a considerable distance away to the south of Boston. This segregation is difficult to explain on the basis of gravitative control unless one postulates an immense volume of basic rocks underlying the granodiorite in southeastern Massachusetts. Transitional phases between the gabbro-diorite and the granodiorite cannot be found. Various phases of the granodiorite are intrusive into the gabbro-diorite indicating that the latter rock had been emplaced and solidified prior to the invasion of the granodiorite magma.

LaForge has a somewhat different explanation for the origin of the rocks of the sub-alkaline group. He postulates that these rocks are the differentiation products derived from a single parent magma that originally had a basaltic composition. Instead of differentiation in place as suggested by Clapp he would have the differentiation take place at a considerable depth below the earth's surface. The resulting fractions of the magma would then invade the upper crust of the earth either separately or together as immiscible phases to produce the rocks as they now exist. He mentions transitional phases between the gabbro-diorite and quartz-diorite but does not give any specific locations where these
may be found. He also fails to give an adequate explanation for the mixtures of gabbro-diorite and granitic rocks and for the hybrid rocks. In writing about the complex relationship between gabbro-diorite and the more acidic rocks he says of them, "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 some 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 large scale, grading from diorite with scattered granite dikes to granite with scattered diorite inclusions, and no sharp boundary can be drawn anywhere in such areas. 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 side by side, as no theory of magmatic differentiation in place seems competent to explain
the phenomena displayed."

The writer does not have any serious objection to the hypothesis that differentiation at considerable depth may have had some part in the formation of the rocks of the sub-alkaline group provided the process is not extended to account for all of the varieties or phases constituting the Dedham Granodiorite Formation. LaForge's description of the field relations between the gabbro-diorite and the granitic rocks is satisfactory except for the implication that completely gradational contacts exist between diorite and granite as a result of differentiation. Such contacts do exist in numerous localities and are not the result of magmatic differentiation or the separation of a magma into immiscible phases but were formed in completely solidified rock by thermal metamorphism and metasomatic replacement. The rocks in these gradational contacts are not transitional phases between diorite and granite but are hybrids. Magmas do not separate into immiscible phases and that portion of LaForge's hypothesis which proposes the simultaneous intrusion of two such phases is not valid. A discussion of liquid

immiscibility in silicate magmas and the impossibility of immiscible phases developing in such melts is given by Bowen\(^1\).

Crosby observed that occasionally the granitic rocks of this area which are closely associated with stratified rocks possessing a gneissic texture or in his words "traces of stratification". While not believing in the Werner hypothesis of sedimentary origin for granites as apparently did some of his early associates or immediate predecessors, Crosby considered the stratified rocks to have had some part in formation of the gneissic granites. He believed that most of the granite was of "exotic", that is, magmatic origin. Crosby's granite includes all of the Dedham Granodiorite and the intrusive bodies grouped under the name of Quincy Granite.\(^2\)

The hypotheses proposed by Clapp, LaForge and Crosby for the origin of the rocks of the sub-alkaline group are

\(\underline{1. \text{Bowen, N. L., The Evolution of the Igneous Rocks,}}\)

\(\text{Pages 7-19, 1928.}\)

\(\underline{2. \text{Crosby, W. O., Contributions to the Geology of Eastern Massachusetts, Occasional Papers of the Boston Society of Natural History, No. 3, Pages 34-39, 1880.}}\)
those which have been most completely presented in the geological literature covering this area. The writer will now present his own views on this problem. The supporting field evidence was gathered from but a comparatively small portion of the entire outcropping area of the rocks of this group but it is reasonable to expect that this evidence will be found to be typical of the entire area occupied by these rocks, therefore the conclusions reached may be applied to the group as a whole.

Field evidence shows that transitional phases between the rocks of the Salem Gabbro-diorite and the rocks of the Dedham Granodiorite do not exist and furthermore that portions of the granodiorite formation are intrusive into the gabbro-diorite. These circumstances indicate two periods of igneous activity. The magma which formed the Salem Gabbro-diorite was emplaced during the first period and after an interval sufficiently long to have allowed these rocks to become completely solidified a second period of igneous activity produced the Dedham Granodiorite. The time interval between the two periods need not have been long and probably was of short duration.

There seems to be no necessity to question the assumed magmatic origin of the rocks of the Salem Gabbro-diorite and therefore this formation will be considered to have been formed by the emplacement of a molten magma. There was a
minor amount of differentiation within the main mass or masses of this magma which was sufficient to develop a rock series completely transitional from olivine-gabbro to diorite. Nothing is known of possible more acidic differentiates that may have solidified in peripheral dikes or apophyal offshoots from the main batholith because any such minor intrusive bodies have not been preserved. The igneous mass that formed the rocks of the gabbro-diorite formation was in part intrusive into the Westboro and Marlboro Formations and into shaly rocks correlated with the Lower Cambrian Weymouth Formation by the writer. The time of the intrusion was therefore post Lower Cambrian. This magmatic mass does not appear to have been subjected to movements or differential stresses of any considerable magnitude during the period of its solidification as is indicated by an absence of cataclastic textures, late stages of crystallization and the presence of predominately euhedral plagioclase grains in the rocks that have crystallized from it. The rate of solidification was slow enough so that a reaction series could develop between the pyroxene-amphibole minerals and zoned plagioclase crystals were rarely formed. The writer did not find any field or microscopic evidence that would indicate these rocks to be incompletely solidified before the invasion of any younger magmas. The suspended reaction type of thermal metamorphism produced as the first stage of hybridization in
aureoles surrounding younger more acidic intrusives is characteristic of changes produced in solid rock.

The second period of igneous activity resulted in the formation of the rocks comprising the Dedham Granodiorite. It is the writers opinion that a large portion of this igneous formation represents the solidification of a magmatic mass having the formation of a large batholithic intrusion with numerous apophyseal offshoots. Assimilation and metasomatic replacement of pre-existing rocks at the roof of the batholith produced some of the varieties of rock belonging to this formation and the manner in which these developed will be described below. Since there is not any evidence that the magma which formed the rocks of the granodiorite separated from the Salem Gabbro-diorite magma by differentiation in place this hypothesis can be discarded entirely. It is desirable to explain why a large portion of this granodiorite is considered by the writer to have solidified from a magma because of theories postulating the possible origin of granodiorites and granites by processes of granitization in the solid state.

The most widespread evidence of a former magmatic condition for these rocks appears in the almost universal fracturing and brecciation of the component mineral grains which in extreme cases has led to the local development of cataclastic textures. This fracturing and brecciation is
most characteristic of the normal and apophysal phases of the Dedham Granodiorite Formation and may be almost entirely missing from portions of the roof phases. It has no apparent relationship to the joint systems of the rock as a whole.
The fragments into which individual grains have been broken are of all sizes and shapes but usually are extremely angular and show no evidence of being segregated according to size. There is a complete absence of "eyed structures", lenticular fracturing and mylonitization such as would be produced by the development of cataclastic textures in solid rock during the course of regional deformation or localized movements. The brecciated material is always cemented together by a late crystallization of quartz or by a mixture of quartz and potash feldspar which may amount to as much as fifteen percent of the total rock volume. No new minerals have been produced during the course of brecciation. Specimens taken from outcrops showing extreme development of cataclastic textures have exactly the same mineral suites as neighboring rock with only incipient fracturing. Features found in conjunction with the brecciation and fracturing are the bent and twisted twinning laminae of the plagioclase grains and the strain shadows of quartz grains. The individual mineral grains possessing these features were not subjected to a sufficiently great stress to cause fracturing. All of the evidence leads to the conclusion that the fracturing and brecciation could not have
been developed in a completely solid rock. They were
developed in a rock that had nearly completed its crystalliza-
tion but still had enough fluidity to permit some movement
of the mass when subjected to differential pressure. The
abrasive action of grain against grain resulted in the
fracturing and brecciation and at the points where flowage
was greatest cataclastic textures were developed. The older
rocks of the area, notably the Salem Gabbro-diorite, do not
show brecciation of individual mineral grains or bending of
twinning laminae in the plagioclase grains. It is obvious
that the older rocks have not been subjected to the condi-
tions which caused these features in the Dedham Granodiorite.
If these features were the result of deformation in a solid
state then the older rocks closely associated with the grano-
diorite would have acquired them also.

Additional evidence for a magmatic origin of some of
the granodiorite is found in the potash feldspars. These
minerals almost universally have intergrowths of albite that
may amount to any portion up to fifteen percent of the
volume of individual grains. It is entirely reasonable to
assume that the potash feldspar contained this albite in
solid solution at the temperature of the crystallizing
magma. During the course of prolonged cooling the albite
was expelled thus producing the perthitic lamellae.
Vogt\textsuperscript{1} gives the following figures for the solubility of albite in orthoclase:

<table>
<thead>
<tr>
<th>Temperature\textdegree C</th>
<th>% Albite in Orthoclase</th>
</tr>
</thead>
<tbody>
<tr>
<td>850</td>
<td>About 32%</td>
</tr>
<tr>
<td>750</td>
<td>27</td>
</tr>
<tr>
<td>350</td>
<td>14</td>
</tr>
<tr>
<td>15</td>
<td>9</td>
</tr>
</tbody>
</table>

In writing of the exsolution (in the solid phase) of the perthitic lamellae he says, "We emphasize that the formation of the perthitic lamels is a process (exsolution) taking place in the solid phase, owing to the diminished solubility of Ab and An in Or and of Or in Ab + An at decreasing temperatures. These data demonstrate the possibility of albite being expelled from potash feldspars by exsolution in amounts up to fifteen percent of the volume of individual grains.

Finally, there is some evidence of magmatic differentiation within the Dedham Granodiorite Formation. This evidence has been discussed in the descriptions of the Stony Brook variety of the granodiorite and of the aplite veins. The apophysal offshoots such as the s\textsuperscript{2}yenodiorite at Arlington Heights and the red granite stock in Stoneham are believed by the writer to be phases that separated from the

\begin{flushleft}
\end{flushleft}
main magma mass by differentiation. The reasons for this conclusion are given with the descriptions of these rocks.

Since there is substantial evidence to indicate that a large portion of the Dedham Granodiorite was formed by solidification from a magma, a problem arises concerning the source of this magma and its relationship to magmas that produced the other igneous rocks of the area, especially the Salem Gabbro-diorite. Two possible relationships exist. The granodiorite may have solidified from an independent magma that in no way was related to any other magma or it may have solidified from a magma that separated by differentiation and fractionation from a more basic parent magma at a considerable depth below the earth's surface. In the latter case the more basic fractions could have remained in place or could have moved nearer to the earth's surface to form rocks such as the Salem Gabbro-diorite. Differentiation at depth has been suggested by LaForge but, as has already been explained in this report, his method of moving two distinct magma fractions simultaneously as immiscible phases cannot be tolerated in view of the physical chemistry of silicate melts. Knowledge which would permit

a reasonable proof of either of the above two relationships is not available and therefore the problem must be considered on the basis of the chemical compositions of the rocks themselves. Another process by which it is conceivable that the granodiorite could have been formed involves granitization in the solid state. In this case magmatic solutions from a deep seated igneous source could have permeated the overlying rocks and by metasomatic replacement converted them to granitic types. If the deep seated igneous source contributed enough heat the portions of the granitized rock closest to it could have become fluid or truly magmatic. Such a situation would result in rocks showing a gradual transition from the original unaltered rock through phases granitized in the solid state to granitic rock that had been melted and resolidified. In the case under consideration the resolidified rocks would be the portions of the granodiorite showing unmistakable evidence of a former magmatic condition and the granitized rocks would be some of the roof phases of the batholith.

The possibility that the Salem Gabbro-diorite and the Dedham Granodiorite may have been formed by differentiation from a parent magma at depth has been mentioned in previous geological literature therefore the manner in which the two rock types could have been separated requires consideration. The time interval between the two periods of igneous activity that produced these rocks probably was not long. This is a
factor favorable to origin by differentiation and fractionation from a parent magma. If it is assumed that the differentiation was a continuous process during a prolonged period of cooling then a series of intrusive rocks showing a complete transition from olivine-gabbro to granite should be found within the area. Since the possible differentiation and fractionation are assumed to have taken place at considerable depth these transitional rock types would be found in a series of successively younger igneous intrusive bodies with the older having the more basic rocks. This situation possibly may exist to a very limited extent. The first and most basic fractions could have produced the olivine-gabbro of Nahant and the gabbros and diorites of the Salem batholith. The diorite stock in Lexington could represent a fraction more basic than the granodiorite and the red granite stock in Stoneham could be a fraction that separated at about the end of the process. There are rather wide compositional gaps between these rock types thus making the rock series incomplete. The amounts of the different rock types exposed at the surface are not in the proportion that would result from the differentiation and fractionation of a single magma. The rocks of the Salem Gabbro-diorite outcrop over a rather extensive area, intermediate types between the gabbro-diorite group and the granodiorite outcrop in an insignificant area and finally the normal type granodiorite occupies an area
several times greater than that of all the other rocks of the group combined. These circumstances make it necessary to postulate the existence of an entirely different proportion between the rock types at depth in order to adjust the sequence to continuous differentiation and fractionation. Field data obtained from outcrops do not adequately support the hypothesis of differentiation and fractionation as a continuous process at considerable depth.

Since the field relations do not satisfactorily support a hypothesis of continuous differentiation and fractionation for the rocks of the sub-alkaline group it is necessary to investigate other possible processes of differentiation. The principal problem is to determine the process by which a basic magma could be separated into two parts, one of which could solidify to form basic rocks with a low silica and potash content such as those of the Salem Gabbro-diorite group, and the other part could solidify to form more acid rocks with a rather high content of silica and potash such as those of the Dedham Granodiorite group and not produce any types intermediate between these two groups. In describing the formation of magmatic liquids very rich in potash feldspar Bowen suggests processes which might possibly lead to this kind of fractionation. He points out the fact that "orthoclase and albite are preferably regarded as
having a eutectic with extensive solid solutions on either side. The relation between potash feldspar and anorthite requires reconsideration. In the first place it is unlikely that the eutectic, if there were one, would lie very far from orthoclase with its melting point (incongruent) at 1170° and that of anorthite at 1550°. In addition there is much evidence in rocks to suggest, if not to prove, that the relation between orthoclase and basic plagioclase, including anorthite, is not of the eutectic kind. On this basis he describes the mantling of labradorite by orthoclase in rocks from several localities and arrives at the conclusion that orthoclase and basic plagioclase form a reaction series which must disappear when plagioclase of approximately An50 Ab50 is reached, the reason being the eutectic relationship between the albite and orthoclase molecules. Expanding the idea further he is able to draw a ternary diagram of the system orthoclase - anorthite - albite with assumed reaction relation of orthoclase to basic plagioclase and incongruent melting point of orthoclase neglected and demonstrate the formation of a potash rich residual liquid as a solid phase is formed. If this residual liquid is removed from the system by fractionation it can give a solid phase much richer in orthoclase and

albite than the solid phase left behind in the original system. Bowen says "If, therefore, this fractionation took place in a basaltic liquid and was accompanied by that impoverishment of femic constituents and those effects that lead to the formation of free silica, we appear to have the definite possibility of the development of residual liquids of the nature of obsidian". While this is a purely theoretical discussion and obsidian is a much more acidic type of rock than granodiorite it indicates a possible method for the separation of a silica-potash rich magma from a basaltic magma without the development of intermediate phases. The efficiency of the fractionation could determine the composition of the liquid phase being separated. The rocks to which Bowen considers such a process applicable might possibly form relatively small bodies while the granodiorite under consideration is a mass of great extent. The mass of this granodiorite formation is probably a great many times larger than any mass of rock that Bowen may have had in mind. A consideration of the lines of equilibrium on Bowen's ternary diagram shows that the amount of basaltic magma required is several times the volume of the potash-rich phase produced. If it is postulated that the Dedham Granodiorite

magma was produced in some such fashion then it necessarily follows that a tremendous volume of basaltic rock exists at depth, that is, the fractionation has been on a truly gigantic scale. Furthermore, since the rocks of the Salem Gabbro-diorite appear not to have taken part in any such process it is necessary to conclude that the magma producing them was a portion of the parent magma that was injected surfaceward early in the process thus escaping fractionation. In the writer's opinion such a process as is outlined above is purely speculative as the knowledge and data by which it could be proved or disproved is not available. It is used merely to show that the possibility of the Salem Gabbro-diorite and the Dedham Granodiorite having originated from a single parent magma is one that cannot be discarded on the basis of present knowledge.

There is the possibility that the magmas which formed the rocks of the Salem Gabbro-diorite and of the Dedham Granodiorite originated in ways totally unrelated to one another. Since it is apparent that these two magmas originated at considerable depth it is unlikely that field relations existing between the two formations at the surface of the earth will be of any great help in solving the problem. The writer did not observe any field relations that could be useful in this respect. The change in mineralogical
composition from gabbro-diorite to granodiorite is somewhat of the character that could be expected to be the result of differentiation and fractionation. If the true relationship between these two formations is to be determined it will be necessary to obtain data by methods other than field observations. The available visual field data only permit speculation, not proof. Additional data in the form of chemical analyses, identification of possible tracer elements that may have been portioned out among the separating fractions during the course of differentiation and age relations determined by radioactivity methods will be useful in attempting to decide whether the Salem Gabbro-diorite and the Dedham Granodiorite represent some kind of a differentiation series or have been formed from two entirely independent magmas. Such data was not obtained during the course of this investigation.

The possibility that the rocks of the Dedham Granodiorite were formed by granitization in the solid state and then in part were heated sufficiently to attain a magmatic condition likewise cannot be completely proved by field relations alone. Assimilation and metasomatic replacement of pre-existing rocks has been responsible for the characteristics of some of the roof phases of the Dedham batholith and there is some field evidence indicating that these phases grade into rocks that formerly existed in a magmatic condition. Whether this
Magmatic condition was the result of actual melting or of complete solution in magmatic emanations or existed because of a truly magmatic intrusion is not satisfactorily indicated by field data. A more satisfactory solution of this problem might be indicated by data that could be obtained from laboratory tests.

In the preceding discussions and descriptions frequent mention has been made of roof phases of the Dedham batholith that are believed by the writer to have been formed by processes involving assimilation and metasomatic replacement of pre-existing rocks. A brief description of the field relations supporting this belief and of the mineralogical changes that have actually taken place in these rocks is now in order.

In the opinion of the writer the rock in the area covered by this report which has been designated as Newburyport Quartz-diorite by previous geologists is a roof phase of the Dedham batholith. The slightly more basic composition of this so-called quartz-diorite is not the result of its being a magmatic differentiate more basic than the normal variety of the granodiorite as has been claimed by some geologists. This rock has been formed by the metasomatic replacement of basaltic lavas. The magmatic solutions responsible for the replacement were derived from the igneous intrusion forming the Dedham batholith. The basaltic lavas had a more basic composition
than the magma of the batholith, this being the factor which
determined to a large extent the composition of the rock pro-
duced by the replacement. The basaltic lavas that were
replaced were portions of the volcanic flows of the Marlboro
Formation.

The so-called quartz-diorite is found only in close
association with the remnants of the basaltic lava flows of
the Marlboro Formation. The two rocks taken together
form a belt one to two miles in width extending from Sluice
Pond in Lynn through Lynn Woods, North Saugus, Wakefield,
Stoneham, the Middlesex Fells Reservation and ending in
Winchester. Neither type of rock is continuous along the
entire extent of this belt. Large masses of the intrusive
rock interrupt the continuity of outcrops of the basaltic
lavas and small irregular masses frequently project through
the lava flows, the latter being especially abundant in the
north part of the Middlesex Fells Reservation and along
the south side of Stoneham village. The so-called quartz-
diorite always contains inclusions and pendants of the
basaltic lavas. These remnants vary from particles almost
microscopic in size up to masses that may have a surface
area of an acre or more. They are most abundant in the vi-
cinity of large unassimilated areas of the lavas and may
constitute any portion up to fifty percent of the surface
area of outcrops. Such remnants were not found to be absent
from any outcrop examined. Ordinarily these remnants do not
show stratification or flow structure but in the few instances where such features can be found a trend consistent with the regional structure is indicated.

The so-called quartz-diorite is actually a granodiorite and differs but little in composition from the normal variety of the Dedham Granodiorite. In general it is slightly more basic with a larger amount of mafic constituents than the normal variety of the granodiorite. The basaltic lavas can be divided into two main groups. One group consists of rocks having an extremely fine grained pilotaxitic texture and a composition of which labradorite feldspar is the principal constituent, dark colored interstitial glassy material and altered mafites are minor constituents and finely disseminated magnetite is an accessory constituent. The other group consists of amygdaloidal lavas composed of labradorite and a large amount of altered mafites. The so-called quartz-diorite has been more completely described in the section covering the Dedham Granodiorite and the basaltic lavas in the section describing the Marlboro Formation.

The change from basalt to granodiorite can be followed most easily in the replacement of the pilotaxitic lavas. A microscopic study of inclusions of this variety of the basalt taken from outcrops of the granodioritic rock shows that the first stage is mainly one of reconstitution by thermal metamorphism. Rather numerous large plagioclase porphyroblasts
have formed within the lavas. These grains tend to have euhedral shapes, may or may not show albite twinning and do not have bent and twisted twinning laminae. This reconstructed feldspar has the composition of sodic labradorite. Proof that these large plagioclase porphyroblasts have been formed in place in solid rock is furnished by the fact that many of the abundantly distributed minute magnetite grains that lay in the path of the growing feldspar grains were enveloped as they expanded. It is impossible to detect the presence of many of the porphyroblasts in plane polarized light. The thin sections present numerous minute magnetite grains, opaque dust particles and small aggregates of altered mafites quite uniformly distributed throughout a colorless aggregate of feldspar showing but few crystal boundaries. When the nicols are crossed the porphyroblasts with a multitude of opaque inclusions can be seen easily. Simultaneously with the formation of the plagioclase porphyroblasts the dark colored glassy interstitial material is reconstituted to minute greenish hornblende grains. The most advanced stages of the thermal metamorphism have recrystallized the feldspathic constituent into large euhedral grains that have been almost completely cleared of inclusions and have gathered the minute hornblende grains into larger units, some of which are poikilitic. The next stage of the conversion to granodiorite began with the introduction of magmatic solutions which initiated the process of metasomatic replacement. The effects
of this action seem to be confined mainly to the plagioclase grains. The grains of this mineral frequently are clouded by an incipient alteration that produced sericite and a powdery material that cannot be identified. The edges of the plagioclase grains have been attacked by the solutions and tend to be irregular in outline. Albite twinning frequently has disappeared. The alteration has removed some calcium from the plagioclase with the result that the grains now have a somewhat zoned appearance. The fact that the outer edges of the grains have become more sodic is indicated by the lesser rotation required to obtain extinction, this rotation gradually becoming less as successive portions taken in an outward direction from the cores are viewed. Small interstitial grains of quartz and potash feldspar begin to appear and in many specimens a portion of these minerals are present as micrographic intergrowths. More complete replacement has gradually produced rocks approaching the composition and texture of granodiorite. The labradorite feldspar has been converted to andesine. Rather abundant quantities of silica and potash have been introduced. These materials have contributed to the formation of numerous grains of quartz and potash feldspar which tend to be rather small and interstitial to the plagioclase. Hornblende in some cases has been unchanged and in others has been converted to chlorite. Specimens showing all stages of the alteration and replacement can
be collected in several localities. The net result of the metamorphism and replacement has been the conversion of an extremely fine grained pilotaxitic textured basalt into a medium grained granitic textured granodiorite with a loss of calcium and a gain of silica and potash.

The conversion of the amygdaloidal lavas has followed essentially the process outlined above with the exception that there has been more activity among the mafic constituents. The chlorite, epidote and uralite of the altered lavas has been reconstituted to form greenish hornblende and brown biotite. Both of these minerals initially accumulated as aggregates of randomly orientated minute grains, some of which have been preserved and some of which have been changed to chlorite. Many of these aggregates contain numerous minute prisms of apatite which were probably formed from material contained in the original basalt. The amygdaloidal basalts contain a larger proportion of mafic constituents than the pilotaxitic variety and as a result of this difference in composition the granodiorite derived from the former is also richer in mafic constituents.

A characteristic feature of the above process is that there is not a wide transition zone between unaltered basalt and rock having the appearance of granodiorite. Inclusions of basalt frequently have sharp, distinct boundaries and the peripheral portions appear to be unaltered when examined microscopically. Microscopic examination of several specimens indicated that the effects of thermal metamorphism extend for
a distance of several feet into the inclusions. Metasomatic replacement has been confined to the edges of the inclusions. There is not a wide zone of hybridization as is the case where magmatic material from the Quincy Granite has attacked the Salem Gabbro-diorite.

The appearance of the granodiorite, or the so-called quartz-diorite, is not uniform but undergoes a gradual change as the distance from the contact with the basalts increases, that is, in a direction deeper into the batholith. The rock gradually assumes a more equigranular granitic texture and at the same time appears to acquire a slightly greater amount of quartz. These features are presumed to be the results of continued reconstitution and replacement after the rock had attained the composition of a granodiorite. Microscopic examination of specimens of this rock from deeper portions of the batholith shows that it contains some large grains of orthoclase. In contrast to the normal variety of the Dedham granodiorite the plagioclase grains rarely show bent and twisted twinning laminae. Also, the quartz grains are rarely fractured and usually have a sharp clear extinction although in some cases faint strain shadows can be found. Cataclastic textures have not been developed. These differences indicate that the rock of this particular portion of the Dedham batholith has not been subjected to the same kind of stresses as has the normal variety of the granodiorite. It lacks those
effects that can be attributed to the deformation of a partially solidified magma mass. This fact substantiates the hypothesis of origin by metasomatic replacement for this variety of the Dedham granodiorite. Outcrops indicating the exact relationship between this so-called quartz-diorite and the normal variety of the granodiorite are not exposed in the area investigated. In the south part of Stoneham there appears to be some interfingering of the two varieties of the granodiorite. This locality lies along the contact of the Westboro and Marlboro Formations and the apparent interfingering could be the result of metasomatic replacement of a few alternating strata of quartzite and basalt with corresponding differences in the character of the granodiorite produced. The usual relations existing between the two older stratified formations are not favorable to the possibility that quartzite and basalt were deposited in alternating strata. Dike-like masses of magmatic material may have invaded the roof phase of the batholith that had been formed by metasomatic replacement and thus produced an apparent interfingering of two varieties of the granodiorite. These outcrops are too small to satisfactorily indicate the relationship between the two varieties of the granodiorite.

The micrographic granodiorite of Malden and Medford is also considered by the writer to be a roof phase of the Dedham batholith that was formed by metasomatic replacement of a
pre-existing rock. This variety of the granodiorite outcrops within a belt that is consistent with the regional trend of the remnants of the older stratified formations. In this case there are not preserved any sizable remnants of the replaced rock that would exactly indicate its original character. The only remnants are small inclusions that appear to have been completely reconstituted by thermal metamorphism and partially altered by metasomatic replacement. The present mineralogical composition of these inclusions is predominately plagioclase feldspar which is accompanied by minor amounts of hornblende, magnetite and apatite. Large porphyroblasts of plagioclase have developed within these inclusions and quartz and potash feldspars are absent. This composition would seem to indicate that the replaced rock was highly feldspathic, possibly a basaltic lava poor in mafic constituents. The micrographic granodiorite possesses some features that are similar to those of the so-called quartz-diorite. The large plagioclase grains show a transitional zoning that has been produced by the extraction of calcium from their outer edges. In the stratigraphically highest part of this rock which outcrops along the north side of the belt, quartz and potash feldspars tend to be present as small interstitial grains. The amount and grain size of these constituents increases geologically downward. Fractured grains, undulatory extinction and bent twinning laminae in the plagioclase feldspar become noticeable only in the lower portions of this
rock, that is, in specimens taken from outcrops along the south side of the belt. Simultaneously with the appearance of the cataclastic features orthoclase grains begin to show some perthitic lamellae indicating that this portion of the rock once existed at a high temperature. In the south end of the Middlesex Fells Reservation the micrographic variety appears to grade into the normal variety of the granodiorite.

Evidence furnished by the micrographic and Newburyport Quartz-diorite varieties of the Dedham Granodiorite indicates that this igneous formation replaced considerable thicknesses of lavas or possibly other kinds of igneous rocks by metasomatic replacement. The method by which it invaded the quartzites now becomes of interest. The best exposures showing relationships between the granodiorite and the quartzites are found in the south part of the Middlesex Fells Reservation, in the area surrounding Stevens Pond in Saugus and on the south part of Marblehead Neck. Dikes of the normal variety of the granodiorite are found cutting the Westboro Quartzite near the contact of the two formations between Spot Pond and the South Reservoir of the Winchester Water Works in the Middlesex Fells Reservation. This feature shows that magmatic material having the composition of the granodiorite invaded the quartzite. In the vicinity of Stevens Pond and on the south part of Marblehead Neck inclusions of micaceous quartzite are extremely abundant in the normal variety of the granodiorite. The writer considers these areas to be near the roof
of the batholith. Stratification in the larger of these inclusions tends to be consistent with the regional trend but in the small members erratic altitudes are observed. There has been but little alteration in the quartzites. The small amount of material other than quartz and detrital feldspar generally has been converted to micas. There is but little evidence of replacement other than that which has taken place at the extreme edges of the inclusions. The granodiorite of these localities possesses the typical characteristics of the normal variety found elsewhere. Microscopic examination of a specimen taken from the midst of several inclusions on Marblehead Neck showed it to have a slight fracturing of the component grains and some strain shadows but no bent twinning laminae in the plagioclase grains. Examination of specimens taken from points a short distance away where inclusions are not as numerous showed them to have strong development of all these features and also some development of cataclastic texture with a late crystallization of quartz and potash feldspar. These observations are evidence of the former magmatic condition of the granodiorite at those portions of the roof of the batholith that were formed by quartzites. All of the above described features indicate that the highly quartzitic rocks were not readily susceptible to metasomatic replacement and alteration by solutions from the granodiorite magma. The method of emplacement was principally one of 'stoping with but minor assimila-
tion and replacement of the quartzites in their original positions.

The Stony Brook variety of the granodiorite is considered by the writer to be a differentiate that solidified near the roof of the batholith. Its composition and the presence of cataclastic features is favorable to this hypothesis. Inclusions of older rocks are rare in this variety of the granodiorite, a situation that is not characteristic of the varieties presumed to have been formed by metasomatic replacement. Other varieties of the granodiorite such as the sennydiorite at Arlington Heights, the red granite of Stoneham and the aplite dikes are of unquestionable magmatic origin.

The writers observations and conclusions regarding the rocks of the sub-alkaline group are summarized briefly in the following manner. Two distinct periods of igneous activity are represented. During the first period the Salem Gabbro-diorite was emplaced as a batholithic magmatic intrusion. There was some differentiation within the magma mass or masses of this intrusion. This differentiation produced a rock series that shows a complete transition from olivine-gabbro to diorite. The Dedham Granodiorite batholith was emplaced during the second period of igneous activity. There is not any evidence to support the conclusion reached by some previous geologists that the rocks of the Salem Gabbro-diorite and the Dedham Granodiorite form a completely transitional
differentiation series with the differentiation having taken place in essentially the position now occupied by these rocks. The available field evidence will not permit any definite conclusions as to whether or not the gabbro-diorite and the granodiorite can be fractions of a single magma that differentiated at a great depth. The time interval between the two periods of igneous activity probably was not long but was of sufficient duration to have permitted the older gabbro-diorite to have become completely solidified. The emplacement of the Dedham batholith was a complex process. The main mass of the batholith formerly existed in a magmatic condition and is composed of the normal variety of the granodiorite. Along some portions of the roof the batholithic invasion progressed by metasomatic replacement and alteration of pre-existing rocks. This method was especially effective against igneous rocks, notably the basaltic lavas of the Marlboro Formation. The roof phase of the batholith produced by the replacement of these basalts is a medium grained granodiorite that has been designated as Newburyport Quartz-diorite by previous geologists. This particular variety of the granodiorite is not a phase transitional between Salem Gabbro-diorite and Dedham Granodiorite as has been claimed by some geologists. Other less extensive varieties of the granodiorite have also been produced by metasomatic replacement. The varieties that have been produced by metasomatic replace-
ment apparently grade downward into the normal variety of the granodiorite indicating that these roof phases became at least partially fluid at depth. The method of emplacement employed against highly siliceous rocks was principally one of stoping since these rocks were not readily susceptible to metasomatic replacement. Apophysal offshoots from the main batholithic mass account for small isolated intrusions of igneous rocks closely related to the granodiorite. Some differentiation took place within the main batholithic mass and produced the Stony Brook variety of the granodiorite and the magmatic material that solidified in aplitic dikes. The granodiorite batholith was injected under considerable pressure, probably during a major orogenic movement. This condition has been made evident by flowage within the partially solidified magma that produced cataclastic features and textures. Such movements did not affect the roof phases of the batholith that were formed by metasomatic replacement and never became fluid. Cataclastic features have not been developed in these roof phases.
HYBRIDIZATION OF THE SALEM GABBRO-DIORITE

In the section describing the Salem Gabbro-diorite it was stated that the rocks of this formation have been preserved in an original unaltered condition only in small localized areas. Most of these rocks have been altered to some degree by invasions of younger more acidic magmatic material with the result that "hybrid" types have been produced. This alteration generally is most intense in the immediate vicinity of plugs, bosses or stocks of granitic rocks formed within the gabbro-diorite and becomes progressively less noticeable as the distance from these plutonic bodies increases. The areas of hybridized rocks are easily recognized in the field. Ordinarily the outcrops of the hybrids are cut by numerous dikes, veinlets and irregular masses of the younger intrusive rock. The originally dark colored gabbroidic or dioritic rock shows a progressively more intense alteration as the bulk of these minor intrusive bodies increases, changing from the normal type gabbros and diorites with predominately ophitic textures to rocks with granitic textures and containing abundant grains of white or pink weathering feldspars. The initial introduction of igneous material into the Salem Gabbro-diorite seems to have been along joints and fractures, a probability indicated by patterns of intersecting dikes and veinlets which unquestionably form intricate networks extending considerable distances from the main granitic plutonic bodies.
At the outer limits of these networks where likes and veins are not numerous there has been but little change in the gabbro-diorite that can be detected by megascopic examination. Close to the granitic plutonic bodies the effects of alteration and replacement of material become easily noticeable. The hybrid rocks have mineralogical compositions that are not consistent with those of any normal types of igneous rocks crystallizing from magmas. These compositions vary from one locality to another, from outcrop to outcrop, and even in different parts of a single outcrop. Labradorite, pyroxenes, hornblende, biotite, microperthite, orthoclase, quartz, magnetite and apatite may be found in varying amounts in specimens of the hybrid rocks.

The hybrid rocks under consideration represent contact metamorphic phases produced in the Salem Gabbro-diorite by the masses of younger more acidic igneous rocks that have invaded this formation. The processes that have been involved are thermal metamorphism and metasomatic replacement. The thermal metamorphism in this case is that of a suspended reaction type. The mineral assemblage of the normal gabbros and diorites becomes a metastable association at temperatures lower than that at which the rocks solidified, therefore, a moderate reheating of the mass results in a resumption of the normal sequence of changes taking place in the reaction series of the pyroxene-amphibole minerals and the plagioclases, the
changes being towards attainment of equilibrium at the lower temperature. Such processes are described by Harker. All of the changes that have taken place in the hybrid rocks could not have been produced by either thermal metamorphism or metamorphic replacement acting alone. All of the changes described below were made while the rocks were in a solid state and at no time did any portion of them become fluid because of being melted by heat from a nearby igneous source. These changes and alterations are not to be confused with the assimilation of xenoliths in the borders of magma masses or with assimilation of wall rock by magmatic material in the process of forming dikes. Absorption of the gabbro-diorite by reaction processes along the borders of the granitic intrusive bodies has taken place to some extent but has not been a factor in producing the hybrid rocks being described.

Several localities of hybridized Salem Gabbro-diorite were found in the area covered by this report. These localities include a belt extending from the shore line of Marblehead southwestward through Clifton village to the south shore of Swampscott, a belt in Winchester and Arlington along the north side of the north boundary fault of the Boston basin, a similar belt in Waltham, Weston and Wellesley and a wide belt extending

from Woburn Center southwestward through Horn Pond Mountain to Mt. Gilboa in Arlington. The younger igneous rocks responsible for the hybridization are phases of the Quincy or Peabody Granites and the Dedham Granodiorite. Field evidence indicates that the granites and the more acid phases of the granodiorite, that is the magmas that were richest in potash feldspars were the most effective in producing hybrid rock types in the gabbro-diorite.

The Marblehead-Swampscott locality was selected as a source of material for studying the mineralogical changes during the process of hybridization. In this area the gabbro-diorite has been invaded by numerous stocks, plugs, dikes and veins of apophysal varieties of the Peabody and Quincy Granites. The structural features which have permitted this invasion will be described in another section and for the present discussion it is sufficient to state that the granitic magma invaded the older basic rock. The mineralogical composition and textural features of the rocks of the Salem Gabbro-diorite formation indicate that this igneous mass had become completely solidified and quite probably had attained a temperature considerably lower than that of the granitic magmas before being invaded. Remnants of the original unaltered gabbro show a coarse grained, ophitic textured rock consisting of euhedral calcic labradorite, large euhedral interstitial pyroxenes and minor green hornblende, brown biotite, apatite, magnetite and olivine. The pyroxenes contain clouds of minute orientated needles of a black opaque
mineral and occasionally are surrounded by narrow reaction rims of green hornblende. The diorites also have an ophitic texture and a composition consisting of sodic labradorite or calcic andesine and green hornblende predominant over pyroxenes. A series of selected specimens ranging from the unaltered gabbros and diorites to hybridized rocks having little resemblance to these original rocks was studied to determine the successive mineralogical changes that took place during the process of hybridization.

The initial changes of the hybridization process were produced by thermal metamorphism and are more noticeable in the gabbros than in the diorites. The progress of these changes was observed by studying a sequence of specimens taken from points beginning within the unaltered rock and constantly approaching intrusive plutonic bodies of granitic rock, that is, in the direction of increasing temperature caused by the younger igneous rocks. It is necessary to postulate that the gabbros, and also the diorites, solidified at a high temperature, were cooled and then were reheated to some extent by nearby granitic magmas in order to explain these changes. The assemblage of minerals constituting these rocks existed in a state of stable equilibrium at the temperature at which it crystallized but is metastable at temperatures ordinarily existing near the earth's surface. The initial step in the hybridization process was a partial reconstitution of the original mineral assemblage towards a mineralogical composition
that would be in equilibrium at the temperature to which the basic rocks had been heated by the nearby granitic magmas, that is, a suspended reaction type of alteration.

The two minerals that were most involved in the initial reconstitution were the labradorite and the pyroxene which are the essential constituents of the gabbroidic phase of the formation. This pyroxene is a pigeonite having a small optic angle and therefore is probably near clino-enstatite in composition, having a high magnesium content and a low calcium content. The larger grains have a pinkish core filled with clouds of minute black needles. The first effects of the thermal metamorphism are to eliminate the pink color and to gather the black needles into a considerably smaller number of minute granules. The next stage is the appearance of minute shreds and flakes of green hornblende at randomly scattered points within the pyroxene grains. At the same stage the plagioclase begins to be clouded by incipient alteration. In some cases the alteration product seems to be an extremely fine flaky sericite. More often the plagioclase is clouded by an extremely fine granular material that is colorless or very faintly greenish, shows first order interference colors and is much too fine to permit definite identification. As the metamorphism proceeds large poikilitic grains of green hornblende replace the pigeonite. These grains were formed by the enlargement and joining together of the initial flakes and shreds of this mineral. In some cases the twinning laminae of the plagioclase grains begins to disappear and individual grains begin to
merge into one another, losing their common boundary. There probably has been some transfer of calcium from the plagioclase to the newly formed hornblende. There has not been any development of epidote or calcite in grains large enough to be identified. In some more cases pyroxene grains lying adjacent to large magnetite grains have been altered to a dark reddish brown biotite. Further metamorphism has caused the development of numerous euhedral grains of green hornblende which largely have been cleared of inclusions. The pyroxene has disappeared almost completely with the only small remnants remaining being enclosed completely in hornblende grains. At the same stage the plagioclase has lost most of its original crystal boundaries and twinning laminae and has developed more equant anhedral shapes. These newly developed feldspar grains tend to be clear, colorless and untwinned. Olivine disappeared early in the above process and apatite appears to have passed through it unaffected. There is some tendency for magnetite granules to gather into larger grains.

Metasomatic replacement appears to have locally entered into the process of hybridization during all but the initial stage of thermal metamorphism with the controlling factor having been the accessability of the original rock to the invading magma. Rapid penetration of magmatic material along joints and fractures permitted metasomatic replacement to begin locally during the early stages of thermal metamorphism and allowed the two processes of alteration to
proceed more or less simultaneously. The principal effects of metasomatic replacement are the introduction of potash and silica and the probable elimination of some calcium. The potash appears in new feldspathic constituents with microperthite seemingly to be always present and orthoclase being found in some specimens and not in others. Quite frequently the magmatic solutions have attacked plagioclase grains and formed a rim of microperthite about a residual core of albite twinned plagioclase. Calcium presumably has been removed entirely from the rock during this process since new calcium-bearing minerals have not appeared. Some specimens of the hybridized rocks show an initial concentration of small interstitial orthoclase and quartz grains along veinlet-like courses or at randomly scattered points. More intense development of metasomatic replacement has increased the amount of potash bearing feldspars and quartz and tended to the alter completely the composition and boundaries of the plagioclase grains. Mineral constituents other than plagioclase apparently have not been affected by metasomatic replacement. In the advanced stages of this alteration the rocks assume typically granitic textures in which the only euhedral crystal forms are those of hornblende and apatite.

The truly hybrid rocks in the Marblehead-Swampscott portion of the Salem Gabbro-diorite Formation have been produced by a combination of the two processes described above.
in these rocks thermal metamorphism has been most effective in reconstituting the mafic constituents while metasomatic replacement has been responsible for much of the alteration of the plagioclase, for the introduction of potash and silica and probably for extraction of some calcium. Some amount of thermal metamorphism, even though it may be incipient, has always preceded metasomatic replacement. Those portions of the gabbro-diorite which have been partially reconstituted by thermal metamorphism but have not been altered by metasomatic replacement cannot be considered to be hybrid rocks.

Specimens of hybrid rocks showing a great variation in mineralogical composition can usually be collected from a single large outcrop, therefore it is not practical to attempt to estimate an average mineralogical composition for these rocks. If the processes involved in this hybridization of the Salem Gabbro-diorite had been carried to completion it is reasonable to assume that a typical hornblende granite would have been the final product. In this case the granite would have microperthite or orthoclase, hornblende and quartz as essential constituents and biotite, magnetite and apatite as accessory constituents.

Field evidence indicates that hybridization of the Salem Gabbro-diorite Formation has been most intense in the areas surrounding intrusions of true granites or the most potash rich phases of the Dedham Granodiorite. A consideration of
the composition of the normal variety of the granodiorite will indicate why this feature should be characteristic of the hybridization. The normal variety of the granodiorite is composed largely of plagioclase having the composition of calcic andesine and has as relatively minor constituents quartz and potash bearing feldspars. A magma rich in constituents tending to crystallize as calcic andesine cannot produce much alteration in a rock having a slightly more calcic plagioclase as its principal constituent and would be likely to produce stocks, plugs and dikes in the rock that it is invading. This result is typical of the manner in which the normal variety and other more basic phases of the Dedham Granodiorite have invaded the Salem Gabbro-diorite.

The writer has made a detailed study of only one area of hybridized rocks found within the Salem Gabbro-diorite Formation but believes the processes involved in the hybridization and the results obtained to have been essentially the same for all areas. The appearance of outcroppings and the macroscopic characteristics of these hybrid rocks are nearly identical for all areas in which they are found.
HYBRID ROCK OF LITTLE NAHANT

The rock outcropping at Little Nahant, with the exception of intrusive dikes and small roof pendants of stratified sedimentary rocks, is a hybridized mass that was formed by the action of silica and potash rich magmatic solutions upon a gabbro or a diorite. A separate description of this hybridized rock is being given because the outcrops of it have a quite uniform appearance over the entire extent of Little Nahant and its composition is somewhat different from that of other hybridized rocks found in the area investigated. Clapp \(^1\) correlated this rock with the Nahant Gabbro which he considered to be a distinct unit while LaForge \(^2\) placed it in the group of basic rocks comprising his Salem Gabbro-diorite Formation, a group which also includes the Nahant Gabbro.

Megascopic examination shows this hybridized rock to have a medium grained granitic texture with a moderate variation in grain sizes. It is rather dark colored, having a mottled appearance caused by an intimate mixture of greenish, white and reddish mineral constituents. Weathered outcrops

---


have a finely pitted surface suggestive of selective extraction of some mineral constituent by weathering processes.

Thin sections of this hybridized rock when examined under the microscope exhibit a rather thoroughly mixed assemblage of original, alteration and introduced mineral constituents. Even though the original constituents to a large extent have been altered or reconstituted to form other minerals it is still possible to make a close estimate of the character of the original rock as it existed prior to hybridization. This rock was composed of labradorite having the shape of long euhedral laths as the principal constituent, a monoclinic pyroxene in smaller quantity and magnetite and apatite as minor accessories. Green hornblende and a brown biotite may have been original minor constituents but since both of these minerals have developed during the course of hybridization it cannot be certain that they have always been present in the rock. The original unaltered rock was therefore a gabbro having a coarse grained ophitic texture. Its present composition would seem to indicate that this rock was slightly less basic than the Nahant Gabbro but because of the apparent approximate similarity in mineralogical composition and close proximity of the two outcropping areas the writer is inclined to believe that the rock of Little Nahant was a portion of the Nahant Gabbro.

The processes that were involved in the hybridization of
this gabbro were hydrothermal alteration and metasomatic replacement. Any preliminary changes that may have been the result of thermal metamorphism are not now noticeable because of much greater changes produced by the later processes of alteration. Because Little Nahant is virtually a small island any outer aureole in which the only changes in the mineralogical composition of this rock might be attributed to thermal metamorphism is not exposed.

The plagioclase constituent which seems to have had the composition of calcic labradorite and which formed more than half of the volume of the original gabbro has been extensively altered. The most abundant alteration product formed from it is a fine, flaky sericite that almost completely clouds many of the grains. Other plagioclase grains do not show sericitic alteration but contain as inclusions small granules of epidote and flakes of chlorite. The plagioclase has also been attacked by solutions which have corroded and altered the edges of many grains. This action has caused the twinning laminae to disappear and in some cases has produced a mantle of microperthite surrounding a core of albite twinned plagioclase. Such grains do not show a sharp boundary between the two varieties of feldspar, thus indicating an extraction of calcium and substitution of potash. The original pyroxene has been almost completely altered and could not be positively identified in any of the thin sections examined.
The first alteration product that was formed from the pyroxene seems to have been a green hornblende as anhedral, poikilitic grains. This hornblende in turn has been almost completely altered to chlorite. In the vicinity of magnetite grains a brown biotite has developed more often than chlorite. Some small grains of hornblende, now almost completely altered to chlorite, and of biotite are randomly scattered throughout the rock. There is not enough evidence to indicate whether these grains are original mineral constituents of the rock or have been formed during the course of hybridization. The alteration and reconstitution was not carried to the point where hornblende could assume euhedral shapes.

The minerals introduced into the rock consist of small interstitial grains of quartz having sharp extinctions and potash feldspars. The potash bearing feldspars appear as microperthite alteration mantles surrounding remnants of plagioclase grains, as small grains of microperthite and orthoclase and as small grains of a micrographic intergrowth with quartz. Weathering causes these feldspars to become reddish in color.

Calcite appears as a rather abundant secondary or alteration mineral in the hybridized rock. It is present in grains varying in size from minute granules up to some of the largest individual particles in the rock. This mineral presumably was formed by hydrothermal processes with calcium extracted.
from the plagioclase and carbon dioxide contributed by magmatic solutions. Solution of this mineral by surface waters could account for the pitted surfaces of outcrops. Tiny grains of epidote are also distributed throughout the rock. This mineral likewise probably was formed by hydrothermal alteration but not as abundantly as calcite.

Apatite has passed through the hybridization processes unaffected in any manner.

The hybridized rocks of Little Nahant have a rather uniform character over the entire extent of the outcropping area. A rough approximation of the mineralogical composition of these rocks is as follows:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plagioclase</td>
<td>50%</td>
</tr>
<tr>
<td>Microperthite</td>
<td>12%</td>
</tr>
<tr>
<td>Chlorite</td>
<td>10%</td>
</tr>
<tr>
<td>Quartz</td>
<td>7%</td>
</tr>
<tr>
<td>Calcite</td>
<td>6%</td>
</tr>
<tr>
<td>Epidote</td>
<td>4%</td>
</tr>
<tr>
<td>Biotite</td>
<td>4%</td>
</tr>
<tr>
<td>Apatite</td>
<td>2%</td>
</tr>
<tr>
<td>Sericite</td>
<td>2%</td>
</tr>
<tr>
<td>Pyroxene</td>
<td>1%</td>
</tr>
<tr>
<td>Hornblende</td>
<td>1%</td>
</tr>
<tr>
<td>Magnetite</td>
<td>1%</td>
</tr>
</tbody>
</table>

The estimated quantity of plagioclase is probably too high because a large amount of quite thoroughly altered material is
included in the above figure. This composition should not be used in an attempt to classify the rock as to a particular type because of the mixture of original, alteration and secondary minerals represented in it.

The magmatic material responsible of the hybridization of the rocks at Little Nahant was most likely derived from an apophysal phase of the Quincy Granite. Granitic rocks of this kind have invaded the gabbro along the north shore of Nahant within a distance of one-half mile of Little Nahant and extend under the bay between the two land areas.
are not recrystallized micaceous sandstones. 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.\(^1\)

The writer could not find any basis in the field relations, mineralogical compositions or degree of metamorphism of these rocks that would justify either the grouping under a new formation name or the possibility of a Pre-Cambrian Age. The writer is of the opinion that these rocks are not the remnants of a Pre-Cambrian formation but are parts of various younger formations that have been erroneously identified and furthermore considers that there is not any basis for the use of the name "Waltham Gneiss". On his map LaForge indicates the rock of three localities to be Waltham Gneiss. These localities are located in the northern part of the town of Waltham, in the southeastern part of Lexington and Burlington and a small area in Woburn lying to the east of Blueberry Mountain.

---

DISCUSSION OF THE ROCKS CALLED WALTHAM GNEISS

Some rocks which LaForge considered to be of probable Pre-Cambrian age have been described briefly by him under the name of Waltham Gneiss. His description implies that the rocks which he groups under this formation name may be older than all others found in the general area. In describing these rocks LaForge says of them, "The formation occupies much of northern Waltham, southeastern Lexington and Burlington, and northwestern Woburn. It is a complex of gneisses of several sorts and is probably mainly igneous.----- The formation comprises several varieties of biotite 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
The rocks in the northern part of Waltham that LaForge places in his Waltham Gneiss Formation are actually remnants of the Westboro and Marlboro Formations and there is also the possibility that some may be remnants of the Woburn Formation. This locality appears to represent a roof phase of the Salem Gabbro-diorite batholith that contains numerous inclusions and pendants of the older stratified rocks. Most of these remnants of the older rocks have been reconstituted by thermal metamorphism and slightly altered by metasomatic replacement with the result that they are now quartzites, micaceous quartzites, quartz-mica schists and plagioclase-amphibolites. Some of these remnants have retained the original stratification. Microscopic examination of several specimens of these rocks collected by the writer showed them to be similar to thermally metamorphosed remnants of the Cambrian stratified formations found elsewhere. Some of the remnants found in the Waltham locality are now quartz-biotite schists which the writer considers to be thermally metamorphosed argillaceous sandstones and are similar to some of the remnants of the Westboro Formation found in Saugus and Lynn. Some of the rocks, which according to LaForge have the appearance of originally having been amygdaloidal lavas, are most likely the least metamorphosed remnants of the basaltic lavas of the Marlboro Formation while the more thoroughly metamorphosed remnants are probably his hornblende gneisses. Remnants of the basaltic
lavas can be traced from the Waltham locality northeastward to the large outcropping area of the Marlboro Formation in Stoneham and Wakefield. All of these remnants are older than the Salem Gabbro-diorite and do not possess any features different from those of the metamorphosed remains of the Cambrian stratified formations found elsewhere. The remains of the older rocks and also the Salem Gabbro-diorite have been invaded by younger granitic magmas that produced numerous dikes and veinlets, some of which have aplitic textures. These younger intrusive bodies are probably the rocks referred to as aplitic varieties of the gneiss by LaForge. Although LaForge does not mention the localities where the different varieties of rocks included in his Waltham Gneiss can be found some of his very brief descriptions of the mineralogical and textural features of these rocks are satisfactory insofar as they apply to the Waltham locality. He apparently underestimated the significance of the thermal metamorphic changes produced in the remains of the Cambrian stratified formations by heat from adjacent large igneous intrusions.

Two types of rocks are found in the Lexington-Burlington locality indicated to be Waltham Gneiss by LaForge. One type consists of small remnants of the Cambrian stratified formations. Portions of the basaltic lavas of the Marlboro Formation that have been thermally metamorphosed to plagioclase-amphibolites are most numerous among these remnants while the remainder consist of micaceous quartzites.
The other type of rock found in the Lexington-Burlington locality forms the greater part of Greenleaf Mountain and a large area extending to the northeast and also Winn Hill and several smaller outcroppings in the vicinity. Several small masses of this rock are intrusive into the Salem Gabbro-diorite on the north side of Whispering Hill at a short distance to the southward in Woburn. This rock is rather dark colored, medium to coarse grained, is porphyritic and has a pronounced foliation with a consistent northeast-southwest strike and a steep northwestward tip. Microscopic examination of a few specimens of this rock showed that the composition varies slightly from one group of outcrops to another. The phenocrysts tend to be arranged in layers thereby producing the foliation and are composed of orthoclase, plagioclase varying in composition from oligoclase to andesine and occasionally quartz. Some specimens show orthoclase to be predominant over plagioclase while others show the reverse situation. A conspicuous feature of the phenocrysts is that they have been rounded into roughly spherical shapes apparently by a process of abrasion. The plagioclase phenocrysts frequently show bent twinning laminae and the quartz has strong strain shadows while phenocrysts of all minerals are usually fractured. The fine grained groundmass has a micro-structure suggestive of well developed flow banding of volcanic rocks. A fine grained greenish brown biotite is a principal constituent of the groundmass.
This biotite appears as numerous nearly parallel orientated flakes and also forms closely adhering envelopes around many of the phenocrysts. Because of its abundance and uniform distribution the biotite causes these rocks to have a dark color. Fine grained quartz and orthoclase are the other principal constituents of the groundmass while magnetite, pyrite, apatite, calcite and epidote are minor constituents. The minerals comprising these rocks are for the most part clear, fresh and unaltered with only a few feldspar grains showing traces of an incipient sericitic alteration. The mineralogical assemblages of the few specimens of this rock examined by the writer are characteristic of biotite granites or acidic granodiorites depending upon the relative proportions of potash and plagioclase feldspars. These rocks are considered by the writer to be of igneous intrusive origin. They do not show any signs of either thermal or regional metamorphism and do not contain minerals other than a minute quantity of calcite, epidote and sericite that can be attributed to a metamorphic origin. These rocks are younger in age than the Salem Gabbrodiorite. The presence of a large amount of mica and generally abundant orthoclase and oligoclase suggests an origin from a magma associated in some way with the Andover Granite which forms a large batholithic mass lying a short distance to the north and northwest of the locality under consideration. This porphyritic foliated rock may be an injection gneiss in which
In the writer's opinion all of the rocks constituting LaForge's Waltham Gneiss can be correlated with the other formations of the area. None of these rocks possess features that set them aside as a separate group. The name Waltham Gneiss should be discontinued for the reason that it cannot properly be applied to a distinct lithologic unit.
the textural features and foliation were developed during the intrusion of a magma under great pressure. Such rocks are described by Harker.¹ A few fine grained inclusions or roof pendants having elongate tabular shapes that parallel the foliation of the igneous rock were found. The rocks of these inclusions have been thermally metamorphosed and partially altered by metasomatic replacement and are essentially plagioclase-amphibolites containing a small amount of biotite and orthoclase. They are probably remnants of the Marlboro Formation. If the intrusive rock just described is related to the Andover Granite then it must be of late Carboniferous age. The writer did not notice anything in its character to suggest that it is a Pre-Cambrian rock.

The rock outcropping in the small area to the east of Blueberry Mountain in Woburn is a complex of Salem Gabbro-diorite, hybrid rock types and younger granitic intrusions. Much of it has a gneissic texture and a mineral assemblage characteristic of the hybrid rocks found elsewhere in the area investigated. The writer did not notice any features during the course of a field inspection that would suggest these rocks to represent anything other than a typical hybridization of the Salem Gabbro-diorite by a younger granitic intrusion.

MIDDLE PALEOZOIC VOLCANIC ROCKS
Three groups of volcanic rocks of Devonian or Carboniferous age are found in the area surrounding Boston. The flows of two of these groups, the Lynn and the Mattapan Volcanics, were accumulated upon an erosional surface of the Dedham Granodiorite and remnants of the Cambrian stratified formations. The rocks of the third group, the Brighton Volcanics, are of somewhat later age and are interbedded with the Late Paleozoic sedimentary strata of the Boston basin. All of these volcanic rocks are restricted to comparatively localized areas. The Lynn and the Mattapan Volcanics were erupted under apparently identical conditions and may be contemporaneous.
LYNN VOLCANICS

The rocks of the Lynn Volcanics were first called petroliolex and then felsites by the older geologists. The name "Lynn Volcanics" was first applied to this formation by Clapp. Almost all of the formation lies within the area covered by this report. Large outcroppings of these volcanic rocks lie within a belt two to three miles in width extending from the eastern part of Lynn through Saugus and Malden to Medford. Other extensive outcroppings are found in a narrower belt extending through North Saugus and the south parts of Wakefield and Stoneham. The volcanic rocks forming the north half of Marblehead Neck are also presumed to be a part of this group of flows. The outcrops at the extreme northern tip of Marblehead Neck form the only portion of the Lynn Volcanics lying outside of the area mapped during the course of this investigation.

The basal flows of the Lynn Volcanics were erupted upon an erosional surface, the greatest part of which exposed rocks of the Dedham Granodiorite batholith and the remainder exposed remnants of the Cambrian stratified formations. A great unconformity exists between the eruptive rocks and the older igneous intrusive rocks and their inclusions and pendants.

of stratified formations. The basal flows contain considerable fragmental detritus derived from the older rocks. This fragmental material varies in size from small granules to boulders fifteen or twenty feet in diameter and is composed predominately of the variety of the older rock underlying the flows in the particular locality in which it is found. Pebbles and boulders of the normal variety of the Dedham Granodiorite are found in many of the outcrops of the volcanic rocks in West Lynn and Saugus. Boulders of an unusually great size are found in the basal flows near the contact of the two formations on the north side of Vinegar Hill in Saugus. Fragments of the Newburyport Quartz-diorite variety of the granodiorite are found in the basal flows near the contact of the formations in the Lynn Woods and fragments of the Westboro Quartzite are found in the volcanic rocks outcropping in the Maplewood section of Malden and near the top of Mt. Hood in Melrose. All of this foreign material is presumably surface detritus picked up by the lavas as they flowed over an erosional terrain. The unconformable contacts between the volcanic flows and the older rocks are exposed in several localities. Contacts of the volcanic rocks with both the normal variety of the Dedham Granodiorite and the Westboro Quartzite are exposed in the south part of the Breakheart Reservation in North Saugus while at the north part of the same reservation contacts with the Newburyport Quartz-diorite variety of the granodiorite are found. Contacts of
the volcanic rocks with remnants of the Marlboro Formation are exposed east and northeast of Griswold and Spring Ponds in North Saugus. Numerous other localities in which contacts of the volcanic rocks with various older formations are exposed could be listed.

All of the rocks of the Lynn Volcanics appear to be of terrestrial deposition. Portions of the formation that could be attributed to water laid deposition of volcanic ash or tuff were not found by the writer although some geologists have stated such strata exist. Specific locations in which supposedly water laid material can be found are not mentioned in any reports therefore the writer doubts the existence of such strata. All of the rocks have solidified from lavas. Localized portions of the formation containing considerable amounts of agglomeritic breccia of possible explosive origin are found. The matrix of these agglomerates always seems to have been a lava. Outcrops of such rock are found in the Franklin Park section of Revere and south of Lynnhurst. The fragmental material in outcrops at these localities is often so abundant that the rock has the appearance of a rather coarse conglomerate but does not show any stratification.

The locations of the vents from which the lavas flowed are not definitely known. Slight variations in the compositions and textures of these volcanic rocks from various localities suggests the possibility that the lavas may have flowed from several vents. It cannot be stated definitely whether the eruptions were in the form of sheet-like masses
that came from dikes breaking through the older formations or came from volcanic plugs. Numerous dike rocks having compositions practically identical with those of the volcanic rocks cut the Dedham Granodiorite and older formations at Marblehead Neck, at Phillips Point in Swampscott, at the south of High Rock in Melrose and in the Maplewood section of Malden. In some cases these dikes can be found cutting portions of the volcanic flows. Because of the absence of cone-like structures it seems probable that the lavas were erupted as sheet-like masses from several dikes such as those mentioned above.

The rocks of the Lynn Volcanics in Stoneham, Wakefield and North Saugus tend to occupy the tops of hills and the more elevated portions of the terrain while the older granitic rocks and stratified formations frequently outcrop in the bottoms of gullies and along the bases of hills. The same situation exists to a lesser degree along the belt of volcanic rocks extending through Medford, Malden and Melrose. In these localities the higher ground is frequently composed of the volcanic rocks while portions of the older formations are found outcropping at lower elevations. At the eastern end of this belt in Saugus and Lynn only volcanic rocks are found. Detrital material from the older formations is rather abundant in many of the outcrops thus indicating that the unconformity with the older formations is probably only a short distance below the surface of the ground. From this
locality the volcanic rocks extend to the southeastward, passing under the water of Nahant Bay. The volcanic rocks of Marblehead Neck also pass under the water of Marblehead Harbor and the Atlantic Ocean. The dissection that has cut entirely through the volcanic series in many localities indicates that a large portion of these rocks has been removed by erosional agencies.

The flows of the Lynn Volcanics have responded to deformation mainly by intense fracturing. These rocks are hard and brittle and the cover, if any, that accumulated over them was thin. Such conditions have not been favorable to deformation by folding. Wherever deforming stresses have been rather intense, as for example adjacent to faults, the rocks are closely jointed and readily separate into tiny angular fragments. This feature is responsible for the extremely rough surface of many outcrops.

It is not easy to distinguish individual flows in the field. Frequently, flows are so thick that they form entire outcrops or else the megascopic characteristics of rocks from adjacent flows are so nearly identical that it is almost impossible to distinguish one from another. Conspicuous erosional surfaces or unconformities between flows are rare. Flow structures often cannot be found in outcrops and when found are likely to have erratic attitudes. These circumstances have prevented an accurate determination of the structural features and the identification of individual
flows of this volcanic formation. During the course of field investigations the writer observed several features which, if combined with a large amount of microscopic work, would probably lead to a more accurate determination of the structural features and identification of individual flows than any that has been made to date. These features are, changes of color caused by varying mineralogical composition, the color of weathered outcrops, a characteristic spalling of tiny chips from the weathered surfaces of some flows causing them to have a spotted appearance, an abundance of finely granular epidote in some flows, the presence or absence of quartz phenocrysts and the presence of older detrital material in the basal beds. The color changes, both in fresh rock and on weathered surfaces, may be nearly imperceptible from one flow to another because of the slight changes in mineralogical composition and therefore a large amount of microscopic work on numerous specimens to check field observations is also essential. Such work was not done during the course of this investigation, therefore the conclusions are rather generalized.

Fragmental volcanic material is abundant in all parts of the formation. As a rule the fragments are small, angular, appear to be identical in composition to the containing rock and are almost invisible on freshly broken surfaces. This fragmental material is quite evidently early solidified surface crust that became incorporated into still fluid flowing lava. It varies considerably in amount but is found to some extent in
most of the flows. The lavas frequently picked up varying amounts of loose detrital material from the surfaces of preceding flows. Such material ranges in size from small granules up to boulders several feet in diameter and cannot be easily distinguished from the containing rock except in the case of distinct differences in color or composition. Good exposures of the volcanic flows containing detritus from preceding members are found on the south side of Candle Hill in the extreme south part of Wakefield and on a hill about one-quarter of a mile to the southward in Melrose Highlands. These exposures show a grayish colored flow containing numerous large boulders of the underlying dark reddish colored member.

With but few exceptions the rocks of the Lynn Volcanics are porphyritic with an aphanitic groundmass. The phenocrysts are small, generally being from two to three millimeters in diameter. The groundmass is ordinarily greatly dominant over the phenocrysts but an exception to this condition is found in the rock of some large exposures on the hills between Towners Pond and Main Street in Malden, on Waitts Mountain in Malden and in the eastern part of the Middlesex Fells Reservation. A thick flow or a series of flows in which the phenocrysts and groundmass are present in nearly equal proportions outcrops along this belt. The minerals forming the phenocrysts vary according to the type of rock in which they are found and may be plagioclase, potash feldspar or quartz. Original mafic
constituents are not represented among the minerals present in the phenocrysts. A few thin flows of dense aphanitic rock without phenocrysts are found but members of this character form an insignificant part of the formation.

Microscopic examination shows the groundmass of all these volcanic rocks to be cryptocrystalline and generally too fine grained to permit positive identification of the mineral constituents. Specimens in which the groundmass is coarsely crystalline enough to permit identification of constituents are found to consist principally of feldspars and quartz accompanied by minor amounts of alteration minerals and occasionally accessory magnetite, pyrite, apatite and zircon. Glass was not observed in any of the thin sections examined but probably was an original major constituent in many of these rocks. Spherulitic growths are abundant in the groundmass of the rock from many of the flows.

Phenocrysts composed of plagioclase feldspars are frequently euhedral. These grains often have been broken, apparently by flowage in a viscous lava. Zoned plagioclase phenocrysts are rare in the rocks of the Lynn Volcanics. Quartz phenocrysts occasionally have euhedral hexagonal outlines but are more likely to be rounded. Orthoclase, microcline and microperthite usually exhibit anhedral shapes. In some of the specimens examined the phenocrysts had been partially rounded by having been to some extent resorbed into the groundmass. None
of the specimens examined contained phenocrysts of original mafic constituents but a few specimens did contain rather small aggregates of chlorite that appeared to be pseudomorphic after euhedral grains of hornblende. The proportion by volume of phenocrysts to groundmass is variable but generally is higher in the more acidic members of these volcanic flows.

A characteristic feature of all of the rocks of the Lynn Volcanics is their small content of mafic constituents. With the possible exception of minute quantities of magnetite none of the original mafic constituents have been preserved. They are now represented as chlorite, epidote, calcite and a powdery red iron oxide. The latter material is finely disseminated throughout the groundmass of the more basic flows, and although it is but a minor constituent the amount is sufficient to give these rocks a brick red color. Many of the flows throughout the formation tend to be leucocratic in composition.

The rocks of the Lynn Volcanics ordinarily are not greatly altered. The small amounts of alteration minerals present are characteristic of hydrothermal changes, such changes most likely having taken place in the flows during the cooling period. In some flows, especially those which are the lowest in content of silica, the feldspar phenocrysts have been clouded by a sericitic alteration but ordinarily the feldspars have not been much affected. The original mafic constituents have always been completely altered but these minerals constituted only
small portions of the rocks. Veinlets filled with quartz and calcite are abundant, the calcite always being later than the quartz. Epidote sometimes fills veinlets and is disseminated as minute grains throughout the rock of some flows. In most cases the veinlets are filled cracks that probably were formed while the lavas were cooling. Amygdaloidal cavities that have been filled with secondary minerals are rare in the rocks of this volcanic formation.

Flow banding often is seen to be prominently developed when the rocks are examined under the microscope although this feature cannot be detected by megascopic examination. The development of flow banding on a microscopic scale is characteristic of the more basic members that contain but few phenocrysts and a small amount of powdery red iron oxide.

A moderate range of rock types ranging from dacites to rhyolites is represented in the Lynn Volcanics. Visual observation indicates that some portions of the formation have little, if any, free silica and therefore can be classified as trachytes. None of the rock types represented is so greatly predominant over the others that it can be considered to be the characteristic type of the formation. It is impossible to make accurate visual estimations of the proportions of the various minerals forming these rocks because of the characteristic great predominence of cryptocrystalline groundmass in which the mineral constituents are too fine grained to be identified by optical methods. It is necessary to have chemical analyses from
which modes can be calculated in order to classify these rocks by a system such as that of Johannsen. The writers identifications of the rock types are based upon the compositions of the phenocrysts in a small number of specimens and not upon data from chemical analyses, therefore the division of the formation into rock types is a crude approximation. Descriptions are being limited to the principal features of the more abundantly distributed rock types comprising the formation.

In general the more basic flows appear to be the oldest. The basic flows frequently contain detritus from the erosional surface of the older formations while the rhyolitic flows rarely contain such material but often do contain fragments from underlying more basic members of the formation. The same type of rock does not everywhere form the basal flows of the series, probably in part as a result of the lavas having been erupted from several fissures at varying intervals of time and in part as a result of the topographic features existing at the time of eruption.

A variety of rock forming a rather large portion of the volcanic series, usually the basal members, is a brick red colored porphyry with a small proportion of white or colorless phenocrysts. This rock outcrops near the north end of Lynn Beach at the point called Red Rock and along the Boston and Maine Railroad in West Lynn. It forms the south part of the hill called High Rock located in the central part of Lynn and the greater
portions of prominent hills bordering the north edge of the Saugus Marshes from East Saugus to the Linden section of Malden. These outcrops are found within a belt trending a little south of northeast and lying along a portion of the south edge of the area occupied by the Lynn Volcanics. Smaller exposures of the same variety of rock are found near the base of the volcanic series in North Saugus and Wakefield. The weathered surfaces of outcrops of this rock have a characteristic dark brownish or purplish red color that distinguishes them from outcrops of the other varieties of rock comprising the volcanic series. Microscopic examination shows this rock to have a prominent flow banding that is not revealed by megascopic examination. The phenocrysts ordinarily do not form more than ten percent of the rock volume and consist of plagioclase, quartz and orthoclase. The plagioclase phenocrysts are much more numerous than those of the other minerals, frequently have euhedral outlines and are indicated by extinction angles to have the composition of andesine. The orthoclase phenocrysts occasionally contain a few perthitic lamellae. Quartz phenocrysts are usually rounded in outline and contain large numbers of minute colorless inclusions. The cryptocrystalline groundmass is too fine grained to permit the identification of its constituent minerals by optical methods. It contains a considerable amount of finely disseminated powdery red iron oxide that gives the rock its brick red color and also causes the
weathered surfaces of outcrops to be dark red. Scattered small aggregates of chlorite, epidote and magnetite are presumed to be alterations of original mafic constituents. Small secondary accumulations of quartz, epidote and calcite have filled fractures. On the basis of the abundance of plagioclase phenocrysts having the composition of andesine as compared to those of the other minerals the writer considers this rock to be a rhyodacite.¹ Some outcrops of the rhyodacite contain sizable irregular streaks of light gray colored rock. Microscopic examination of specimens of the light gray rock shows them to differ from the red phase only by the absence of finely disseminated red iron oxide. The rhyodacite outcropping in the central and eastern portions of Lynn contains numerous small fragments of a pilotaxitic textured basalt identical in appearance to that of the Marlboro Formation. The texture and composition of these basaltic fragments can be identified only under the microscope. The presence of these basaltic fragments indicates the older Marlboro Formation may unconformably underlie the Lynn Volcanics in this locality. Outcrops of the rhyodacite in west Lynn contain numerous detrital fragments of the Dedham Granodiorite.

Northward from the main outcropping area of the rhyodacite and stratigraphically upwards in the series of volcanic flows

the rocks gradually become more acidic, finally reaching the composition of true rhyolites. The transitional flows are characterized by gradually decreasing quantities of plagioclase phenocrysts and corresponding increases in the quantities of potash feldspar phenocrysts, by a gradual disappearance of red iron oxide from the cryptocrystalline groundmass and by a gradual change from a brick red to a light gray color. The composition of the plagioclase changes from that of andesine to that of sodic oligoclase. The mineral forming the potash feldspar phenocrysts varies from one flow to another and may be orthoclase, microcline or microperthite. Simultaneously with the decrease in the content of red iron oxide the weathered surfaces of outcrops become whitish because of a thin film of kaolin that accumulates upon them. There appears to be a considerable number of flows in the transitional zone between rhyodacite and rhyolite but the change from one to another is so slight that it is difficult to distinguish individual members of the series by field methods.

The true rhyolites are light gray in color and weather to a whitish surface. The phenocrysts consist mainly of potash feldspars and quartz accompanied by occasional grains of oligoclase. The cryptocrystalline groundmass is free from red iron oxide and does not show flow banding. The gray color appears to be caused by a minute quantity of finely disseminated chlorite and epidote. Outcrops of the rhyolites are found in the vicinity of Pine Grove Cemetery and at the east side of Breed's Pond in
Lynn and at several places in Saugus at the north side of the area of red rhyodacite. These outcrops seem to lie in the trough of a synclinal structure. Other exposures of the grayish rhyolite are scattered throughout the North Saugus and Wakefield area.

Volcanic rocks having the composition of trachytes are found in Melrose and Malden. These rocks are gray or grayish green to purplish in color and generally weather to a light gray surface. The phenocrysts are much more abundant than in the other varieties and may form nearly half of the rock volume. A plagioclase constituent which forms the greatest number of phenocrysts is usually clouded by a sericitic alteration thus making identification uncertain but is probably sodic oligoclase. Orthoclase phenocrysts tend to be clear and colorless. Most of the specimens examined did not contain any grains that could be identified as quartz. A mafite, probably hornblende, originally formed fairly numerous euhedral phenocrysts but has been replaced by aggregates of chlorite or epidote. The cryptocrystalline groundmass does not contain disseminated red iron oxide but sometimes shows a small amount of greenish chloritic material. Minute spherulitic growths are abundant. Some specimens show a faint flow banding when examined under the microscope. This volcanic rock differs in composition and texture from that found in Lynn and Saugus and may have been erupted from a different fissure. It seems to contain a greater amount
of plagioclase than is consistent with Johanssen's description of trachyte but fits this classification more closely than that of any other.\(^1\) Most of the volcanic rock outcropping in the south part of Melrose, on Waitts Mountain in Malden and in the east part of the Middlesex Fells Reservation is of this variety.

The volcanic rock outcropping on the portion of Marblehead Neck covered by this report is also a trachyte similar to that of Melrose and Malden. The color is generally slightly reddish because of a small amount of finely disseminated red iron oxide in the groundmass. The outcrops tend to weather to a whitish color thus indicating that the iron oxide content is small. The plagioclase phenocrysts are composed of calcic oligoclase and are not altered to the extent of being completely clouded. Orthoclase forms some rather large phenocrysts but is not abundant. Ordinarily quartz is not present in recognizable grains. The groundmass of these rocks is cryptocrystalline but slightly coarser grained than that usually found elsewhere in the Lynn Volcanics.

Several other varieties of rock form minor portions of the Lynn Volcanics. A rather dark colored, greenish gray dacite outcrops in the north part of Cliftondale and on Vinegar Hill.

---

A few thin flows of dark gray cryptocrystalline rock without phenocrysts are found on Pine Hill in Lynn. Clapp\(^1\) reports the presence of amygdaloidal andesites in Melrose but the writer did not find any rocks fitting his description in this locality. An isolated outcrop of a light greenish amygdaloidal basalt is found in the southeast corner of the intersection of Main Street and Central Street in Saugus. This rock seems originally to have had a pilotaxitic texture but has been altered to an aggregate of epidote, chlorite and calcite with scattered groups of minute plagioclase laths. The amygdules are filled with epidote and calcite. This basalt is much lighter colored than the volcanic rocks of the Marlboro Formation, does not remotely resemble any portion of the Lynn Volcanics observed by the writer but does resemble much of the rock of the Brighton Volcanics.

The attitudes and structures of the volcanic flows are rather uncertain because of the lack of distinguishing features within the formation. The individual flows are not easily recognized and flow banding is generally absent therefore it is difficult to determine the attitude of the formation in most localities. There is not any definite indication that individual flows covered the entire area occupied by the formation, in fact it seems more likely that several groups of flows

were erupted from several fissures with the amounts of lava and topographic features determining the area covered by each flow. Also the thicknesses of the flows probably varies greatly from place to place. In a general way it appears that the formation has been arched into a broad anticline with an axis striking northeast-southwest. The outcrops in Stoneham, Wakefield and North Saugus are on the northwest limb of this anticline while those in Medford, Malden and the south parts of Melrose and Saugus are on the southeast limb. The nose of the structure is in Lynn. This major structure is complicated by minor structures, especially in the Lynn-South Saugus where there are good indications of a synclinal structure along the flank of the larger fold. The volcanic rock of Marblehead Neck probably was originally continuous with that of Lynn but has become isolated because of an uplifted fault block between the two localities. Any volcanic rock that may have existed on the uplifted block has been removed by erosion. The formation has been locally displaced by small faults having a general north-south strike and which appear to be related to the north boundary fault of the Boston basin. The volcanic rocks have been brecciated and closely jointed in the immediate vicinity of faults.

There are not any exposures available from which a reasonably accurate estimate of the original thickness of the volcanic formation at any particular locality can be made. Although the base of the formation is exposed in many places the top has
always been removed by erosion. Data on the thicknesses and attitudes of flows is not good enough to be used in estimations of the total thickness. It is probable that the total thickness of the flows varied greatly from place to place with the possible maximum being between two thousand and three thousand feet.

The age of the Lynn Volcanics is not definitely indicated by relations with other formations. The flows were erupted upon an erosional surface of Dedham Granodiorite and older formations. There are not any sedimentary strata interbedded with the flows and there is not any evidence of other rocks having been deposited upon them. The volcanic flows do not make contact with any of the intrusive bodies of Peabody or Quincy Granite. Clapp reports finding two small intrusions of Quincy Granite in the volcanic rocks of Lynn but the locations he mentions are now parts of the built-up area of the city in which the exposures have been removed, therefore his observations could not be checked. The volcanic flows and the underlying older granitic rocks have been cut by numerous large diabasic dikes that cannot be found in the adjacent Peabody Granite. The volcanic rocks have been deformed and closely jointed by a deformation of which there is no evidence in the rocks of the Peabody Granite. These two features would seem to indicate that the volcanic rocks are

older than the granite. Somewhat similar volcanic rocks are found approximately fifteen miles north of the Lynn area in the Newbury basin. At least one fossiliferous sedimentary stratum is interbedded with the volcanic flows in the latter area. The fossils are rather poorly preserved and completely satisfactory identifications have never been made. On the basis of tentative identifications of these fossils Emerson assigned a late Silurian or Early Devonian age to the Newbury Volcanics. On the basis of his own tentative identifications Ilsley considered these rocks to be of Lower Devonian Age. If the Lynn Volcanics can be properly correlated with those of the Newbury basin a Lower Devonian age for all of these rocks is indicated.

The rocks of the Mattapan Volcanic Complex outcrop along the south border of the Boston basin with exposures being found on both sides of the hypothetical south boundary fault. The name Mattapan Volcanic Complex was first used by LaForge who wrote the description of this formation that is contained in Emerson's report on the geology of Massachusetts and Rhode Island. ¹ This name is derived from the Mattapan section of Boston where numerous outcrops of these volcanic rocks are found. The largest and most numerous outcrops are found within an area approximately one and one-half miles in width extending in an east-west direction from Milton Lower Mills to the southern-most part of West Roxbury. Another belt of much smaller exposures extends from the Oak Hill section of Newton westward through Needham. In writing of these volcanic rocks LaForge states "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".² LaForge

erroneously mapped large areas of the Dedham Granodiorite, including all of the fine grained Stony Brook variety found at the south of Boston and in Needham, as volcanic rock and therefore the areal extent of the Mattapan complex is considerably smaller than is indicated on his map. Some of LaForge's description applies to the granodiorite rather than to the volcanic rocks. The Mattapan complex is of smaller areal extent than the Lynn Volcanics.

The surface conditions that existed when these volcanic rocks were erupted appear to have been identical with those existing when the Lynn Volcanics were erupted and therefore the two groups may be contemporaneous. Both groups were erupted upon an erosional surface consisting mainly of Dedham Granodiorite. Fragmental detritus from the granitic formation is found in the basal flows of both groups of volcanic rocks. Outcrops exposing the unconformable contact between the basal flows of the Mattapan complex and the Dedham Granodiorite are uncommon with the best of these exposures being found in the north end of the Stony Brook Reservation.

Several varieties of rock comprise the Mattapan Volcanic complex. The earlier flows are generally the most acidic and the lighter colored while the later flows are more basic and dark colored, a change which is the reverse of that apparently exhibited by the Lynn Volcanics. Instead of a gradual transition in the composition of successive flows the last acidic
and the earlier basic members are interbedded with one another. In some localities, particularly in the Mattapan section of Boston, this feature makes possible an easy field identification of successive flows or groups of flows and the determination of structural attitudes. It is possible to trace some members of the complex for a distance of approximately two miles through this locality. The rocks of the Mattapan complex found in the Newton and Needham section are thick and massive with poorly developed flow structures. Differences in the compositions and appearances of the volcanic rock from various localities suggests the probability that the lavas were erupted from several vents.

In some sections of the Mattapan complex sufficiently long intervals of time elapsed between successive eruptions to permit the accumulation of lenticular masses of conglomeratic material. Such strata consist for the most part of debris eroded from the surfaces of underlying flows but also contain pebbles and boulders of the older Dedham Granodiorite and quartzite formations. The volcanic detritus is present in all sizes from dust-like particles up to boulders at least three feet in diameter. The pebbles and boulders are only crudely rounded indicating a short distance of transportation. The finer grained matrix is dull reddish or grayish in color and forms a large enough portion of the sedimentary material so that in general the strata have these colors. This matrix is largely composed of altered fine grained detritus from earlier
volcanic flows or may possibly be partly volcanic ash and contains numerous angular quartz grains probably derived from the Dedham Granodiorite. Bedding features are poorly developed and scarce. These lenticular conglomerates are strictly localized accumulations of ungraded sedimentary material that collected in favorable spots between eruptions of lava. The deposition was probably entirely terrestrial. These sedimentary strata differ considerably from those of the Roxbury Conglomerate and are not considered to be any portion of the latter formation by the writer. Some good exposures of the interflow conglomerates are found in the south end of the Wright Golf Course near Hyde Park.

The rocks represented in different portions of the Mattapan Volcanic Complex will be described briefly with only the most characteristic features being mentioned.

A series of light and dark colored flows and tuffs outcrops in the vicinity of Mattapan Square. The basal flows are the most acidic and have light pink, whitish, faintly greenish or purplish colors. The later flows are dark gray or reddish in color and frequently are amygdaloidal. There is not a continuous transition from the light to the dark colored rocks but instead there is some interstratification of the two varieties.

The light colored members of this series generally show rather good to excellently developed flow banding. Some of the flows contain large amounts of fragmental material which in some cases consists of small angular fragments with flow banding
that probably represent a broken up early formed surface crust and in other cases appears to be of detrital or explosive origin. These rocks are prophyritic with the groundmass greatly predominant over the phenocrysts. Microscopic examination indicates that most of the phenocrysts originally had euhedral shapes but have been partially rounded, probably by resorption into the magma during the last stages of cooling. The minerals forming the phenocrysts are microperthite or orthoclase with the former being found most frequently, sodic oligoclase and quartz. The potash feldspar and oligoclase seem to be present as phenocrysts in about equal quantities in the rock from most flows. The two varieties of potash feldspar are not ordinarily found together in the same specimen. Quartz phenocrysts are abundant in specimens from some flows and are almost absent in others but in all cases are subordinate to the feldspars. These rocks are leucocratic. The original mafic constituents were insignificant in quantity and with the exception of a few minute magnetite grains have been completely altered. The groundmass is cryptocrystalline and usually too fine grained to permit identification of the mineral constituents by optical methods but appears to consist of mixtures of feldspars and quartz. Some specimens contain rather numerous tiny spherulitic growths. Alteration minerals usually form at least five percent of the rock volume. The most abundant alteration mineral is calcite which is found as scattered large grains, as aggregates of minute grains and as the filling of veinlets. Either clinozoisite or
epidote generally is present in small quantities and the faintly greenish rock contains a small quantity of a greenish chlorite-like mineral. There is always some sericite in the groundmass. In those portions of the flows that have not been deformed the sericite is found as scattered randomly orientated flakes. Rock that has been sheared as in the vicinity of faults contains a considerably greater amount of sericite that tends to form an interlacing mesh of more closely orientated flakes and also forms a thin film surrounding phenocrysts. Because of the great predominence of the cryptocrystalline groundmass in these rocks it is impossible to make reasonably accurate estimates of the mineralogical compositions without chemical analyses. Specimens from some flows show fairly abundant quartz phenocrysts and among the feldspar phenocrysts the potash variety is predominant over plagioclase therefore these rocks can be classified as rhyolites. Specimens from other flows seem to have very little if any free silica and an abundance of microperthite and plagioclase and therefore tend to have the composition of trachytes.

There is an abrupt change in composition between the light colored acidic flows and the later dark colored basic members. The latter are usually both amygdaloidal and porphyritic. Microscopic examination shows them to have pilotaxitic textures. The principal mineral constituent is a plagioclase crystallized in minute laths and having a composition at least as calcic as
that of calcic andesine. In addition to the small feldspar grains there are large plagioclase phenocrysts that are slightly zoned and a few large untwinned grains that cannot be identified. All of the feldspars are somewhat clouded by incipient alteration thereby making identification rather uncertain. Quartz phenocrysts are rare and small. With the exception of magnetite all of the original mafic constituents have been completely altered. Magnetite varies in amount from one specimen to another and is usually found as finely disseminated particles in the material interstitial to the feldspars. The interstitial material probably originally consisted almost entirely of mafic constituents but has been thoroughly altered to epidote or clinozoisite, chlorite and a reddish iron oxide. Epidote and calcite are also present as irregularly scattered grains and aggregates and also fills cracks. The amygdules are filled with epidote, quartz and iron oxide with the epidote generally being the earlier. The color of the rock depends upon the relative proportions of iron oxide and epidote, the former material when present in large quantity causing a dark reddish color and the latter a grayish color. These rocks are andesites. Some of these more basic members are distinctly fragmental in character but the degree of alteration is great enough so that features which would indicate the manner in which the fragments originated have been obscured.
The two varieties of volcanic rock described above can be traced through the Mattapan section of Boston in a northeast-southwest trending belt roughly paralleling the Neponset River. The light colored flows appear to be the uppermost part of a thick volcanic mass, the main portion of which lies a short distance to the northwestward in the Clarendon Hills. The vent from which the lavas were erupted may have been located in the vicinity of these hills since the flows of this particular phase of the volcanic rock become thinner to the northeastward - and possibly also to the southwestward. There is a large quarry in the light colored volcanic rock of the hill called Sally Rock. Practically all of this mass is leucocratic in composition and has a whitish color tinted with faint shades of pink, green or purple. An occasional distinctly pink member is found. But little of this rock is siliceous enough to be called a true rhyolite and in some of the specimens examined plagioclase phenocrysts having the composition of sodic oligoclase were found to be predominant over the potash feldspar phenocrysts. Most of the rock in this vicinity has more closely the composition of acidic trachyte.

To the westward in the Stony Brook Reservation and in the southernmost part of West Roxbury the volcanic rock is generally light gray to gray in color and has almost the same composition as that of the whitish phases. The gray color seems to be caused by a small amount of an extremely fine grained chloritic
alteration mineral disseminated in the cryptocrystalline groundmass. Some of the specimens examined were found to contain a few tiny quartz phenocrysts while others were found to be deficient in this constituent. The volcanic flows in this locality show slight variations in composition ranging from rhyolites to acidic trachytes.

The volcanic rock of the Mattapan Complex outcropping in the Newton-Needham locality is light gray in color. Plagioclase phenocrysts having the composition of calcic oligoclase are more abundant than phenocrysts of potash feldspar while quartz forms only a few recognizable grains. These rocks appear to have the composition of rhyodacite but because of the apparent small quantity of free silica trend towards the composition of trachyte.

In the Newton-Needham locality there seems to be some indication that the rocks of the Mattapan Volcanic Complex may grade upwards into the more basic Brighton Volcanic Complex. Here the light colored flows of the Mattapan Complex are slightly more basic than those of the Mattapan-Hyde Park locality. Some dark colored volcanic rocks that the writer considers to be a part of the Brighton Complex outcrop along the south edge of the golf course of the Charles River Country Club in the Oak Hill section of Newton. Outcrops of light colored Mattapan Volcanic rocks are found a short distance northward on the golf course. The dark colored rocks are closely related to the rocks of the Brighton complex in both composi-
tion and appearance and also seem to be the westward extension of a large mass of this formation outcropping in the Thompsonville section of Newton and in Brookline. Some of the rocks exposed at the south edge of the golf course are pilotaxitic textured andesites composed of at least eighty percent by volume of minute plagioclase laths having the composition of calcic andesine. There are not any exposures that indicate the exact relationship between the two kinds of volcanic rock but the field relations are favorable to the possible existence of an unconformable contact. Outcrops of the two kinds of rock are separated by a short distance in which no other kind of rock is exposed. A small isolated outcrop of a light gray rock having the megascopic appearance of the Mattapan rhyodacite but microscopically showing a pilotaxitic textured groundmass is found at the south side of Cedar Street on the Wellesley side of the Needham-Wellesley town line. This rock appears to be intermediate in composition between the rhyodacite and the pilotaxitic textured andesite. These features found in the Newton-Needham locality combined with the appearance of andesitic flows in the upper portion of the Mattapan section suggest the possibility that the Brighton Volcanic Complex may be a late phase of the Mattapan activity.

With the exception of the uppermost flows having a basic composition all of the rocks of the Mattapan Volcanic Complex have some features in common. They are leucocratic and light
colored having had only insignificant quantities of original mafic constituents. They are porphyritic with a cryptocrystalline groundmass. Although some flows seem to have an abundance of free silica these rocks generally appear to be low or deficient in this constituent. The predominant type of potash feldspar is microperthite. All of these rocks contain an appreciable quantity of alteration minerals of a hydrothermal type consisting of epidote or clinozoisite, calcite, chlorite and sericite. The most abundant rock types are rhyolites and acidic trachytes but the classifications of the writer are admittedly crude because of being based only upon the identification of phenocrysts which constitute but a small portion of the rock volume.

The flows of the Mattapan Volcanic Complex most likely were erupted from several vents. The variations in the composition of the rock from one locality to another is a factor favorable to this hypothesis. The apparent absence of plugs or cone structures suggests that the lavas flowed from dike-like fissures. Dikes of acidic rocks having compositions closely related to those of the volcanic flows are found cutting the Dedham Granodiorite in the vicinity of large masses of the volcanic rocks. Such dikes are displayed in the quarries in the north part of the Stony Brook Reservation.

The major structural features of the Mattapan Volcanic Complex are rather simple. In the Mattapan-Hyde Park locality
the flows have a northeast-southwest strike and a steep southeastward dip. In the Newton-Needham locality they are exposed along the breached crest of a broad anticlinal structure that is outlined by sediments of the Roxbury Conglomerate outcropping along the flanks. The flows have been displaced by some of the larger faults of the area and locally have been broken up by numerous smaller faults. These features will be discussed more fully in the section covering the structure of the area. The total thickness of the volcanic formation probably varies greatly from one locality to another and even at points a short distance apart within the same locality. A maximum thickness of a thousand feet is not unreasonable.

The age of the Mattapan Volcanic Complex is presumed to be essentially the same as that of the Lynn Volcanics since the basal flows of both formations were erupted upon an identical kind of terrain. There is sedimentary material interbedded with the Mattapan flows but it is not fossiliferous. The formation is not associated with other rocks of definitely known age. On the basis of field relations a Lower Devonian Age such as is possible for the Lynn and Newbury Volcanics seems to be a reasonable estimate for the age of the Mattapan Complex.
STRATIFIED ROCKS OF THE BOSTON BAY GROUP
The stratified rocks of the Boston Bay Group consist of conglomerates, sandstones, siltstones, tillite and volcanic flows. With the exception of the volcanic flows these rocks have been formed from sedimentary material that accumulated within and around the borders of a lowland called the Boston Basin. The greater portion of the sedimentary material was deposited in one or more bodies of standing water. Much of the coarser conglomeratic material was accumulated in a piedmont environment at the border of the basin and a small amount was deposited by glacial ice both on the piedmont slopes and within the basin.

The rocks of the Boston Bay Group are divided into the Roxbury Conglomerate, the Brighton Volcanic Complex which is interstratified with the conglomerate, the Squantum Tillite and the Cambridge Siltstone. Most geologists have treated this sequence of rocks as though the individual types form continuous or nearly continuous horizons throughout the extent of the basin which is an assumption that may be considerably in error. A complete stratigraphic column has never been obtained in any part of the basin, this being a circumstance that has led to great difficulty in correlating strata and interpreting structure. It is highly probable that there is considerable lateral gradation from coarse to fine grained sedimentary rocks and therefore the character of the strati-
graphic column varies considerably from the border to the central part of the basin. There are local lenticular masses of either coarser or finer grained material enclosed in strata of wide lateral extent.

At the southern and western borders of the Boston Basin the sediments were accumulated unconformably upon an erosional surface of the Dedham Granodiorite and the Mattapan Volcanic Complex. There is not any available information that indicates the character of the floor upon which the sediments accumulated in other parts of the basin but it would seem reasonable to assume that it is an erosional surface of the Dedham Granodiorite, the Mattapan Volcanic Complex or parts of the early Paleozoic stratified formations.

**ROXBURY CONGLOMERATE:**

The Roxbury Conglomerate forms the basal portion of the stratified rocks of the Boston Bay Group at the borders of the basin. It is not known from outcrops whether a basal conglomerate persists throughout the entire extent of the basin or if the conglomerate laterally grades into sandstone and siltstone. The name "Roxbury Conglomerate" seems to have been used first by Shaler¹ who applied it to all of the conglomeratic

rocks found in the Boston Basin. The stratigraphically highest beds of conglomeratic rock found in the Boston Basin were recognized to be glacial deposits by Sayles\(^1\) and therefore were separated from the Roxbury Conglomerate and named the Squantum Tillite by him. Emerson\(^2\) later divided the Roxbury strata into the basal Brookline Conglomerate member and the Dorchester Slate member underlying the Squantum Tillite. The term "Roxbury Conglomerate" is properly used to designate the coarse basal conglomerate of the sedimentary rocks of the Boston Basin.

The typical Roxbury Conglomerate is an aggregate of poorly sorted boulders, cobbles and pebbles and sandy matrix. The proportion of detrital material of pebble size or larger (exceeding 4mm. diameter) usually varies from thirty-five to seventy percent of the total rock volume and generally exceeds fifty percent. The proportions existing between boulders, cobbles and pebbles vary from the basal to higher strata and also in a lateral direction with the coarsest material being found in the basal strata and closest to the original source. In the localities where unconformable contacts with the igneous basement rocks are exposed the con-


glomerate contains occasional boulders three feet in diameter and quite numerous individuals having a diameter of two feet. The boulders and cobbles are usually sub-angular to sub-rounded and only occasionally are rounded. The pebbles are usually sub-rounded and in those instances where they form the larger sized detritus of water laid strata are likely to be rounded. Microscopic examination of several thin sections made from the matrix shows it to consist principally of sand and silt sized particles. Clay sized material seems to have been washed away from the sediment. Except for the elimination of extremely fine grained material the detritus that formed the conglomerate was ungraded.

The coarse boulder conglomerate is found adjacent to the contacts with the underlying basement rocks, as for example, in the Nantasket area and in East Dedham. Most of the exposures in Brookline, West Roxbury and the northern part of the Forest Hills Cemetery and Franklin Park consist of coarse boulder conglomerate that forms the core of an easterly plunging anticlinal structure. Although it is not exposed, the basement complex probably underlies the boulder conglomerate at a rather shallow depth. This anticlinal structure has been almost completely leveled off by erosional agencies with the result that a substantial portion of the stratigraphic column of the basin sediments is exposed. The upper portion of the conglomerate which outcrops on the flanks and at the easterly plunging nose of the fold contains finer
fragmental material.

Stratification is almost non-existent in the coarse boulder conglomerate with many large outcrops of this phase not exhibiting any recognizable bedding features. Some outcrops do contain small lenses or streaks of sandy material. The finer conglomerate such as that found on the flanks of the anticline described above usually has some recognizable bedding features and in some outcrops is found to be excellently stratified in a manner that indicates deposition in a body of standing water. It is quite possible that much of the coarse boulder conglomerate was accumulated in a terrestrial environment at the base of a range of hills or mountains and the finer material was transported a slightly greater distance to be deposited in a body of water occupying a valley.

The clastic material that has formed the Roxbury Conglomerate was derived from local sources with little, if any, having been transported for distances exceeding fifteen miles. It is probable that a large amount of this material is now resting at a distance of less than five miles from its point of origin. The clastic material has been derived almost wholly from the Dedham Granodiorite, the Mattapan Volcanic Complex and a whitish quartzite formation that probably was a part of the Westboro Quartzite and formed the roof of the Dedham batholith in the locality in which the sedimentary material originated. In localities where basic flows of the
Brighton Volcanic Complex are interstratified with the conglomerate considerable amounts of detritus from the flows may be found in the overlying conglomerate such as is the case at Hough's Neck in Quincy. In other localities the overlying conglomerate is almost completely devoid of detritus from the Brighton volcanic flows. In the Nantasket area the conglomerate contains a large proportion of dark red colored clastic material of volcanic origin, some of which more closely resembles varieties of rocks found in the Lynn Volcanics than those of the Mattapan Volcanic Complex. It is possible to examine the entire surface of large outcrops and identify every visible fragment contained in them as having come from one of the formations mentioned above. The proportions of material derived from the three principal contributing formations, that is the Dedham Granodiorite, the Mattapan Volcanic Complex and the quartzite, vary from one locality to another and each of the three types can be found to be locally predominant.

The Roxbury Conglomerate is generally rather light colored. The individual fragments from the largest to the smallest that can be seen megascopically usually have retained the colors of the original rocks or minerals from which they have been derived. The Dedham Granodiorite, the Mattapan Volcanic Complex and the quartzite formation are all composed of predominately light colored rocks and the clastic material derived from these formations is found in the
conglomerate in an unaltered condition. The fine grained matrix is composed of a mixture of white, pink, greenish and colorless mineral grains and minute rock fragments. In some localities the matrix is stained faintly greenish by a slight epidotic or chloritic alteration. The only parts of the conglomerate formation that have a red color are those which are composed predominately of clastic material with an original red color or those that have been heated and altered by overlying volcanic flows or adjacent intrusive dikes.

The fragmental material comprising the conglomerate is tightly bound together by a siliceous cement thereby producing a homogeneous rock that breaks across pebbles and boulders as readily as through the matrix. The joints in the rock normally pass undeflected through fine grained matrix and coarse fragmental material. Many outcrops exhibit smooth joint surfaces with areas up to several hundred square feet in which the fractures cleanly pass through every fragment. It is rather unusual for the rock to break around pebbles, cobbles and boulders and when this condition does exist it is usually the result of an incipient flow cleavage that has developed in the sheared zones adjacent to faults.

Microscopic examination of several thin sections made from the fine grained matrix of the conglomerate shows it to consist of fragments of mineral grains and minute rock particles. There is but little extremely fine grained clastic material thus indicating that most of the particles of clay
or fine silt size were washed out of the sediments that formed the conglomerate. There is a continuous gradation in particle sizes from those of pebbles on down to fine silt without any noticeable break or gap in the sequence. The fine particles are generally angular with only a few being sub-rounded. Rounded fragments less than 4mm. in diameter are uncommon. An outstanding feature of the fine grained fragmental material is the completely unaltered character of the minerals of which it is composed. Fragments of orthoclase; microcline, microperthite and plagioclase feldspar grains, all of which show no signs of alteration or decomposition by surface weathering agencies, can be found in abundance in most specimens. In addition to the feldspars there is a large amount of fragmental quartz and minute rock particles. These features indicate that the fine grained clastic material of the conglomerate is composed of pulverized rock. It does not have the features characteristic of fine grained sedimentary material that is produced by decomposition or disintegration by the common agencies of surface weathering.

The fine grained matrix is bound together by a siliceous cement that has almost completely eliminated the original pore spaces. Minute aggregates of secondary quartz can be recognized as having filled cavities. Tiny veinlets of quartz and calcite are found in some specimens. These secondary minerals always have been introduced and are not the products
of alteration of any of the material constituting the conglomerate. Some specimens collected from the vicinity of volcanic flows show a slight epidotic alteration that evidently was produced as a result of the action of heat and solutions from the lavas. Such alteration is of strictly local extent. Conglomerate that has been sheared may show a small amount of an intergranular sericitic mineral.

The Roxbury Conglomerate has been folded and has been ruptured by many faults. This deformation has not been sufficient to change the shapes of boulders, cobbles or pebbles except in the shear zones of some of the larger faults. The joint systems of the rock pass through the fragmental material as well as the matrix. Boulders, cobbles and pebbles having fractures that are not a part of the joint systems of the conglomerate as a whole and which have been produced during the deformation of the conglomerate formation are uncommon. The more intensely folded conglomerate frequently has an incipient flow cleavage in the fine grained matrix that is accompanied by a crude alignment of pebbles and cobbles. The alignment of the pebbles and cobbles parallels the cleavage and gives to the rock an appearance of stratification that can be mistaken for bedding.

In some portions of the Boston Basin there are well stratified deposits of sandstone or arkose, reddish gray siltstone and fine conglomerate overlying the typical coarse Roxbury Conglomerate. The sedimentary material that has
formed these rocks was deposited in bodies of standing water. Ripple marked beds are rather common and the finer grained phases are usually varved. The individual strata appear to be of strictly local extent and the sequence that is found in one locality may or may not be present in another. The entire sequence of these medium and fine grained phases of the Roxbury Conglomerate is found to be absent in some localities. These strata are evidently lenticular deposits that were accumulated in small bodies of water. The sediments appear to have been deposited in an environment of rapidly changing conditions with frequent changes in the character of the clastic material. These rocks are not as resistant to erosion as is the normal coarse phase of the Roxbury Conglomerate and therefore are not frequently found outcropping. In some localities they are overlain by thick accumulations of the normal coarse conglomerate. A few outcrops are found on the south limb of the central anticline in Dorchester and rather numerous outcrops are found on the north limb in Brighton and Newton. In the Dorchester area the series includes a thick bed of reddish gray siltstone that has been called the Dorchester Slate. A similar thick bed of the same kind of rock is found in the vicinity of the Chestnut Hill Reservoir in Brighton and Newton and also on the south slope of Codman Hill in Dorchester. The finer grained sedimentary rocks on the south limb of the central anticline in Dorchester are overlain by Squantum Tillite and
in the Chestnut Hill and Codman Hill localities are overlain by thick strata of the normal coarse Roxbury Conglomerate. The most persistent member of the finer grained strata is the thick mass of reddish gray siltstone but there is not enough field data available to indicate whether or not it was deposited as several lenticular bodies or as one continuous horizon.

With the exception of a few isolated outcrops all of the conglomeratic rocks are found near the central or south portions of the Boston Basin. The isolated outcrops of conglomerate are found in Watertown, West Medford and Saugus. There are two outcrops of conglomerate near the west side of the Coolidge School in Watertown, one being located in the school yard and the other one block to the westward. This conglomerate is made up of a large proportion of fine grained matrix, numerous large fragments of siltstone and a few small pebbles of Dedham Granodiorite and quartzite. The presence of the siltstone fragments shows that this rock lies well up in the stratigraphic column of the Boston Bay Group. In West Medford there are a few small isolated outcrops of a conglomerate composed predominately of small rounded pebbles of quartzite. These outcrops appear to lie on the north side of the north boundary fault of the Boston Basin. They do not have good stratification and their attitude and relations with other rocks of the area are uncertain. Near the west end of Birch Pond in Saugus there is
a low lying ledge of conglomerate exposed at the east end of the short street connecting Central and Walnut Streets. This rock is composed of pebbles of quartz, chert, dark gray chloritic quartzite and a sandy matrix. A thin section of the matrix showed it to contain a large amount of fresh unaltered feldspar fragments, numerous detrital quartz fragments and minute rock particles and practically no material smaller than silt size. It is cemented with silica. This rock is similar in many respects to the normal Roxbury Conglomerate. This outcrop does not have any stratification and its relations to the Lynn Volcanics and Dedham Granodiorite outcropping in the surrounding locality cannot be determined. The conglomerate exposed in Watertown is definitely a part of the Boston Bay Group, that in West Medford and Saugus presents unsolved problems.

SQUANTUM TILLITE:

The Squantum Tillite was first described and explained as being of glacial origin by Sayles. ¹ This rock lies stratigraphically above the Roxbury Conglomerate and apparently below a large portion of the Cambridge Siltstone. It is a localized horizon in the stratigraphic column of the

sedimentary rocks of the Boston Bay Group. The largest and best exposures of the tillite are found at Squantum Head, on the southeast shore of Squantum and on the grounds of the Squantum Naval Air Base. Smaller exposures are found on the south limb of the central anticline in Dorchester and West Roxbury. Some of the latter outcrops are located at the corner of Blue Hill Avenue and Harvard Street, fifty yards south of the intersection of Canterbury Street and Morton Street, in the central part of the Forest Hills Cemetery, on the south side of Weld Street both to the east and west of Center Street and on the west side of Maple Street. An outcrop that possibly may be tillite is located in a railroad cut about three-quarters of a mile north of Readville.

The best exposures of tillite are found at Squantum Head where it forms high seaward facing cliffs. In this locality the formations strike from N50E to N65E and dip southeastward at angles of 30 to 40 degrees. The strata are upright with top side being to the southeast. On the beach along the northwest side of the head there is exposed a reddish gray siltstone similar to the so-called "Dorchester Slate" member of the Roxbury Conglomerate. Immediately overlying the siltstone and forming the seaward facing cliffs there is the tillite. The stratigraphically lowest beds of the siltstone that are exposed on the beach are evenly bedded, are varved and show only a minor amount of disturbance caused by mud flows in
the unconsolidated sediments. The siltstone immediately underlying the tillite has been intensely disturbed while in an unconsolidated state, presumably as a result of having been over-ridden by glacial ice. It contains occasional large erratic boulders that range up to three feet in diameter. These erratics are completely isolated and enclosed in the siltstone and the manner of disturbance of the stratification indicates that they were dropped into soft unconsolidated sediments. The siltstone was deposited in a body of standing water and the most likely method of transportation of large boulders to such an environment was by ice rafting.

The tillite is a heterogeneous assortment of coarse and fine clastic material. It has a large proportion of an extremely fine grained clay-like or "pasty" matrix. The clastic material shows a continuous gradation in particle size from that of the clay-like matrix up to boulders three feet or more in diameter. The proportion of boulders, cobbles and pebbles to matrix is smaller than is characteristic of the Roxbury Conglomerate. The tillite is unstratified and ungraded with the coarser material being distributed entirely at random throughout the finer matrix. The pebbles, cobbles and boulders are angular to sub-rounded and are frequently grooved or beveled on one or more sides. The tillite is light colored, mostly having buff or pinkish shades that have been inherited from the parent rocks of the clastic material. It is composed of material derived from local formations and in
this respect is identical to the Roxbury Conglomerate. The tillite at the Squantum Head locality is approximately 600 feet thick. There is a water laid gravel stratum some twenty feet thick in the central portion of the tillite and this may possibly represent a temporary retreat of the ice.

The tillite at Squantum Head is overlain by a reddish siltstone which, in its basal portion, contains a large number of lenticular masses of lighter colored sand and gravel. These lenticular masses vary from a few inches to a foot or more in thickness and from four or five feet to at least thirty feet in length. They have been deformed and folded in exactly the same manner as the enclosing siltstone strata. The most reasonable explanation for the presence of these coarser grained lenses is that they represent masses of gravel frozen together and rafted into the lake on the under surfaces of blocks of ice. When the ice had partially melted the weight of the gravel caused the remainder to sink to the bottom of the lake where the melting was completed and the gravel was deposited upon the silty bottom and buried by continued deposition of silt.

The tillite at the southeast side of Squantum is similar to that at Squantum Head with the exception that it contains rather numerous fragments of siltstone. The outcrops in the Dorchester and West Roxbury localities are small and are not exposed in contact with strata of other types of sedi-
mentary rocks.

Many of the pebbles in the tillite have been ruptured by tension cracks that were produced during the deformation of the area. The pebbles were subjected to stresses which tended to lengthen or "stretch" them and relief was attained by the development of numerous tension cracks rather than by plastic deformation. Some pebbles that were originally approximately two inches in diameter have as many as five parallel cracks. The tension cracks of all the pebbles of an outcrop have approximately the same orientation. The development of such tension cracks is not a common feature in the pebbles of the Roxbury Conglomerate.

CAMBRIDGE SILTSTONE:

There is a fine grained grayish sedimentary rock that has been called a shale, a slate and an argillite underlying most of the central, the northern and the West Roxbury parts of the Boston Basin. This rock has been called the "Cambridge Slate" by Shaler¹ and the "Cambridge Argillite" by Billings².

The writer prefers to call the rock a "siltstone" for reasons that will be explained in the following description. The maximum thickness of the formation is not known but has been estimated to be possibly as much as 3500 feet by Emerson.

The sedimentary material that formed the Cambridge Siltstone was deposited in a body of standing water, presumably a fresh water lake. The rock always has or shows evidence of originally having had good stratification. Outcrops of the siltstone found close to contacts with the Roxbury Conglomerate or near to the borders of the basin and in which the stratification has not been greatly disturbed frequently exhibit excellent wave formed ripple marks. In these same localities much of the stratification has been greatly distorted by mud flows and other deformation that took place while the sediments were in an unconsolidated condition. Outcrops of the siltstone found well within the basin do not show as much evidence of "soft rock" deformation and rarely contain ripple marked strata. The distribution of these features indicates that the silty sediment was deposited on slopes around the borders of the lake at about the maximum angle of repose of this material with the result

that unstable conditions were frequently attained and the mud flows resulted. In the central portion of the basin the sediment was deposited in a more stable condition and mud flows were less frequent events.

The bedding of the siltstone is ordinarily easily recognized. Individual beds vary from a small fraction of an inch to several inches in thickness with the smaller dimensions being those most often found. The siltstone is usually varved and this is the feature that has been taken to indicate deposition in a fresh water lake. The varves are most readily seen in the more thinly bedded, finer grained portions of the formation.

The siltstone ordinarily has an excellent cleavage along the stratification planes and much of it can be split into thin slabs, each having the thickness of an individual bed or varve. This feature apparently has been used by some geologists as a basis for calling the rock a "slate". Outcrops in which the rock shows a true slaty cleavage cross-cutting the bedding are rare. There has not been any schistosity developed in this siltstone, even including the localities where it has been folded and caught in the shear zones of faults.

The color of the siltstone is ordinarily a light gray but occasionally is medium gray. The varved strata show the characteristic light and darker colored banding caused by the deposition of summer and winter layers. Some minor
portions of the formation have a faint reddish color.

Microscopic examination of several thin sections showed that the rock is composed predominately of fine grained clastic material of silt size (0.06mm. to 0.0039mm. dia.). The particles are angular. The most abundant mineral constituent present in particles large enough to be identified by optical methods appears to be quartz. Some specimens were found to contain numerous fragments of clear, unaltered feldspar.

The composition of the extremely fine grained material interstitial to silt particles and comprising the winter layer of varves cannot be identified by optical methods. The material that is smaller than silt size generally forms less than one-third of the rock volume. In some specimens this material was found to be altered to a sericite-like mineral but its quantity is not sufficient to produce a schistosity. Specimens having a faint reddish color contain a small amount of finely disseminated earthy red material that is probably an iron oxide. The microscopic examination indicated that the sedimentary material which formed the siltstone was composed of finely ground rock dust or "flour" and was not a product of decomposition.

The following definition of a siltstone is given by Shrock.¹ "The term 'siltstone' is in common use for

indurated silt. It is composed chiefly of mineral, rock and fossil fragments with maximum dimensions from 0.06 (1/16mm.) to 0.0039 (1/256mm.)". This definition is a satisfactory description of the rock under consideration. The term "argillite" is properly used to designate a metamorphosed sedimentary rock that was originally composed of argillaceous material. This definition does not fit the description of the Cambridge formation. It has neither schistosity nor true slaty cleavage and therefore cannot properly be called a "slate".

BRIGHTON VOLCANIC COMPLEX:

The flows of the Brighton Volcanic Complex are, for the most part, interstratified with the Roxbury Conglomerate. These volcanic rocks are found outcropping in the Nantasket and Hingham areas, on Hough's Neck, along the north flank of the central anticline of the Boston Basin in Allston, Brighton, Newton and Wellesley and on the crest of the anticline in Brookline and Newton. The flows of the Brighton Complex outcropping on the crest of the central anticline in the southwestern part of Newton appear to rest directly upon flows of the Mattapan Complex and to underlie the basal strata of the Roxbury Conglomerate. Some of the volcanic rocks belonging to this group were originally called "Brighton
amygdaloid" by Dodge\textsuperscript{1} because of the amygdaloidal character of the flows outcropping in Brighton. Emerson\textsuperscript{2} included these rocks in his description of the Mattapan Volcanic Complex. LaForge\textsuperscript{3} applied the name "Brighton Melaphyre" to all of the volcanic flows interstratified with the Roxbury Conglomerate. According to Johannsen\textsuperscript{4} the definition of melaphyre is, "A term originally used for any dark porphyry but later applied to Carboniferous and Permian basalts. Since the age classification is no longer in use the term should be dropped". Since it is questionable that these volcanic flows are actually of Carboniferous or Permian age and because the term "melaphyre" is no longer in good usage, and also because many of the flows of the

1. Dodge, W. W., Proceedings Boston Society of Natural History, Vol. 21, Pages 205-208, 18-


group are not amygdaloidal, the writer proposes the name "Brighton Volcanic Complex" as being a more suitable designation for these volcanic rocks. The complex includes flows and numerous dikes and plugs which apparently were feeders to the volcanic vents.

The rocks of this complex consist of greenish, purplish and gray andesites and basalts. The last flows to be erupted are more amygdaloidal and generally thinner than the earlier members. The writer did not make a detailed petrographic study of these rocks and therefore will present only a few comments concerning their characteristic features. All of the rocks of the complex contain an abundant amount of alteration minerals, the more important of which are epidote, chlorite and calcite. The purplish flows contain a small amount of earthy red iron oxide. These alteration minerals are responsible for the colors of the rocks. The feldspars, which ordinarily form fifty to seventy percent of the rock volume, are slightly clouded by incipient alteration. The original mafic constituents have been completely altered. The uppermost portions of the thick early flows are slightly amygdaloidal while the thin later flows tend to be highly amygdaloidal with epidote, calcite and quartz being the minerals that have filled the cavities. Quartz does not appear to have been present as a primary constituent. The earlier flows are the most acidic and have the composition of andesites while the later members are basaltic.
There are some indications that the flows of the Brighton Complex represent the last stages of a period of vulcanism that commenced with the eruption of the Lynn and Mattapan Volcanics. The Mattapan Complex grades from rhyolites in its basal portion to trachytes and rhyodacites and finally in its uppermost portion contains a few flows of dark colored andesites. There is but little, if any, difference in composition between the andesitic flows of the Mattapan Complex and those of the Brighton Complex that are interbedded with the basal strata of the Roxbury Conglomerate. At the south side of the golf course of the Charles River Country Club in the Oak Hill section of Newton trachytic flows of the Mattapan Complex are found outcropping at the crest of the central anticline of the Boston Basin. Large outcrops of pilotaxitic textured andesites that appear to be a part of the Brighton Complex outcrop a few yards to the southward. There is not any evidence indicating that a stratum of conglomerate lies between the two types of volcanic rocks. This feature suggest a possible short time interval between the eruptions of the two kinds of lavas.

The flows of the Brighton Volcanic Complex appear to have been erupted intermittently throughout the time that the Roxbury Conglomerate was being deposited. The individual flows seem to have been of rather limited extent and probably were erupted from several vents, some of which may have been
located in the Nantasket area, at Crow Point in Hingham, in Brighton, in the south part of Newtonville, in the western part of Brookline and in Auburndale. There is not any field evidence that indicates whether or not the flows extended into the main part of the Boston Basin and were interstratified with the Cambridge Siltstone. The flows in the vicinity of Allston, Brighton and Newtonville are interstratified with the uppermost portion of the Roxbury Conglomerate. These flows contain a large amount of fragmental reddish gray siltstone that probably was derived from the same horizon as outcrops in the vicinity of the Chestnut Hill Reservoir.
ORIGIN OF THE SEDIMENTARY ROCKS OF THE

BOSTON BAY GROUP
ORIGIN OF THE SEDIMENTARY ROCKS OF THE
BOSTON BAY GROUP

The rocks of the Roxbury Conglomerate, the Squantum Tillite and the Cambridge Siltstone were formed from clastic sediments having several characteristic features in common. The sedimentary material of all three formations is composed almost wholly of pulverized rock and rock fragments. The sedimentary material is fresh and unaltered quite in contrast to the condition usually characteristic of sediments produced by weathering agencies of decomposition and disintegration. The sedimentary fragments and particles of all three formations are generally angular to sub-rounded. The material has been derived from local sources and is composed of detritus from the Dedham Granodiorite, the Mattapan Volcanic Complex and a quartzite formation. The small dimensions of the clastic material comprising the siltstone make a positive identification of its origin somewhat uncertain but on the basis of the abundance of quartz and fresh unaltered feldspar fragments contained in it an origin from the same sources as produced the sediments of the conglomerate and tillite seems most reasonable. The colors of the sediments that produced the conglomerate, tillite and siltstone were those of the parent rocks. All three formations are non-fossiliferous. These features indicate that the three formations are closely related in origin and were deposited under similar climatic conditions.
Any attempt to determine the environments under which the sediments comprising the rocks of the Boston Bay Group were deposited is handicapped by the lack of complete stratigraphic columns. It is necessary to build hypothetical columns from fragmentary field data.

At the south and west borders of the basin the normal coarse Roxbury Conglomerate was deposited upon an erosional surface of the Dedham Granodiorite and the Mattapan Volcanic Complex. The contacts are exposed or have been uncovered at several localities. This basal phase of the conglomerate appears to have varied considerably in thickness, and possibly may have attained local thicknesses of 5000 feet. Detailed measurements by Billings¹ show that in the Nantasket and Hingham areas the conglomerate was deposited on a surface of high relief. He reports that in the Hingham area the conglomerate increases in thickness within less than a mile from 1840 feet in the southern part to 3440 feet or more in the northern part and interprets this to mean that the basement complex had a relief of not less than 2100 feet with slopes of fourteen degrees or more. Billings apparently includes

the finer grained water laid strata that frequently are found flanking outcrops of the coarse boulder conglomerate in the total thicknesses quoted above. There is substantial evidence that the poorly stratified coarse boulder conglomerate was deposited on a terrain of considerable relief and that much of it was deposited in a terrestrial environment. This environment logically would be the lower slopes of hills or mountains surrounding the basin. It is not definitely known whether or not a basal conglomerate persists throughout the entire extent of the basin. The probabilities are that a basal conglomerate either does not persist throughout the basin or if it does then the thickness is greatly reduced in the central area. The only indication of what may be the stratigraphic column in the central part of the basin is contained in the following statement by Hunt. "It is known to many that a well has within the last few years been sunk at the works of the Gas Light Company in Causeway Street in Boston. This boring was carried to a depth of 1750 feet, and though I have not been able to obtain an exact record of it, it is said to have been almost wholly in argillite or clay slate, though

at the bottom a crystalline rock was reached. This paper does not contain any further information concerning the kinds of rocks encountered in the boring and therefore it would appear that there is not any substantial thickness of conglomerate underlying the siltstone in this locality. It would seem reasonable to postulate that the Roxbury Conglomerate was deposited mainly on the lower slopes of hills or mountains surrounding the Boston Basin and that a large portion of the formation was deposited in a terrestrial environment.

The Cambridge Siltstone was deposited entirely in an environment of standing water. The universal water laid stratification, which is usually varved, and abundant ripple marks leave no question concerning deposition under these conditions. Since it is established that the siltstone was deposited in a standing body of water in the central portion of the basin it is now logical to assume that the fine grained clastic material was being deposited in this environment at the same time as coarse grained clastic material was accumulating on the slopes surrounding the basin. The matrix of the conglomerate contains but little clastic material of silt size and it is obvious that the finer grained particles were washed out to be transported and deposited in the central part of the basin. The conclusion is that the Roxbury Conglomerate and the Cambridge Siltstone to a large extent were deposited simultaneously. Deposition
of silt probably continued for sometime after the accumulation of the coarse clastic material ceased because of conditions that will be described later in this section.

The simultaneous deposition of coarse clastic material on the slopes surrounding the basin and of fine grained material in the central portion of the basin implies a transition from the one phase to the other and a probable inter-fingering or alteration of fine and coarse grained strata in the zone of transition. That such conditions actually exist is indicated by interstratified sandstones, siltstones and fine conglomerates found outcropping on the flanks of the central anticline in Dorchester and in Brighton and Newton and by similar transition phases in the Hingham area. Unfortunately the transition strata are not particularly resistant to erosional agencies and therefore outcrops of them are scarce and a continuous sequence from coarse boulder conglomerate to siltstone is not demonstrated by surface exposures. The outcrops of the transition phases found in the three localities are situated on the limbs of beveled anticlinal structures, the cores of which are formed of the coarse conglomerate. This feature might seem to indicate that the fine grained strata formerly extended continuously over the crests of the folds but it is also possible that there could have been transitions to coarse material or lensing out of the fine-grained strata in the directions of the crests of the two anticlinal structures.
Since it is probable that the conglomerate and the siltstone were deposited simultaneously to a considerable extent it is desirable to determine the climatic conditions existing at the time of the deposition and the process by which the sediments were produced. Clues are found in the color of the sediments, the varved stratification of the siltstone, the lack of fossils and the physical character of the sediments.

The colors of the sediments that formed the conglomerate and the siltstone are those of the parent rocks. Twenhofel\(^1\) makes the following statement; "Sediments that have colors that are those of the parent rocks suggest rigorously cold or rigorously arid climatic conditions, extremely steep slopes, or beaches and near shore bottoms of rivers, lakes, and the sea." In the case of the sedimentary rocks of the Boston Basin the possibility of a rigorously arid climate can be eliminated. The steep slopes, beaches and near shore bottoms of bodies of water were existant. The climatic condition was presumably rigorously cold.

In describing the effects of weather changes on sediments Twenhofel\(^2\) makes the following remarks; "Changes of

---


Rainy weather produces floods which would bring much sediment to sites of deposition, and thick and widespread deposits of clastics may be made. Times between floods produce thin deposits of particles of smaller dimension and perhaps different composition. Stratification due to changes of weather may be expected to be most obvious in sediments deposited in land environments. Much change of weather is related to seasons. Seasonal deposition of sediments is best shown in lakes receiving melt waters from glaciers. Rapid melting in summer releases relatively large volumes of clastic sediments to melt waters, and at any place in such lakes deposits of a certain degree of coarseness and thickness are made. As weather becomes colder the volume of melt water progressively decreases, and progressively finer sediments are deposited. Finally ice covers the waters, and colloidal materials held in suspension are gradually deposited, with the very finest last. Thus the coarser deposits of summer grade into the finer deposits of winter, and, as the latter represent those held in suspension for a long time, some oxidation may be expected to have taken place, with the consequence that winter deposits have darker colors than those of summer. Melting in the spring abruptly renews summer deposition, and thus the change from the finer sediments of winter to the coarser of summer is sharp. The composition of winter and summer layers is much the same,
except that the former contain more clay and ferric oxide. A summer and a winter layer form a varve, or the deposit of a year."

The thinly varved stratification of much of the Cambridge Siltstone indicates seasonal changes of weather that persisted for a long period of time. Alternating warm and cold seasons would be necessary to produce the varves. Some sections of the siltstone are made up of a great number of varves of almost uniform thickness and this is a condition that would not likely result from floods. Floods can be expected to vary considerably in the volume of water involved and the amount of sediment transported and therefore the varves would vary in thickness.

Deposits of varved sediments generally are considered to be formed in bodies of fresh water. The results of a series of experiments by Fraser\textsuperscript{1} led him to conclude that, "The maximum salinity permitting the formation of varves of coarse clay seems to be about 1/50 that of normal seawater." The material which he used was composed of approximately 50\% silt (.05 - .005mm.), 40\% coarse clay (.005 - .001mm.) and 10\% fine clay (.001 - 1000mm.). This mixture

\textsuperscript{1} Fraser, H. J., An Experimental Study of Varve Deposition, Transactions Royal Society of Canada, Vol. 23, Sec. 4, Pages 49-60, 1929.
probably does not differ greatly from that which was de-
posited to produce the Cambridge Siltstone. The deposits
of fine grained sediments laid down in temporary fresh
water lakes following the retreat of the Pleistocene con-
tinental glaciers are frequently varved while truly varved
deposits which may have originated in bodies of saline water
appear to be unknown. These observations suggest the pro-
bability that the Cambridge Siltstone was deposited in a
body of fresh water that was subjected to seasonal climatic
changes.

The Roxbury Conglomerate, the Squantum Tillite and the
Cambridge Siltstone are non-fossiliferous and do not contain
any carbonaceous material. The only discovery of possible
fossils consists of a few cylindrical structures that were
found in a sandy stratum overlying the normal boulder phase
of the Roxbury Conglomerate in the Forest Hills Cemetery.
These structures have been described by Burr\(^1\) with the
suggestion that they may be casts of tree trunks. A study
of his paper leads one to believe that Burr was not sure that
the structures actually were fossils. An absence of fossils
may indicate an absence or scarcity of plant and animal life.

---

1. Burr, Henry T., and Burke, Robert E., The Occurrence of
Fossils in the Boxbury Conglomerate, Proceedings Boston
Society of Natural History, Vol. 29, Pages 179-184, 1901.
One condition which can produce such a scarcity is a rigorously cold climate. The absence of fossils in the rocks of the Boston Bay Group is not conclusive evidence of a rigorously cold climate at the time the sediments were deposited but does serve to substantiate a similar conclusion based on other observations.

The evidence that can be obtained from the sediments forming the rocks of the Boston Bay Group is favorable to the hypothesis that a cold climate with seasonal changes existed during the time of deposition. The presence of a large body of fresh water in which the great thickness of Cambridge Siltstone accumulated during the course of a considerable length of time seems to rule out the possibility of a rigorously arid climate.

The processes by which large volumes of clastic sediments can be produced in areas having cold climates are limited in number. Chemical decomposition is not an important process of rock destruction under rigorously cold climatic conditions. Processes of disintegration produce large amounts of sediments in cold regions and are usually accompanied by a minor degree of decomposition or surface alteration. The microscopic study of thin sections made from the fine grained portions of the conglomerate and of the siltstone showed an almost complete absence of recognizable decomposition products in the rocks of the Boston Bay Group. The
sedimentary material for the most part, even down to the finest particles, exhibits a remarkably fresh and unaltered appearance. This feature would seem to eliminate the usual processes of surface disintegration and decomposition as having produced the sedimentary material.

A glacial origin for the sedimentary material that has formed the rocks of the Boston Bay Group most satisfactorily explains the characteristic features found in it. A glacial origin satisfies the requirement of a cold climate. Glacial sediments ordinarily have the colors of the parent rocks. Glacial deposits rarely contain fossils. Glacial action could also produce the great range of size of fragmentary material contained in the conglomerates, sandstones and siltstones of the group. Glaciers produce a great volume of finely pulverized rock or "flour" such as that which has formed the Cambridge Siltstone.

A glacial origin for the Roxbury Conglomerate has been proposed in a paper by Sayles and LaForge\(^1\). Shortly thereafter Sayles\(^2\) more completely described the outcrops mentioned

---


in the original paper and identified them as parts of a tillite horizon which he named the Squantum Tillite. Whether or not Sayles regarded the main portion of the Roxbury Conglomerate as being of glacial origin is not made clear in his later paper describing the Squantum Tillite. The section in Emerson's bulletin describing the rocks of the Boston Bay Group was written by LaForge with the suggestion of a possible glacial origin but there is not any substantial evidence presented to support this hypothesis. Conglomerates and varved shales of the Sudbury District in Ontario have been described by Coleman with the explanation that these formations are of glacial origin. His descriptions of these rocks indicate that they are similar in many respects to those of the Boston Bay Group.

A mountain type of glacier presumably was involved in the production of these sediments. During the greater part


of the activity the terminal moraines were located well up on the mountain slopes. The melt waters carried large volumes of clastic sediments down to the foothills and into the basin. The conglomeratic material, for the most part, was deposited on the lower slopes and at the edges of the basin while the finer grained sediments were carried out into the basin. At the same time as the melt waters were distributing coarse material over the lower slopes a large portion of the finer material of silt size was being washed out and carried into the lake in the central portion of the basin. There is nothing to indicate whether the lake was present prior to the glaciation or that it came into existence as a result of glacial debris obstructing a valley.

The probability of the terminal moraines having been located well up on the mountain slopes during the greater part of the glaciation is indicated by the limited amount of tillite found within the sedimentary rocks of the basin. The Squantum Tillite represents a maximum advance of the ice, probably with a retreat and a readvance, that took place close to the end of the glacial activity. That the ice advanced well out into the basin is demonstrated by the tillite resting upon thinly stratified, varved siltstone at Squantum Head. There does not appear to be any great amount of conglomeratic material occupying a position stratigraphically higher than the Squantum Tillite and this is taken to mean that the tillite represents a late stage of the glaciation.
it is entirely possible that there may have been an earlier advance and retreat of the ice with the moraines having been reworked and rendered unrecognizable.

Since it appears highly probable that the sediments which have formed the rocks of the Boston Bay Group are of glacial origin it is possible to arrive at additional conclusions regarding the stratigraphic column. The initial contribution of sedimentary material was a large amount of till and whether this was carried far down to the lower slopes by the ice or was deposited at a high altitude is not known. The till was reworked by melt waters which washed out most of the silt sized material and carried it out into the central portion of the basin to be deposited in a lake. The coarse material was spread over the slopes of the foothills, filled valleys and gullies and overlapped the borders of the basin lake. The coarsest boulder material traveled the shortest distances and was left as the poorly stratified Roxbury Conglomerate, probably in large part deposited in a terrestrial environment. In the vicinity of the borders of the basin there should be a gradual transition from conglomerate to siltstone but a horizon demonstrating this feature is not anywhere exposed. During the course of the glacial activity it can be assumed that there were minor advances and retreats of the ice and periods when melt waters were being produced in greater than normal volume. Such conditions would cause conglomeratic material to be carried
greater distances into the basin and result in an inter-
fingering of conglomerate, sandstone and siltstone strata at the borders of the basin. Such alternating strata are found at several localities. It is possible that temporary lakes may have formed at the borders of the basin, possibly by the obstruction of valleys or by the development of delta kames. Lenticular deposits of stratified sediments would have collected in such lakes and this may be the explanation of some apparently lenticular bodies such as the reddish gray siltstone in the vicinity of the Chestnut Hill Reservoir and at Codman Hill. The Squantum Tillite seems to represent an advance of the ice over a small portion of the basin.

The discussion so far has proposed the simultaneous deposition of conglomerate and siltstone. There is field evidence indicating that some of the siltstone overlies the conglomerate. When the glacier made its final retreat it is probable that there was an increased volume of melt water and the basin lake was increased moderately in area so as to overlap the terrain covered by conglomerate. The ice at this stage had become stagnant and was not producing great quantities of new sedimentary material. The contribution of coarse grained sediment may be considered to have practically ceased. The last melt waters continued to rework the sediments on the slopes and removed a large amount of silt to be deposited in the glacial lake. The deposition of silt continued for a considerable length of time after
the deposition of conglomeratic sediments had practically ceased and resulted in the uppermost strata of the Cambridge formation being stratigraphically higher and overlapping the conglomerate. If the stratigraphically highest rock of the Boston Bay Group is the fine grained reddish sandstone called the Tufts Quartzite member of the Cambridge "Argillite" by Billings\(^1\) it is possible that this sedimentary material, having been the last to be washed into the basin, was slightly oxidized in a terrestrial environment after the glaciation had ceased and thereby attained a reddish color. The probability that the conglomerate and a major portion of the siltstone were deposited simultaneously in different portions of the area may account for the inability to obtain a stratigraphic column including all of the rocks of the group.

The clastic material comprising the rocks of the Boston Bay Group seems to have been carried into the basin from the south and southwest. The limited assemblage of rock types represented in the pebbles, cobbles and boulders of the Roxbury Conglomerate is characteristic of the formations found to the south and southwest of the Boston Basin. The

---

Mattapan Volcanic Complex with its distinctive light colored rhyolites is found only in this direction. The Dedham Grano- diorite outcrops more extensively to the south of the basin than to the northward or westward. The quartzite formation that contributed a large amount of detritus evidently formed the roof of the Dedham batholith and has been almost completely removed by erosional agencies. If the clastic material had been carried into the basin from the northward or northwestward it would be logical to assume that the conglomerate would contain detritus derived from some of the formations of the Fells Upland, that is, the Lynn Volcanics, the basaltic lavas of the Marlboro Formation, the so-called Newburyport Quartz-diorite, the Salem Gabbro-diorite and the Nahant Gabbro. With the possible exception of the Lynn Volcanics, fragmental material from these formations is not present in the conglomerate. In the Nantasket area the conglomerate contains large numbers of reddish volcanic pebbles and cobbles that are similar to some phases of the Lynn Volcanics. Outcrops on the beach at Lynn show that these volcanic flows extend eastward or southeastward under the ocean for an unknown distance. The size of the clastic material in the conglomerate decreases in a westerly direction from Nantasket, thus indicating a possible origin from the east. Since pebbles of this particular kind of red volcanic rock are found only in the conglomerate at Nantasket it is possible that there may have been movement of sediments from the south-
east or east in this particular locality. Elsewhere along the border of the basin the gradation in fragment size appears to decrease to the northward. Along the extreme south border of the basin the conglomerate ordinarily contains a large proportion of detritus from the basement rock of the immediate vicinity, this being a feature indicative of local origin.
AGE OF THE ROCKS OF THE BOSTON BAY GROUP
AGE OF THE ROCKS OF THE BOSTON BAY GROUP

The age of the Boston Bay Group never has been satisfactorily determined because these rocks are not fossiliferous and are not associated with formations of definitely known age. The group generally has been considered to be of Carboniferous or Permian age. The basis for a Carboniferous age has been a possible correlation with fossiliferous conglomerate, sandstone and shale formations of the Norfolk and Narragansett Basins, some of which contain coal beds and fossils that show them to be contemporaneous with the Monongahela Formation of Pennsylvania. The basis for a Permian age has been the possible correlation of the Squantum Tillite with deposits produced by Permian glaciation in other areas. The proponents of a Carboniferous age and also those of a Permian age never have been able to present conclusive evidence to substantiate their claims.

The possible correlation of the rocks of the Boston Bay Group with those of the Narragansett and Norfolk Basins is concerned with the conglomerates of these areas. The Roxbury Conglomerate of the Boston Basin is supposedly contemporaneous with either the Pondville or the Dighton-Purgatory Conglomerate of the southern basins. The Pondville Conglomerate is the basal formation of both the Norfolk and the Narragansett Basins and is stratigraphically lower and therefore older than the coal measures. The Dighton-Purgatory Conglomerate overlies the coal measures and therefore is younger. The correlation
of the Roxbury Conglomerate with either of the formations of the southern basins cannot be demonstrated satisfactorily.

The probability that all glacial activity of the latter part of the Paleozoic was confined to the Permian must be looked upon with considerable doubt. There is not any reason why, given high mountain ranges and abundant snowfall on their summits, glaciers of the mountain type should not have existed during all periods of the earth's history.

The determination of the age of the rocks of the Boston Bay Group must be based upon their relations with other formations of uncertain age and the effects produced in the various formations by the Paleozoic orogenies. The rocks of the area, including those of the Boston Bay Group, were folded and faulted during the Appalachian orogeny. The sediments of the Boston Basin had become sufficiently indurated prior to this deformation to cause them to behave as competent formations. This feature indicates that the sediments were laid-down well in advance of this orogeny and therefore cannot be of Permian age. In order to present a reasonable hypothesis for a more exact determination of the age of these rocks it is necessary to make a thorough investigation of the underlying igneous formations and the sedimentary formations of the adjoining Norfolk and Narragansett Basins.

The Roxbury Conglomerate was deposited upon an erosional surface of the Dedham Granodiorite and the Mattapan Volcanic
Complex. The age of the Dedham Granodiorite is not important to this discussion. Portions of the granodiorite batholith were laid bare by erosional agencies with the result that the lava flows of the Mattapan Volcanic Complex and the Lynn Volcanics were erupted upon a deeply weathered surface of the intrusive igneous rock. The age of these volcanic flows becomes a matter of considerable interest but unfortunately there is not any field data furnished by interstratified fossiliferous sedimentary beds or contacts with rocks of definitely known age to present a definite solution to this problem. It is necessary to attempt to make a correlation between the Lynn and Mattapan Volcanics and similar formations found elsewhere.

In the Newbury Basin of the northeastern part of Massachusetts there is a volcanic formation that was erupted under conditions similar to those of the Lynn and Mattapan Volcanics. Although the contacts are not exposed, it appears that the Newbury Volcanic Series rests upon an erosional surface of the Dedham Granodiorite batholith. A thin, fossiliferous, calcereous shale stratum is interbedded between volcanic flows. The fossils are rather poorly preserved and are difficult to identify. Emerson\(^1\) says of them, "The

\[\text{---}\]

fossils have not been studied in detail and only one species has so far been identified, but according to Mr. Ulrich the fauna appears to be similar in a general way to that of the Chapman Sandstone of northeastern Maine, which he regards as of Oriskany age. The fauna at Rowley may, however, according to Mr. Ulrich, be somewhat older and more nearly contemporaneous with the Pembroke and Eastport formations of the Eastport region, which have been classed as Cayugan. The age of the Newbury complex therefore, is not definitely determined, but it appears to be either late Silurian or Early Devonian. Ilsley made a collection of the fossils and on the basis of several tentative identifications decided, "The fauna is more similar to the Chapman Sandstone of Maine than to the Pembroke or Eastport Formations. This suggests an Upper Heldebergian or Lower Devonian age for the Glenn Mills fossils". These observations would seem to indicate that the Newbury Volcanic Series is probably of Lower Devonian (Heldebergian) or uppermost Silurian age.

In Maine volcanic rocks associated with conglomerates and fossiliferous shales and sandstones are found in the Perry Basin located on the west side of Passamaquoddy Bay. The Perry Basin has been studied in considerable detail by

several investigators. The rocks of this locality are divided into two groups, the oldest of which consists of volcanic flows and shales carrying a marine fauna, and the youngest consists of volcanic flows, sandstones carrying a terrestrial flora and conglomerates. The two groups are separated by an unconformity. The volcanic rocks are reported to be mostly of acidic types with rhyolites predominating. The lower group of strata comprises several conformable formations, the uppermost of which are the Pembroke and Eastport Formations. The upper group of strata comprises the Perry Formation. Smith and White report that a part of the strata of the lower group, apparently those of the Pembroke and Eastport Formations, contains a Heldebergian fauna and therefore they consider these rocks to be of Upper Silurian age. They place the Perry Formation in the Upper Devonian. Bastin and Williams likewise place the Pembroke and Eastport Formations in the Upper Silurian and the Perry


Formation in the Upper Devonian. The same formations are found outcropping on the Canadian side of Passamaquoddy Bay. Alcock\(^1\) indicates the Mascarene Group containing the Pembroke and Eastport Formations in its uppermost part to be of Upper Silurian Age and the Perry Formation to be of Upper Devonian age. A comparison of descriptions suggests that the Newbury Volcanic Series is more likely to be contemporaneous with the lava flows of the Upper Silurian Pembroke and Eastport Formations than with the Upper Devonian Perry Formation.

The preliminary geologic map of Maine by Keith\(^2\) shows several areas in which rhyolites are associated with Silurian and Devonian sedimentary formations. These volcanic rocks lie in a belt extending entirely across the northern part of the state in a northeast-southwest direction. In his report on the manganese deposits of Aroostook County White\(^3\) gives a stratigraphic column of the Presque Isle area in which volcanic rocks of Lower Devonian age underlie the Chapman Sand-

---

stone and overlie Silurian formations with a slight unconformity.

In the Chaleur Bay area of Eastern Canada there are volcanic flows interstratified with fossiliferous Lower Devonian and Silurian sedimentary formations. One such sequence found at Dalhousie on the northern coast of New Brunswick is described by Alcock as follows; "The Lower Devonian series of much of the Lower Restigouche and Upper Chaleur Bay region is such an intimate succession of interbedded sediments and volcanic rocks that only on large scale maps can these types be separated. The Dalhousie section has long been famous on account of its easy accessibility, its good exposures, and the abundance of Helderberg fossils that certain of its beds contain. It belongs to the division consisting dominately of volcanics, but shows a higher proportion of sediments than the division as a whole." The following observations are included in Alcock's description of the Silurian section. "The Black Cape section is on the Gaspe Coast about 45 miles west of Port Daniel. It shows a continuous succession of strata, dipping 60 degrees to the southwest, along nearly two miles of coast. The basal beds

begin about 1 mile east of Little Cascapedia River. At the eastern end of the exposure the Black Cape limestones are involved with marine lava flows that end in land flows of great thickness."

An investigation of the geological literature shows that a belt of intimately related volcanic and sedimentary formations extends in a northeasterly direction from Eastern Massachusetts through New Hampshire, Maine, New Brunswick and the Gaspe Peninsula. The locations briefly commented upon are but a few of several that have been described. The age of the volcanic flows in many cases is definitely indicated by interstratified fossiliferous sedimentary rocks. The majority of these flows are reported to be of either late Silurian or early Devonian age, with the Heldebergian time being indicated most frequently. Some writers have placed the formations of Heldebergian time at the top of their Silurian column while others place them at the base of the Devonian column. In a few instances volcanic flows are indicated to be of middle Silurian age. The only volcanic activity that occurred after the Middle Devonian Acadian orogeny described in the several reports examined by the writer was that which produced the flows in the Upper Devonian Perry Formation of the Perry Basin. There are not any volcanic rocks in this region which are described as being of Carboniferous or Permian age. The evidence which has been briefly summarized indicates that the region from
Eastern Massachusetts to the Gaspe Peninsula was the scene of intense volcanic activity during the Upper Silurian and Lower Devonian. On this basis a late Silurian or Early Devonian age for the Lynn Volcanics and the Mattapan Volcanic Complex seems most probable.

The relationships between the Lynn and Mattapan Volcanics and the intrusive masses of Quincy Granite, including the Peabody stock and the related nordmarkites and seyenites, are not anywhere indicated by outcrops. Volcanic flows are not found resting upon the granitic rocks at any place. Neither the granitic rocks nor dikes of aplites and pegmatites that are associated with the granitic rocks are found to be intrusive into the volcanic flows. The granitic masses are not cut by dikes or plugs that were feeders to the volcanic vents. These features suggest the possibility that the granitic rocks and the volcanic flows may have been of contemporaneous origin. This hypothesis is further substantiated by a consideration of the mineralogical compositions of the two types of rocks. The granitic and volcanic rocks tend to be either leucocratic or to have only a small quantity of mafic constituents. The feldspars of the granitic rocks consist of microperthite as a major constituent and sodic plagioclase as a minor constituent. The feldspar most frequently found forming the phenocrysts of the volcanic rocks is microperthite and next in abundance is sodic plagioclase. Chemical analyses of the granites and
the volcanic rocks show only minor differences in composition. The following tabulation shows an analysis of a composite sample of the acid volcanics of the Neponset Valley as given by Bascom\(^1\) and some typical analyses of the Quincy Granite of the Blue Hills as given by Warren\(^2\).

<table>
<thead>
<tr>
<th></th>
<th>Mattapan Volcanic</th>
<th>Coarse Granite</th>
<th>Fine Granite</th>
<th>Granite Porphyry</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO(_2)</td>
<td>72.85</td>
<td>74.86</td>
<td>71.41</td>
<td>72.88</td>
</tr>
<tr>
<td>ZrO(_2)</td>
<td>-</td>
<td>.20</td>
<td>.10</td>
<td>.10</td>
</tr>
<tr>
<td>Al(_2)O(_3)</td>
<td>12.92</td>
<td>11.61</td>
<td>12.74</td>
<td>12.30</td>
</tr>
<tr>
<td>Fe(_2)O(_3)</td>
<td>2.98</td>
<td>2.29</td>
<td>1.75</td>
<td>1.67</td>
</tr>
<tr>
<td>FeO</td>
<td>-</td>
<td>1.25</td>
<td>2.33</td>
<td>2.10</td>
</tr>
<tr>
<td>MnO</td>
<td>-</td>
<td>.02</td>
<td>.10</td>
<td>.10</td>
</tr>
<tr>
<td>MgO</td>
<td>.38</td>
<td>.05</td>
<td>.06</td>
<td>.09</td>
</tr>
<tr>
<td>CaO</td>
<td>.90</td>
<td>.41</td>
<td>.85</td>
<td>.87</td>
</tr>
<tr>
<td>Na(_2)O</td>
<td>7.08</td>
<td>4.30</td>
<td>4.59</td>
<td>4.43</td>
</tr>
<tr>
<td>K(_2)O</td>
<td>3.01</td>
<td>4.64</td>
<td>5.00</td>
<td>4.90</td>
</tr>
<tr>
<td>H(_2)O</td>
<td>.65</td>
<td>.35</td>
<td>.66</td>
<td>.46</td>
</tr>
<tr>
<td>CO(_2)</td>
<td>-</td>
<td>-</td>
<td>.40</td>
<td>.30</td>
</tr>
<tr>
<td>TiO(_2)</td>
<td>-</td>
<td>.20</td>
<td>.38</td>
<td>.35</td>
</tr>
<tr>
<td>P(_2)O(_5)</td>
<td></td>
<td>tr</td>
<td>.22</td>
<td>tr</td>
</tr>
<tr>
<td></td>
<td>100.77</td>
<td>100.18</td>
<td>100.59</td>
<td>100.55</td>
</tr>
</tbody>
</table>

---


Analyses of a rhyolite from the Lynn Volcanics of Marblehead Neck, a quartz-keratophyre from West Lynn and a specimen of the Peabody Granite are given by Clapp1.

<table>
<thead>
<tr>
<th></th>
<th>Peabody Granite</th>
<th>Quartz Keratophyre</th>
<th>Rhyolite</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>71.90</td>
<td>69.64</td>
<td>70.64</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>12.98</td>
<td>13.04</td>
<td>15.34</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>.81</td>
<td>4.15</td>
<td>1.83</td>
</tr>
<tr>
<td>FeO</td>
<td>2.35</td>
<td>1.98</td>
<td>1.10</td>
</tr>
<tr>
<td>MgO</td>
<td>.02</td>
<td>.32</td>
<td>.52</td>
</tr>
<tr>
<td>CaO</td>
<td>1.04</td>
<td>.54</td>
<td>1.24</td>
</tr>
<tr>
<td>Na₂O</td>
<td>4.19</td>
<td>5.46</td>
<td>5.23</td>
</tr>
<tr>
<td>K₂O</td>
<td>5.60</td>
<td>3.55</td>
<td>3.55</td>
</tr>
<tr>
<td>H₂O</td>
<td>.40</td>
<td>.69</td>
<td>.52</td>
</tr>
<tr>
<td>TiO₂</td>
<td>.34</td>
<td>.55</td>
<td>.90</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>.04</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MnO</td>
<td>.08</td>
<td>-</td>
<td>tr</td>
</tr>
<tr>
<td>BaO</td>
<td>tr</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ZrO₂</td>
<td>.12</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SrO</td>
<td>tr</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

99.87     99.92     100.37

These analyses show that the volcanic rocks and the granites are essentially alike in chemical composition and do not differ in the percentages of the various constituents by amounts greater than could be reasonably expected to be found in the intrusive and extrusive phases of a magmatic activity. On the basis of the chemical and mineralogical similarities and the absence of contacts or intrusions of one type into the other it seems reasonable to postulate that the granitic and volcanic rocks represent different phases of a single magmatic activity and therefore are of the same age. The portions of the magma that were erupted onto the earth's surface formed the flows of the Lynn and Mattapan Volcanics and the portions which remained at depth formed the granites and related s/he/nites and nordmarkites. The age of the group of granitic rocks comprising the various intrusive masses included in the Quincy Granite formation is therefore Upper Silurian or Lower Devonian. The emplacement of the granitic rocks and the eruption of the volcanic flows are considered by the writer to be events of the Acadian orogeny.

Since there is a reasonable basis for considering the Quincy Granite and the Mattapan Volcanic Complex to be of identical age it is possible to arrive at some definite conclusions regarding the age of the sedimentary rocks of the Boston Bay Group. The Roxbury Conglomerate is in part deposited upon the flows of the Mattapan Volcanic Complex and
thus is indicated to be the younger of the two formations. There is not any prominent unconformity between the two formations and it appears that the basal conglomerates were deposited shortly after the cessation of the volcanic eruptions. The Roxbury Conglomerate does not contain any detritus derived from the Quincy Granite of the Blue Hills. The writer did not find any such material in the conglomerate and its presence there has never been reported in the literature although many geologists have searched diligently for fragments of the Quincy Granite. It is apparent that the granite mass was not exposed to erosion at the time the Roxbury Conglomerate was being laid down and therefore must have existed under a cover of older rocks. The conglomerate has not been invaded by dikes that might be related to the granite, this being a feature which further indicates an older age for the granite.

In the northeast part of the Norfolk Basin the Pondville Conglomerate rests upon the Quincy Granite of the Blue Hills. The relationships of the Pondville in this locality are described as follows by Shimer¹. "The Pondville grades upward from a giant conglomerate, to coarse grit, to grit and pebble layers interbedded with sandstone, and finally to

typical Wamsutta which has also at times some minor layers
of grit and pebbles. There is no distinct break between
the formations, ----. The giant conglomerate has a bedding
contact with the Quincy Granite porphyry on the south side
of the Blue Hills. The basal few hundred feet are composed
of a residual conglomerate consisting entirely of Quincy
Granite porphyry in a matrix of arkose. The pebbles range
in size some being over a foot across. This part of the
conglomerate is apparently composed of weathered boulders
formed on an old Quincy Granite land surface. Many of the
boulders have probably not been moved at all and represent
the partially weathered upper surface of the Quincy Porphyry".

Conclusive evidence that the Quincy Granite porphyry
had been exposed and deeply weathered prior to the accumula-
tion of the Pondville Conglomerate is furnished by the basal
portion of the sedimentary formation. In the Narragansett
Basin the Pondville Conglomerate underlies the Wamsutta
Formation and coal measures correlated with the Monongahela
Formation of Pennsylvania and therefore is considered to be
of Lower Pennsylvanian age. 1 The Quincy Granite is older

1. Woodworth, J.B., U. S. Geological Survey Monographs,
   i. 33, Geology of the Narragansett Basin, Pages 133-210,
   1899.
than the basal sedimentary rocks of the Norfolk and Narragansett Basins and therefore must be of Pre-Pennsylvania age.

If the Roxbury Conglomerate had been laid down in either Carboniferous or Permian age it is highly probable that some of the detrital material contained in it would have been derived from the Quincy Granite since the latter formation was exposed to erosion during at least a portion of this time. The only circumstances that could have prevented granitic detritus from entering this conglomerate would have been the existence of a mountain with the granite outcropping on the southern slopes and the Roxbury Conglomerate being deposited on the northern slopes or a thick cover of early Pennsylvanian sediments resting upon the granite while the conglomerate was being accumulated in Late Pennsylvanian or Permian time. In the second case a large amount of second cycle sedimentary material showing the effects of intense decomposition and alteration would have found its way into the Boston Basin sediments. Such material does not appear to be present in these sediments. The close proximity of the Roxbury Conglomerate and the Quincy Granite along the south border of the Boston Basin is not favorable to the hypothesis that a mountain formerly separated these formations. Even granting that the granite has been overthrust onto the conglomerate along a major fault, the horizontal displacement would have to be many thousands of feet to provide the space required by the hypothetical mountain, which, if it ever
existed, has been completely obscured by the overthrust. There is not any field evidence to support this hypothesis and therefore the possibility of a mountain range having been fortuitously situated between the granite and the area of deposition of the Roxbury Conglomerate is unlikely.

The writer offers a hypothesis for the age of the rocks of the Boston Bay Group, the Mattapan Volcanic Complex and the Quincy Granite that is believed by him to be more in accordance with the field relations existing between the formations of the area.

On the basis of the evidence already presented it seems highly probable that the Mattapan Volcanic Complex and the Quincy Granite are of an identical age which is either Upper Silurian or Lower Devonian. The igneous activity that produced these rocks can be considered to have been a phase of the Acadian orogeny. Prior to this orogeny the surface formations of the area consisted of parts of the Dedham Granodiorite batholith and the remains of its cover of sedimentary rocks. The area had been subjected to a long interval of erosion during which all of the sedimentary material produced evidently was transported to a distant region since no trace of it can now be found. This circumstance suggests that the area had a relief and gradient that prevented the accumulation of terrestrial deposits upon its surface. During the Acadian orogeny a mountain or mountain range of considerable height came into existence to the south and southwest of
the Boston Basin. The rocks exposed on this mountainous terrain were the Dedham Granodiorite, the remains of a quartzite formation and flows of the Mattapan Volcanic Complex. The intrusive mass of the Quincy Granite was in existence below the surface and was nowhere exposed to erosion. The uplift of the Acadian orogeny is everywhere indicated to have been completed by Middle Devonian time since a marked unconformity exists between stratified formations of the Lower and Upper Devonian. It can be reasonably assumed that the uplift to the south and southwest of the Boston Basin had been completed by Middle Devonian time.

The sediments that have formed the rocks of the Boston Bay Group are of glacial origin. The most favorable conditions for the development of mountain glaciers are likely to exist when the mountains have high elevations. The glaciation under consideration probably occurred shortly after the close of the Acadian orogeny, that is during the Middle or Upper Devonian.

Prior to the Acadian orogeny the sedimentary material produced in the area was transported to other regions. There is not any reason to believe that the uplift alone created changes in the topography of the area that permitted the development of a large lake from glacial melt waters and in which sedimentary material suddenly began to accumulate. It is more likely that a valley was dammed by either glacial ice or glacial deposits or volcanic flows. It cannot definitely
be stated whether the obstruction was formed to the eastward or the westward but the writer is inclined to believe that it was to the eastward since the basin sediments seem to have originated at the southwest and were moved eastward. The obstruction most likely was caused by volcanic flows blocking a valley. A dam of volcanic rocks would have been a much more permanent obstacle than glacial ice or unconsolidated sediments and would have permitted the existence of the lake for a long period of time as seems to have been the case and also would have retained the unconsolidated sediments after the glacial activity ceased. The eastern part of the Boston Basin is now submerged under the water of the Atlantic Ocean and therefore the character of the rocks in that locality is unknown. The flows of the Lynn Volcanics continue to the eastward from the shores of Lynn and Marblehead Neck and conceivably could have been responsible for obstructing a valley and forming the Boston Basin. The fact that vulcanism persisted into the time of the glacial activity is demonstrated by the flows of the Brighton Complex that are interstratified with the Nantasket Conglomerate. Thick flows of these volcanic rocks are found near the base of the sedimentary series in the Nantasket area and therefore it is equally possible that a part of the Brighton Complex could have obstructed the valley.

In Middle or Upper Devonian time the summits of the mountains were glaciated and the debris was deposited in the
newly formed Boston Basin. The glaciation did not cut to a
depth that permitted erosion of the Quincy Granite and there-
fore detritus from this formation is not found in the basin
sediments. The granite batholith is a comparatively small
mass and possibly may have occupied a position at depth below
the foothills that were not eroded as intensely as were the
glaciated summits. After the glaciation had ceased it appears
that the area was subjected to a long period of erosion that
extended through Mississippian time. The products of this
erosion evidently were completely removed from the area be-
cause sedimentary formations of Mississippian age have not
been recognized in Eastern Massachusetts. Much of the sedi-
mentary material may have been carried across the filled
Boston Basin in which the glacial sediments were being re-
tained by the obstruction of volcanic rock. The Mississippian
erosion stripped the cover from the Quincy Granite batholith
so that at the end of this period the uppermost part of this
igneous mass was being subjected to surface weathering. In
early Pennsylvanian time a thick residual layer of arkosic
material developed upon the surfaces of the Quincy Granite
and the Dedham Granodiorite and became the basal portion of
the Pondville Conglomerate. Whether or not the elevation of
the granitic surface was low enough so that portions of the
Wamsutta Formation were deposited upon it is not definitely
known, but, it appears that erosion of the granite ceased at
about the end of Pondville time. Shimer\textsuperscript{1} says of the detritus comprising the sedimentary formations at the south border of the Blue Hills, "A decrease in the relative amount of Quincy porphyry in the conglomerate and an increase in the number of rock types represented takes place higher up in the beds, until a short distance into the smaller grained phase of the Pondville conglomerate the Quincy porphyry has ceased to appear at all". Thoughout Pennsylvanian time the more highly elevated portions of the region were subjected to erosion and sedimentary material was deposited in the Norfolk and Narragansett Basins. There is not any evidence of Pennsylvanian sediments having been deposited in the Boston Basin. Such sediments may have been deposited and subsequently were removed by erosion or the basin may have been filled with Devonian glacial sediments and was not in a condition to collect Pennsylvanian deposits.

The next major event was the folding and faulting of the rocks of the area during a great orogeny which, most likely, was the Appalachian. The glacial sediments of the Boston Basin had become sufficiently indurated by this time so that they behaved as competent formations. The granite

mass of the Blue Hills was faulted along both its northern and southern borders and thrust northward over the sedimentary strata at the south edge of the Boston Basin. The north side of the granite mass was relatively uplifted with respect to the south side and this movement resulted in the Pondville Conglomerate lying on the south flank of the Blue Hills being rotated into an almost vertical attitude. Loughlin makes the following comment concerning the attitude of the Pondville Conglomerate in this locality; "The lowest member of the series is called by Prof. Crosby a 'giant conglomerate'. It is exposed intermittently along the base of the Blue Hills from north of Great Pond westward to Houghton's Pond. Its dip is nearly, or quite, vertical". The Roxbury Conglomerate lying along the north side of the overthrust was steeply upturned or possibly even overturned. The structural features existing along the north border of the Blue Hills will be described in the section of this report covering the structure of the area.

The preceding discussion has outlined the basis upon which the writer proposes an Upper Silurian - Lower Devonian age for the Lynn Volcanics, the Mattapan Volcanic Complex and the various intrusive masses of Quincy Granite and a Middle

or Upper Devonian age for the rocks of the Boston Bay Group. While this hypothesis is not satisfactory in all respects and leaves some questions unanswered, it seems to be satisfied by the field relations and characteristics of these rocks to a much greater degree than are the hypotheses for a Carboniferous or a Permian age for the rocks of the Boston Bay Group that have been advanced in previous reports.
DIKE ROCKS
DIKE ROCKS

Several varieties of dike rocks are found in the Boston Metropolitan Area. The writer did not make a detailed study of the dikes and therefore will make only a few brief comments concerning them.

The most abundant variety is a dark gray diabase or "trap" dike that is found cutting all of the formations of the area. These dikes are generally considered to be of Triassic age. They are more numerous and of greater size in the northern part of the Boston Basin and in the Fells Upland than in the southern part of the area. These dikes generally strike in approximately east-west or north-south directions. The great Medford Diabase dike is the largest of these minor intrusive bodies and has been described in several papers. Similar dikes or sills form most of the outer islands of Boston Harbor. The great diabase sill that forms Outer Brewster Island is especially interesting because of its prominent banding. This banding consists of alternating coarse and fine grained layers of which the finer grained members have the darker colors. This feature causes the high cliffs at the south side of the island to have the appearance of being composed of stratified rocks.

Older dikes of several kinds are found cutting the Nahant Gabbro and the Salem Gabbro-diorite. A large lamprophyre dike, apparently the only one of its kind exposed in the area studied, extends for a considerable
Distance along the north shore of Nahant. Rather numerous basic dikes are found in the cliffs on the shores of Nahant, Swampscott and Marblehead.

An unusual kind of dike is found on the hillside about seventy-five yards east of the intersection of Parkland Avenue and Walnut Street in Lynn. This dike is grayish in color, has chilled contacts and the central portion contains enormous tabular plagioclase phenocrysts with some of the crystals being four inches in length and two inches in width.

Light colored acidic dikes that apparently are associated with the Lynn Volcanics are found at Marblehead Neck, at Phillip's Point in Swampscott and in the northern part of Melrose. Similar dikes that appear to be associated with the Mattapan Volcanic Complex are found in the abandoned quarries in the Stony Brook Reservation in the Hyde Park section of Boston.

Dark greenish colored basic dikes associated with the Brighton Volcanic Complex are found cutting the Roxbury Conglomerate in the localities where the flows have been erupted. These dikes appear to have compositions identical with those of the volcanic flows.
STRUCTURAL GEOLOGY OF THE BOSTON METROPOLITAN AREA
The structural geology of the Boston Metropolitan Area is complex and not easily deciphered. It is characterized by broad folds and a multitude of faults, some of which have displacements of hundreds, if not thousands, of feet. The structural features of large segments of the area are obscure or unknown because of the impossibility of obtaining field data. Ground moraine, drumlins and outwash deposits left as a result of the Pleistocene continental glaciation blanket much of the terrain and marshes and tidal flats cover large portions of the bedrock along the coastline thereby completely hiding the underlying geological features. The complete stratigraphic sequence of the sedimentary rocks of the Boston Bay Group is not exposed anywhere in a continuous section and is imperfectly known, therefore, the correlation of stratigraphic horizons and determination of structure in this group of rocks is rather uncertain. The structure in the igneous rocks of the area appears to be less complex than that of the sedimentary rocks but is difficult to decipher because of a lack of outcrops in some localities and because some large areas of essentially homogeneous rock do not exhibit many structural features. It is possible to collect enough field data to permit the determination of the major structural features of most localities in the area and in some cases to work out minor structures in
considerable detail.

The Boston Metropolitan Area is divided structurally into three principal parts. That part comprising the greater portion of the area covered by this report is a central lowland called the Boston Basin. The folded and faulted Late Paleozoic sedimentary rocks of the Boston Bay group outcrop in this lowland. To the northward of the Boston Basin, and sharply delineated from it by a prominent escarpment, which extends southwestward from the western part of Lynn and passes out of the area in Wellesley, is a highland area composed predominately of igneous rocks which is called the Fells Upland or the Middlesex Fells Highland. To the southward of the Boston Basin there is another complex of igneous rocks, the border of which generally is not sharply outlined by topographic features. In the southeastern portion of the area in the vicinity of Hull and Hingham there is not any topographic feature marking the border of the Boston Basin and the lowland continues uninterrupted from a terrain of sedimentary rocks to one of igneous intrusive rocks. The latter terrain gradually rises from the coastline inland in a southeasterly direction and is called the Sharon Upland. A short distance westward from the coastline at Hingham the Blue Hills rise prominently above the surrounding country and form the only major topographic expression along the south border of the Boston Basin. The border of the basin swings northward from the west extremity of the Blue Hills and passes out of the area in the northern part of Needham.
igneous complex bordering the basin from the Blue Hills westward is called the Needham Upland and is marked along its northern boundary by a low escarpment. The terrains of the Fells Upland, the Boston Basin and the Needham Upland tend to converge and merge imperceptibly into one another to the westward of the metropolitan area. The low elevations of the Boston Basin are erosional features produced as a result of the less resistant character of the sediments as compared to that of the igneous rocks of the Uplands.

The rocks of the Fells Upland and the Boston Basin have been crumpled into broad folds with axes trending from an east-west to a slightly northeast-southwest direction. Most of these folds plunge gently to the eastward. The steeply dipping attitude of the bedding in the stratified remnants of the Early Paleozoic formations found as inclusions and pendants in the igneous rocks indicate that the broad folding has been superimposed upon an earlier deformation that preceeded the deposition of the basin sediments. The igneous rocks of the southern uplands were not studied during the course of this investigation and therefore it will not be possible to make any statements concerning deformation that possibly may exist in them. The sedimentary rocks of the Boston Basin appear to have been caught between and to have been over-ridden by two great overthrust fault blocks which encroached upon them from opposite directions, the rocks of the fault blocks being the igneous complexes of the upland areas. The thrust faults form
the northern and southern boundaries of the basin. All of the rocks of the area have been broken and displaced by great tear faults that run in approximately north-south directions and probably have nearly vertical dips. The sedimentary rocks of the basin also have been broken and displaced by a series of east-west trending thrust faults approximately paralleling the great south boundary overthrust fault. These faults have broken the sediments into a series of segments of which the southernmost has always over-ridden its neighbor on the north. These minor thrust faults appear to be absent from the central and northern portions of the basin.

The structural features of the Boston Metropolitan Area can be described most effectively by first considering each of the major divisions separately and then by considering the structures in relation to the entire area. In accordance with this scheme the northern boundary overthrust fault, the structures of the Fells Upland, the structures of the Boston Basin and the southern boundary overthrust fault will be described in the order named. Discussion of the structural features of the southern uplands will be omitted because sufficient data was not collected during field investigations. Only the major structural features of the area will be described.

**NORTHERN BOUNDARY FAULT OF THE BOSTON BASIN:**

The igneous rocks and remnants of the Early Paleozoic stratified formations comprising the Fells Upland appear to form
an overthrust fault block that has moved southward over-riding the Late Paleozoic sedimentary strata of the Boston Basin. The Fells Upland ends abruptly at its southern edge in a prominent escarpment extending almost continuously in a south-westerly direction from the western part of Lynn to Wellesely where it passes out of the area studied. This escarpment is one of the most prominent topographic features of the Metropolitan area. The igneous rocks rise from fifty to one hundred and fifty feet above the lowland and in places form steep southward facing cliffs. The scarp is a resequent fault-line scarp produced by the differential erosion of the rocks on opposite sides of the fault plane. The Cambridge Siltstone outcropping to the south of the fault line is more susceptible to removal by erosional agencies than are the igneous rocks outcropping on the higher ground to the north. The continuity of the scarp is broken by a few embayments, the more prominent of which are occupied by the valleys of the Saugus and Mystic Rivers. It is possible that the locations of these embayments have been determined by the position of north-south trending tear faults.

The plane of the overthrust fault is not exposed at any place and has never been encountered in the course of excavations, therefore, the existence of the fault must be postulated on the basis of topography and features found in the adjacent rocks. The igneous rocks forming the face of the scarp have
been sheared and brecciated and are altered to a much greater degree than is characteristic of the same kind of rocks found elsewhere in the area. The alteration is principally one of kaolinization and presumably has been produced by groundwaters percolating through the brecciated zone adjacent to the fault surface. There are not any stratified rocks outcropping along the scarp. Outcrops of sedimentary rocks in the lowland adjacent to the scarp are small and widely scattered. In the Faulkner section of Malden several small outcrops of Cambridge Siltstone are found within distances of one hundred and fifty to four hundred yards from the base of the scarp. In these outcrops the siltstone is somewhat sheared and brecciated but retains enough bedding features so that the attitude of the strata can be determined. The strike varies from N50E to N60E and the dip varies from 70 to 80 degrees NW. The strata are overturned. The strike of the fault scarp at this locality is approximately N80E and therefore it would appear that the sedimentary strata are truncated by the fault plane. Two isolated outcrops of siltstone are found farther to the southward. One, called Bell Rock, is located in a small park on the west side of Main Street to the south of Malden Square and about five-eights of a mile south of the scarp. Here the strata strike N20E, dip 35 degrees SE and are upright. The other outcrop is found on the north slope of a hill in the extreme north part of Everett at a point about one-quarter of a mile due north of the LaFayette School and three-quarters of a mile
south of the scarp. The strata strike N43E, dip 41 degrees SE and are upright. The differences in the attitudes of the strata of the outcrops at Faulkner and of those a short distance to the southward indicate that the siltstone formation has been overturned along its northern border thus furnishing evidence of having been over-ridden by the thrust block of igneous rocks forming the Fells Upland. A few small outcrops of Cambridge Siltstone are found at the northwest end of Meeting House Hill in Watertown and Belmont. The shortest distance from the scarp to any of these outcrops is five-eights of a mile. The siltstone in this locality is in a badly decomposed condition which makes an accurate measurement of dip and strike nearly impossible. The best measurements that could be obtained by the writer indicate that the strata strike approximately east-west, dip about fifty degrees northward and are upright. These outcrops are not of any assistance in proving the existence of an overthrust fault block to the northward. A few small outcrops of Cambridge Siltstone are found near the east bank of the Charles River at a short distance to the north of Auburndale. The scarp is about one-half mile distant on the west bank of the river. The siltstone in this locality is quite thoroughly sheared and brecciated. The most northerly outcrop and the one closest to the scarp has traces of bedding with the strike being N40E and the dip 48 degrees NW. The only time the writer saw this outcrop was during a shower and it was impossible to detect features on the wet surface which
would indicate whether or not the strata are in an upright position. Dumbros\textsuperscript{1} states that these strata are overturned. The siltstone outcrops in the three localities described above are the only exposures of the sedimentary rocks of the Boston basin found within one mile of the scarp for a distance of approximately twenty-two miles along its length. These outcrops furnish little evidence of an overthrust fault along the north boundary of the basin. The most favorable indications of the existence of such a rupture are given by the overturned siltstone strata in Malden and Auburndale. In view of the existence of the scarp, the brecciated and altered condition of the igneous rocks on its face and the meager evidence found in the most northerly siltstone outcrops of the lowland the probability of an overthrust fault at the northern border of the Boston basin appears to be a reasonable hypothesis. The fault line can be traced easily from Wellesley to the north side of the Saugus marshes. Its position to the eastward of the marshes becomes indeterminate because of a lack of outcrops. In this discussion the igneous rocks of the Fells Upland are described as being overthrust upon the sedimentary formations of the Boston basin. This possible movement is a convenient way of describing the relative displacement between the two

\begin{flushright}
\end{flushright}
groups of rocks. Although unlikely, the movement conceivably could have been one of underthrusting.

**THE FELLS UPLAND:**

**DIVISIONS OF THE FELLS UPLAND:** The structure in the complex of igneous rocks and remnants of Early Paleozoic stratified formations that comprise the Fells Upland will be described briefly because large portions of the terrain are covered with glacial deposits and large masses of the rocks are essentially homogeneous and do not exhibit many structural features. The Fells Upland will be divided into four parts, each of which is a distinct lithologic and structural unit. The most easterly unit includes Phillips Point in Swampscott, Marblehead Neck and a few offshore islands in Massachusetts Bay. This unit will be called the Seaboard Unit. On the west side of the Seaboard Unit there is an uplifted fault block containing the gabbro-diorite of Marblehead, Swampscott, Lynn and Salem and the granite stock of Peabody. This unit will be called the Marblehead-Swampscott-Peabody Fault Block. Next westward there is a broad anticlinal arch extending from the eastern part of Lynn westward to the valley of the Mystic and Aberjona Rivers. This unit will be called the Saugus-Melrose anticline because these localities occupy the central portion of the structure and also because the name has already been
used by Clapp.\textsuperscript{1} An upland area in which the Salem Gabbro-
diorite is the predominating rock extends from the valley of
the Mystic-Aberjona Rivers to the western limit of the Metro-
politan area. This unit will be called the Western Upland.
The Seaboard Unit appears to be separated from the Marblehead-
Swampscott-Peabody Fault Block by a major fault that will be
called the Marblehead Fault. The fault block is separated from
the Saugus-Melrose anticline by a major fault that will be
called the Lynn Fault. The evidence of a possible fault along
the valley of the Mystic-Aberjona Rivers is obscure and the
Western Upland is segregated from the Saugus-Melrose anticline
principally on the basis of the rock types outcropping in each
unit.

THE SEABOARD UNIT: The rocks of the Seaboard Unit are
composed mainly of the coarse grained normal variety of the
Dedham Granodiorite. It forms almost all of Phillip's Point
and most likely continues uninterrupted under the water of
Massachusetts Bay to Marblehead Neck where it outcrops on the
south half of the peninsula. Ram Island and Tinkers Island
lying offshore and intermediate between the two localities
are also composed of the granodiorite. On the north part of
Marblehead Neck flows of the Lynn Volcanics unconformably
overlie the granodiorite. The relationship between the two

\textsuperscript{1} Clapp, Charles H., Geology of the Igneous Rocks of Essex
County, Massachusetts, U. S. Geological Survey Bulletin
704, Page 109, 1921.
kinds of rocks is rather obscure at the beach exposures because of some large basic dikes outcropping close to the contact but is clearly exhibited by exposures in the interior of the peninsula. The volcanic flows dip moderately to the northward with the maximum inclination probably not exceeding thirty degrees. It is not known how much of this inclination may have been original and how much has been produced by deformation subsequent to the volcanic activity.

The granodiorite on the south part of Marblehead Neck contains numerous inclusions and pendants of stratified sedimentary rocks. The bedding in the larger of these remnants has a strike varying from N30E to N50E and a dip of about 60 degrees to the northwest. This attitude is most likely the result of two deformations, one of which has been superimposed upon the other. The first deformation either preceded or was contemporaneous with the emplacement of the Dedham batholith and the second followed the eruption of the volcanic flows. The most reasonable assumption regarding the sequence of deformation at this locality is that the first folding gave to the sediments a moderate northwestward dip and the second folding tilted the strata to a steeper inclination. In both instances the anticlinal axis is located to the southwest. The amount of inclination produced during the second deformation must have been something less than thirty degrees which is the present inclination of the volcanic flows. The
possibility that the present attitude of the volcanic flows is entirely original and that only one period of deformation is represented is unlikely in view of the folded character of the adjacent regions where volcanic flows contemporaneous with those of Marblehead Neck have been deformed. Any combination of folding other than that suggested above would require a greater degree of deformation than that indicated by the condition of the rocks. The outcrops in this locality do not exhibit features characteristic of a high degree of deformation. There are not any stratified inclusions in the granodiorite at Phillip's Point. The only volcanic rock in this locality is a small outcrop that does not show flow structure and is not found to be in actual contact with the granodiorite.

THE MARBLEHEAD FAULT: The Marblehead Fault is not exposed at any place and its existence is inferred from topography and the condition of the rocks along the fault line. A low lying depression devoid of outcrops which occupies the ground between the Dedham Granodiorite on the southeast and the Salem Gabbro-diorite on the northwest begins at Fisherman's Beach in Swampscott and runs in a northeasterly direction to Phillips Beach. This depression evidently continues on in the same direction under that portion of the water of Massachusetts Bay lying between the mainland and the offshore islands called Ram Island and Little Pig Rocks and at the
northeastern part of the area passes between the mainland and Marblehead Neck. In Swampscott and along the shoreline extending northward from the north end of Phillips Beach the gabbro-diorite rises up in a steep southeastward facing scarp. The gabbro-diorite is locally sheared and brecciated and along the entire length of the scarp it has been extensively hybridized and invaded by numerous granitic and pegmatic dikelets and veins. Since there are not any bodies of granitic rock outcropping along the fault line it is reasonable to propose that the granitic magma found an upward path along the brecciated fault zone.

THE LYNN FAULT: The Lynn Fault likewise is not exposed at any place. The fault line is marked by a depression extending from King’s Beach in the eastern part of Lynn north-westward through Flax Pond and Sluice Pond and then swings westward through the gorge occupied by Walden Pond. This fault line follows the course of Clapp’s Lynn Fault from King’s Beach to the east end of Sluice Pond. Clapp places the westward extension of the fault along the contact of the Lynn Granodiorite Volcanics and the quartz-diorite variety of the Dedham/in the Lynn Woods and North Saugus. This contact is an unconformity and is not related to faulting in any way. Topographic features indicate the probability of a fault passing through the gorge

---

structural weakness. The younger Peabody Granite forms precipitous cliffs on the north shore of the pond while the older quartz-diorite variety of the Dedham Granodiorite, showing no indications of being affected by a nearby granitic intrusion, outcrops on the hillsides along the south edge of the pond.

It appears that these two kinds of rock lie on opposite sides of a fault plane.

On his map Clapp shows the Lynn Fault extending westward to the vicinity of Wakefield. Because of a lack of outcrops the writer was not able to find any field evidence to justify mapping the fault beyond the west end of Walden Pond.

THE MARBLEHEAD-SWAMPSCOTT-PEABODY FAULT BLOCK: The Marblehead and Lynn Faults form the southeast and southwest boundaries of the uplifted Marblehead-Swampscott-Peabody fault block. It almost appears that these two ruptures join to form one major fault but since the point where the two parts should meet lies under the water of Nahant Bay it is not possible to determine the exact relationship between them. Evidence that the Marblehead-Swampscott-Peabody fault block is relatively uplifted is largely circumstantial. The best indication of this relative movement is found in the absence of flows of the Lynn Volcanics

occupied by Walden Pond at a short distance to the northward of the contact. The writer considers the retention of the name "Lynn Fault" to be desirable and therefore uses it to designate this structural feature after the necessary corrections have been made.

Outcrops and evidences of faulting along this rupture are scarce. Scattered outcrops of entirely different types of rocks are found on the opposite sides of the fault-line. At the northeast side of the fault-line the rocks consist of Salem Gabbro-diorite with small intrusive plugs of Peabody Granite and at the north side of Walden Pond there is the main stock of Peabody Granite. On the southwest side of the fault-line the rocks consist of Lynn Volcanics and the quartz-diorite variety of the Dedham Granodiorite. The flows of the Lynn Volcanics terminate abruptly at the fault-line even though it is apparent from the outcrops that these rocks have a considerable thickness. The outcrops of the volcanic rocks found on the west side of Chestnut Street in Lynn, to the west of Flax Pond and west of Wyoma are locally brecciated, are silicified and carry quartz veins. The Peabody Granite is not found invading the older rocks on the southwest side of the fault-line but does form numerous small plugs in the gabbro-diorite on the northeast side and has hybridized much of the latter rock. The gorge occupied by Walden Pond is an erosional feature, the location of which has been determined by a structural weakness in the igneous rocks. A fault zone would be a logical cause of the
on the surface of the Salem Gabbro-diorite outcropping in the
fault block. The considerable thicknesses of the volcanic
rocks found in the central part of Lynn and on Marblehead Neck
indicates a probable former continuity of the flows between
the two localities. That portion of the volcanic formation
which presumably rested upon the surface of the uplifted block
has been removed by erosional agencies. Further evidence of
uplift is furnished by the rocks of the Dedham batholith out-
cropping in the Seaboard Unit and the Saugus-Melrose anticline.
Numerous detrital fragments of the normal variety of the Dedham
Granodiorite are found in the basal volcanic flows in West Lynn
and in the Pine Grove Cemetery which is but a short distance
from the Lynn Fault. The granodiorite and the volcanic flows
are exposed in unconformable contact on Marblehead Neck. In
the Lynn-Saugus locality the quartz-diorite variety of the
Dedham Granodiorite outcrops in a belt along the north border
of the normal variety and terminates against the Lynn Fault.
On his map Clapp\(^1\) indicates the rock comprising Lowell Island
and Bakers Island near the entrance to Salem Harbor to be
quartz-diorite. These islands lie to the eastward of the
Marblehead Fault and may be parts of the Seaboard Unit. They

\(^1\) Clapp, Charles H., U. S. Geological Survey Bulletin 704,
Geology of the Igneous Rocks of Essex County, Massachusetts,
1921.
lie within the trend of the belt of quartz-diorite in Saugus and Lynn. These locations of outcropping areas of the normal and quartz-diorite varieties of the Dedham Granodiorite in the Seaboard Unit and the Saugus-Melrose anticline indicate that the continuity of the belt is interrupted by the Marblehead-Swampscott-Peabody fault block.

Minor structures within the Marblehead-Swampscott-Peabody fault block are not always clearly indicated because of the nearly homogeneous character of the rocks comprising large segments of the major structure. Numerous deep ravines running in north-south or northwest-southeast directions have been cut in the gabbro-diorite forming the greater part of the fault block. These ravines appear to have been formed along lines of structural weakness such as minor faults. The displacement along faults of this character cannot be great since different varieties of rocks have not been brought into contact. Basic dikes with strikes approximately parallel to the direction of the ravines are rather abundant. Many small plugs of nordmarkite and granite surrounded by hybridized aureoles are found in the gabbro-diorite. All of these minor intrusive bodies are found within a distance of one mile of the fault-lines of the Marblehead and Lynn Faults. This circumstance combined with the extensive hybridization of the gabbro-diorite along the major fault lines suggests that the Marblehead and Lynn Faults have rather low dips to the northward and that the Marblehead-Swampscott-Peabody fault block
has been overthrust to the southward. The granitic magmas that formed the minor intrusive bodies may have moved surface-ward along the major fault zone and penetrated the hanging wall for short distances. The intrusive bodies that can be observed at the surface of the earth would therefore be found near the thin edge of the overthrust.

In the northeastern part of Lynn several small remnants of stratified sedimentary rocks are found in the Salem Gabbrodiorite. The attitude of the stratification in these remnants is somewhat erratic but generally has a north to northwest-ward strike and a steep eastward to northeastward dip. It is probable that the sedimentary rocks were deformed prior to the emplacement of the gabbro-diorite batholith. It is not possible to correlate this attitude of the stratification with that of remnants in adjacent localities.

SAUGUS-MELROSE ANTICLINE: The Saugus-Melrose anticline is a broad open fold having an axis running in a northeast-southwest direction and a gently northeastward plunge. It occupies all of the territory between the Lynn Fault on the east and the valley of the Mystic-Aberjona Rivers on the west. The fold is truncated at its eastern end by the Lynn Fault and at its western end by the north boundary fault of the Boston Basin. The rocks exposed on this structure consist of several varieties of the Dedham Granodiorite, numerous large remnants of the Early Paleozoic stratified formations
and local covers of the Lynn Volcanics.

The existence of a broad easterly plunging fold is best indicated by the flows of the Lynn Volcanics. The brick red rhyodacite flows at the base of the volcanic series outcrop in a V-shaped pattern of which the point is near the Lynn Fault at the east side of Breed's Pond in Lynn, the south wing extends through West Lynn and along the border scarp of the Fells Upland to the Linden Section of Malden, and the north wing extends past Birch Pond into North Saugus and Wakefield. The flows of light gray colored rhyolite of the upper part of the series can be traced in nearly the same pattern but less easily because of fewer exposures. A much smaller synclinal structure in the central part of Lynn is outlined by the same flows. The synclinal axis runs north-eastward and lies a short distance south of Breed's Pond. Clapp identifies two small anticlinal structures in the North Malden and Maplewood sections of Malden, apparently on the basis of exposures of Dedham Granodiorite breaking through the cover of volcanic rocks in these two localities. The writer believes the present exposures of Dedham Granodiorite can be the result of topographic features existing at the time.

of the volcanic activity and that evidence of folds is unsatisfactory.

A prominent feature of the Saugus-Melrose anticline is the succession of various types of rocks outcropping along the structure in northeast-southwest trending belts. Disregarding the local covers of volcanic flows these rocks in the order of appearance from southeast to northwest are, the micrographic variety of the Dedham Granodiorite, the normal variety of the granodiorite, the Westboro Quartzite and a mixed belt of the Marlboro Formation and the quartz-diorite variety of the granodiorite. The manner in which these different kinds of rocks outcrop is characteristic of stratified formations. The Westboro Quartzite and the Marlboro Formation are stratified and as explained in the section of this report concerning the origin and relations of the Dedham Granodiorite the micrographic and quartz-diorite varieties of this igneous formation are considered by the writer to have been formed by the metasomatic replacement of earlier stratified rocks. This mode of origin for the igneous rocks brings up a question concerning the relationship between the structural position of the stratified formations at the time of the emplacement of the Dedham batholith and the present arrangement of the varieties of rocks in belts along the length of the Saugus-Melrose anticline. At the present time the remnants of the stratified formations have a
general northeast-southwest strike and a steep northwestward
to vertical dip. All of the remnants are found on the north-
west flank of the Saugus-Melrose anticline. In the opinion
of the writer the present steep attitudes of the stratifica-
tion are the cumulative results of at least two periods of
deformation. The initial deformation occurred prior to or at
about the same time as the emplacement of the Dedham batholith.
It is probable that the stratified formations had a gentle
northwestward dip as the magmatic invasion commenced and this
dip may have been intensified during the course of the em-
placement and shortly thereafter. It is probable that the area
was crumpled into broad open folds as the result of the first
period of deformation. The second period of deformation came
some time after the eruption of the Lynn Volcanics and a gentle
warping that produced the Saugus-Melrose anticline caused the
remnants of the stratified formations on the northwest flank
of this structure to be rotated into a more steeply dipping
attitude. This sequence of deformations is the same as that
proposed for the Marblehead Neck locality and it is entirely
possible that the major structures of the area formerly may
have been continuous between the two localities. Some geolo-
gists have postulated that the older stratified formations of
Eastern Massachusetts were compressed into isoclinal folds
prior to the emplacement of the batholiths, apparently on the
basis of the nearly uniform dips and strikes exhibited. This
hypothesis cannot satisfactorily be applied to the Boston Metropolitan Area. If isoclinal folds were formed before the invasions of the igneous rocks then those roof phases of the Dedham batholith that are the result of the metasomatic replacement of the stratified rocks must represent either the troughs of the folds or the penetration of great distances into nearly vertical strata. In the first instance it would be reasonable to expect to find some nearly flat attitudes of stratification in the remnants. Regardless of the amount of subsequent rotation some part of the trough of an isoclinal fold has to have a nearly horizontal attitude. There is not any reason to believe that metasomatic replacement proceeded for great distances upward into the roof of the batholith and field evidence seems to support this view.

Minor structural features in the Saugus-Melrose anticlinal segment include many small faults, several of which are apparently related to the north boundary overthrust of the Boston Basin. The displacement along the minor faults has been small and generally not sufficient to bring different rock types into contact. There are several large basic dikes in the segment, most of which run in approximately east-west directions but with a few exceptions running in nearly north-south direction. The great Medford Diabase dike is one of the latter.

THE WESTERN UPLAND: The Western Upland is separated from
the Saugus-Melrose anticline by the valley of the Mystic and Aberjona Rivers. This lowland may be the site of a fault-line but there is not much evidence to prove the existence of a major rupture. The remnants of the Early Paleozoic stratified formations appear to pass uninterrupted from Medford and the eastern part of Winchester across the lowland into Arlington and the western part of Winchester. Outcrops along the borders of the upland are widely scattered. On the west side of Upper Mystic Lake there are some outcrops of the Marlboro Formation that are sheared and brecciated. The Salem Gabbro-diorite in the southwest part of Woburn has been hybridized and has a gneissic texture. The features exhibited by the few outcroppings do not warrant the mapping of a fault along the valley of the Mystic and Aberjona Rivers. The rocks of the Western Upland consist mainly of Salem Gabbro-diorite that has been locally hybridized and invaded by small plugs associated with the Dedham batholith. Remnants of the Early Paleozoic stratified formations are abundant in the south part of the upland and in a belt extending from Lexington to Woburn. There are some large masses of granitic rock in the extreme northwest corner of the area.

Outcrops in the western Upland tend to be concentrated in a few localities that are separated by wide expanses of terrain covered by glacial debris. Because of the absence of outcrops on large portions of the upland and because of the similar
types of rock found in neighboring localities it is not possible to identify many structural features. The south edge of the upland is broken by a few minor faults associated with the north boundary overthrust of the Boston Basin. Remnants of the Early Paleozoic stratified formations found in Arlington, Belmont and Waltham generally have a northeastward strike and a steep northwestward dip. The location and attitude of these remnants suggests a continuation of structure from the Saugus-Melrose anticline. Stratified remnants of the same formations found in Lexington and Woburn have similar attitudes but there are not enough outcrops in the vicinity to furnish data that would give an explanation for the apparent repetition of structure. The attitude of stratification in the volcanic flows of the Woburn Formation indicates the probability of a fault passing along the ravine called Shaker Glenn in the southwestern part of Woburn. The flows forming the entire northwest slope of the ravine dip steeply to the southeast while the southeast slope is composed of Salem Gabbro-diorite and minor intrusions of Dedham Granodiorite. The deep ravine indicates a line of structural weakness such as could be caused by a fault.

**Nahant:**

One of the structural puzzles of the Boston Metropolitan area is furnished by the mass of basic igneous intrusive rock comprising Nahant and Little Nahant and which has the appearance
of a group of islands rising up out of the Boston Basin. This igneous rock is closely related to the Salem Gabbro-diorite in composition and apparently is a part of the Early Paleozoic igneous complex. Because of its isolated position in Massachusetts Bay with all other outcrops, except for Egg Rock, being located at distances of three miles or more there is not any available data by which the structural relations of Nahant can be determined.

There are three possible ways of accounting for the presence of the igneous rock mass comprising Nahant, none of which can be proven on the basis of present knowledge. Nahant may have been an island or a local highland in the basin in which the sediments of the Boston Bay Group were accumulated. In this case the north boundary fault of the Boston Basin would presumably be continuous with the Marblehead fault or else would pass to the eastward a short distance to the south of Phillip's Point. A second possibility is that the north boundary fault of the Boston Basin swings southward from the vicinity of the Saugus marshes and passes eastward to the south of Nahant. Nahant in this case would be a part of the Fells Upland, the southeastern portion being submerged under the water of Massachusetts Bay. A third possibility is that Nahant is a local uplifted block surrounded by faults. The eastern tip of Nahant is composed of the Lower Cambrian sedimentary Weymouth Formation and is known to be separated from the gabbro by a fault with the igneous rock forming the relatively uplifted block. Whether or not other faults surround
the locality is not known. The three possible explanations for the presence of the igneous rock of Nahant outlined above are merely speculative. The location of possible faults existing in the vicinity cannot be determined by visual field methods although data might be obtained by geophysical methods.

THE BOSTON BASIN:

PRINCIPAL DIVISIONS: The structural geology of the greater part of the Boston Basin has been described and discussed quite thoroughly in two papers by Billings\textsuperscript{1-2}. Since the writer is in agreement with the greater part of the descriptions presented in these papers, the nomenclature and plan used by Billings will be followed closely in the following discussion.

Billings divides the Boston Basin into three main structural divisions which are, a northern synclinorium, a central anticline and a southern shingle-block zone. Each of these main divisions is further divided into individual structures.


\textsuperscript{2} Billings, Marland P., Loomis, Frederic B., Jr., and Stewart, Glenn W., Carboniferous Topography in the Vicinity of Boston, Massachusetts, Bulletin Geological Society of America, Vol. 50, Pages 1367-1384, 1929.
THE NORTHERN SYNCLINORIUM:

Outcrops in the northern part of the Boston Basin are widely scattered and for the most part consist of siltstone. The siltstone horizons are most characteristic of the upper portion of the sedimentary series of the Boston Bay Group that accumulated near the central portion of the basin. Billings identifies the following individual structures within the northern synclinorium; the Tufts syncline, the Somerville monocline, the Watertown faulted anticline or shingle block, and the Charles River syncline.

TUFTS SYNCLINE: Billings states "In the vicinity of Tufts College, Medford, the highest stratigraphic unit in the Boston Basin, the Tufts Quartzite is exposed in a doubly plunging syncline. The Cambridge Argillite on the north limb dips 60° to 70°S and on the south limb 45°N".¹ The outcrops showing this structure evidently have been removed or covered in the course of grading preparatory to planting lawns because the writer was unable to find them. A few siltstone outcrops located a short distance to the southwest indicate the presence of an anticlinal axis passing immediately to the southward of Tufts College. This structure verifies the presence of a synclinal axis in the immediate vicinity of the college. The

writer is of the opinion that there is not sufficient evidence to warrant designating any statum found in this locality as being the highest stratigraphic unit of the Boston Basin.

SOMERVILLE MONOCLINE: Billings describes the structure in this locality thusly "Throughout Cambridge and Somerville the argillite is folded very gently and dips over 25° are rare. As a rule the strata dip to the south, but an occasional northerly dip has been recorded indicating some warping of the monoclinal structure". The writer's observations verify this statement.

WATERTOWN AREA (WATERTOWN SHINGLE-BLOCK OR FAULTED ANTI-CLINE: The outcrops existing at present in this locality are small and not too satisfactory for the purpose of determining structure. Comments in some of the older geological reports lead one to believe that several outcrops that formerly may have existed in this locality have been removed during the course of building a residential district. The writer found four siltstone outcrops in the vicinity of Meeting House Hill. One was at the south side of the hill in an excavation in Kimball Street. Here the bedding strikes N82E and dips 71 degrees NW. Three small exposures of the siltstone are located

near the northwest end of Meeting House Hill. The rock in these outcrops is sheared, brecciated and rather thoroughly decomposed thereby making the determination of attitude of stratification rather uncertain. In the most southerly outcrop the bedding strikes N75W, dips 55NE, in the intermediate outcrop the strike is N80E, dip 50 degrees NW and the most northerly outcrop was so thoroughly shattered that measurements could not be made. The intensity of the brecciation in these outcrops increases as the north boundary fault of the Boston Basin is approached. The only outcrops of conglomerate in the Watertown locality lie at the west side of the Coolidge School. This conglomerate has a large proportion of sandy matrix, contains a few streaks of fine grained gravel, a few small pebbles of quartzite and Dedham Granodiorite and numerous fragments of siltstone, some of which are two feet in length. One outcrop is in the school yard at the west side of the building. The strike of some gravel streaks is N80E but the outcrop is flush with the hard packed surface of the ground and an accurate measurement of the dip could not be obtained. The dip appears to be towards the northwest. Another outcrop of the conglomerate is found one block northwest of the school. This exposure is cut by some basic dikes and does not exhibit good bedding. The strike appears to be approximately N85E and the dip 55 degrees NW. The strata in all of the siltstone and conglomerate outcrops observed are
in an upright position with topside towards the northwest. The writer disagrees with Billings interpretation of structure in the Watertown locality in two respects. The conglomerate in this locality is not at the base of the sedimentary series as he indicates but is well up in the stratigraphic column as is shown by its content of siltstone fragments. The strike of its stratification indicates it to be interbedded between the siltstone at the south and the siltstone at the north of Meeting House Hill. The writer's measurements of dip are all to the northward while Billings shows his to the southward.

Billings description of the Watertown locality is as follows; "On meeting House Hill, Watertown, the top of the Roxbury conglomerate is exposed beneath the slates of the Cambridge formation. Mr. Robert W. Sayles informs me that the upper ten feet of the conglomeratic rock consists of Squantum tillite. The strata strike N80W and dip 28°S. Inasmuch as the region to the north and south is underlain by the Cambridge formation, the appearance of the Roxbury conglomerate must be due to an anticlinal structure. Mansfield reached the same conclusion. Although the southern limb of this anticline is exposed, no northern limb is known. There are two possible explanations for this fact; the northern limb may be present but buried beneath the glacial outwash immediately to the north of Meeting House Hill or there may be no northern limb due to the fact that the Roxbury conglomerate is thrust over the Cambridge
argillite. The latter interpretation is accepted as the correct one, for it is in full accord with the structural characteristics of the southern part of the Boston Basin, where the structures are more readily determined.¹ The outcrops in the Watertown locality are not sufficiently abundant to indicate structure in a satisfactory manner. It is known that large areas of siltstone lie both to the north and to the south of the conglomeratic rock. The presence of siltstone fragments in the conglomerate is proof of a stratigraphically lower siltstone horizon. Although a tightly folded anticlinal structure is possible the writer is inclined to doubt this interpretation of the structure. Because of the poor quality of the rock exposed in the outcrops it is possible that either Billings or the writer may have made some incorrect measurements of the strike and dip.

CHARLES RIVER SYNCLINE: The Charles River syncline occupies the north central portion of the Boston Basin. Billings apparently uses the term in a restricted sense as applying to the Brighton-Newton-Watertown locality but the writer prefers to use it in a much larger scope and extend the structure far out into Boston Harbor. The syncline is

bounded on the south by the northward dipping limb of the central anticline and on the north by the southward dipping strata of the Somerville monocline. Data obtained from exposures in Boston Harbor demonstrate the eastward extension of the structure. Prof. R. R. Shrock informed the writer that he saw siltstone in the excavation made during the course of construction of the drydock in the South Boston Navy Yard. The bedding has an approximate east-west strike and a dip of 20 degrees to the north with the topside being up and to the north. At the extreme south end of Governors Island siltstone is found striking N75E and dipping 45 degrees NW. About two hundred and fifty yards north of the south end of the island and stratigraphically upwards there are some outcrops of a rather fine grained friable dark red sandstone. It is possible that this rock can be correlated with Billings' Tufts Quartzite. The siltstone at the Navy Yard and at Governors Island lies on the south limb of the Charles River syncline.

CENTRAL ANTICLINE:

The central anticline is a broad simple fold occupying the south central part of the Boston Basin. The axis of this structure strikes slightly north of a due east-west direction beginning at the Charles River in the Oak Hill section of Newton and passing into Boston Harbor at about a mile to the north of Savin Hill in Dorchester. The fold is partially
truncated at the southwest by the south boundary fault of the Boston Basin and plunges gently to the eastward so that stratigraphically higher horizons are encountered in this direction. The strata forming this structure outcrop through a distance of approximately five miles in a north-south direction from Brighton to West Roxbury. This width narrows to the eastward because of the plunge of the fold. The north limb of the fold has the flatter dips and therefore is slightly wider than the southern limb. The anticline is broken by a great north-south tear fault which passes through the east end of the Arnold Arboretum, Jamaica Pond and along the course of the Muddy River and is called the Stony Brook tear fault. The western segment of the structure has moved northward approximately three-quarters of a mile with respect to the eastern segment.

Much of the conglomerate in the central anticline has an incipient flow cleavage developed in the sandy matrix. The outcrops in which this cleavage is best developed often exhibit a crude alignment of pebbles that gives to the rock an appearance of stratification that apparently has been erroneously used to interpret structure by some investigators. Throughout the anticline this cleavage strikes approximately parallel to the axial line of the fold and dips steeply to the northward. Occasional thin sandy lenses in the conglomerate show fracture cleavage. The relationship between the stratification and both kinds of cleavage verifies the
determination of an anticlinal structure.

The stratigraphically lowest horizon exposed on the central anticline is a small part of the Mattapan Volcanic Complex found on the golf course of the Charles River Country Club in the Oak Hill section of Newton. This rock outcrops at the crest of the structure. Next higher in the stratigraphic column are some basic volcanic flows that the writer considers to be a part of the Brighton Volcanic Complex. The outcrops of this rock are somewhat scattered but show an arrangement controlled by the anticlinal structure. The Roxbury conglomerate outcrops over the greater portion of the structure and the hard resistant beds of this rock form a rough, hilly terrain with elevations of fifty to two hundred feet higher than than of the bordering lowlands. The basal Roxbury beds consist of a coarse boulder conglomerate with almost no grading of sedimentary material. The clastic material becomes finer and better graded in stratigraphically higher beds until finally an interstratified sequence of sandstone, siltstone and pebble conglomerate is found along the outer edges of the conglomerate outcrops along the flanks of the anticline. The fine grained strata are not particularly resistant to erosion and therefore outcrops of them are rare. Some of the best exposures are found on the east side of Center Street between V. F. W. Parkway and Weld Street in West Roxbury. Scattered outcrops of a conglomeratic rock believed to be the Squantum Tillite are found along the north
edge of the lowland on the south flank of the anticline. This member of the sedimentary series apparently is missing on the north flank. Basic flows of the Brighton Volcanic complex are interbedded with the uppermost conglomerate strata on the north flank of the anticline. Local lenticular masses of siltstone and sandstone are found interbedded with the conglomerate strata on both flanks.

A large mass of dark reddish gray varved siltstone lies in the north flank of the central anticline in the vicinity of the Chestnut Hill Reservoir. Good exposures of this siltstone can be seen between the two parts of the reservoir and in cuts along the railroad to the south of the reservoir. The same rock is found underlying conglomerate along the north side of Beacon Street about a mile to the west of the Reservoir. Several explanations to account for the presence of this siltstone are found in the literature. Some geologists have suggested that it is a down folded mass of the Cambridge Siltstone forming a tight syncline with the conglomerate having been thrust over the structure along the Chestnut Hill overthrust. Other geologists have considered the siltstone to be interbedded between conglomerate strata which is also the view held by the writer. The relations of the siltstone to the underlying conglomerate can be seen in outcrops in the cuts along the railroad to the south of the reservoir. The contact is conformable. The relations with the overlying conglomerate can be seen in several exposures along the north side
of Beacon Street. Here the siltstone dips northward and its upper surface has been grooved by wide erosion channels. The overlying conglomerate fills the erosion channels and dips northward with an angular unconformity of approximately five degrees. There is not any evidence of faulting along the contact. The stratification in the siltstone is not disturbed, none of the rock is brecciated and there is not any gouge along the contact. The siltstone has fallen away from the conglomerate at a few places thereby exposing several square feet of the contact surface on the base of the conglomerate. There are not any slickensides or other structures associated with faulting. The only conclusion that satisfies the observed field relations is that the siltstone is interbedded between conglomerate strata with a short erosional period being represented by the unconformity at its upper surface.

A small overthrust fault can be seen in the conglomerate outcrop on the east shore of the Chestnut Hill Reservoir. This fracture appears to be one of small displacement and does not bring different rock types into contact with one another. The rock on the north side of the fault plane appears to be overthrust to the south. This rupture is evidently a minor local fault but it has been mentioned frequently in older geological reports of the area and has been called the Chestnut Hill overthrust.

At Newton Upper Falls a small fault can be seen on the
banks of the Charles River just to the south of the Worcester Turnpike. The fault strikes northwestward. The relative displacement of the southwest segment northward by approximately one hundred feet is indicated by parts of a basic flow of the Brighton Volcanic Complex exposed on the banks of the river.

**SOUTHERN SHINGLE BLOCK ZONE:**

The structure of the southern part of the Boston Basin has been determined by Billings to be an imbricate or shingle-block zone of ruptured anticlines and overthrusts. A discussion of the possible tectonic forces that could produce this structural pattern is presented in his paper. The structure in the southern shingle-block zone is most conveniently described by dividing it into three segments with the north-south Stony Brook and Quincy tear faults being the division lines. Billings recognized the following individual structural features in the southern zone; Franklin Field faulted syncline, Mt. Hope thrust, Calvary shingle-block, Sally Rock thrust, Dorchester faulted anticline or shingle-block, Lower Mills syncline, Neponset thrust and the Milton

faulted anticline or shingle-block. The writer is in agreement with the main features of Billings' description and therefore will make only brief comments concerning the individual structures.

FRANKLIN FIELD FAULTED SYNCLINE: The Franklin Field faulted syncline lies south of and parallel to the Central Anticline with the northwest limb of the syncline being the southeast limb of the anticline. In the segment east of the Stony Brook tear fault the uppermost strata of the typical Roxbury Conglomerate outcrop in the extreme western corner of the Forest Hills Cemetery and can be followed northeastward along a line striking approximately N65E through the Scarborough Golf Course in Franklin Park, Mt. Bowdoin and Meeting House Hill in Dorchester and finally ending at Savin Hill on the shore of Dorchester Bay. The dip of these strata is approximately 60 degrees SE in the Forest Hills Cemetery and flattens gradually to become 30 degrees at Savin Hill. Immediately overlying the conglomerate are interbedded sandstones, red siltstones and fine grained conglomerates having good water laid stratification. These finer grained clastic sediments are not particularly resistant to erosion and therefore outcrops are rare. Next higher in the stratigraphic column is a stratum of conglomeratic rock correlated with the Squantum Tillite of which outcrops are found at the corner of Harvard Street and Blue Hill Avenue, fifty yards southwest of the
corner of Canterbury Street and Horton Street, and in the central part of the Forest Hills Cemetery. South of the tillite there is a lowland one-half mile to one mile in width that is almost completely devoid of outcrops. A few exposures of Cambridge Siltstone are found along the south border of the lowland. At the west end of the segment in the Mt. Hope Cemetery the stratification in the siltstone outcrops shows a synclinal structure with a northeastward plunge. The southeast limb is almost completely cut off by rocks of the Mattapan Volcanic Complex thus indicating an overthrust fault contact. About one mile east of the Mt. Hope Cemetery the Cambridge Siltstone is exposed in an abandoned quarry at Willowood and Dumas Streets. The bedding strikes N66E and dips 70 degrees to the southeast with the strata in an upright position and topside to the southeast. The Mt. Hope thrust apparently passes a few yards to the south of this siltstone exposure. Billings reports, "The actual contact of the Cambridge argillite and the Roxbury conglomerate is exposed a few hundred feet to the west in Middleton Street, Dorchester. It is clearly a thrust contact. The argillite is sheared to a slate and the conglomerate has been reduced to a mylonite. At the immediate contact two thin slices of the mylonitized conglomerate have been driven into the slate. The shearing planes dip about
indicating that the thrust plane has been greatly steepened since it was first formed. ¹ In this locality the Roxbury Conglomerate has replaced the rocks of the Mattapan Volcanic Complex on the south border of the thrust because of the easterly plunge of the structures. The siltstone appears to extend eastward where it underlies Dorchester Bay and Boston Harbor. In speaking of the Dorchester Bay locality Billings says, "During the last century a sewage tunnel was driven through the bed-rock underlying Dorchester Bay from a point on the peninsula just north of Savin Hill southeasterly to Squantum Head. The northwesterly four hundred feet of the tunnel lies in conglomerate but whether it is tillite or ordinary conglomerate is not recorded. The remainder of the tunnel lies in the Cambridge argillite of the Franklin Field faulted syncline." ² The tillite of Squantum Head most likely has been overthrust onto the Cambridge Siltstone with the fault line passing under the water.

of Dorchester Bay a few yards to the northward of the shore-
line. At no other place in the Boston Basin are outcrops
thought to be tillite found to be separated from the Roxbury
Conglomerate by at least twenty-five hundred feet of siltstone
as is the case between Squantum Head and Savin Hill. An
overthrust is the only explanation that satisfactorily ties
in with the structure to the westward.

The axis of the Franklin Field faulted syncline lies
close to the Mt. Hope thrust. The greater portion of the
southwest limb of the syncline has been eliminated by the
Calvary shingle-block.

In the segment to the west of the Stony Brook tear
fault the same sequence of strata from Roxbury Conglomerate
to siltstone is found. The entire segment has been displaced
at least thirty-five hundred feet to the northward. The
sandy and silty strata lying between the conglomerate and the
tillite can be seen in a road cut on the east side of Center
Street just to the north of the intersection with Weld Street
in West Roxbury. Exposures of tillite are found on the south
side of Weld Street both to the east and west of Center Street
and on the west side of Maple Street one block south of Weld
Street. Several outcrops of the Cambridge Siltstone are found
in Roslindale and West Roxbury and are sufficiently distrib-
uted to indicate the presence of a large mass of this rock.
The strike is always to the northeastward and the dips are
approximately 65 degrees SE. Several large exposures of the siltstone are found in the vicinity of the railroad bridge at Temple Street. Approximately three hundred yards to the south of these exposures there are outcrops of the Dedham Granodiorite. An overthrust with a displacement of several thousand feet is indicated since the entire south limb of the syncline has been faulted out of position. The northern edge of the igneous rocks can be traced eastward to the Clarendon Hills where it is lost under the glacial terrain. This overthrust is presumed to be the westward extension of the Mt. Hope thrust.

**MT. HOPE THRUST:** The Mt. Hope thrust is the fault along which the Calvary shingle-block has been overthrust onto the Franklin Field faulted syncline. The best evidence for the existence of this rupture is seen in the south part of the Mt. Hope Cemetery where rocks of the Mattapan Volcanic Complex are exposed along the southeast border of the Cambridge Siltstone. Since evidence from other localities shows conclusively that the Mattapan Volcanic Complex was erupted onto an erosional surface of the Dedham Granodiorite and underlies the basal strata of the Boston Bay Group, a displacement that can be measured in hundreds, if not thousands, of feet is necessary to bring volcanic rock into a position opposite the siltstone. Billings's description of a contact between "argillite"
and conglomerate in an outcrop that formerly existed on Middleton Street and which is quoted above is further proof of a thrust fault.

The Mt. Hope thrust is extended to the northeast to account for the tillite of Squantum Head being in a position overlying the siltstone in Dorchester Bay. Outcrops at Squantum Head and on the beach down to the low tide mark do not show any evidences of faulting and therefore the thrust plane, if it exists in this vicinity, must be offshore at a short distance to the northward. The lack of exposures by which it would be possible to connect the tillite of Squantum Head with other outcrops of the same rock makes it necessary to postulate an overthrust. The tillite on the north flank of the Franklin Field faulted syncline cannot be extended to Squantum Head without cross-cutting a great thickness of siltstone, this being an impossible situation. The most reasonable hypothesis fitting the available field data is that the tillite of Squantum Head is a part of the Calvary shingle-block and has been overthrust onto the siltstone to the north. Positive proof of the fault should have been obtained when the sewage tunnel was driven under Dorchester Bay but unfortunately there seems to be no record of the conditions
encountered during this construction.

CALVARY SHINGLE-BLOCK: The stratigraphic sequence in the Calvary shingle-block is displayed most completely in a section extending from the Mt. Hope Cemetery southeastward through the New Calvary Cemetery. In the southeast edge of the Mt. Hope Cemetery there are outcrops of the Mattapan Volcanic Complex. A few yards southward on the south side of Harvard Street there is Roxbury Conglomerate with interbedded sandy strata striking N35W and dipping 74 degrees SW. Sedimentation features and excellent fracture cleavage in the sandy strata show the beds to be in an upright position with topside to the south. The conglomerate is thin in this locality and on the south side of the cemetery there is exposed approximately one hundred feet of gray siltstone strata. Field relations do not satisfactorily indicate whether this fine grained sedimentary rock is a part of the main body of the Cambridge siltstone or is a thick stratum interbedded with conglomerate and can be correlated with that exposed in the Lower Hills syncline. The bedding in the siltstone strikes N35W and dips 35 degrees SW. The next outcrops are located about three hundred yards to the southeastward on the southside of Itasca Street and are composed of volcanic rock. Another overthrust fault, the Sally Rock thrust, presumably separates the siltstone and the volcanic rocks. Eastward from the above locality the
outline of the Calvary shingle-block becomes obscure because of a lack of outcrops. Sayles\(^1\) describes an outcrop near the east side of the New Calvary Cemetery that he thought might have been Squantum Tillite. This outcrop has been removed but if the siltstone in the south edge of the cemetery is the Cambridge member of the Boston Bay Group then the location is favorable for the tillite. Five miles to the eastward the tillite at Squantum Head and the thick siltstone member comprising the main part of Squantum are considered to be a part of the Calvary shingle-block.

**SALLY ROCK THRUST:** The Sally Rock thrust is the fault along which the Dorchester faulted anticline or shingle-block has been thrust over the Calvary shingle-block. The evidence indicating the presence of this rupture is largely circumstantial. Rocks of the Mattapan Volcanic Complex at the base of the stratified series are found a short distance south of the southward dipping siltstone outcropping in the south part of the New Calvary Cemetery. There are not

---

any outcrops in the locality showing a reversal of attitude of stratification and therefore it is necessary to conclude that the volcanic rock has been thrust over the sedimentary rocks. About one mile to the eastward in the vicinity of Morton Street the same relationship exists. The rupture is extended to the eastward to account for the position of the large mass of tillite on the southeast shore of Squantum. This tillite is presumably thrust over the thick sequence of siltstone strata occupying the central part of the peninsula. The outcrops in the locality do not show any signs of the existence of a major overthrust but there are wide drift covered gaps in which no outcrops are found and through which the fault line could pass. Billings\(^1\) extends both the Mt. Hope and the Sally Rock thrusts to the westward of the Stony Brook tear fault. Many of the outcrops that he used as evidence for the westward extension of these ruptures have been removed during the construction of a residential district. There is undisputable evidence that the Dedham Granodiorite has been thrust over the Cambridge Siltstone of West Roxbury and Roslindale along what is presumably the westward extension of the Mt. Hope thrust. The westward extension of

the Sally Rock thrust is not clearly demonstrated by the remaining outcrops.

DORCHESTER FAULTED-ANTICLINE OR SHINGLE BLOCK: The Dorchester faulted anticline has been thrust over the Calvary shingle-block. Only the southeast limb of this structure is preserved and all strata dip in this direction. The sequence of strata is best exposed along a northwest-southeast traverse passing about one-half mile to the northeast of Mattapan Square. Along the northwest edge of the structure and adjacent to the Sally Rock thrust the flows of the Mattapan Volcanic Complex are exposed as the core of the fold. The volcanic rocks disappear to the northeastward because of the plunge of the structure. The stratigraphic column consists of several hundred feet of volcanic rocks, nearly a thousand feet of conglomerate, a thick grayish siltstone stratum and an upper conglomerate member. The siltstone member which is exposed on the grounds of the Boston City Sanatorium and on the south slope of Codman Hill is not the Cambridge Siltstone but a local stratum interbedded in the conglomerate. The Dorchester anticline extends to the northeastward to include the tillite and siltstone on the southeast shore of Squantum. The conglomerate that extends southwestward into East Dedham appears to be a continuation of the Dorchester anticline that has been displaced to the northward
along the Stony Brook tear fault. The conglomerate in the East Dedham locality apparently unconformably overlies Dedham Granodiorite without any intervening volcanic rocks or thrust fault.

LOWER MILLS SYNCLINE: The Lower Mills syncline forms a continuous structural sequence with the Dorchester faulted anticline, the southeast limb of the anticline being the northwest limb of the syncline. This structure is a south-westerly plunging fold which is an exception to the characteristic attitude found in the Boston Basin. The structure is most readily seen in Dorchester Park about one-half mile to the northeast of Milton Lower Mills. The stratification in numerous outcrops of conglomerate shows that the nose of the fold is located in the park. A short distance to the west of the park on the south slope of Codman Hill there is exposed the thick siltstone member interbedded with conglomerate. Drag folding developed in the siltstone along the contact with the overlying conglomerate indicates the major structure to be a southwestward plunging syncline. The siltstone is again exposed in a railroad cut on the south bank of the Neponset River, here dipping northward on the southeast limb of the syncline. The synclinal structure extends southwestward to the vicinity of Mattapan Square where it is apparently cut-off by a fault. According
to Billings shale (siltstone) was exposed in sewer excavations in the vicinity of Mattapan Square in 1927.¹ The synclinal axis lies a short distance northwest of the north bank of the Neponset River. A few outcrops of conglomerate lying to the east and northeast of Dorchester Park have stratification striking northeastward and dipping to the southeast.

**NEPONSET THRUST:** Immediately south of Mattapan Square in the north part of Milton rocks of the Mattapan Volcanic Complex are found outcropping a few yards south of exposures of conglomerate and siltstone lying on the bank of the Neponset River. Billings explains this relationship by means of an overthrust which has brought the volcanic rocks at the south over the sediments at the north.² This rupture is presumed to die out about one and one-half miles to the eastward in the vicinity of Milton Lower Hills. The field evidence that can be presented as a basis for postulating a

---


large scale overthrust in this locality is rather obscure. There are no outcrops of sedimentary rocks in the immediate vicinity in which definitely northward dipping stratification can be found and thereby indicate that the volcanic rocks have been brought to the surface on the south limb of the Lower Hills syncline. A badly sheared outcrop of conglomerate on the river bank appears to have vertical stratification but the condition of the rock prevents a positive identification of the topside of the strata. The writer is inclined to believe that a tightly compressed synclinal fold with minor local faulting is a more reasonable interpretation of structure for this locality than is an overthrust block.

MILTON FAULTED ANTICLINE OR SHINGLE-BLOCK: This anticlinal structure lies in the north part of Milton. Whether or not it is faulted depends upon the possible existence of the Neponset thrust. The rocks exposed on the structure consist almost wholly of parts of the Mattapan Volcanic Complex. An outcrop of conglomerate in which the stratification strikes N60E and dips 70 degrees SE is found at the corner of Valley Road and Lancaster Lane. This outcrop of conglomerate is surrounded at short distances by outcrops of volcanic rocks and except for the steep dip field relations indicate it to be an erosional remnant lying on the crest of the fold. A few outcrops of conglomerate are found along the south border of the volcanic rocks. A wide expanse of drift covered terrain lies to the southward of these
last mentioned outcrops.

**SOUTHEASTERN PART OF THE BOSTON BASIN:**

The extreme southeastern part of the Boston Basin can be divided into four parts, the Nantasket, the Hingham, the Rock Island and the Quincy areas. The Nantasket area includes that part of the Boston Basin extending from the northeast part of Cohasset on the east to Hingham Harbor on the west. The Hingham area extends from Hingham Harbor westward to the Quincy tear fault which runs approximately north-south through the middle of the town of Quincy. The Rock Island area occupies the south part of the peninsula north of Quincy that is called Hough's Neck. The Quincy area lies in the north part of the town of Quincy. Field work by the writer did not cover the south border of these areas and therefore some of the material used in the following descriptions is taken from other sources.

**NANTASKET AREA:** The rocks exposed in the Nantasket area are parts of the Dedham Granodiorite, the Roxbury Conglomerate and the Brighton Volcanic Complex. The conglomerate lies unconformably upon the granodiorite. The contact can be seen on several outcrops, the best of which are located on both sides of George Washington Bouvelard about one-half mile south of Nantasket Beach. The volcanic flows are inter-stratified with the conglomerate.

The principal structural feature of the Nantasket area
is a shallow syncline having an axis striking approximately N30E and pitching gently in the same direction. The dips on both limbs of the syncline are rather flat, not exceeding thirty degrees. The axis of the fold lies a short distance north of the Weir River. The fold extends into the Atlantic Ocean on the northeast and is not apparent at the southwest because of a large mass of granodiorite in which structural features cannot be seen. This granodiorite formed a hill in the basin at the time the conglomeratic strata were being deposited and is exposed at present because erosional agencies have removed whatever sedimentary strata may have covered it during the past. The synclinal axis passes through the mass of granodiorite and is easily detected in sedimentary rocks exposed in the adjoining Hingham area.

The synclinal structure is broken by several minor faults of small displacement. The largest of these minor faults is a thrust exposed at a distance of one hundred to two hundred yards north of the Weir River. It has an approximate east-west strike and the south side has moved relatively upwards. This fault appears to die out near the east side of the area but in the central portion it may have a displacement of a hundred feet or more. A normal fault having but a few feet of displacement strikes approximately east-west along the north edge of the outcrops one-quarter of a mile to the south of Nantasket Beach. The north side is relatively downthrown. Another normal fault of similar displacement cuts
across the tip of the rocky point one-half mile northeast of Planters Hill. Crosby places a major thrust fault with an approximate east-west strike in the granodiorite immediately to the south of the area investigated by the writer. ¹

An isolated outcrop of reddish gray siltstone is found on the south shore of Hull at a distance of approximately three and one-half miles northwest of Nantasket. This is one of the few exposures of rock having a slaty cleavage to be found in the Boston Basin. The bedding strikes N57E and dips 12 degrees SE while the cleavage strikes N58E and has a vertical dip. The relationship between cleavage and bedding indicates an anticlinal axis to the northwest and a synclinal axis to the southeast.

HINGHAM AREA: The principal structures in the Hingham area are an anticline and a syncline with east-west trending axes and two thrust faults, one of which marks the south border of the basin sediments and the other passes in an east-west direction through Quincy Bay. The anticlinal structure and the bordering overthrust fault at the south have been described in great detail by Crosby. ²

anticlinal axis passes between Squirrel Hill and Baker Hill in the north part of Hingham and through the extreme south end of Hingham Harbor. The structure plunges steeply to the westward. The core of the fold consists of Dedham Granodiorite while stratified rocks of the Roxbury Conglomerate and the Brighton Volcanic Complex are found on the north limb and the westerly plunging nose. A fault has eliminated most of the south limb with the Dedham Granodiorite of the Sharon Upland having been overthrust onto the structure.

The synclinal axis, which is the westward continuation of the Nantasket structure, passes a short distance to the southward of Sarah and Ragged Islands and Walton Cove in Hingham Harbor and continues on across Crow Point to pass through Hewitt's Cove on the east shore of Weymouth Back River. The fold has a westerly plunge in this area. The south limb of the syncline is the north limb of the anticline described above. Starting near the south side of Baker Hill on the south limb of the anticline it is possible to trace the conglomerate strata around the westerly plunging nose of the fold to the north limb near the northwest part of Squirrel Hill and thence in a wide sweeping arc around the nose of the westerly plunging syncline to the north side of Crow Point, the entire traverse having the form of a reversed letter S. The structure on the north limb of the syncline in the vicinity of Walton Cove and the islands in Hingham Harbor is somewhat difficult to visualize because the
stratification in the conglomerate is seemingly truncated by a large mass of Dedham Granodiorite that crosses the synclinal axis and forms the entire shoreline along the east side of the harbor. This situation was formerly explained by postulating the existence of a north-south tear fault passing through Hingham Harbor but recent detailed studies by Billings\(^1\) indicate that the conglomerate strata were deposited in a deep valley and abutted against the granodiorite. A thick mass of basic volcanic rock lies in the north limb of the syncline on Grow Point and further tends to obscure the structure.

The structure of the westerly plunging syncline is most readily seen at Hewitt's Cove where the base of the Cambridge Siltstone is exposed. The continuity of the siltstone in this locality is broken by a few east-west trending normal faults of small displacement along which small segments of conglomerate have been uplifted. On the north side of the cove the siltstone strata strike N\(^{35}\)W and dip 65 degrees SW, on the east side the strata strike N-S and have a steep westerly dip and on the south side of the cove the strike is N\(^{15}\)E and the dip is 54 degrees NE. These

\(^{1}\) Billings, Marland P., Loomis, Frederic B., Jr., and Stewart, Glenn W., Carboniferous Topography in the Vicinity of Boston, Massachusetts, Bulletin Geological Society of America, Vol. 50, Pages 1367-1884, 1929.
attitudes of the stratification demonstrate the synclinal fold.

On Slate Island and Grape Island lying about one-half mile off the north shore of Hingham there are outcrops which apparently are part of the Cambridge Siltstone. Crosby reports that Slate Island is practically bare of glacial drift, is composed of "slate" with minor diabase dikes and that the stratification strikes approximately N65°E to N70°E and dips 85 degrees SE. Bedrock is exposed at only two places on Grape Island, one being on the north shore where the stratification strikes N70°E and dips 75 degrees SE and the other being on the south shore where the stratification strikes N75°E and dips 85 degrees SE. A fault having a large displacement passes between these islands and the mainland and is considered to be the eastward extension of the Rock Island Thrust. This rupture cannot be seen at this locality but at extreme low tide a large mass of shattered and brecciated siltstone is exposed along the north edge of the mainland and indicates the fault-line to be only a short distance offshore.

ROCK ISLAND AREA: Rock Island is a rocky knob surrounded by salt marshes located on the south part of the peninsula.

called Hough's Neck. Three groups of outcrops are found
in this locality. The rocks exposed at Rock Island are
parts of the Roxbury Conglomerate and the Brighton Volcanic
Complex with most of the latter formation being represented
as a thick flow lying between sedimentary strata. The
stratigraphically lower horizon which is exposed along the
north side of the outcrops consists of normal Roxbury Con-
glomerate having an east-west strike and a dip of about
56 degrees S. The basic volcanic rock forms a horizon about	
two hundred feet thick and is overlain unconformably by
more conglomerate, the basal part of which contains numerous
large boulders from the volcanic flow. Several sandy lenses
and strata in the uppermost conglomerate have a strike of
N78W and a dip of 75 degrees SE. All of these stratified
rocks are in an upright position. The east end of this
group of outcrops is crossed by a north-south tear fault
along which the western segment has moved a short distance
to the northward.

On Racoon Island lying off the east shore of Hough's
Neck and almost in the line of strike of the outcrops on
Rock Island there are outcrops of Cambridge Siltstone and
rather fine grained conglomerate. The siltstone forms the
northern three-quarters of the island and has stratification
striking N85E and dipping 75 degrees NW. There is not any
satisfactory stratification exhibited in the conglomerate.
The writer did not find features that conclusively indicated topside of the strata. The dip of the siltstone strata is in the opposite direction from that of the conglomerate on Rock Island and since the latter is a stratigraphically lower horizon a thrust fault is indicated.

A few small outcrops of siltstone are found about three-quarters of a mile due west of Rock Island at the northeast corner of the salt marsh called Broad Meadows. The stratification strikes N82W and dips 80 degrees NE which is an attitude close to that of the siltstone on Racoon Island. The siltstone of these two localities is presumed to lie on the north side of the overthrust fault.

QUINCY AREA: Outcrops in the north part of Quincy are too few and too widely scattered to permit the determination of any structural features. At North Quincy on the north side of Billings Road there is an abandoned quarry in siltstone. The strata strike N75E and dip 85 degrees NW. The next nearest outcrops are the conglomerates and tillite exposed on the west side of the Squantum Naval Air Base at a distance of about one mile to the northward. In a southerly direction there is an outcrop of siltstone at the intersection of Furnace Brook Parkway and the Old Colony Railroad, the distance being approximately one and a half miles from the abandoned quarry. The strata strike N55E and have a vertical dip. There is an outcrop of silt-
stone on the Stony Brae golf course at the south side of Furnace Brook Parkway. Here the strata strike N75E and dip 85 degrees NW. A few feet to the southward there are conglomerate outcrops having stratification nearly parallel to that of the siltstone. Satisfactory indicators of tops and bottoms of strata are not found in these outcrops. A few yards of drift covered terrain separates the conglomerate from exposures of the Quincy Granite.

ROCK ISLAND THRUST: The Rock Island thrust extends almost due west from the north part of Hingham Harbor, passing between Slate Island and the mainland and thence continuing along a line passing to the south of Raccoon Island, to the north of Rock Island and to the south of the siltstone outcrops at the north edge of Broad Meadows. The rupture is not exposed at any place and its existence is inferred from the attitude of stratification in the few outcrops found along the fault-line. In the north part of Hingham in the vicinity of Crow Point the Roxbury Conglomerate strikes northwestward and appears to be truncated a short distance offshore by siltstone striking northeastward. The brecciated character of the siltstone exposed offshore near the mouth of Weymouth Back River at extreme low tide is indicative of a nearby fault. The opposing dips of the conglomerate at Rock Island and of the siltstone at Raccoon Island and at the north edge of Broad Meadows suggests
the probability of a large overthrust with the Rock Island conglomerate being a part of the overthrust block and the steeply upturned siltstones being parts of the over-ridden block. The eastward and westward extensions of this trust are obscured by glacial drift and bodies of water.

OUTER ISLAND OF BOSTON HARBOR:

The rocks comprising several small islands in the outer portion of Boston Harbor have been described in considerable detail by Crosby.\(^1\) Of the several islands having outcrops only Outer and Middle Brewster Islands have been visited by the writer and therefore most of the following brief description has been taken from Crosby's paper.

Outer and Middle Brewster Islands consist mainly of a great sill of coarse grained diabase that has been injected into strata of the Cambridge Siltstone. A small exposure of northward dipping siltstone is exposed on the southwest part of Outer Brewster Island near the U. S. Army wharf but otherwise these islands consist entirely of diabase. It is impossible to determine the exact thickness of the sill but at least seventy-five feet is exposed in the cliffs on the south side of Outer Brewster Island at low tide. Crosby

369

describes southward dipping "slates" on Calf Island and suggests a synclinal structure with this island being on the north limb and the Brewster Islands being on the south limb. Shag Rocks and Lighthouse Island lying about one-quarter of a mile to the south of the Brewster Islands are composed of diabase and northward dipping "slate" and Crosby suggests that the two groups of islands are separated by a longitudinal (northeast-southwest) fault with the southeast side being downthrown. There is not enough evidence available to support this interpretation of structure. The most northerly line of islands, that is, the Graves, the Roaring Bulls and Green Island, are composed of coarsely crystalline diabase and are probably parts of a great dike or sill. All of these islands owe their existence to the resistant character of large diabase dikes or sills, portions of which have remained intact while the enclosing siltstones have been removed by erosional agencies. These rocks are too far removed from other Boston Basin exposures to permit correlation with other structural features.

Crosby also reports that Hangman's Island in Quincy Bay is composed of diabase and "slate". LaForge's map shows

outcrops of Cambridge "slate" on Rainsford Island. The stratification strikes east-west and a synclinal axis is indicated. These exposures are likewise too isolated to be correlated with other structures.

TEAR FAULTS:

The south border of the Boston Basin is offset by at least three north-south trending tear faults. The western segment has moved northward with respect to the eastern segment along each of these ruptures. With the exception of the Stony Brook fault the outcrops which demonstrate these ruptures lie to the south of the area investigated by the writer. The largest of these faults is the great Stony Brook tear fault which passes through the Readville marshes, along part of the course of Stony Brook, through the east end of the Arnold Arboretum and thence northward into an area thickly blanketed with glacial debris. The relative displacement of the western segment northward by approximately three-quarters of a mile is indicated by displaced strata of the Roxbury Conglomerate in Mattapan and East Dedham and by strata of Roxbury Conglomerate and Squantum Tillite on the south limb of the central anticline. A second large tear fault passes through the central portion of the city of Quincy and has offset the northern boundary of the Quincy Granite batholith. It is not known how far this rupture extends into the sedimentary rocks of the
Boston Basin because the northern part of Quincy is heavily covered with glacial deposits. A third large tear fault passes through the middle of the town of Weymouth and also has offset the northern boundary of the Quincy Granite batholith. This fault likewise passes northward into drift covered terrain. A small tear fault has displaced the stratified rocks at the east end of Rock Island with the western segment being relatively displaced to the northward. Billings¹ has presented a discussion of the possible tectonic forces that might have been responsible for these tear faults.

THE SOUTH BOUNDARY FAULTS OF THE BOSTON BASIN:

A large part of the south boundary of the Boston Basin lies outside of the area investigated by the writer and therefore much of the following description has been taken from previous geological reports of the area. A study of the literature indicates that the igneous rocks comprising the Sharon Upland, the Blue Hills and the Needham Upland have been overthrust onto the south border of the sedimentary strata of the basin. The trace of the thrust fault, or faults, is not simple because the original rupture has been offset by the north-south tear faults and it may be possible

that two or more thrust faults are arranged in an en echelon pattern. The faults along the south border of the basin are not exposed in any locality and it is necessary to postulate their existence from the types and structural attitudes of the rocks found along the border of the basin and the highlands. Outcrops of the stratified rocks of the basin are generally separated from those of the igneous rocks comprising the highlands by wide expanses of drift covered terrain. This feature makes the determination of structure difficult and uncertain.

BLUE HILLS THRUSTS: The character of the contact between the Quincy Granite batholith forming the Blue Hills and the stratified rocks outcropping at short distances to the northward has received more attention than any other portion of the south boundary of the Boston Basin. The granite outcrops through a distance of approximately ten miles extending from the western part of Weymouth westward to the edge of the Readville marshes. The faults along which this granite mass has been overthrust onto the sedimentary strata of the Boston Basin are called the Blue Hills thrusts.

The nearest approach to a contact between the Quincy Granite and the stratified rocks of the Boston Basin that can be seen in surface exposures is found at the extreme south end of the Stony Brae golf course. In this locality
outcrops of granite are separated from outcrops of Roxbury Conglomerate by a few yards of drift covered terrain. The conglomerate does not contain any pebbles or detrital material that could have been derived from an erosional surface of the Quincy Granite. It does not show any evidence of having been affected in any way by a nearby large magmatic intrusion. These features would seem to indicate that there is a fault of large displacement separating the two kinds of rock and that the granite was deep seated and not exposed to erosional agencies and therefore could not have contributed any sedimentary material to the conglomerate. The short distance separating outcrops of the two kinds of rock is favorable to this hypothesis. The conglomerate is poorly stratified but appears to have a vertical dip and a north-eastward strike varying from N55E to N75E. This direction of strike makes it appear that the conglomerate strata are truncated by the granite at a short distance to the south-westward. In describing this locality Walker makes the following comments concerning the granite; "At the edge of Adams Street the granite was exposed in a small cut which had been blasted out in widening the road. Here, the granite is fine grained and very highly fractured. That the

fracturing is not the result of blasting is revealed by a statement of the gentleman who conducted the work. He stated that he had been amazed that, after blasting, the rubble was so fine that it could be loaded into trucks with a hand shovel, quite in contrast to the usual large boulders that result in blasting a granite ledge. This bears out the contention of earlier investigators that the boundary between the Boston basin sediments and the Blue Hills is a major fault".

Between the Stony Brae golf course and the Readville marshes, a distance of approximately six miles, the granite outcropping along the north edge of the Blue Hills is separated from outcrops of the stratified rocks of the Boston basin by a wide expanse of drift covered terrain in which only a few small exposures of a quartzitic sandstone are found. This quartzitic sandstone has been considered to be a part of the Roxbury Conglomerate by some geologists\textsuperscript{1,2} to be a basal

---

arkose of the Roxbury Conglomerate that rests upon an erosional surface of the Quincy Granite by others (Mansfield) and to be a distinct formation by still others. The relationship existing between the quartzitic sandstone and the adjacent rocks to the northward that definitely are part of the Boston Bay Group is not indicated by outcrops. Loughlin describes its relations with the Quincy Granite as follows; "A band of arkose, measuring from 400-450 feet across the strike and dipping steeply to the north, extends eastward along the boundary fault from Great Blue Hill as far as East Milton. Its terminations east and west are concealed under drift but evidence as a whole favors the conclusion that its eastward end is beveled off by the fault. Overlying the arkose is a bed of purplish slate 100 feet thick, and over that a conglomerate extending through Milton Center and south of Forbes Hill in Quincy, where it is in contact with the boundary fault. The dip of the sediments varies from 40°W to vertical or even slightly overturned to the north and is attributed in part to the drag effected by the faulting. The so-called arkose was believed by both Prof. Crosby and Dr. Mansfield to contain detritus of Quincy Granite but microscopic evidence fails to confirm this opinion. Further

evidence against this suggestion was found by the present writer in the summer of 1909 at Blue Hill Village, where a new road cut had exposed the Quincy granite in fault contact with the "arkose". The exposure was small but showed the fault to be reversed. Its strike crossed that of the "arkose" at a very low angle and its dip was uneven but averaged 80° south. The dip of the arkose was very steep to the north. Regardless of whether or not the quartzitic sandstone is a part of the Roxbury Conglomerate it appears that a fault separates it from the Quincy Granite.

Eastward from the Stony Brae golf course to the north part of Hingham the geological structure is almost totally unknown because of a lack of outcrops. The northern boundary of the Quincy Granite appears to be offset by both the Quincy and Weymouth tear faults with the western segment having moved relatively northward along both ruptures. In the northern part of Hingham a large overthrust cuts off the sedimentary strata on the south limb of the anticline and marks the south border of the rocks of the Boston Bay Group. Billings\(^1\) describes this thrust in the following manner.

"In Hingham however, the easterly extension of the Blue Hills thrust is excellently demonstrated. The Dedham granodiorite forms the core of an anticline plunging to the west. Resting on the granodiorite is the Roxbury conglomerate, about 1,750 feet thick, and above this is the Cambridge argillite. The Squantum tillite is absent. The Dedham granodiorite to the south has been thrust over this anticline in such a way that the thrust plane cuts obliquely across the strike of the strata on the south limb and thus cuts out successively the Cambridge argillite and the Roxbury conglomerate so that along the eastern portion of the thrust plane the Dedham granodiorite of the overthrust block is nearly brought into direct contact with the granodiorite in the core of the plunging anticline". Farther to the east the Blue Hills thrust is either non-existant or has not been recognized because of granodiorite having been thrust over granodiorite.

Crosby\(^1\) considered the northward facing granodiorite cliffs located along the south side of Straits Pond and the Weir River in the Nantasket area to have been formed as the result of a large fault with the downthrown side to the northward. Any fault that may exist here is to the northward of the probable eastward line of extension of the Blue Hills

---

thrust. Unconformable contacts between the Roxbury Conglomerate and the Dedham Granodiorite are exposed at several points north of Straits Pond and the Weir River, therefore, any fault that may exist here is not significant in marking the boundary of the stratified rocks of the Boston Bay Group.

In consolidating the rather scanty structural data that can be obtained along the portion of the south border of the Boston basin extending from Nantasket on the east to the Readville marshes on the west it appears probable that the igneous rocks comprising the Blue Hills and a part of the Sharon Upland have been overthrust to the northward onto the sedimentary rocks of the Boston Bay Group. The rupture along which this movement took place is called the Blue Hills thrust. The thrust has not been traced to the east of Hingham, either because it dies out in this direction or because granodiorite has over-ridden granodiorite and therefore it has not been recognized. Billings\(^1\) makes the following statement concerning the Blue Hills thrust. "The main Blue Hills thrust has thus been traced nearly twelve miles, from the Readville marshes on the west to Hingham on the east. The stratigraphic throw is at least two thousand feet.

The northern Blue Hill thrust has been traced for four miles, from the Readville marshes on the west to East Milton on the east but the amount of movement cannot be estimated due to the lack of adequate data. To the northeast of Hingham in the Nantasket area the border of the Boston Basin is marked by the unconformable contact between the Roxbury Conglomerate and the Dedham Granodiorite.

HYDE PARK-DEDHAM LOCALITY: The information which is available at the present time seems to indicate that the Blue Hills thrust does not have an extension to the west of the Stony Brook tear fault. If the structural relations are consistent a westward extension of the thrust would be displaced to the northward and would pass through Hyde Park and East Dedham. The rocks in these localities do not show any easily recognizable indications of large scale over-thrusting. Several large outcrops of Roxbury Conglomerate lie between Cleary Square in Hyde Park and the Oakdale section of Dedham. The stratification in these exposures strikes approximately N55E, this also being the direction of alignment of the outcrops. This conglomerate appears to be the basal part of the Roxbury strata and, although contacts are not exposed, a depositional unconformity between it and the underlying rocks of the Mattapan Volcanic Complex and the Dedham Granodiorite is indicated by its abundant content of volcanic and granodiorite pebbles and boulders and the close
proximity of outcrops of the sedimentary and volcanic rocks. The alignment of conglomerate outcrops along the strike of the stratification is not noticeably offset at any place. In the vicinity of Hyde Park the conglomerate rests upon rocks of the Mattapan Volcanic Complex while to the southwest in Dedham it rests upon Dedham Granodiorite. This situation is easily explained by the localized extent of the volcanic flows. The sedimentary rocks in the Hyde Park-Dedham locality lie on the southeast limb of an anticlinal fold which is probably the westward extension of the Dorchester anticline. To the southeastward there is a large area devoid of outcrops with the exception of one exposure of conglomeratic rock in a railroad cut three-quarters of a mile north of Readville. This isolated outcrop exhibits some of the features characteristic of the Squantum Tillite.

The character of the sedimentary rocks and the original form of the extreme south part of the Boston basin in the North Milton-Hyde Park-Dedham locality are not definitely known. The long arm of conglomerate extending into Dedham is highly suggestive of deposition in a deep elongate valley that extended in a southwesterly direction from the main part of the Boston basin. Exposures of granodiorite completely enclose this extension of conglomerate on all except the easterly side where glacial debris completely hides the bedrock. Since this extension of the Boston basin lies to
the westward of the Stony Brook tear fault it is considered to have moved somewhat northward from its original position. On the east side of the Stony Brook tear fault the south border of the basin has been over-ridden by the Blue Hills thrust and it is probable that the sedimentary rocks originally extended much farther to the southward than their present boundary.

WEST ROXBURY LOCALITY: From the vicinity of the Clarendon Hills due westward to the Charles River the south border of the Boston basin is marked by an overthrust fault that Billings¹ considers to be the westward extension of the Mt. Hope thrust. Although the fault is not exposed the locations of outcrops and attitudes of stratification indicate that the Dedham Granodiorite on the south has over-ridden the Cambridge Siltstone on the north. This relationship is best seen in West Roxbury where outcrops of southward dipping siltstone on Temple Street are located approximately three hundred yards north of outcrops of granodiorite. Numerous exposures of rocks of the Mattapan Volcanic Complex are found resting on the granodiorite to the south of the

fault line. This portion of the volcanic formation is considered by the writer to have flowed over a highland area and therefore is not a part of the stratified sequence of rocks of the Boston basin.

NEWTON-NEEDHAM LOCALITY: The relationship existing between the stratified rocks of the Boston Bay Group outcropping in the western part of Newton and the southern part of Wellesley and the igneous rocks comprising the Needham Upland is unknown because of the lack of suitable outcrops which would indicate the structure. The two groups of rocks are separated by a wide expanse of glacial terrain that is completely devoid of outcrops. The writer is of the opinion that the Central Anticline of the Boston basin may extend, without being interrupted by a major fault from Newton into Needham and possibly westward. The continuity of conglomerate strata in the vicinity of Newton Upper Falls and the south eastern part of Wellesley is suggestive of this interpretation of structure. The West Roxbury overthrust may extend westward along the valley of the Charles River between Dedham and Needham and in this case some of the northeastward striking strata on the south limb of the Central Anticline are truncated by the fault plane.
HISTORICAL GEOLOGY
The main features of the historical geology of the Boston Metropolitan Area are briefly summarized in the following comments. The data and field relations upon which these comments are based have been discussed in the sections of this report describing the individual formations.

The oldest rocks of the Boston Metropolitan Area are the scattered remnants of stratified formations of Early Cambrian age. The Westboro, Marlboro and Woburn Formations apparently belong to this group but there is not any conclusive evidence that definitely fixes their ages in this period. It appears probable that these formations were in existence prior to the deposition of the fossiliferous Lower Cambrian Weymouth Formation and the Middle Cambrian Braintree Formation. Nothing is known of the character of the floor or basement complex upon which these stratified formations were accumulated because it has been completely obliterated by later Paleozoic igneous intrusive rocks. The Pre-Cambrian history of the area is a total blank.

The Westboro Formation appears to be of marine origin. The formation grades from a quartzite of high purity in the lowest strata that have been preserved to a micaceous quartzite in the uppermost strata, thus indicating the deposition of an increasing quantity of argillaceous material in the later stages of sedimentation. This feature may have been the
result of the shore line having retreated from the area of deposition. In the Metropolitan area the Marlboro Formation consists almost entirely of basaltic lavas. It has not been possible to determine whether the eruptions occurred in a marine or a terrestrial environment. The basaltic lavas overlie the Westboro Formation with a slight unconformity and contain detritus composed of quartzite. The time and environment of eruption of the volcanic flows of the Woburn Formation are not definitely known. The Marlboro and Woburn volcanics were probably erupted during the same period of vulcanism because remnants of both formations are found as inclusions and pendants in the Salem Gabbro-diorite batholith. The oldest rocks of the area that are dated by fossils are those of the Lower Cambrian Weymouth Formation which consist of indurated marine shales and thin strata of limestone. The fossiliferous Middle Cambrian Braintree Formation also consists of marine shales and fine grained sandstones.

The definitely known Cambrian history of the area is one of deposition of a great thickness of marine sediments. If the Marlboro and Woburn Formations are of early Cambrian age then an interval of prolific vulcanism is represented.

It is probable that the seas retreated from the area during Upper Cambrian time because marine sedimentary rocks younger than the Middle Cambrian Braintree Formation have never been found. The events of the Ordovician and the early
part of the Silurian are not recorded in sedimentary rocks and therefore it is probable that the area was subjected to a long period of erosion. During some portion of this period the sub-alkaline batholiths were emplaced. The basic magmas which formed the Nahant Gabbro and the Salem Gabbro-diorite invaded the upper crust first and were followed after a short interval by the magma that produced the granodiorites of the Dedham batholith. The intrusion of these batholiths may have been a phase of the Taconic orogeny of Ordovician time. There is not any reason to believe that the Cambrian stratified formations had been greatly deformed prior to the igneous invasions, in fact, it is quite probable that the strata had nearly horizontal attitudes. Some folding and a considerable amount of uplift undoubtedly took place during the orogeny and in conjunction with the emplacement of the sub-alkaline batholiths. In late Ordovician and early Silurian time the erosion stripped much of the sedimentary cover from the batholiths thereby exposing the igneous rocks.

In late Silurian or early Devonian time the area became the scene of intense volcanic activity with the flows of the Lynn and Mattapan Series being erupted upon the erosional surface of the sub-alkaline batholiths and the remains of Cambrian stratified formations. The emplacement of the alkaline batholiths of granitic rocks presumably was contemporaneous with the outpourings of the lavas. This igneous activity was most likely a phase of the Acadian
orogeny of late Silurian or early Devonian time. During
this orogeny it is probable that mountains of considerable
altitude came into existence in the surrounding region
and especially to the southward and southwestward of the
Metropolitan Area.

By Middle Devonian time the uplift of the Acadian
orogeny had been completed and mountain glaciers developed
on the uplands to the south of the area. The ice flowed
in a general northerly direction causing the glacial sedi-
ments to be deposited in a lowland that is now called the
Boston Basin. The volcanism which began in the Late
Silurian or Early Devonian persisted into the glacial epoch
with the result that the flows of the Brighton Volcanic
Complex are interstratified with the basal portions of the
Roxbury Conglomerate. The terminal moraines of the glaciers
for the most part were located high up on the mountain
slopes. The outwash from the moraines deposited the coarse
Roxbury Conglomerate on the lower slopes of the foothills
and at the borders of the Boston Basin. The fine grained
sediments were carried into a lake in the main portion of
the basin and were deposited there to form the varved
Cambridge Siltstone. During the later stages of the glacia-
tion the ice advanced far out into the basin and left a
deposit of till that has become indurated to form the
Squantum Tillite. It is probable that the glaciation had
ceased by the end of Devonian time.
The Mississippian period was one of erosion. The sediments which were produced evidently were transported to other regions since sedimentary formations of Mississippian age are not known to exist in the eastern part of Massachusetts. By the end of the period the Quincy Granite batholith of the Blue Hills had been stripped of its cover and was exposed to weathering agencies. The mountains that had been created during the Acadian orogeny probably became much reduced in altitude.

During the early part of the Pennsylvanian a thick layer of arkose accumulated on the surface of the Quincy Granite and parts of the Dedham Granite and this became the basal portion of a thick series of sedimentary strata in the Norfolk and Narragansett Basins. Sedimentary material of Pennsylvanian age apparently was not deposited in the Boston Basin. Judging by the volumes of sediments that were deposited in the southern basins a considerable reduction in the heights of the mountains took place during this period.

By the time of the Permian Appalachian orogeny the glacial sediments of the Boston Basin had become sufficiently indurated so as to behave as competent formations. During this orogeny all of the rocks of the area were compressed into northeast-southwest trending folds with the deformation being more pronounced in the sedimentary rocks of the Boston Basin than in the igneous rocks to the north and south. The more rigid masses of igneous rocks became parts of great
fault blocks that were overthrust onto the sedimentary formations of the basin. The overthrust faults strike in northeast-southwest and in east-west directions. The overthrust from the south caused the sedimentary rocks at the south side of the basin to be compressed into tight folds, some of which were ruptured along the anticlinal crests and the south limbs thrust over the structure to the northward. Great north-south trending tear faults were also developed. The segment on the west side of the tear faults has always moved northward with respect to the segment on the east side.

The history of the area from the close of the Appalachian orogeny to the Pleistocene seems to have been one of continuous erosion. There are not any sedimentary rocks in the area that are of younger age than those of the Boston Bay Group. At some time during this interval a large number of basic dikes were injected into all of the formations of the area. This activity presumably occurred during the Triassic. The dikes evidently did not reach the surface of the earth since there is not any evidence of lava flows having been erupted during this period.

During the Pleistocene the area was subjected to continental glaciation. When it is considered that the glaciation smoothed off the hills to some extent and filled the valleys with debris it becomes evident that the pre-glacial topography of the area, particularly of the uplands, was very
rough. The continental glaciation blanketed the terrain with great deposits of outwash and ground moraine and left numerous eskers and drumlins. These unconsolidated glacial deposits form an important part of the present topography of the area.
BIOGRAPHICAL SKETCH
BIOGRAPHICAL SKETCH

Kenneth Grenville Bell

Born: November 6, 1911 at Plymouth, N. H.
Father: Kenneth Gould Bell
Mother: Anna Wells Bell

Education:

SB in Geology, Massachusetts Institute
of Technology, 1939.

SM in Geology, Massachusetts Institute
of Technology, 1940.

Graduate student at Massachusetts
Institute of Technology, 1946 - 1948.

Professional Experience:

Geologist for United States Gypsum Company,
1939 - 1942.

Military Service:

United States Army, July 1942 to September 1946.