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Prof. Jules Marcou, with the kind regards of W. O. Crosby

CONTRIBUTIONS

TO THE

GEOLOGY

OF

EASTERN MASSACHUSETTS.

BY
WILLIAM O. CROSBY.

BOSTON:
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PREFACE.

EARLY in the summer of 1875 I began a systematic study of the rocks in this vicinity, with the view of collecting such data as, added to my previous knowledge, would enable me to prepare a thesis for graduation in the department of Natural History of the Massachusetts Institute of Technology, on the "Geology of the Environs of Boston." In the beginning of the following winter I was charged by Prof. A. Hyatt, under the direction of the Massachusetts Commission to the Centennial Exhibition, with the task of preparing a geological map of the State, for exhibition at Philadelphia. Opportunity was afforded me by the Commission to visit all parts of the State. The Boston Society of Natural History generously permitted the use of my time as assistant in their Museum for this purpose, and, as that winter was unusually favorable for exploration, I was in the field almost constantly. The Centennial map and the report on the same were completed in the following spring. The wider range of observation which this work for the State had afforded seemed to justify me in extending the scope of my thesis so as to include the whole of Eastern Massachusetts, and it was accordingly finally written, under the title of this paper. The thesis was accepted for publication by this Society, and the Government of the Massachusetts Institute of Technology made an appropriation to pay for printing the map.

I resolved, however, partly on the suggestion of Prof. Hyatt, to test my conclusions by another year of field work, and various circumstances have conspired to extend this time to nearly two years. By this means my original observations have been doubled, and, although the general plan of the paper remains the same, it far exceeds its former limits, and many of the geological boundaries on the map have been brought nearer to an expression of the truth.

In deference to the view of Dr. T. Sterry Hunt, expressed to me personally, and before this Society, I have given the rocks, which in the original paper were designated as the Norian system, a name having no chronological signification. The Huronian petrosilex and felsite are no longer regarded as synchronous with the breccias; but the latter rocks, together with the amygdaloids, which appear to belong to the same horizon, are set apart as a distinct formation under the name of the Shawmut group. The conglomerates about Boston have been found to underlie the slates, and hence are now regarded as Primordial instead of Carboniferous.

For assistance received my acknowledgments are due, first of all, to Prof. Alpheus Hyatt, who generously placed at my disposal his original notes, sketches, and collection, representing observations made during several years on the geology of Essex County; and I am also indebted to him for many opportunities for investigation in the field and laboratory.

To Dr. T. Sterry Hunt I am indebted for much valuable instruction, advice, and criticism, while a student in the Massachusetts Institute of Technology and since, without which the performance of this work by me would have been impossible. Though placed in a position most favorable to a thorough acquaintance with Dr. Hunt's views concerning the origin of crystalline rocks and their relations to the more recent, fossiliferous rocks, I entered the field with a general disbelief in their applicability to the rocks of this region, which my first observations only strengthened; and any conclusions in harmony with these views which may be found in this paper have been reached in opposition to preconceived ideas wholly at variance with them.

For valuable data, freely contributed, my acknowledgments are also due to Mr. L. S. Burbank, of Woburn; Mr. T. T. Bouvé, President of the Boston Society of Natural History; Mr. F. W. Very, of Hyde Park; Prof. W. H. Niles, of the Massachusetts Institute of Technology; Mr. W. W. Dodge, of Cambridge, and others.

The chemical analyses recorded in this paper were made in the Woman's Laboratory of the Massachusetts Institute of Technology, and for these I am under special obligations to Mrs. Alice B. Crosby, Mrs. Ellen H. Richards, Miss E. M. Walton, Miss H. A. Walker, and Miss Jennie M. Arms.

The President and Directors of the Eastern Railroad Company have assisted very materially in the exploration of Essex County by granting free passes over their line.

BOSTON, August, 1878.

INTRODUCTION.

THE vast region extending from Long Island Sound, northeasterly, and nearly insulated by the St. Lawrence, Richelieu, and Hudson Rivers, and Lake Champlain, is well marked off, geographically, from the rest of the continent. Dr. Ezekiel Holmes,[1] recognizing the geographic distinctness of this most eastern member of the continent, and its almost complete isolation by water, an isolation that appears to have been perfect during the first part of the Paleozoic era, has correctly termed it a peninsula. Newfoundland is a detached portion of this geographic unit. In its geologic relations, also, the region indicated is readily separable from the adjoining territory. The rocks are mainly crystallines, and, except in the lower part of the valley of the Hudson, cannot be connected, along their strikes, with the rocks of other regions.[2] The

[1] Ann. Report on the Agriculture and Geology of Maine, 1861, p. 100.

[2] The Paleozoic sediments of this region, it is true, are continuous through the broad interval between the Adirondacks and the Highlands of the Hudson, and were probably connected, at one time, through the valley of the St. Lawrence, with the more extensive deposits of the same age to the westward. Yet the crystallines are to so great an extent the predominant rocks of this large territory, and, as the writer conceives, have had, as a whole, an origin so vastly more remote than the most ancient of the uncrystalline sediments (these newer formations being regarded as merely superficial deposits, often obscuring, but not essentially altering, the main structural features of the region), as to warrant leaving the latter out of view in these general remarks.

north-easterly strike prevalent north-east of a line extending, in a general way, from Boston, *via* the White Mountains, to the northern end of Lake Champlain, would, if continued south-westerly, carry the crystallines of New England over New York, and the Middle States generally. But beyond the line indicated the formations bend to the south, and throughout south-western New England are characterized by approximately north and south strikes, being cut off at right angles by the waters of Long Island Sound. Along the New York boundary, in southern Connecticut, however, the north-east strike is resumed, and the rocks of that district sweep across Manhattan Island and the Hudson. The breadth of New England strata subjected to this westerly deflection is probably not so great as at first sight appears. The crystallines of the Highlands of the Hudson are Laurentian, and are recognized by all geologists as older than those farther south, in the vicinity of New York. It is the latter only that can be traced easterly into New England, or that are here considered as really belonging to this great geological province. The Laurentian strata of the Highlands have a north-north-east strike, varying toward north and south; and it is probable that in their northerly extension, although soon dipping beneath more recent formations, they sweep around to a course parallel with the one hundred and fifty miles of newer crystallines on the east, and reappear in Washington and Saratoga Counties in New York; thus connecting the Laurentian of the Highlands and New Jersey on the south with the great Adirondack area on the north, and constituting at all points a barrier against which abut the western edges of the crystalline series proper to New England. The complete absence, so far as has been definitely ascertained, of Laurentian rocks from western New England corroborates this view. In short, the crystalline formations of the northern half of the Atlantic seaboard exhibit, in their strikes, a grand double curve. Beginning in the north-east with a trend parallel with the St. Lawrence and the Laurentide

Mountains, they bend to the south in southern New England, and conform with the Laurentian barrier just pointed out; while the remnant that is not cut off in the southern extension, by the Atlantic, finally regains the former strike, and spreads across southern New York and New Jersey. This great Laurentian wall, which is doubtless continuous, under the Paleozoic deposits, from Labrador to Virginia, or beyond, formed the western shore of the ocean, in which the newer crystallines of the Atlantic slope were deposited; and, subsequently, in its southern half, it became the eastern border of the great Paleozoic sea. It has been a primary axis of continental oscillations, a centre of disturbance — itself undisturbed. The importance of this ancient Laurentian axis, as a structural feature of the continent, makes still clearer the isolation and unity of what may be called the New England or North-Eastern geological province. It is not intended to deny the existence in New England of the older crystalline formations, for Hitchcock has shown that they certainly occur in the White Mountain region; but I may safely assert that their occurrence in the western and central portions of this province is always something exceptional. They are not characteristic of any considerable areas.

This north-eastern province is naturally divisible, in a geographical sense, at least, into two parts, — a south-eastern and a north-western. The division is marked by a line of valleys parallel with, but subordinate to and less distinct than, that isolating the province on the north and west. This axis of depression follows the valley of the Connecticut, from Long Island Sound, to near its source; then, curving north-easterly, and skirting the northern base of the White Mountains, it is marked by the valley of Lake Umbagog, and the great lake region of Northern Maine, passing to the northward of the Katahdin Range. Entering New Brunswick, it is continued, with the same trend, through the valley of the Restigouché River and Bay of Chaleur, to the Gulf of St. Lawrence. This secondary line of depression, like the first, is marked throughout the greater part of its extent by considerable deposits of uncrystalline sediments. These are, however, almost wholly of early Paleozoic age, and show that these valleys are of very great antiquity.

The rocks forming the subject of this paper occur wholly in the more south-eastern of the two divisions, or sub-provinces, above indicated. This division embraces that great deflection of our Atlantic coast-line known as the Gulf of Maine. The head of the Gulf of Maine is at Portland; and its apparently but slightly contracted mouth is guarded by the two salient angles, Cape Sable and Cape Cod; while the Provinces of New Brunswick and Nova Scotia enclose its north-eastern end as Eastern Massachusetts does its south-western. The line joining the head of the Bay of Fundy and Plymouth, in Massachusetts, may be regarded as the axis of the gulf, and is about three hundred and seventy-five miles long, with a trend approximating north-east and south-west. This line is of fundamental importance in the structure of this region, a base line for both geography and geology. The maximum breadth of the gulf at Portland is one-third of its length, or one hundred and twenty-five miles. The prevailing and all but universal line of strike throughout this entire region, from Rhode Island to the Gulf of St. Lawrence, as already stated, is north-east and south-west, — parallel with the axis of the Gulf of Maine. The rocks which meet the water of this large gulf are, for the most part, ancient crystallines; and, whereever these are exposed to observation, the indications are plain that the gulf is the product of erosion, — has been carved from the ancient strata by which it is bordered, — and is not the result of a synclinal or other depression of this portion of the earth's surface. The agent of erosion appears, at first sight, to have always been the waves of the Atlantic, and to have acted uniformly from the east toward the west. A study of the true contours of this body of water, however, brings to light facts which seem to militate against this view. An examination of a Coast Survey chart of this region shows that the water does not become constantly deeper as we proceed seaward from the shore, anywhere between Portsmouth, N.H., and Eastport, Maine; but, on the contrary, the water is usually as deep at twenty to fifty miles from shore as at any greater distance less than two hundred and fifty miles, beyond which the abysses of the ocean begin, and the bottom falls away rapidly to twelve hundred and fourteen hundred fathoms; and not unfrequently the depth is actually greater at the lesser distance from shore, so that the water shallows seaward. Thus, the greatest depth recorded in the region of the Gulf of Maine, one hundred and sixty fathoms, is only fifty miles from Portsmouth; and thirty-five miles from Mt. Desert gives us one hundred and forty-five fathoms: while beyond this the water shallows sensibly, and an equal depth is not found nearer than one hundred and fifty miles from shore.

Extending easterly from Cape Cod, for nearly two hundred miles, is a broad expanse of shallow water, with depths ranging from five to fifty fathoms, and including George's Bank, which reaches the surface one hundred and twenty miles from land. A similar but less distinctly marked area of shallow water stretches southward from Nova Scotia, with a breadth of sixty miles, and a maximum depth of seventy fathoms. Separating these two areas of moderate depths is a strait of deeper water, eighty to one hundred and fifty-five fathoms. Following the fifty-fathom line, this strait is, perhaps, fifty miles wide; while for the one-hundred-fathom line it is reduced to thirty-five miles. It is plain that a broad submarine ridge or plateau extends over nearly nine-tenths of the distance between Nova Scotia and South-eastern Massachusetts, forming a nearly complete barrier between the comparatively deep water of the Gulf of Maine and the greater depths of the ocean beyond. If the sea bottom were elevated fifty fathoms, the Gulf of Maine, although still three hundred miles long, and having a maximum depth of one hundred and ten fathoms, would be changed from a broad-mouthed bay to an almost completely land-locked gulf.

The glaciating agent operated powerfully to obliterate that feature of the Gulf of Maine, upon which I am here insisting, viz., its nearly continuous eastern rim; which, though no less real than the western border of the gulf, escapes recognition through its submergence beneath the waters of the Atlantic. One of the most important effects of glacial action was the transportation of immense quantities of detrital materials from the north and north-west toward the south and south-east. According to Prof. Hitchcock, the sheet of drift covering South-eastern Massachusetts is at least three hundred feet thick; and any one familiar with the geology of this region, who notes the characters of the pebbles and boulders which this drift contains, cannot doubt that it has been largely derived from the land to the northward; nor will it seem improbable that Northern Massachusetts, and even New Hampshire, may have contributed something to the result. We have no reason to think the action of the ice-cap in this instance was anything exceptional; it probably swept Northern as well as Southern New England, and in even a more thorough manner. Where now is the vast accumulation of debris that, according to this supposition, must have been removed from portions of Maine and New Hampshire? I believe it has been shoved, in large part, beyond the present limits of the land, and is now spread over the bottom of the Gulf of Maine; contributing largely to the elevation of this bottom to the level of the eastern rim, and thereby tending to obliterate the latter as such. Jeffrey's Bank and Cashe's Ledge, lying off the mouths of the Kennebec and Penobscot Rivers, sixty to seventy miles long, two-thirds as broad, rising from a depth of one hundred and sixty fathoms, and approaching at many points within five to fifty fathoms of the surface, should, apparently, be regarded as a huge pile of glacial detritus, which, although everywhere distinct from the eastern rim of the gulf, greatly obscures its basin-like character. That the glacial action, while tending to fill up the gulf, has contributed little or nothing to the formation of the ridge or plateau constituting its eastern border becomes sufficiently obvious when we note the remoteness of this barrier from the land, and observe that a considerable breadth of deep water intervenes at all points between it and Jeffrey's Bank. If, then, the debris were removed from the bottom of the Gulf of Maine, it would doubtless appear much more clearly than now to be a genuine depression, or basin, shut off from the outside ocean by a broad barrier; which, whether we consider it to have been, at the time when this gulf was eroded, above the sea, and backed, may be, by an Atlantis, or as having been always submerged, constitutes a serious objection to the view that the erosion of the Gulf of Maine has been effected wholly or mainly by the waves of the Atlantic. Without intending or desiring to raise the question of the existence in past geologic time of an Atlantic continent, it will be shown in the sequel that there are other reasons than those here advanced for believing that the Gulf of Maine was, at least during the period of its formation, land-bordered on the east as well as on the west; that it was eroded mainly, if not entirely, before the beginning of Paleozoic time; and that the rocks bordering this gulf, in Eastern Massachusetts at least, are so disposed about the line which I have denominated the axis of the gulf as to indicate that this line is really the axis of a great anticlinal or series of anticlinals, the erosion of which, after the usual manner of anticlinal erosion, has, I conceive, produced the depression in question.

It has long been known that the rocks bordering the Gulf of Maine exhibit a general uniformity along the strike. This likeness is usually believed to extend not only to the Paleozoic and more recent sediments and their relations to the crystallines, but also to the crystallines themselves, which are conceived to be arranged in broad irregular belts, parallel with the axis of the Gulf of Maine, and each of which is, in a general way, of the same age and composition throughout its extent. Careful comparisons of the rocks, especially the crystallines, of these various districts, have never been instituted; and the prevalent opinion here alluded to, though probably correct, is based upon general impressions gathered from hasty, bird's-eye-view surveys, rather than detailed and accurate knowledge. During the last decade, various members of the Canadian Geological Survey, and especially Mr. G. F. Matthew and Prof. L. W. Bailey, have greatly extended our knowledge of Acadian geology. Their labors, however, have been mainly confined to New Brunswick; and Nova Scotia is yet, as regards an accurate knowledge of the composition and relations of the crystalline formations of the province, well-nigh an unknown land. Our knowledge of the crystallines of Maine, also, is wholly inadequate for the purposes of comparative geographic study. In the study of the rocks of Eastern Massachusetts presented here, a detailed comparison of this region with those to the north-east has not been attempted; our knowledge, as just stated, not being considered ripe for accurate generalization over so wide an area. Yet, although the end kept steadily in view has been merely to advance in some degree our knowledge of the character, distribution, and relations of the various rocks occurring in a limited district, it is hoped the way has been, in a measure, prepared for the higher study hinted at.

TOPOGRAPHY AND GENERAL OUTLINES.

The extent of territory coming within the scope of this paper is intended to be shown by the smaller of the two accompanying maps. It includes in a general way all that part of the State east of the north-south range of highlands of which Mt. Wachusett is the culminating point, and north of the Rhode Island boundary; comprising the whole of Essex, Middlesex, Norfolk, and Suffolk Counties, the eastern half of Worcester County, and the northern portions of Bristol and Plymouth Counties. As shown by the map, the length and breadth of the district are approximately equal, and the area is not far from three thousand square miles, or about three-sevenths of the State.

The topographic descriptions given us by the elder Hitchcock and other writers, and the general evenness of the surface, obviate the necessity for extended remarks under this head here; and, furthermore, the trends of the principal water-courses and shore lines are sufficiently obvious on the map. I would call attention, however, to the general relation of the topographic features to the geologic structure, — a point likely to be overlooked in a level and drift-covered region like this. The prevalent line of strike in Massachusetts, as is well known, is north and south, and in the western half of the State there are no exceptions of importance to be noted. East of the Nashua valley, however, a north-east and south-west strike prevails, especially in Essex and Middlesex Counties; a comparatively limited area in the south-eastern part of Worcester County and the adjacent portion of Rhode Island exhibits a strike at right angles to this, or north-west and south-east; while among the Paleozoic strata a nearly east and west strike is most common. That "geology is revealed in topography" is a trite axiom of the science, which is well exemplified, even in this extensively glaciated region. In a recent paper in the American Naturalist,[1] "On the Surface Geology of Eastern Massachusetts," I have discussed at some length the relations of the topography of this district to the glaciating agent and to the geologic structure. The general conclusion reached is, "that, comparatively speaking, the ice-cap rested lightly upon the land, and that the topographic features having a skeleton or framework of rock are, as a rule, of pre-glacial origin." In other words, to quote further, "it appears probable that if the present mantle of drift were entirely removed from the face of the country, leaving a surface of naked rock, we should have in all important respects a restoration of the pre-glacial contours. And this ancient topography having been, as I conceive, fashioned mainly by agents more subtle than an ice-cap, and hence taking a deeper hold on geologic structure, would, if thus undisguised, reveal a closer correspondence with the structure

[1] Vol. xi., pp. 577, *et seq.*

lines of the subjacent rocks than we are able to detect in the existing hills and valleys considered as a whole." One of the most remarkable facts in the distribution of glacial detritus, or drift, in Massachusetts, as I have already observed, is the comparatively great depth to which it has been accumulated over the south-eastern portion of the State. There is a marked paucity of rock outcrops in the southern half of Plymouth County; south of Plymouth and east of Middleborough they are rarely met with; and Barnstable County is absolutely destitute of them. It is not improbable that the solid rocks in this region are so deeply buried by the unconsolidated superficial deposits, that, if the latter were removed, the whole of Barnstable County and a considerable part of Plymouth County would be invaded and covered by the sea. Certainly here, if anywhere, we may expect lake basins and river valleys to exhibit in their forms and trends a complete independence of the underlying rocks; and, as I have shown in the paper above cited, this expectation is fully justified by the facts. In Worcester County, and north of this region of excessive drift, however, the dependence of the surface lineaments on the geologic structure is very marked. This is especially noticeable in the case of the larger features, such as the Blackstone, Nashua, Merrimac, Parker, Ipswich, Charles, Neponset, and other rivers; the Wachusett range of highlands; the parallel range forming the eastern rim of the Nashua valley; the somewhat irregular belt of hills extending from Cape Ann to Beverly; the well-known range sweeping with bold front from Swampscott to Waltham; and the Blue Hill range in Milton and Quincy. The last three lines of hills, being principally composed of unstratified rocks, are less regular and distinct than the others; yet they no less clearly reveal the structure of the rocks composing them; for exotic rocks, being, in a certain sense, structureless, only conform with the general law in giving rise to a systemless topography.

The rocks of Eastern Massachusetts admit of a convenient, and, it is believed, a chronologic, division into two great groups, — the crystallines and the uncrystallines. The former predominate, constituting the surface rocks over fully nine-tenths of the area to which this paper particularly relates. The chronologic distinctness of these groups will probably not pass unquestioned. Yet it is true that, with the exception of the argillites of the Nashua valley, which Prof. C. H. Hitchcock [1] has correlated with the Primordial slates about Boston, none of the crystallines of the eastern part of the State have, of late years, been regarded as of Paleozoic or more recent age, by any geologist familiar with the rocks of this region.

I have studied the relations of our Primordial strata to the crystallines at every accessible point within my knowledge, and in all cases, where the evidence is of a decisive nature, it affords unequivocal support to the view, that between the crystallines and the oldest uncrystallines there is a great chronologic break, a "lost interval" of immense duration; for the unconformability is perfect, and the imperfect lithologic resemblance sometimes observable is due in every case to derivation or to very local alteration. Furthermore, it will be shown in the sequel, mainly on stratigraphic grounds, that the oldest rocks in the State are on its eastern border, facing the Atlantic, and that the various crystalline series appear to be so arranged geographically as to become successively newer as we proceed from Massachusetts Bay to the Berkshire Hills; so that, even if there were crystallines of Paleozoic age in Massachusetts, they would not probably be found in the eastern portion of the State. I cannot but regard the distinctness of these two great classes of rocks in this region as the most certain of all the conclusions reached in this paper. Considering the Primordial horizon as the base of the Paleozoic system, then it is true that, in this region at least, the profound break between the crystallines and the uncrystallines is coincident with that recognized generally between the two grandest chronologic divisions, the

[1] Geological Map of Massachusetts, in Walling's Atlas, 1871. Subsequently, in the final report upon the Geology of New Hampshire, Prof. Hitchcock has referred these argillites to the ancient Huronian system.

Eozoic and the three succeeding eras, — Paleozoic, Mesozoic, and Cenozoic, — for which, taken collectively, geologists have failed to provide a name.

Several divisions have been established among the crystallines of Eastern Massachusetts, based, for the most part, on lithologic and stratigraphic characters. The groups thus formed are believed to have chronologic value, to be chronologically distinct. It is not without hesitation that, in describing these series as both lithological and chronological, I raise the vexed question of the value of purely physical characters as tests of age among crystalline rocks; for I began my study of the crystallines of this State with a wholesome distrust of the value of lithological data in establishing chronological divisions, and am not yet wholly prepared to apply this principle to wider regions. Within my limited field of observation, however, I am satisfied that its application is safe. It adapts itself so perfectly to all the facts, so far as I know them, that I do not hesitate to assert that the lithological characters of the divisions which have been worked out among the crystallines of Eastern Massachusetts — the chronological and geographical distinctness of which can scarcely be doubted — are as unlike as the faunæ of any two successive geological formations.

EOZOIC FORMATIONS.

The oldest of these crystalline series is the smallest in extent. I propose to designate it, provisionally, as the Naugus Head series, — in allusion to the promontory of this name on the Marblehead shore, where the rocks of this series are best developed and were first observed. Succeeding the Naugus Head series, in the order stated, are the Huronian and Montalban systems, and a series of semi-crystalline rocks, of very dissimilar composition, but appearing to be identical in age and geognostic relations, which, having their greatest development in the vicinity of Boston, I have named collectively the Shawmut group, — Shawmut being the ancient Indian name of Boston.

In employing the names "Huronian," "Montalban," etc., terms having chronological signification, to designate the crystalline divisions of Eastern Massachusetts, I mean to assert the general lithological and stratigraphical resemblance, but not necessarily the chronological equivalence, of the groups thus designated to the great and generally recognized Eozoic divisions of other regions. My views on this subject cannot be justly characterized as merely speculative; for at all important points they rest on the solid ground of facts. My position with respect to our crystalline or Eozoic formations, briefly stated, is this: There exists in Eastern Massachusetts a great series of crystalline schists agreeing in all important respects with the Montalban system as defined by Dr. T. Sterry Hunt. Farther east is another vast crystalline formation, differing widely from the first, and possessing all the essential characters of the Huronian. This second series is plainly older than, and underlies, the first; and it is underlaid in its turn by a still more ancient-looking terrane which, consisting principally of coarsely crystalline, and frequently exotic, basic rocks, presents a general resemblance to the Upper Laurentian or Norian series of the Canadian geologists. This, as above stated, I have named, provisionally, the Naugus Head series. In other words, the crystalline divisions of Eastern Massachusetts agree in composition and sequence with those established in neighboring regions; that this implies chronological equivalence might fairly be questioned, and I do not assert it.

NAUGUS HEAD SERIES.

Several small areas of the rocks referred to this series have been marked on the accompanying map.[1] Of these, two are of especial importance; the first includes the city of Salem, Salem Neck, the islands of Great Misery and Little Misery, Baker's Island, Naugus Head on the north end of Marblehead, various small islands between Marblehead and Great Misery, and several narrow strips along the Beverly shore; while the second area embraces all but the seaward end of Large Nahant. A glance at the map will show that these areas lie contiguous to the sea-shore; and this fact — since these shores are for the most part rocky — has enabled me to trace their boundaries with considerable accuracy. In Salem and Peabody, however, the rocks marked as belonging to this series seem to have been more or less fluent, and are blended with the diorites of the Huronian formation in inextricable confusion; which, together with the absence of outcrops north of North river, has rendered the determination of the western boundary of this area difficult; and the line as laid down on the map is partly hypothetical.

The rocks of this series, though frequently stratified, appear in general to have been somewhat fluent, and usually exhibit more or less extravasation; but doubtless in some cases the metamorphic action has stopped short of this extreme term, though destroying all traces of bedding. In many places, as notably on Winter Island and Great and Little Misery, the entire formation seems to have been plastic, and the extravasation has been so extensive that the character of the rock

[1] See post., p. 23.

changes at nearly every rod. One important fact should be noted here, viz., nowhere in this region does the Naugus-Head series appear to be cut by eruptives belonging to another formation; for all the exotic rocks of this group may be easily referred to, or shown to be derived from its stratified members. The stratified rocks occur chiefly in Marblehead, and on the Beverly shore west of Curtis Point. In Marblehead the strike is E.–W., with a vertical dip; while on the Beverly shore the strike varies from N.–S. to N.E.–S.W., and the dip is thirty degrees to vertical to the N.W. The average strike of the whole system is N. E.–S.W. More or less distinct bedding has also been observed on the north side of Great Misery, at several points on Salem Neck, on Coney Island, and at one point on the north-east shore of Nahant.

The rocks of this series are composed chiefly of feldspar and pyroxene. These minerals occur mixed in very various proportions. Perhaps the most characteristic rock is one composed almost entirely of feldspar, containing little pyroxenic or hornblendic material, and frequently destitute of it. It is usually coarsely crystalline, this variety prodominating along the Beverly shore east of Curtis Point; and the crystallization is sometimes extremely coarse, as, notably, on the Beverly shore, near the western end of West Beach, and in Marblehead, especially about Dolliber's Point. At the former locality the rock is evidently exotic, and some of the feldspar crystals are of immense size, ranging from three to six inches in length, and one to two inches in breadth; but at Dolliber's Point it is distinctly bedded, and is interstratified with fine-grained pyroxenic rocks. Another, but less abundant, variety, is fine-grained, presenting a very uniform texture and appearance, and approaching the compactness of felsite. This occurs at many points, but is most largely developed on Baker's Island, which is principally formed of it. A dark, heavy, usually coarse-grained diabase or norite, varying greatly in composition, and frequently occurring as a nearly pure pyroxene rock, is the most abundant rock of this series. It is the prevailing rock on

Nahant, where it is frequently very coarse and pyroxenic, with a high specific gravity. A more feldspathic variety exhibits traces of bedding on the north-east shore of this peninsula, as already noticed. This stratified rock is about midway between the Spouting Horn and Maolis Garden, and is of very limited extent. The lines of bedding trend E.–W. for one hundred feet or more, and then toward the west curve abruptly, but smoothly, around to the south, forming a right angle. Dip vertical. This pyroxenic rock, in its several varieties, and the feldspathic rock just noticed, occurring chiefly as eruptives, underlie the city of Salem, and form the peninsula of Salem Neck, and the islands of Great Misery, Little Misery, Pope's Head, and Eagle Island. The stratified rocks of this series consist usually of interstratified, frequently alternating, pyroxenic and feldspathic beds. They are of all textures, from the finest to the coarsest; the stratified pyroxenic rocks, however, are generally fine-grained, schistose, and very distinctly bedded. These last are well developed on Marblehead, west of Dolliber's Point, and especially about Naugus Head.

It has been suggested that some of the coarse feldspar, so abundant in the rocks of this series, may be labradorite; but the analyses thus far made do not support such a view. Yet, as only two specimens have been submitted to analysis, the question cannot be regarded as settled. The first specimen analyzed was taken from the very coarsely crystalline, stratified, feldspar rock on Dolliber's Point, Marblehead, and was placed in the hands of Mrs. E. H. Richards, of the Massachusetts Institute of Technology, who made the following report:—

SiO_2	66.639
Al_2O_3	19.375
K_2O	4.500
Na_2O	10.011
CaO	traces
H_2O	traces
	100.525

Such a chemical constitution belongs to no known species or variety of feldspar, though coming very near orthoclase; and, fearing there had been an error in the first analysis, a second was made from the same piece, — a clear, apparently unweathered specimen, — with a like result. A careful inspection of a large number of specimens seemed to explain the anomaly, by showing that the feldspar, although coarsely and perfectly crystalline, is probably a mixture; the crystals appearing to be formed of thin interlaminated plates of at least two different feldspars. This can be seen only on slightly weathered surfaces, one of the feldspars decomposing more readily than the other. The constituent layers were not analyzed, as it seemed impracticable to separate them. But if, as appearances indicate, it is a mixture, and a mixture of two species only, they are probably orthoclase, and albite or oligoclase, the former predominating. The color of this feldspar is bluish-gray, weathering white, and its sp. gr. varies from 2.55 to 2.60. Disseminated through it are numerous small crystalline grains of magnetite. The coarse feldspar of the Beverly shore, similar in physical characters to the preceding, was analyzed by Mrs. Crosby, and found to have substantially the same chemical constitution, containing one-half of one per cent. of calcium oxide. The specimens just described, from the coarsely crystalline, nearly pure, feldspar rock, are certainly not labradorite, and yet that this species exists in some of the rocks of this series does not, in my mind, admit of reasonable doubt. Much of the labradorite in the norite of Essex County, New York, and probably of other localities, is of a pale-green color and waxy lustre, and seemingly compact. In the coarse pyroxenic rock of Nahant, the feldspar is frequently physically identical with this, and yields by analysis a larger percentage of lime. The silica and calcium oxide only were determined, with the following result: —

	SiO_2	CaO
Labradorite from Westport, N.Y. . . .	54.60	4.85
Feldspar from Nahant	48.71	8.70

The same feldspar, apparently, occurs on Salem Neck, and at several other points in that region. In a formation so destitute of free silica as the Naugus Head series, it were natural to expect to find the feldspar mainly triclinic; and this expectation is fully realized, for, save in the very coarse feldspar rock of the preceding paragraph, I have rarely failed to observe the striæ indicative of plagioclase; and in not a few instances, judging by physical characters alone, this plagioclastic feldspar is most probably labradorite. A triclinic feldspar from the west end of Salem Neck, apparently little altered, afforded Mr. Geo. H. Barton fifty-seven per cent. of silica.

Dark-colored mica, probably biotite, is common in the rocks of this formation, though seldom abundant. Pyroxene appears as a principal constituent, and hypersthene is believed to occur. The massive, coarsely crystalline diabase, or norite, at Nahant is often decidedly epidotic; and the epidote is particularly abundant on the south shore, east of the steamboat wharf. The most striking, and probably the most important mineralogical character of this series of rocks is, that all members of it are absolutely destitute of quartz. Lithologists will recognize, in the complete absence of quartz from this formation, a strong indication that the principal constituent, after feldspar, is pyroxene, and not hornblende; and it is probable that every basic rock of this series may be properly classified, in a general way at least, as either diabase, norite, or pyroxenite. The coarse feldspar rock, mentioned above, and consisting mainly of orthoclase, is probably often a true syenite.

That this series of pyroxenic and feldspathic rocks, with its associated minerals, — which is sometimes stratified, oftener eruptive, frequently very coarsely crystalline, and always quartzless, — is distinct from anything observed elsewhere in Massachusetts, cannot be doubted. Lithologically at least, it may be said to be *sui generis* in Massachusetts geology. The great disturbance which the Naugus Head series everywhere exhibits, and its thoroughly crystalline appearance, stamp it as older than the Huronian and Montalban formations; and other and more important considerations confirm this view. The northern or Salem area of this series is bounded everywhere either by the sea or by rocks belonging to the Huronian system. On the north, in Beverly, we have coarse Huronian granite, such as is quarried in Quincy and Rockport; while to the west and south, in Peabody, Salem, and Marblehead, are dioriteand fine-grained hornblendic granite, also Huronian. What, now, are the geognostical relations of the Naugus Head series to these Huronian terranes? It underlies them. Everywhere, along the boundaries of the Naugus Head areas, we find the various members of this series penetrating and cutting through the Huronian rocks. But the converse of this is never observed. Nowhere, so far as my observations extend, does the Naugus Head series appear to be cut by the adjoining Huronian rocks; nor by any member of the Huronian system; nor, in fact, by any rocks not easily referable, as already stated, to the stratified portions of this series itself. In short, the Naugus Head series appears to be, as it were, at the bottom; and, while it has been extravasated extensively through superjacent formations, it is penetrated by nothing foreign to itself. The relations of the Naugus Head series and the Huronian formation are best displayed in the cliffs along the shores of Beverly and Manchester. Here the Huronian granite, already mentioned, is cut extensively by great dykes and eruptive masses of rocks, both pyroxenic and feldspathic, clearly belonging to the Naugus Head series; the feldspathic dykes appearing, usually, to be older and larger than the pyroxenic. But this granite, although it has evidently been more or less fluent, is never found cutting any member of the Naugus Head series; and we are thus forced to the conclusion that this series is older than the granite.

The Norian beds of Canada and Labrador were formerly regarded as forming part of the Laurentian, bearing the name "Upper Laurentian"; and, wherever their relations to the underlying terranes have been observed, they lie directly upon the Laurentian, never upon the Huronian or Montalban. The

Huronian, also, has heretofore, wherever its foundations could be clearly made out, been found resting on a Laurentian floor. The Norian and Huronian have never been observed under conditions favorable for the accurate determination of their mutual stratigraphic relations, and hence these are not positively known. Prof. Bailey and Mr. Matthew, however (in the Geological Survey of Canada, Report of Progress for 1870–71, p. 41), report the occurrence, seven miles east of St. John's, in the Province of New Brunswick, of a small area of crystalline, anorthic, and hypersthenic rocks, which are regarded as Norian by Dr. T. Sterry Hunt, after an examination *in situ;* and ocncerning the geognostical relations of which they say, "On the north side these anortholite rocks are met by red gneiss and granite, similar to the Laurentian gneiss at Indiantown, and on the south are covered by conglomerates and diorites of the Huronian series."

This language is explicit, and indicates that here, at least, the normal position of the Norian is *below* the Huronian. Yet it seems doubtful if this can be regarded as proved by the facts observable at this place; for, according to Dr. Hunt, these Norian rocks are, apparently, devoid of stratification, and may belong to an extravasated mass; while the adjoining Huronian beds are vertical. The mere occurrence, however, of these Norian outcrops between ledges of Laurentian and Huronian rocks, suggests that this is their normal position, and if their geognostical relations to the Laurentian and Huronian beds are regarded as due to the action of eruptive agencies, it is hardly conceivable that they have come from any horizon above the Huronian. Although conclusive proof that the Norian system is older than the Huronian has not been afforded us by a study of their relations at the only point where they are known to occur together *in situ*, yet the bulk of the evidence points in that direction; and the general facts, that the Norian rocks are usually more crystalline, have in every respect a more ancient aspect, and always exhibit less unconformability with the Laurentian than the Huronian, increase the probability that this is the true sequence of these great crystalline formations. This, it may be added, is the sequence deemed most probable by Dr. Hunt, viz., Laurentian, Norian, Huronian.

The Naugus Head series is certainly distinct from, and (as I have already shown) probably underlies, the Huronian; and, since it bears no likeness to the Laurentian system, we are brought to the conclusion, that, if it is to be correlated with any series already described, that series is the Norian. In short, the Naugus Head series does not resemble the Laurentian, and is, stratigraphically, where we should expect to find the Norian; and these are, mainly, the considerations which led me to designate this series as the "Norian," on the Centennial Geological Map of Massachusetts, and in my report on the same. Having been informed, however, by so good an authority as Dr. T. Sterry Hunt, whose opinion I had no opportunity to obtain before the publication of the report above referred to, that this series, chiefly on account of the supposed absence of labradorite, cannot be regarded as of Norian age, I have employed here, and on the accompanying map, a provisional designation having no chronological signification. I am constrained to believe, however, that, save in not holding labradorite as a principal constituent, if such proves to be the fact, the Naugus Head series presents a fair agreement, lithologically, with the essential characters of the Norian, as the latter has been described by Dr. Hunt. It is proper to state, in this connection, that Dr. Hunt, in 1869,[1] identified, as belonging to the Norian formation, a boulder found on Marblehead Neck, and possibly derived from the Naugus Head areas to the northward. I know by personal observation that the Naugus Head rocks are scattered as erratics all over the town of Marblehead, including the Neck. Prof. A. Hyatt long ago recognized the rocks about the city of Salem as probably older than the petrosilex of Marblehead Neck; but he did not separate them from the Huronian diorites of Salem, Swampscott, and Marblehead.

[1] Amer. Jour. Sci. (2) XLIX., 183, 398.

The only rocks in Massachusetts that have been observed passing below the Huronian system, or cutting through its lower members, are those composing the Naugus Head series; and this, together with its crystalline character and immense disturbance, convinces me that this series is the oldest in the State. In the light of our present knowledge the conclusion cannot be avoided, that the Naugus Head series is the real base of the geological column of Massachusetts.

The coarse-grained, readily disintegrating exotic diabase, so extensively quarried in Medford,—and also occurring in Somerville, Brookline, and, probably, other places,—bears a strong resemblance to certain members of the Naugus Head series, especially to the coarse pyroxenic rock of Nahant and Salem Neck; and the idea is natural that they are extruded portions of this series, which may, I think, be regarded as the probable seat of many of the eruptive masses cutting the newer formations of this region.

For the accurate identification of these exotics in Medford, Somerville, Brighton, Brookline, etc., we are indebted to Mr. M. E. Wadsworth.[1] This observer has found that the principal dark constituent of these rocks, in the unaltered condition, is always pyroxene, never hornblende; a fact which accords well with the general conclusion already stated with respect to the composition of the basic rocks of the Naugus Head series. The forms and general relations of these masses will be more fully described in connection with the uncrystallines which they intersect.

The small area of basic exotics exposed near the head of Washington avenue, in Chelsea, has been doubtfully referred to the Naugus Head series. North of Wenuchus Lake, in Lynn, is a hill composed of a nearly pure feldspar rock,— a coarse, whitish fieldspar, apparently the same as that so well developed on the Beverly shore. The rock is massive, having the aspect of an exotic; and around the base of the hill it can

[1] Proc. B. S. N. H., xix., 217.

be seen penetrating the Huronian diorite. It is undoubtedly safe to regard this as an outlier of the series in question. In what precedes I have described all the areas of the Naugus Head series marked on the map; but recent observations have convinced me that others exist. The hills immediately north of Wadsworth's Station on the New York and New England Railroad, in Franklin, appear to be entirely composed of a rock very similar to the prevailing type on Salem Neck, — quite destitute of quartz, and consisting chiefly of a coarse, triclinic feldspar, of bluish and grayish colors, with some mica, dark-colored, and often bronze-like, a green mineral that may be hypersthene, and a very little hornblende or pyroxene. No stratification is visible; and the boundaries of this area are entirely unknown, save that it does not appear to extend much, if any, south of the railroad. The high hills in Sharon, near Sharon Centre, and on either side of the Boston and Providence Railroad, appear to afford another area of these rocks. These hills are near the centre of the large area marked on the map as Huronian diorite; and some observations made by Mr. F. W. Very, in Foxboro', in connection with my own, lead me to suspect that, on the geological map of the future, the Naugus Head series will demand a considerable portion of the territory here assigned to a newer formation. Among the rocks occurring here I have recognized the most of those found in the Salem and Beverly areas. They are of all textures, and some varieties hold abundant grains of magnetite or menaccanite. In passing over the road leading north-easterly from Reading Village, and about one mile from the Boston and Maine Railroad, I have observed several ledges of a coarse, apparently exotic, dioritic rock, the chief constituent of which is a coarsely crystalline plagioclase, which I am strongly inclined to believe is labradorite; the rock, in that event, probably being a norite. It is in a region where outcrops are few and far between, and I could learn nothing of its extent.

HURONIAN.

The rocks that may be referred to this system in Massachusetts, like those of the Naugus Head series, are believed to occur only in the eastern portion of the State. They cover a wide area; and, except where the Naugus Head series, Shawmut group, and rocks of Paleozoic age face the Atlantic, they form the seashore from the New Hampshire line to Plymouth. This formation is bounded on the north and north-west by a line running south-westerly from Salisbury through Essex and Middlesex Counties to Concord. Here, after giving off a long and narrow deflection, which continues nearly twenty miles farther to the south-west, the line bends to the south, and continues through Framingham, Holliston, Medway, and Bellingham, to the north-east corner of Rhode Island. On the south, it is met mainly by the carboniferous rocks of Bristol and Plymouth Counties.

The Huronian area has an extreme length, measured from the New Hampshire line in Salisbury to Manomet Hill in Plymouth, of sixty-five miles; and a maximum breadth of forty miles across the southern end, not counting the narrow band stretching from Concord to Westborough. It is almost completely divided near the middle by the Primordial, and, possibly, more recent rocks, which lie about the shores of Boston Harbor, extending westerly to Natick, and south-westerly to Rhode Island. On the accompanying maps the Huronian series comprises the areas marked as "syenite," "porphyry," and "hornblende slate," on the geological map of Massachusetts, prepared by Professor Edward Hitchcock.[1]

The existence in Eastern Massachusetts of rocks of Huronian age was first announced by Dr. T. Sterry Hunt, in 1871. In a paper on "Granites and Granitic Vein-stones"[2] he speaks of the "felsites" and "felsite porphyries," or "orthophyres," oc-

[1] I have marked the Huronian boundary on the map with a heavy line, for the sake of greater distinctness.

[2] Chemical and Geological Essays, p. 187.

curring in Lynn, Saugus, Marblehead, and Newbury; and says in this connection, "These rocks are, throughout this region, distinctly stratified, and are closely associated with dioritic, chloritic, and epidotic strata. They appear to belong, like these, to the great Huronian system." Dr. Hunt has included here all the rocks which it is proposed to refer, in this paper, to the Huronian series, save the binary and hornblendic granites (which are so characteristic of Eastern Massachusetts) and the limestones. In consequence of finding the *Eozoon canadense* in the serpentinic limestone of Newbury, Dr. Hunt, in 1870,[1] referred this limestone and the associated rocks, as well as the more crystalline and less serpentinic limestones of Chelmsford and Bolton, and the gneiss in which they are included, to the Laurentian system. He made no mention, in this connection, of the serpentinic limestone in Lynnfield, which is probably of the same age as the Newbury deposit, since the associated rocks appear to be the same. Prof. C. H. Hitchcock, also, in 1871,[2] referred to the Triassic period, certain diorites in the vicinity of Salem and Boston, which are here referred in part to the Naugus Head series, and in part regarded as of Huronian age. And more recently, in his late report (1875) on the geology of New Hampshire, he has applied the term "Labrador" to this broad Huronian area, although these rocks have scarcely a single character in common with the Labrador or Norian series as defined by Dr. T. Sterry Hunt and the Canadian Geological Survey.[3] It will be shown in the sequel, however, that all the rocks within the area described probably belong to one and the same lithological and stratigraphical series, the general characters of which stamp it as Huronian.

A glance at the maps will show that the attempt to delineate this formation lithologically, *i. e.*, to show the distribution of its various lithological members, has been attended by moderate

1 Amer. Jour. Sci. (2), XLIX., 75.

2 Geological Map in Walling's Atlas.

3 Still later, in the atlas of the New Hampshire Survey (1878), Prof. Hitchcock recognizes the existence of several limited Huronian areas in Essex County.

success. More might have been accomplished with a longer time for exploration; yet much must ever remain undone, on account of the great extent to which the rocks are, in some districts, concealed by superficial deposits. A special color has been used to represent the general Huronian formation wherever the particular lithological representative is not known; but the probabilities are great that the rock, whatever it is, belongs to this age.[1]

The Huronian system in this region, like the Naugus Head series, though in a somewhat less degree, exhibits great disturbance. Distinctly bedded rocks are the exception; and, although many apparently structureless rocks are probably really stratified, it is undoubtedly true that a large part, perhaps the greater part, of the formation has been more or less fluent, and extravasation may be set down as a characteristic structural feature. The extent to which some of the rocks of this series, in Eastern Massachusetts, are characterized by a condition approaching chaos, can be fully appreciated only by those who have studied them somewhat in detail in the field. The stratified portions of this series have usually a N. E.–S. W., varying to E.–W., strike; and the areas of unstratified and extravasated rocks generally exhibit in their trends a tendency to parallelism with the strike of the stratified rocks. The latter usually dip steeply to the north-west.

The Huronian series of Eastern Massachusetts is principally composed of the following rocks, or, rather, groups of rocks:—

1. Granite (hornblendic and binary).
2. Petrosilex (passing into felsite and quartzite).
3. Diorite (unstratified and largely exotic).
4. Hornblendic Gneiss, Stratified Diorite, etc.
5. Limestone.

1 In adopting the plan, wherever practicable, throughout this work, of mapping the various formations lithologically rather than geologically, I have done much to keep my facts and theories separate.

Although so connected lithologically and stratigraphically as to be clearly members of one great series, yet these various groups are, on the whole, well separated, occurring mainly in large masses. The stratigraphic distinctness would be much more striking but for the wide-spread extravasation which some of the divisions have experienced. Their general separateness implies that they are, for the most part, of different ages, — are chronologically distinct; and may each be regarded as a sort of sub-formation. Whence it follows that, in all their more special relations, they admit of separate description; and that is the plan adopted here. The different groups will be taken up in regular order, beginning with the oldest. The true sequence, excluding some of the limestone, is expressed in the foregoing classification.

GRANITE.

The typical granite of this region, as shown at the quarries in Quincy and other places, is a coarsely crystalline aggregate of orthoclase, quartz, and hornblende. Orthoclase is the predominant mineral, and in its abundance constitutes the leading character of the rock; this is pre-eminently a feldspathic granite. The hornblende is usually small in amount, and the rock frequently passes, through the disappearance of hornblende, into binary granite. All the Huronian granites of this region, and especially this typical variety, are remarkably firm and coherent, being strongly contrasted, in this respect, with the most of the granite of the Montalban and newer formations. In Topsfield, in and near the village, the granite is locally rather loose and friable; but this is the only instance of the kind within my knowledge which is not clearly the result of atmospheric action. And it may be said that these granites, as a rule, resist chemical quite as well as mechanical forces. The colors of the granite are mainly due to the feldspar, the hornblende seldom being sufficiently abundant to sensibly darken the tint of the aggregate. The feldspar is usually grayish or bluish, though different shades of red and pink are very common, and green and other tints are frequently met with. Feldspars of several distinct colors are sometimes commingled in the same hand specimen. A beautiful granite occurs in West Dedham and Dover, for example, in which the feldspar is chiefly of a light-green color, but contains interspersed through it numerous crystals of a flesh-red feldspar. Such instances are common, especially among the granites in Dedham and Dover, and along the Swampscott shore. The occurrence of masses of red and white granite on the south-western end of Marblehead Neck, in close juxtaposition, but not blended, is well known, and has been noted by Dr. Hunt, Prof. Hyatt, and other observers. The hornblende of the granites presents a variety of aspects, frequently having a greenish-slaty, or chloritic appearance; and it is probable that our Huronian granites are often, locally, of the variety called "protogine" by the French geologists.[1] It is worthy of note that the Huronian granites of Eastern Massachusetts are usually destitute of mica, the micaceous granite of Rockport and Gloucester, to which attention has been specially directed by Mr. M. E. Wadsworth,[2] probably constituting the single notable exception.

These granites, as every observer well knows, are subject to extensive variation in both texture and composition, and the varieties are so numerous, pass into each other so frequently, and are so perfectly blended, that their distinction on the map would be, at least in the present state of our knowledge, a hopeless task, and I have not attempted it. Since, however, there is such a deficiency of definite knowledge concerning the geographic relations of the different varieties of granite, even a general sketch of the distribution of the leading types may prove useful as a basis for future observations. For this purpose I will consider the granites as embracing three principal varieties. These are, (1) the coarsely crystalline, little horn-

[1] According to Prof. Haughton, the green mineral of protogine is never talc, but usually chlorite, or some kindred mineral.

[2] Proc. Bost. Soc. Nat. Hist., XIX., 309.

blendic, typical granite, already mentioned; (2) a finer-grained, less hornblendic, euritic variety, sometimes approaching petro-silex; (3) the very hornblendic, commonly fine-grained granite, which is usually poor in quartz and frequently passes into diorite.

1. The coarse, typical granite above described, well known in Quincy, where it is so extensively quarried, may be traced the entire length of the Blue Hill range; but with greatly diminished breadth towards the west. Westerly, it is limited to the northern side of this group of hills, and at no point does it appear to reach their southern border. A fine example of the typical granite forms the northern shore of Cohasset Harbor; and it is the prevailing variety in Cohasset and Hingham. Indeed, judging from the observations of myself and others, and the specimens collected by Prof. Hitchcock, and now in the State cabinet, I conclude that the broad area of granite which sweeps through northern Plymouth and Bristol and southern Norfolk Counties, is mainly, and towards its eastern end almost entirely, composed of this variety. In the northern part of Plymouth County, south-east of a line drawn from Scituate to Abington, rock outcrops are few and far between, and the granite marked on the map as occurring in Kingston, Duxbury, Marshfield, etc., is largely conjectural. I have seen no indications, however, of the existence here of any other rock; and hence I have ventured to color the entire area as granitic, instead of employing the general Huronian color, which would, perhaps, have been the wiser course. I suppose that this granite is mainly of the typical variety. I have observed this kind *in situ* in Marshfield; and Mr. Elmer Faunce reports an exposure of the same rock on Jones River in Kingston.

At some points in this southern region the coarse granite is porphyritic with feldspar crystals. Prof. Hitchcock[1] mentions several localities, and I have observed a good example on Thaxter Street in Hingham. It is always of local extent. The

[1] Final Report Geol. of Mass., p. 669.

granite in the western part of Wrentham is mainly of the typical variety; and the same may be said of the granite in West Roxbury, and of that in the immediate vicinity of Dedham Village, and southward to the New York and New England Railroad. The large granitic area in Dover, Medfield, Natick, and Sherborn is mainly composed of the variety under consideration, which is here largely characterized by a greenish feldspar. In the northern part of Needham, also, it asserts itself, nearly to the exclusion of all other varieties; but ceases to be the prevailing rock as we pass into the southern part of Weston. The granites of these western towns —Dedham, Norwood, Dover, Sherborn, Natick, Needham, etc. — are almost universally of a reddish or pink color, sometimes greenish, but very rarely dark gray or bluish, as in Quincy, Rockport, Peabody, and other towns to the east and north-east. The granite about the southern end of Spot Pond, in Medford and Stoneham, is, so far as I know, all of the coarse typical variety; and the same is true, with unimportant exceptions, of the areas in the northern part of Stoneham, and in Wakefield and Reading.[1] Well-marked typical granite occurs in Saugus, south of North Saugus, and in all parts of the large granitic area in Peabody, Lynnfield, and Lynn, north of Wyoma Lake in the latter town. The so-called "Peabody granite" cannot be distinguished from that quarried in Quincy. The granite in eastern Lynn, on the Swampscott shore, and on Marblehead Neck and the adjacent islands, though subject to considerable variations, may be nearly all referred to the typical variety. The granite composing the small area of this rock in the southern part of Marblehead contains little or no hornblende, is coarsely crystalline, and would belong to the typical variety but for the fact that it is nearly destitute of quartz. A somewhat similar rock, in which there is an entire absence of quartz, forms a large hill immediately north of the eastern arm of Wenuchus Lake, in Lynn. It does

[1] I am indebted to Mr. J. S. Diller for knowledge of a small area of granite, not marked on the map, which exists in Malden, north of Salem Street and between Prospect Hill and Maplewood.

violence to the rules of lithologic nomenclature to call this rock granite. It closely resembles a rock of the Naugus Head series on the Beverly shore; and it is probably an outlier of that formation. It occurs as an eruptive, cutting the adjoining diorites; and I have given it the Naugus Head color on the map. Continuing northward, we find the granite of the large area between Beverly and Rockport characteristically coarse, and, as a rule, little hornblendic, especially towards the north-east, where, as already noticed, the hornblende is sometimes replaced by mica. The granite in Essex, Ipswich, Hamilton, and Topsfield, so far as observed, appears to belong here. In the latter town it disintegrates readily, and is known as the "rotten rock." Coarse, little hornblendic granite occurs in Rowley, along the railroad, north of the station, and at several points in Newbury, north of the river Parker. In both towns it becomes finer-grained towards the west.

We have traced this type over a large area, and have found it everywhere presenting substantially the same characteristics. Though the limits of local variation in texture and composition are wide, yet to the general view it remains essentially unchanged; and the observer feels that, from Plymouth to the Merrimac, from Rhode Island to Cape Ann, it must be, in its origin and petrologic relations, one and the same rock.

2. The fine-grained, little hornblendic granite contains even less hornblende than the typical variety; and, like that, it is frequently a binary granite, — composed entirely of orthoclase and quartz. This variety not unfrequently appears, when containing little or no hornblende, to pass through eurite into petrosilex. I am unable to point to any particular locality as affording incontestable evidence of this transition; yet indications of such a passage are constantly presented to the observer. He meets on every hand partial proofs; and, whether studying granite or petrosilex, he is ever finding rocks which are neither, but both, — until the gradation is complete, and the conclusion is forced upon the mind that these rocks must be unequally metamorphosed portions of one and the same original rock. This

is the view held by Prof. Edward Hitchcock,[1] after many years of observation; and the same conclusion has also been reached by Mr. T. T. Bouvé.[2] Such specific evidence as can be adduced on this point will be presented after the description of the petrosilex.

The euritic, or fine-grained binary granite of this region is as wide-spread, but not so abundant, as the type. The fine-grained granite in the vicinity of the trilobite quarry on Quincy Neck, along the east side of Payson's Hill, the west and north side of Weymouth Fore River, and south and west of the Braintree station on the Old Colony Railroad, may be referred to this variety. In the western part of Braintree there can be little doubt that the rock in question passes into the Blue Hill petrosilex. The granite adjacent to the slates at Mill Cove, in North Weymouth, is identical with that adjoining the Paradoxides quarry on the opposite side of the river. These euritic granites differ from the type only in texture; they are undoubtedly identical with it in origin, and the impracticability of a geographic separation becomes apparent as we study their distribution; for the two varieties are everywhere found intimately associated. We have just seen that the Quincy range of granite, though mainly composed of the typical variety, is bordered, about its eastern end, by a fine-grained, sub-crystalline species; and in traversing the broad areas composed chiefly of typical granite, in southern Norfolk and northern Bristol and Plymouth Counties, and in Essex County, between Beverly and Rockport, the observer is constantly encountering small patches of this rock, which is usually of a pale pink or reddish color. I have seen it in Cohasset, along the Old Colony Railroad in North Easton, on the New York and New England Railroad in Walpole and Norfolk, in the vicinity of Pride's Crossing in Beverly, and in the neighborhood of Rockport on Cape Ann. On Marblehead Neck there is a rock which is closely associated

[1] Final Report Geol. of Mass., p. 667.
[2] Proc. Bost. Soc. Nat. Hist., XVII., 220.

with the typical granite on the one hand, and with the petrosilex on the other; and it has been regarded by Prof. Hyatt as transitional between them. Although this is undoubtedly its true position, yet it probably belongs on the petrosilex side of the imaginary line separating these two rocks. A somewhat coarser, but otherwise identical, rock in the vicinity of Woburn and Purchase Streets, in West Medford, appears to be similarly related to the granite and petrosilex of that town. In the immediate vicinity of the Clarendon Hills Station, on the Boston and Providence Railroad, are outcrops of a rock which, though marked on the map as petrosilex, and unquestionably closely associated with the petrosilex of that region, probably belongs, in a lithologic sense, with the fine-grained granite. The coarse granite about Dedham Village passes on the north and west into a finer-grained variety; which becomes finer the farther we trace it from the type, and appears to cover all the northern and north-western parts of the large area in Dedham, marked as granitic on the maps. This rock, quarried in West Dedham, is the principal material used in the construction of Trinity Church in Boston. Beyond the Charles River, in Needham, it becomes so fine-grained and cryptocrystalline as to appear at some points inseparable from the adjoining granitoid petrosilex, or quartz porphyry. Here, as elsewhere, a sharp line of demarcation between these rocks cannot be avoided on the maps, but it probably does not exist in nature. The rocks in Needham, however, are extensively drift-covered; and this inference as to the relations of the granite and petrosilex of this town might not be sustained by the facts, could they be fully known. The granite in the southern part of Dover is similar to that just described; and there are abundant indications of a passage into the petrosilex on the east, the evidence in this instance being clearer than in the other. This variety of granite occurs in the western part of Newbury, along the river Parker, and its characters are especially distinct south of this stream, on the road leading south from Byfield Parish. The granite bordering either side of the Merrimac, in Newburyport and Salisbury, appears to be intermediate between this variety and the preceding. Portions of it, however, approximate to the third variety in the proportion of hornblende they contain.

3. The more hornblendic of the Huronian granites are usually fine-grained, and the increase of the hornblende is commonly attended by a diminution of the quartz; so that the rock exhibits, through the entire absence of quartz, and, probably, a concomitant change from orthoclase to a triclinic feldspar, frequent passages into diorite.

This variety is subject to equal or greater variation in composition and texture than those already described, and its boundaries are even more difficult to trace. In northern Lynn and Saugus, between the petrosilex on the south and the typical granite of Lynnfield and Peabody on the north, is a belt of this rock nearly a mile wide and more than three miles long. Geographically, it sometimes occurs, as in this instance, between petrosilex and granite; but, as a rule, it is associated with diorite, and this association is usually very intimate. This diversity of petrologic relations is due to the fact that, as regards its origin, we are dealing with more than one rock. Those portions only of this variety that are associated in their distribution with either the typical or euritic varieties, or with petrosilex, are marked as granite on the maps; when connected with diorite alone, it has been (for reasons that will appear farther on) regarded as diorite, and has not received a distinctive color. This rock is always finer-grained and more hornblendic when accompanying diorite than when connected with petrosilex, or with other granites; and, in the former association, it rarely approximates to either the typical or euritic varieties, or to petrosilex; in fact it is doubtful if in such cases the feldspar is orthoclase, plagioclase being more probable, — in which event the rock becomes, of course, simply a quartzose diorite.

The Huronian granites of this region sometimes exhibit traces of stratification. This structure has been observed in the fine-grained hornblendic variety north of Linmere in the southern part of Peabody, and very locally at several points in Salem, Swampscott, and Marblehead. A stratified hornblendic granite, or gneiss, occurs to a limited extent among the other stratified rocks in Reading, conforming with them in dip and strike. In Peabody, on the Newburyport turnpike north of Locust Dale and near the Danvers line, Prof. Hyatt has observed a granitoid gneiss, apparently conformably interstratified with the hornblende slate occurring there. This is probably a true gneiss. The typical granite along the Eastern Railroad in Rowley, and in Newbury south of the river Parker, presents a coarse but imperfect gneissic structure at several points. I observed the strike in one place to be N. 60° W., dip vertical. Portions of the granite on the west side of Hospital Point, in Beverly, have a peculiar schistose structure; the constituent minerals, especially the quartz, appearing not as grains or crystals, but as small lenticular sheets, lying in parallel planes. This appears to be the *granulite* of the books; strike, north-west. Granite possessing a more normal gneissic structure also occurs in this locality. In Arlington, north-west of Spy Pond, there is some stratified granite, or granitoid gneiss; the bedding is quite distinct at some points; strike, north-east. A rock similar to the stratified granite of Rowley is exposed in the railroad cut at Natick, east of the station, and appears, in part, to be intercalated with the hornblende slate and diorite. In the north-eastern part of Dover, near Mill Brook, Mr. F. W. Very has observed an interesting series of stratified hornblendic and petrosilicious rocks, some of the latter of which approximate to the euritic variety of granite. The average strike is north-south. Most of the rock on the Cohasset shore, between Little Harbor and Black Rock, is a little quartzose gneiss, which, to the general view at least, does not seem to be wholly foreign to the surrounding granite, but has the appearance, rather, of being a portion of the granite which still retains a trace of the structure that originally characterized the whole. The strike is quite constant, and averages about north-west. So far as my observation extends, the hornblendic material of the stratified granite is never distinctly crystalline, but always presents the slaty or chlorite appearance already noticed (ante, p. 28) as frequently characterizing the hornblende of our Huronian granites. This incipient or bastard hornblende, although characteristic of the stratified granites, is not peculiar to them.

The above are all the instances of any importance that have come under my notice, of the occurrence of stratification, or a structure resembling stratification, in the granites of this formation. Many examples of well-marked bedding have probably escaped observation; and there can be little doubt that the granites in some cases really possess a gneissic structure where the rock is too coarse and massive to enable the eye to detect it. Yet I do not hesitate to assert that such phenomena must, wherever occurring, be very local; for it can be proved beyond a doubt that the Huronian granites of this region are mainly exotic. We have seldom far to look to find, in the form of enclosed, angular fragments of clearly-stratified rocks, evidence of their extravasation; and near the boundaries of the granites we often observe them cutting the adjoining rocks, especially if these are stratified, in a manner incompatible with any theory that would regard them, in their present condition, as chiefly indigenous. It is not meant that the extravasation has been universal; it may not have been even general, but certainly a sufficient amount of the granite bears evidence of a foreign birth to warrant the belief that the greater part of this rock has at least been fluent. Prof. N. S. Shaler, in 1869,[1] announced the discovery, in the Quincy granite, of structure lines, which he regarded as traces of stratification; and he was led, in consequence, to suggest the original sedimentary condition of all the granite of that range. The evidence of bedding here is certainly much less clear and unequivocal than in the instances cited above; and although believing with Prof. Shaler, and also with Mr. T. T. Bouvé, that all these granites

1 Proc. Bost. Soc. Nat. Hist., XIII., 173.

are metamorphosed sediments, I conceive that the peculiar planes of separation (joint structure) referred to by Prof. Shaler demand a different interpretation from that proposed by him, for evidence is not wanting of the extravasation of the granite at many points along the Blue Hill or Quincy and Milton range. Following are the clearest cases with which I am acquainted. It is well known that the Quincy granite is met along its northern border by conglomerate and slate. Interposed between these uncrystalline sediments and the granite at some points is a compact, greenish, slaty rock, which is occasionally felsitic, but oftener heavy and semi-crystalline, approaching diorite. It exhibits obscure traces of bedding in a few places. The actual contact of this rock with the granite is seldom observed; it is displayed, however, at a place about one-half mile west of the Old Colony R.R., and immediately north of a quarry situated a few rods south of the southernmost part of Adams Street, on the west side of the private road that runs from Adams Street to the quarries. The contact line is extremely irregular; and the relation of the granite to the semi-crystalline rock is unquestionably that of an exotic. Some three miles to the south-west, near the centre of this large granite range, about three-fourths of a mile east of Randolph Turnpike, and near the reëntrant angle in the western boundary of Quincy, is an island of this same dark-colored, slaty rock, but more distinctly argillaceous, and the traces of bedding a little less obscure. It is very distinctly cut by dykes and irregular strings of the underlying and surrounding granite. According to Prof. W. H. Niles, the relations of the granite and slate on Weymouth Fore River, near the trilobite quarry, afford equally conclusive evidence that at least a portion of the granite has experienced some extravasation since the deposition of the slate. The slates on the South Shore R.R., immediately east of the station at Weymouth Landing, are in contact with the granite, which cuts through, and overlies them in a manner possible, apparently, only with an exotic; and at the contact of the granite and slate south-west of the station, Prof. Niles has observed angular fragments of slate actually enclosed in the granite, though lying only a few inches from their original positions in the parent bed. The induration, as if by heat, of the slate and conglomerate at most points where they adjoin the granite, and the frequent development of amygdaloidal characters in the slate in those places, are also facts which tell strongly in favor of the former igneous condition of the granite. The evidence of the extravasation of the granite afforded by a study of its relations to the uncrystalline rocks appears to be sufficiently conclusive as regards the portions of granite immediately involved. But since we know that the extrusion of this rock occurred mainly at a period anterior to the deposition of these uncrystallines, it is to the relations of the different varieties of granite to each other and to the other crystallines that we must look for proof of the exotic nature of the granite taken as a whole; and here the evidence is both abundant and convincing. Following are the more striking of the many proofs of the extravasation of the granite that have come under my notice. At Hospital Point on the Beverly shore, near the water's edge south of the lighthouse, is a considerable mass of a distinct mica-slate enclosed in the coarse, structureless granite. A smaller mass of a similar stratified schist is enclosed in the granite near the northern end of the railroad-cut in Beverly. On Marblehead Neck the relations of the granite to the fine-grained, distinctly stratified schist occurring there, are such as to leave no doubt that the granite is exotic. Along the shore, at the south-western end of the neck, the exposures are magnificent, and one can see, especially at low tide, numerous angular, ragged, contorted masses of the schist, of various sizes, enveloped by the granite. Farther east, at the northern limit of the granite on the eastern shore of the neck, a large dyke of this rock cuts through the adjoining petrosilex. The granite composing the small area of this rock on the west side of Wenuchus Lake, in Lynn, is mingled with the adjoining petrosilex in such inextricable confusion as to force the conclusion, that at least one of these rocks has been fluent; and near the lake shore, enclosed in the granite, are angular fragments of a schist resembling that on Marblehead Neck. The same phenomenon has been observed by Prof. Hyatt and myself at many points in Peabody and Lynnfield, especially in the quarries about the village of Peabody, and along the western border of this large granitic area. In North Saugus, on the high hills to the west of the private road running north from Forest Street and Central Brook to Water Street we have, perhaps, the finest example of the extravasation of the granite yet observed in this region. The exposures of the rock here are remarkably good; and the granite is coarse and sharply defined, where it penetrates the adjoining petrosilex and hornblende slate in irregular dykes, or envelops isolated masses of these rocks that have been wrested from the parent beds. The relation of the granite and stratified rocks along the railroad in Natick appears to approximate to this in part. In the western part of Wrentham, about one-half mile from the western boundary of the town, and the same distance north of the Rhode Island line, what appears to be Huronian granite has been observed cutting fine-grained schists that I refer to the Montalban age. To the north of this, about Wadsworth's Station on the New York and New England Railroad, and generally throughout this southern region, especially in Foxborough, Sharon, Canton, Franklin, etc., the granite and diorite are so related that one must be exotic, probably both.

A glance at the map suffices to show that the geographical distribution of the granite is in harmony with the theory of its extravasation; for it is seen to occur among the other members of the Huronian series in a manner decidedly irregular. It does not form continuous, well-defined areas; but is found in isolated patches, with boundaries difficult to define, and such as can be readily accounted for only on the supposition of a former plastic or fluent condition of this rock. The large area marked as granite between Boston Harbor and the Carboniferous formation of Plymouth and Bristol Counties would appear to be an exception to the above statement; but it should be said of this area that it is largely covered by drift material, especially toward the southern border, and comparatively few observations of the rocks have been made. Slates are said to occur in Abington; and it is known that there are occasional small masses of diorite included in or cutting through the granite. These appear to be very irregular in outline, and are most numerous toward the west, where we approach the large area colored as diorite on the map. The accurate mapping of these limited patches is practically impossible; and, since we know, from such observations as have been made, that the diorites can form but a small proportion of the whole, I have ignored them on the map, marking the entire region as granitic. A more detailed map, such as it is hoped the student of the near future will construct, would show the boundaries of the granitic areas to be much more complex than they are here represented, where we have hardly an approximation to the intricacy of nature.

A farther inspection of the map will make it evident, however, that the granite is not without some system in its distribution. The granite areas north of the Boston and Albany Railroad, and south of the Essex branch of the Eastern Railroad, are arranged along a line having a direction about N. 50° E.; forming a discontinuous band of variable width, which extends from Natick to Rockport, on Cape Ann, a distance of forty-five miles; and we readily find in this wall of granite, probably the most resistant rock of this region, a sufficient cause for the existence of this prominent headland. The slate and conglomerate in Newton and Watertown are probably underlaid by granite, which would account for the discontinuity of the range here. The granite in Marblehead and Swampscott, though considerably out of the line of this belt, is evidently connected with it; and, if the water were removed from those shores, we should probably find that these isolated patches are really united, forming an irregular offshoot or spur of the large granitic area of Lynn and Peabody. Similarly, the granite in Reading and Wakefield may be regarded, not as an isolated mass, but as connected, under the drift, with the larger tract of granite on the east. This connection is indicated on the map. I have sought in vain for a surface connection between the Peabody granite and that in Beverly. Between this Natick and Rockport granite belt and the large area of granite, already noticed, on the south, are several considerable masses of this rock, of which the Blue Hill range is one; and it is probable that part at least of the territory marked on the map as general Huronian, in Medway, Medfield, and Franklin, now extensively drift-covered, is underlaid by granite. The attempt to detect any system in the arrangement of these masses has been attended with poor success; and I can only say that their present complicated and apparently systemless disposition appears to be due to two forces operating to arrange the granite along two distinct lines; one line coinciding in direction with the Natick and Rockport belt, north-east and south-west, and the other having an east and west trend. It will be readily observed that the Dover, Dedham, and Blue Hill granite masses are in line with each other, and appear to form an east-west band of this rock, connected with the Natick and Rockport band, in Natick, and with the broad southern area, in Braintree. But this may be illusory, a more probable view, perhaps, being that these masses are portions of independent north-east and south-west bands parallel with that already described, the south-western extensions of which are concealed by newer rocks or drift.

North of the Natick and Rockport granite range, in Essex County, we find a parallel but shorter belt stretching through southern Ipswich, Hamilton, and Topsfield. The granite in Essex connects this band with the longer range. Another band runs with nearly the same course through Rowley and Newbury, south of the river Parker, branching westerly; and north of this stream a narrow band of variable width reaches from Byfield, where it appears to connect with the area last mentioned, along the north side of Kent's Island and Old Town Hill, probably, under the drift, to Plum Island River. Still farther north is the Salisbury and Newburyport band, which extends from the western boundary of the formation, along either side of the Merrimac to its mouth. This is the shortest of all the bands, and its boundaries are the least perfectly known.[1] These four granite ranges — the Ipswich, Rowley, Newbury, and Salisbury ranges — are essentially parallel with each other, and with the Natick and Rockport zone on the south. They all narrow rapidly westward; so that only one, the Salisbury range, appears to reach the western limit of the formation. In the Rowley and Newbury bands, notably, the granite is coarsest toward the east. Toward the northern end of Essex County, in Newbury and West Newbury, granite is known to exist outside of the areas indicated above. It occurs in narrow bands and irregular patches, parallel, in a general way, with the large areas between which they lie, and too small for delineation on the map. The number and boundaries of these small areas remain to be determined.

The granite described in the preceding pages is not known to occur in Massachusetts beyond the limits here assigned to the Huronian system. Two areas of "syenite," it is true, are represented on the geological map prepared by Prof. Hitchcock as occurring in the Connecticut Valley; one in Belchertown and Ludlow, and the other in Hatfield and Whately. But these rocks are really, for the most part, hornblendo-micaceous granites, which have a Montalban rather than a Huronian aspect, and are intimately associated with the Montalban rocks

[1] The northern half of Essex County is extensively drift covered; and, notwithstanding this county was regarded by Prof. Hitchcock as, on the whole, the most rocky in the State, outcrops are wanting over most of the area north of the Beverly and Cape Ann range of hills. My opportunities for exploration in that region, also, have been rather limited. And hence the boundaries of some of these granitic areas, as they appear on the map, are, within certain limits, largely conjectural. Where outcrops were wholly wanting, I have been guided by the character of the boulders contained in the drift.

of that region. The relations of the granite here referred to the Huronian system, to the Naugus Head series, have been discussed (*ante*, p. 19). It can scarcely be doubted that it overlies this ancient series, and belongs to a newer system. It is associated in some part of its distribution with every member of the Huronian series, and in all cases the indications are plain that the granite is the older rock. It has been set down by all observers as the oldest rock in this region, and this view is abundantly justified (except as regards the Naugus Head series), not only by its generally coarsely crystalline aspect and the great disturbance and almost complete absence of stratification which it everywhere exhibits, but also by the general fact that it cuts, as an exotic, all the other members of the Huronian system. In fact, it pierces, in its well-nigh universal extravasation, every rock in this region, save the Naugus Head series and the newer uncrystallines. In its geographical distribution we have a strong indication that the granite belongs to the Huronian system; for it is co-extensive with that system, and does not occur beyond its limits. And it will be shown farther on that its lithological relations point indubitably to the same conclusion. But its petrology makes it clear that, if the granite is referred to the Huronian series, it must be regarded as the lowest, and hence the oldest member of that series. It appears, in fact, to be the foundation of the Huronian system in Massachusetts.

It will not have escaped observation that this so-called Huronian granite has, as a whole, a decidedly Laurentian aspect; and some geologists would probably refer it to that great fundamental system. Indeed, the granite of the Newbury belt, described above, is one of the rocks associated with the serpentinic limestone of that town, and referred by Dr. T. Sterry Hunt to the Laurentian, as noticed (*ante*, p. 25). The most characteristic rock of the Laurentian system, it is well known, is a firm, coarse, granitoid, and, to the eye, frequently unstratified gneiss, composed chiefly of orthoclase and quartz, with little hornblende and less mica, — a description which applies very well to the granites in question, save that they are generally exotic. There are, however, two important considerations which, in my estimation, throw the weight of evidence against the view that these granites are Laurentian. These have already been stated. First, the relations of the granite to the petrosilex make it necessary to regard these two rocks as members of the same series, so that if one is Laurentian, the other must be also. Now, the petrosilex is taken as the most typical Huronian rock in this region; and, if it is included in the Laurentian system, there is really no reason why the other rocks, here referred to the Huronian age, should not be disposed of in the same way; for they appear to be as intimately associated with the petrosilex on one side as the granite is on the other. Second, this granite overlies the Naugus Head series, and hence, if the former is Laurentian, the latter must be a distinct formation below the Laurentian; which is, to say the least, highly improbable. It might be urged by some that we have here an inversion of the natural order; that the granite, though belonging to an older system, overlies the Naugus Head series in consequence of some gigantic fault, overturn fold, or igneous overflow; the extravasation of the Naugus Head series through the granite having occurred subsequently to the inversion. This violent hypothesis, however, is entirely unsupported by facts, except that evidences of stratification are more frequently met with in the Naugus Head series than among the granites, indicating that the latter are the older rocks; and this indirect evidence is offset by the fact that the Naugus Head rocks, especially the feldspathic varieties, are, as a rule, much more perfectly and coarsely crystalline than the granite.

Of course, that the granite occupies the geologic horizon here claimed for it can be proved directly and conclusively only with respect to those portions of this rock showing either a passage to petrosilex, or intersection by rocks of the Naugus Head series, — a small part of the entire granite formation. Hence the way may be considered open for the introduction of evidence pointing to a division of the granite between two distinct formations, the Huronian and something older; but I have seen no evidence of this character; all the facts, so far as I have observed, going to show that, as respects its origin at least, the granite is a single rock. Although well satisfied that a large proportion of the granite has been in a state of igneous plasticity, yet its relations to the stratified petrosilex and the many traces of bedding which it still retains forbid me to believe that the mass of this rock has been elevated from any vast depth; it seems rather like an extensive stratified formation which has been softened *in situ*, and then to a greater or less extent forced out of its normal position by the pressure of surrounding and overlying terranes.

PETROSILEX.

The determination of the relations of the group of rocks here included under the general name of petrosilex is the most difficult problem in the geology of Eastern Massachusetts. No other rock in this region is subject to such great variations in composition and structure, or is more puzzling in its petrologic relations. This diversity is not apparent at first view. On the contrary, these rocks are likely to strike the casual observer as comparatively uniform throughout their distribution and simple in their relations; and it is only by a careful study of the whole field that the mind is finally divested of this idea, and the conclusion reached that these rocks are not one, but many.

Porphyry is a much-abused word, which, like syenite (by syenite is not meant the aggregate of orthoclase and hornblende to which this term is now applied), has outlived its usefulness, and should, in the opinion of the best geologists, be allowed to become obsolete in its substantive use, as a geological term. Much of the rock in this region to which the term porphyry is applied is not even porphyritic; showing into what logical errors we are led when we choose for the basis of a lithological name a property common to many rocks, and which cannot be correlated with any particular chemical constitution. A character so superficial as the one in question, which is common to rocks so unlike chemically as a hornblendic diorite and a quartzose petrosilex, and which is constant in no rock, appearing to be indifferently present or absent in rocks which, saving this property, are identical; which is, in fact, as inconstant and fleeting as color; is certainly valueless for the purposes of lithological classification. Those geologists who favor a reform in lithological nomenclature usually employ "petrosilex" and "felsite" to designate the rocks under consideration, but make further reform necessary by treating these terms as synonyms and applying them indiscriminately. These rocks have a wide range in mineralogical and chemical composition, and include two types that should probably be regarded as specifically distinct: one consisting of an intimate mixture of orthoclase and quartz, or of orthoclase alone; and the other composed essentially of a plagioclase feldspar, and rarely containing much quartz, frequently destitute of it, but often appearing, when poor in quartz, to contain some hornblendic material. It seems best to agree with Prof. Phillips in restricting "petrosilex" to the former rock, and "felsite" to the latter. Many lithologists apply the term "porphyrite" to the basic division or species, but this name appears to be quite as objectionable as porphyry. In many cases it is hardly possible to determine, without a chemical, or at least a microscopical, analysis, to which type a rock may belong; for they agree closely in most of their physical characters; but this cannot be urged as an objection to the proposed limitation of the meaning of the terms, nor to their intelligent use where possible, any more than in the case of diorite and dolerite, or of any compact rocks having a strong physical resemblance. It is probably true that in this region these rocks pass into each other insensibly, constituting a perfect series, to the two extremes of which only, the terms petrosilex and felsite, as here defined, are strictly applicable. But this is after the manner of all rocks, and is as true of granite and diorite, slate and conglomerate, as of those in question.

In geology, as in nature generally, hard and fast lines of demarcation are the rare exception.

We must rely mainly upon chemical and microscopical analysis for the data necessary for the separation of the petrosilex and felsite. But few analyses have been made for Eastern Massachusetts; so that, although well satisfied of the existence of both these rocks in this region, I have not attempted to trace the distribution of each separately on the maps. There can be no doubt that the petrosilex is much more abundant than the felsite, and hence on the maps, and, frequently, in these pages, I have, for obvious reasons, included both rocks under the former term.

Relations of the petrosilex to the Shawmut Group.— But a much greater difficulty now confronts us. The petrosilex of this region is overlaid at many points by a group of rocks, including the well-known petrosilex breccia, which appear to be in every case merely the more or less thoroughly reconsolidated mechanical débris of petrosilex itself. This second group of petrosilicious rocks constitutes one member or division of a formation much newer than the Huronian, for which I have proposed, provisionally (*ante*, p. 13), the name Shawmut group: a semi-crystalline series which, as will appear in the sequel, underlies the Primordial slate and conglomerate of Eastern Massachusetts, coming between these oldest Paleozoic sediments and the Huronian beds, and appearing to have been formed toward the close of Eozoic time. The petrosilicious portion of the Shawmut group includes rocks of all textures, from a coarse breccia to a compact, homogeneous rock which the naked eye cannot distinguish from the parent petrosilex. They are proved to be of more recent origin than the Huronian petrosilex, not only by their petrological relations, since they everywhere overlie the Huronian, but also and most conclusively by the fact, already stated, that they are composed mainly of the débris of petrosilex, which, where the material is coarse, can be plainly seen to be identical with that which may be referred with certainty to the Huronian system. In short, the so-called porphyries of this region are separable chronologically into two kinds, which are genetically related, and the real petrosilex, which belongs exclusively to the Huronian formation, is the oldest. The non-petrosilicious members of the Shawmut group are in the main lithologically distinct from anything in the Huronian system; and the same is true of the petrosilicious portions of this group, where the breccia or conglomerate character is well developed. But where, as sometimes occurs, the recomposed rock has been formed as a fine-grained, compact, flinty-looking sandstone or slate, or, as is also perhaps not infrequently the case, has reached this condition by the loss of the breccia structure through subsequent metamorphic processes, the separation of the Shawmut rock from the Huronian petrosilex becomes a matter of extreme difficulty. The parent and offspring are then chemically and, to the naked eye, lithologically indistinguishable, and we are obliged to rely upon their petrological relations and microscopical characters for the means of disguishing them. And since, throughout its distribution, the new, *pseudo* petrosilex lies for the most part directly upon the old, sometimes in such a manner that the finer-grained, more truly petrosilicious portions are brought in contact with the vastly more ancient parent rock, from which the whole were derived, and which they so closely resemble; and since there is not wanting abundant evidence that all these rocks have been subject in a great degree to the action of disturbing and metamorphic agents subsequently to the deposition of the Shawmut group, not only increasing their strong lithological resemblance, but adding immensely to the complexity of their petrological relations, — it will be readily seen how puzzling a problem it is to determine, for the purpose of accurate delineation on the map, or for detailed study, the limits of the Huronian petrosilex. So intimate is the association of the Huronian petrosilex and the petrosilicious rocks of the Shawmut group, and so complete, apparently, is the gradation existing between the typical varieties of the former rock and the normal or unaltered petrosilex breccia, — a gradation due partly to the conditions of deposition of the Shawmut rocks, and partly to the unequal and in some cases extreme metamorphism of the breccia, whereby have been reproduced in this newer formation several types of structure characteristic of the parent beds, — that most observers have failed to distinguish them, considering the whole as of approximately the same age. This manner of regarding the phenomena in question leads naturally to views concerning the origin of these rocks which find their culmination in that proposed by Prof. Alpheus Hyatt and Mr. T. T. Bouvé,[1] according to which all these rocks, including the homogeneous, structureless petrosilex, had originally a conglomerate structure, the present variety being mainly due to the unequal and unlike metamorphism of different portions of the primitive conglomerate.

Substantially the same idea was subsequently expressed in my report on the Geological Map of Massachusetts, with the important exception that I there dissented from the conglomerate origin of the homogeneous petrosilex and the evenly banded petrosilex, claiming that these were deposited as fine sediments bearing the relation to the other rocks of slate to conglomerate.

A more extended and careful study of these rocks than was possible before the publication of that report, however, has greatly increased my knowledge of their relations and distribution, and led me to the adoption of the conclusion stated on the preceding page; which, in its essential features, — as regards the separation of the petrosilicious rocks here referred to the Shawmut group from the Huronian petrosilex, and the mutual relations in time and space of the two series thus formed, — is identical with the view previously held by Dr. T. Sterry Hunt.[2]

The difficulty of distinguishing the Huronian petrosilex from

[1] Proc. Bost. Soc. Nat. Hist., xviii, 217.

[2] President Hitchcock, also, with his usual sagacity in such matters, expressed the same idea, with singular clearness, nearly forty years ago.

the more recent rocks resembling it is not diminished by the fact that a portion at least of the ancient-looking petrosilex of undoubted Huronian age contains *petrosilex pebbles.* These pebbles are usually somewhat angular, often of the same color as the enclosing rock or matrix, and although, as a rule, sharply outlined, yet frequently very inconspicuous, requiring weathering to make them visible. The inconspicuousness of part of the pebbles seems to arise in some cases from their identity with the enclosing rock, and sometimes from the partial blending of the pebbles and paste, whereby the outlines of the former are destroyed, and the pebbles, even when differing in color from the paste, appear as mere ill-defined spots or blotches in the latter. The pebbles seldom appear to be abundant or evenly distributed, the rock rarely presenting the aspect of a normal conglomerate or breccia. Concerning the true signification of these pebbles three hypotheses naturally suggest themselves: First, that they represent traces of a conglomerate structure originally characterizing, perhaps, considerable portions of the Huronian petrosilex. Second, that they have resulted from the local disturbance and internal movement and crushing of the petrosilex, and the subsequent partial cementation (lithologic regelation), under peculiar conditions of heat, moisture, and pressure, of the fragments thus produced; a supposition which, according to Prof. Pumpelly,[1] accounts for the breccia structure of portions of the petrosilex of Pilot Knob, Missouri. Third, that the pebbles have become imbedded in the petrosilex while the latter was in a liquid or plastic state, perhaps undergoing extravasation.

That the Huronian petrosilex is now for the most part a stratified rock, and was originally wholly so, I cannot doubt; and it appears most probable that the conditions presiding over its deposition differed in degree only, if at all, from those that have obtained in more recent geologic times. Extensive beds of Huronian conglomerate, it is well

[1] Geological Survey of Missouri: Preliminary Report on the Iron ores and Coal-fields, 1872.

known, occur among the other rocks of that age in the Lake Superior region; while in New Brunswick Messrs. Bailey and Matthew report[1] the occurrence of well-marked conglomerate or breccia in each of the three groups which they have established among the Huronian rocks of that province; hence I conclude there is, on general principles, no *a priori* improbability in the supposition that the pebbles in our Huronian petrosilex were deposited cotemporaneously with the other materials composing this rock. There are many instances where the second of the hypotheses above stated is an adequate explanation of the phenomena in question. The pebbles in these cases are usually obscure, often escaping observation on the first view of a fresh or polished surface. They possess a special interest at some points, as throwing light on the origin of a peculiar variety of banded petrosilex, and will be noticed again farther on. Limiting our attention now to the more conspicuous of the included pebbles, we find that, as a rule, they are either too rounded, or differ too much in color and texture from the enclosing paste, to be brought within the scope of the regelation theory; and although the first hypothesis is beset by no special difficulty, save that it involves the existence of some older petrosilex from which the pebbles were derived, I am constrained to believe that we must look to the third supposition for the true explanation. For, so far as I am aware, those limited portions of the Huronian petrosilex containing distinctly marked pebbles occur chiefly in the immediate vicinity of the petrosilex breccia of the Shawmut group; and in nearly every instance the evidence is plain that the petrosilex has experienced some extravasation, and has, consequently, been in a more or less fluent state. The point where the enclosure of pebbles in Huronian petrosilex is least open to doubt is on the eastern shore of Marblehead Neck. The rock exposures here are exceptionably good, and afford ample facilities for the study of the mutual relations of the Shawmut group and the Huronian system. The former re-

[1] Geological Survey of Canada; Report of Progress, 1870–71.

poses directly upon the latter; and both series have evidently suffered great disturbance. The light-colored Shawmut breccia is cut and torn in every direction by tortuous dykes of the black petrosilex, which itself very clearly holds angular pebbles of different varieties of petrosilex. Many of these pebbles are of the same general character as the enclosing rock, often appearing to be identical with it, and as a consequence very inconspicuous; but those which first arrest the observer's eye, including a large proportion of the whole, are a highly crystalline, whitish variety of petrosilex which is precisely similar to that forming large ledges a few rods to the northward. The main point to be proved in this connection is brought out at this locality with especial clearness; viz., that the very same petrosilex which holds pebbles underlies, and is in part eruptive through, the breccia, forcing the conclusion that, in spite of a certain superficial resemblance, these are distinct formations. This interesting locality is more fully described on a subsequent page.

There are other localities where the evidence is nearly as plain, and points to the same conclusion. Among these are the vicinity of Cliftondale Station on the Saugus Branch of the Eastern Railroad, West Dedham, and Hyde Park. At Cliftondale and in Hyde Park, the majority of the included fragments are of precisely the same character as the enclosing petrosilex, and are sufficiently accounted for by the internal crushing and regelation theory; but other blocks — of quartzite, diorite, and granite — must have been introduced from without, and imply some plasticity in the petrosilex at the time of their enclosure. To summarize, the facts observable at the places named, and elsewhere, compel us to suppose that the petrosilex, while suffering great disturbance, has been locally crushed and brecciated, and that certain portions of this rock, perhaps as a consequence of enormous friction, have been softened to an extent that would permit the envelopment of extraneous masses. In saying this I am conscious that such inferences must be drawn with the utmost caution, if we would avoid mistaking petrosiliceous breccia for brecciated petrosilex.

Returning now to the question of the geographic separation of the Huronian petrosilex and the petrosilicious rocks of the Shawmut group, it is hardly necessary to observe that the distinctness and simplicity of their common boundaries, as represented on the map, are in most cases a very inadequate expression of the complexity observable in the field. Along the River Parker, in Newbury, the Shawmut rocks are non-petrosilicious, or, when petrosilicious, so far as I have observed, they are never compact, but have a distinct breccia structure; and hence they may be readily distinguished from the adjoining petrosilex. On Marblehead Neck there are several limited areas of breccia. These are mere superficial patches lying irregularly upon the petrosilex; and they are much smaller and more numerous than indicated on the map. They are represented as occurring chiefly along the shore; but it is not improbable that more or less breccia exists in the central portion of the Neck, covered by the soil. The islands north-east of Marblehead Neck marked on the map as composed wholly of petrosilex, nearly all comprise more or less Shawmut rock. It is represented as occurring on Lowell's Island, and I have also observed it on Marblehead Rock, Half-Way Rock, and South Gooseberry Island. The Shawmut breccia appears at Red Rock on the Lynn shore, but does not, apparently, extend far inland. The petrosilex in the immediate vicinity of Dungeon Rock, in Lynn, is distinctly stratified, and may belong to the Shawmut group; yet I think it is more probably Huronian. As already indicated, the breccia occurs at many points, but not continuously, through southern Saugus; and I have observed it as far north as the Pirate's Glen, where the pebbles are small and the rock more compact than south of the railroad. In Malden, east of Maplewood, the petrosilex is skirted at intervals along its southern border, following Salem Street, by breccia. This breccia is also less distinct, and more like petrosilex, than that in the vicinity of Cliftondale and East Saugus. Following the road north from Maplewood, we find nothing but breccia between the Saugus Branch R.R. and the granite in Melrose.

West of the Boston and Maine R.R., in Malden and Medford, the Shawmut petrosilicious rock covers a considerable area. It is a well-marked breccia in the vicinity of Salem Street, but becomes smaller grained toward the north and west; and near the southern boundaries of Stoneham and Melrose it is often practically indistinguishable, with the naked eye, from Huronian petrosilex. The Shawmut rock composing the wedge-shaped area in West Medford, along the north side of the Mystic River, is, in the main, impalpably fine, and easily mistaken for a Huronian rock, yet portions of it have a sandy or slaty texture, and determine the age of the whole. The region between the Malden Highlands and Maplewood has been but slightly examined. It embraces some petrosilex; but breccia is probably the prevailing rock. The petrosilicious rocks in northern Saugus and Melrose, and southern Wakefield, belong largely to the newer series. A considerable area of Huronian petrosilex, however, occurs in the vicinity of Crystal Lake, and the Greenwood Station, in Wakefield; and it crops out at many points in Saugus and Melrose, a few only of which are indicated on the map. The relative distribution of these two series in this region, — Saugus, Melrose, Malden, and Medford, — as shown on the map, can be regarded as accurate only in the most general sense. I have traced the boundaries of none of the areas; and in some places, especially in North Saugus, the Huronian and Shawmut rocks are so difficult to distinguish lithologically, and are so closely involved petrologically, that it is doubtful if their limits ever can be satisfactorily determined. I believe, however, that I have succeeded in separating roughly the areas in which petrosilex predominates from the areas in which breccia is the prevailing rock.

The Shawmut rock in Needham, not being petrosilicious, is easily separated from the petrosilex. Although the petrosilex of West Dedham and Dover is without doubt mainly Huronian, I am not confident that it all belongs to that ancient system. The area marked as breccia on the map includes all of that rock and a portion of the petrosilex. The petrosilex west of the

Boston and Providence Railroad, in Hyde Park and West Roxbury, is certainly mainly of the ancient type. Proceeding eastward, as we mount the bold ridge east of the Clarendon Hills Station, breccia again makes its appearance. Further east it occurs in large patches, but not continuously, from Calvary Cemetery on the north, nearly to Hyde Park Station on the south. It increases rapidly eastward, and covers the most of the area between Back Street and the New York and New England Railroad, the petrosilex appearing at intervals. East of this railroad the petrosilicious character of the Shawmut rocks appears to die out, and they are no longer difficult to distinguish from the Huronian beds. The same is true south of the Neponset, in Milton, except about the eastern end of the more eastern of the two petrosilex areas occurring there ; at this point the breccia reappears.

In the foregoing attempt to separate the Huronian petrosilex from the Shawmut group I have determined which rocks are Huronian mainly by the following criteria : —

All compact, flinty rocks, having a clean fracture, and which (to the eye) are perfectly homogeneous (except where porphyritic or banded), showing no traces of a pebbly structure, were regarded as Huronian ; also all petrosilicious rocks, pebbles of which have been found in the Shawmut breccia. This last test is applicable only where the rock possesses peculiar characters by which it can be unfailingly identified. The separation is not, and is not claimed to be, exact, but simply the best that my data will allow. Many of my earlier observations are rendered worthless for this purpose because I did not, at the time they were made, recognize the Shawmut rocks as belonging to an age distinct from the Huronian.

DETAILS OF THE PETROSILEX.

Petrosilex in Newbury. — The Newbury belt of petrosilex extends along the valley of the River Parker from the mouth of this stream to Byfield Parish, a distance of five miles. The general trend of the belt is E.N.E. Its width is very variable, a few rods to one and a half miles; this results mainly from the irregular manner in which the newer rocks — Shawmut and Primordial — are superimposed upon the petrosilex. Leaving these more recent rocks out of view, the petrosilex appears to be bounded on all sides by granite; lying between the Rowley granitic belt on the south and the Newbury belt on the north. This petrosilex is, on the whole, remarkable for its uniformity. The prevailing color is a deep red, or brownish-red; but it is sometimes purplish, pinkish, or grayish, and occasionally nearly white. It is never distinctly porphyritic, but nearly always has a well-marked banded structure. To the north of Old Town Hill and between that and Kent's Island, however, much of the petrosilex is not banded. Its colors here are different shades of red and gray, varying from a dirty white to nearly black, but all weathering reddish. Some of it is distinctly quartzose and has a granular or euritic aspect. The banded structure so characteristic of most of the Newbury petrosilex is produced by the interlamination of layers of quartzose and feldspathic materials. The quartzose or jaspery layers are darker colored than the feldspathic, and the latter are prone to weather white; so that the banding is most conspicuous on weathered surfaces. The thickness of the laminæ usually varies from a fine line to one-sixteenth of an inch, and seldom exceeds one-eighth of an inch. The individual laminæ are generally continuous for several feet or yards, except where broken by faults or other disturbance; and adjoining laminæ, at least the larger ones, rarely coalesce or divide. As a rule, each layer maintains the same thickness throughout its length; the shorter ones, however, are sometimes lenticular, and these occasionally coalesce. The petrosilex has been immensely disturbed, and consequently the laminæ strike and dip in every possible direction; yet there are a certain general strike and dip which predominate and are characteristic of the rock as a whole. This prevailing strike ranges from N.E.-S.W. to E.-W., parallel with the general trend of the belt; the corresponding dip is to the N.W. and N., and usually quite steep.

This banding or lamination is frequently met with in the petrosilex and felsite of other regions, and is familiar to all geologists. In England and on the continent of Europe, where it is the universal belief that petrosilex and felsite are always and everywhere of igneous origin, where they are regarded as trappean rocks, and so classified by systematic lithologists, this banded structure is naturally and commonly interpreted as probably resulting, like the variously hued lines and bands in a slag from an iron furnace, from the motion of the mass when in a pasty and semifluid condition. In this country radically different views are gaining ground. Prof. Dana, in his "Manual of Geology," classes the petrosilicious group as metamorphic rocks; and Dr. Hunt has long taught their aqueous or sedimentary origin. This view is the only one in harmony with the facts observed in this region, and especially with the banding, or, as I prefer to call it, stratification, of the petrosilex. The bands in question are undoubtedly lines of bedding; and the lamination has substantially the same signification in petrosilex as in slate or sandstone. The petrology of the banded petrosilex at some points in Eastern Massachusetts yet to be described, absolutely forbids the acceptance of the motion-in-a-plastic-mass theory of the origin of the banded structure.

The Newbury rock is, for the most part at least, a genuine petrosilex. A typical specimen of the banded variety from Kent's Island contains 75.7 per cent. of silica. This indicates at least 25 per cent. of free quartz in the rock. Another specimen from a point further west, near Dummer Academy, afforded 76.4 per cent. of silica.

Concretionary structure. — South of the River Parker and near the road leading south from Old Town, at a place known as the Bartlett Mine, is a rock with a singular concretionary structure, which the miners call "toad stone." It presents a spotted appearance, whence the name. This rock must, I think, be regarded as a variety of the petrosilex; in fact, a part of this mass is a compact and, to the naked eye, structureless petrosilex, of a greenish color. Chemical analysis, too, shows that the "toad stone" has the composition of a true petrosilex; a slightly weathered, but otherwise typical, specimen affording Miss E. M. Walton the following result: —

SiO_2	77.200
Al_2O_3	12.482
Fe_2O_3	1.570
CaO	.800
K_2O	1.230
Na_2O	4.423
H_2O	2.004
MnO	trace
	99.709

As in the banded petrosilex, there is here a partial separation of the quartzose and feldspathic materials. Instead, however, of forming thin sheets or laminæ, we have one of the constituents — the feldspar — segregated into small spheroidal, ellipsoidal, or almond-shaped masses; while the interstices between these are filled with the quartz, — not necessarily pure silica, but quartzose material, — which is usually small in amount. The feldspathic aggregates sometimes appear of very irregular shapes and sizes; but usually they are regularly rounded, of uniform size in the same part of the rock, and have their longer axes parallel, giving the mass a faint appearance of stratification. At one point, too, they are arranged in lines, which are straight and parallel; or, more exactly, the quartzose material is in thin layers, and each attenuated stratum has a layer of feldspathic nodules on either side of it. The nodules, thus arranged, sometimes coalesce, forming continuous laminæ, and reproducing the banded structure. The strike and dip, as indicated by the parallel arrangement of the nodules, appears to be the same in all parts of the rock, and agrees with that recorded above for the petrosilex generally. The almond-shaped masses vary in size from mere specks to one-fourth of an inch in diameter. Their structure is concentric as the rule, and radiate as the rare exception. Each aggregate (except the smallest, which are usually homogeneous to the eye) consists of a layer of white material enclosed concentrically between a dark-colored centre or nucleus and a thin layer of greenish-white, which comes between the white zone and the external quartzose material. In the unweathered state these different layers have a uniform hardness about equal to orthoclase; but, when weathered, the dark nucleus becomes of a dull-green color and yields readily to the knife; and both it and the white band yield the more readily the more the rock is weathered. Where the almond masses are large it can be plainly seen (and probably all would show it under the microscope) that in each of them the general structure of the whole rock is reproduced on a smaller scale, each nodule containing a number of smaller masses of the same form and structure as itself. These smaller or secondary aggregates also have their major axes parallel. They are most conspicuous in the green nucleus. This rock is susceptible of a tolerable polish.

The question naturally arises as to whether the structure of the "toad stone" is original and general, or due to local alteration. I incline to the former view, although evidence supporting the latter is not wanting. This rock forms the south side and summit of a small hill rising from the tide-water marshes of Mud Creek, and is met on the north by a petrosilex breccia. The junction of the two rocks is marked by a trap dyke, several feet wide, which dips steeply to the north. Now it is in the immediate vicinity of this dyke that the rock in question possesses the banded structure described on the preceding page; beyond six inches or a foot from the eruptive mass the banding appears to be wholly wanting. The bands are exactly parallel with the dyke. These facts might be considered as proving a causal connection between the dyke and the pseud-oölitic structure of the adjoining rock. But I think this is illusory; for in other parts of the petrosilex belt, on Kent's Island, and to the westward, there is evidence showing that this peculiar concretionary structure is really wide-spread, and is probably in every case an original structural feature of the petrosilex. Extended observation has convinced me that this structure, more or less perfectly developed, characterizes most of the petrosilex of this belt, especially the banded variety. It can usually be detected only on weathered surfaces, but is sometimes so pronounced as to be observable in the mass of the rock. The concretions are all small, and, as in the "toad stone," are confined to the feldspathic material. The nucleus can usually be seen, indicating the concentric structure; but I have failed to detect the greenish layer. The resemblance, though not complete, is probably sufficient to establish the essential identity of the two rocks.

A small mass (probably an erratic) of petrosilex breccia, found on Marblehead Neck by Prof. Hyatt, contains pebbles of a banded petrosilex similar to that in Newbury, which are characterized by a nodular structure, differing somewhat, but probably not essentially, from that described above. In the banded petrosilex of Marblehead Neck, also, I have observed abundant traces of a similar structure. On the northern end of the Neck, near the light-house, the stratified petrosilex contains numerous intercalated layers, varying in thickness from an inch or less to a foot, which are largely, and, in some cases wholly, composed of concretions or nodules. The concretions are of all sizes, from those requiring a magnifier to make them visible, to two inches in diameter. The smaller concretions are all spherical, but those exceeding half an inch in diameter are more or less flattened on the under side, and the largest are disc-shaped. There is little appearance of separation according to sizes, the large and small being usually intermingled. When crowded the larger nodules give the upper surface of the layer a botryoidal aspect. A concentric structure is sometimes observable in the concretions; but usually they appear quite structureless, save in this: the regular banding or stratification of the petrosilex is continuous through the nodules. The banding, both in the nodules and outside of them, is quite independent of the forms of the nodules, showing no tendency to conform with their outlines. In short, these concretions are essentially identical with those occurring in the most recent deposits of sand or clay. The concretions weather less readily than the matrix, and are usually quite inconspicuous on unweathered surfaces. The larger nodules, however, are sometimes partially decomposed exteriorly; and in these may be discerned traces of a secondary concretionary structure, or nodules within nodules. In this locality (near the light-house) the banding of portions of the petrosilex is unusually fine and even, yet much contorted; and some of the more feldspathic layers have a finely granular or brecciated appearance, precisely as if the layers had been crushed *in situ* and reconsolidated. The minute fragments appear at first sight to be quite sharp and angular, — and so they are, as regards the fracture planes producing them; but close observation shows that most of the grains are more or less rounded and concentric. In fact, they are concretions, and, like those just described, they weather less readily than the matrix. The concretionary structure appears to be wholly wanting in none of the banded petrosilex on Marblehead Neck, and it may be occasionally detected in other varieties. In the petrosilex of West Dedham, west of Woodland Street, Mr. F. W. Very has observed a band or bed about three feet wide, strike N. 30° E., in which the spherulitic structure is well developed. The rock shows traces of stratification, and consists of a greenish base enclosing occasional crystals of reddish-brown feldspar, and numerous spherical concretions of a dark-purple color, about a line in diameter, and without apparent structure. The spherules are more quartzose than the matrix, appearing in relief on weathered surfaces. The base itself is also concretionary, resembling the "toad stone." There is no visible quartz in this rock, although grains of this mineral occur in the bright-green petrosilex by which the stratum is bordered. On the line between Hyde Park and West Roxbury, near Muddy Pond, Mr. Very has found a dirty, greenish-white, stratified petrosilex with scattering spherical concretions, the largest of which are about one-fifth of an inch in diameter. They have a radiate structure, and appear to consist of crystalline quartz. The greenish tinge of this rock is due to a soft, brownish-green mineral resembling serpentine, which forms layers in the rock. It is, however, probably aluminous rather than magnesian. The same observer also reports the occurrence of concretions in an otherwise structureless petrosilex in Hyde Park Village. The petrosilex ridge between Pine Garden and Calvary Cemetery, in Hyde Park, — especially towards the southern end, — affords the best example which I have yet observed of the concretionary structure in the petrosilex. This is a white, banded variety of petrosilex, and the concretions are usually spherical, varying in size from a pin-head to five inches in diameter. Occasionally they are so numerous that the rock is almost entirely composed of them, and the weathered surface has the aspect of a pudding-stone. The nodules are commonly purplish, weathering white, and showing but faint indications of concentricity. In some limited masses of the petrosilex of a bright-red color, the concretions are small, white, and distinctly stellate. On the east side of the ridge, toward Back Street, the spherical concretions are mostly wanting, and are replaced by small, purple layers, which, though of very irregular shapes and sizes, always present botryoidal surfaces and a concentric structure. They coincide with the banding of the petrosilex; are rarely more than an inch thick, but often two feet or more in length. Abundant concretions have been observed in a portion of the petrosilex forming the rounded north-east corner of the Blue Hill area of petrosilex. They are mostly small, generally spherical and radiate, but sometimes elongated and concentric. Small fragments of a feldspathic rock containing concretions have been found near the trilobite quarry in Braintree. This rock has not been observed *in situ*. It holds scattering feldspar crystals, which are much fewer and several times larger than the rounded nodules; each crystal, however, is enveloped in a whitish layer, giving it a concentric appearance. The foregoing are all the instances that have come under my notice where the concretionary or pearlstone structure in the petrosilex is well marked; but indications are not wanting that this structure, or a tendency toward it, is very general in this rock.

Petrosilex on Marblehead Neck and the adjacent islands. — There are several distinct varieties of petrosilex on Marblehead Neck. The most conspicuous and beautiful of these is the banded variety already alluded to. This has substantially the same characters as in Newbury. The bands, however, are generally broader, — one-sixteenth to one-eighth, and sometimes one-fourth of an inch. The feldspathic layers are rarely reddish, usually gray, bluish, or purplish, but always weathering whitish. The banding is often very indistinct on a fresh surface. The bands are, perhaps, less regular and continuous than in the Newbury rock, coalescing and dividing more frequently. They exhibit greater disturbance, and at many points are locally resolved into a condition approaching the chaotic, portions of the rock appearing to have been crushed and partially fused; yet, on the whole, a north-easterly strike appears to prevail, and this is no less clearly a stratified rock. Crystals of feldspar are common in this rock, but are rarely numerous enough to give it a porphyritic aspect. This variety of petrosilex is well developed on the north-west side of the Neck, and in the vicinity of the light-house at the northern end. Several small patches also occur on the eastern shore near Castle Rock, and to the northward. A typical specimen from near the southern border of the petrosilex, on the harbor side of the Neck, contains 77.5 per cent. of silica. This indicates probably thirty or forty per cent. of free quartz, and shows that the rock must be regarded as a true petrosilex: a conclusion which might have been inferred with hardly less certainty from its great hardness (above 6) and its jaspery fracture. This is a much-jointed rock. At some points, especially in the small patches on the eastern shore, the banded petrosilex where most disturbed passes into an unstratified variety, which becomes porphyritic with feldspar crystals, and very rarely exhibits slight traces of banding where a fragment of the original rock has not been entirely crushed, or, more probably, fused. These transformations occur chiefly in the immediate vicinity of the Shawmut breccia, where, as already shown, we have incontestable evidence of the extravasation of portions of the petrosilex.

The stratified petrosilex of Marblehead Neck, as above stated, is, in the main, less regularly and continuously banded than that in Newbury. The layers are shorter, more lenticular, and more prone to coalesce and divide; *i.e.*, the structure is more schistose and less laminated. The petrosilex of Marblehead Neck is very variable in this respect, and it is possible to select a series of specimens which shall exhibit every variety of structure from a regular, agate-like banding to a distinct schistosity where the most of the individual quartzose layers are less than three inches long and decidedly lenticular. The principal members of such a series are shown in Pl. 1, figs. 1–3, drawn from nature and of natural size; the shaded portions representing the quartzose layers, and the white the feldspathic. Thus I believe we may pass by insensible steps from the most regularly banded petrosilex to the variety represented by fig. 4, also occurring on the Neck. In this there are lighter and darker irregular parallel layers, of varying width, which are characterized by a perfect schistosity,—coarse in the darker bands, but very fine and minute in the lighter. There are interspersed crystals of feldspar, but these are neither large nor numerous, and the rock is not distinctly porphyritic. The feldspar crystals, occurring only in the feldspathic layers, could not be shown in the figure. Some of the smaller, dark, lenticular patches have a greenish tinge and are probably epidotic. Such is the weathered aspect; on a fresh fracture we have simply a black base in which the more prominent structure lines may be dimly discerned. Other parts of the same rock, in some cases of the same hand specimen, have the structure represented in fig. 5. Here we approach the vanishing point of the regular, continuous lamination with which the series began; and from this rock the passage is natural and easy to one in which that structure is almost wholly wanting. Such a type exists on Marblehead Neck, and is represented by fig. 6. Compared with the first member of the series it may be regarded as a distinct variety of petrosilex. This rock occurs at several points on the Neck, but has its greatest development at Castle Rock on the eastern shore, where it is associated with the types represented in figs. 4 and 5. Like these, it shows on a fresh fracture a compact black base, with faint traces of lighter and darker stripes; and on the weathered surface the structure comes out prominently, revealing numerous elongated, more or less parallel, usually lenticular, black, brownish-black or ash-colored layers, of all lengths up to three inches, and varying in width from a mere line to one-fourth of an inch. As shown in the figure, the smaller layers predominate, the rock being finely schistose, with now and then a coarse layer. The outlines of the layers are not smooth and regular; on the contrary, they are exceedingly broken and uneven; being frequently curved and ending abruptly, or the edges are bifurcated or split up irregularly into several prolongations of varying thickness, but often of extreme tenuity. Many of the larger layers are themselves schistose. The brownish and ash-colored patches have a granular texture, are less firm than the rest of the rock, and some of them appear to be epidotic. The strike of this rock, although very variable, averages north-east. The parallel arrangement of the layers and the general evenness of the structure have been much disturbed in a small way, which is not apparent at first view. It is as if the rock had been wrenched or shaken in such manner as to produce numerous small dislocations, contortions, and local crushings. The structure of some portions of this rock, in the vicinity of Castle Rock, is still farther complicated by the presence among the layers of distinct pebbles. These are of all sizes up to two inches in diameter, and their outlines are sharp and angular. Occasionally they are of the same character as the enclosing rock, and may then be explained by the theory of internal fracture and reconsolidation, as explained *ante*, p. 50; but as a rule they consist of a very crystalline, white petrosilex, identical with a large mass which occurs *in situ* immediately north of the rock in question. The pebbles are not numerous,—perhaps one of the larger pebbles in a square foot or even in a square yard; and their distribution is far from uniform. They are scattered about here and there without any regard to system or definite arrangement. A characteristic example is shown in Pl. 1, fig. 7; and here it can be plainly seen that the dark, schistose layers are squeezed and crowded together on either side of the pebble as if to make room for it. Yet in some cases, probably in all, if we could see all sides of the pebbles, it is clear that in one direction from each pebble the schistose structure is greatly disturbed, or entirely broken up and destroyed. In brief, the relations of these pebbles to the enclosing rock are precisely such as would result if the pebbles were imbedded in the rock while the latter was in a plastic or semi-fluid state; and this, I have little doubt, is the true explanation. This rock is very intimately related, petrologically, to the Shawmut breccia occurring here, and it is chiefly this variety of petrosilex to which allusion was made, *ante*, p. 52, as having been extravasated through the breccia. The exposures are so good as to place the relations of these rocks beyond dispute, and there can be no doubt whatever that portions of the schistose petrosilex have been in a plastic and yielding condition. It is unnecessary to suppose that the extravasation has been great; that would, indeed, be contrary to the plain facts. In the first place, the breccia at this point evidently reposes for the most part directly upon this variety of petrosilex, pebbles of which enter largely into its composition, showing that this is the normal and original relation of the two rocks. Secondly, the structure of the petrosilex evinces, as already explained, that the disturbance which it has experienced has not been excessive. The schistosity is frequently preserved intact even in contact with the breccia, and as a rule it is wholly lost only where the petrosilex has been forced into narrow, tortuous crevices in the breccia. In fine, the petrosilex has been softened *in situ*, and, while portions of the plastic mass were extravasated through the breccia, the remainder continued in a more or less tranquil state. The clearly extravasated portions of the petrosilex are charged with a greater number and variety of pebbles than the relatively undisturbed portions already described. Yet these exotic masses never come to resemble the breccia. The latter rock is always light-colored, while the former is black; hence the contrast is great and the contacts are very distinct, and easily traced.

This variety of petrosilex, in its origin and relations, has been justly regarded as presenting one of the most difficult problems which this, geologically, very complex locality affords. The explanation proposed above, in which this rock is regarded as essentially stratified, its structure differing in degree only from the more normal stratification of the regularly banded petrosilex, as shown by the transitional types of structure; and the enclosure of pebbles accounted for by envelopment while in a plastic state, the softened condition being demonstrated by the exotic nature of portions of the rock, differs widely from any that has been advanced heretofore. Yet I am convinced that this is the only hypothesis affording a rational explanation of all the facts. In the view proposed by Prof. Hyatt,[1] and partially adopted by the present writer in the report on the Centennial Geological Map of Massachusetts, this petrosilex was regarded as originally identical with the breccia, representing a portion of the latter rock which had been so metamorphosed that the pebbles were flattened out into thin lenticular sheets, each pebble in the breccia giving rise to one of the layers mentioned in the foregoing description of the petrosilex; while the undistorted, angular pebbles in the petrosilex were considered as having successfully resisted the flattening process, and as proving the original pebbly or breccia structure of the entire rock. This point reached, and the evidence appearing irrefragable, it was natural and easy to conceive the pebbles, under continued compression, as becoming still thinner, and

[1] Proc. Bost. Soc. Nat. Hist., XVIII., 223.

the attenuated layers thus produced as coalescing at the edges, forming larger sheets, which, as the process continued, became ever more regular and continuous, developing in succession the different grades of lamination noticed above, and finally ending in the agate-like banding of the most regularly stratified petrosilex. My endorsement of this view extended only so far as to admit the breccia or conglomerate origin of this most schistose variety, which I have long been accustomed to speak of as having a "flattened pebble" structure, or as the "flattened pebble" petrosilex; always regarding the other varieties of banding as original and due to sedimentation. Prof. Hyatt, also, although believing the banding to have resulted in every case from the alteration of the breccia, did not attribute the flattening of the pebbles wholly to compression, but conceived that the elongated appearance might be in part accounted for by the manner in which the finer material or paste was deposited around the pebbles, subsequently uniting with the pebbles so firmly that the outlines of the latter were lost.

The theory of the conglomerate origin of the banded petrosilex, although presenting at first view, perhaps, a consistent explanation of the phenomena, is, I think, based upon an entire misapprehension of the principal facts. The main point in this theory, viz., that the banded petrosilex and breccia are of the same age, is opposed by the undeniable fact that the latter rock is largely composed of pebbles of the former. In many cases the identity of the breccia pebbles with this variety of petrosilex is clear and perfect; and where the pebbles are not banded they usually consist of other varieties of petrosilex which have been recognized as existing in this locality, and which are clearly synchronous with the banded rock. The extravasation of portions of the petrosilex through the breccia tells with nearly equal force against the view that they were originally identical. So far as my observations extend, the only evidence of the flattening of pebbles in these rocks is that afforded by the lenticular layers in the schistose petrosilex, or so-called "flattened pebble" rock, and this is wholly illusory. These layers are decidedly flat, and, what is more to the point, the degree of flatness is nearly uniform in them all. Transitional stages between these attenuated layers and wholly unflattened pebbles are entirely wanting. There are no slightly distorted pebbles to mark the beginning of the flattening process, or to show whether it was initiated by compression or by the peculiar mode of deposition invoked by Prof. Hyatt. The angular pebbles in the "flattened pebble" petrosilex exhibit no distortion whatever, and they are far more distinctly outlined, less intimately united with the enclosing rock or paste, than is common with the pebbles in the breccia. Between the schistose petrosilex and the evenly banded petrosilex, also, intermediate degrees of flattening are not to be found, for the types of structure represented by Pl. 1, figs. 4 and 5, although truly transitional if regarded as original, as the direct result of sedimentation, could scarcely be the outcome of continued flattening and coalescence of the layers in fig. 6. But the most conclusive evidence against the pebble origin of the layers in the schistose petrosilex is found in the nature of the layers themselves. In the first place the forms of the layers are in most cases such as could not result from the flattening of any ordinary pebbles, being ragged, fringed, or deeply bifurcate on the margins. Secondly, the great physical, and probably also chemical, uniformity of these limited sheets would, to say the least, be very exceptional in a conglomerate rock, and is not found in any of the undoubted breccia on Marblehead Neck. The fragments entering into the composition of a breccia, however, are less likely to be of a multiform character than the pebbles of a pudding-stone, since they are usually deposited nearer the parent ledges. Therefore, we will grant the possible existence of a breccia composed of materials as homogeneous as these schistose layers and confine our attention to the inquiry whether this schistose structure could, by any conceivable process, be developed in it. Here, I think, the answer should be in the negative. As already observed, the great majority of these layers are very minute, often containing no more matter than a small grain of sand; and, even supposing that the larger layers may have resulted from the flattening of pebbles, it seems contrary to reason that the deformation should have extended to the finer materials constituting the paste, reducing and extending each minute grain in the same proportion as the larger masses. A degree of plasticity which would permit the flattening of the large pebbles would apparently tend to equalize the pressure on different sides of the smaller particles. And probably none of the material, coarse or fine, could experience flattening save where there was room for the lateral expansion of the rock; where the rock was confined on all sides, mutual indentation of the pebbles might follow the application of enormous pressure, but there could be no sensible flattening. The "flattened pebble" petrosilex, if derived from the breccia, must have had its lateral extension increased at least two-fold. Such a prodigious squeezing out may be conceivable in a limited mass like the rock in question; but it certainly passes the bounds of probability where the mass affected is miles in extent, as is the banded petrosilex in Newbury. It will probably be claimed, however, that what I am here unwilling to admit for the petrosilex is a well-known and demonstrable fact for many cleaved slates, in which fossils and even pebbles have suffered great distortion, although the cleavage is mainly due to the flattening in parallel directions of the minute granules of the rock; but this objection appears of little weight when we consider that the petrosilex shows no cleavage, that many of the layers have forms incompatible with the compression theory of their origin, and that they are far more rigid than anything occurring in an ordinary cleaved slate. It is not easy to say under what probable conditions sedimentation would give rise to these different types of banding and schistosity; but I would suggest that the definiteness of the structure, the separation of the materials into well-defined quartzose and feldspathic layers, may be partly the result of a segregating process subsequent to the deposition.

Traces of the schistose or imperfectly banded petrosilex have been observed on Marblehead Rock, Half-way Rock, and North Gooseberry Island. On Marblehead Rock, especially, it passes into the compact porphyritic varieties next to be described. On Half-way Rock it is of a brownish-red color and the structure is very indistinct; and, since it here contains a few small pebbles and irregular amygdaloidal cavities, it must be regarded as possibly belonging to the Shawmut group. On Marblehead Neck, at the large outcrop west of Castle Rock, and also at the northern end of the Neck, is a grayish rock, very porphyritic and weathering white, which contains a few small, black and ash-colored petrosilex pebbles, numerous grains of vitreous quartz, and shows, occasionally, distinct traces of the schistose structure; the layers having precisely the same texture and general appearance as in the typical schistose petrosilex. It is with hesitation that I put this rock down as petrosilex; and yet I am unable to regard it as anything different. A few small patches have the aspect of coarse granite, though appearing too ill-defined for pebbles.

Among the more normal types of petrosilex in this Marblehead region, perhaps the least important is the compact, homogeneous, little porphyritic variety. It is devoid of visible structure, and is not an abundant rock, although occurring in small patches at many points. The principal colors are black, grayish, red, and brown. The schistose petrosilex passes into this variety when extravasated; in fact when dark-colored this rock usually has the aspect of an exotic, at least as regards its petrologic relations. It occurs on Half-way Rock, where the colors are red and brown, and the Breakers south of Baker's Island are entirely composed of it. The black and apparently exotic portions of this rock on the Breakers, South Gooseberry Island, and Marblehead Rock and Neck, sometimes hold scattering pebbles, as already explained in connection with the schistose variety. The percentage of silica in the black rock on the Breakers, as determined by one analysis of an average specimen, is rather low for petrosilex, 70.3.

From this petrosilex, which can hardly be regarded as a distinct variety, we pass to the much more abundant rock in which feldspar crystals are numerous and conspicuous, — a typical porphyry according to the old nomenclature. As before, the base is compact and structureless ; its colors are black, gray, and purplish. The largest mass of this rock, perhaps, is on the seaward side of the Neck, immediately south of the beach. At this point the base has a finely granular aspect, and the feldspar crystals are large and numerous, and in addition there are many small roundish masses of epidote. The rock is tough and does not break with a smooth fracture. The general tint is dark purple, but the weathered surface is white ; and it is said that from these bold cliffs of white petrosilex the town of Marblehead derives its name. At the contact of this petrosilex with the granite on the south there are two alternations of petrosilex and granite within a distance of four or five rods, and it is clear that one of these rocks has played the rôle of an eruptive. There appears to be a considerable area of this coarsely porphyritic, purplish petrosilex in the central portion of the Neck. On Marblehead Rock and the small island east of Lowell's Island the base is black. At the first locality the rock is heavy and trappean, and unquestionably eruptive through the Shawmut slate and breccia occurring there ; while at the second point the aspect is much the same, but the rock is more porphyritic. A fair specimen from this small island contains only 69 per cent. of silica, hardly enough for genuine petrosilex ; and the Marblehead Rock exotic, although it has not been analyzed, is certainly still more basic, and may be set down as a true felsite.

In the southern part of Marblehead Neck there is a gradual transition from this normally porphyritic type of petrosilex to a rock in which the compact base is wanting, or nearly so, being crystalline throughout. This variety is of an ashen-gray color, weathering a dull white. I have observed it principally in the immediate vicinity of the granite toward the south-western end of the Neck, yet it forms a large mass on the ocean side, midway between Castle Rock and the northern end, and also occurs near the light-house. It is the rock, pebbles of which are enclosed in the schistose petrosilex, as already described. On a preceding page I have mentioned this rock as transitional between petrosilex and granite. It appears at first view to contain no quartz, but a closer examination reveals very many minute grains of this mineral in some portions of the rock, with occasionally a speck or small scale of hornblendic material. As regards texture, at least, the gradation between this crystalline petrosilex containing quartz in visible grains and the coarsest granite on the Neck is nearly perfect; and I cannot refrain from expressing the opinion that Prof. Hyatt's view of the transitional nature of this variety of petrosilex is well sustained by the facts. This variety and the preceding seldom occur in contact with the breccia, and have not been observed to hold pebbles. Yet it is probable that these, no less than the compact and schistose varieties, have been subject to softening and extravasation.

Still another variety of petrosilex is known to occur in the Marblehead region. This consists of a compact, jaspery base enclosing feldspar crystals and grains of vitreous quartz, — the so-called quartz-porphyry or elvanite. In a small mass of this rock on the west side of Castle Rock the base is dark-gray, the feldspar crystals are inconspicuous, and the quartz grains small and numerous. A band of this rock about one hundred feet wide crosses Lowell's Island toward the southern end, in a N. E.-S. W. direction. This is a handsome rock; the base is dark purple, weathering red; and the quartz, which appears to be in the form of crystals, is more abundant than the crystalline feldspar. Of course such a rock must be highly acidic; and this is proved by analysis, the specimen analyzed yielding 82.4 per cent. of silica, which indicates nearly fifty per cent. of free quartz. Part of the exotic petrosilex on South Gooseberry Island belongs here; it is of a dull-black color. On the north-west shore of Marblehead, opposite the city of Salem, and in other parts of this town, there are masses of the elvanite cutting through the Huronian diorites. Here the base is of different shades of drab, red, and brown; and here, also, the quartz is crystalline, and the crystals of both it and the feldspar, which is pink and white, varying with the base, are quite large and very distinct. A rock very similar to this occurs on the Beverly shore, in the bay between Woodberry's Point and Hospital Point. It forms several large masses, and is cut by the coarse granite found here, and also by the feldspathic diorite of the Naugus Head series. This elvanite is associated with the granulite noticed *ante*, p. 35. The structure of the latter rock is very similar to that of the schistose petrosilex on Marblehead neck, the principal difference being that the feldspathic matrix is more crystalline and the schistose layers more distinctly quartzose; the granulite, also, contains traces of micaceous material.

Petrosilex of the Lynn and Medford Area. — The petrosilex in Lynn, Saugus, Wakefield, Melrose, Malden, and Medford, would probably be found continuous, or nearly so, but for the patches of Shawmut breccia reposing upon it, and hence it is proper to regard this as one large irregular area. Many of the varieties occurring in the Marblehead region are found here; but they have not in every case the same relative importance, so that the general aspect of the formation is different in the two areas. The normally banded petrosilex is rare in the Lynn and Medford region. Prof. Hyatt's collection, however, contains specimens of it from several points in Lynn, and I have observed a rock showing traces of this structure between North Saugus and Saugus Centre, forming a high ridge along the east side of the road from the former place to Lynn. A specimen from this Saugus locality yielded 76 per cent. of silica, from which we may safely infer that this rock is a true petrosilex. The schistose variety is more abundant. It is usually of different shades of red, brown and purple; and the structure is, for the most part, very fine, with now and then a coarse layer. It is even more evident here than on Marblehead Neck that this structure cannot have resulted from the alteration of a conglomerate; yet, like the Marblehead Neck rock, it contains an occasional pebble of a different kind of petrosilex. There are also a few scattering crystals of feldspar. Weathering or polishing sometimes reveals the schistosity in rocks which appear otherwise to be destitute of it. This is the case in the vicinity of Cliftondale in Saugus. Here we have jagged patches of a bright-red color and somewhat lenticular outlines enclosed in a dark brownish-red base, and arranged with just enough irregularity to suggest the notion that this rock has resulted from the partial breaking up, *in situ*, of a very finely schistose petrosilex. These ragged layers have themselves a schistose structure, and in addition to them the base includes pebbles of quartzite and petrosilex (fig. 9, pl. 1), which have sharp, well-defined boundaries, showing no signs of deformation, and unquestionably belonging in the same category with the angular pebbles in the schistose petrosilex on Marblehead Neck. There are many small crystals of feldspar in this rock, mainly in the base. A very similar rock occurs on Oliver Street, near Salem Street, in East Malden (fig. 10). In North Saugus, near the Wakefield line, and east of the road leading north from Central Brook, there are several small areas of a rock which agrees closely with the schistose petrosilex on Marblehead Neck, appearing to differ only in this, that the structure is more reticulated and the base is more porphyritic. The plan of its structure is shown in fig. 8. Many of the dark, often more or less epidotic, irregular, lenticular bands are decidedly schistose; and unmistakable pebbles of this rock have been observed in the adjacent breccia. At Dungeon Rock, in Lynn, there is a distinctly stratified rock in which black, compact layers, varying in width from a mere line to an inch or two, alternate with layers which are grayish and crystalline, consisting largely of feldspar crystals, with a small amount of a black base similar to the alternating layers, and an occasional grain of quartz. On a preceding page I have expressed a doubt as to the Huronian age of this rock, and this is not removed by a farther examination. It is quite basic, the crystalline layers affording only 63.6 per cent. of silica; hence, whether Huronian or not, it is probably a true felsite.

The compact, non-porphyritic, red petrosilex occurring in Saugus — the so-called "Saugus jasper" — is well known. It covers but a small area, and is found on the south side of the Saugus River, a few rods north-east of the station in Saugus Centre. An analysis, made many years ago by Dr. C. T. Jackson, showed that this rock is essentially feldspathic, and not, in any proper sense, a jasper; and its superior fusibility points to the same conclusion. Having been unable to find any record of Dr. Jackson's analysis, I will append the results of a single analysis made by Mrs. Crosby: silica, 81.1 per cent.; sesquioxides of aluminum and iron, 13.35 per cent.; alkalies, not determined. These data make it clear that this interesting rock is not only feldspathic, but a veritable petrosilex. Dr. Jackson gives the following analysis[1] of a "green petrosilex" (probably compact) from Melrose: —

Silica, ...	86.00
Oxides iron and alumina, .	2.00
Lime, ...	1.12
Magnesia, ...	1.10
Water, ...	1.50
Alkalies, ...	8.28
	100.00

I have not seen this rock, and do not know its exact locality, but its composition is so anomalous for petrosilex that I conclude it must be an impure quartzite. The large percentage of alkalies in an apparently uncombined state, however, suggests an error in the analysis.

The great mass of the petrosilex in Lynn and Southern Saugus, the characteristic variety, is little porphyritic, frequently quite compact, and usually of some shade of red, brown, or

[1] Proc. Bost. Soc. Nat. Hist., XII., 84.

purple. It rarely holds pebbles, and might be described as devoid of all traces of sedimentary structure but for the limited patches of banded petrosilex above described, which occur in it, and differ from it only in being banded. We have no reason to doubt that this rock is mainly petrosilex. A characteristic brownish-red specimen from Lynn contains 73.9 per cent. of silica. Towards the north, in Lynn, the rock varies much, is frequently of a gray or drab color; and near the reservoir, on the road to Dungeon Rock, it holds grains of quartz as well as feldspar. Where the tongue of granite penetrates the petrosilex on the west side of Wenuchus Lake, these two rocks appear to have reacted upon each other, producing mutual modifications, so that the contact is now marked by a zone of debatable ground, in which one seems to find all sorts of transitions between petrosilex and granite; and it is clear that one, perhaps both, of these rocks must have been fluent.

Of the same general character — frequently quite compact, and never very porphyritic — is the most of the petrosilex in the north-west corner of Saugus and the adjacent portions of Wakefield and Melrose; also in Medford, north of the Naugus Head diorite, where it shows frequent local approximations to granite; in short, this is the prevailing, the characteristic variety of petrosilex for the entire Lynn and Medford area. A grayish, non-porphyritic specimen from Maplewood gave 72.6 per cent. of silica. At many points in North Saugus, between Main Street and Saugus River, the rock is more than usually porphyritic, yet it holds numerous pebbles, and may possibly belong with the breccia; this, however, is improbable, since the undoubted breccia contains pebbles of this pebble-bearing petrosilex. Are there two breccias here? I think not, although the appearances are not wholly inconsistent with that view.

Along Fulton Street in Medford, between Salem Street and the granite on the north, there is a large area of a dioritic rock which appears to alternate between granite and felsite. It is composed mainly of pinkish and greenish feldspar, with some hornblendic material which, inconspicuous and slaty-looking, as a rule, occasionally assumes the form of slender crystals half an inch long. Grains of quartz are rare, and usually wanting. Some of the feldspar, at least, is triclinic; and, although marked on the map as petrosilicious, this rock, in the vicinity of Fulton Street, is more properly a diorite. To the eastward, however, its physical characters change; and near the line between Medford and Melrose it appears through the Shawmut breccia as a compact gray base, holding conspicuous crystals of plagioclastic feldspar and slender needles of hornblende. Thus it is clear that we here have a felsite passing into diorite. A somewhat similar, but more porphyritic, rock is found still farther east, beyond the Boston and Maine Railroad. This closely resembles the crystalline layers in the stratified felsite at Dungeon Rock in Lynn, and, like that, it has the composition of a true felsite, the percentage of silica being not quite 63. It carries a few pebbles, however, and hence I am obliged to regard it as possibly a recomposed rock, related to the diorite only by derivation. Near the northern boundary of Melrose it appears again, decidedly crystalline and free from pebbles; and on the west side of the railroad at Greenwood Station there is an immense exposure of a light-colored, feldspathic, crystalline rock resembling that on Fulton Street in Medford, but finer grained, which should be set down as diorite, though probably passing into felsite. It is very basic, yielding only 57 per cent. of silica. Indications are not wanting that all of these dioritic felsites in Melrose and Wakefield may belong to the Shawmut group.

Granitoid petrosilex, such as occurs on the south-western end of Marblehead Neck, has been observed at only two points in the Lynn and Medford area, on the Newburyport turnpike in Malden, and in North Saugus, near where Main street crosses the Wakefield line. At both places the rock is very local, and yet its transition character is plain.

This extended area of petrosilicious rocks, although many times larger than the Marblehead Neck region, and fully equalling that limited area in structural complexity and the variety of problems which it presents, has been the field of even fewer observations; in an area where the student should traverse nearly every square rod, there are almost whole square miles which I have not seen. The insufficiency of my observations has necessitated the foregoing summary treatment of this interesting region. Any other course would have involved me in serious errors of commission as well as omission.

There are petrosilicious rocks in Reading and Woburn, interstratified with quartzite, hornblendic gneiss, and other rocks; but since the amount is small and the close relations to the associated rocks very evident, I will defer further mention of them until that group is taken up.

Petrosilex in Needham. — Outcrops are very rare in the narrow strip marked as petrosilex south of the Boston and Albany Railroad, in the northern part of Needham, and hence this area is largely conjectural. Near the station in Wellesley the rock is reddish-brown, compact, and has a quartzose appearance. It is probably continuous with the quartzite in Natick, and appears to be everywhere closely associated with the coarse granite.

Quite distinct from this is the petrosilex of the large area in the central and southern portions of Needham. The rock is remarkably uniform over this entire area. It always presents a compact, grayish or greenish-white base, porphyritic with feldspar crystals, and the most of the rock is elvanite, holding grains of transparent quartz in addition to the crystalline feldspar. The quartz grains are half a line to a line in diameter, more conspicuous than the feldspar, and they seldom assume the shape of crystals. Toward Newton Upper Falls, and east of the Charles River, in Newton, the visible quartz is wanting. So far as observed, the rock never holds pebbles nor exhibits any traces of bedding; and yet very commonly it presents a slaty appearance and yields to the knife, raising doubts as to its Huronian age. The base is sometimes absent, or nearly so, the rock being crystalline throughout, and approaching granite. A specimen from the railroad, one mile south of Needham Station, afforded 75.45 per cent. of silica, from which, and its great uniformity, I infer that this rock is all petrosilex. The vertical joint planes in this rock frequently intersect in such a manner as to develop a beautiful and perfect columnar structure. The columns are not uncommonly hexagonal, four to eight inches in diameter, eight to twelve feet or more in length, and as true and regular as any in basalt. Several fine examples of this structure are exposed in the cuts on the New York and New England Railroad, north-east of Charles-River Village.

Petrosilex in Dover, Medfield, and Dedham. — The two small patches of petrosilex along the railroad in Dover and Medfield exhibit local transitions toward granite and diorite. The rock is of greenish and grayish hues. My data from this region are meagre, and further exploration would probably discover more of these small islands of petrosilex among the granite and diorite. The petrosilex of the large area in Dover and West Dedham presents many varieties. As a rule it becomes more crystalline toward the west, appearing to pass insensibly into the granites which border it in that direction. On the other hand, we are as yet unable, as already stated, to separate the petrosilex from the breccia on the south. The difficulty here arises from the enclosure of pebbles in portions of the petrosilex adjacent to the breccia; and the question is unsettled as to whether the explanation found adequate on Marblehead Neck will fit the similar phenomena in West Dedham. The magnificent exposures in the former locality greatly facilitated the determination of the relations of the rocks. The main body of the petrosilex in the vicinity of the breccia is of a greenish hue, waxy lustre, usually not very hard, and, save when holding pebbles or an occasional grain of quartz, quite compact. It seems to have the composition of petrosilex, an average specimen from the hill west of the "Oven Mouth," on Main Street, giving 72.35 per cent. of silica. Yet its inferior hardness, usually yielding to the knife, suggests recomposition, though it may mean simply decomposition. It does not differ in this respect, however, from much of the elvanite in Needham.

What appears to be the same rock, minus the pebbles, and sometimes more crystalline, covers a large area to the north and west, being the prevailing variety in this region. The pebbles are very rare, except in the immediate vicinity of the breccia, and here they are never so numerous as to give the rock a conglomerate aspect; *i.e.*, as regards texture, there is nothing like a transition from the petrosilex to the breccia. Morover, the breccia holds pebbles of a petrosilex indistinguishable from that in question. The pebbles are usually petrosilex, but many granitic pebbles have been observed; these are fine-grained. The petrosilex pebbles are commonly pinkish, and this is the color of many of the pebbles in the breccia.

At the corner of Main and Pond Streets in West Dedham, and quite near the breccia, there is "flattened pebble" or schistose petrosilex, identical, save that it has a reddish tinge, with that studied on Marblehead Neck. It bears no resemblance as regards either structure or component materials to the adjoining breccia. More or less distinctly banded petrosilex is known to occur at several points in this Dedham and Dover area, but always in small patches. On Dover Street, in Dover, it holds rounded grains of quartz. Toward the east, on and near Fox Hill, we have the most typical petrosilex which this area affords. It is black, hard, and compact, except at one point where Mr. Very has observed banding. The bands are distinct on the weathered surface, but entirely wanting on the fresh fracture; and, since this petrosilex is very homogeneous throughout, we conclude that it was probably all banded originally. This rock has contributed many pebbles to the breccia. A specimen from Fox Hill has been found to contain 72.9 per cent. of silica, and 18.7 per cent. of aluminum and iron sesquioxides. A red, banded petrosilex, apparently more quartzose than the last, occurs *in the breccia* at the "Oven Mouth." It forms a layer or bed about a foot wide, and seems to be contemporaneous with the enclosing breccia, but it more probably owes its position to some dislocation of the rocks. It also occurs a mile to the north, in Dover, and probably at other points.

Petrosilex in West Roxbury, Hyde Park, Milton, and the Blue Hill Region. — In passing from the coarse granite of Bellevue Hill, in West Roxbury, southerly to the petrosilex, along almost any line, the observer will traverse a zone of elvanite of greater or less width. It consists of a grayish-white base, holding inconspicuous crystals of feldspar, and very prominent grains of crystalline quartz. The texture is variable, becoming more crystalline and coarser northerly, and less so southerly; so that this rock certainly appears to connect the granite with the petrosilex. The same rock is abundant at the Clarendon Hills Station, on the Boston and Providence R.R. The most of the petrosilex of this area, west of the railroad, besides the elvanite, is grayish or greenish, weathering white. It is usually quite compact, but sometimes becomes banded or porphyritic. Large masses have a quartzose aspect, appearing to approach quartzite, and contain pyrite crystals.

The last variety occurs again east of the railroad and southwest of Calvary Cemetery. The pyrite at this point is in minute grains, and abundant; and as a consequence the rock weathers deeply and yellowish. To the east and south this prominent ridge is composed almost entirely of a white or whitish, more or less distinctly banded petrosilex, with here and there a small irregular area or spot of purplish or red petrosilex in which the banding is less distinct or wanting. The banding is usually very fine, even, and continuous, and very clearly results from the alternation of quartzose and feldspathic layers.

It is at the abrupt southern end of this ridge that the spherical concretions are so well developed, as noticed, *ante*, p. 62; while the concretionary *layers* are found mainly on the east side of the ridge, toward Back Street. The banding is usually not apparent in the portions of the rock holding spherical concretions. Between Back Street and the New York and New England R.R., the petrosilex, wherever it protrudes through the covering of breccia, is mostly compact or little porphyritic, but banding is not uncommon. Only a few of these limited areas are shown on the map.

The most interesting, and at the same time the most beautiful, petrosilicious rock in this Hyde Park region is the schistose or striped variety. The best exposure of this is near the Neponset River, in Hyde Park Village, at the intersection of River and Arlington Streets. The general plan of the structure is the same as in the "flattened pebble" petrosilex on Marblehead Neck. The rock is mainly of two varieties, red and gray, and these are quite distinct; the former predominating. The red variety consists of a reddish and sometimes pinkish base, with irregular lenticular layers of a darker red; these are of all sizes, up to an inch thick, and nearly a foot in length; as a rule, however, they are not more than one-fourth of an inch thick, and four to six inches long. It will be noticed that the layers are longer than in the Marblehead rock; and they are also more numerous, the base being relatively less abundant. The very fine schistosity, though not wholly wanting, does not characterize the rock to the extent observed in other places. On the fresh surface the lenticular layers are little conspicuous; but weathering brings them out distinctly. They are more quartzose than the base, which is usually soft and whitish where exposed.

Other layers or patches, still more irregular, and much fewer than those described, are bright red or light pink, have a jaspery appearance, and are wholly unaffected by weathering. These jaspery patches sometimes form thin sheets, similar to and parallel with the other and more feldspathic layers. (Pl. 2, fig. 2.) As a rule, however, they have the general shape of angular pebbles; and yet they certainly are not pebbles, for in nearly every case one or more of the angles are drawn out into thin, sharp-edged, curving layers or strings, which would be extremely unlikely to result from any conceivable mode of fracture, and which, on the other hand, cannot be appealed to as evidence of softening and flattening, since the general outlines are, apparently, entirely undistorted, being rarely or never indented by adjoining pebbles or layers. Although usually quite homogeneous, a few instances have been observed where the jaspery patches were marked by parallel, narrow bands of lighter and darker red. These coincided in direction with the general lamination of the rock, and yet seemed to be independent of it. Small irregular spots and stripes of the jaspery material are common in the dark-red lenticular layers, and do not appear to be easily separable from an important feature of the latter now to be described. The great majority of these layers have a more or less distinctly concentric structure. They consist of an outer feldspathic portion enveloping a quartzose nucleus or axis. The distinctness of this concentric division into two layers is inversely proportional to the relative thickness of the sheets; the axis being usually wholly unobservable in those layers which are thickest relatively to their lengths, appearing as an ill-defined darker band in those of medium flatness, and having a sharply marked boundary only where the thickness does not exceed about one-tenth of the length. There is no minimum limit; it being possible to detect the axis in layers which are themselves almost too thin to be seen with the naked eye. The axial sheet becomes more quartzose as it becomes more distinct, often reaching the condition of vitreous quartz in the finer layers. It is not uncommon to find several overlapping laminæ of quartz in the same lenticular layer, — a schistose structure in the constituent layers of a schistose rock. These quartz laminæ are occasionally of quite irregular forms, tinged with red or pink, and indistinguishable from the jaspery patches or stripes. In fact, I believe these two features of the rock are essentially the same, and there can be no doubt, whatever, but that they have both been produced by segregation.

This schistose petrosilex holds pebbles, and, as elsewhere, they are angular and sharply outlined. They are usually small, although fragments four or five inches across have been observed. There are a few fine-grained granitic and dioritic pebbles; but the great majority are petrosilex. The petrosilex pebbles or fragments are of the same color and general appearance as the enclosing rock, but are often larger, apparently, than could be obtained by breaking up any of the lenticular layers now exposed. But this appearance is merely illusory in many cases at least, resulting from the fragments being looked at flatwise; and often the unbroken lenticular layers themselves have sharply cut, angular outlines when viewed in this manner. In some portions of the rock the pebbles are rare or wanting, while in other parts they are very numerous, forming a considerable proportion of the whole, well-nigh obliterating the schistosity, and giving the rock quite the aspect of a breccia. But, as just explained, this appearance is likely to be more pronounced on a surface parallel with the schistosity; the pebbles in such a view being partly real and partly lenticular layers seen flatwise. Occasionally the pebbles are banded or striped, and can then be certainly identified with the enclosing rock. In such cases the banding is very likely to form an angle, sometimes a high angle, with that exterior to the pebbles; and in every instance the bands of the surrounding petrosilex immediately adjacent to the pebbles are deflected so as to conform to their outlines.

There is but little of the gray, schistose petrosilex in sight. So far as observed, it contains fewer pebbles than the red, and the structure is less disturbed; but otherwise, save that the base, the lenticular layers and the jaspery patches are different shades of gray and white instead of red, the two rocks appear to be identical. A singular fact observed in connection with these two varieties of petrosilex is that, although occurring in contact or nearly so, and both showing considerable disturbance and holding pebbles, neither contains fragments that can be referred to the other; they seem to be petrologically distinct. On the west side of River Street the striping of the gray petrosilex is nearly wanting, and the rock is decidedly crystalline, holding crystals of feldspar and quartz.

As already observed, the structure of these striped rocks in

Hyde Park is substantially a repetition of that studied on Marblehead Neck and at other points. The jaspery patches and quartzose axes or nuclei, however, have not been distinctly observed elsewhere, and in these, it seems to me, we have another strong argument against the hypothesis that the lenticular layers are flattened pebbles. Such uniformity of composition and structure in the pebbles of a conglomerate rock would be something marvellous, but still more unique must the parent rock have been, from which such quartz-centered, feldspathic pebbles could be derived. I have already stated that the separation of the quartzose and feldspathic materials is the result of a segregating process. This is sufficiently proved in the case of the axial layers, by the various degrees of distinctness which they exhibit, and very conclusively in the case of the jaspery patches, by the fact that undoubted pebbles are penetrated, or cut entirely across, by narrow threads or veins of the red, jaspery material, which are sometimes connected with adjoining patches or masses of the same; *i.e.*, are prolongations of them. In one case (Pl. 2, fig. 3) a well-defined triangular fragment of a greenish diorite is neatly divided by a narrow vein of jasper, which penetrates the petrosilex on either side an inch or more. Such examples, while proving the origin of the jasper by segregation, also show that the segregation has been effected, partly, at least, since the enclosure of the pebbles; but not wholly, for some of the petrosilex pebbles themselves enclose isolated grains and small masses of jasper.

Those believing in the pebble origin of the lenticular layers will probably suggest that the segregation of the quartz may have gone on simultaneously with the flattening of the pebbles, the plasticity which permitted the latter favoring the former. The principal answer here must be the uniform character of the layers. One thing is certain, — the unflattened, angular pebbles or fragments in the rock cannot be appealed to as evidence in favor of the flattened pebble theory, for it is perfectly clear that the petrosilex fragments post-date the lenticular layers. These fragments have originated in this rock subsequent to its formation and subsequent to the development of the schistosity; and, since it is in the highest degree probable that all the fragments are of the same age, we find it necessary to conclude that, while those composed of petrosilex are most likely the result of internal fracture and crushing, the granitic and dioritic fragments must have been introduced from without, apparently while the rock was in a plastic state, and before the segregation of the quartz had ceased. The numerous dislocations and the local crushing *in situ* of portions of this rock are illustrated, though on a small scale and rather inadequately, in fig. 1. In this specimen the schistosity is unusually fine. The fact that fragments of the red petrosilex are never found in the gray, and *vice versa*, greatly strengthens the view that the petrosilex fragments have originated in or near their present positions; for, if they were of foreign birth, this relation to the adjoining rock would be very difficult to explain. It is natural, at this juncture, to compare the concentric lenticular layers of this petrosilex with the layer-like concretions in the banded petrosilex west of Back Street. But there are conspicuous differences, the true concretions being broadly and smoothly rounded on the margins, and presenting everywhere rounded botryoidal surfaces, very unlike the ragged outlines of the schistose layers. I am still obliged to regard the latter as probably resulting primarily from some peculiarity in the mode of original deposition, modified subsequently, in most cases, by a process of segregation which sharpened the outlines of the layers and developed the quartzose axes.

This schistose petrosilex, both red and gray, occurs very locally at several points in Hyde Park Village, and along the New York and New England R.R., between Mattapan Station and Oakland Street; also near the end of Bird's Lane west of the railroad. In some places it either holds so many pebbles as to be nearly indistinguishable from breccia, or else the breccia contains an occasional flattened layer, derived, perhaps, with the rest of the material, from the petrosilex. Along the west side of the railroad, near Mattapan Station, there are several very fine exposures of the contact of the schistose petrosilex and the overlying breccia. The contact surfaces are extremely irregular, and indicate much movement, if not fluency. Small patches of conglomerate have also been observed reposing upon the striped petrosilex here. These are quite readily distinguished from the breccia, making it impossible to regard the latter as *the* conglomerate, and thus remove this variety of petrosilex from the Huronian formation, by referring it to the Shawmut group. In some of these exposures the schistosity approaches regular banding.

On River Street, in Hyde Park, near the schistose petrosilex, there is an outcrop of a stratified petrosilicious rock, which I introduce here with considerable hesitation. There are two varieties, greenish-white and dark-purple; these are interstratified, but the lines of bedding, which are quite regular and continuous, are found chiefly in the former. Both varieties weather deeply, though turning the knife on fresh surfaces. What appears to be the same rock occurs on Blue Hill Avenue, south of the Neponset, where I have represented it as covering a considerable area. The boundaries of this area are almost entirely conjectural; and it is not unlikely that true Huronian petrosilex is wholly wanting here. The petrosilex east of Blue Hill Avenue, in Dorchester, is for the most part, at least, very finely and evenly banded or stratified. The bands do not exceed one-half a millimeter in thickness, are quite continuous, and are all of a uniform whitish color, the structure being visible only on the weathered surface. Limited portions of the rock are of a pinkish or even red color, and more coarsely banded. The rock sometimes cleaves readily in the direction of the bedding. The strike is N.E.–S.W.; dip, vertical. The petrosilex in Milton, between the Neponset River and Pine Tree Brook, is very similar to that west of Back Street. It is generally of a whitish color, although toward the northern boundary there are irregular, ill-defined patches of purple. The rock is nearly all distinctly banded, but the banding is sometimes obscure or wanting in the purple patches. The banding is mostly very even and continuous, consisting of alternating grayish and purplish layers a millimeter thick, or less, which have all the characters of true beds.[1] The grayish layers become white by weathering, while the purple remain unaltered. The strike varies from E.–W. to N.E.–S.W., and the dip is northerly and steep. This rock, and probably, also, that in Dorchester, is mainly felsite. A typical specimen from the centre of the Milton area afforded only 66.3 per cent. of silica. These are the most clearly and indubitably stratified of all our petrosilicious rocks; and to deny that they are stratified is to throw doubt on the sedimentary origin of even such rocks as sandstone and slate. Yet we cannot question for a moment that they are essentially one with the great body of the petrosilex.

At the eastern end of this Milton area portions of the felsite, where it crops through the conglomerate, pass, apparently by decomposition, into a soft, greenish, unctuous rock, which most observers have mistaken for serpentine; but which appears to be aluminous, rather than magnesian, and is probably a variety of pinite, as suggested to me by Dr. T. Sterry Hunt. This mineral, although appearing to originate in the petrosilex, is of very common occurrence as a pebble-forming material in the Primordial conglomerate of this region, and a more detailed account of its composition and petrological relations will be deferred until that formation is reached.

Not the least interesting of our petrosilicious rocks is that so extensively developed in the southern half of the Blue Hill region. This rock, which is properly an elvanite, consists of a dull brown or gray base, holding numerous crystals of feldspar and quartz. Its texture and composition are remarkably uniform, agreeing in this respect with the elvanite in Needham. It is more crystalline, more granitic, than the Needham rock, or, in fact, than any other petrosilex in Massachusetts; and this character becomes more marked northerly. The northern and eastern boundaries of this area are difficult to determine with accuracy, partly on account of the drift, but mainly because there appears to be no sharp line of demarcation between the elvanite and granite; but a gradual transition from

[1] The lamination-cleavage is often strongly marked.

the one to the other. I have observed the granite becoming finer-grained toward its southern border, until it was indistinguishable from the elvanite; and the reverse is the fact when the contact is traversed in the opposite direction. And yet there is no room to doubt that this rock is a true petrosilex, and not merely a fine-grained granite. The evidence on this point is conclusive. A recent traverse across the Blue Hill range brought me in contact with just the facts necessary to place beyond question the relations of the elvanite both to the granite and to the other types of petrosilex. I set out in a south-west direction from the station in West Quincy, with a view to finding and studying the contact of the granite and petrosilex. The granite becomes sensibly finer-grained, in the direction indicated, for about one mile. Here I came to a line of well-marked and precipitous escarpments, with a north-west and south-east trend; just such a break in the topography as would lead a geologist to suspect a fault. These cliffs are a good granite, but the first outcrops a few rods beyond are petrosilex; the cliffs mark the contact of the two formations, the transition here being very abrupt. The petrosilex is of the same gray color as the granite, or a little darker, and in a comparatively small area presents several varieties of texture and composition. It is for the most part a good elvanite, the feldspar crystals, however, predominating; sometimes it is porphyritic with this mineral alone, and occasionally it is quite compact. It has a bedded structure in many places, with a southerly dip. The banding by which the stratification is indicated is abundantly obvious for recognition; and yet the bands are not, in general, so sharply defined as in other localities, having more the appearance of normal stratification, though frequently showing a tendency toward the schistose or "flattened pebble" structure. Other portions of the rock bear plain marks of extravasation; the evidence being similar to that noted on Marblehead Neck. At other times the enclosure in the petrosilex of pebbles and fragments of the same rock, giving rise to a breccia structure, is clearly the result of internal crushing and reconsolidation; and in still other cases there appear to be small patches of genuine breccia. A concretionary structure is common in this petrosilex, as noticed *ante*, p. 62; and the color sometimes changes to reddish or brown. But the important point is that nearly all these different varieties contain free silica in grains of sensible size, and exhibit frequent passages into the typical Blue Hill petrosilex or elvanite. Continuing my south-west course, when about one-fourth of a mile beyond the line of escarpments, I came to a well-marked and beautiful elvanite, holding abundant crystals of orthoclase and quartz, both finely crystallized, in crystals 1 to 8 mm. across, averaging 3 to 4 mm.; the orthoclase predominating. Small crystals of hornblende occasionally make their appearance; in fact, it is almost precisely as if the constituent crystals of the ordinary granite were slightly separated and imbedded in a petrosilicious matrix. The aspect is often that of graphic granite. This rock is recognized at once as essentially the same with the Blue Hill elvanite; and yet it is surprisingly near the granite, requiring for its conversion into that rock, simply that the compact matrix, which already forms but a small part of the whole, should become crystalline. And this final step is supplied by the same locality; the rock just described becoming in some parts crystalline throughout and passing into true granite. The most of this elvanite is as destitute of stratification, apparently, as the granite; but occasionally traces of the original banded structure appear, even in that which is now decidedly granitic. In short, these rocks, as I read them, afford evidence of a gradual and *bona fide* transition from banded petrosilex to granite. This is the view of the relations of the Blue Hill elvanite and granite held by President Hitchcock. (See *post*, p. 95.) A typical specimen of the elvanite or granitoid petrosilex from the principal summit of the Blue Hills yielded 71.84 per cent. of silica, which is, I believe, about the silica ratio of the Quincy granite.

Petrosilex in Hingham and Plymouth.—There is an interval of more than six miles between the most easterly of the Blue Hill petrosilex and the small area of this rock in Hingham, which is the last that remains to be described. The petrosilex in Hingham is on the west side of Hingham Harbor, and is found chiefly in the form of loose masses in the meadows adjacent to Lincoln Street, east of Thaxter Street. President Hitchcock described the rock as occurring here *in situ;* but for many years no true ledge was visible; recently, however, Mr. T. T. Bouvé has re-discovered the original exposure under the road-bed of Lincoln Street at about the point where this street approaches nearest to tide water. The ledge had been blasted away in grading the street, and thus rendered inconspicuous. This petrosilex has a distinctly schistose structure; yet it is not coarsely schistose, as in Hyde Park and other places, but very finely, like the petrosilex at Cliftondale in Saugus, and on Oliver Street in East Malden. Portions of it, however, are less brecciated and more vividly colored than in either of these cases. It is the handsomest rock which I have met in Eastern Massachusetts. The color is deep red, brighter than in the Hyde Park rock, and matched only in some portions of the "Saugus jasper." The schistosity is very fine, with now and then a coarser layer; these coarser layers, especially, are very even and continuous, and appear to link this structure with the regular banding. Portions of the rock hold petrosilex pebbles, and the attendant phenomena are apparently the same as in Hyde Park.

Petrosilex is not known to occur *in situ* to the southward of this Hingham locality; granite is, apparently, the all-prevailing rock in that direction, and I have mapped it as extending without interruption to the border of the formation. That region, however, is so extensively drift-covered as to render this purely negative evidence of the absence of petrosilex of little value; while some observations made by Prof. Hitchcock incline me to the opinion that petrosilex probably occurs *in situ* within the limits of Plymouth, and possibly of Carver and Kingston. In the State Cabinet collected by Prof. Hitchcock are specimens of petrosilex from Manomet Hill in Plymouth, and in his

Final Report, p. 151, we find it stated that the beach, a mile or two in length, skirting the foot of this hill, is largely composed of pebbles and boulders of petrosilex. The small area of petrosilex in Hingham is twenty-five miles distant in a north-westerly direction, while more nearly to the north petrosilex does not appear above the water at a point nearer than Marblehead, fully forty miles distant. In short, the abundance of these loose masses of petrosilex at a point so remote from the nearest known source suggests the existence of a less distant source now unknown; and I should not be surprised to learn that Manomet Hill itself has an axis of petrosilex.[1]

The analyses of the petrosilicious rocks recorded in the foregoing descriptions do not represent any one locality more than another, and in selecting the specimens for analysis those were chosen which seemed to be most characteristic of the areas which they respectively represent, and without regard to whether they would probably prove to be acidic or basic. Hence, nothwithstanding their small number, these analyses indicate approximately the relative importance of the petrosilex and felsite; the former rock being far more abundant than the latter. The felsite is nearly always of a pale color, — drab, gray, or greenish-white; on Marblehead Rock and the small island east of Lowell's Island, however, it is black, and the banded felsite in Milton contains some purple. These light tints are common to portions of the petrosilex also, but the colors eminently characteristic of this rock and peculiar to it, or nearly so, are the following: red, brown, brownish-purple, and black. In some cases the felsite can be recognized by the triclinic form of the feldspar crystals; it may also be usually known by its

[1] This is precisely the conclusion reached by Prof. Hitchcock. He describes (p. 374) a block of porphyry on Manomet Hill sixty feet in horizontal circumference, and, on p. 379 he adds: "Indeed, so abundant and so large are the porphyry boulders here that I can hardly conceive they could have been brought from the Blue Hills, which are nearly thirty miles distant; and I am disposed to believe that this rock exists in place not far north of Plymouth." In yet another place he describes the granite at one point in Kingston as having the texture and general appearance of the Blue Hill porphyry.

inferior hardness and more waxy lustre. In the Lynn and Medford area the felsite appears to lie mainly to the north of the petrosilex, and, since the prevailing dip here is north-westerly, the former rock probably overlies the latter; this, I believe, is their normal relation.

That the banded petrosilex is stratified may be regarded as fully proved; and that the schistosity of the schistose rock, although, perhaps, not the direct result of sedimentation, corresponds to or represents genuine stratification, *i.e.*, is some modification of an originally sedimentary structure, is almost equally certain. Now, since there is not a considerable mass of petrosilex in this region in which examination will not disclose traces at least of one or other of these structures, I think the inference is legitimate that all our petrosilicious rocks are of aqueous origin. Yet it is unquestionable that, in its present condition, some of the petrosilex is exotic.

The great mass of the rocks here described under the head of petrosilex is undoubtedly Huronian; but it is by no means certain that this system will include them all; for, as already hinted, indications of a difference of age are not wholly wanting, especially among the felsites. It seems best, however, in the absence of satisfactory evidence to the contrary, to continue to refer the whole to the same horizon. If proved to belong to distinct epochs, I should assign the more ancient to the Huronian system.

In its general distribution the petrosilex obeys the same law as the granite. The areas usually have trends approximating N.E.–S.W., and are so disposed as to form ranges or belts parallel with the ranges of granite. The Newbury area is one of the simplest of these belts, and it conforms perfectly with the trend of the enclosing granite. Our longest line of granite, the Natick and Rockport belt, is bordered on the south by the longest range of petrosilex. This begins as a narrow band skirting the granite in South Natick and northern Needham, and is probably continuous, under the conglomerate and slate in Newton, Watertown, Belmont, and Arlington, with the petrosilex in Medford. Here the discontinuity of the granitic belt permits the expansion of the petrosilex northerly through Melrose and Saugus into Wakefield. The petrosilex in Lynn is entirely disconnected from that in the Marblehead region by extensive masses of eruptive granite; but that they were formerly continuous is in the highest degree probable. It is very evident that the petrosilex of Marblehead Neck and the adjacent islands forms but one area. These are geographic, but not geologic islands. The length of this petrosilex belt, from South Natick to Half Way Rock, is thirty-three miles. An outlying patch of petrosilex is said to occur on the Manchester shore, on the line of this belt. The north-east and south-west trend is conspicuously marked in the petrosilex areas of Needham, Hyde Park, and Milton. In Dedham and Dover the petrosilex partakes of the complexity which appears to reign in that region. If the Shawmut and Primordial rocks were removed, we should probably find that these isolated masses of petrosilex to the south-west of Boston are really the beginnings of ranges similar to and parallel with that above described. In fact, it is likely that the petrosilex in central and southern Needham is a detached portion of the Natick and Marblehead belt. The remarkable chain of islands stretching from Squantum to the Outer Brewster is directly in line with the petrosilex areas in Hyde Park and northern Milton, and certainly suggests their extension in that direction.

Relations of the petrosilex and granite. — After many years of field work, Prof. Edward Hitchcock summed up his observations on the relations of the granite and petrosilex in the following language:[1] "The porphyry (petrosilex) is associated, both on the north and south of Boston, with syenite (granite); and in all cases, so far as I have observed, *the porphyry lies above the syenite*, and there is a gradual transition between the two rocks. This fact is most obvious in the Blue Hill Range, where one is often much perplexed to

[1] Final Report on the Geol. of Mass., p. 667.

decide whether the rock be syenite or porphyry. The syenite in these cases, however, is never, so far as I know, that variety consisting of compact feldspar and hornblende (diorite), which occurs as a member of the overlying family of rocks, but that variety composed essentially of feldspar, quartz, and hornblende." This is a concise and accurate statement of the conclusion which I have reached by a re-survey of the facts. The principal result of my study of these rocks is simply a confirmation of the views expressed by this sagacious observer more than a generation ago.

The superposition of the petrosilex on the granite is proved by the following facts: In the first place, the entire aspect of the petrosilex tells us that it is the newer rock; it is much less crystalline than the granite, and far more generally stratified. It is stratified as the rule, and exotic as the exception, while the granite is exactly the reverse. The granite is often clearly eruptive through the petrosilex; but I have never observed an indubitable instance of the opposite case. An inspection of the map will suffice to show that the petrosilex is always adjacent to the granite, and especially that no other rock ever comes stratigraphically or geographically between these two.

I have alluded, on a preceding page, to the very numerous instances which this region affords of rocks transitional between petrosilex and granite, and to the general abundance of the evidence that, in this region, these two important lithologic types have had a common origin. Much of this evidence has been given in the foregoing descriptions of the petrosilex and granite, and I should not venture to introduce the following summary of the whole were it not that its intimate relations to the petrosilex constitute our principal and only conclusive reason for including the granite in the Huronian system. I take the petrosilex as the type of the Huronian series in Eastern Massachusetts, and assume that whatever appears to be stratigraphically and lithologically connected with it, as the granite certainly does, must be referred to the same general horizon. It might be argued that the transition from petrosilex to granite is due to derivation, and is no indication of synchronism, the petrosilex being regarded as a recomposed rock formed from the débris of the granite. There are instances where this might very well be the case, but in general the facts lend little support to this view. Besides, such an hypothesis would make the petrosilex a shallow water deposit, since it everywhere lies in close proximity to or directly upon the granite masses from which, according to that view, it was derived. Whereas, reasoning from analogy, it is far more probable that this rock, which is of very uniform composition and almost chemical fineness, and which is to a large extent characterized by a banded or stratified structure of remarkable evenness and regularity, was formed amid conditions of long-continued tranquillity such as obtain only in the greater depths of the ocean. Possibly we have something analogous at the present day in the deposits of aluminous silicate (red clay), which recent explorations show to be forming over millions of square miles in the abysses of the ocean, and which appear to take their origin chiefly in the volcanic dust and pumice disseminated by winds and currents, these materials being usually more or less extensively decomposed subsequently to their deposition; and I would suggest in this connection that the silicious shells of Diatoms and Radiolaria which have been rained down upon the ocean floor in a steady shower uninterrupted through countless ages are a possible source of the free quartz which, in addition to alkalies, would be needed to give this aluminous deposit the chemical aspect of a petrosilex.[1] Assuming, then, that the transition in question, if it really exists, is due to alteration and indicative of at least approximate synchronism, and that it is a transition *from* the petrosilex *to* the granite, we may premise, in the first place, that, on *a priori* grounds, such a gradual passage is in the highest degree probable. All authorities are agreed that, chemically and mineralogically, these rocks are essentially identical, differing only in texture; and in this region, as, doubtless, in others, the range of variation in the

[1] For further remarks under this head, see my paper "On a Possible Origin of Petrosilicious Rocks," Proc. Boston Soc. Nat. Hist., xx.

texture of both species is so wide that we frequently have granite more compact than some petrosilex, and *vice versa.* Such lithologists as Von Cotta, who hold to the igneous origin of both granite and petrosilex, regard these rocks as products of essentially the same mineral dough, differing only by reason of the slower or more rapid cooling of different portions of the original fluid mass. This view is diametrically opposed to that proposed here, and yet they are parallel; for I regard the granite and petrosilex as unequally metamorphosed portions of an originally stratified, compact, petrosilicious rock. They are not strictly synchronous, but, as I conceive, the petrosilex represents, in a general way, the higher and the granite the lower part of the same vast formation. Hence the gradual transition from the one rock to the other should occur, normally, in a vertical direction; and we can expect to find the intermediate textures that prove the passage only where the denudation or upturnings have exposed the *original* zone of contact. Now, as previously shown, the granite, in its present condition, is generally exotic; although as a rule it has not probably been extravasated very far; and it were manifestly absurd to suppose that any contact between these two rocks which we may chance to traverse will or should afford evidence of a gradual transition, regardless of the mode of formation of the contact. Contacts resulting from extravasation will usually be found abrupt, and most of the contacts are of this kind.

It is worthy of note that the granite is very commonly of about the same color as the adjoining petrosilex, especially where there is any evidence of a transition; and not infrequently they have other characters in common. Thus, in Newbury the petrosilex, judging from its deep-red color, is decidedly ferruginous; moreover, it appears to occupy a basin having a granitic border, and where the petrosilex adjoins the granite, especially to the north of Kent's Island, there is not only evidence of a transition in texture, but the granite shares the ferruginous character of the petrosilex, portions of it being so charged with iron, chiefly in the form of carbonate, as to weather deeply and reddish; and at some points the rock might be properly called an iron ore. Where there is a large area of granite unbroken by petrosilex, as between Ipswich and Gloucester, and also to the southward of Boston Harbor, there are two suppositions consistent with the view here advanced: the petrosilex has been swept away by denudation; or it has been all metamorphosed into granite. I think in some cases the latter is the true explanation. It should be said, however, that neither of the extensive areas indicated has been explored with sufficient thoroughness to place the entire absence of petrosilex beyond reasonable doubt. The fine-grained, nearly compact eurite, into which the less hornblendic portions of the granite so frequently pass, appears to be most characteristic of those parts of the granite adjacent to the petrosilex; and where the granite over a wide area is devoid of petrosilex, and yet embraces much of the eurite, it seems fair to conclude that it comes under one of the cases supposed above, where the petrosilex has been removed by erosion or completely altered.

Much of the granite cutting through the diorite in Marblehead is almost as cryptocrystalline as petrosilex, and the elvanite holding the same relation to the diorite on the shore of Salem Harbor approaches very close to granite. The elvanite also occurs at Hospital Point, on the Beverly shore, and in the granulite at this place, as already noticed, we find a structure which is very characteristic of much of the petrosilex. The very crystalline petrosilex on Marblehead Neck is certainly nearly as good a granite as some of the adjoining eurite. Through the Lynn and Medford area of petrosilex there are many instances where this rock appears to pass into eurite and granite. At Wellesley the granite and petrosilex are in contact and of the same deep-red color. In southern and eastern Needham these conditions are repeated, but the color of both rocks is greenish-white. The transition here seems to be perfect, at least as regards texture; and the granite becomes gradually coarser as we leave the petrosilex, passing into the coarse, typical granite of Dedham and Dover. Substantially the same phenomena are presented along the western border of the petrosilex in West Dedham and Dover; as already noticed, the petrosilex along this line becomes very distinctly, and, apparently, very gradually, more crystalline westward, and is finally indistinguishable from the granite bordering the petrosilex in that direction. Similarly, in traversing the *zone* of contact between the granite of West Roxbury and the petrosilex on the east and south there is an undoubted transition. In the case of the Blue Hill petrosilex I consider the evidence irrefragable; it unquestionably passes into the granite on the north and east, and probably into the Dedham granite. A broad band of eurite forms the southern border of the Blue Hill granite, extending from the petrosilex eastward to Weymouth Fore River. Patches of granitic petrosilex (elvanite) have been observed in the granite on the Cohasset shore.

In a paper on the Geology of the Vicinity of Boston,[1] by Dr. T. Sterry Hunt, I find a partial expression of a view of the relations of the granite and petrosilex similar to that held by President Hitchcock, and insisted upon in this paper. After speaking of the "felsite" and "felsite-porphyries," he says: "Associated with them is a granular quartzo-feldspathic rock which is often itself porphyritic, with feldspar crystals, and sometimes appears as a fine-grained syenitic or gneissoid rock, often distinctly stratified. This has been described by Hitchcock as intermediate between porphyry and syenite; his syenites with 'a nearly or quite compact feldspar base,' and some of his porphyritic syenites will probably be found to belong to these granular eurites, which I connect with the porphyries."

Again, in his Chemical and Geological Essays, pp. 186–187, the same author says: "The rocks having the mineralogical composition of granites present a gradual passage from the coarse structure of ordinary micaceous, hornblendic, and binary granites to finely granular and even impalpable mixtures of the constituent minerals, constituting the rocks known as felsite, eurite, and petrosilex. These rocks are often porphyritic from

[1] Proc. Bost. Soc. Nat. Hist., vol. XIV., 45.

the presence of crystals of orthoclase, and sometimes of crystals or grains of quartz imbedded in the finely granular or impalpable paste. These felsites and felsite-porphyries are, in very many cases at least, stratified or indigenous rocks, and they are sometimes found associated with granular aggregates of different degrees of coarseness, which show a transition from true felsites into granitic gneisses."

DIORITE.

It is intended to include here only clearly eruptive rocks, using the term eruptive in a general sense that will embrace all rocks that have been *fluent*, whether extravasated or not. There are stratified diorites in this formation, but they are inseparable from the other members of the stratified or gneissic series, and may be most conveniently described in that relation; although, as will appear farther on, the chief distinction between the dioritic group and the stratified group consists in the greater disturbance and alteration which the former has experienced, the two having been originally essentially the same.

Even as thus limited the dioritic group includes a considerable variety of rocks as regards both texture and composition; and diorite, although probably the best lithologic designation that can be employed, is far from being descriptive in every case. As a rule the diorite is fine-grained, sometimes impalpably fine, exhibiting local transitions to felsite, as already explained, and never attaining the degree of coarseness common with the granites. In composition it has a wider range; and we not only find all gradations from a rock composed almost wholly of feldspar to one in which hornblende is the sole constituent or nearly so; but each of these, especially the less hornblendic, is prone to pass, by the addition of quartz, into hornblendic granite. In fact, the areas colored as diorite on the map embrace a large amount of fine-grained, hornblendic granite. This is the granite referred to on a preceding page as always associated with diorite, and rarely with the typical granite and petrosilex. It is frequently little more than a quartzose diorite, and the seemingly gradual transition between this granite and the diorite is undoubtedly real and perfect. All observers of these two rocks will agree with me that they admit of neither a lithologic nor a geographic separation. As a rule they are both evidently eruptive, and over large areas they have been extravasated through each other so extensively, and the action has been so mutual, that the confusion is complete, and I have long been accustomed to speak of these as "mixed rocks;" and I know now of no term that will better express their relations lithologically or petrologically. Those desiring to study the complication of these rocks, in the field, will find the best exposures for that purpose in Marblehead and Salem, especially along the shores in the former town.

Most observers have failed to discriminate between the various granitic and dioritic rocks of Eastern Massachusetts, classing them all together under the general term "syenite." At some points there is at best but little difference, but the same is true of any series of rocks; the adjacent members of the series must approximate. This is a fundamental principle of the science, growing out of the mode in which sediments laid down by water must necessarily be arranged. The law of continuity certainly holds in lithology. Yet, though we cannot separate the fine-grained, dioritic granite from the diorite, we can and ought to distinguish between the latter and the coarse-grained, little hornblendic granite. I have been able to recognize two varieties of the hornblendic granite associated with the diorite. In one the hornblende is very abundant, the feldspar is gray, and the texture of the rock granular or crystalline. This variety is far more abundant than the other, in which the hornblende is little conspicuous, and the feldspar usually red, sometimes gray, and always more or less compact, resembling petrosilex. The second variety is more quartzose than the first, and the quartz is in the form of rounded grains.

The term diorite, as here used, probably covers a whole family of basic rocks; these are supposed to consist essentially, however, in each case, of a plagioclase feldspar and some variety of hornblende. I think the feldspar is not always of the same species, and the same is probably true of the hornblendic material; but I have not investigated, or tried to separate, the various rocks thus resulting.

Dark-colored mica (biotite) is of very common occurrence in the diorite series, and yet it is rarely abundant. It is more characteristic of the diorites proper than of the granites. These rocks are occasionally epidotic and chloritic, but neither of these minerals can be regarded as characteristic. Like the granite and petrosilex, they are poor in accessory minerals. Thin seams of specular iron are not uncommon, however, and this series carries all, or nearly all, of the argentiferous galena of Newbury and adjoining towns. Prof. A. Hyatt has called attention to the remarkable extent to which this formation, in some parts of its distribution, has been broken and shattered by some upheaving or plicating force, and the numerous irregular, angular crevices and fissures thus produced, filled with what appear to be sometimes endogenous, and in other cases exotic, veins of flesh-red feldspar, mingled, usually, with coarsely crystalline quartz, and, occasionally, with epidote. In many cases the fractures are, locally, so numerous that the rock is entirely broken up into small angular fragments, and has a distinctly brecciated aspect, the endogenous feldspar forming the paste. The structure is such that if the paste were removed the fragments would fall together, and fit as neatly as the pieces of a puzzle. The best exposures of these feldspar veins in their various degrees of complexity are on the southeast shore of Marblehead.

The large area in Sharon, Stoughton, and Foxborough, colored as diorite on the map, may contain patches of other rocks; but Mr. Very and I have traversed it from north to south, along several different lines, and found little or nothing but diorite; and hence we conclude that it must be mainly of the dioritic or "mixed" series. The boundaries are largely conjectural, especially toward the east. The rock is for the most part very fine-grained; but in the hills of Sharon it is sometimes decidedly coarse, and Mr. Very has observed the same in Foxborough. It is quite possible, as already suggested, that these coarse varieties should be referred to the Naugus Head series. This area is probably continuous, under the band of uncrystalline strata to the westward, with the smaller area along the New York and New England R.R. The characters of the rocks, so far as observed, are substantially the same.[1] In Medfield, Dover, and Norwood, also, the diorite is mainly fine-grained, frequently compact, approaching felsite. These southern dioritic areas do not embrace so large a proportion of the quartzose diorite and fine-grained, hornblendic granite as those to the north and east.

Of the distribution of the diorites little need be said. It is very obvious that they obey the same general law as the granite and petrosilex, forming ranges or belts trending approximately north-east and south-west. In the northern half of Essex County, the diorite is found mainly to the west of the granite and petrosilex, and the different belts are united in that direction, cutting off and enclosing the belts of granite. Farther south we have a broad and nearly continuous zone of diorite reaching from Natick to Essex, parallel with and mainly to the north of the Natick and Rockport line of granite. Wherever occurring, the diorite is adjacent to granite or petrosilex. In its normal position it overlies the petrosilex; and hence its contacts with granite must be due to faults, to the extravasation of the granite, or to the conversion of the petrosilex at these points into granite. The diorites of Salem, Swampscott, and Marblehead appear to lie outside of the Natick and Essex range, and are nearly separated from it by granite and Naugus Head rocks. The diorites, like the granites, are divided by the Naugus Head area, passing to the north and south of it.

[1] Recent observations have shown that in the vicinity of Franklin Centre and City Mills the rock is not principally diorite, as represented on the map, but coarse, typical granite, which appears to cover a wide area in the region north of the railroad, marked as general Huronian; while the correlation of the coarsely crystalline basic rocks north-east of Wadsworth's Station, with the Naugus Head series, is regarded with even greater satisfaction than heretofore.

HORNBLENDIC GNEISS, ETC., — STRATIFIED GROUP.[1]

The petrosilex in Saugus, along the road from Lynn to North Saugus, becomes more quartzose northward, approaching quartzite. This petrosilex, as already observed, shows traces of banding, and the quartzite is distinctly stratified. Occasional beds of the quartzite are slightly micaceous, and these become interstratified with large masses of fine-grained hornblendic rocks, — diorite and hornblendic gneiss, the former predominating. These various rocks appear to be conformable, and the dip is steep to the north-west. The stratification, however, is much disturbed, and in considerable portions of the diorite it is wholly wanting to the eye, and these are then indistinguishable from the eruptive diorites just described.

This belt of stratified rocks is cut off toward the west by eruptive granite, but reappears beyond the Newburyport turnpike, and extends along the north side of Central Brook into Melrose. On Main Street, near the brook, there are large beds of massive quartzite interstratified with felsitic and micaceous beds, and passing on the north into dioritic rocks as before. The strike and dip remain unchanged. The contact of this series with the granite on the high hills half a mile east of Main Street, affords, as previously stated, conclusive evidence of the extravasation of the latter rock; in this direction also the bedding is much disturbed, and in the hornblendic rocks especially it becomes more and more obscure, and is finally lost; another example connecting the stratified with the unstratified diorite. The quartzose portion of the diorite — the hornblendic gneiss — is converted *pari passu* into fine-grained hornblendic granite; and here we find a complete explanation of the intricate and intimate relations of the granite and diorite in the so-called "mixed" series. For in the first stage of the mixing the rocks are interstratified, with frequent alternations of the strata and perfect transitions between them; and partial

[1] The stratified group is represented on the map by color laid on in lines, and these lines have in every case the direction of the average strike.

fusion, accompanied by more or less extravasation, readily develops in such a series all the complexity observed. There are but few outcrops on the line of this stratified belt in Melrose, east of the Boston and Maine R.R., but west of this railroad the series is well developed and the exposures are good. This locality places beyond question the fact that there is a gradual transition between the quartzite and petrosilex, and that portions of the latter rock are intercalated in the stratified group. The stratified group at this point is evidently a continuation, under different conditions, of the unstratified diorite on the west. The narrow strip of stratified rocks south of the granite in Melrose consists of a finely stratified gneiss with thin partings of mica in minute scales.

The locality affording at once the greatest variety, and the finest and most instructive exposures, of the stratified rocks is in the north part of Reading. As shown on the map, the village of Reading is underlaid by coarse eruptive granite; this extends a short distance north of the village, where it is met abruptly by quartzites, and fine-grained, slaty, hornblendic rocks beautifully stratified. Succeeding these are many alternations of quartzite, felsite, diorite, and gneiss, all conformably interstratified, and dipping steeply to the north-west, save where, as is not infrequently the case, the strata are contorted and twisted; the disturbance being so great in some instances as to obliterate all traces of the bedding. The diorite presents every variety of texture and composition, but rarely contains much quartz; *i.e.*, it seldom passes into well-marked gneiss. Occasional layers are decidedly epidotic, and the rock as a whole is very hornblendic, frequently appearing as a nearly pure hornblende rock. The bedding is fine and even. The petrosilicious strata have commonly the aspect of felsite rather than petrosilex. They are sometimes crystalline or porphyritic, and are usually marked by lines of bedding; and it is interesting to observe that these structure lines, which here no one, probably, would question as indicating sedimentation, are exceedingly like the ordinary banding of the petrosilex; moreover, they embrace all the principal varieties of structure characterizing the great mass of the petrosilex, and in the case of the schistose structure, especially, the identity seems to be perfect. The petrosilicious rocks are of two colors, white and pink, and the latter, particularly, makes decided approaches to granite. The felsite is often inseparable from diorite. The quartzite is usually gray and more or less micaceous, but there are large masses of nearly vitreous quartz of a snow-white color. The quartzites lie mainly to the south, or under the diorites, the series becoming more hornblendic northward.

The rocks of this large area are well exposed, also, at several points on the Boston and Lowell Railroad. Here, interstratified, we have distinct argillite, diorite of many different textures, felsite, gneiss, and various nondescript rocks transitional between those mentioned. The strata are much contorted in some places, and yet they seem to be entirely conformable. The normal dip is N. 30° W. 70°–80°. The argillite is fissile, with shining surfaces. The felsite near the chemical works in North Woburn is very similar to that occurring at Dungeon Rock in Lynn. These rocks probably extend north to the Montalban boundary, and south-west to Concord, and they have been so represented on previous maps; but the wide-spread drift deposits make this point difficult to determine, and I deemed it best not to map beyond my observations in a region so complicated as this.

The long Huronian tongue penetrating the Montalban formation south-westerly from Concord, lies directly in the trend of the area just described, and, since it is entirely composed of similar stratified rocks, the probability is strong that these two areas are really one. Indeed, I have no doubt that these dioritic rocks do form the entire north-western border of the Huronian system, from North Reading to Concord; the only question is whether they are always stratified or not, and it is probable that they are. I have made but one section across the Concord and Westborough band, viz., in Marlboro'; but, according to Prof. Hitchcock, the rocks are the same at all points. They are largely hornblendic—diorite and gneiss—with thin beds of a distinct mica slate; while there is but little to represent the felsitic and quartzose beds of Reading and Woburn. This agrees with the observations made in those towns, however, that the rocks become more hornblendic and micaceous toward the border of the formation. The stratified rocks in Marlboro' are cut by fine-grained granites, which are micaceous, and may be Montalban. In fact, the whole band might very well be referred to this system, rather than the Huronian, so far as lithological characters are concerned. It is in its geognostic relations, chiefly, that we find evidence justifying the correlation here made. Southward from Concord, also, the country is largely drift covered; but it is probable that the stratified group covers the most of the area between Concord and Natick marked as general Huronian on the map. In the vicinity of Snake Creek, in the eastern part of Wayland and northern Natick, there are distinct gneisses, which belong, lithologically, to the Montalban series; and it is possible that the Montalban boundary is deflected this far to the east, but more probable that the strata are Huronian. The strike is very variable, average N.E.–S.W.; dip, vertical, or steep to N.W. These beds are cut by extravasated masses of the adjoining granite and diorite. In Natick, well exposed in the railroad cut east of the village, are quartzite, diorite, fine-grained hornblendic gneiss, and coarse granitoid gneiss, all distinctly and conformably interstratified. These rocks cover a considerable area in Natick, probably larger than I have indicated on the map; and at many points they exhibit immense disturbance and alteration, the stratified diorite and hornblendic gneiss becoming structureless and eruptive. As usual, the quartzite is most abundant toward the south; and it appears, as previously stated, to pass, on the east, into the petrosilex in Wellesley. Prof. Hitchcock mentions "porphyry" (petrosilex) as occurring in Natick; but this quartzite is the nearest approach to it I have observed.

The stratified rocks in Sherborn are diorites and imperfect gneisses. Strike S. 20°–70° E. Judging from the nature of the drift, this area extends south-westerly into Holliston. The area in Dover is less gneissic and more felsitic, consisting of alternating bands of diorite of various textures, and hornblendic felsites, and passing on the south into the "mixed" series. Stratified Huronian rocks, other than petrosilex and felsite, are of rare occurrence south of the Charles River. Besides those last mentioned, I know of only one instance worthy of note. This is on the Cohasset shore, between Black Rock and Little Harbor, and has been described in connection with the granites.

Returning to our starting point in Essex County, however, and looking north-easterly, we find several important areas of bedded rocks. Along the road running from Lynnfield Centre north-westerly are many croppings of interstratified quartzites, and fine-grained, often aphanitic, or slaty-looking, diorites. These continue for one and a half miles, and are met in the direction of North Reading by the unstratified diorite. The rocks in this section are almost identical with those in Reading, and the strike and dip are the same. Between Lynnfield Centre and Middleton the rocks are rarely exposed; but in traversing this region I have observed that the boulders in the drift, especially the larger and more angular ones, which evince the least transportation, consist largely of imperfect gneisses and stratified diorites. These rocks are quite distinct from those in the direction of North Reading, but closely resemble the gneiss in Wayland; and, like the Wayland rock, they are possibly, but not probably, Montalban. The stratified rocks in southern Middleton are probably more abundant than I have ventured to represent them.

The long and narrow stratified belt beginning at the Salem and Lowell R.R. in Peabody and reaching into Wenham is based mainly upon observations made by Prof. Hyatt. The strike is parallel with the belt, and both are, perhaps, a little more easterly than represented. The dip is 60° and upwards to the north-west. The only rocks observed here are diorites, more or less micaceous, passing into coarse feldspathic gneiss, as at Natick, but nothing like quartzite or felsite. There are frequent passages into the exotic series. According to Prof. Hyatt, the character of the drift in the vicinity of Wenham Lake indicates the occurrence there of much stratified rock; and the area just described is probably continued in that direction. The rocks about Wenham Lake, judging from the specimens in Prof. Hyatt's collection, are much the same as in the Reading series. A finely stratified rock, similar to the principal member of the Reading series, sometimes a diorite and sometimes a gneiss, and occasionally epidotic, composes most of the area in Boxford and Rowley. I have little doubt that this area extends south-westerly with increasing breadth to the Montalban border. The dip and strike are as before, and the indications of a passage into the eruptive diorites very plain. Among the diorites in Newbury, north of the Boston and Maine R.R., there is a considerable amount of stratified rock similar to the last, but including quartzite. Strike, N.E.; dip, N.W. It occurs in small patches, which have not been explored sufficiently for their delineation on the map.

The well-known schist enclosed in the granite on Marblehead Neck undoubtedly belongs to the stratified group. It is a fine-grained rock, often largely quartzoze, and always containing more or less micaceous or hornblendic material, usually in a condition so fine and obscure as to be scarcely recognizable with the naked eye. Large masses of a similar schist occur in the granite at Hospital Point, on the Beverly shore; and also in the Naugus Head eruptions on the north side of Great Misery; though in this last case I am not certain that the stratified rocks do not belong to the Naugus Head series.

In what precedes I have, I think, placed beyond question the proposition that the stratified group and the unstratified diorites are essentially one and the same series; and yet the strongest evidence remains to be adduced. Irregular fragments and patches of the micaceous quartzites and felsites are of common occurrence in the diorite formation of Marblehead, Swampscott, Salem, etc.; and the diorite itself is frequently stratified, especially the quartzose portions. It is unnecessary to append a list of localities where the stratification of the diorite has been observed, since the student can hardly fail to meet instances of this structure in any part of the area indicated. As a rule these stratified patches are not sharply outlined, but are gradually merged with the enclosing rock, the bedding becoming less and less distinct and insensibly vanishing as we proceed from their centres outward. The large area of diorite stretching from Stoneham to Weston includes numerous small patches of stratified rocks, — diorite, hornblendic gneiss, felsite, and quartzite. A few of these patches have been represented on the map, but many more, probably, remain undiscovered. They are usually narrow, parallel with the strike, and vary in length from a few rods to a mile or more. Strike, N.E.–S.W.; dip, steep to N.W. They frequently pass into the enclosing rock, showing that they are mere remnants of a vast formation, which yet preserve traces of the structure once possessed by the whole mass of the rock. The stratified rocks composing these narrow bands are similar to those forming the large areas already described, comprising, chiefly, diorite, felsite, and quartzite; it is probable, however, that they generally include more quartzite and less diorite. This is precisely what must result when such a lithologic series as that in question is metamorphosed; the hornblendic rocks are most susceptible of alteration and are the first to yield, those containing the largest proportion of hornblende, the diorites, being altered more readily and extensively than those which are largely feldspathic or quartzose. Felsite and petrosilex may be changed, but less easily, into feldspathic diorite or granite; but the quartzite is almost incapable of alteration. Excessive disturbance may obliterate the lines of bedding, and the rock may become more or less vitreous, but it is a stratified quartzite still; quartzite being the last rock that we can expect to find playing the rôle of an eruptive. Consequently, it is not uncommon, in traversing the dioritic areas, to find limited beds of quartzite which still preserve their normal strike and dip, although enclosed on every side by eruptive or semi-eruptive diorite. Such masses, when the bedding is indistinct, sometimes have the appearance of huge veins traversing the diorite. One of the largest of these quartzitic islands is well exposed in the vicinity of Shaker Glen, on Mill Brook, in Woburn. It is a beautifully and evenly stratified quartzite, or something between quartzite and petrosilex. The comparatively large area of stratified rocks enclosed in the diorites in the north-east corner of Weston is itself largely dioritic, consisting of fine-grained, slaty rocks. The foregoing remarks concerning the occurrence of stratified rocks in the Salem and Marblehead and the Stoneham and Weston areas of diorite are true in a general way of all the dioritic areas.

The conclusion is now certainly safe that the eruptive diorites and the stratified group are unequally metamorphosed portions of one great series of basic rocks. The metamorphism reaches its extreme in the southern part of Norfolk County and in the Salem and Marblehead area; and it is the general law that, in each of the great belts of basic rocks, the metamorphism increases southward or south-easterly, the exotic lying mainly to the south of the stratified portions. This is most noticeable in the northern part of Essex County, and in the region between Essex and Wayland. Now, since the normal dip of the entire Huronian formation, and especially of this portion of it, is toward the north and north-west, it follows that in the main the dioritic or eruptive group underlies the stratified group; *i.e.*, the metamorphic action has affected the lower terranes of this great basic series more than the upper.

LIMESTONE.

The Huronian limestone of Eastern Massachusetts also belongs to the stratified group. It is the least abundant of all our Huronian rocks. Prof. Hitchcock showed that it is always magnesian, being more properly a dolomite than a limestone; but usually a considerable proportion of the magnesia appears to be in the form, not of a carbonate, but of a silicate — serpentine and bowenite. This is, I believe, the only serpentine-bearing rock in the Huronian series of this region. The best known deposits are in Newbury. In early colonial times these were extensively wrought for lime, and "Devil's Den" and "Devil's Basin" are the modern designations for the long-abandoned quarries. There is considerable serpentine at these places, but it is not uniformly distributed through the limestone, which also contains asbestus, wollastonite (Mr. Wadsworth has shown that this radiated, fibrous mineral is not tremolite), and siderite; though, unlike the similar deposits in the Montalban system, it is not rich in accessory minerals as regards either variety or quantity. The question has been raised as to whether the Newbury limestone is endogenous or indigenous. I am well satisfied in my own mind, however, that these deposits are truly stratified. At the Devil's Den, especially, the lines of bedding are very distinct in a portion of the rock, and, moreover, the strike is parallel with the trend of the mass, N.E.–S.W., while the dip is steep to the N.W., agreeing with the stratified diorites on the north and the petrosilex on the south. In fact, the stratification is as well preserved in all the limestone as could be expected, considering the great disturbance and alteration exhibited by the enclosing diorites. These last, as can be seen on the map, belong to the exotic or "mixed" series; they include much granite, and appear entirely devoid of stratification. The question may be asked how, if the limestone is contemporaneous with the diorite, any of its bedding has survived the disturbance which entirely destroyed that structure in the diorites? The answer is found in the nature of the rock. Limestone, like quartzite, is an inert substance, little susceptible of metamorphism; and the ordinary metamorphic agents, — heat and pressure in the presence of water, — while competent to soften and extravasate the diorites, must leave the limestone almost unchanged. The latter rock may be folded and faulted, and may become more or less crystalline, but it is practically infusible. These limestone beds have been preserved intact in substantially the same manner as the isolated masses of quartzite already described. Regarding the limestone as of sedimentary origin, the wonder is, not that the bedding is not more perfect, but that it is not wholly obliterated, and this is explained by the refractory nature of the rock. The Devil's Den and Basin are about half a mile apart, and the line connecting them seems to run a little more northerly than the strike of the deposits, which have not been stratigraphically united, though there is little doubt that originally they formed one continuous bed. An observation recorded in Prof. Hyatt's notes is of special interest in this connection. He found a ledge of crystalline limestone about one-third of a mile south of the city of Newburyport, and on the general line of strike of the Newbury deposits. From the Devil's Basin this ledge is distant, probably, about one mile. It is not shown on the map, and the other deposits are represented as one on account of their nearness and the small scale of the map. The occurrence of the *Eozoon canadense* in the Newbury limestone has been noticed, *ante*, p. 25. The siderite mentioned above as associated with the limestone, is found only at the Devil's Basin, and appears to be the same with that characterizing the adjacent granite and diorite. Indeed, I regard this mineral as going far to prove the connection of these various rocks. In the first place, it does not occur in the form of veins, but, as previously stated, is diffused through the rocks almost as a regular constituent; and in its composition again we have evidence pointing to the same conclusion, for the siderite not only appears to be the same, whatever its association, but analysis also proves its essential identity with the limestone itself. Following is an analysis, made by Professor Hitchcock,[1] of the siderite occurring in the granite immediately north of Kent's Island: —

[1] Final Report on the Geol. of Mass., p. 191.

Carbonate of lime	45.67
Carbonate of magnesia	8.97
Proto-carbonate of iron	21.76
Proto-carbonate of manganese	16.10
Silica and alumina	3.34
Loss	4.16
	100

It is interesting to observe that a substantial agreement exists between this analysis, and that made by Miss E. H. Swallow,[1] of the siderite occurring in the gangue of the vein of argentiferous galena at the Chipman Mine, about a mile north-west of the limestone.

The limestone in Lynnfield is far more serpentinic than that in Newbury. The serpentine appears to be everywhere present and abundant; in fact, Prof. Hitchcock did not seem to regard this rock as limestone at all, but described it under the head of serpentine; and a specimen analyzed by Dr. C. T. Jackson contained no calcic carbonate. There is no doubt, however, that the rock as a whole is a very serpentinic limestone. There can be no question about the indigenous nature of this limestone, for it is distinctly stratified; and a glance at the map will show its intimate relations with the regular stratified group on the west. But few exposures of this serpentinic limestone have been observed, and yet these are so disposed as to indicate that it covers a considerable area; and the distribution of the limestone boulders in the drift to the southward tells the same story. I have mapped it chiefly in accordance with the views of Prof. Hitchcock and the observations of Prof. Hyatt. Toward the east the limestone is met by unstratified diorites, and in general the petrologic relations appear to be the same here as in Newbury.

Next in order is the well-known dolomite in Stoneham. This is not serpentinic, but holds the allied mineral, bowenite; and, although of a beautiful white color, it contains less than

[1] Proc. Bost. Soc. Nat. Hist., XVII., 464.

sixty per cent. of calcic carbonate. The bed is only a few feet wide, and shows no distinct traces of stratification, but is much broken and contorted; the trend, however, is north-easterly. The enclosing rock is likewise entirely devoid of apparent stratification, consisting mainly of diorite and hornblendic granite, with limited masses of petrosilex. Yet I am convinced that this dolomite belongs to the stratified group, and is contemporaneous with the associated rocks ; in other words, its mode of occurrence admits and necessitates the same explanation that was offered in the case of the similarly isolated masses of quartzite.

I have not examined the limestones in Concord and Natick; according to Prof. Hitchcock, however, they are magnesian, non-serpentinic, probably stratified, and intimately connected petrologically with the stratified group.

GENERAL RELATIONS OF THE HURONIAN ROCKS.

Having proved that the stratified group, including the limestone, and the eruptive diorites, taken together, constitute one great basic or dioritic series, having the terranes of the former group mainly at the top and of the latter at the bottom, the inquiry is now in order as to what are the relations of this basic series to the petrosilex and granite. In the first place I would observe what might, perhaps, have been better noted before, viz., that the petrosilex and granite form another great series, structurally parallel with the dioritic series, but in striking contrast with it chemically; the one series being, as we have seen, decidedly basic, while the other is, as a whole, highly acidic. The typical and euritic granites, consisting mainly of orthoclase, but containing much quartz and poor in hornblende, are, of course, types among acidic rocks. It is true that the rocks described under the head of petrosilex include much felsite, which, according to our definition, is basic; yet petrosilex proper is by far the prevailing species and our petrosilicious rocks, taken as a whole, are unquestionably acidic, although the silica ratio is probably less than among the granites. In characterizing this acidic series as structurally parallel with the basic series I refer to the probable fact that the granite and petrosilex are unequally metamorphosed portions of one and the same set of beds which were originally of substantially similar structure and composition throughout, becoming, however, less acidic upwards; and to the undeniable fact that the petrosilex or stratified part of this series overlies the granites, just as the so-called stratified group or gneissic part of the basic series overlies the unstratified diorites or "mixed" group. We thus find that all the rocks belonging to the Huronian series in Eastern Massachusetts may be naturally divided into two great groups, which, although defined by their chemical characters alone, are petrologically mutually exclusive, or nearly so.

Resuming now the inquiry as to the relations of these fundamental divisions, it can be easily shown that the basic division overlies the acidic. In a region of almost universal north-westerly dips those strata are probably the newer which lie to the north-west, as does our basic group as a whole with relation to the acidic. I have already noted the stratigraphic continuity of the two series in North Saugus and at other points, where the petrosilex passes insensibly north-westerly into diorite and gneiss. Such localities afford us a clue to the normal arrangement: for these gradual transitions between the petrosilex and hornblendic rocks preclude the idea that the former have been thrown down by a fault so as to appear to underlie rocks older than themselves. The granite has been frequently and extensively extravasated through the diorites in some districts; and the petrosilex, although far less generally eruptive than the granite, also penetrates the basic series. Instances of this on the north-west shore of Marblehead, where the elvanite cuts the diorite, have been described, *ante*, p. 73. Another example, not before mentioned, occurs on the north-east corner of Marblehead, near Fort Sewall; here the diorite is cut by a regular dyke of petrosilex, which is nearly black, fine-grained and compact.[1]

[1] Since the above was written, I have become aware that Prof. C. H. Hitchcock, in the recently published report on the Geology of New Hampshire, recognizes the fun-

The true sequence, then, of our Huronian terranes is as follows: granite, petrosilex, diorite, and stratified group; and coincident with this lithologic series we have a gradual passage from highly acidic rocks to those that are almost entirely composed of basic minerals. This chemical gradation has long been recognized as essential to the constitution of every complete series of sedimentary rocks, representing one prolonged period of subsidence or elevation of the ocean bed; and Dr. T. Sterry Hunt has correlated this theoretically invariable succession of the strata with the different degrees of mobility possessed by the various products of the decay of crystalline rocks and the order observed in their removal. The same authority, reasoning from well-established chemical principles, has demonstrated that, from the period of the first-formed sediments on the globe to the present day, the proportion of the alkalies potash and soda in the rocks of the successive ages must, on the average, have steadily diminished; and each complete lithologic series, each rounded cycle of sedimentation, is an epitome in this respect of the vast cycle of which it forms but one of the stages. Now this principle is well exemplified in the Huronian system of Massachusetts, for in going up from the granites at the base of the system, through the petrosilex, hornblendic gneiss, and diorite, to the more or less micaceous beds at the summit, we find a gradual diminution in the proportion of potash and soda which the rocks contain.

I have no data upon which to base trustworthy estimates of the thickness, either absolute or relative, of the different members of the Huronian system. I can only assert positively that the aggregate volume is something enormous, and that the acidic

damental division of the Huronian series of this region here insisted upon. He says, Vol. II., p. 669, "It appears that there are two well-marked divisions of this system, the upper quite chloritic, and the lower quartzose and feldspathic. The greenstones of our State seem to be closely allied to the upper Huronian, and the porphyries of Lynn, etc., Mass., to the lower division. It is possible that our supposed eruptive porphyries of the White Mountains belong to this lower division. They certainly possess the same lithological features, and in some cases have been protruded through what we consider the upper division."

group probably surpasses the basic. From the granite in northern Plymouth County to the Montalban gneiss in Concord, this formation measures not less than thirty miles across the strike, and the rocks, when not eruptive, appear, usually, to be nearly or quite vertical; but we get from this simply a maximum limit which is far in excess of the bounds of probability, for there is no doubt but that the repetitions resulting from folds, faults, and extravasation, have increased the apparent breadth or thickness of the series at least fourfold. There are, however, no bilateral repetitions of the rocks of such magnitude as to render probable the existence of extensive folds involving the whole thickness of the formation. On the contrary, the more important repetitions, so far as I have observed, are such as could be produced by faults alone.

Summarizing what has been said concerning the distribution of these rocks, we find, proceeding from south-east to north-west, the following general geographical arrangement. In northern Plymouth and southern Norfolk Counties there is an immense mass of granite covering hardly less than two hundred square miles. It is elongated transversely to our line of section; and, although largely exotic, it must be regarded, when viewed as a whole, as essentially in its normal position with relation to the remainder of the formation. Succeeding the granite, disregarding the uncrystalline rocks underlying Boston and its environs, we appear to have a broad belt of petrosilicious rocks extending to the northern boundary of the Natick and Marblehead range; and following this is a yet broader belt of diorites and stratified rocks reaching to the Montalban border. This generalized geographical arrangement corresponds with the stratigraphical succession.

Now it is an interesting fact that, in the northern half of Essex County, we find substantially the same geographical arrangement and corresponding stratigraphical succession, but on a smaller scale. There, as farther south, the stratified crystallines all dip to the north-west; and we have, on the south-east, the granite of Essex, Ipswich, Rowley, etc., succeeded by the petrosilex of Kent's Island and the River Parker, and this by the eruptive diorites, hornblendic gneiss, and stratified diorite, between the River Parker and the Merrimac. We cannot, of course, believe that there are here two distinct series of rocks precisely alike lithologically, and presenting the same succession. The corresponding members of the two series must be stratigraphically as well as lithologically equivalent; and, since the terranes are repeated in the same and not in the contrary direction, the repetition is probably to be explained by a fault, and not by a fold. This grand repetition of the strata seems to necessitate the existence of a gigantic fault extending south-westerly from the shore in Ipswich, and having the down-throw in part, at least, on the south-east. The distribution of the rocks toward the south-west indicates that the fault wanes in that direction, the vertical displacement being insufficient to bring up the granite beyond Middleton; but it is conceived that the line of fracture extends along the southern border of the Montalban formation through Concord, and does not finally die out before reaching Westborough; and it is suggested that we may find in this great dislocation a sufficient cause for the existence of the peculiar Huronian peninsula lying between these towns. This is the grand fault of this region, but many minor fractures exist; every exotic mass being probably accompanied by a greater or less dislocation of the adjacent strata. A short distance south of the Merrimac, in Newburyport and West Newbury, the stratified group is met abruptly by granite, which extends northerly over a large part of Salisbury, reaching probably into New Hampshire. At this line of contact a second large fault appears to supervene, inaugurating a second general repetition of the strata.

It will be observed that between the Rhode Island line on the south, and the New Hampshire line on the north, the Huronian boundary presents two salient angles to the west, one in Concord and one in Groveland. These important deflections or sinuosities are of very similar form, but of unequal size; the angle having its vertex in Concord being more prominent than that nearer the Merrimac. Each of these angles, as we have seen, is probably on the line of a fault, and the magnitude of the fault in each case is probably proportioned to the prominence of the angle. Connected with the Concord angle is a conspicuous tongue of Huronian strata which continues the north-east and south-west boundary line to Westborough, and the point I wish to make here is that evidence is not wholly wanting of a similar peninsula extending from Groveland into Lawrence. In passing from the Montalban granite in Andover to the Merrimac, I crossed nearly vertical strata of stratified diorite identical with the diorite so characteristic of the Huronian area; the strike is north-east. But for the Concord and Ipswich fault, the Montalban strata would extend easterly over Boxford, Georgetown, Rowley, Newbury, etc.; and, but for what may be designated as the Merrimac fracture, these newer rocks would similarly spread over Salisbury to the coast. The great uplifts indicated by these faults have raised large areas of Montalban strata above the present plane of denudation, and given rise to the *en échelon* form of the Huronian border.

In the boundaries of the exotic rocks, especially the granite, we have evidence that the lines of fracture are sometimes exceedingly tortuous and complex. One of these demands special mention. The great mass of diorite in Marblehead, Swampscott, and Salem has undoubtedly been thrown down by a fault so as to come geographically between the petrosilex of Marblehead Neck and the Naugus Head series. The proofs of this are: (1) In its present position the diorite inverts the normal order as established in less disturbed regions. (2) This diorite area is nearly surrounded by a belt of eruptive rocks. A continuous line of granite extends from Peabody to the shore in Lynn. The Swampscott shore is partially skirted by granite, and this rock appears on Ram Island, Little Pig Rocks, Tinker's Island, and the southern and western shores of Marblehead Neck; so that we are warranted in concluding that there is, under the water, a continuous belt of granite reaching from the Lynn shore to and through Marblehead harbor. On the north the diorite is met by the Naugus Head rocks; and the contact of these two formations is marked, as already described, by extravasated masses of the last-named series, which have penetrated the Huronian diorites in every direction. It is clear that this girdle of eruptive rocks, this line of fire, indicates a continuous line of fracture; and movement only is needed to convert this into a fault. (3) There is an abrupt lithological break between the diorite and the petrosilex of Marblehead Neck and Lynn; no indications of a transition anywhere. The extravasation of the petrosilex through the diorite, the evidence for which was given on a preceding page, proves that the former rock underlies the latter and has been carried down with it. It is probably to this great fault that we owe the exposure of the Naugus Head series at this point.

EOZOIC FORMATIONS. — *Continued.*

MONTALBAN.

The rocks in Massachusetts here referred to the Montalban series cover a wide area, forming the greater portion of the State. They extend uninterruptedly from the western boundary of the Huronian formation to the Triassic sandstones of the Connecticut valley, and spread over most of the area between these Mesozoic rocks and the Hoosac Mountains. They are also wide-spread in the southern portions of Bristol and Plymouth Counties, about the shores of Buzzard's Bay. The Montalban areas on the accompanying map comprise, with slight exceptions, the areas marked as "granite," "gneiss," "mica slate," "argillite," "metamorphic slate," and "quartzite," on the geological maps of Prof. Edward Hitchcock. This series is also, in this State, nearly equivalent to the "White Mountain group," "granite," "Merrimac schists," "calciferous mica schist," and "St. John's group" on the map of Prof. C. H. Hitchcock, in Walling's "Atlas of Massachusetts," 1871.

To Dr. T. Sterry Hunt, as is well known, belongs the credit of first correlating the various members of this formation in Massachusetts and announcing their equivalence, collectively, with the similar rocks of Newfoundland, the White Mountain region, and, generally, with a considerable, yet even in the present imperfect state of our knowledge, tolerably definite portion of the belt of crystalline rocks skirting the eastern base of the Appalachians from the Gulf of St. Lawrence to Alabama. This new system, first outlined in a published letter to Prof. Dana, in 1870, was formally announced under the name White Mountain series, in 1871, in an address to the American Association for the Advancement of Science, where it is described[1] as "characterized by the predominance of well-defined mica-schists interstratified with micaceous gneisses.

[1] Chemical and Geological Essays, p. 244.

These latter are ordinarily light-colored from the presence of white feldspar, and, though generally fine in texture, are sometimes coarse-grained and porphyritic. They are less strong and coherent than the gneisses of the Laurentian, and pass, through the predominance of mica, into mica-schists, which are themselves more or less tender and friable, and present every variety, from a coarse, gneiss-like aggregate down to a fine-grained schist, which passes into argillite. . . . The White Mountain rocks also include beds of micaceous quartzite. The basic silicates in this series are represented chiefly by dark-colored gneisses and schists, in which hornblende takes the place of mica. These pass occasionally into beds of dark hornblende rock, sometimes holding garnets. Beds of crystalline limestone occasionally occur in the schists of the White Mountain series, and are sometimes accompanied by pyroxene, garnet, idocrase, sphene, and graphite. . . . The limestones are intimately associated with the highly micaceous schists containing staurolite, andalusite, cyanite, and garnet. These schists are sometimes highly plumbaginous. . . . To this third, or White Mountain, series of crystalline schists belong the concretionary granitic veins abounding in beryl, tourmaline, and lepidolite, and occasionally containing tinstone and columbite."

Although designed merely as a general statement of the characteristics of the Montalban formation, applicable to the series as a whole in its widest distribution, and without special reference to any particular region, no student of experience in the geology of Massachusetts will fail to recognize the foregoing brief synopsis as a singularly comprehensive and accurate enumeration of the rocks composing the areas designated above as Montalban. But if we would include in the Montalban formation all the rocks properly belonging there, according to the above definition of the system, it will be necessary, I think, to extend the limits which Dr. Hunt has assigned this series in Massachusetts. In 1870,[1] and again in the following year,[2] this authority referred the limestone in Chelmsford containing

[1] Amer. Jour. Sci., II., XLIX., 75.

[2] Chemical and Geological Essays, p. 249.

Eozoon canadense, together with the accompanying gneiss, to the Laurentian system. The *Eozoon* has also been found in the limestone in Bolton; and there can be no doubt that the range of limestone deposits extending through Bolton, Boxford, Littleton, and Chelmsford, and coinciding in trend with the strike of the enclosing gneiss, is of the same age throughout. Now these limestones are rich in accessory minerals, and contain the most of the species named by Dr. Hunt as occurring in Montalban limestones. Taken collectively, these deposits have afforded the following list of mimerals:[1] scapolite, boltonite, nuttallite, chondrodite, petalite, sphene, pyroxene, diopside, apatite, actinolite, asbestus, augite, allanite, coccolite, pargasite, chromite, pyrite, magnesite, phlogopite, talc, ophite, chrysotile, satin spar, rhomb spar, spinel, and garnet. The gneisses accompanying the limestone appear to be indistinguishable from those forming a large part of the Montalban series in Massachusetts, and, furthermore, they contain, or are directly in the strike of similar gneisses containing limited beds or concretionary veins of coarse pegmatite rich in muscovite, and holding tourmaline, garnet, beryl, and other minerals. On stratigraphic grounds, also, we seem compelled to regard these gneisses and included limestones as Montalban; for, as Mr. Burbank has shown, they form part of one and the same continuous and conformable series extending from Concord to the Nashua River, the other members of which, especially towards the west, are unquestionably of this age. Then, again, the occurrence of considerable deposits of steatite at various points in this gneiss tells strongly against the view that it is Laurentian, for this mineral is said *never* to occur in the Laurentian formation. According to Hitchcock,[2] a bed of steatite, not less than fifty feet thick, is distinctly intercalated with the gneiss in Andover. The steatite in Millbury and

[1] According to Mr. L. S. Burbank, who has given much attention to the study of the distribution, mode of occurrence, and mineral contents of the limestones in the towns named.

[2] Final Report on the Geol. of Mass., p. 157.

Worcester is on or near the line of strike of the Chelmsford and Bolton gneiss; and I have been informed by Mr. Benj. E. Brewster that a large boulder of steatitic gneiss, apparently not far travelled, occurs in Milford. The steatite in Groton is well known. It occurs as a bed ten or twelve feet thick, enclosed in mica slate, which is lithologically and stratigraphically identical with the mica slate that, farther south-east, is so intimately associated with the gneiss in question. It will have been observed, also, that talc is included in the list of minerals occurring in these so-called Laurentian limestones; and this mineral is abundant in the Montalban limestone of Smithfield, R.I.

West of the Connecticut we find the belt of so-called talcoid slate lying between this river and the Hoosac Mountains, and stretching from Vermont southerly nearly across the State, presenting decided Huronian characters; yet, on the other hand, there are good reasons for believing that it is Montalban. This belt appears in fact to combine the characters of both the Huronian and Montalban; resembling the former in consisting largely of hydro-micaceous and chloritic slates enclosing beds of serpentine and talc, and containing chromic iron and emery; and yet including extensive beds of hornblende slate and stratified hornblende rock which hold garnet and other minerals, and appear to represent the basic silicates of the Montalban series. The section from Greenfield to Williamstown, which appears in the report of Prof. Hitchcock on the geology of Vermont, shows that this belt probably marks the axis of a synclinal; for these hydro-micaceous rocks usually exhibit, on the line of this section, and elsewhere, approximately vertical dips, while the mica slate and gneiss on either side dip toward the belt in question, appearing to pass under it. Prof. Hitchcock evidently regarded the talcoid slate as newer than the mica slate, as his section shows, and yet as essentially a part of it; for he says, in his "Final Report on the Geology of Massachusetts" (p. 597): "Near the central part of the Hoosac Mountain range of mica slate occurs a range of talcose (talcoid) and chlorite slates, in conformable order, and passing insensibly into the mica slate." These mica slates, especially on the east, are unquestionably Montalban, and are so regarded by Dr. Hunt;[1] and it is probable that the gneiss succeeding the mica slate on the west and forming the Hoosac Mountains, although apparently referred by Dr. Hunt to the Huronian system,[2] really belongs in this newer formation. This gneiss is indistinguishable from that composing a large part of the Montalban series in Massachusetts, and appears, as is the habit of the gneisses in this part of New England generally, to underlie conformably the mica slates. It is true it holds beds of serpentine and talc, — minerals which are usually regarded as characteristic of Huronian strata; yet a glance at the geological map of this State suffices to assure us that neither of these mineral species can be regarded as foreign to the Montalban series. In no respect germane to this question does the Hoosac gneiss resemble the undoubted Huronian rocks of eastern Massachusetts, and in its petrological relations it exhibits not a tithe of the disturbance characterizing these truly ancient deposits. In short, I regard as probable the view that the Hoosac gneiss passes under the hydro-micaceous slate and enclosing mica slate to the eastward, reaches the surface in an anticlinal axis at Shelburne Falls on the Deerfield River, dips beneath the crystalline schists and Mesozoic sandstones of the Connecticut Valley, and, save where broken by faults, is stratigraphically continuous with the gneisses east of the Connecticut; and, since on either side of the Connecticut the rocks lie for the most part in parallel north-south bands, continuous with similar bands in New Hampshire and Vermont, I am obliged to consider the Green Mountain gneiss as also probably Montalban; whence it follows, with a like degree of probability, that the Green Mountains themselves are of the same age as the White Mountains.

In Rhode Island we find another set of doubtful beds. These occupy an irregular area in the towns of Cumberland, Smith-

[1] Chemical and Geological Essays, p. 248.
[2] Ibid.

field, and Johnston, marked as "hornblende rock" on the geological map of Rhode Island prepared by Dr. C. T. Jackson and accompanying his Report on the Geology and Agriculture of that State (1839); and, like the talcoid band west of the Connecticut, they appear to possess lithological characters belonging partly to the Huronian series and in part to the Montalban. According to Dr. Jackson these rocks are substantially the same throughout their distribution. I have examined them in Smithfield, where they consist largely of fine-grained, little micaceous mica slate, approaching argillite, and closely resembling much of the Montalban mica slate of the Nashua and Merrimac Valleys in Massachusetts. And interstratified with this slate are large beds of chlorite slate, fine-grained, green, and soft, and dark-colored, obscurely crystalline, slaty-looking hornblendic rocks, and other rocks having, frequently a quartzitic, and sometimes a felsitic, appearance. The limestone deposits of Smithfield and adjoining towns, some of which are quite extensive and of considerable economic importance, belong in this series, and are enclosed in the rocks above named. The limestone appears to be stratified, is usually more or less, frequently largely, magnesian, and contains a good variety of accessory minerals, among which talc is, perhaps, the most abundant; and Dr. Jackson states that limited beds of talc are of frequent occurrence in other portions of this series. All these rocks, including the limestone, have the same general strike and dip throughout, and appear to be conformable in this respect with the enclosing Montalban gneisses. Strike, S. 45°–60° E.; dip, N.E., steep. Associated with these stratified rocks, and occurring abundantly in the interval between the principal beds of limestone, is a rather fine-grained, apparently exotic, granite. It is hornblendo-micaceous; and, although probably a Montalban granite, it cannot be regarded as a typical variety. The proof of the Montalban age of this series of rocks is found mainly in their stratigraphic relations to the bordering gneisses, and in the small disturbance which they exhibit as compared with even the least disturbed of our Huronian beds. Relative disturbance is, of course, valueless as a test of age, when applied to widely separated rocks; but within the same limited region such indications should, I think, be allowed some weight, in the absence of better criteria.

All the Montalban rocks in Massachusetts, west of the Nashua Valley, have approximately N.–S. strikes. East of the Nashua River, and north of Worcester, however, the line of strike gradually shifts toward N.E.; and between the eastern rim of this valley and the eastern border of the formation the beds of this series conform closely in strike with the stratified rocks of the Huronian system. South of Worcester, along the valley of the Blackstone River and east of the same to the limits of the formation, the strike is at right angles to that just noted, or N.W.–S.E. This continues through the north-east corner of Rhode Island, gradually approximating more nearly to E.–W.; and beyond the Carboniferous formation and Narragansett Bay the Montalban strata reappear and extend through southern Bristol and Plymouth Counties with an E.–W. strike, varying toward the north, and again exhibiting a tendency to parallelism with the fundamental structure lines of the Huronian system.[1]

The principal lithological constituents of the Montalban series in Eastern Massachusetts are: —

1. Granite,
2. Gneiss,
3. Mica Slate,
4. Argillite,
5. Limestone.

As in the Huronian system, these groups or divisions are believed to have chronologic as well as lithologic value; and their order of sequence, with the exception perhaps of the limestone, is as stated above. Prof. Hitchcock, in his final re-

[1] These various lines of strike, as well as other points of interest in the geognosy of the State, are well shown on the map prepared for that purpose by Prof. Edward Hitchcock, and contained in his Final Report on the Geology of Massachusetts.

port on the Geology of the State, has given us descriptions of the lithologic characters of these rocks which are for the most part comprehensive and accurate; and this part of the subject may be passed with brief notices here.

GRANITE. — The granites are of two distinct kinds, — distinct in origin, but often difficult to distinguish with the eye. They are *exotic* and *endogenous.* The exotic or eruptive granite is of most importance. It is usually whitish or gray, — seldom red or greenish, as the Huronian granite frequently is; and it differs further from the Huronian granite, in that it is always more or less micaceous, and rarely contains any hornblende.

This variety, especially, is everywhere intimately associated with the gneiss, and it is clearly to be regarded as a part of the great gneissic terrane which has been softened and forced out of its original position. The evidence on this point is of the strongest character.[1] In considerable masses of the gneiss, however, the metamorphism has apparently stopped short of actual extravasation, although all traces of bedding are lost. And in still other cases, probably, the gneiss wears a granitoid aspect where it has experienced no special alteration, having always been coarse-grained and massive. As may be readily conceived, it is often a matter of extreme difficulty to distinguish these granitoid gneisses or indigenous granites from the truly eruptive rock. The exotic granite passes insensibly into

[1] It is a remarkable fact, and one strongly suggestive of the derivation of the exotic rocks, in these cases, from the stratified rocks which they penetrate, that, although the Huronian and Montalban granites are strikingly contrasted in their mineralogical characters, each presents a substantial agreement in this respect with the indigenous terrane which it intersects, or with which it is most intimately associated. To appreciate the force of this statement, and to realize that the granites have originated in, and hence are peculiar to, and, in the fullest sense of the words, essentially a part of, the great formations with which they are respectively connected, it would seem to be only necessary to compare (1) the red, brown, greenish, and gray Huronian granites, which consist essentially of orthoclase and quartz, with the similarly colored and constituted stratified petrosilex of that formation; and (2) the light-colored, almost white, micaceous Montalban granite with the intersected gneiss, from which it is usually distinguishable only by the absence of stratification.

the indigenous variety, while the latter becomes as gradually merged with the distinctly stratified gneiss; and hence I am well satisfied that, on the map, much genuine gneiss has been included with the granite. Both the granite and the granitoid gneiss are sometimes porphyritic with feldspar crystals, which are occasionally very large.

The most interesting area of Montalban granite in Eastern Massachusetts is the long but narrow belt which extends from Worcester to Dracut. This range has been carefully studied by Mr. L. S. Burbank, and I am indebted to him for the data necessary for its accurate delineation on the map. The boundaries of this granitic belt have never been drawn with even approximate accuracy on any previous map. The granite appears to be mainly of the indigenous variety, frequently passing into or including distinctly stratified gneiss, especially toward the north-eastern end of the belt, in Ayer and Westford. Yet there can be no doubt that portions of the rock have experienced some extravasation. Such appears to be the case with most of the granite in Worcester and Harvard, and, probably, at many points along the range. From Groton southward to Boylston it is decidedly porphyritic, and in Clinton and Berlin the crystals of orthoclase are very large and perfect, often two inches or more across. Farther south it passes into porphyritic and ordinary gneiss. In Harvard, where the granite adjoins the argillite and conglomerate, the latter show extensive alteration, and the granite contains much slaty material, is destitute of mica, and frequently occurs as a schistose, feldspathic gneiss in which slaty particles take the place of mica, while the feldspar is in imperfect rounded crystals, giving a porphyritic aspect to the rock.[1]

The granite in Andover occurs in large masses, apparently

[1] Most of the facts embodied in the descriptions of the rocks in the region of the Nashua Valley, given in this paper, as well as some of the language, have been taken by permission from the sketch of the geology of this valley prepared by Mr. L. S. Burbank, and accompanying my report on the Centennial Geological Map of Massachusetts.

disconnected, yet covering in the aggregate a considerable area. This region is largely drift-covered and the relations of the granite to the enclosing gneiss are difficult to determine. In Andover Village the granite appears to be interstratified with the gneiss; but to the eastward, so far as I have observed, it exhibits no trace of bedding; while at some points, especially east of Frye Village, near the Shawsheen River, its relations to the gneiss are plainly those of an exotic. This granite is for the most part very coarse, contains much muscovite, and, in these respects, at least, bears a striking resemblance to the endogenous granite of this formation. According to Prof. Hitchcock,[1] granite similar to that in Andover occurs in Billerica, Stow, and other towns in this Middlesex County range of gneiss. There can be but little doubt that the major part of this is indigenous. And the band of granite represented as bordering the Middlesex gneiss on the south-east, on the earlier of the several geological maps of Massachusetts prepared by Prof. Hitchcock, simply expressed the undoubted fact that there is through that region, along with some fine-grained gneiss and intercalated mica schist, much coarse, granitoid gneiss, or indigenous granite. The granite quarried in Concord, and also that just mentioned in Stow, belong here. Immediately north of the Huronian boundary in the western part of Newburyport, and in West Newbury, there is considerable coarse, feldspathic granite, very coarsely porphyritic with feldspar crystals; crystals of orthoclase five inches long having been observed. Succeeding this rock on the north are fine-grained, gneissic schists. The extended and little-known area of granite lying north of the gneiss in Plymouth and Bristol Counties is referred to this age on account of its intimate relations to the gneiss, and its general unlikeness to the Huronian granite. The greater part of this belt, especially toward the north-east, is deeply buried by the drift mantling this region; and, consequently, little is known concerning its limits and

[1] Final Report on the Geology of Massachusetts, p. 681.

petrologic relations. Taken as a whole this granite is decidedly not of a uniform character, and yet a fine-grained, little micaceous, variety appears to prevail. In Fall River it is fine, contains some hornblende, and the quartz is opalescent. When of this character it bears some resemblance to the Huronian granite; but in the next towns to the south-west, Tiverton and Saugkonnet, granite which, though coarser and more micaceous, is unquestionably the same as that in Fall River is so intimately associated with the typical Montalban gneiss occurring there, being sometimes interstratified with it, that the age and true relations of this end of the granite belt, at least, can no longer be regarded as an open question. In the interstratification of portions of the granite with distinct gneisses we have an indication that much of the granite of this range is probably indigenous. On the Centennial Geological Map of Massachusetts I have represented this granitic belt as extending from the southern part of Middleborough easterly through Plymouth, south of Manomet Hill, to the shore; instead of spreading northward through Carver, Plympton, and Kingston into Duxbury, as has been done on previous maps. The reasons for this course have already been given in part (p. 29), but a further reason is found in the following quotation from Prof. Hitchcock's Final Report, p. 682: —

"On my former map I colored a deposit of granite, connected on the north with that just described, and extending to Brewster on Cape Cod. I did this because a ridge of considerable elevation extends down the Cape to Brewster, and many boulders of granite are found of great size upon the hills. But re-examination renders it probable that the largest and most abundant of these boulders are granitic gneiss, approaching so near to real granite as easily to be mistaken for it."

Now, if we regard the granite in question as mainly indigenous, and this is certainly the most probable view, and consider that from Tiverton to Middleborough at least it undoubtedly lies parallel with the strike of the gneisses on the south, and that these gneisses have throughout this region a nearly east-west strike, it seems reasonable to infer that this granitic belt extends eastward beneath the southern part of Cape Cod Bay, and that it is the source of the granitic boulders mentioned by Prof. Hitchcock as strewn over the Cape to the southward.

The granite cutting the Carboniferous and more ancient slates near Newport, R.I., is also regarded as Montalban, and as probably connected with the belt just described. It is mostly fine-grained, usually contains some hornblende, and appears to resemble the quaternary granites of the Connecticut Valley. These latter occur in several large masses along the borders of the Triassic sandstone, and, though beyond the proper geographic range of this paper, merit some attention here as being the only granite of Montalban or any other age occurring in large masses in Massachusetts, west of the Nashua Valley. The large granitic area in Williamsburg, Goshen, Westhampton, and Northampton, and also that east of the Connecticut, in Amherst, include, according to the observations of Prof. Hitchcock,[1] considerable mica slate, which is associated with the granite in such a manner as to prove the exotic nature of much of the latter. A glance at a geological map of the State will show that the granite of Williamsburg and Westhampton lies on the line of strike of the gneiss at Shelburne Falls, and that this granitic area is elongated in a north and south direction. It represents, as I conceive, the extension southward of the Shelburne anticlinal previously mentioned (p. 127). And the great disturbance observable in the gneiss in the Deerfield River at Shelburne Falls has only been carried a step further to produce the extravasated granite of Williamsburg. The rocks composing the two areas, one in Northampton and Hatfield, and the other in Ludlow and Belchertown, marked as "syenite" (hornblendic granite) on the geological map of Prof. Hitchcock, are here included among the Montalban granites. My reasons for this are: (1) These syenites, so-called,

[1] Final Report on the Geol. of Mass., p. 682.

frequently contain nearly or quite as much mica as hornblende, and closely resemble portions of the adjoining micaceous granite. They are really hornblendo-micaceous or quaternary granites, and bear but little likeness to the hornblendic granites of the Huronian formation. (2) Prof. Edward Hitchcock, on his revised map of 1844, represented a small patch of "granite" (micaceous granite) enclosed in the Ludlow and Belchertown area of syenite. (3) Hornblendic gneiss, hornblende slate, and even pure hornblende rock, though not characteristic Montalban rocks, certainly occur in this formation; and, since the granites have resulted from the metamorphism of the stratified rocks, I can see no reason why the Montalban granites may not sometimes be hornblendic. The hornblendo-micaceous granite of Smithfield, R.I., has already been noticed, *ante*, p. 128.

The endogenous or vein granites are usually coarser than the preceding and more distinctly crystalline; never exhibiting traces of schistosity, or genuine stratification. They sometimes possess, however, the banded appearance due to their mode of formation, which may be readily mistaken for stratification, since the veins are frequently of a lenticular form, usually occur in gneisses of similar composition, and conform in trend and dip with the bedding of the enclosing rock. These granites are, as Dr. T. Sterry Hunt has shown to be the case with endogenous Montalban granites generally, characterized by the abundance and variety of the accessory minerals which they contain, though appearing to be poorer in this respect than the endogenous granites of some other regions. The endogenous granite is usually associated with gneiss, though not infrequently occurring in mica-slate. In Eastern Massachusetts it is most abundant in the gneiss of Middlesex County, especially through the north-western half of this range. For obvious reasons the endogenous granite has not been indicated on the map.

Gneiss. — This is the most abundant rock in Massachusetts, forming nearly one-half the State. It occurs of all textures from the finest to the coarsest, medium varieties predominating; and, though usually distinctly stratified, the bedding is frequently so obscure, and the texture so coarse or crystalline, that the rock becomes the indigenous granite. The gneiss is nearly always more or less micaceous, and, when of a fine texture, often passes through an excess of mica, into mica slate; and it is rarely hornblendic, very rarely largely so.

There can be little doubt, as was long ago pointed out by Prof. Hitchcock,[1] that the gneiss of Plymouth County extends easterly under the superficial deposits of Barnstable County, forming the axis of Cape Cod as far east at least as Orleans.

At all points east of the Worcester and Dracut range of granite, and north of the long peninsula of Huronian rocks extending from Concord to Westborough, the gneiss dips towards the north-west and west. The dip is usually steep, averaging perhaps 70°, but ranging from 20° to vertical. South of the Huronian peninsula just mentioned the gneiss dips at moderate angles, average about 30°, to the north-east; and this dip continues through Rhode Island. The gneiss in Bristol and Plymouth Counties has for the most part gentle dips to the north and north-west; and on the western border of the Nashua Valley the dips are easterly, ranging from 10° to 30°.

Mica Slate. — East of the Connecticut Valley there is in Massachusetts, disregarding a few small patches which are mainly local variations of the gneiss, only one area of mica slate; this enters the State on the north-east, in Amesbury and Haverhill, with a breadth of seven or eight miles; and extending thence south-westerly along the Merrimac it becomes narrower, and in Methuen, where it meets the north-eastern end of the Worcester and Dracut range of granite, it appears to divide into two bands, which continue, one on either side of the granite, in the same general direction. The southern band leaves the Merrimac at Lowell, and, with a breadth varying from one to two

[1] Final Report on the Geol. of Mass., p. 682.

miles, extends south-west through Westford and Littleton to Harvard, and thence with a diminished and uncertain breadth to Worcester. The northern band becomes very contracted in Dracut, and then widens somewhat, passing along the north side of the granite through Tyngsborough and southern Dunstable to Groton, where it joins a great body of the same rock, which, trending in a more nearly north and south direction, extends south between the granite and the argillite on the west, becomes rapidly narrower, and disappears in Harvard. It reappears in Bolton, and stretches thence, one to two miles wide, to Worcester, where it reunites with the first band, about thirty-five miles from their point of separation. A third band of mica slate crosses the New Hampshire line in Townsend, and, widening rapidly, spreads southward through Lunenburg and Fitchburg, where it is six miles wide; then, narrowing gradually, it continues through Leominster and Sterling to Worcester, where it is joined by the other two belts, and stretches on thence with an average breadth of about three miles through Auburn, Oxford, and Webster to the Connecticut line.

The rock composing the irregular area outlined above is subject to extensive variations, and comparatively little of it can be regarded as typical mica slate. It is usually less crystalline, and frequently less micaceous and more argillaceous, than the mica slate beyond the Connecticut. The quartz is often the predominant constituent; and in some places, notably in Clinton and Boylston, numerous bands of a distinct quartzite are interstratified with the slate.

Argillite. — Argillite of several distinct ages occurs in Massachusetts; but to the Montalban age is referred the argillite of the Nashua and Connecticut Valleys only. A broad belt of argillite occupies the centre of the Nashua Valley, lying between the second and third bands of mica slate. It enters the State on the north with a breadth of four miles; widens gradually southward, attaining its maximum breadth of six miles in Lancaster and Harvard; whence it stretches south-south-westerly, with constantly diminishing breadth, to Worcester. The argillite of this large area is usually fine-grained, homogeneous, and black, and smooth and lustrous on the surfaces produced by division planes. According to Mr. Burbank, the bedding of the argillite is very obscure, and it appears for the most part to be much contorted; while veins and lenticular masses of quartz are not of infrequent occurrence. In Lancaster and Shirley, however, he says some of the beds are quite regular and the lamination smooth and even, forming a good roofing slate. The most interesting variety of the argillite is that containing chiastolite. This mineral, as is well known, is very abundant in the argillite of Sterling, Lancaster, and Clinton; and it not improbably occurs at other points in the valley. In Harvard, as already observed, there is a break in the second or middle band of mica slate, and here, as is distinctly shown on the map, the argillite lies in contact with the Worcester and Dracut range of granite. Crossing the granite at this point, we find along its eastern border, wedged in between it and the first band of mica slate, a narrow strip of argillite and conglomerate, — argillite on the west and conglomerate on the east. This small mass, almost too small to be accurately represented on the map, constitutes the most interesting geologic feature of that region. It has been carefully studied in its distribution and relations by Mr. Burbank, to whom I am mainly indebted for the following facts. The argillite and conglomerate composing this area are distinctly and conformably interstratified, although, as just stated, the argillite is found mainly on the west side of the belt, and the conglomerate on the east. The dip is N.W. and W. 45°–80°; so that the conglomerate clearly underlies the argillite. The latter rock appears to be limited to the northern and broader end of the belt, and is lithologically indistinguishable from the argillite of the large area one mile to the westward. The conglomerate begins in Harvard, near Harvard Centre, with a breadth of less than five hundred feet, and extends in a south-south-west direction to the northern border of Berlin. As already stated, this belt is met by granite on the west and mica slate on the east; and yet the conglomerate contains not a single pebble of either of these rocks, or of any rock known to exist in its immediate vicinity; but, on the contrary, the pebbles appear to have been derived from a gray quartzite, and a slaty rock inclining to argillite rather than mica slate, the quartzite pebbles predominating. Some ten miles to the south-west of Harvard, however, in Clinton and Boylston, Mr. Burbank has discovered extensive beds of slate and interstratified quartzite, which closely resemble the materials of the pebbles that form the mass of the conglomerate. This slate is the mica slate of the second or middle band. The conglomerate is especially interesting on account of the extensive and remarkable alteration that it has experienced at most points. The metamorphism is best shown in Harvard, near the village, where the rock is well exposed and has been extensively quarried. In many cases the pebbles have been flattened, bent, and even drawn out into lenticular layers, developing a schistose structure in the rock.

LIMESTONE. — The Montalban limestones in Massachusetts are rarely serpentinic, and are probably less magnesian than those of the Huronian system; though this is not very clearly shown by the analyses made by Prof. Hitchcock.[1] The limestone occurs in numerous, small, somewhat lenticular beds, usually interstratified with gneiss and mica slate. The deposits east of the Nashua Valley are regarded by Mr. Burbank, with apparently good reason, as partaking mainly of the nature of veins, rather than stratified beds; but, west of the Connecticut, as Prof. Hitchcock has pointed out,[2] some at least of the deposits are distinctly and regularly stratified. And evidence of stratification is certainly not wanting in the limestone of Smithfield, R.I. Of course where occurring as veins the limestone deposits must be newer than the enclosing rock, and may not be of Montalban age at all. The limestone of Chelmsford and Bolton has afforded specimens of the *Eozoon canadense;* and, since this peculiar structure has also

1 See Final Report on the Geol. of Mass., pp. 80–81.

2 *Ibid.*, pp. 562, 566–7.

been found in Laurentian, Huronian and Taconian limestones,[1] those believing in its organic origin must admit that the animal producing it had a very long range in time.

GENERAL RELATIONS OF THE MONTALBAN ROCKS.

The considerations supporting the view that the rocks described in the preceding pages, and designated as Montalban, are newer than the Huronian system; and that, like the Huronian rocks, they constitute a series which may be characterized as both lithologic and chronologic, fall naturally under two distinct heads: (1) Lithologic; (2) Stratigraphic. The lithologic evidence will be considered first.

No one familiar with these rocks as they occur in the field will require further proof of the connection of the exotic and indigenous granites with the gneiss. That the gneisses are frequently granitoid, — *i.e.*, coarse, crystalline, and apparently unstratified, — and that the indigenous granite thus resulting exhibits frequent transitions into undoubted exotic granite, are among the most patent and often-recurring facts in the geology of this region. If this is the true relation of the granite and gneiss, then it were reasonable to suppose that the granite has been derived mainly from the more ancient and lower portions of the gneiss; and that, where the granite has experienced little or no extravasation, it should be found to-day occupying the stratigraphic and geographic position of the gneiss which it represents. Now, leaving out of view the endogenous granite, — which, of course, was deposited subsequently to the gneiss, — it cannot be questioned that the

[1] The *Eozoon canadense* has been reported by competent observers as occurring in the Laurentian limestones of Canada, New York, Bavaria, etc.; in the Huronian limestone of Newbury, Mass.; in the Montalban limestone of Chelmsford and Bolton, Mass.; and in the limestone in Hastings County, Canada, which Dr. T. Sterry Hunt has recently assigned to the Taconian (see Second Geological Survey of Pennsylvania, vol. E, pt. 1, pp. 171, 177, and 241). While Mr. R. J. Lechmere Guppy (Quart. Journ. Geol. Soc. Lond., xxvi, 413–414) has given the name of *Eozoon caribbæum* to a supposed organism found by him in the Caribbean series of the island of Trinidad; a group of semi-crystalline beds which the present writer has correlated provisionally with the Taconian of Berkshire County, Mass. (Proc. Bost. Soc. Nat. Hist., xx., 55.)

granite is found for the most part in just the position indicated. When we come to consider the stratigraphic relations of these rocks it will be shown that the oldest gneisses of Eastern Massachusetts occur mainly along the eastern border of the Middlesex County area, and in Bristol and Plymouth Counties; and here it is, as we have already seen, that the granitoid character of the gneiss is most perfectly and extensively developed. It is in these regions, too, that it presents, on the whole, the steepest dips, the greatest disturbance, and the most thoroughly crystalline appearance. I am aware that in other parts, also, of the former area, and in the Nashua and Blackstone Valleys, the gneiss sometimes exhibits a decidedly granitoid aspect. In most instances, however, these apparent disagreements with the view here proposed will disappear if we are careful to exclude all the endogenous granite, and to distinguish between gneisses that are merely coarse, and those that are truly crystalline; while in other cases I think it can be shown, or at least may be reasonably inferred, that the granitoid patches in question are portions of the lowest and oldest beds of gneiss, which have attained their present positions through the agency of either faults or folds of the strata. The Worcester and Dracut range of granite and granitoid gneiss is the most considerable of these outlying areas; and in another place (*post*, pp. 156–158) I shall attempt to prove that this belt has been brought to the surface by two profound fractures of the crust, and probably represents a relatively ancient and deep-seated portion of the gneiss.

Of the passage of the gneiss into mica slate we have abundant evidence. Much of the gneiss of the broad area in Middlesex County and the eastern part of Worcester County is highly micaceous, and includes numerous limited beds of distinct mica slate (marked as gneiss on the map). Professor Hitchcock, in describing this gneiss, says[1]: "It passes frequently into mica slate; the two rocks often alternating, and indeed, in some places, the slate predominating. Indeed, it would not be

[1] Final Report on the Geol. of Mass., p. 629.

strange if some future geologist should regard a part of this range as mica slate." Substantially the same remark is repeated in connection with the gneiss of Plymouth and Bristol Counties. The gneiss of the great central area between the Nashua and Connecticut Rivers is seldom very micaceous; yet, toward its western border, it encloses several considerable bands of mica slate, and appears to pass gradually into the mica slate of the Connecticut Valley; and along the eastern margin we find the gneiss of Mt. Wachusett, and the range of highlands of which this summit is the culminating point, rich in mica, in many places at least, and occasionally passing into mica slate. The mica slates here considered are everywhere intercalated in the gneiss, and are essentially a part of it; but the important bands of mica slate, already described, in the Nashua and Merrimac Valleys, are undoubtedly newer than the gneiss; and yet, it is believed, exhibit at many points a gradual passage downwards into that rock. The lower and older parts of the mica slate pass insensibly into the upper beds of gneiss, on which they repose. Of the mica slates of the first or eastern band, Mr. Burbank says:[1] "They are very variable in mineralogical character; but all become coarser toward the south-eastern border, and finally pass into gneiss." And in another place[2] he speaks of the petrologic relations of the Middlesex County gneiss as follows: "This belt of gneiss is bounded on the north-west by the slates of the Nashua and Merrimac Valleys, which apparently rest conformably upon it. Moreover, there appears to be a gradual transition in passing westward, from the coarsely crystalline gneiss, through mica and hornblende schists, to the thin-bedded clay slates like the roofing slate of Lancaster. . . . . From a series of careful observations on these rocks, I am convinced that the slates above referred to cannot be separated from the underlying gneiss, but *form with it a continuous series*." Toward the

[1] Sketch of the Geology of the Nashua Valley, accompanying my report on the Geological Map of Mass., p. 45.

[2] Proc. Bost. Soc. Nat. Hist., xiv., 190.

western margin of the third belt of mica slate, where we approach the Wachusett gneiss, the same gradual transition is observed, and is, perhaps, even more marked. The stratigraphic connection here is not so complete as on the east; for the slates are not seen to repose on the gneiss of the Wachusett range, and are probably separated from it by an extensive fault. But the general fact remains that, in spite of a complete stratigraphic inversion, the slate of this belt becomes coarser and more decidedly micaceous as we proceed from its newer to its older beds. Prof. Hitchcock, speaking of the mica slate of the Nashua Valley as a whole, as one belt, says:[1] "As we approach the east and west sides of this range the characters of the mica slate become more decided; and in this slate of apparently greater antiquity the veins and protruding masses of granite are more numerous."

Looking now in the opposite direction we see the mica slate passing upwards into the argillite. The evidence of a gradual transition appears, on the whole, even more conclusive here than along the lower limits of the mica slate, where it meets the gneiss. The views of Mr. Burbank on this point are clearly expressed in what I have above quoted; and Prof. Hitchcock undoubtedly regarded this mica slate as a sort of transitional rock between the gneiss below and the argillite above. Considerable portions of the mica slate, especially toward its upper border, might be properly called argillite; and much of the rock marked on the map as argillite is more or less micaceous. This gradation is apparent at most points where the two rocks approach each other and are not drift covered, but is perhaps best shown along the western border of the argillite, in Lunenburg, Leominster, and Sterling; where, according to Mr. Burbank, it is well-nigh perfect. The extensive drift deposits of this region, however, render it impossible to prove the absence of any break whatever along this line; while in the Harvard conglomerate we seem to have, notwithstanding the evidence to the contrary, a strong indication of at least a

[1] Final Report on the Geol. of Mass., p. 598.

partial interruption of the lithologic gradation between these terranes. There is no room to doubt that the conglomerate is, petrologically, a part of the argillite, being conformably interstratified with it; and farther on I shall be able to show that the conglomerate is, stratigraphically, at the bottom of the argillite, and probably marks the beginning of its deposition. Yet the fact that the conglomerate, so far as we know, reposes conformably upon and contains no material derived from the mica slate, allows us to believe that it does not indicate a very prolonged chronological break. These various rocks, of course, are not to be regarded as perfectly conformable, nor as having been deposited with chronologic continuity. They constitute a vast formation having a volume of many thousands of feet, and probably represent, in their deposition, a lapse of time comparable with such more modern periods, as the Cambrian, or Silurian, or even perhaps with the whole Paleozoic era. Hence it seems only reasonable to expect to find in portions of the Montalban series indications of more or less irregular and discontinuous deposition, — stratigraphic and chronologic breaks of magnitudes comparable with those characterizing the newer formations named.

Unique evidence pointing toward the integrity or unity of this series is afforded by a comparison of the textures of the various rocks composing it. It will have been observed that, in passing from the granite to the gneiss, from the older, indigenous gneiss to the newer varieties shading into mica slate, from the older to the newer varieties of mica slate, and from these to the argillite (omitting the Harvard conglomerate), we proceed constantly from coarser to finer grained rocks; the extremely coarse, porphyritic granite and the fine-grained, impalpable argillite constituting the extremes of a series which is both mechanical and chronological. This formation, viewed as a whole, presents a regular, graded series of textures, which is exactly coincident with the order of sequence of the rocks to which the textures belong.

That the Montalban rocks of this region, with the exception of the endogenous granite and limestone, are mainly of mechanical origin, may be regarded as highly probable; and I am inclined to consider that the coarser texture of the older members of the series is not in general, so far as the mere coarseness is concerned, to be regarded as due to their greater age and consequent greater metamorphism and more crystalline character, but rather as an indication that these were *originally* the coarser-grained rocks; the coarse gneisses and schists, at the time of their deposition, probably bearing the relation to the finer-grained, newer rocks — mica slate and argillite — of conglomerate and sandstone to slate. I realize to how great an extent the last statement clashes with the views held on this subject by many geologists. It is not intended, however, to deny *in toto* the existence of chemically deposited gneisses. Such gneisses probably exist; but the facts that have been observed in this region by Mr. Burbank, Prof. Hitchcock, and other geologists, do not favor the conclusion that the gneisses of Eastern Massachusetts are all or principally of this sort. The mechanical origin of the argillite and much of the mica slate is sufficiently obvious, and requires no special proof. In the Harvard conglomerate, moreover, we have evidence amounting to a demonstration that the argillite was deposited after the manner of more recent rocks; and since the argillite and mica slate are so conformable with, and pass so insensibly into, the underlying gneisses, the conclusion is suggested, that these too, though differing more widely than the other rocks named from any modern sediments, have shared the same origin. Fortunately we seem to have better evidence than that derived from analogy. I refer particularly to the narrow belt of altered slate and conglomerate in Bellingham. This limited band, which was described by Prof. Hitchcock under the head of "metamorphic slate," is of especial interest here as throwing some light upon, or at least suggesting new views concerning, the origin of a portion of our crystalline schists. Its petrological relations to the gneiss will be best shown by a brief sketch of the stratigraphy of that section of the State.

The axis of a well-marked anticlinal extends from the south-west end of the Concord and Westborough peninsula of Huronian beds through Grafton, Milbury, Sutton, and the western part of Douglass to and along the western border of Rhode Island. West of this somewhat curving axial line the gneiss dips to the W. and W.N.W. at angles varying from 25° to 75°, passing beneath the Worcester and Webster belt of mica slate, which lies in a closed synclinal. On the east the prevailing dips are to the E. and E.N.E.; and the anticlinal is less steep in this direction, the inclination of the strata falling, usually, between 25° and 50°. Crossing this eroded anticline from the crest eastward, we pass, of course, as on the west, from older to newer rocks. Beginning in Douglass, for instance, with the coarse, granitic, frequently but little micaceous and often apparently unstratified gneiss, which forms the base of our Montalban, we pass up gradually, in Uxbridge, to gneiss which is more micaceous, and distinctly stratified in thin beds, with now and then a layer of true mica slate. While still higher, in Blackstone, we find fissile gneisses, rich in mica, alternating with and gradually giving place to mica slate and quartzite; mica slate being the prevailing rock in the eastern half of this town. Although this Blackstone mica slate is less easily separable from the underlying gneiss than the great mica slate formation of the Merrimac, Nashua, and Blackstone Valleys, so much so that it can hardly be mapped as a distinct lithologic belt, yet I am obliged to regard it as occupying essentially the same horizon, and as being, in a general way at least, the stratigraphic equivalent of the mica slate on the west side of the anticlinal, in Webster and Oxford.

The mica slate seems to pass gradually upward into and to be continuous with the "metamorphic slate," which begins in the eastern part of Blackstone, near Mill River, and extends into the western edge of Franklin, showing at most points E. or E.N.E. dips of 20° to 40°, and having a breadth of about three miles. On the line of the New York and New England Railroad it is met abruptly on the east by coarse, granitoid gneiss with a steep north-east dip, which appears to be the lower portion of the Montalban brought up by a fault. Beyond this, just west of Wadsworth's Station, and a little farther east than represented on the map, we cross the Huronian border. The contact is not seen here, but farther south, in West Wrentham, the "metamorphic slate" belt swings to the east and meets the Huronian granite, which is clearly eruptive through it, showing that these altered rocks, although dipping toward the Huronian, undoubtedly belong to a newer system. There is evidence of extensive vertical movements all along this part of the Huronian boundary.

According to Hitchcock and Jackson the belt of altered rocks is traceable southerly as far as Providence, Rhode Island, or beyond, though the conglomerate character, to which it owes its chief interest here, is less pronounced in that direction; and the micaceous, chloritic, and quartzitic beds in Smithfield and Cumberland, mentioned on p. 128, which clearly underlie this belt, may, with much probability, be connected with the mica slate, etc., of Blackstone. Toward the north the rocks in question cannot be followed much if any beyond the northern line of Bellingham, giving way to gneiss in that direction.

The so-called "metamorphic slate" of Bellingham, which we have now located stratigraphically, begins on the west as a well-marked hydro-mica slate, alternating repeatedly with beds of sandstone and conglomerate, which are also more or less micaceous, the sandstone and smaller-grained conglomerate, especially, being, on this account, often with difficulty recognized as such. The best exposure of this part of the series which I have seen is in a cut on the New York and New England Railroad (main line) a short distance east of Mill River and near the eastern boundary of Blackstone. Farther east the formation appears to undergo a gradual change toward argillite, becoming at once less micaceous and less conglomerate; and the highest beds observed are a very good argillite, though still slightly micaceous.

The facts seem to warrant the correlation of these argillaceous beds with the argillite of the Nashua Valley. If this is done, then it is clear that the conglomerate portion of the Bellingham series is the stratigraphic equivalent of the Harvard conglomerate; the conglomerate in both cases coming between the mica slate below and the argillite above, and not being well marked off from either. As in Harvard, so in Bellingham, the most of the conglomerate has suffered more or less extensive alteration; and this brings us back to the main point, viz., to the bearing of these altered rocks, in the last-named town especially, on the origin of the underlying schists and gneiss. In this connection, the interest attaches chiefly, though not entirely, to the conglomerate.

The metamorphic process here is substantially the same as that which has been so fully described and illustrated by Prof. Edward Hitchcock,[1] in connection with the conglomerates of Plymouth and Wallingford, Vermont, and Newport, R.I.; also by Mr. George L. Vose,[2] as characterizing the conglomerate in the vicinity of Rangely Lake, in Maine; and, later, by Mr. L. S. Burbank,[3] in his researches on the Harvard conglomerate. It consists essentially, in every case, in the flattening or drawing out of the pebbles into thin, lenticular layers, which interlace and give rise to a distinctly schistose structure. The deformation of the pebbles, in Bellingham at least, is an undeniable fact; and no one who has seen the rock will hesitate to admit it. In this locality, however, it is quite evident that the metamorphism has been mainly a drawing-out or stretching, rather than a flattening process; it is as if the pebbles had experienced an endwise pull, instead of compression by a force exerted in one direction only. The typical form of the distorted pebble is not a lenticular layer, but a spindle-shaped rod, which is sometimes nearly cylindrical or prismatic, and usually presents transverse sections of similar shape in all parts of its length. The pebbles are all elongated in the same

[1] Am. Jour. Sci. (2), xxxi., 372.
[2] Memoirs Bost. Soc. Nat. Hist., i., 482.
[3] Proc. Bost. Soc. Nat. Hist., xviii., 224.

direction, and this is invariably parallel with the strike of the beds, which, as already stated, are inclined to the E.N.E., 20° to 40°. The structure is such that any vertical surface cutting across the strike affords the aspect of a normal conglomerate, the pebbles exhibiting no sensible deformation; while on any surface parallel with the strike, whether in the plane of the beds or cutting them at any angle, there is nothing to suggest the real nature of the rock; for, viewed in this manner, it shows no trace of pebbles, but only a beautiful schistosity, resulting, apparently, from the interlacing of thin lenticular layers of various colors and diverse composition; although, as stated, on the cross-section these seeming layers are seen to be rods.

This curious structure clearly admits of but one explanation: viz., the horizontal force which folded the strata, and operated in a direction at right angles to the strike, has been accompanied by a sensibly equal vertically acting force or pressure, and, under the combined influence of these, the beds, and likewise their constituent pebbles, have been squeezed out in the direction of least resistance, or parallel with the strike. Occasionally one may see a pebble of epidote or other refractory material which has successfully resisted the drawing or squeezing-out process, and is now enveloped by the lithologic strings resulting from the deformation of the more yielding adjacent pebbles, which are wrapped about it so as to conform closely with its surface. The pebbles are all well rounded, and consist largely of quartzite, though granite, diorite, petrosilex(?), and chloritic, slaty and epidotic rocks and epidote are represented in their composition. I have seen no pebbles which seemed to have been derived from a micaceous rock; and for the most part they have a Huronian rather than a Montalban aspect. That the pebbles are *real* pebbles, and not concretions of any sort, is shown by the forms of those that retain their original outlines, by their varied composition, and by their textures.

Every pebble is enveloped in a layer of micaceous material, and the original paste is to a great extent replaced by this mineral, which it seems necessary to regard wholly as a product of the alteration which the rock has undergone. During the elongation of the pebbles, or subsequently, while they were yet subject to the action of the mechanical and chemical forces by which their forms were distorted and constitutions altered — for, as Prof. Hitchcock has distinctly pointed out, there is little room to doubt that the conditions were favorable for chemical change, and that there must have been considerable interchange of material, especially alkalies, among the pebbles, and between the pebbles and paste, — the material of the more feldspathic pebbles appears to have passed from the compact or granular to the crystalline state. It is certainly conceivable that forces competent to develop a schistose structure in a conglomerate largely composed of pebbles of quartzite, granite, and epidote, might induce conditions favorable for the partial crystallization of the semi-plastic materials.

Briefly stated, the transformation, where complete, appears to be as follows: the pebbles, as such, disappear, leaving a schistose or foliated structure; the greater part of the paste, and probably a portion of the pebbles, are converted into a distinct mica or hydro-mica; and, finally, crystalline feldspar and vitreous quartz appear in the substance of some of the original pebbles. Thus the pudding-stone is changed to something which is not easily distinguishable from a coarsely schistose,[1] micaceous gneiss, such as abounds in the neighboring towns of Blackstone, Mendon, and Uxbridge. And it is highly interesting to observe that these same gneisses possess some of the most striking structural peculiarities of the altered conglomerate. For instance, I have repeatedly observed in the gneiss that a transverse vertical section shows no schistosity, no stratification, only a coarse, granitoid aspect; while on a strike section the schistose structure stands out promi-

[1] I employ the term *schistose* here, as elsewhere throughout this work, as a name for the texture which a rock possesses when composed of limited, lenticular, and overlapping layers; although I am aware that most geologists give the word a different and wider meaning, allowing it to stand as a general name for the texture of any distinctly stratified, crystalline rock.

nently, which shows that in the gneiss, as in the conglomerate, the mica, feldspar, etc., are not in layers, but strings. On account of possessing this semi-fibrous structure, the dip of the gneiss is not always easy to determine. Simultaneously with the alteration of the conglomerate to a gneiss-like rock the arenaceous and argillaceous beds are changed with less difficulty to quartzite and mica slate; though it is likely that much of the true argillite must always remain essentially unaltered, being, for chemical reasons, insusceptible of metamorphism.

As already remarked, conglomerates exhibiting extensive alteration are known to occur at many points throughout New England; and the number of these localities will probably be increased by more extended and careful observation. These conglomerates are probably of several different ages; and yet the metamorphic process appears to have been substantially the same in every case. As a rule, the altered conglomerate is closely associated, geognostically, with gneiss or mica slate; and in every such instance the product approximates to one or the other, or both of these rocks. All observers agree that these remarkable passages of sandstone and conglomerate toward mica slate and gneiss are due to alteration and not to derivation; there can be no doubt on this point. And yet, as previously stated, the gneiss-like products of the alteration of the conglomerate are frequently difficult to distinguish from the schistose gneisses forming a large part of this great gneissic formation. Such identity in the effects seems to imply similarity in the causes, some community of origin; and I am somewhat inclined to regard the small area of semi-crystalline rocks in Bellingham as essentially a part of the gneiss and mica slate formation, and to see in the more conglomerate portions an indication of the condition of a large part of our schistose gneisses at some time in the remote past, — a small sample arrested in its development, and now available as a key to the origin of thousands of square miles of crystalline rocks.

To recapitulate briefly, we may say, concerning the genesis of our Montalban rocks: the argillites were deposited as such, and have suffered little alteration; the mica slates, especially the finer-grained varieties, have been derived from slaty rocks which differed from the existing argillite chiefly in containing a larger proportion of alkalies, and being in consequence more susceptible of metamorphism; the coarse-grained mica slate, the quartzite, and the evenly bedded, laminated gneisses may probably be referred back to uncrystalline deposits analogous to sandstone; while the coarse, schistose gneisses, which are frequently no more crystalline than the finer-grained varieties, have possibly resulted, in some instances at least, from the extreme metamorphism of conglomerates. We should thus find that the cycle of sedimentation so constantly recurring in the deposits of later ages is exemplified, and that, too, on a grand scale, among these ancient crystallines. This conclusion accords perfectly with the conditions that, we have reason to believe, presided over the deposition of sediments in the Montalban seas; for certainly there is nothing in our knowledge of the past history of the earth to warrant the supposition that the process of sedimentation was materially different during Montalban time from what it is now. For long ages, viz., since the beginning of the Laurentian era, the ocean had been, chemically and physically, sufficiently near its present *status* to permit the deposition of vast beds of limestone, and the existence of vegetable and, probably, animal life. It is simply impossible to believe that the action of such a sea upon the land — for land must have existed during this period, and, probably, in masses of continental extent — did not result then as now in the formation of conglomerate, sandstone, and slate. As before stated, the slates, little altered, now appear as argillite and mica slate; the sandstones are reasonably accounted for in the form of quartzites and laminated gneisses, and, probably, some of the finer-grained schistose gneisses; but the conglomerates, which, with the rare exceptions noted, cannot now be found, offer greater difficulty, unless we admit that, if not the only, they have been, through their metamorphism, a common source of the coarse schistose gneisses. And since the Montalban seas, in common with the seas of all ages, must have formed — and, as the existing remnants testify, actually did form — conglomerates; and in view of the facts already cited concerning the alteration of this class of rocks, what conclusion is more natural?

The chemical gradation shown to exist in the rocks of the Huronian system is repeated in our Montalban strata, the proportion of the alkalies potash and soda steadily diminishing as we proceed from the granite and gneiss, at the base of the series, to the argillite at the top; and there is very evidently, as pointed out by Dr. Hunt, a concomitant decrease in the capacity for metamorphism which the various rocks possess.

In this and the succeeding paragraph I have stated briefly the main points in the evidence which the stratigraphy of this region affords that the rocks here designated as Montalban are newer than the Huronian. A glance at the map will show that the geographic disposition is such that, in going from the older Montalban rocks to the newer, from the gneiss to the argillite, the passage is away from the Huronian. In other words, the only Montalban strata in contact with the Huronian are, generally speaking, those forming the base of this system, — the granite and granitoid gneiss; and at most points, viz., everywhere between Salisbury and Natick, we find this Montalban base in contact with the rocks that we have learned to recognize as the summit of the Huronian. This is certainly a strong indication of the more recent age of the Montalban, and it becomes stronger when we observe further, that from Salisbury to Westborough the gneisses dip away from the Huronian diorites, appearing to overlie them. This point is offset, however, by the contrary dips which obtain further south and in the Buzzard's Bay region. Still it is now generally recognized by geologists that rocks may, and often do, dip toward older formations. The Triassic sandstones of this State are a good example among newer rocks. In the west part of Wrentham, as already stated, the Huronian granite has been extravasated through schists that appear to be Montalban.

The fact that our Montalban strata are farther removed than the Huronian from the axis of this region, as represented by the Naugus Head series, is, I am persuaded, of some value as an indication of their more recent formation. The rocks of the Naugus Head series and the granite to the south of Boston, are not only, as I conceive, in the stratigraphic axis of this region, but they unquestionably represent the centre or axis of disturbance for a large territory. We have seen how the disturbance of the Huronian beds gradually diminishes from Boston harbor north-westerly, and this gradation is continued without interruption across the entire breadth of the Montalban to the argillites of the Nashua Valley. The line connecting Hingham and Shirley, or, what is the same thing, the line joining the oldest Huronian and the newest Montalban, begins in the most and ends in the least disturbed rocks of these two systems, and there is a regular gradation between them. In fine, it must be in the experience of all observers in Eastern Massachusetts, that the Montalban terranes exhibit on the whole vastly less disturbance than the Huronian; and that, as a rule, this disturbance diminishes as we recede from the Huronian border. Distinctly and evenly stratified rocks are the rule in the Montalban formation, and the exception in the Huronian.

STRATIGRAPHY OF THE NASHUA AND MERRIMAC VALLEYS.

Since the days of the elder Hitchcock it has been known in a general way that the Nashua Valley is a synclinal; but the careful studies of Mr. Burbank in the middle portion of this basin have greatly advanced our knowledge of the relations of the rocks, and furnished the key to a better notion of the structure of that entire region than has heretofore existed. The principal facts bearing on this problem are as follows: Between the western boundary of the Huronian formation and the mica slates of the Nashua Valley, in the northern part of Middlesex County, the gneiss all dips to the W.N.W.; the amount of the dip varying from 50° or less to vertical. There are, as is clearly shown on the map, three N.–S. bands of mica slate in the Nashua Valley, each of which dips steeply to the west. Between the first and second of these belts, reckoning from east to west, is a long and narrow range of granite and granitoid gneiss; while a broad band of argillite, which has also steep westerly dips, separates the second and third belts of mica slate. Between the first range of mica slate and the granite, in Harvard and Bolton, lies the narrow strip of conglomerate and argillite — conglomerate on the east and argillite on the west — already described under the head of argillite. This, like all the preceding, dips to the west. West of the third range of mica slate is a broad expanse of gneiss, which, along its eastern border, dips gently, 15°–25°, to the east; and resembles, in its essential lithological features, the gneiss of Middlesex County.

From Concord to Leominster, as just explained, a steep, westerly dip is almost universal; and, apparently, this great breadth of strata, from the oldest gneiss to the newest argillite, passes beneath the, lithologically, equally ancient-looking, but nearly horizontal, gneiss of the Wachusett range. It would be difficult to believe that the argillite is older than the Wachusett gneiss, and this consideration, together with the fact that the mica slate occurs on both sides of the argillite, long ago suggested the notion that these rocks form a huge, closed, synclinal fold with its axial plane dipping to the west. According to this view, the broad band of argillite is a stratum, apparently not less than 10,000 feet thick, folded sharply upon itself, forming the centre of the synclinal. Enclosing the argillite is a stratum of mica slate, forming, by its outcrops, the second and third bands of that rock; while the gneiss on the east of the valley is stratigraphically equivalent to that on the west, forming the outermost and deepest layers of the synclinal. At the contact of the third band of mica slate and the gneiss on the west, there is, as already indicated, an abrupt change of dip; the slate dips steeply to the west, while the gneiss has gentle eastward dips. This may be considered as proving the existence of a fault on the west side of the synclinal. The downthrow was to the east; and the high range of hills, of which Wachusett forms the culminating point, is possibly a remnant of the grand escarpment produced by this dislocation of the strata, marking the point where the downthrow was greatest. This great stratigraphic break is clearly indicated in the east-west section across the central portion of the State, forming part of plate 54 in Prof. Hitchcock's Final Report on the Geology of Massachusetts.

The common boundary of the first band of mica slate and the narrow band of granite and granitoid gneiss, on the east side of the valley, marks the position of a second great fault, parallel with that just described. Here, also, the downthrow was to the east, and has been sufficient to cut off very obliquely a great thickness (4,000 or 5,000 feet) of mica slate and bring the underlying gneiss up to the present plane of denudation. The lateral displacement produced by this fault has not been less than a mile, being measured by the distance between the centres of the first and second bands of mica slate; these two bands having, prior to the fracture, formed a single continuous stratum, which, as already stated, is the stratigraphical equivalent of the third band. The apparent thickness of the mica slate is less than one-third as great on the east side of the argillite as on the west. This enormous expansion may be due to the inaccurate determination of boundaries, since the argillite, on the west especially, passes rather insensibly into the mica slate; or it may result from subordinate faults or folds, yet undetected, involving the mica slate alone. The second fault probably extends as far south as Worcester. Northward it cuts the rocks a little obliquely, so that near the southern line of Bolton we find it leaving the western boundary of the first band of mica slate and passing to the westward of the attenuated southern end of the Harvard and Bolton belt of argillite and conglomerate.

Pl. 3, fig. 1, represents a general section of the Nashua synclinal, beginning in the central part of Bolton, and extending through Lancaster and Sterling to Mt. Wachusett in Princeton. It shows the probable relations of the rocks, the positions and direction of the faults mentioned, and especially the way in which the second fault has duplicated the mica slate on the east side of the syncline. To the north of this section the line formed by the intersection of this fault and the present surface follows the western side of the strip of argillite and conglomerate to its termination near Harvard centre. This isolated mass of argillite is the key to the structure of the whole eastern side of the valley. It is clearly a small slice cut off by the granite from the great mass of argillite on the west, with which it is unquestionably identical, lithologically. In its present position, conformably overlying the first band of mica slate, it affords an accurate measure of the horizontal displacement resulting from the fault, and proves conclusively the stratigraphic equivalence of the first and second bands of mica slate. Of course, the assertion that the conglomerate, in its normal position, conformably underlies the great mass of argillite unavoidably raises the question as to why it is not found in that relation in other parts of the valley. Why is not this parting of conglomerate found in every section across the common boundary of the argillite and mica slate? The answer is, that, in the first place, the conglomerate is thin and may be of local extent; secondly, these rocks are so extensively drift-covered that the precise boundaries are rarely seen; and, thirdly, evidence is not wholly wanting of the occurrence of the conglomerate at other points in the valley. Mr. Burbank has observed, in the drift near the city of Worcester, boulders of conglomerate identical with the conglomerate of Harvard; and yet, if transported by glacial action, these boulders could not have been derived from the Harvard belt, but must have come from some point as far west as the western border of the argillite. Along the geological boundary just mentioned, in Lunenburg and Leominster, the same observer has also found a rock *in situ* which appears to be an altered conglomerate.

Beyond the northern boundary of Bolton the second or middle band of mica slate disappears, but reappears five miles farther north, near the common boundary of Harvard and Ayer; and the granite, which begins to widen here, is brought, by the disappearance of the mica slate, in contact with the argillite on the west, being bordered by argillite on both sides in this part of its course. Unless the mica slate has actually thinned out to nothing here, which is impossible, because the displaced portion of the same bed only one and a half miles to the east is 4,000 or 5,000 feet thick, we can only account for this contact of the granite and argillite by assuming the existence of another fault, with the downthrow on the west. This fault probably commences in the northern part of Bolton, where the middle band of mica slate begins to disappear; but only after it enters Harvard does the downthrow become sufficient to carry all the mica slate below the present surface. The probable relations of this fault to the strata which it cuts and to the fault on the east side of the granite are shown in Pl. 3, fig. 2, which represents a section across the valley parallel with the first section, but five miles farther north, cutting the conglomerate near Harvard Centre.

It is now clear that the mica slate of the middle belt, in Harvard, was carried up on the wedge of granite and gneiss, and has been removed by denudation. The fault on the west side of the granite is much shorter southward than that on the east, and the downthrow attending it appears to have been less. These two faults account perfectly for the present relative positions of the granite, mica slate, argillite, and conglomerate, in this part of the valley; and in the great disturbance, of which these fractures are an index, we find a probable cause for the alteration of the conglomerate and the conversion of much of the gneiss along this line into granite. There are abundant indications that some of these rocks were in a yielding condition at the time of their disturbance; and Mr. Burbank is probably right in insisting that the complication of this region is largely due to ill-defined, vertical movements of partially plastic materials, rather than to well-marked faults in rocks essentially rigid.[1]

In passing through Harvard and Littleton, the first band of mica slate sweeps around to a north-easterly course, parallel with the Merrimac Valley; and beyond Harvard the dip is to the north-west. The second band of this rock, reappearing in the north part of Harvard, widens rapidly northward through Ayer and Groton, until it meets the gneiss in southern Dunstable; here it divides into two branches, the principal of which continues due north, with westerly dips, into New Hampshire, while the other strikes a north-east course, running parallel with the first band to and probably across the Merrimac. The two parellel bands of mica slate here indicated as diverging in a north-east direction from the main Nashua synclinal, and extending, the one from Harvard to Lowell, and the other from Ayer to Tyngsboro', dip toward each other, forming, as Mr. Burbank has pointed out, a well-marked synclinal. In short, the first and second bands of mica slate are one and the same bed, which, from Worcester to Harvard, has a nearly uniform dip to the west; but north of Ayer it becomes warped, and instead of forming, as it were, one side of a synclinal it now forms three sides; *i.e.*, in the place of a single synclinal, we have two synclinals and an intermediate anticlinal; the great synclinal of the Nashua Valley sending off a branch to the north-east. The main or parent synclinal continues northward to the New Hampshire boundary, and then bends to the north-east, and runs through southern New Hampshire, following the north-west side of a long and narrow area of Montalban gneiss, and possibly older rocks, which begins in Dunstable. This is an anticlinal ridge, having a synclinal on either side of it. Before leaving Massachusetts the main synclinal exhibits great

[1] Concerning the structure of the region about the Harvard conglomerate, the view here proposed bears some resemblance to that previously advanced by Mr. Burbank, and wherever the two views coincide his is entitled to priority.

disturbance; it is nearly cut off, as Mr. Burbank has observed, by considerable areas of granite; and the axial plane appears to be shifted or warped so as to dip toward the east.

That the two bands of mica slate extending north-easterly from Harvard and Ayer form a synclinal is apparent not only from their convergent inclination, but also from the fact that the underlying gneiss in each case shares the dip of the mica slate. But that the two sides of the synclinal do not meet is evident from the fact that a broad belt of granitoid gneiss, an expansion of the Worcester and Dracut range, lies between them. In other words, the bottom of the synclinal has been entirely removed, exposing the underlying granite and gneiss. To raise this immense mass of the subjacent rocks to their present position and leave the band of mica slate on either side unremoved by denudation requires two faults, one on each side of the valley between the granite and mica slate, with the downthrow in each case on the side toward the latter rock. But in Harvard we already have two such faults bounding the granite; and we have only to conceive these to diverge slightly and extend north-easterly along the margins of the Merrimac synclinal, and the structure of the whole region becomes clear immediately. Pl. 3, fig. 3, represents a general section across the Merrimac synclinal from Westford to Dunstable. This section fully accounts for the absence of argillite from the Merrimac synclinal, that rock having been raised, with the most of the mica slate, far above the present surface, and subsequently entirely swept away by denuding agents. It must have required an uplift of 10,000 or 15,000 feet to raise the lowermost stratum of the mica slate above the present surface.

The mica slate on the north side of this synclinal cannot be certainly traced much beyond the Merrimac; and it seems to become quite narrow before reaching that point. This is readily accounted for by supposing that the northern line of fracture swept so far to the north as to make it possible for the present surface of denudation to cut below the mica slate. The granite and gneiss are not found in Methuen or beyond; and the faults probably unite in one, or perhaps die out, there. North-east of Dracut the synclinal is certainly known to contain only mica slate; but indications are not wholly wanting of the existence in the axis of the synclinal of conglomerate and, possibly, argillite. This part of the State has a thick covering of drift and outcrops are few, but Mr. C. W. Kempton has observed a distinct conglomerate, apparently *in situ*, in Haverhill, about midway between the Merrimac and the State line. This conglomerate appears to be identical or nearly so with that in Harvard; and, since the latter is intimately associated with argillite, I should not be surprised to hear of the discovery of argillite in the valley of the Merrimac. In fact it is well known that much of the so-called mica slate in this basin is more argillaceous than micaceous.

The striking parallelism of the principal faults of the Montalban system with those of the Huronian suggests their synchronism; and this view is strengthened by the probability already pointed out that some of these great dislocations traverse the strata of both systems.

GENERAL RELATIONS OF THE OLDER CRYSTALLINE FORMATIONS OF EASTERN MASSACHUSETTS.

The oldest and most thoroughly crystalline rocks in Massachusetts, so far as known, are those composing the Naugus Head series. This series, in its normal position, underlies all else in this region; and reposing directly upon this most ancient formation we have the Huronian system, — granites first and diorites last. The Huronian granites are to a large extent exotic, and hence are out of their normal or original position with relation to the other members of the system; but this is believed not to be the case with the large area in southern Norfolk and northern Plymouth and Bristol Counties, viewed as a whole. This immense mass of granite is the centre or axis of our Huronian series; the strata become newer as we recede from it northwesterly; and the probable existence of petrosilex on its southern border suggests the idea that the entire series, above the granite, may be repeated in that direction, though covered, for the most part, by the Montalban terranes. This theory places the granite in the axis of a vast anticlinal fold of comparatively low altitude and great breadth, and involving all the crystallines of this region. The normal position, according to this view, for the Naugus Head series, is in the axis of this anticlinal; but the erosion of the granite has not apparently been sufficient to expose it along that line. The exposure of this series farther north is due, as already explained, to a system of faults.

This great regional axis is depressed toward the south-west, allowing the Montalban strata to sweep directly across its course; the Huronian area of Massachusetts being entirely surrounded, except seaward, by rocks of Montalban age. South of the latitude of Worcester the strike of the Montalban strata gradually shifts from north-east through north-south to south-east, the terranes of this age passing with the latter strike under the Carboniferous basin and Narragansett Bay and reappearing in the Buzzard's Bay region with an east-west strike. There are good reasons, as Prof. Hitchcock long ago pointed out, for believing that Cape Cod, as far east as Brewster, and probably also the southern half of Cape Cod Bay, are underlaid by gneiss. I am of the opinion that could we trace these rocks we should find the strike bending to the north-east, having doubled upon itself since leaving Worcester, and proving the stratigraphic equivalence of the gneisses of Essex and Plymouth Counties.[1]

Although appearing to die out south-westerly, there are good reasons for believing that this fundamental axial line is continued north-easterly across the Gulf of Maine, reappearing on the shores of the Bay of Fundy and, possibly, in Newfoundland. The Naugus Head series is represented in New Bruns-

[1] In the second volume of the recently published Report on the Geology of New Hampshire, page 23, Prof. C. H. Hitchcock has described a substantially similar concentric arrangement of the crystalline formations of south-eastern New England, having the petrosilex and granite adjacent to the Boston basin as a centre or nucleus.

wick by the Laurentian and Norian deposits of that province, and by the same formations in central Newfoundland. The Huronian is well developed about and upon these more ancient terranes in Newfoundland, and, likewise, in New Brunswick; and rocks clearly recognizable as Huronian occur at intervals along the coast of Maine, serving to connect those last mentioned with the well-known area in Eastern Massachusetts. There is a broad Montalban belt which extends without interruption from Long Island Sound, along the north-west side of the Massachusetts Huronian, through New Hampshire and Maine, to New Brunswick; and rocks of this age appear on Newfoundland, between the Laurentian rocks in the middle of the island and the Paleozoic along the western coast. Crystallines having Montalban characters are well developed over the south-eastern half of Nova Scotia; and these, I venture to suggest, may be continuous, along the submarine ridge already pointed out (*ante*, p. 7), with the Montalban of south-eastern Massachusetts.

Here, then, we have, indistinctly outlined, the great ge-anticlinal, the erosion of which has given rise to the Gulf of Maine. The eastern side of this eroded anticlinal, borne beneath the waves, is represented by the submarine ridge connecting Newfoundland and Nova Scotia with Cape Cod. The erosion of the Gulf of Maine was substantially complete before the beginning of Paleozoic time, and this fact alone shows that an enormous period elapsed between the close of the Montalban era and the deposition of our Primordial slates.

SHAWMUT GROUP.

The rocks included in the Shawmut group are those commonly known in the vicinity of Boston as the breccia and the amygdaloid. They are found chiefly within a radius of ten to fifteen miles of Boston, but occur also on Marblehead Neck and the neighboring islands and in the basin of the River Parker. They are everywhere seen to repose unconformably upon the upturned or extravasated Huronian terranes; and in the case of the breccia, at least, their derivation from the Huronian series is beyond question. Looking in the opposite direction we find the Shawmut group, in its turn, overlaid by the Primordial strata of Eastern Massachusetts and contributing very largely to the formation of the conglomerates of that age. In fine, the Shawmut group is newer than the Huronian and older than the Primordial; and that it belongs, in *time*, nearer the latter than the former we have abundant evidence. It has never been observed in contact with Montalban rocks, but I think no doubt can rest upon the view that it is newer than that great and truly crystalline series; for it is clear, as already stated, that the Gulf of Maine was eroded mainly, if not entirely, after the deposition of the rocks of Montalban age, and of course the erosion of this gulf must have preceded the formation of rocks now resting unconformably upon its floor, as do both the Shawmut and Primordial groups. The very general absence in the Shawmut group, as will presently appear, of crystalline characters, is, too, a strong indication that it post-dates the Huronian and Montalban systems. We have come, apparently, to a zone of debatable ground between those two grandest divisions known among the geological formations, — the crystallines and the uncrystallines.

Subsequently to the erosion of the Gulf of Maine, and after the sea, which stood at a higher level, relatively, than now, feeling its way between the Natick and Cape Ann granite range on the north, and the granite of Cohasset, Hingham, and Quincy on the south, had excavated Boston Harbor with a maximum breadth of nearly twenty miles, and with its head in South Natick or farther west, and at a time when the similarly formed but much smaller basin of the River Parker in Newbury was open to the sea, were deposited the breccias and slaty rocks of the Shawmut group; the last-named rocks becoming by subsequent alteration the amygdaloid of the present day. According to the evidence afforded by this region these were the first sediments laid down in this part of the Gulf of Maine, and their occurrence in the minor basins above indicated shows that at that early day the gulf had very nearly its present outline. Following these deposits, after a "lost interval" of unknown, but probably great, duration, came the conglomerates and slates now recognized as belonging to the Primordial horizon; and the Paleozoic era was fairly ushered in. Extensive denudation and the deposition of more recent sediments have conspired to obliterate the surface exposures of the Shawmut group, and hence this formation is found now only in limited and isolated areas, which lie, for the most part, along the common border of the crystallines and the Primordial system; the stratigraphic relations of the group being well expressed in the geographic distribution.

With regard to the mutual relations of the two principal constituents of the Shawmut group — the breccia and the amygdaloid — the evidence is not so clear. I have been unable to fully satisfy myself as to whether the breccia underlies the amygdaloid, or *vice versa*. These rocks occupy areas which are for the most part quite distinct, and we have little evidence of their synchronism save what is afforded by their relations to the subjacent and superjacent formations. They both, as already pointed out, represent a horizon above the Huronian and below the Primordial. At several points, which will be specially noticed in the descriptions that follow, I have observed indications, more or less plain, of a gradual lithologic passage between the breccia and amygdaloid, and this inclines me to the view that they are strictly cotemporaneous deposits; slate in the deeper water and breccia in the more shallow being formed at the same time. On the other hand I find that the amygdaloid has contributed far more material than the breccia to the formation of the Primordial conglomerate, — a circumstance which appears to favor the view that the amygdaloid is the newer rock; and in this case we might regard the breccia as the lower and the amygdaloid as the upper part of the same continuous formation, the lithologic passage supposed to exist between the two divisions being vertical instead of horizontal.

I have already indicated (see under petrosilex) that the term breccia is not descriptive of all the rocks here included under that name, which is employed in a geologic rather than a lithologic sense, designating a group of rocks, and not a single type only. The fragments in the breccia are often sufficiently rounded to warrant calling them *pebbles* and the rock *pudding-stone;* so that there is a certain propriety in using the terms fragment and pebble without discrimination, as I have done in the following descriptions. The breccia is everywhere highly feldspathic, being almost entirely composed of the débris of petrosilex; and the fragments are always firmly imbedded in the paste; the latter, however, weathers more readily than the former. The intricate and puzzling relations of this breccia group to the Huronian petrosilex have also been sufficiently noticed. Most observers of these rocks have regarded the amygdaloid as an eruptive; but I am well satisfied that it has played this rôle only as the exception and not as the rule. Many instances of apparent extravasation are due to faulting; and I see no room to doubt that this is essentially a stratified rock. Indubitable evidence of the extravasation of the amygdaloid is wanting save where it cuts through the conglomerate, as in Brighton and some other places; and, since it is certain from the abundant enclosure of amygdaloid pebbles in the conglomerate, that the former was the surface rock during the deposition of the latter, the inference is plain that, where exotic, the amygdaloid is not far removed from its original seat. As in the case of the breccia, the name of this second division of the Shawmut group is little descriptive; for only a small proportion of the rock here included is a true amygdaloid.

DETAILS OF THE SHAWMUT GROUP.

Shawmut Group in Newbury. — The rocks of this age in the basin of the River Parker belong chiefly to the amygdaloid division. This type is extensively developed over the southern half of Kent's Island, and the exposures are good. It is rarely distinctly amygdaloidal, but is usually compact, of a dull greenish color, and slaty appearance. The bedding is frequently quite distinct, and the ledges trend in a direction parallel with the strike, N.E.–S.W. to E.–W. The dip is always northerly and steep; and there is little evidence of extravasation. Much of the rock is decidedly chloritic, and might be properly called a massive chlorite slate. The chlorite sometimes occurs in minute, scale-like layers. Small strings and patches of epidote are common. At several points on Kent's Island, and likewise along the railroad, on the south side of the River Parker, the rock is of a deep purplish-brown or chocolate color, and is evidently little more than a slightly arenaceous slate. The joint surfaces of this variety are covered with chlorite and small scales of mica. Other portions of the so-called amygdaloid resemble felsite, and are perceptibly crystalline. These lead naturally into the breccia; which, however, is not certainly known to occur on Kent's Island, but is found in several small patches to the westward, near the Newburyport turnpike. The pebbles are usually quite small, and appear to be derived mainly from the red, banded petrosilex of the region. The base is compact, hard, felsitic, and of a pale greenish color. The rock sometimes affects an imperfectly schistose or banded structure, and is always distinct from the Primordial conglomerate of that district. The amygdaloid follows the course of the River Parker westward, nearly to Byfield Parish, presenting everywhere substantially the same characters as on Kent's Island. Along the Newburyport turnpike I have observed the amygdaloid at a point one-half mile south of Mill River; where it includes irregular patches of mottled green and brown, which have the aspect of petrosilex, are quite compact, and hard as jasper. East of Kent's Island the breccia and amygdaloid have been traced to the edge of the salt marshes, beyond which there are no ledges.

Shawmut Group in the Marblehead Region. — On Marblehead Neck and the adjacent islands the Shawmut group is represented by the breccia division alone. This division, however, is here exceedingly heterogeneous, comprising rocks of all textures, from an impalpable felsite to a coarse breccia holding fragments several inches in diameter. The paste is always felsitic, and is usually quite compact, though sometimes developing feldspar crystals ; these appear to be mainly, if not wholly, triclinic, and are sometimes so numerous as, when the pebbles are small or the paste relatively abundant, to give the rock a decidedly porphyritic aspect. With comparatively rare exceptions the fragments are some variety of petrosilex, such as is indigenous in this region ; in a few cases they are granitic, while others appear to be derived from the feldspathic rocks of the Naugus Head series. Magnetite is rarely, if ever, wanting in the Marblehead breccia. It is found chiefly disseminated in minute grains in the paste, seldom occurring in the pebbles ; and it is most abundant, or at least most noticeable, in the rocks of medium fineness, — the grits and sandstones. Since this mineral is of rare occurrence in the petrosilex and felsite I conclude that it may have come in part from the Naugus Head series. Pyrite is also a common mineral in certain of the breccias ; it occurs in much the same way as the magnetite, but less abundantly, and it has more the appearance of being indigenous.

On Marblehead Rock there is a distinctly stratified, non-porphyritic felsite, or felsitic slate, alternating with sandstones and grits. These beds are much broken and twisted by the petrosilex in which they are enveloped, and which is eruptive through them. Approximate strike, east-west ; dip, southerly. Lowell's Island is largely composed of a firm feldspathic sandstone of a normal and very uniform texture. Strike, N.E.–S.W. ; dip, south-east. It is on this island that the Shawmut rocks approach nearest, geographically, to the Naugus Head series ; and it is interesting to observe that this feldspathic sandstone is especially rich in magnetite. Small-pebbled breccia, in which the paste largely predominates, and which is often distinguishable with difficulty from petrosilex, occurs on the Gooseberry Islands. On Marblehead Neck a true breccia occurs at many points; but nowhere is it so well developed as in the vicinity of Castle Rock. Here the fragments are of all sizes up to two inches across, and represent every type of petrosilex and felsite occurring in the region. The larger fragments, especially, are usually quite angular, and none, so far as I have observed, exhibit any traces of distortion; but, on the contrary, as already stated, this breccia rests upon, and has been cut after the manner of an exotic by, the schistose or "flattened pebble" petrosilex, fragments of which are included among the pebbles of the breccia. Being simply the very thoroughly reconsolidated débris of petrosilex and felsite, the breccia, especially the more compact varieties, is often practically indistinguishable by the unaided vision from the parent rocks. Between Castle Rock and the north end of the Neck there is a large mass of rock which is decidedly porphyritic, and holds but few distinct pebbles; and yet, notwithstanding its compact texture and ancient aspect, it is certainly newer than the banded petrosilex on the north, and it is met and distinctly cut by eruptive, crystalline, grayish and black petrosilex on the south. A similar rock, but containing much free quartz, occurs on the north end of the Neck, and at other points. As a rule the compact feldspathic rocks of the Shawmut group have the waxy lustre and inferior hardness of felsite, rarely resembling true petrosilex.

Shawmut Group in the Lynn and Medford Region. — As in the Marblehead district, the Shawmut group in the large area between eastern Lynn and Medford, and between the south part of Malden and Wakefield, is, so far as I know, represented by the breccia division alone; with the single exception of the, in part, well-marked and beautiful amygdaloid found in Saugus Centre, on a small conical hill between the Saugus River and the railroad. This is evidently of very limited extent; but its boundaries and relations cannot be observed on account of the drift. The base of the rock is of a dull green color and slaty texture; the amygdaloidal kernels are numerous, small, have a radiate structure, and are composed of feldspar. Red Rock, on the Lynn shore, is composed mainly, if not wholly, of breccia. There are two distinct colors, brownish-red and gray. A small mass on the west side of the point has the aspect of conglomerate. Breccia is known to occur at many points in the west part of Lynn; but the areas have not been indicated on the map. The breccia of East Saugus, Cliftondale, and Franklin Park has been described, and the relations to the underlying petrosilex noted (*ante*, p. 52). The large areas marked as breccia in Wakefield, Melrose, and Malden, have been only very imperfectly explored, and it is not unlikely that they include considerable petrosilex. There are many types of breccia here, but they agree very well with those of Marblehead Neck, and are similarly related to the petrosilex. Some of the breccia in Malden and Melrose is much coarser than any that occurs in the Marblehead region; and the base is sometimes more porphyritic, though in other cases it is quite compact. Occasionally there is an obvious tendency to develop a schistose structure similar to that characterizing a portion of the petrosilex of this and other areas, but it never passes the incipient stage; and it can throw no doubt on the chronological distinctness of the petrosilex and breccia, because, as already noted (p. 75), fragments of the schistose petrosilex are included in this same breccia. Although derived mainly from the different types of petrosilex occurring in those towns, yet the breccia of Malden, Melrose, etc., holds occasional pebbles of granite and diorite. Magnetite is of rare occurrence in these rocks. The wedge-shaped area marked as breccia in West Medford includes no true breccia, but is composed of a fine-grained arenaceous and slaty rock, which resembles at different points quartzite, eurite, and felsite. The stratification is sufficiently obvious, and I have no doubt that it is a recomposed rock.

Shawmut Group in Brighton, Newton, and Needham. — We come once more to a district characterized by the Shawmut group, in which amygdaloid is the prevailing type. The large and irregular area of the rocks of this age enveloping the Huronian petrosilex in Needham, and sending tapering, finger-like extensions north-easterly through the conglomerates of Newton, Brookline, and Brighton, and south-westerly into Natick, affords breccia very locally at two or three points only. These may be conveniently described first. In Newton, south of Newton Centre and east of Upper Falls, in the angle between Dedham Street and Boylston Street, and along a new street connecting these two, I observed the following section from south to north: (1) The usual slaty amygdaloid of that region; (2) A very firm, indistinct, and slaty-looking conglomerate or breccia, holding pebbles of petrosilex (several varieties), granite, diorite, and quartzite, and with a granitic, dioritic, felsitic, or slaty paste; the pebbles are sometimes wanting, when the rock becomes a slaty felsite. In my mind, some doubt attaches to the Shawmut age of this conglomerate. (3) Primordial conglomerate of the usual type, holding pebbles of amygdaloid, and dipping to the north. (4) A true breccia containing fragments of dark-colored petrosilex and eurite, which are mostly small, and rather rare, with a greenish-white felsitic paste. This is succeeded without any marked line of division by (5) a dark purplish rock, which, though in the main of quite compact appearance, is in part a distinct and very irregular breccia, holding angular masses of quartzite and petrosilex, while in other portions there is a manifest tendency to develop an amygdaloid structure, and still other parts are decidedly porphyritic. It is apparently a transition type between the compact rocks of the breccia division and the amygdaloid. Overlying this is (6) Primordial conglomerate, most of which is exceedingly coarse. The conglomerate (3) appears to form an isolated superficial patch between the two masses of Shawmut rock.

In South Natick a band of stratified rocks follows the course of the Charles River and Elm Street from the Needham boundary nearly, if not quite, into Sherborn. The strike is N.E.–S.W.; and the whole series has steep north-westerly dips. Two distinct formations appear to be included here. On the north-west are slates and conglomerates which have been marked as Primordial; while to the south-east, and apparently underlying these, are a somewhat brecciated, though mostly fine-grained or compact, felsitic rock, and a slaty rock, evidently an incipient amygdaloid, both of which I refer to the Shawmut group. If this correlation is just, then we have here some evidence that the breccia is newer than the amygdaloid. This is not seen in their stratigraphic relations, which are rather obscure, but in the fact that pebbles probably derived from the latter rock are found in the former. I traversed this ground very hastily, and am not confident that the foregoing interpretation of the facts is quite correct. One and one-half miles east of Charles River Village, and just north-west of where the road turns south to the river, there is a small patch of breccia. It contains numerous angular, usually large, irregular fragments of the surrounding petrosilex, and the paste is the same material more finely comminuted.

The amygdaloid of the large area under consideration presents too many varieties to admit of proper description in one general definition. It is rarely amygdaloidal, and nowhere more perfectly so than at the well-known localities in Brighton. The amygdules, here, are of pretty uniform size, the majority varying from 2 mm. to 5 mm. in diameter. The minerals most commonly found in these are epidote, quartz, chlorite, and calcite, though baryte, gypsum, chalcopyrite, hematite, and orthoclase are also believed to occur; several minerals, especially the first two named above, are frequently concentrically arranged in the same kernel. Besides the proper amygdules, these minerals form many exceedingly irregular and vein-like masses, traversing the rock, sometimes for a distance of several feet. The Brighton amygdaloid also contains numerous minute segregated masses of jasper. These are usually marked by various shades of lighter and darker red, brown, yellow, etc., in parallel, horizontal bands, after the manner of onyx; appearing to be essentially identical in this, as in other respects, with the banded jaspery concretions in the brecciated petrosilex of Hyde Park. (See *ante*, p. 84.) Rocks which it seems necessary to regard as belonging with the amygdaloid are sometimes decidedly arenaceous, ranging from a distinct sandstone to a slightly micaceous quartzite. These may be observed one-half mile south-east of Auburndale Station in Newton, and at the corner of Lake and Washington Streets, Brighton. At the latter place, however, the sand rock may belong with the conglomerate.

In Brookline and the southern part of Newton, especially, the amygdaloid has frequently in some degree the aspect of felsite or petrosilex, though never attaining the hardness proper to these. At the corner of Newton and Vine Streets it holds free quartz in a finely divided state and minute crystals of feldspar. To the west of this, on Nahanton Street, the rock is a dark purplish slate, very compact. On Newton and Hammond Streets, in Brookline, it is of various shades, purplish, brownish, and dark-green, and very generally semi-brecciated, resembling the felsitic rock in the section described on p. 171. The northern amygdaloid area in Newton is largely composed of a compact epidotic rock characterized by greenish tints. At one point at least this rock is interstratified with a mottled greenish and brownish argillite; while in certain directions it passes gradually into a less epidotic variety, which is quite massive and decidedly porphyritic.

The amygdaloids of this district are rarely quite free from epidote; in Needham, however, the chloritic character prevails. Exposures are wanting over most of the area marked as amygdaloid in this town, but the rock can be seen to good advantage along the roads running east and west from Charles River Village, and on the line of the Sudbury River aqueduct, about one mile W.S.W. from Newton Upper Falls. In both places the amygdaloid is traversed locally by small parallel and intersecting veins of a brown, jaspery material in such a way as to give it quite the aspect of a breccia. In the aqueduct cutting, also, I have observed small irregular patches of a white jasper in the greenish, slaty matrix. The relations of these rocks to the conglomerate are often very puzzling. The amygdaloid pebbles in the conglomerate, however, make it impossible that any doubt should arise as to the true sequence of the two formations.

Distinct stratification is rarely met with in the amygdaloid of this district. And yet the very evident slaty structure observable at most points; the parallelism of the areas with the strike of the conglomerate, a feature often noticeable, too, in the disposition of the individual outcrops; the general uniformity in the lay of many of the ledges, on both a large and small scale, indicating a nearly constant dip; and the paucity of indubitable evidence of extravasation, convince me that, considered as a whole, this must be regarded as essentially a stratified rock.

Shawmut Group in Dedham, Hyde Park, Dorchester, and Milton. — The breccia in West Dedham has been described, *ante*, pp. 80–81. The rocks of this age in the other three towns named above may be conveniently and properly regarded as forming one large irregular area, since, as a matter of fact, they would do so but for the overlying conglomerate. Both divisions of the Shawmut group are found in this area, and they are of approximately equal extent. The amygdaloid occurs mainly on the east side, and the breccia on the west side, of the New York and New England R.R.; and there are indications along the line of this railroad of a lithologic passage from the one division to the other. The breccia here is very variable in texture and color, and is often distinguishable with difficulty, if at all, from the petrosilex, especially if the latter rock is of either the schistose or brecciated varieties, for the schistose structure cannot be regarded as wholly foreign to the breccia. (See under petrosilex.) To the westward of the Boston and Providence R.R., and south of West Street, it is doubtless more abundant than represented on the map. East of this railroad, however, I have marked only a few of the many islands of petrosilex occurring in the breccia,—knobs and bosses of the underlying, but evidently not deeply buried, formation, which erosion has exposed to observation.

Other islands in the breccia are formed of conglomerate, small remnants of a once continuous sheet which erosion has failed to entirely remove. Mr. F. W. Very and I have observed exposures here in which the three formations — petrosilex, breccia, and conglomerate — can be clearly seen resting in uncomformable position one upon another in the order named. Although the chronological distinctness of the breccia and the most of the conglomerate does not admit of question, yet it is not always easy to separate them in the field. For example, in Mount Hope Cemetery, near the gate on the Back Street side there are ledges of a recomposed felsitic rock which belongs stratigraphically with the conglomerate, while lithologically it is a good breccia.

On the New York and New England R.R., in the vicinity of Bird's Lane, there is a rock transitional in character between the felsitic breccia and the amygdaloid. On the south it is in contact with slate and conglomerate; and the latter is largely composed of pebbles of this rock and the breccia. The breccia north of the amygdaloid in Mattapan is mostly compact, and light-colored, weathering white. Farther north-east, on Washington Street, the rock has a more normal texture, but the small area marked here is based on a single ledge protruding through the conglomerate. South of the Neponset the general character of the breccia, which is small in amount, is the same as in Hyde Park; sometimes, however, the bedding is unusually distinct and the rock takes on a very slaty aspect. The amygdaloid agrees very well with that of Needham, being usually epidotic or chloritic, rarely amygdaloidal, and showing decided approximations toward the more compact of the breccias. At several points where it meets the conglomerate the evidence of a slight degree of fluency and extravasation is very plain.

Shawmut Group in the South Shore District.[1] — Distinct breccia is not certainly known to exist in this sixth and last

[1] For a description of the massive, flinty slate, and allied rocks, occurring as an island in the Blue Hill granite and cropping at several points along the northern border of this range, see *ante*, p. 37.

of the districts characterized by the Shawmut group; but the amygdaloid is found in abundance at various points, and presents many varieties. On Hough's Neck, in Quincy, the amygdaloid is a green, slaty rock; it is sometimes amygdaloidal, and sometimes porphyritic, and includes masses which resemble felsite. It occupies the axis of an anticlinal in the conglomerate; and also cuts the latter rock very freely, after the manner of an eruptive. In Hingham, along the railroad, the amygdaloid appears as a narrow band separating the granite and conglomerate. Immediately north and west of the petrosilex in this town it is, in part, typically amygdaloidal. Farther north, in the vicinity of Hewitt's Cove, there is a considerable area of this rock, which here embraces nearly every variety that has been noticed in the preceding descriptions. The relations of the amygdaloid to the conglomerate and slate are well displayed along the shore of the cove.

To the Shawmut amygdaloid must be referred that great mass of amygdaloidal and nondescript rocks so intimately associated with the conglomerate in the southern part of Hull, south of Nantasket Beach. The relation to the conglomerate is similar to what obtains in Brighton, though, perhaps, on the whole, more complicated. The amygdaloidal character is very frequently and perfectly developed, especially in the southern part of the area. Toward the north the rock is chiefly compact and epidotic or chloritic; large masses, however, hold much quartz — crystalline and chalcedonic — in irregular veins, and have a brecciated aspect. In this direction, too, traces of bedding and an arenaceous texture are visible. On the island of Black Rock, off the Cohasset shore, the prevailing rock shows a dark, apparently compact, base, holding crystals of triclinic feldspar. This passes into a less porphyritic, stratified rock of the same dark color, but holding rounded grains of epidote, and evidently inseparable from the amygdaloid. Irregular masses are greenish-white, compact and epidotic.

GENERAL RELATIONS OF THE SHAWMUT GROUP.

Dr. T. Sterry Hunt, failing, it seems to me, to appreciate the distinctive characters, mineralogical and petrological, of the amygdaloid division of the Shawmut group, has referred this important set of beds, apparently *in toto*, to the Huronian series. In 1870[1] he divided the rocks in the vicinity of Boston into three classes: "A, the crystalline stratified rocks; B, the eruptive granites; C, the unaltered slates, sandstones, and conglomerates." In the class A he recognized two divisions, the first of which comprises the acidic rocks, petrosilex, eurite, etc.; while the second "includes a series of dioritic and chloritic rocks, generally greenish in color, sometimes schistose, and frequently amygdaloidal. They often contain epidote, quartz, and calcite, and occasionally actinolite, amianthus, scaly chlorite, and copper pyrites. This series holds a bed of dolomite at Stoneham, and serpentine in Lynnfield, where bedded serpentines, dipping at a high angle to the N.W., occur apparently in the strike of these dioritic and epidotic rocks, which include the greenstones of Dr. Hitchcock, described by him as occasionally schistose, and passing into hornblende slate; and also his varioloid wacke, under which name he describes the green and chocolate-colored amygdaloidal epidotic and chloritic rocks of Brighton." Having thus clearly grouped together as belonging to one and the same series the amygdaloids, and the diorites and dolomites here referred to the Huronian, Dr. Hunt proceeded, in the following year, as noticed *ante*, p. 25, to include the whole, together with the acidic rocks named above, in the great Huronian system.

The basic Huronian rocks of Eastern Massachusetts are rarely chloritic, and very rarely conspicuously so; in this region this mineralogical character is found well developed in the amygdaloids alone; and the correlation of these imperfectly crystalline sediments with the crystalline Huronian dio-

[1] Proc. Bost. Soc. Nat. Hist., xiv., 45–46.

rites and gneisses is all the more singular, since the two series are everywhere as distinct petrologically as mineralogically. Reference to the map will show that there is scarcely a point where the amygdaloid is in contact with the diorites, either stratified or unstratified. The fact that the diorites, partially interstratified with the petrosilex (our typical Huronian terrane), are found over this entire region, being in a certain sense coextensive with the Huronian series, and are characterized by a prevailing N.E.–S.W. strike and north-westerly dip, indicating a general independence of the present configuration of the surface; while the amygdaloid is confined to the margins of basins which have very clearly been eroded from the upturned and extravasated dioritic and other Huronian terranes,—is satisfactory proof of the entire distinctness and separateness of the two formations.

The amygdaloid can be connected with the diorites in only one way, and that is by the bond of derivation; the two formations are probably genetically related. The chemical decay and disintegration in ancient times of the basic division of the Huronian series must have yielded sediments similar to those required for the formation of the amygdaloids. The feldspar of the diorites was extensively kaolinized, and the hornblendic material changed so as to have the chemical aspect of chlorite; species of alteration to which, as geologists are aware, these minerals have been subject in all ages, when exposed to the action of atmospheric agents. Still clearer is the derivation of the breccias from the acidic division of the Huronian series. The disintegration in this case was more mechanical than chemical; still there is evidence that much feldspar was changed to kaolin and to a hydrous aluminous silicate approaching pinite. Thus from the ruins of the Huronian series was formed a second twofold formation; the primary divisions of which, although presenting important chemical differences when compared with the parent terranes in the ancient system, may yet, like them, be distinguished as basic and acidic. It is here easy to see how this most fundamental distinction among silicate rocks is handed down from one formation to another. Like begets like in geology as well as in biology. The offspring always resembles the parent, with certain modifications; the likeness being strongest with the more important characters.

If the Montalban gneisses and mica slates had contributed appreciably to the formation of any part of the Shawmut group, a marked difference in chemical composition and crystalline character would, of course, be apparent in the latter. Now the Taconian series of Western New England — the quartzite, hydro-mica slate, and argillite of which have probably been derived from the underlying Montalban of the Green Mountain range — appears, in the opinion of many geologists, to occupy about the same intermediate position between the Eozoic and Paleozoic that I have assigned to the Shawmut group; and I would suggest that the chemical and mineralogical contrasts presented by the two series are not greater than their unlike origins would lead us to expect.

Geologists are now pretty well agreed that to this same transition period belong the copper-bearing beds of Lake Superior; and Dr. Hunt appears recently to have correlated these provisionally with the Taconian of the Appalachian region.[1] Here, again, the underlying crystalline series, for the most part at least, is the Huronian; and it is in the highest degree interesting to observe that the derived series has the same twofold aspect, and, omitting the copper, presents the same general chemical and mineralogical characters as in Eastern Massachusetts. In both districts we have petrosilex breccias and sand-rocks forming an acidic group, and a basic group composed of chloritic and epidotic, slaty and amygdaloidal beds.

I have but little hesitation in referring to about the same horizon as the Shawmut group the hard, argillaceous, silicious, chloritic, and serpentinic slates (the "flinty slate" of Hitchcock, by whom it is well described, p. 550), and the associated dolomite, that come between the Montalban granite and Carboniferous argillite on the peninsula of Newport, R.I.; the more

[1] Chemical and Geological Essays, preface to the second edition.

especially since Dr. Hunt[1] has regarded them as identical in age with the rocks in the vicinity of Boston forming the basic division of the Shawmut group, though referring them, along with the latter, to the Huronian system. Without considering their relations to the rocks of this vicinity, it is sufficiently evident to my mind that the altered slates of Newport cannot be Huronian, since they appear to be cut by, and at least overlie, granite which is almost certainly Montalban. In part these slates are brecciated, and hold jaspery patches and pebbles of petrosilex; other small portions exhibit a tendency to develop amygdaloidal characters; while the mass of the rock is very similar lithologically and petrologically to the slate forming the island in the Blue Hill granite in Milton.

I have never obtained any reliable data on which to base even a probable estimate of the thickness of the Shawmut group. Such indications as we have, however, point to the conclusion that, comparatively speaking, the volume is not enormous; possibly two thousand feet as a maximum. The little that is known of the stratigraphy of this group will be most conveniently introduced in connection with the structure of the succeeding formation, — the Primordial.

[1] Proc. Bost. Soc. Nat. Hist., xiv., 46.

PALEOZOIC FORMATIONS.

Like the Shawmut group, the Paleozoic rocks of Eastern Massachusetts occur, as already indicated, only in limited basins or depressions excavated in the ancient crystalline formations. Three of these basins have been recognized, and they are almost as well marked in the modern as in the ancient topography; for I hold the view that these basins probably existed as such before the deposition of the sediments which they contain. In this connection it is interesting to observe that Messrs. Bailey and Matthew, as one result of their researches in New Brunswick, have found that the Cambrian strata of that Province are confined almost entirely to the depressions of the present surface, which probably existed as genuine valleys of erosion, arms of the Gulf of Maine, in pre-Cambrian time. In Newfoundland, too, we find substantially the same relation between these oldest uncrystalline formations and the larger features of the modern topography; the evidence all pointing to the great antiquity of the latter, where carved from the crystalline rocks.

The smallest and most northerly of the Massachusetts basins is that now traversed by the River Parker, in Newbury. The second in point of size, and the best known, holds Boston and its environs; while the third, largest and most southerly, extends from Newport and the western shore of Narragansett Bay, north-easterly through Bristol and Plymouth Counties in Massachusetts, and has been called the Narragansett basin. Near the north-east corner of Rhode Island the last-mentioned basin divides, a narrow branch sweeping first to the north and then to the north-east, through Norfolk County to Braintree, where it nearly, but probably not quite, connects with the Boston basin. All these depressions have approximately the same E.N.E. trend.

Prof. Shaler[1] has described the Boston and Narragansett basins as overlapping troughs; the first expanding and deepening

[1] Proc. Bost. Soc. Nat. Hist., XVII., 488.

toward the north-east, and the latter toward the south-west. I conceive, on the contrary, that when these different basins were occupied by the sea, and the sediments which they now hold were accumulating, the Narragansett basin, equally with the other two, communicated with the Gulf of Maine, and had its head toward the south-west, in the vicinity of Newport. The oscillation which submerged the eastern border of the Gulf of Maine, or some similar tilting of the land,[1] has subsequently brought about a change of level in this trough, so that what was formerly its head is now open to the sea. The proofs of this are: (1.) The crystalline Montalban strata appear to pass on the south-west entirely around the uncrystalline sediments of this basin. (2.) The outcropping of the earlier deposits in the basin from beneath the newer, as where the rocks referred to the Shawmut group come up between the granite and the Carboniferous beds on Newport Neck, is what we should expect at the head of a filled-up arm of the sea, but not towards its mouth. Along the west side of Narragansett Bay, and farther north on the same line, there are slates and conglomerates between the crystallines and the Carboniferous, which differ widely from the latter, and are almost certainly older, — possibly Devonian, as suggested by President Hitchcock. (3.) If the drift were removed from eastern Plymouth County, where it has a probable thickness, according to Hitchcock, of three hundred feet, this part of the trough in question would doubtless also be invaded by the sea, and, what is more to the point, it would probably be observed that the Carboniferous beds extend, in this direction, to and under Cape Cod Bay, though they have never been so represented on a geological map.

It has been suggested that the strata occupying these basins were once continuous over the intervening crystalline areas; the broad anticlinals having been removed by subsequent erosion. I have seen no evidence of the correctness of this

[1] The upturned Miocene beds on Martha's Vineyard are evidence of the existence of efficient level-disturbing forces in this region, in comparatively recent geologic time.

opinion, but have observed many facts pointing to the contrary conclusion; viz., that the areas covered by the uncrystallines of Eastern Massachusetts have never much exceeded their present limits. These sediments, consisting of conglomerates, sandstones, and slates, have evidently been deposited in shallow water, and in close proximity to the land; the arenaceous beds particularly being often ripple-marked, and also showing wave action in their irregular stratification. Mr. Matthew appears to hold a similar view with respect to the Cambrian beds of New Brunswick, the evidence being plain that they were formed at a time when the sea and land had something near their present relations. The indisputable want of synchronism between the deposits of the Boston and Narragansett basins is inconsistent with the theory of their original continuity.

I have noted the occurrence of rocks of the Shawmut group in each of these ancient bays, and in a preceding paragraph it is implied that the Narragansett basin is filled mainly with Carboniferous strata. The River Parker and Boston basins, on the contrary, contain, so far as known, in addition to the Shawmut breccia and amygdaloid, only rocks of Cambrian age. These last are believed to all represent about the same horizon as the Paradoxides bed in Braintree, belonging, with that, to the Acadian epoch of the Primordial period.

PRIMORDIAL.

Boston Basin.

The most diligent search, continued for many years, by, in the aggregate, a small army of observers, has failed to bring to light, among the rocks of the Boston basin, more than one locality affording fossils. This is the celebrated slate quarry on the south shore of Hayward's Creek, in the extreme northeast corner of Braintree. These slates, containing *Paradoxides Harlani*, are on the southern edge of the basin, and closely involved with the granite; but this highly characteristic fossil serves to connect the strata holding it with the Primordial rocks in New Brunswick, at the opposite end of the Gulf of Maine, and in Newfoundland.

In determining the relations of the other uncrystallines of the Boston basin to the Braintree beds, we are obliged, on account of the entire absence in the former, so far as known, of recognizable organic remains, to be guided wholly by their lithological and stratigraphical characters. The stratigraphical test is, of course, all-sufficient, where it is possible to command the data necessary for its application; but the rocks in question have been folded, faulted, denuded, and drift-covered to an extent which makes the structure of the region exceedingly difficult to unravel. The construction of a detailed geological map of this basin, however, has assisted very materially in furnishing a clue to the disposition of the strata below the surface. Although geologists are well agreed that, as a general rule, lithological and mineralogical characters are of little value as tests of age among uncrystalline sediments; yet every observer knows that where the area considered is not great, this sort of evidence often leads to conclusions of the highest certainty, the rocks not infrequently possessing peculiar characters by which they may be unfailingly identified; and, as a matter of fact, it is in this way, more often than in any other, that formations are traced and mapped. The student neither needs nor expects to find the characteristic fossils in every outcrop. The true horizon of a set of beds having been definitely determined by paleontologic or stratigraphic evidence at one or more points in a given district, it is then perfectly legitimate to note the distinctive features — either of composition or structure — of the beds, and proceed to trace their distribution by reference to these marks alone.

The Paradoxides bed in Braintree is, of course, the established base line for the stratigraphy of the Boston basin; and, proceeding in the manner indicated above, supplementing the imperfect stratigraphical evidence by lithological data, I have endeavored to ascertain the positions with reference to this known horizon of the other rocks of this basin. The general result reached has already been stated; viz., that all the rocks in the

Boston basin, above the Shawmut group, and including the Paradoxides bed, belong to one and the same essentially conformable series. Although contravening the recorded opinions of many competent observers, I experience but little hesitation in announcing this important correlation. The evidence upon which it is based will be found in the general account of the stratigraphy of the basin which follows.

The uncrystalline sediments in the vicinity of Boston are commonly classified as conglomerate, or "Roxbury pudding-stone," and slate. The existence in this district of sandstone, grit, and limestone, is also well known; but still these are of very subordinate importance. The conglomerate and slate occur principally in large masses, each rock covering tracts some of which are ten to twenty square miles in extent. All the areas of these rocks are elongated in an E.N.E. and W.S.W. direction, parallel with the general line of strike and the axis of the basin; so that a north-south traverse shows several alternations of belts of conglomerate and slate. The general separateness of these two rocks is an important and well-established fact; for, although beds of fine material, sandstone, and even slate, are of common occurrence in the conglomerate, yet they are essentially a part of that rock, are always of limited extent, and clearly to be distinguished from the great mass of the slate. These intercalated layers, however, are of considerable assistance to the observer, since without them it would rarely be possible to determine the strike and dip of the conglomerate. They have, of course, been ignored on the map, and this circumstance helps to a still better appreciation of the fact that the true conglomerate and slate are rarely interstratified in any detailed manner.

Nevertheless, the precise stratigraphic relations of the conglomerate and slate have long been a vexed question with the students of our local geology. Observers are divided on the question as to whether the slate underlies the conglomerate, or *vice versa;* while some have supposed that there are two slate formations, with the conglomerate between; and others that there are two zones of conglomerate, the one intercalated with the slates, and the other overlying them. The mass of opinion, however, is in favor of the view distinctly expressed by Mr. W. W. Dodge,[1] that most of the conglomerate, at least, is more recent than most of the slate. The Paradoxides has been found only in connection with the slate, and hence lithological evidence of the Primordial age of these rocks is only indirectly applicable to the conglomerate. The general resemblance of the last-named rock to the Carboniferous conglomerate of the Narragansett basin has led those believing in its superior position with respect to the slate, to infer that it, too, is of Carboniferous age. That view was entertained by the writer when compiling the Centennial Geological Map of Massachusetts; but subsequent investigations have convinced me (1) that there is in the Boston basin essentially but *one conglomerate* and *one slate*, and (2) that *the former underlies the latter*. Whence it follows that, if, as I shall endeavor to show, we are obliged to regard the slate as Primordial, the conglomerate must be of the same age, or older. But the conformability of the slate and conglomerate, and the probable continuity of their deposition, are shown, not only by a general agreement in strike and dip, but also by the phenomenon, observable at many points, of a gradual lithologic passage between them. Most observers have noted this, and it is generally admitted that such a transition exists, the only question being as to the sequence; assuming this to be as I have stated, and that these rocks constitute but one series, it may be said that the entire lower half of the formation is merely transitional; for, taking a general view, the gradual passage often begins at the very base of the conglomerate.

As a rule, the portions of the conglomerate showing the maximum of coarseness and irregularity in texture are those in immediate contact with the underlying crystallines. Here the conglomerate is sometimes a genuine breccia, and usually holds fragments or boulders of large size; masses one to two

[1] Proc. Bost. Soc. Nat. Hist., XVII., 411.

feet in diameter are common, and I have observed those which were four, and even six, feet in the largest dimension. Passing upward, this gives way to the more normal and common type of conglomerate, — the true pudding-stone, in which the pebbles rarely exceed six inches in diameter, and are well rounded. Still higher, limited beds and patches of grit and sandstone are intercalated, as already described; and these appear more frequently as the pebbles become smaller, finally including layers of slate; and thus the complexion of the formation is gradually changed from a coarse breccia to an impalpable and homogeneous argillite. From the earliest conglomerate to the latest slate, the deposition has evidently been substantially uninterrupted, and has gone on during a period of progressive subsidence with which the growth of the deposits did not keep pace. In mapping these rocks, my rule has been to draw the boundaries so as to include all the grit and sandstone with the conglomerate.

The suggestion advanced by some writers, that the conglomerate may be an ancient glacial deposit analagous to our modern drift, a Paleozoic boulder-clay, seems to be disposed of by the lithologic passage just described, which certainly exists as a general fact, though perhaps not observable at every exposure of the contact; and by the undoubted conformability of the conglomerate and slate, and the very evident stratification of much of the former, together with the entire absence, so far as known, of striated pebbles, and the extremely local origin of the materials. The general absence, in the conglomerate, of far-travelled materials, except perhaps in the case of some of the quartzite pebbles, is very noticeable. The pebbles of the conglomerate, too, form a larger proportion of the rock, are generally smaller, and of more uniform size in the same part of the rock (showing the sorting power of water), than is usual with the modern till. There are, probably, also, few physical geologists who would now admit the possible existence of glacial conditions in Paleozoic times.

In what precedes I do not mean to assert that all the conglomerate is strictly inferior to, *i. e.*, older than, all the slate;

for it is in the highest degree probable that these rocks are in part contemporaneous deposits, slate in the deeper water and conglomerate in the more shallow being formed simultaneously. In other words, the deposition of the conglomerate began first, but had not entirely ceased in some parts of the basin when the deposition of the slate had begun in other parts; so that chronologically the two deposits overlap, and have not everywhere the same relative thickness.

The principal facts proving that the conglomerate underlies the slate are: (1.) At most points around the margin of the basin the conglomerate comes between the slate and the crystalline rocks (classing the Shawmut group as crystallines), precisely as the Shawmut group was shown to outcrop chiefly along the line separating both the conglomerate and slate from the more ancient formations, the true border of the basin. In many places, it is true, this conglomerate border appears to be wanting, even as represented on the map; but the most important of these apparent exceptions occur where the rocks are entirely concealed by drift, and we can not know with certainty what they are. This is the case along nearly the whole of the north side of the basin; the nearest outcrops are slate, and consequently this rock has been represented as extending to the crystallines; yet toward the south-west, in Needham, the conglomerate very plainly intervenes. In some of these exceptional cases, again, there are indications of faults, which, with the downthrow on the side toward the slate, have carried the conglomerate below the present surface. In still other instances the contact of the slate with the bordering crystallines may, with considerable probability, be regarded as true overlap resulting from the progressive subsidence during and preceding the deposition of the slate. This explanation seems applicable at some points in the South Shore district. The geographic relation here insisted upon is best shown around the three peninsulas or tongues of the ancient formations (principally Shawmut group) which project into the basin from the west. The isolated masses, or islands, of the crystallines, too, where not clearly eruptive, are usually entirely surrounded by a zone of conglomerate.

(2.) The conglomerate almost invariably dips *towards* the outcrops of the slate, and in not a few cases can actually be seen to pass beneath them. The reverse of this sometimes occurs, as in the Beacon Street section near Newton Centre (Pl. 5, fig. 1); but I shall endeavor to show on a subsequent page that this may be properly explained as due to an inversion of the beds (see also Pl. 5, fig. 3), — an explanation which, however, will not apply in the far more numerous cases where the conglomerate is the underlying rock. (3.) In fact, save where occurring on the margins of the basin or exposed through the agency of faults, the conglomerate never comes to the surface except through denuded anticlinals from which the slate has been eroded away; though in some cases the conglomerate too has been worn through, bringing into view the crystalline axis beneath.

The statement has been made that the slate as a whole is characterised by steeper dips than the conglomerate, implying greater age; but I have not been able to verify this observation. Both these rocks are for the most part highly inclined, often vertical, and yet they generally appear to be entirely conformable. The large mass of conglomerate in Dorchester, Roxbury, West Roxbury, and Brookline, usually exhibits very gentle dips, and in some parts is quite horizontal; but this is accounted for by the fact that it here covers the crest of a very broad anticlinal; besides, this area of slightly inclined conglomerate is offset by the gently dipping slate of Somerville and Cambridge. I have prepared lists of all the dips of both slate and conglomerate recorded in my notes, but fail to discover any decisive difference between the averages.

The supposed occurrence of pebbles of the slate in the conglomerate has been confidently appealed to as conclusively proving the greater antiquity of a portion at least of the former rock; but after a critical examination of many hundreds of these "slate pebbles" I am fully convinced that I have not seen a single genuine pebble that can be clearly identified with any part of the slate formation now exposed to observation. Many seeming slate pebbles are merely very limited, lenticular layers of slate intercalated in the conglomerate. Good examples of such false pebbles resulting from irregular sedimentation occur in North Quincy, one-half mile north-east of Atlantic Station, and on the north side of North Beacon Street, in Brighton. The conglomerate of the last-named locality is well known, and several observers have noted the occurrence in it of the "slate pebbles." A careful study, however, has satisfied me that the pebble appearance is illusory, these masses being indigenous in their present positions, and not imported. In most cases the material seems far too shaly and fragile for the formation of transportable pebbles of the sizes observed; the largest being a yard or more in diameter, and yet only two or three inches thick. And the rare occurrence of the so-called slate pebbles, except along particular planes in the rock, where they are very numerous, is decidedly a suspicious circumstance; while peculiarities of form in many cases, as where they envelop pebbles of other material or enclose arenaceous strings which are continuous with the general paste of the conglomerate, seem to complete the proof.

The conglomerate is in many places largely composed of pebbles of the Shawmut amygdaloid; and among these there exists, just as may be observed in the yet uneroded portion of that formation, a perfect series, having as extreme terms an almost entirely unaltered slate and a typical amygdaloid. The pebbles derived from the Shawmut group, however, appear to include a larger proportion of the slaty rock than now exists in the parent ledges, indicating that this older series of rocks experienced a portion of its metamorphism after the deposition of the Primordial beds. In many instances, among the pebbles of the conglomerate, partially decomposed petrosilex or felsite may be easily mistaken for slate. I am not prepared to deny positively the possible existence in the conglomerate of genuine "slate pebbles," and yet I must insist that the occurrence of such has not been proved.

I have often wondered if some of the very numerous quartzite pebbles in the conglomerate might not some day afford Scolithus, or Lingula, as have the well-known pebbles of a very similar rock in the Carboniferous conglomerate at Fall River. Of course one bit of evidence of that nature clearly established would invalidate all conclusions inconsistent with the post-Primordial origin of the conglomerate, or of a certain part of it at least. Pebbles of *conglomerate*, too, are known to occur in the conglomerate, and from these Mr. Dodge[1] has inferred the existence of a more ancient formation of that rock. Unlike the slaty fragments, these conglomorate pebbles are rather rare; and all that I have seen were undoubtedly derived from the Shawmut breccia. I have failed to find that this class of pebbles is peculiar to any part or area of the conglomerate. Their rarity is very surprising, considering the abundance of the breccia and the generous manner in which the other member of the Shawmut group has contributed to the formation of the conglomerate.

No one, so far as I am aware, has ever recognized in either the slate or the conglomerate lithological peculiarities which were so localized stratigraphically or geographically as to afford a proper basis for, or even suggest, a chronological division. The most general distinctions are those resulting from the gradual passage already noted, from the base of the conglomerate upward; but here the evident gradation destroys the inference. The slate, especially, is a very variable rock. The principal colors are black, bluish-black, gray, greenish, brown, and brownish-red. It may be very thin-bedded and beautifully laminated, or so massive as to appear unstratified. It may possess a well-developed cleavage or joint structure, or both these may be almost entirely wanting. But none of these differences admit of correlation with the distribution. Locally this rock is subject to great variation, but to the general view it is decidedly homogeneous. Perhaps the greatest general contrast is between the slate of Somerville and Cambridge, and that of the South Shore district; and yet most observers have

[1] Proc. Bost. Soc. Nat. Hist., XVII., 409.

concluded, apparently on lithologic grounds, that they are synchronous.

The slate in the Paradoxides quarry is greenish-gray, somewhat silicious, fine-grained, and remarkably uniform. Minute grains of pyrite are pretty generally diffused. In the quarry the rock is apparently only very coarsely jointed; but the weathered surface reveals much finer division by this means. The stratification is very massive and can hardly be detected, except by means of the trilobite remains; these may be supposed to lie in the plane of the bedding, and according to this indication the strike is E.–W., and the dip S. 80°–85°. Across the strike, southerly, the slate, still apparently maintaining a high dip in that direction, is met at a distance of perhaps three hundred feet by fine-grained grayish and reddish Huronian granite, while on the west the same granite cuts off the slate at about twice the above distance from the trilobite quarry; that is, the contact of the two formations, as shown on the map, is oblique to the strike of the slate.

Following this line of strike directly across Weymouth Fore River to Mill Cove, we find substantially the same relation of granite and slate. The small tongue of land projecting into the cove on the east is composed of granite similar to that on Hayward's Creek, and this rock outcrops at several points between the cove and the second street east. This boundary is not accurately represented on the map, for on the line of the street mentioned the granite extends as far north as the brook. The slate, which succeeds the granite on the north, though not seen in actual contact with it, the nearest outcrops of the two rocks being several rods distant, is in part very similar to the Paradoxides slate; but this variety is interstratified in thin beds with a purplish-brown and chocolate-colored slate, which is the prevailing type. The strike varies from E.–W. to N. 70° W.; while the dip is southerly and very steep, above 80°. Much of the slate is characterized by a well-marked cleavage, which shows a northerly dip of 70°–80°, and greatly obscures the bedding.

The elongated amygdaloidal vesicles or nodules, however, are the most striking feature of this rock. These are smoothly rounded, presenting botryoidal surfaces, very rarely nearly spherical, but usually much extended in planes parallel with the bedding. They are of all sizes up to a foot or more in length, and one to two inches wide, and occur only along certain definite planes, appearing on the surface as parallel lines or strings of vesicles. They contain more or less mineral matter, concentrically arranged; but the larger ones especially are seldom entirely filled. The minerals which I have observed are quartz, epidote, calcite, asbestus, and chlorite. The epidote is most abundant, though scarcely ever pure; while the asbestus and chlorite are mainly confined to narrow veins occupying joints in the rock. There can be no doubt that this coarse amygdaloidal structure is the result of igneous action, the source of heat being the adjacent granite. Both the amygdaloidal structure and the cleavage are found principally in the purplish-brown slate, and the former diminishes sensibly as we recede from the granite. Interstratified with these grayish and brownish slates are several thin beds, six inches to two feet thick, of white or greenish-white limestone. This rock, too, is somewhat epidotic and amygdaloidal; and contains in some parts small quantities of a dark mineral, with metallic lustre, resembling galena.

After examining the rocks at Mill Cove, I returned to Hayward's Creek, for the purpose of comparing the two localities. Almost the first exposure outside of the trilobite quarry, following the shore to the north-west, shows the bluish-gray slate of the quarry interstratified with a brownish variety identical with that at Mill Cove. At this point the dip is steep to the north; but the slate shows no special alteration, although traversed by dykes of diorite. Toward the granite on the south and west, however, as noticed by previous observers, the slate is decidedly indurated; it is more or less epidotic, and in its hardness approaches novaculite. As at Mill Cove, the slate is changed by contact with the granite; but in a different manner, the amygdaloidal structure not appearing.

On the north side of Hayward's Creek the massive grayish slate of the Paradoxides quarry is well exposed, and may be traced by almost continuous outcrops for nearly one-fourth of a mile in a north-west direction, maintaining an approximately E.-W. strike and nearly vertical dip.[1] As before, it is cut off abruptly and irregularly by the granite on the west, and the slate near the contact is more or less altered. Layers of the purplish-brown slate are now and then included; and I observed, in not a few ledges, a coarse amygdaloidal structure like that at Mill Cove. The almost perfect agreement here demonstrated in strike and dip, relations to the granite, and lithological and mineralogical characters, of the slate on the north and south sides of Hayward's Creek and at Mill Cove, places their essential identity beyond reasonable doubt.

As Mr. Dodge has remarked,[2] the slate along the Monatoquot River, in Braintree, is very like that of the Paradoxides locality, and is similarly related to the granite; and these two areas are doubtless continuous, under the bed of Weymouth Fore River, with each other and the slate at Mill Cove. On the west side of the river, at the first bend north of Weymouth Landing, the slate is greenish-gray and purplish-brown. Between Quincy Point and the Old Colony Railroad there are no outcrops; but west of the railroad the slate is exposed immediately north of the granite, and agrees in all important respects with that at Hayward's Creek and Monatoquot River. It can be shown that the slate in the vicinity of Mill Cove is probably continuous across Weymouth Back River with the slate in the north part of Hingham.

This species of investigation has been extended over the entire basin, with substantially the same results; the facts everywhere favoring the view that the slates are all of the same age; though of course the proof becomes, on the whole, less conclusive the farther we recede from the fossiliferous beds. Occa-

1 The first re-entrant angle in the boundary of the slates on this side of the creek is not so deep as represented; in fact, it scarcely exists.

2 Proc. Bost. Soc. Nat. Hist., XVII., 403.

sionally, however, we find unique evidence connecting the slates of widely separated localities. Thus, the slate forming East Point, Nahant, is enclosed in, and extensively cut by, the coarsely crystalline pyroxenic rocks of the Naugus Head series; and near the crystallines it is usually altered in two distinct ways; (1) by induration, as in the vicinity of the trilobite quarry, and (2) by the development of a coarse amygdaloidal structure, which is exactly identical with that characterizing the slate at Mill Cove. This slate, except where it is vesicular, is of a uniform grayish-black color, being more homogeneous than the Mill Cove rock; but, like that, it holds thin beds of limestone, aggregating, perhaps, twenty feet of calcareous matter. The characters of the limestone, and its mode of occurrence, are precisely the same at the two localities, although thirteen miles apart; and the evidence of synchronism is much strengthened by the fact that these are the only points in the Boston basin where this rock is known to occur. The absence of limestone at points farther west is readily accounted for by the greater shallowness, in ancient as well as modern times, of the water in that direction. The often cited occurrence of fragments of Paradoxides in the drift of George's Island, six miles north-north-east from Hayward's Creek, is generally and justly recognized as a strong indication that the slates are of the same age on opposite sides of the basin.

Stratigraphy of the Boston Basin. — The idea has long been prevalent, that the uncrystallines of the environs of Boston form one huge synclinal through coextensive with the basin in which they lie; the slates on the north and south being supposed to dip toward the centre of the basin, passing beneath the great mass of conglomerate occupying that position. And on this notion has been founded an argument for the more recent age of the last-named rock. But, although there doubtless was a time, during and immediately following the deposition of the sediments, when the structure of the basin was characterized by the simplicity which this theory requires, it is now vastly more complex. Instead of one great downfold of the strata, there is a series of synclinals and anticlinals; and, as already stated, the most of the conglomerate has reached the light through the eroded crests of the latter.

Whether or not the period of disturbance here implied followed close upon the deposition of the slates, the absence of more recent beds makes it impossible certainly to determine. The amount of disturbance is clearly greater than among the Carboniferous beds of the Narragansett basin, and probably exceeds that of the rocks underlying these, and marked as Devonian on the map. It is likely that all the deposits of the Acadian epoch in this north-eastern border region were upturned simultaneously; and hence, since it is known that, in Newfoundland, the Potsdam beds lie unconformably upon the Acadian, I conclude that although the disturbance of the Boston series, like the preceding subsidence, may have been gradual, and of even greater duration, yet it had its beginning, at least, before the close of Primordial time.

The disturbance of this formation is manifested in three distinct ways; by folds, by faults, and by exotic masses. I have named these stratigraphic features in the probable order of their relative importance; and yet I am not fully satisfied as to whether plication or fracture is the more characteristic. The plicating force appears to have operated with nearly equal intensity from the north and south, or, rather, from the north-north-west and south-south-east; producing folds with approximately east-west trends, though showing a tendency at most points to parallelism with the adjacent crystalline border. As the detailed descriptions and sections will show, these flexures of the strata vary greatly in form and size; including some that are exceedingly narrow, closely folded, and even inverted, and others that are very broad and gently arched. In the first kind the strata are much broken by reason of having been so sharply bent; and in the second class the same result appears to have been reached through the enormous weight of the beds themselves, the arches not being self-sustaining. I do not consider, however, that all the fractures of the slate and conglomerate have *originated* in these rocks, for in many cases they are probably but the upward extension of dislocations which had their inception in the underlying crystallines. The very considerable narrowing of the Boston basin, of which the folded slate and conglomerate afford abundant evidence, must have necessitated a yielding of the crystalline floor; and there are many indications that this was effected with the development of a minimum of plasticity; faulted folds being the rule, and igneous extrusions the comparatively unimportant exception.

South Shore District. — At the southern end of Nantasket Beach, in Hull, the rock lying farthest to the north, and accessible only at low tide, is a very distinct conglomerate. It holds many pebbles of greenish amygdaloid, including both the slaty and typical varieties of that rock, and much of the paste has evidently been derived from the same source; there are also numerous pebbles of granite[1] and petrosilex; and I have observed several pebbles unquestionably representing the Shawmut breccia. The petrosilex pebbles embrace several varieties, mostly reddish. On the north side of the ledge a layer of very fine red sandstone or slate is intercalated with the conglomerate, while on the south side it is overlaid by a laminated slate of a beautiful green color. These finer-grained rocks show a southerly dip of 10°–20°.

The conglomerate exhibits no special disturbance or alteration, but the most casual examination of the slate shows that it is greatly indurated, having about the hardness of orthoclase. A dyke of a black, crystalline, basic rock divides the ledge in the direction of the dip, and is accompanied by a slight dislocation of the beds. After three or four feet in thickness of the green, novaculitic slate, the section is inter-

[1] Wherever, in these descriptions, granite pebbles are mentioned as occurring in the conglomerate, the coarse, typical Huronian granite is to be understood, save where it is otherwise stated.

rupted by a similar but larger dyke (twenty to thirty feet wide), parallel with the strike. Here, too, there is a fault, with the downthrow on the north; for the rock bounding the dyke on the south is not slate or conglomerate, but a massive, almost crystalline variety of amygdaloid. This has decidedly the aspect of an eruptive, although easily distinguished from the dyke rock. It is overlain a few feet farther south by a greenish and yellowish sandstone, which has suffered an extraordinary degree of alteration. The bedding is, for the most part, entirely destroyed; and where this structure yet remains it is greatly disturbed; but it can still be seen that the general dip is S., about 10°. This rock is thoroughly indurated, and holds numerous irregular masses of endogenous quartz. The contact with the amygdaloid is well exposed; and it is of such nature as to show that, although apparently coinciding with the bedding, it may be due to the extravasation of the last-named rock. The alteration of this sandrock is without a parallel elsewhere among the Primordial rocks of the Boston basin. So great is the change that most observers, I believe, have failed to distinguish the sandstone from the amygdaloid, through contact with which it has experienced its metamorphism. The derivation of the sandstone from the amygdaloid is evident from its color.

A few rods to the westward, just at the end of the beach and the foot of the hill, are several good ledges of a similar but less altered greenish sandstone, interstratified with beds of rather an obscure conglomerate. The latter rock is largely composed, both pebbles and paste, of amygdaloid. The dip, as before, is S., 10°–20°; but the beds are cut off in that direction by the base of the hill, which is a great mass of amygdaloid. There is a very obvious strike fault here, but the contact is quite complicated, the amygdaloid having played to some extent the role of an eruptive; and the two formations are, in consequence, difficult to separate. These stratified beds are undoubtedly the same, or nearly so, as the highly altered mass on the east, but a transverse fault evidently intervenes.

We have now a clue to the structure of this entire area of amygdaloid and conglomerate. Originally the surface was entirely composed of the former rock; and over this was deposited by the Primordial sea a continuous sheet of conglomerate, with sandstone and slate toward the top. The Primordial beds were first tilted so as to have a nearly uniform southerly dip of 10°–20°, and then broken by numerous transverse and strike faults, the latter predominating and having the downthrow apparently always to the north. In some cases the faults are traceable for considerable distances, nearly a mile, and are marked by a downthrow of hundreds of feet; while others are short, with a dislocation of tens of feet or even less. Very often, as in the examples described, the faults are accompanied by dykes of diorite; and as these, by reason of their jointing, are more easily removed by the agents of erosion than the tough amygdaloid and indurated conglomerate, there results the curious checker-board topography noticed by many observers; the surface being, to a considerable extent, divided by narrow defiles into square or rectangular hills with precipitous slopes. In some cases, however, the cliffs seem to be the product of the dislocations alone.

Although the amygdaloid is undoubtedly exposed mainly through the agency of faults, yet some of the masses of this rock are too irregular and tortuous to be accounted for in this way, and it appears necessary to regard them as exotic. In the second ledge noticed above, where the amygdaloid underlies, with some appearance of conformability, strata which are almost certainly not the base of the conglomerate, it probably forms an intrusive bed. Another example, precisely similar, occurs a few rods farther south, at the north-east corner of the large hill on which the Atlantic House stands. Here a small mass of beds identical with those already described as abutting against the north base of this hill on the same line of strike, but farther west, — gray and greenish sandstone interstratified with conglomerate holding abundant pebbles of amygdaloid, — is not only cut off by the amygdaloid in the direction of the dip, but is also underlaid by the same rock ; which penetrates the sandstone in a manner possible only with an eruptive. The great uniformity in the dip and strike of the conglomerate over this entire area of a square mile or more, however, appears inconsistent with the extravasation of much of the amygdaloid.

On the map I have attempted to trace the distribution of the different rocks in this Nantasket district only in the most general way. The exposures are uncommonly good, but the areas are too small and complicated for accurate representation on this scale. There is more amygdaloid on the west side of the road running south from the beach than I have indicated. This rock here includes nearly every variety known to occur in the Boston basin, but there is a larger proportion of the typical amygdaloid than I have observed elsewhere. The conglomerate farthest to the east, near the island of Black Rock, is coarse and reddish ; consisting chiefly of the large grained, pinkish granite of the adjacent mainland, in well-rounded masses of all sizes up to a foot or more in diameter ; but it also includes pebbles and boulders of amygdaloid. The whole rock is thoroughly indurated, though this is most noticeable in the finer layers. West of the road mentioned, the conglomerate is also sometimes quite coarse ; and the colors are reddish and gray, rarely greenish. The principal constituents are granite, petrosilex, and amygdaloid. Intercalated layers of red sandstone show that the dip already stated characterizes the entire area. Igneous agency has given portions of the sandstone the hardness of jasper. In the small bay immediately south of the steamboat wharf, the conglomerate can be seen reposing upon the amygdaloid ; and it is here a very coarse rock, holding masses, often angular, one to two feet in diameter, of granite and petrosilex and of the very same amygdaloid which it overlies. The rocks on the north-east side of Planter's Hill, in Hingham, are a continuation along the strike of those in the Nantasket area, and the relations are the same.

It is impossible to determine the thickness of the conglomerate in this district ; but it is probably not less than three or four hundred feet. Single cliffs cut the strata at right angles for seventy-five feet or more. According to the explanation of the structure here offered, the beds on the north, which, in consequence of the faulting, appear to underlie those to the south, are probably the newer; and this is in harmony with the fact that the finest material is found in the most northerly ledges. The remaining part of Hull is marked on the map as slate; although between the southern end of Nantasket Beach and Point Allerton, a distance of more than three miles, there is not a single outcrop. The loose materials, shingle and drift, however, include a large proportion of slate and considerable sandstone; but, so far as I have observed, little or no conglomerate.

Planter's Hill is probably entirely composed of granite; and hence there is, apparently, no stratigraphic connection, on the land, between the uncrystallines of the Nantasket area and those of Hingham Harbor and the district to the westward. The islands in this harbor are all conglomerate, with, I believe, southerly or south-easterly dips; and ledges of the same rock are prominently placed in the Melville Garden, at Downer Landing; but there is scarcely enough fine material included to furnish a clue to the structure. Between Hingham Harbor and Weymouth Back River, however, the key to the stratigraphy is unquestionably to be found in the disposition of the granite and amygdaloid; the complication observable originating chiefly in the large triangular mass of amygdaloid east of Hewitt's Cove. In this area of about two square miles, we find the structure so characteristic of the Nantasket beds, and resulting from dislocations, combined with sharp synclinal and anticlinal folds. As for the Nantasket area, the map is here only approximately correct, the general outlines alone being given.

Otis Hill and the hill south-west of Crow Point are of drift formation. On the west side of the last-mentioned elevation, near the base, there is conglomerate, a continuation of that in Melville Garden, with a westerly dip of 10°–30°; this passes upwards into grit and sandstone, and is finally overlaid conformably by perhaps one hundred feet (traverse measure) of a purplish-brown slate banded with gray. Toward the north the strike of these rocks changes to north-north-east, while in the opposite direction it appears to curve gradually around to north-west, and at last, near the road, to west-north-west, or even to east-west; the dip being in succession, west, south-west, and south. Beyond the slate, in a westerly direction from Downer Landing, the fine pebble conglomerate appears again, with the same dips, a fault with the downthrow on the east probably separating it from the slate. This conglomerate, like the first, becomes grit and sandstone on the west. It has a breadth of one to two hundred feet; and is succeeded, after a narrow belt of brownish slate (partly concealed), by a grayish and greenish banded slate which is considerably contorted and has a westerly dip of 40°–60°. This holds for perhaps five hundred feet; and then, after becoming in part of a purplish-brown color, it passes without change of dip through sandstone and grit to small pebble conglomerate; and a few rods farther this is met by the eastern border of the large triangular area of amygdaloid.

To recapitulate; the observed succession of beds characterized by a westerly dip, from the drift-hill on the east to the amygdaloid on the west, is as follows: —

(*a.*) Conglomerate, becoming smaller-pebbled upwards.
(*b.*) Sandstone.
(*c.*) Purplish-brown slate, cut-off by a fault.
(*a.*) Conglomerate, small-pebbled, changing to
(*b.*) Sandstone.
(*c.*) Purplish-brown slate, upper part concealed.
(*d.*) Grayish and greenish banded slate.
(*c.*) Purplish-brown slate.
(*b.*) Sandstone, passing gradually into small-pebbled
(*a.*) Conglomerate.

The best explanation of this succession seems to be that suggested by the letters; viz., a closed synclinal fold, with its axial-plane dipping to the west, and having the strata repeated on the east side by a strike fault. (See Pl. 4, fig. 1.) According to this view, the gray slate (*d.*) is folded sharply upon itself in the centre of the synclinal; and the true thickness of all the slate involved can scarcely exceed two hundred or three hundred feet; while the volume of the conglomerate is probably not much greater. Here, as elsewhere in the Boston basin, no sharp distinction is possible between the brownish and grayish slates. The most that can be said is, that the slate immediately overlying the conglomerate is very likely to be of brownish or purplish tints, and that these colors are rare in slates not occupying this stratigraphic position.

The trend of this synclinal is much more nearly north and south than represented on the map; and, like the conglomerate and purplish-brown slate on the east, it shifts to an east-west course in its southern extension; but the rocks are mostly hidden in that direction, and it is highly probable, too, that the syncline is changed to a faulted monocline. The gray slates outcrop at two points along the road on the north side of Otis Hill, with a southerly dip of 10°, or thereabouts.

On the south side of the eastern extension of the amygdaloid area, which is the cause of the swerving of the synclinal just described, there is, first, a range of small pebble conglomerate and sandstone, which is overlaid at one point, at least, by a grayish and greenish slate precisely similar to that filling the synclinal on the north; the whole dipping south and south-south-east at an angle of about 10°. Following this is a narrow belt of amygdaloid (marking a fault), then more conglomerate, and lastly the broad band of amygdaloid lying between Otis Hill and the petrosilex and granite on the south. This amygdaloidal belt is broader than represented, extending nearly as far north as where, on the map, the tide-water brook crosses the road to Downer Landing. Proceeding from the intersection of this road and Lincoln street, on a direct line towards Hewitt's Cove, we have the succession represented on the map, viz., —

Amygdaloid, the belt last mentioned.

Conglomerate, mostly concealed and probably more or less faulted.

Slate, forming the centre of a synclinal.

Conglomerate.

Amygdaloid, extending to the shore of the cove.

The synclinal between these two large masses of amygdaloid is quite narrow as regards the slate, which shows a north-east strike and nearly vertical dip. These are the same beds as those mentioned in the first part of the preceding paragraph, the syncline changing to a faulted monocline, as the strike shifts toward east-west; and, comparing this stratified belt with that west of Downer Landing, we see that two synclinals are swerved and broken by the eastern extension of the main mass of amygdaloid.

Along the east side of Hewitt's Cove the amygdaloid comes very near the water, but enough conglomerate and slate intervene to afford several interesting sections. The strike is N. 25°–30° E., and the dip westerly, or away from the amygdaloid, and steep — 60° and upwards. The slate is of a uniform gray or grayish-black color, distinctly stratified, and in part very beautifully jointed. At the south side of the cove the slate rests against the amygdaloid, and is somewhat altered near the contact. Immediately north of this is the following section from east to west: amygdaloid; concealed, forty feet; conglomerate, passing into slate, twenty feet; slate, forty feet. The next section, one hundred feet farther north, shows slate in contact with amygdaloid, no conglomerate visible. The amygdaloid here has clearly experienced some extravasation. Fifty feet north of this gives the following: amygdaloid; slate, with layers of sandstone and pebbles, fifty feet. One hundred and fifty feet beyond, the apparent succession is as follows: amygdaloid; not exposed, twenty feet; slate, twenty feet; not exposed, probably concealing fault, sixty feet; slate and sandstone, fifteen feet; conglomerate, forty feet. This conglomerate is in part very coarse, holding boulders one to six feet in diameter, which are composed chiefly of amygdaloid, petrosilex, and granite. I observed in it one mass, nearly a foot in diameter, of gray limestone, somewhat crystalline. Along the north side of the cove the section is more extended, including perhaps six hundred feet (traverse measure) of slate, but no conglomerate; the part of the section where this rock might be expected to appear affording no outcrops. A generalized section along the north side of the cove is shown in Pl. 4, fig. 2.

The evidence is plain: (1) That the bulk of the conglomerate in these sections belongs below the slate, thin beds sometimes alternating with the slate, near the contact. (2) That the rocks are cut by transverse and strike faults, one or two of the former being particularly evident, producing a lateral displacement of several hundred feet; while the downthrow of the latter has been mainly on the west, concealing the conglomerate and diminishing the apparent thickness of the section. (3) That the amygdaloid is in part exotic, though elevated chiefly through the agency of faults. Portions of the slate on this shore have a pretty fair cleavage, which, according to the rule in the Boston basin, trends east-west, with a steep dip to the north. Following the slates to the north side of the amygdaloid area, the strike is observed to change abruptly to nearly east-west, conforming with the border of the amygdaloid. A traverse from the amygdaloid northward, or toward Slate Island, shows only slates, dipping steeply in that direction and considerably contorted, all the way to the shore. The conglomerate is here concealed by a fault. The conglomerate and slate on the different sides of this mass of amygdaloid afford a good example of quaquaversal dips.

Recent observations have shown that the narrow south-western angle of the amygdaloid, and the anticlinal which it represents, are continued nearly, if not quite, to Weymouth Back River. The trend of the anticlinal gradually shifts toward east-west, so that where it crosses Beal Street the strike is N. 60° E. The anticlinal appears to be much faulted, for the conglomerate and amygdaloid are greatly mixed up, but this might result in part from the extravasation of the latter. South of Hewitt's Cove the slate is not exposed on the north-west side of this anticlinal, but on the south-east there are numerous outcrops, and its position is at all points very clearly synclinal. On the north-west side of Baker's Hill the granite extends about one-eighth of a mile farther than it is indicated on the map, and the belt of amygdaloid skirting the granite is continued south-westerly, probably to Beal Street. So that from Baker's Hill, north-westerly, the following succession can be made out; (*a.*) granite; (*b.*) amygdaloid; (*c.*) conglomerate; (*d.*) slate, forming centre of synclinal; (*c.*) conglomerate; (*b.*) amygdaloid. Pl. 4, fig. 3, represents a section across this synclinal. The dip, wherever observable, is vertical, or nearly so. The volume of the conglomerate appears to exceed that of the slate; and the latter rock is very similar to that in the Downer Landing synclinal, the two varieties, brown and gray, being represented. The disposition of the amygdaloid and conglomerate along the railroad, near West Hingham Station, appears to be about as mapped. This is probably a small synclinal, too shallow and narrow to hold any slate. Between this and Weymouth Back River the boundary between the granite and conglomerate is located very exactly at several points, and the amygdaloid seems to be wanting here.

In North Weymouth there are no outcrops, except in the vicinity of Mill Cove, and, according to Mr. W. W. Dodge, between Rowe's and Great Hills on Eastward Neck; the former are described on p. 192, and the latter I have not seen; but Mr. Dodge[1] describes the rock as slate, "black, thin and contorted." In the Mill Cove slate there are evident indications of a passage to conglomerate toward the north; and it seems probable that the anticlinal crossing Beal Street, in Hingham, is continued through North Weymouth; the strike shifting to E.–W. The slates of the two localities are very similar. The Paradoxides bed is apparently on the south side of this line. The absence, so far as known, of conglomerate between the granite and slate in North Weymouth might be explained by a fault; for the slate beds are here either cut off on the south by a wall of granite, or they are folded in a sharp synclinal, and the former view is most probable. The occurrence of calcareous

[1] Proc. Bost. Soc. Nat. Hist., XVII., 404.

layers in the beds of slate adjoining the granite is a plain indication that these are near the top of the series. The alteration of the slate near the granite seems to show, however, that the latter has reached its present position in part at least through extravasation.

In the relations to the granite of the narrow and tapering band of slates along the South Shore Railroad and Monatoquot River we have yet clearer evidence of discordant movements in these two rocks; and at some points the extravasation of the granite seems beyond question. Now, since the general movement has been upward on the part of the granite and downward on the part of the slate, it is possible to extend the explanation of the preceding paragraph and say that here, too, the conglomerate is concealed beneath the slate; but this will be regarded as hazardous, since in an area so disturbed and irregular as this the underlying beds might be expected to crop somewhere. If, however, it is asserted that the conglomerate is an overlying rock, and has been eroded away in this instance, the absence of the amygdaloid still remains to be explained; for it will be noticed that, in general, wherever the conglomerate fails to intervene between the slates and the crystallines, the amygdaloid is wanting also; and of course the latter rock cannot be taken as superior to the slate. The dislocation theory accounts for the absence of both the conglomerate and amygdaloid, and seems fairly satisfactory; and yet I am rather more inclined toward the view, already stated (*ante*, p. 188), that these are examples of true overlap, points where the slate, during the gradual but irregular subsidence of the Boston basin, has reached beyond and concealed the edges of the conglomerate. The sediments accumulating in Weymouth Fore River at the present day include no coarse material, but only fine mud, which, when consolidated, will form true slate. Why may not similar conditions have obtained in this locality in early Paleozoic time? I presume that this river may have been then, as now, a tranquil, land-locked arm of the sea, gradually silting up with the finest mechanical sediment. It is interesting to observe that the chief invertebrate inhabiting this water to-day — Limulus — is one of the nearest living allies of the primordial Paradoxides entombed in the bordering slates.

On White's Neck and along the Monatoquot River the strike of the slate is approximately E.–W., varying to N. 70° E.; and the dip is 75°–90° on either side of the vertical. The general resemblance at most points to the slate of the trilobite quarry has been noted. Near the granite some sort of alteration may usually be detected. In the railroad cuts north-east of Weymouth Landing the slate is very shaly, soft and unctuous, and with glistening surfaces, especially in the vicinity of the quartz veins, which are numerous. The fresh surface is black, but becomes bronzed by exposure. One principal set of joint planes produces a sort of cleavage parallel with the bedding. The slate is backed on the south by granite, which comes at some points quite up to the railroad; and the contact is extremely irregular. As remarked by previous observers, the granite is in part clearly exotic; and the adjacent or enclosed slate is sometimes of flinty hardness. The slate is much faulted on a small scale, but is comparatively free from folds and contortions.

The vertical position of the slates of the narrow band in question indicates a very great lateral contraction, during the period of disturbance, not only of the slates themselves, but also of the underlying granite; and this is another proof of the former plasticity of the last-named rock; though it is conceiveable that the same effect might result in part at least from a series of faults converging downwards.

Quincy and Milton. — Between the granite of Quincy Neck and the belt of conglomerate one mile farther north, as already observed, there are no croppings, except in the angle on the west of the Old Colony Railroad. Here the slate strikes E.–W. with vertical or high southerly dips. At points it is thoroughly indurated, and the relation to the granite is substantially the same as farther south. The conglomerate band just mentioned marks an anticlinal axis; but what the structure may be between this and the supposed anticlinal of North Weymouth and

Quincy Neck we can only conjecture; in a general way, however, it is almost certainly synclinal.

On Hough's Neck, in Quincy, along the north side of Rock Island Cove, there are prominent ledges of conglomerate flanking a large mass of amygdaloid, and the latter rock crops through the former in isolated bands due to extravasation or faulting. The conglomerate strikes about east-west, and shows nearly vertical dips to the north and south, dipping away from the amygdaloid. It holds unmistakable pebbles of Shawmut breccia. This is clearly a faulted anticlinal fold. Toward the north, over the area marked as slate, the rocks are all concealed by drift; but on the south the conglomerate shows very plain indications of a passage to slate.

Raccoon Island consists of a homogeneous, gray, sandy slate. This is on the north side of the anticlinal; strike, east-west; dip, vertical. Slate with irregular dips is exposed on the south side of Grape Island; and Slate Island is entirely composed of a beautiful black variety, having a well-developed cleavage parallel with the bedding. Strike, N. 80° E.; dip, vertical. The disturbed condition of the rocks in the adjacent part of Hingham makes it unsafe to speculate concerning the relations of Slate Island to the anticlinal of Rock Island Cove. One and a half miles east of the Old Colony Railroad, on the road to Hough's Neck, there is slate with a high northerly, nearly vertical, dip. Like the Raccoon Island slate, this is evidently on the north side of the anticline. Along the railroad, just north of Black's Creek, the conglomerate crops a second time. The pebbles are small, and often distinguishable with difficulty from the slaty paste; and on the north the conglomerate passes through greenish and slaty sandstones to true slate. The latter rock is bluish-black, and distinctly stratified. There is some exotic diorite exposed here. The inclination of the beds is variable, but a nearly vertical dip to the north prevails.

West of the railroad the section is very interesting. On a line parallel with the track, and nearly one-fourth mile distant, the succession from the granite northward is as follows (Pl. 4, fig. 4): first, at least three hundred feet of the grayish-black and frequently indurated slates, already mentioned, with a nearly vertical southerly dip. On the south the slate appears quite near the granite, while the most northerly outcrop comes within, perhaps, three hundred feet of Adams Street. Beyond this the section is concealed almost to the brook; and then coarse-pebbled conglomerate appears for about two hundred and fifty feet, passing into sandstone on the north. The sandstone continues for sixty or seventy feet, gradually changing to slates, of which about one hundred and fifty feet are exposed. The normal strike for the entire section is east-west, or N. 80° E., and the slate on the north has a high dip in that direction. But the bedding is much disturbed locally by masses of eruptive diorite; so that, at some points, the dip is reversed, and the strike shifted to N. 65°–70° E. The slates at the north end of the section are apparently the same as those south of the brook, but, being farther from the granite, are less indurated. This sandstone and slate are in the same part of the section, *i. e.*, on the same line of strike, as the similar beds along the railroad, which are also north of the brook. The conglomerate is largely composed of granite, but holds pebbles of petrosilex, amygdaloid, and, occasionally, of breccia. It can be traced to the west, by almost continuous outcrops, for nearly one-half mile, occurring, in this direction, wholly on the south side of the brook.

About one hundred and twenty-five rods west of the section just described, and nearly one-fourth mile east of where Adams Street crosses the brook, I have measured another section of this Black's Creek and Rock Island Cove anticlinal (Pl. 4, fig. 5). From the main range of granite northwards, on this line, we have the following: — 1, granite; 2, the narrow belt of greenish, semi-crystalline rock referred to the Shawmut group, and apparently cut by granite; 3, granite, not indicated on the map, extending to the north side of Adams Street; 4, conglomerate, at least six hundred feet, traverse measure, reaching nearly to the brook. The junction of the granite and conglomerate is about on the line of strike of the most northerly outcrops of slate, south of the conglomerate, in the first section; indicating that the concealed portion of that section is probably conglomerate, and that on the line of the second section the granite has cut off all of this band of slates. Where it approaches the granite, the conglomerate, like the slate, becomes very hard and firm. In the second section, as well as the first, this rock is appreciably finer and more arenaceous toward the borders. These two sections are complementary, both being essential to a proper understanding of the structure of this uncrystalline belt.

After crossing Adams Street, going west, the next outcrop on the line of this anticlinal occurs immediately west of the Granite Branch of the Old Colony Railroad, very near where it crosses the common boundary of Milton and Quincy. The rock is a coarse conglomerate, similar to the last, but more distinct. Beyond this, I could find no ledges of either slate or conglomerate, until near Randolph Turnpike. The intervening drift, however, is full of large boulders of both these rocks, especially the latter, a plain indication of the continuance of the anticline in this direction. The hard, obscurely stratified, argillaceous (or felsitic) and quartzose beds forming a narrow band between the uncrystallines and the granite, and marked on the map as belonging to the Shawmut group, may possibly be of Primordial age; the stratigraphic position, however, is almost certainly between the conglomerate and granite.

On Randolph Turnpike, the granite is succeeded toward the north by a considerable amount of exotic rock, probably diorite, which is followed by several hundred feet, traverse measure, of stratified beds, consisting of grits, sandstone, quartzite, and slate, all distinctly interstratified, and dipping N. 30°–60°. Some of the sandstone, consisting entirely of the débris of the granite, would be difficult to distinguish from the parent rock, but for the narrow intercalated bands of brownish slate. The same series is exposed south of the cemetery, a few rods east of the turnpike. It appears to be rich in endogenous quartz. The exotic diorite can be traced east half a mile or more.

I consider these beds as representing the north side of the Black's Creek and Rock Island Cove anticlinal, and to my mind it is clear, that in this part of the Boston basin the structure of the conglomerate and slate is not determined by the outlines of the granite masses, but the faults which appear usually to bound the latter have cut through the folds of the Primordial beds irregularly and without essentially disturbing them. This is well illustrated by the border of the granite as it zigzags across the strike of the slate from Hayward's Creek north-westerly; so that the anticlinal in question, which is complete and symmetrical on the east, is more than half cut away on the west. One and three-fourths miles W. by S. from the section on Randolph Turnpike, exactly the same rocks crop again, on the west side of Robbins Street, between Washington Street and Pine Tree Brook. There are no other exposures of uncrystallines on this line east of the Boston and Providence Railroad.

The country between this long anticlinal skirting the Blue Hills, and the Neponset River, an area of at least ten square miles, is almost wholly drift-covered, and the structure is mainly a matter of conjecture. This tract widens rapidly eastward; and the strike of the rocks along the north side appears to shift toward the north-east, so that it is parallel with the general course of the Neponset. The hypothetical nature of this part of the map will be appreciated, when it is stated that the large and eastwardly expanding area marked as slate includes but one rock exposure, besides those already described: this is at the slate quarries north of Sachem's Creek, in North Quincy.

The conglomerate on the south shore of Squantum, and south of the railroad at Milton Lower Mills, dips S. 20°–30° E. steeply, 60°–80°; with indications, especially at the last-named locality, of a passage to slate southerly. Between this range of conglomerate and the Black's Creek and Rock Island Cove anticlinal I think there are at least two synclinals of slate. These folds, like the area in which they are included, probably expand easterly; and under the harbor they may be more numerous than on the land. The axis of a synclinal appears to pass near the mouth of Black's Creek and the southern end of Half Moon Island, and then, bending to the north, to run in the direction of the outer end of Hull, parallel with Peddock's Island and the north shore of Hough's Neck. Slate occurs *in situ*, on the south side of the village of Hull, precisely as stated by President Hitchcock. It is exposed at the base of the hill, perhaps thirty rods east of the steamboat wharf; and is a grayish and brownish-black variety, distinctly stratified, but with the bedding very much disturbed. The contortions of this slate, no less than its geographic position, indicate that it lies in a synclinal. An erratic of slate observed south of Strawberry Hill, but probably derived from this synclinal, is decidedly calcareous.

Hangman's Island is marked by Hitchcock as syenitic; but I find that this rocky islet consists largely of a grayish slate,— much contorted and broken,— but still distinctly stratified. The strike and dip are very variable, but the former is mainly east-west. The "syenite" is really a fine-grained, but distinctly crystalline, basic rock, probably diorite. It cuts the slate in every direction, in dykes and large irregular masses; and forms the shore around the whole island, protecting the slate from the wash of the sea. Some of the diorite is of a fine-grained, slaty texture, but this is no less clearly eruptive than that which is coarse. These exotics do not belong to the Shawmut group, except, perhaps, the slaty variety. I am of the opinion that Hangman's Island lies on a broken anticlinal. This hypothetical arch may be continued to the north-east by the Shag Rocks, which appear to be of similar formation; and it is almost certainly represented on the main land by the elongated area of petrosilex and rocks of the Shawmut group crossing Blue Hill Avenue, in Milton, and extending into Hyde Park. Exposures are few in this direction, but enough exist to prove a patch or island of the older rocks named, extended in an east-north-east direction, and surrounded by conglomerate, apparently a denuded anticlinal. This conglomerate is principally composed of the petrosilex and amygdaloid which it overlies. These rocks can be observed to the best advantage in the area north of Pine Tree Brook, and east of Blue Hill Avenue.

North of this somewhat uncertain anticlinal, and south of the conglomerate of Squantum and Dorchester, there is but one exposure of slate. This, as already stated, is at the quarries in North Quincy, near the harbor and north of Sachem's Creek. It is a beautiful black and brown banded slate, elegantly jointed, breaking into oblique rhombohedrons of small size. Strike, E.N.E.; dip, northerly, but nearly vertical. The bedding is remarkably straight and regular, being free from contortions and other inequalities. The nearest outcrops on this line of strike, to the eastward, are on Quarantine Rocks and Rainsford Island, four miles down the harbor. Here, too, the rock is all slate; it is a homogeneous, grayish-black variety, much like the slate of Raccoon Island, but finer, and differing from that at the Sachem's Creek quarries chiefly in being only occasionally banded with brown. But, though not essentially unlike the slate of the locality last named, and having the same strike, — N. 60°–70° E., — the conditions of its occurrence are very different. On Rainsford Island the outcrops are confined to the western half of the island, which is crescent-shaped, two projecting points of land enclosing a semicircular bay. The dip of the slates is everywhere very variable and undulating. On the northern horn of the crescent it is sometimes to the north, but will average to the south, or south-south-east, at a low angle, probably 20°–30°. The strata are really considerably contorted on a rather large scale, presenting in a small area good examples of normal, overturn, and faulted folds. The bedding is more or less obscured by the cleavage, which is quite well developed in portions of the rock; this is parallel with the strike, and dips north, as usual, about 80°, entirely independent of the stratification. On the south side of the bay, substantially the same phenomena are repeated, but the dip here averages gentle to the north. The cleavage is less perfect in this direction.

This little bay opening to the south-west is unquestionably on the axis of a synclinal, and the slates on either side have the contortions belonging to flexible beds in this position. The structure is typical and instructive. Quarantine Rocks south-west of Rainsford Island form four small islands lying in a north-south line, all but one of which, the most northerly, are entirely submerged at high tide. This principal rock lies farther north than represented on the map, and, following the line of strike of the slates, is about opposite the middle of the crescent-shaped bay on Rainsford Island; *i. e.*, it is on the very axis of the synclinal. And here, accordingly, we fail to observe any prevailing dip; but the beds are most wonderfully contorted and folded; presenting anticlines and synclines of every variety, — large and small, open and closely folded, normal, inverted, and faulted. But few of the contortions are very small; they are mostly to be measured by feet rather than inches. This structure is unparalleled among our Primordial strata, and certainly could only be developed among the upper beds in a synclinal fold. That these are the same beds as those worked in the Sachem's Creek quarries will hardly be questioned, notwithstanding the seemingly great difference in structure; but this is probably synclinal in each case, a closed fold on the main land apparently changing to an open, corrugated trough farther east.

The other Quarantine Rocks are composed of the same grayish-black slate, but the structure seems to be more like that on the south side of Rainsford Island, *i. e.*, with a prevailing northerly dip; the exposures, however, are very poor. Sunken Ledge, nearly a mile south of Quarantine Rocks, consists of loose materials; one large, angular mass, however, appears to be *in situ*, or nearly so. It is a brownish slate holding an occasional pebble, and evidently marking a passage between slate and conglomerate. This is on about the same line of strike as Hangman's Island.

The general absence of conglomerate from both the bed-rock and drift of the harbor islands and peninsulas is a remarkable fact, the true signification of which appears to be that, whereas on the main land, where the strata are more elevated, the anticlinal crests have been worn away, exposing the conglomerate, and in many cases the underlying crystallines, under the harbor these are yet substantially intact, and the inferior division of the formation is concealed. And then, again, it is highly probable that as we recede from the ancient shore line the volume of the slate is augumented at the expense of that of the conglomerate, the latter rock having its greatest and the former its smallest development toward the head of the Primordial bay. If the bottom of the harbor could be mapped geologically, the contraction of the conglomerate belts and the expansion of the slate belts eastward would probably be very conspicuous, this relation being due in part to the diminished erosion toward the east, and partly to the increased ratio of the slate to the conglomerate in that direction. It will be observed that this view is diametrically opposed to that commonly held, according to which the conglomerate is the overlying rock, and is absent from the harbor while yet remaining on the main land in consequence of the supposed greater deundation suffered by the former district. I conceive that the axes of the folds in our Primordial beds, following the ancient sea bottom, dip down toward the east or seaward.

Lying in the course of the Rainsford Island synclinal, toward the north-east, are George's Island, the Great, Middle, and Outer, Brewster Islands, and Martin's Ledge; and on all of these, so far as known, the rock is slate.

The Hyde Park, Mattapan, and Squantum Belt.—The belt of country one to two miles wide extending E. by N. from Hyde Park to the outer end of Squantum, including the valley of the Neponset, and marked on the map mainly as conglomerate, is very complicated stratigraphically. In a general way the region indicated is anticlinal, lying between the synclinal last described and the well-defined band of slate on the north, which marks the position of another main axis of depression; but it also includes a narrow and much-faulted syncline.

In Hyde Park and the north-east corner of Dedham the pudding-stone lies irregularly among and upon the crystallines, usually dipping away from the latter at low angles. I have recently observed ledges of Huronian petrosilex and Shawmut breccia between the Boston and Providence and New York and New England Railroads, a few rods north of the Readville Station, and within the area mapped as wholly composed of conglomerate. These ledges are probably a continuation of the axis of older rocks marked as extending over Fairmount and Brush Hill into Milton. At some points the conglomerate can be observed in close proximity to the Shawmut breccia and brecciated petrosilex (see *ante*, p. 175), but it is seldom difficult to distingush the different formations. This conglomerate occasionally passes into arenaceous beds, but I have observed no true slate in Hyde Park. Between the elongated area of petrosilex and amygdaloid already described, crossing Blue Hill Avenue, in Milton, and the petrosilex and breccia north of the Neponset, the conglomerate undoubtedly forms a synclinal. Farther east this broadens, and is divided by the other island of ancient rocks south of the river, between Mattapan and Milton Lower Mills, into an anticlinal and synclinal; so that, including the conglomerate on the north of the breccia, in Dorchester, this part of the Hyde Park and Squantum conglomerate belt, which is here one and a half miles broad, forms two anticlinals and a synclinal; the crests of the former having been removed, exposing broad bands of the underlying crystallines. Occasional isolated patches of the conglomerate scattered over these crystalline areas prove the former continuity of this rock. In this part of its course the synclinal begins to include some slate; and a generalized north-south section from Pine Tree Brook to the broad band of slate in Dorchester is represented by Pl. 4, fig. 6.

The slate in this narrow or Neponset synclinal is not continuous along the strike, but the evidence is plain that the strata have been broken by transverse faults producing extensive lateral displacement; and in some cases, too, the structure is apparently not synclinal at all, but monoclinal, where strike faults have allowed portions of the slate to drop below the present surface of denudation. I do not consider that the whole thickness of the slate is represented in any part of the Neponset synclinal, but this is to be regarded as a narrow, pinched-up, and broken trough holding only the lower beds of slate.

The most western exposure of slate is on the New York and New England Railroad, just north of River Street, and near the Hyde Park boundary. It is thin and shaly, with sandy and pebbly layers, and a nearly vertical dip S. 30° E. A few feet farther north-east the beds have apparently been dislocated by a transverse fault, and are now exposed in a quarry some ten rods north-west of the railroad. At this point a very clear passage from conglomerate to slate can be made out, and the latter rock is considerably contorted; the general dip, however, remaining the same as before. The next point where the slate appears is on the south-east side of the railroad, a few rods south of Oakland Street. Here we pass from a true slate, plainly ripple-marked and dipping S.E. 70°, through sandstone to conglomerate on the south. It crops again on the same line in Oakland Street, and between that street and Blue Hill Avenue, dipping as before, and with the conglomerate exposed on both sides. The thickness of the slate, which is evidently increasing north-easterly, does not here exceed one hundred feet, supposing it to be doubled upon itself. The passage through sandstone to conglomerate can be observed both ways from the slate. These rocks bear evidence of being squeezed in among the crystalline masses, and the slate especially is frequently much contorted and faulted on a small scale. The nearness of the slates to the crystallines at some points suggests the existence of strike faults concealing part of the conglomerate. The slates of these different localities vary much in color and texture, as this rock is likely to near the conglomerate.

The area of indigenous petrosilex between the New York and

New England Railroad and the Neponset River, and east of Blue Hill Avenue, extends across the course of this band of slate, causing its lateral displacement toward the south; and it next appears on the south side of the river along the Shawmut Branch of the Old Colony Railroad. Sandy beds in the vicinity of the Mattapan Station on this railroad indicate that the slate probably reaches as far west on this line as Blue Hill Avenue. On the south side of the river it lies near, but not in contact with, the petrosilex. This is a fine-grained bluish-gray and greenish slate; strike, N. 60°–70° E.; dip, nearly vertical. It shows the usual passage into conglomerate, and can be traced half the distance to the mouth of Pine Tree Brook, being replaced by conglomerate along the strike in that direction.

On the north side of the river the contact between the conglomerate and petrosilex can be made out very satisfactorily. The portion of the conglomerate lying immediately upon the petrosilex is a true breccia holding large angular fragments of the same petrosilex, and of amygdaloid. This gives way to arenaceous beds showing a nearly vertical south-east dip. The slate band is resumed again on this side of the river, appearing north of River Street, and one-fourth mile west of Cedar Street, as a homogeneous gray variety, with a high south-east inclination, and a well-marked cleavage, which shows the usual trend and dip. It is underlaid by conglomerate on the north; and the conglomerate on the south holds arenaceous beds, which are characterized by the same dip as the slate. This slate evidently continues but a short distance, when the band is again thrown to the south side of the river, appearing along the railroad east of Pine Tree Brook. The slate is here thrown into an unsymmetrical and faulted anticlinal fold, the axis of which is cut out obliquely by the railroad. The strike is as above, and the dip at the east end of the cut is southerly, 70°–80°. Toward the west the beds gradually become horizontal, and finally descend gently to the north. The rock is greenish-gray, distinctly stratified, and well jointed.

About the area of petrosilex and amydaloid on this side of the river, the conglomerate has quaquaversal dips; and at the western end it is curiously involved with the semi-exotic amygdaloid, of the debris of which it is principally composed. At the eastern end, on Central Avenue (a new street not shown on the map), some of the conglomerate is a coarse irregular breccia, with layers of finer material which show a high dip to the south-east. The most interesting rock at this point, however, is a conglomerate composed mainly of a brownish, slaty paste, enclosing many small pebbles of a soft, greenish, and somewhat unctuous substance, which is some form of the mineral pinite, — a hydrous, alkaline silicate of aluminum, — appearing to come nearest to the variety agalmatolite.

This mineral, which most observers have mistaken for serpentine, is of comparatively frequent occurrence in the conglomerate of the Boston basin, though nowhere so abundant as in this Milton locality. At some points the paste or cement of the conglomerate appears to include much pinite, yet in its purest state this substance occurs mainly in the form of pebbles; and these, on account of the inferior hardness of the material, are usually very much flattened in parallel planes, as if by pressure; giving rise, where they are sufficiently abundant, to a decidedly schistose structure in the rock, or, more properly, an imperfect cleavage.

Pinite conglomerate, having a strongly marked cleavage, is well exposed in a cut on Central Avenue, about a quarter of a mile south of the railroad, where it lies upon, and may be seen in contact with, the purplish petrosilex described on page 89; which appears to have been, by a species of sub-aerial decomposition, partially converted into a soft, greenish, hydrous aluminous silicate, precisely similar to that so abundant in the conglomerate. In fact, it is easy, as remarked on the page just cited, to see whence the pinite of the conglomerate, which is very clearly an imported constituent, has been derived. For farther observations on this point the reader is referred to the mineralogical notes that complete this account of the Primordial formation.

The petrosilex is exposed only on the north-west side of Central Avenue, forming the south-west end of a section which is mainly conglomerate. The contact between the petrosilex and conglomerate is straight and well defined. It strikes east-west, and dips to the north 80°, being exactly parallel with the schistosity or cleavage of the last-named rock; while this imperfect cleavage agrees perfectly in dip and strike with that observed elsewhere among the slates and conglomerates of the Boston basin. The contact just noticed almost certainly marks a line of fault, and both it and the cleavage are entirely independent of the bedding. The bedding, however, is much obscured by the cleavage, though it can still be made out by careful observation. The strike and dip are the same as in the other masses of conglomerate in the vicinity; the strike being N.E.–S.W., or nearly parallel with the avenue, and the dip very steep to the south-east. The pinite in the conglomerate diminishes rapidly as we recede from the outcrop of petrosilex.

The slates in the railroad cut west of the Milton Lower Mills Station can be traced east to where the railroad crosses the river; but the structure in this direction appears to be wholly monoclinal; and we find, between Adams Street and a point one-fourth mile south of the railroad, several alternations of conglomerate, grits, rippled sandstone, and slate, all dipping S. 20°–30° E. 50°–80°. The indications are that the synclinal is here replaced by one or more strike faults, with the downthrow on the north.

Toward the north-east the rocks are concealed on the line of this synclinal for a distance of two miles, appearing again in North Quincy, nearly one-half mile north-east of the Old Colony Railroad and one-fourth mile north-west of the road to Squantum. Here the structure is once more clearly synclinal. Advancing from the south, there are, first, several hundred feet of conglomerate, with a high northerly dip, and becoming smaller-grained in that direction; and then, after a few feet concealed, sandstone passing to true slate. There are at least one hundred and fifty feet of the slate, traverse measure; it is fine, gray, sometimes banded with brown, and thin-bedded, with a few small contortions; dip, average vertical. Beyond this there is a gradual passage back to conglomerate, which continues with a nearly vertical southerly dip for perhaps two hundred feet, and then disappears beneath the drift. The general line of strike is N. 60° E. Slaty beds in the conglomerate show distinct cleavage oblique to the bedding, and dipping north at the usual angle. The slate in this section is not shown on the map.

One-half mile further east, near the shore, there are many large, loose masses of conglomerate with grits and sandstone; and one block, which appeared to be *in situ*, shows a high southerly dip.

On the outer end of Squantum the rocks of this belt are well exposed, and the section is both complicated and interesting. The synclinal is not clearly shown, but the faults are sufficiently obvious. Beginning at the north shore, the first rock is a slaty and sandy conglomerate, with many soft pebbles and an imperfect sort of slaty cleavage, which shows the high northerly dip characteristic of that structure in this region. The dip of the conglomerate is S. 20° E. 50°–60°. This rock continues for perhaps eighty feet, and is then overlaid conformably by about three hundred feet, traverse measure, of a purplish-brown slate, of a somewhat arenaceous texture, and occasionally banded with greenish-white. This slate possesses true cleavage, and has a southerly dip of 45°–60°. It is succeeded by conglomerate, but the contact here is obscure, and I could not determine its nature satisfactorily. There seems to be no reason to doubt, however, that the slate is either thrown down by a fault, or that it lies in an inclined syncline, the latter theory being, perhaps, the more probable. This second band of conglomerate has a breadth of five hundred or six hundred feet, dipping S. 20° E. 30°–50°. At first there is considerable sandstone interstratified, but higher the conglomerate is very coarse and irregular, holding masses of granite, amygdaloid, etc., one to three feet in diameter. Farther on it becomes finer again, and finally passes gradually into brownish slate, very similar to that on the north of the conglomerate, but with a gentler dip and less perfect cleavage; it is also more distinctly laminated. If the slate north of the conglomerate lies in a syncline, as conjectured, then the conglomerate itself forms an overturned and denuded anticline; a view which is confirmed by the exceedingly coarse texture of the middle portion of the conglomerate belt, the pebbles becoming gradually smaller toward the slates above and below.

The slate overlying the conglomerate on the south continues for four hundred feet, the dip gradually diminishing from 40° to 15°; and then the section is concealed for about five hundred feet, and, after a few feet of slate similar to the last, and dipping south 20°–30° (?), for four hundred feet more. Following this are two hundred and sixty feet of the same slate, overlaid conformably by one hundred feet (traverse measure) of a greenish-white, or grayish, massive slate. The bedding of this variety is much disturbed, the dip varying from 30° to 60°, but remaining always southerly. Beyond this the section is concealed to near the south shore, where the conglomerate reappears with a high dip S. 20° E. The same conglomerate outcrops on the eastern end of Moon Island, where it is intersected by endogenous quartz, and holds arenaceous beds, which show a dip S. 20° E. 70°–80°. This rock, here, as on the south shore of Squantum and in the vicinity of Milton Lower Mills, is on the northern border of the Rainsford Island synclinal. The west end of Moon Island is probably slate. The slate on the north side of Squantum is not shown on the map.

The rocks of the Neponset and Squantum belt probably occur on Long Island, under the drift, and, possibly, form the foundations of Gallop and Lovell's Islands. Green Island and the Calf Islands are about on this line. These are slate; and, as already shown, this rock may be expected to predominate in this direction.

The West Roxbury and Dorchester Synclinal. — North of Milton Lower Mills the dip of the conglomerate changes to northerly, and at the quarry near the corner of Dorchester Avenue and Codman Street the inclination in this direction amounts to about 15°. The conglomerate is here conformably overlaid by a distinctly stratified bluish-gray slate. It will be observed that this is north of the anticlinal axis indicated by the amygdaloid belt to the westward. Still farther north, on Washington Street, near Fuller Street, a fault has brought the Shawmut breccia to the surface; and beyond that, obscurely bedded conglomerate extends to Amadine Street. This is followed by perhaps one hundred feet of thin-bedded, vertical, greenish-gray slate; and then, after several hundred feet concealed, the conglomerate reappears with indistinct pebbles, some of which are pinite, and a northerly dip of 70°. The slate probably owes its position between the conglomerate masses to a fault having the downthrow on the south.

Westward, on this line, the conglomerate is found skirting the crystallines as far as Washington Street in West Roxbury, showing at most points where the dip is observable a high inclination to the north. The ledges are numerous in the vicinity of the New York and New England Railroad, Blue Hill Avenue, and Mount Hope and Mount Calvary Cemeteries. At the last-named locality arenaceous and slaty beds are frequently included. On Back Street, about the middle of Mount Hope Cemetery, the Shawmut breccia has apparently been brought to the surface again; though this is one of the points where it is difficult to determine whether the rock is conglomerate or breccia. It is on nearly the same line of strike as the breccia already noticed on Washington Street, one and a half miles to the eastward; and the conglomerate on the south has in part, at least, a southerly dip, though nearly vertical. This breccia is not indicated on the map. North of the breccia the conglomerate changes gradually, but rapidly, to a true slate, which is dark colored, homogeneous, obscurely bedded, and vertical. The gradual passage between the conglomerate and slate is particularly evident here. In the cut on the Boston and Providence Railroad, at the crossing of Canterbury Street, and also at the ledge one-fourth mile west of the railroad, the conglomerate is massive and the stratification obscure. The next and last point where conglomerate crops on this line is a few rods south-west of Beach Street, and nearly midway between Washington and Poplar Streets. It here very clearly forms an isolated patch resting on the granite; this is not indicated on the map. Continuing on this line, the uncrystallines are concealed for more than a mile; and then slate appears in West Roxbury Village quite near the granite, the conglomerate being probably cut off by a fault. Large conglomerate boulders in the drift indicate that this rock separates the granite and slate for a considerable distance west of Washington Street, farther than mapped, though finally disappearing before reaching the Dedham Branch Railroad.

The band of slates of which we have now reached the southern border is the best defined and most uniform rock belt in the Boston basin. It has a nearly constant breadth of about five-eighths of a mile, and the dip of the slate is at most points nearly or quite vertical; while the strike ranges from E.–W. to N. 70° E. This is a very homogeneous, and yet for the most part distinctly stratified, grayish-black variety of slate; the bedding is usually very even, and free from contortions. The outcrops are confined mainly to the middle portion of the belt; the land on this line, east of Dorchester Avenue and west of the Dedham Branch Railroad, being mainly of drift formation; and the rock boundaries in these directions, as marked on the map, are consequently somewhat hypothetical. The most western exposures are those on either side of the railroad and near the granite in West Roxbury Village. The dip at this point is southerly, but very variable, 50° to vertical. On the railroad, at the Beach-Street crossing, and between Central Station and Roslindale, the dip is S. 80°. This is near the northern border of the belt. On Maple Street, south-west of Roslindale Station, the strata are quite vertical. The next outcrops are those already described in Mount Hope Cemetery, on the south side of the belt; and exposures occur on the same line in Madison

Street, near Blue Hill Avenue. North of this, between the avenue and the New York and New England Railroad, the slate is exposed almost continuously for five hundred feet across the strike, the dip ranging ten degrees either side of the vertical. At the corner of Dorchester and Welles Avenues, slightly arenaceous slate shows a southerly dip of 80°. This slate belt outcrops for the last time east of Dorchester Avenue and south of Centre Street; but, if continued, it must underlie Thompson's and Spectacle Islands.

The position and structure of this band of slate are unquestionably synclinal. I have already shown that the conglomerate on the south side of the slate dips toward the latter, as if passing beneath it. On the north side the relation is the same, the conglomerate masses showing a high dip to the south, or toward the slate. This geological valley is well represented in the modern topography, the low meadows along this belt being in striking contrast with the broken conglomerate hills to the north and south. As well remarked by Mr. Dodge, the Dedham Branch Railroad turns aside to utilize the convenient course which nature has provided. The form of the valley is obscured at some points by drift hills, but the general course corresponds with the strike of the slates and the trend of the belt. If we regard this as a simple synclinal, free from faults, then the volume of slate involved can scarcely be less than fifteen hundred feet. I have observed no reliable indications of dislocations, but the slate is so homogeneous that fractures might easily exist undetected.

Toward the north, especially, there is an evident passage from the slate to the conglomerate. This is seen most clearly in the angle between Florence Street and Hyde Park Avenue, just north of Mt. Hope Station on the Boston and Providence Railroad. The rock here is mainly a slaty conglomerate, or rather a fissile slate with interspersed pebbles of small size; sometimes, however, approaching a normal pudding-stone, with pebbles three to four inches in diameter. The pebbles are mainly petrosilex, occasionally granite. Some of the beds are quite like sandstone. Strike, N. 80° E.; dip, vertical; thickness exposed, traverse measure, probably three hundred feet. These are beds of passage, and serve to locate with exactness the boundary between the two terranes at this point. There are no other outcrops on this line of strike, either to the east or west. On the map the northern boundary of the slate band is carried too far to the north at the east end, a line bisecting Commercial Point probably coming nearer the truth. The gradual passage from the slate to the conglomerate on the south side of the synclinal is well exposed in Mount Hope and Mount Calvary Cemeteries, as already noticed.

North of this West Roxbury and Dorchester slate belt the conglomerate maintains a high southerly dip for a considerable distance, giving for this rock, as for the slate, a great apparent thickness. In this instance, however, we have satisfactory evidence of strike faults, with the upthrow on the south, augmenting the apparent volume of the strata. In West Roxbury, at most points along a line about one-half mile north of the slates, the country rises abruptly; the uplift forming, for considerable distances, a nearly continuous line of escarpment facing the south, a prominent feature in the topography of the region. It is less distinct through Dorchester; but the abrupt southern slope of Savin Hill is about on this line, and serves to locate the eastern end of the break. The narrow belt between this topographic uplift and the slate band affords several interesting north-south sections; the best, however, is that exposed on the line of Morton Street, near Forest Hills Cemetery. The escarpment, which is well-marked here, is backed by conglomerate; and this changes on the face of the cliff, as it were, through grits to sandstone. The dip is south 70°. After perhaps four hundred feet concealed, there are whitish slates, ripple-marked and dipping S. 75°; and, a few rods beyond these, conglomerate passing into soft, light-colored slates, with a southerly dip of 80°. Several hundred feet farther south, just across Canterbury Street, the conglomerate reappears with a high southerly dip, and probably continues without interruption to the main band of slates. Although there is ground, in these facts, for the opinion that several considerable beds of slate are intercalated in the conglomerate, and pass with it beneath the main band of slate; yet to my mind the conclusion is more reasonable, more in harmony with the facts observed elsewhere, that these different beds of slate are detached portions of the great mass of that rock; and that this section is broken by one, possibly two, faults. The probable position of one fault is shown in Pl. 5, fig. 3. According to this view the gradual passage between the conglomerate and slate is repeated several times on the surface.

One-half mile east, on and near Blue Hill Avenue, the section, though not so well exposed as on Morton Street, appears to be very similar. Just south of Williams Street, and also near the crossing of Washington Street and the New York and New England Railroad in Dorchester, there is conglomerate with sandy beds passing to slate, and showing a high dip to the south. On Canterbury Street, near the avenue, is a ledge of slate and sandstone, with a nearly vertical southerly dip; and conglomerate at the corner of Back Street is on a line with, similar to, and probably represents that on Morton Street, south of Canterbury. At Field's Corner Station, on the Shawmut Branch of the Old Colony Railroad, the conglomerate is small-grained and evidently changing to sandstone; the dip is 80° or more to the south. According to Mr. Dodge, erratics of sandstone from this belt occur on Commercial Point.

Following this faulted belt west from Morton Street we find the escarpment well marked in Forest Hills Cemetery, dividing the cemetery into two nearly equal parts, which are strongly contrasted; that on the north being characterized by numerous bold ledges of conglomerate, while south of the escarpment the land is level, with a few obscure croppings of conglomerate, but no slate so far as I have observed. Conglomerate occurs at two points on Walk Hill Street, and beyond this there are no exposures for nearly a mile. Bussey Street, where it runs east-west, is on the northern border of the belt, the conglomerate ridge being well marked in Bussey Woods. The uplift is much obscured in this part of its course, and farther west, by large drift hills on the south. On Centre Street, near Weld, there is a compact gray slate with conglomerate toward the south. I have seen no slate west of this, but conglomerate, arenaceous and slaty, and with a high southerly dip, occurs on South Street, near Weld Street, and on Maple Street, between Weld and Centre Streets. West of the point last named there are no outcrops. For convenience' sake the slates of the narrow belt of variable lithological character just described, which are considered, for the most part at least, as detached strips of the main band of slate on the south, have not been separately represented on the map, but are included with the conglomerate.

The Brookline and Roxbury Conglomerate Belt. — We are now on the southern border of the largest mass of conglomerate in the Boston basin, a band averaging nearly three miles wide and covering not less than twenty square miles. It is split along the middle, for a distance of four miles from the western end, by the great mass of amygdaloid in the south part of Newton and the adjacent portion of Brookline. North of the Forest Hills and Savin Hill escarpment slaty and sandy beds are almost entirely wanting in this area; the rock is mainly large-pebbled; and, although over a large part of the belt the ledges are very prominently placed, giving rise to the most picturesque scenery of this region, and affording magnificent exposures, there are comparatively few points where satisfactory observations of the dip can be made.

The straight, smooth slopes of rock, and the narrow, vertical-walled defiles so characteristic of this conglomerate, originate mainly in the larger joints of the rock. These planes of division are found in all the conglomerate of this region, but have their best development in the area in question, where their striking characters have attracted the attention of all observers. Many of these master joints have approximately east-west trends, producing ridges and escarpments substantially parallel with the strike of the rock; and another well-marked set cuts the beds in the direction of the dip. Wherever the conglomerate is composed of hard materials, well cemented and firm, the joints cut pebbles and paste alike, so that, considering the coarseness and heterogeneous composition of the rock, the joint surfaces are remarkably smooth and even. This structure is very clearly the effect of unequal transverse or vertical movements of the formation, and not of the contraction resulting from the consolidation of the sediments; nothing but a sudden shearing motion being considered competent to form fractures that are almost mathematically plane in a rock consisting of irregular rounded masses of quartzite, petrosilex, granite, and other hard substances, cemented by a paste of comparative softness, and without regard to the internal structure of these masses. President Hitchcock, in describing the similar, but possibly still more perfect, joint structure of the conglomerate in the vicinity of Newport, Rhode Island, concludes that the rock must have been plastic at the time this structure was developed; finding evidence of the plasticity in the well-known distortion of many of the pebbles of that conglomerate. This explanation, however, seems entirely inapplicable in the case of the Boston conglomerate; for where the joint structure is most perfect in this rock there are no indications whatever of a plastic condition subsequent to the original consolidation of the beds. Where the conglomerate is largely composed of soft material, pinite, or kaolinite, as in Milton, the deformation of the pebbles by compression is very evident, the rock being permanently plastic, as it were; but it is not here that the jointing is most marked.

As elsewhere in the Boston basin, veins of endogenous quartz and dykes of exotic basic rocks are of frequent occurrence in the conglomerate; and these show a general parallelism with the master joints of the formation. One example of the intrusive masses merits special mention. In Brookline, just east of the amygdaloid, the conglomerate is cut by an immense north-south dyke of coarse diabase precisely similar, as regards its general aspect, its disintegration where exposed to atmospheric agencies, and the formation of boulder-like masses by exfoliation, to the diabase of Somerville and Medford; and I have ventured to refer it, along with that, to the Naugus Head series. It crops at two points, about one-half mile apart, on a north-south line; and I have recently been informed, by Mr. Cabot, that exactly the same rock occurs about a mile southwest of this locality, on Lagrange Street.

The Roxbury and Brookline conglomerate has the same wide range in composition as that of other localities, pebbles of quartzite, petrosilex, granite, and amygdaloid predominating, as usual. At some points there is much pinite in both pebbles and paste. The pinite pebbles are occasionally well rounded and undistorted, but more commonly they are so compressed as to partially envelop adjacent pebbles of harder material. The physical characters of this mineral appear to be very constant. Although, as a rule, the conglomerate of this area is decidedly coarse, pebbles or boulders six to ten or twelve inches in diameter being common in some parts, yet it is generally to be observed that the texture becomes finer toward the northern and southern borders of the belt.

Along the middle of this conglomerate belt the beds lie nearly horizontally; but from this line the dip gradually increases on the north to thirty or forty degrees, and on the south, as we have seen, to nearly vertical. To the general view, at least, the stratigraphy of this belt is exceedingly simple; for it forms a single broad, low, denuded, anticlinal fold. This arch is unsymmetrical, the south side sloping down steeply to a nearly vertical-walled synclinal, while the north side is characterized by comparatively gentle dips at all points. The axis or crest of the anticlinal is indicated by the tongue of petrosilex and amygdaloid projecting from Needham into Newton and Brookline, and the band of level strata extending east on this line to Savin Hill. It is in this part, where the lowest beds are exposed, that we find the largest pebbles; and, as we pass to higher beds with steeper dips, toward the borders of the fold, there is, to the general view, as just stated, a concomitant diminution in the size of the pebbles.

The relations of the conglomerate to the amygdaloid in Newton and Brookline are very puzzling at some points, indicating that here, as in the South Shore district and Milton, the amygdaloid has been, locally, plastic and intrusive. The occurrence of the Shawmut breccia here (see *ante*, pp. 171 and 173) also increases the confusion, and adds to the difficulty of tracing the exact limits of the conglomerate. The conglomerate in the vicinity of Holyrood Cemetery, and generally around the borders of the amygdaloid, is unusually coarse. The isolated patches, veritable islands, of conglomerate lying on the amygdaloid are of especial interest, as showing the former continuity of the Primordial beds over this denuded crystalline axis, and proving the inferior position of the conglomerate with respect to the slates. These islands seem to be numerous, but I have only shown on the map the one first observed, and probably the largest. The isolated masses of amygdaloid in the conglomerate between the main mass of the amygdaloid and the slates on the north, which are likewise much more numerous than represented, appear to be narrow, elongated, dyke-like masses, conforming with the strike of the conglomerate; but they are probably to be explained partly by faulting, and not wholly by extravasation, though there can be no question that some of the material is truly exotic.

It is, of course, not improbable that such a broad, unsymmetrical fold should be somewhat broken. Evidence of one or more faults along the southern border has been already pointed out, and others doubtless exist; but the rock is too homogeneous for their detection. The strongest argument for their occurrence is the consideration that, otherwise, even if we assume the average dip to be as low as fifteen degrees, and it certainly exceeds this, the volume of the conglomerate would be so great as to be entirely inconsistent with the sections measured elsewhere. An average dip of fifteen degrees would, if the section were unfaulted, correspond to a maximum thickness of nearly two thousand feet. From its southern border northward, the conglomerate maintains a high southerly dip, 60°–90°, for at least three-fourths of a mile across the strike, *i.e.*, to a point one-fourth mile north of the Forest Hills escarpment; equivalent to fully thirty-five hundred feet of unfaulted beds. Beyond the line indicated the inclination probably diminishes gradually, but it is a region unfavorable for accurate observation.

In the woods north of Williams Street, and east of Forest Hills Street, the dip is not less than twenty-five degrees to the south. In the high conglomerate masses on either side of Glen Road there are obscure indications of a southerly dip of fifteen degrees. On Walnut Street, between Glen Road and School Street, the dip is about the same; and the conglomerate is extremely coarse. South of Seaver Street the dip is, perhaps, as low as ten degrees; but it is still southerly. About midway between the Boylston Street and Jamaica Plain Stations on the Boston and Providence Railroad the inclination appears to be zero; but north of this, between Spring Park Avenue and Boylston Street, the beds are still inclined perceptibly to the south. Beyond this there seems to be, as already stated, a broad band of nearly level strata. As indicated on the map, the anticlinical is undoubtedly narrower toward the east, and in this direction the crest is reached at a shorter distance from the southern border. On the line of the New York and New England Railroad, from south to north, the following dips have been observed: at Mt. Bowdoin Station, a high but uncertain angle to the south; at Wales Place, midway between Green and Quincy Streets, S. 20°–25°; in the vicinity of Bird Street Station, S. 5°–10°; and between this point and Dudley Street, the beds are horizontal or nearly so. About Meeting-House Hill there is a perceptible southerly dip. I have not been able to make out any reliable indications of bedding in the conglomerate at Savin Hill, but it is probably about horizontal. The rock is here very neatly divided by veins of quartz running both with and across the strike, following the master-joints. The only exposure of conglomerate north of Savin Hill is on Dorchester Avenue, south of Mt. Vernon Street, where a great mass of conglomerate boulders overlies a low ledge of the same rock. The arenaceous beds are irregular, but seem to indicate a low dip to the north. This conglomerate has been encountered under Mt. Vernon Street, in the tunnel for the Moon Island sewer.

On Warren Street, near Quincy Street, and on Washington Street, near Codman Avenue and Townsend and Elmore Streets, the conglomerate, though slightly undulating, will average horizontal. This general absence of dip continues all the way to Alpine Street, where the level layers of sandstone stand out very distinctly; but between James and Cliff Streets the most northerly exposure on Washington Street shows an apparent dip to the north of perhaps fifteen degrees.

On this line and farther east the central band of approximately horizontal strata is nearly a mile wide, but along the Boston and Providence Railroad it is narrower. In the vicinity of the Whispering Chimney, in the angle between Centre and Highland Streets, the strata are about horizontal, showing only a slight easterly dip. A large east-west dyke traverses the north side of this ledge. On the hill above, near the Stand-Pipe, the dip is unsettled, but begins to be northerly. On and near the railroad, between Heath and Roxbury Stations, at the large quarry already mentioned, on Tremont Street, nearly one-fourth mile west of the railroad, and east of the railroad, in the bold ledge at the western end of Linden Park, there is a pronounced northerly dip of ten to twenty degrees. On Warren Street, near Walnut Street, in Brookline, the conglomerate is canted slightly to the north; and on the Woonsocket Division of the New York and New England Railroad, nearly half a mile east of Brighton Street, it dips north at an angle of perhaps twenty-five degrees. West of this, along the north side of the amygdaloid, all my observations show the same general fact, a northerly dip not exceeding thirty or forty degrees, and diminishing rapidly toward the south.

Taking a general view, I have observed that the conglomerate not only becomes smaller-pebbled north and south from the amygdaloid axis, but also toward the east. This may be the result of increasing distance from the ancient shore line, or of a declination of the axis in that direction, so that the beds exposed on the crest of the fold in Dorchester overlie those on the same topographic level farther west; the latter view appears most probable.

The low dips, and in many cases entire absence of inclination, characterizing a large part of the Roxbury and Brookline conglomerate, afford the principal basis for the prevalent idea that this rock is newer than and overlies the highly inclined slates on either side; but I fail to see that this view is warranted by the facts indicated. Along the middle of the belt the evidence is plain that the conglomerate simply forms a broad, low, flat-topped arch; but towards the borders all the circumstances of dip and texture lend unequivocal support to an opinion the contrary of that commonly held. The fact is that, as I have frequently stated, as regards both dip and strike, the conglomerate and slate seem to be everywhere perfectly conformable; and the former underlies, always, save where the strata are faulted or inverted, dipping toward the nearest band of slate; while the slate just as invariably dips away from the nearest conglomerate. I am speaking now with special reference to this large area of conglomerate and the slates which border it; and yet I consider that, with some unimportant exceptions, which are more apparent than real, the foregoing statement holds true for the whole Boston basin.

The Upper Falls, Chestnut Hill, and Boston Slate Belt. — Boston proper, South Boston, and the northern half of Roxbury, are unquestionably underlaid mainly, if not wholly, by slate; but, since these districts constitute a region of almost unbroken drift, and the first rock met on the south is conglomerate, the determination of the boundary between the Roxbury conglomerate and the slate is largely a matter of conjecture. The magnificent ledge of conglomerate west of the Roxbury station, on Tremont Street, formerly extended as far north as Conant and Station Streets; and conglomerate ledges are prominently placed on the east side of the railroad immediately north of Roxbury Street; but north of this, and of a line from here to Mt. Vernon Street in Dorchester, everything is concealed. The fact that at Mt. Vernon Street the conglomerate has scarcely begun to show a northerly dip, and the abundance of the loose masses of conglomerate scattered over the extreme northern end of Dorchester, convince me that here at least the border of this rock runs farther north than indicated on the map.

According to Mr. W. W. Dodge,[1] there was formerly a quarry of slate in the north-west part of South Boston, near the corner of Fourth and E Streets. A dark-colored, homogeneous slate is now exposed on F Street, north of Broadway, dipping north in the neighborhood of sixty degrees. I was directed to this exposure, which appears to be the only one now existing in South Boston, by Mr. Henry Richards. A "slate ledge," it is well known, exists in the shallow water off the north side of South Boston. One and a fourth miles east of this sunken ledge there is compact gray and grayish-black slate on Governor's Island. I have not visited this island, but, according to the labels on specimens collected, and given me, by Prof. W. B. Rogers, the rock is much disturbed, the strike varying from N. 80° W. to N. 10° E., a range of ninety degrees. There are no natural exposures of the rocks in East Boston or Boston proper; but the artesian well of the Boston Gas Company, on Causeway Street, 1,750 feet deep, was bored almost wholly in slate, the last fifty feet only being in a harder rock, apparently crystalline, though this may be conglomerate. Of course the nearly seventeen hundred feet through slate affords no clue to the thickness of that rock at this point, farther than to determine a maximum limit, for the beds are probably highly inclined, the well cutting them very obliquely. Dr. T. Sterry Hunt has shown,[2] that the water from this well, while differing widely in chemical composition

[1] Proc. Bost. Soc. Nat. Hist., xvii., 411.
[2] Proc. Bost. Soc. Nat. Hist., xvii., 486.

from modern sea-water, agrees closely with the water obtained by similar wells from the Cambrian strata of Canada, — a fact which points to the Cambrian age of our Boston slate. Slate has also been encountered in the bottom of a well eighty or ninety feet deep at the corner of Brookline Street and Harrison Avenue, and in a well one hundred and seventy feet deep at No. 791 Tremont Street.

Assuming, as I think we may, that a broad band of slate underlies the districts mentioned in the preceding paragraph, including Governor's Island, and tracing it toward the west, we find that its breadth is diminished rapidly where it passes like a wedge between the immense masses of conglomerate on the north and south. There is conglomerate in Brookline, on Cypress Street, north of the New York and New England Railroad, and on the south side of this railroad nearly one-half mile east of Reservoir Station. Conglomerate and amygaloid form extensive ledges south-west of the crossing of Brighton and Harvard Streets in Brighton; the former rock outcrops on the north-west side of Corey's Hill, and almost continuously from this point to where Beacon Street meets the Chestnut Hill Reservoir. In the vicinity of the reservoir the breadth of the slate band cannot exceed one-fourth of a mile. On Beacon Street, where it crosses the Brighton and Brookline boundary, the thin-bedded, gray and brown slate has a variable, mostly gentle, dip to the north. At the crossing of Brighton Street and the New York and New England Railroad, Reservoir Station, the same slate, mostly grayish, inclining to black, and somewhat contorted, has a northerly dip of 25°–30°. The magnificent section transiently exposed during the construction of the Chestnut Hill Reservoir has been described by Prof. N. S. Shaler[1] as follows: " On the south border of the lower reservoir at Chestnut Hill there is an outcrop of rocks in all important respects closely resembling the Cambridge slates. These are traceable for a distance of about seven hundred feet in a northerly direction across the floor of the reservoir, having

[1] Proc. Bost. Soc. Nat. Hist., XIII., 176.

a nearly north dip at an angle of about fifteen degrees. Immediately above these and without any discordance comes the first of the conglomerate beds, which consists of a bed about ten feet thick of pebbles mingled with slates. This is surmounted by about thirty feet [traverse measure?] of slates having a most perfect cleavage in the plane of stratification. It is not difficult to split a sheet a foot square having a thickness of not over one-twentieth of an inch. Immediately above this slate the conglomerate comes in again and continues with its northern dip for a horizontal distance of over a mile."

This slate belt, still narrowing, crops next on the north side of Beacon Street, just east of Newton Centre, and near the western end of the long tunnel on the new or Sudbury River aqueduct. At this point we have, from the New York and New England Railroad (Woonsocket Division) northwards, the section represented in Pl. 5, fig. 1. It begins with the northern border of the great mass of conglomerate which spreads south of the railroad, with rapidly diminishing dip, for nearly a mile. This is cut off by amygdaloid, which forms a band less than fifty feet wide, running parallel with the strike of the conglomerate and the master-joints, which are well developed here, and traceable in that direction for about one-fourth of a mile. This is one of the many isolated masses of amygdaloid cutting through this belt of conglomerate. The rock is the usual chloritic variety, and only slightly amygdaloidal. It is bounded on the north by about twenty feet of brownish-red slate, ripple-marked, and including sandy beds with layers of pebbles. The contact of the slate and amygdaloid can be distinctly observed at several points, and it places beyond question the exotic nature of the latter rock. Above the red slate, which is merely a part of the conglomerate, there are at least five hundred feet, traverse measure, of small-pebble conglomerate, with limited sandy layers, reaching to the south side of Beacon Street. There are no exposures in the street, but it is probably underlaid here by slate; and on the north side is the well-known ledge of this rock. The bedding of the slate is very thin and even. The slate is gray, or, in part, of a purplish-brown color, and somewhat contorted. It reaches about half way up the slope above the road, and is then overlaid by conglomerate, which extends, without sensible interruption, to the great mass of amygdaloid on the north, a distance of half a mile.

All the stratified rocks in this section have a northerly dip of 30° to 40°, and from the slate downwards they appear entirely conformable. The slate and the overlying conglomerate, however, are clearly unconformable. In the first place the passage is perfectly abrupt, no shading of the one rock into the other; and the conglomerate cuts off the slate very obliquely, both in the direction of the dip, *i.e.*, the conglomerate has a steeper dip than the slate, and along the strike, so that the conglomerate gradually approaches the street as we follow the contact east or west from the highest layer of slate. In fact, the portion of the slate exposed here is almost as limited along the strike as across it, being entirely cut off by the conglomerate at a distance of a few rods towards the east, and the same appears to be true on the west; but in this direction the unconformity might result in part from a transverse fault. The unconformability of the slate and conglomerate is proved, also, by the aqueduct tunnel, which has a course almost exactly parallel with the strike of the beds; it begins on the west in conglomerate, but soon passes into the slate, which it follows for perhaps one hundred and fifty feet, and then re-enters the conglomerate, both transits being entirely abrupt.

I have searched in vain for croppings of slate between this place and the reservoir; but when drawing the map I considered the slate as continuous between these points, though concealed by the drift; it now seems probable, however, that this view will have to be abandoned, for a portion of the distance at least, since over much of the intervening ground the conglomerate ledges are so numerous as to practically leave no room for any considerable bed of slate.

West of Newton Centre the slate appears again in an obscure ledge on Beacon Street, immediately north of Baptist Pond. It is of a pure gray color, and so massive that I could not determine the dip. Beyond this there are no outcrops for more than a mile; but the slate-belt is well exposed between Woodward Street and the Charles River. It here experiences a southerly deflection, the strike of the beds shifting to north-east. The strike of the conglomerate, south of and under the slate, also changes, so that the two rocks remain entirely conformable. The southern portion of this conglomerate, where it adjoins the amygdaloid, is exceedingly coarse, and lies almost horizontal. A good point to observe this is on the new street leading south from Newton Highlands Station on the New York and New England Railroad (Woonsocket Division). Proceeding northward the dip in that direction gradually increases, and the pebbles become smaller.

Between the railroad and Boylston Street the river has cut a gorge through high masses of conglomerate; and just south of Boylston Street these include gritty layers, which show a north-west dip of 35° to 40°. One-fourth mile north-east of this point, on the line of the Sudbury River aqueduct, the same horizon of conglomerate crops again. The beds transiently exposed here during the construction of the aqueduct contain a large amount of pinite, resembling the conglomerate at the east end of the petrosilex in Milton. It is traversed along the strike by a mass of amygdaloid, apparently in the same way as in the glen east of Newton Centre. The dip and strike are the same as on Boylston Street, and toward the north-west the conglomerate passes into and is conformably overlaid by a distinct, ripple-marked, brownish-gray sandstone, which becomes finer away from the conglomerate. This passage can be traced in almost continuous outcrops, the ledges having trends conspicuously parallel with the strike. North-west of the sandstone, after two hundred feet concealed, is an outcrop of brownish or purplish-gray arenaceous slate, also ripple-marked, and dipping north-west 35°. Following this line of strike back to the river, we have, at a distance of perhaps five hundred feet north of Boylston Street, exactly the same slate, though somewhat contorted as well as ripple-marked, dipping N. 50° W. 38°. At both points this slate is very fissile in the direction of the bedding, and near the river it holds an occasional stray pebble. About two hundred and fifty yards north of the exposure on the river bank there is a more prominent ledge of slate; this rock is very fine, showing no trace of ripple marks or of an arenaceous or pebbly texture, and is of a pure gray color. It is very thin-bedded, and much crinkled. The dip is N. 45° W. 33°. On the southern end of this ledge the slate is cut off along the strike by amygdaloid.

North and west of these slate ledges there is a wide area of unbroken drift, and the overlying rocks cannot be seen. On the west side of the river there is no slate exposed; but on the line of strike of the slate belt, north of Boylston Street, there is first conglomerate, with arenaceous beds, dipping to the north, then a large, high mass of amygdaloid (probably connected with that lying to the north-east on the east side of the river, and mentioned in the last paragraph), which is followed by more conglomerate in obscure ledges not showing dip; and beyond this, both north and west, everything is hidden for nearly a mile. South of Boylston Street, west of the river, the conglomerate outcrops abundantly and in large masses; and where it adjoins the amygdaloid on the west the relations of the two rocks are well displayed. The conglomerate is thoroughly consolidated and indurated near the contact, and yet it is largely composed of pebbles of apparently the same amygdaloid with which it is so curiously involved. The contact is extremely irregular, and portions of the conglomerate appear to be isolated from the main mass.

More than one observer has appealed to the Upper Falls and Chestnut Hill band of slate as proving conclusively that there is at least one considerable body of slate in the Boston basin underlying, in its *normal position*, a portion, at least, of the conglomerate. That this slate overlies the conglomerate on the south can scarcely be questioned, and is generally admitted.

Not only do all the circumstances of dip favor that view, but the increasing fineness of this conglomerate toward the slate points to the same conclusion. The slate almost as clearly underlies the conglomerate on the north. According to Prof. Shaler this was shown very distinctly when the bottom of the Chestnut Hill Reservoir was exposed, and it may be seen now along the eastern border of the reservoir. At the Newton Centre ledge the superposition of the conglomerate is very plain, but west of this the contact is not exposed again. One of two things must be true: either the slate actually passes beneath the conglomerate as it appears to do, or this appearance is due to a complicated fault with the downthrow on the south. Something may be said in favor of the latter view.

At Newton Centre, as already stated, the slate appears to be dislocated along the strike by a transverse fault, and the transition to the overlying conglomerate is very abrupt, with a very evident, though slight, unconformability. At the Chestnut Hill Reservoir, too, there are abrupt changes of dip; thus the most of the slate in and about the reservoir is inclined to the north at low angles of fifteen to thirty-five degrees; but on the western side of the lower basin, just south of Evergreen Cemetery, there is a small mass of gray slate with a northerly dip of not less than seventy degrees; while the conglomerate of the northern band shows dips in the same direction, ranging from thirty to seventy degrees. The passage here is sufficiently gradual, being marked by several alternations of slate and conglomerates. This border zone is now well exposed in the embankment on the east side of the reservoir, and Pl. 5, fig. 2, shows that we actually have at this point indubitable evidence of at least local strike-faulting. The conglomerate in this section is obscurely bedded, and the dip cannot be determined with certainty; but it is undoubtedly the same as that of the intercalated slates, which is variable and very high — seventy to ninety degrees to the north. The joint or cleavage planes of the slate, which have some resemblance to stratification, show a northerly dip of about forty-five degrees.

Notwithstanding, however, that these facts favor the dislocation theory, I am more inclined to accept the view that the slate actually underlies the conglomerate; but now another question arises, Is this the *normal* and *original* position of the slate? *i.e.*, are there really two distinct zones of conglomerate, separated by a formation of slate? I think not. The dislocation theory would require us to believe that the conglomerates on the north and south of the slate are the same, and to my mind this is equally consistent with the view here adopted. In other words, I regard these rocks as forming an inverted, closed, and doubtless more or less faulted synclinal fold. I conceive that the conglomerate underlying the slate on the south is continuous beneath the surface with that overlying it on the north, and that the slate is folded sharply upon itself. The unquestionable fact that there is a well-marked passage both ways from the slate to the conglomerate is favorable to this view, and the way in which the conglomerate appears to bend around the slate at the western end of the belt harmonizes better with a synclinal structure than any other.

The northern band of conglomerate is not exposed on the surface between the Charles River and Newton Centre; but that it actually exists there is plainly indicated by the abundance of conglomerate in the drift north of Newton Upper Falls, though of course it may not be represented with entire accuracy on the map. There are abundant outcrops on this line east of Newton Centre, and wherever discernible the dip is northerly. On Grant Avenue, one-half mile north of Beacon Street, a slaty band in the conglomerate dips north sixty or seventy degrees. The vicinity of Newton Centre is a good point to study a section of the synclinal, for there are almost continuous outcrops from the amygdaloid on the south to that on the north. In the vicinity of Waban Hill there are no ledges, but east of Lake Street, as already stated, they are as numerous as could be desired.

As the syncline of slate expands eastwardly it probably becomes more normal in form; while the broadest portion of this belt, underlying Boston and the harbor, if unfaulted, must include several distinct folds. As already stated, the failure of the slates to appear on the surface between the reservoir and Newton Centre can scarcely be attributed to a scarcity of outcrops, for these are abundant. There are three other hypotheses which suggest themselves, but neither of them affords an explanation which is entirely satisfactory. Firstly, we may suppose that in this part of the syncline the denuding agents have cut below the bottom of the slate. But this is improbable, because the ground at this point is higher than to the east or west, where the slates are now exposed; and then it is unlikely, too, that the not less than eight hundred feet, traverse measure, of slate underlying the reservoir would taper out to nothing, either vertically or horizontally, in so short a distance. Secondly, it is possible that the slate is concealed by a strike-fault, having the downthrow on the north. This might be an approximately vertical fracture; or, thirdly, we may suppose that the inverted anticline represented by the conglomerate on the north of the slate has been broken along the crest at some points, and the upper half forced, by the horizontal pressure producing the fold, beyond the lower half, cutting the slate off in whole or in part. The last seems, on the whole, the most satisfactory view; for that this horizontal pressure has been exerted, and that it has produced fractures in that direction, to a certain extent at least, we have evidence in the section represented by Pl. 5, fig. 2; which may, I think, be regarded as an example on a small scale, affecting a single layer of slate, of the fracture and dislocation which have at certain points concealed the whole breadth of that rock.

I would suggest, too, that we may find in the pressure of this overturned anticline, which originally embraced twice the entire volume of both the conglomerate and slate and was forced by tangential pressure as well as gravity against the slate folded in the syncline, an adequate explanation of the eminent cleavage parallel with the bedding — lamination-cleavage — which forms the leading characteristic of the slate in this belt.

The Conglomerate bordering the Newton Lower Falls and Brighton Band of Amygdaloid. — I have not observed any isolated patches of conglomerate in the Newton Lower Falls and Brighton band of amygdaloid, save in the detached portion at the eastern end; but this band is represented by so few outcrops that many such islands might easily exist undiscovered. The amygdaloid, however, is bordered by a continuous belt of conglomerate on the north similar to that on the south, and these two are almost certainly connected in Brighton, and were probably once continuous across the amygdaloid at least as far west as the Charles River. The great overturned anticlinal of which these two bands of conglomerate are merely remnants, the roots, as it were, and the amygdaloid the denuded axis, is completely broken down in Brighton by strike faults, many of which have been attended by extravasation of the amygdaloid. The structure of this district is very similar to that of the Nantasket area, consisting of monoclinal dips, faults, and igneous intrusions. The prevailing dip is northerly, twenty to forty degrees; and the principal dislocations are along east-west lines, with the downthrow in each case on the south, and so great that in several instances considerable masses of the overlying slates have been dropped below the present surface, and thus preserved from denudation. As may be observed on the map, several of these slate patches are beyond the borders of the amygdaloid, showing that some of the faults failed to expose the latter rock; and it seems fair to conclude that there are probably still other faults not now marked by either amygdaloid or late, and for that reasons undiscoverable.

In this broad band of conglomerate, which is not less than a mile wide, and has an average and nearly uniform northerly dip of at least thirty degrees, we are able to see, by means of the strips of slate and amygdaloid and the faults which they represent, that the apparent thickness of the conglomerate, about twenty-five hundred feet, must greatly exceed the true thickness, perhaps several times; and this adds immensely to the probability of the conclusions I have stated in the preceding pages concerning the structure of, and volume of strata involved in, the other broad areas of conglomerate characterized by a monoclinal dip. In this Brighton district, and also in the Nantasket area, the faulted structure may have, perhaps, an extreme development, as regards the number of fractures, or amount of dislocation, or both; and yet I believe that the same type of structure, although far less evident, characterizes a large part of the Boston basin.

The scale of the map is too small for the accurate delineation of the rocks of this complicated area; but the general outlines given suffice to show the plan of the structure. The portion of this conglomerate belt mapped as occurring in Brookline is hypothetical, with the exception of an outcrop on the western end of Corey's Hill, and several ledges on Washington Street. There are magnificent exposures of the conglomerate on this line south of Washington and Union Streets in Brighton; and the dip, wherever observable, is about thirty degrees to the north. On Breck Street, in the angle between Washington and Allston Streets, the conglomerate, small-pebbled and arenaceous, is overlaid by perhaps two hundred feet, traverse measure, of a soft, homogeneous, pure gray or slightly greenish, slate. It is thin-bedded, and dips N. 35°. The actual contact with the conglomerate is not seen on either side, though ledges of this rock approach very near on both the north and south; but the slate is probably cut off by a fault in the direction of the dip, and does not underlie the conglomerate to the northward. The rock exposed between Washington and Warren Streets is mainly conglomerate; but on Allston Street, between Summit Hill Avenue and Warren Street, and north of the line of strike of the slate on Breck Street, there is brownish and grayish slate. The bedding is distinct, but shows immense disturbance, standing nearly vertical, and striking toward all points of the compass. This slate has a well-marked, but irregular cleavage dipping north-north-east about forty-five degrees. Nearly due east of this, in the large gravel quarry on Winchester Street, the same slate, but perhaps a little less disturbed, is exposed again. The general line of strike is evidently east-west, and the bed has a greater extent in that direction than is indicated on the map. A similar grayish and slightly arenaceous slate appears on the south side of Warren Street, a few rods west of Allston Street; it is still considerably contorted, but has a settled dip and strike, the beds inclining to the north twenty to thirty degrees. These three croppings of gray contorted slate probably belong to the same bed; but, if so, the one last described is separated from the other two by a fault.

North of this line of strike, and farther west, along the south side of Warren Street, there are extensive ledges of grit and sandstone, with pebbly layers at the base, and passing to slate at the top; the dip is northerly twenty to thirty degrees. Immediately north of these ledges Warren Street appears to be underlaid by amygdaloid; but on the north side of the street the sandstone, distinctly ripple-marked, dips N. 10° W. 30°. On the east this is underlaid by amygdaloid, and indurated near the contact; and a little farther east it is apparently overlaid by, but cannot be seen in contact with, a contorted and rippled gray slate, which crops at two points along the strike, and dips N. 10° W. 25°–35°. A little south of this gray slate, and yet farther east, is amygdaloid, overlaid on the north by a brownish-red, arenaceous slate striped with green, dipping N. 20°–30°, and thoroughly indurated near the amygdaloid, the contact showing clearly the intrusive nature of the last-named rock. This brownish slate probably passes on the west between the gray slate and the sandstone; its geographic position shows this; and, besides, about ten rods farther north there is another ledge of amygdaloid, overlaid on the north, again, by a brownish-red slate precisely similar to the last, but passing upward into the homogeneous gray slate, which is very thin-bedded and dips N. 25°–30°. As before, the slate is well baked near the amygdaloid; the contact is extremely irregular, typically igneous, though showing at the same time much faulting. A study of these patches of sandstone and slate teaches that these rocks are not only cut off and faulted by the amygdaloid transversely and along the strike, but that they have also been forced asunder at intervals by intrusive beds of this semi-igneous material.

Immediately north of the ledge last described there is another long narrow mass of the indurated red slate, with the usual dip. It is of almost jaspery hardness, and is overlaid by amygdaloid; in fact, though much broken and contorted, and of very irregular outline, it appears to be entirely isolated by that rock which is part of a prominent east-west ridge of amygdaloid extending from Cambridge Street nearly to the Brookline boundary.

The amygdaloidal texture is well developed in the most of this great mass; and it is an interesting observation that the only two localities in all this region characterized to any extent by a typical amygdaloid — Brighton and Nantasket — show this rock occurring under precisely similar conditions as regards its relation to the slate and conglomerate, and are at the same time the points affording the most indubitable evidence of its extravasation. Just west of Allston Street this ridge is flanked on the north by a brownish slate dipping N. 40°–45°, and very plainly cut off by the amygdaloid toward the east; it is also traversed by a north-south, vertical trap-dyke four feet wide.

Though not traceable all the distance on the surface, this bed of slate, with a breadth of from one hundred to two hundred feet, appears to extend to and across Cambridge Street, running between two amygdaloid ridges. Just south of Cambridge Street the red slate can be seen passing beneath the amygdaloid, or abutting against it with a northerly dip of thirty-three degrees. On the north side of Cambridge Street, near the Brighton Water-Works, the slate, considerably faulted on a small scale, intersected by endogenous quartz, and dipping N. 25°–30°, is very clearly overlaid by the amygdaloid; and both rocks are cut by north-south vertical dykes of diabase, one of which, about twelve feet wide, is well known as an admirable example of the formation of boulder-like masses *in* *situ* by the decomposition and exfoliation of the irregularly cuboidal blocks into which the rock joints.

East of Allston Street the amygdaloid on this line appears to divide so as to include a large mass of conglomerate, with sandy layers, and the usual northerly dip. Directly north of the Water-Works, and midway between Cambridge and North Beacon Streets, a thin-bedded, undulating, gray slate dips N. 20° E. 32°; and this is followed on the north side of North Beacon Street, a few rods west of Everett Street, by conglomerate with sandy and slaty beds dipping N. 10°–15° E. 30°–35°. Along certain lines, especially, the slaty layers, as already observed (*ante*, p. 190), are small and lenticular, often resembling pebbles. In this ledge, which is on the edge of the Charles River alluvial flats, and the last exposure south of the river in this part of its course, the finer materials are most abundant toward the north, indicating a passage to slate in that direction; and since we are now beyond the range of the amygdaloid, and fewer repetitions of the strata are to be expected, I think it is safe to conclude that the flats are underlaid chiefly, if not wholly, by slate. This conclusion, as will presently appear, is confirmed by observations made farther west.

This band of conglomerate bordering the amygdaloid on the north is represented by few and widely separated exposures in its western extension. It shows everywhere a northerly dip, and generally at high angles, especially along the northern edge, where, as just hinted, there are plain indications of a passage to slate. The relations of the slate and conglomerate on this line appear to be essentially the same as along the northern border of the West Roxbury and Dorchester slate belt.

At the corner of Lake and Washington Streets, sandstone and conglomerate, closely involved with the amygdaloid, dip gently to the north. A short distance east and south-east of the station at Newton Corner, on and near the railroad, there is an unquestionable gradual transition from conglomerate to slate northwards. The conglomerate is small-pebbled and schistose, containing pinite, with arenaceous beds, which appear to increase and become finer, until the formation is changed to a compact gray slate. All these rocks are greatly disturbed by trap dykes, some of which are quite large, and of coarse texture; and the slate especially seems to dip in all directions and at all angles; but the prevailing dip for both the slate and conglomerate is steep — 70° to 80° — to the north. Nearly two miles west of this, on the south side of the railroad, the same conglomerate, with intercalated sandstone, strikes N. 70° E. with a vertical dip. Near the West Newton Station there is slate just south of the railroad; and in the vicinity of Auburndale Station, on the same side of the track, conglomerate passing to slate, with a high, nearly vertical, north-north-west dip.

The Conglomerate and Slate in Needham and South Natick. — Between Auburndale and the crystallines west of the Charles River exposures are wanting; and towards the south and south-west there is a wide area of unbroken drift. I have represented the conglomerate and slate which we have traced from Brighton nearly to the Charles River as extending south-westerly between the amygdaloid and the crystallines on the north-west, the conglomerate as a double band enclosing the slate, which, as usual, has a synclinal position, the axial plane of the syncline dipping at a variable angle toward the north-west. This narrow geologic trough is very prolonged, extending through Needham and South Natick nearly, if not quite, to the boundary of Sherborn. The observations upon which these conclusions are based, though few, are fairly satisfactory.

East of Grantville Station on the Boston and Albany Railroad, after crossing the petrosilex, there is conglomerate passing to slate, with a north-west dip. According to Mr. Dodge, conglomerate occurs about three-fourths of a mile E.N.E. of Wellesley Station, near the road to Newton Upper Falls. On the road running south from Wellesley, south of Dewing Brook, I found conglomerate with grits, and on the line of the

Sudbury River Aqueduct a purplish slate dipping N.W. perhaps forty-five degrees. South of the slate there is room for more conglomerate before the first of the amygdaloid is reached, but I believe none is exposed. The aqueduct tunnel one-fourth mile north of the Charles River, in the Village of South Natick, is excavated in the rocks of this synclinal; and they are also exposed in natural ledges at either end. Two bands of conglomerate enclose a band of slate, and all show a very high north-west dip. The conglomerate is brownish and greenish, small-pebbled, schistose, and largely composed of pinite. The slate is of the same colors, soft and unaltered. On the north the conglomerate is in contact with, apparently dipping against, Huronian quartzite; while on the south it appears to overlie the slaty and felsitic rocks which I have referred to the Shawmut group. This pinched up and overturned synclinal, growing gradually narrower, but still including some slate, and otherwise essentially unchanged lithologically, may be traced south-west as far at least as the east end of the Rockland Street tunnel of the aqueduct, one-fourth mile west of Cottage Street. The slate at this point is reddish-brown, and divides into small lenticular masses, with surfaces of chlorite.

According to my observations, this is the extreme western limit of the uncrystallines of the Boston basin; and I think we may safely conclude that they never extended much farther in this direction. For the rocks of this long narrow syncline—which has been traced fully six miles from the point where it branches off from the great mass of the conglomerate and slate in Newton, with a breadth probably not exceeding one-half mile, and gradually diminishing westward—are clearly an estuary deposit, having been laid down in an elongated arm of the sea. In other words, when, taking a general view, the western shore of Boston Harbor was near the eastern boundary of Needham, a contracted channel, analogous to the lower or tide-water portion of the modern Charles, reached six miles farther west. Of course folding and denudation have greatly diminished the breadth of this belt of rocks, and yet that they were formed under the conditions named above is indicated by their lithologic characters. The comparative tranquillity of the water is proved by the fineness of the material deposited. The conglomerate is small-pebbled and slaty, consisting mainly of pinite and the débris of argillaceous amygdaloid, with very few pebbles of harder rocks; while the ferruginous character of both the conglomerate and slate, especially toward the west, is a strong indication that the water was of limited extent, and communicated but imperfectly with the external ocean.

The tongue of amygdaloid projecting east between the granite of Dover and the petrosilex of Needham points to an extension of this primordial estuary in that direction, the main trough probably giving off a branch about midway of its length; and this surmise is confirmed by the occurrence north and east of Charles River Village of a band of conglomerate and sandstone splitting the amygdaloid. Toward the west this conglomerate is concealed by the drift, and its connection with the Newton and Natick band cannot now be proved; and yet there can be little doubt that this was its original, if it is not its present relation. As usual, under like circumstances, the conglomerate is closely involved with the amygdaloid upon which it rests and of the débris of which it is largely composed. The pebbles, except at a few points where the rock is very coarse, are small; and sandy and even slaty beds are frequently included. Much of the rock is of a deep red color, being highly ferruginous. This variety is well exposed in the cuts on the New York and New England Railroad, Woonsocket Division. At no other point in this region is the ferruginous character of the conglomerate and slate so strongly marked as here; and it is highly instructive to observe that this is the portion of the Boston basin which, during primordial times, was most completely landlocked and most remote from the open sea. The color of these beds is an indication at once of their estuary origin and of their narrow limits in ancient as well as modern times.

The broad Slate Belt, between the Boston and Albany

Railroad and the Crystallines of Waltham, Arlington, Medford and Malden. — Between the Boston and Albany Railroad and the Charles River on the north I know but one exposure of the rocks, and this I have not seen. It occurs in Morse's Field, near Newton Corner, and is described by Mr. Dodge[1] as varying from pure slate to fine sandstone, with a dip N. 20° W. 50°. On the north side of the river, according to the same observer, there is slate in the cattle market. The first rock exposed north of this is in the square bounded by Mt. Auburn, School, Belmont, and Grove Streets. Here is found the only ledge of conglomerate known between the Charles and Mystic Rivers. The rock is small-pebbled, slaty, and evidently composed mainly of the débris of amygdaloid. The dip is not observable in the conglomerate, but toward the south this rock is clearly traceable into a sandy slate with a moderate southerly dip; and this changes on the south, again, as is indicated by a ledge a few rods south-east of the conglomerate, to a fine, gray slate, dipping S. 20° E. 70°–80°. The material evidently becomes finer, and the dip steeper, away from the conglomerate. The imperfect cleavage of this slate dips north in the neighborhood of seventy degrees. There is evidently exposed here only the upper part of the conglomerate formation, where it is changing to slate; and its position is undoubtedly anticlinal. The slate between this point and the conglomerate south of the river, it will be observed, shows synclinal dips; but the breadth of this belt, together with the high average dip, leads to the inference that there is probably an anticlinal entirely concealed here. Near the junction of Common and Orchard Streets, in Watertown, there is enough conglomerate in the drift to warrant the belief that this rock actually occurs here *in situ*, though not exposed. It is of the same general character as that between School and Grove Streets, and is on precisely the same line of strike, though nearly a mile distant; this is a pretty strong indication that the conglomerate anticline is continued in this direction.

[1] Proc. Bost. Soc. Nat. Hist., XVII., 401.

Obscure outcrops of homogeneous gray slate are numerous between Belmont and Orchard Streets, near Lexington Street, but they afford no reliable indication of the dip. The slate on North Street, just west of Common Street, is gray, distinctly stratified, and without cleavage; it dips N. 20°–25° W. about 60°. One-half mile east, a short distance west of School Street and midway between Belmont and Washington Streets, a soft, slippery, well-cleaved slate has substantially the same dip as the last. The foregoing are all the exposures of the uncrystallines with which I am acquainted in Watertown; and while, in connection with the drift, they show that the rock is mainly slate, the structure of the region remains almost entirely a matter of conjecture. These meagre data, however, afford some ground for the opinion that the rocks of this district are thrown into a series of folds running parallel with the crystalline border on the north, the position of one anticlinal axis being marked by the conglomerate.

In Belmont and Arlington the uncrystallines do not reach the surface, and the same is nearly true for Cambridge. Excavations made for a sewer in the yard at Harvard College, in 1871, exposed the slate at a depth of twelve feet, with a gentle southerly dip. The general absence of conglomerate from the drift of this large area of thirty or thirty-five square miles, lying between the conglomerate of Brighton and Newton on the south (this border being pretty accurately marked by the Boston and Albany Railroad), and the crystallines of Malden, Medford, Arlington, Belmont, and Waltham on the north, together with the testimony of such outcrops as occur, renders it certain that the underlying rock is almost wholly slate. In Somerville, as is well known, there are abundant exposures of this variety. This city and, probably, Cambridge constitute a region of monoclinal dips. Except at a few points, where the slates are locally disturbed by intrusives, the strike in Somerville ranges between E.–W. and N. 60° W., averaging about W.N.W.; while the dip, with rare exceptions, is southerly, and usually at low angles, the average inclination probably not exceeding thirty degrees. The slates on the north are, therefore, presumably the oldest and lowest.

The Somerville slates are, on the whole, quite homogeneous; the texture is usually fine and even, and the principal colors are gray, bluish-gray, and nearly black. The stratification is marked in colors, and is ordinarily distinct, although the bands are narrow and little conspicuous. Taking a general view, the slate, as noted by Mr. Dodge, becomes gradually coarser and more arenaceous toward the north. This is a significant fact, as indicating a passage to conglomerate in that direction, or downwards, and thus showing a harmony between this and the other slate areas in the Boston basin. Pyrite cubes are of common occurrence in the slate, and at some points the slate is decidedly pyritiferous. Wave-marks, contortions, minute faultings, and anything approaching cleavage, are of rare occurrence. The slate is frequently altered in the immediate vicinity of intrusives, but never to the extent observable in Brighton or Nantasket. The steepest dips are on the north, and in this direction particularly there are frequent and abrupt changes in the direction and amount of the dip; so that in a distance of a few rods, or even yards, we may pass from horizontal strata to those that are vertical.

These slates are traversed by many dykes of diabase and, possibly, other basic exotics. The dykes are so numerous that nearly every quarry and outcrop show one or more, and they are of all sizes, from mere threads to masses hundreds of feet across; while the coarseness of the material is, in general, obviously proportional to the size of the mass. According to their trends, the dykes may be divided roughly into two sets,—one set coinciding in a general way with the strike of the slates, and the other running at right angles to this, or parallel with the dip. Many of these exotic masses, including to some extent the similar rocks of adjoining towns, have been studied microscopically by Mr. M. E. Wadsworth,[1] to whom we are indebted for all that is definitely known concerning their composi-

[1] Proc. Bost. Soc. Nat. Hist., XIX., 223.

tion and lithologic relations. He finds, as a general result, that the present diversity of composition, and, in some cases, of texture, is due to subaërial decomposition; the original essential constituents of all the rocks examined having been augite, feldspar, and magnetite, agreeing with diabase among the older exotics, or dolerite and basalt among the newer. The coarsest texture is found in the large quarry at the head of Granite Street, off Somerville Avenue (the well-known prehnite locality), and at the Powder House, near the corner of Elm Street and Broadway. These are both large masses: the latter has a trend about N. 20° E., and can be traced for one-fourth of a mile; but the boundary of the former cannot be seen at any point, and the shape of the mass is unknown. By reference to the map, it may be observed that these are nearly south of, and approximately on a line with, the immense dyke in Medford, with which I have already (*ante*, p. 22) connected them, this correlation being sustained by the observations of Mr. Wadsworth; and toward the south we find on the same south-by-west line the dyke near the Brighton Water-Works, which, though of finer texture, shows the same concentric decomposition as the rock in Somerville and Medford; while still beyond are the very large dykes in the west part of Brookline and on Lagrange Street, in Newton. This line is not less than ten miles long.

At least two of the dykes cutting the Somerville slate in the direction of the strike are traceable with considerable certainty for long distances. One of these first appears on the west in the large quarry on Tannery Lane, near the Cambridge Almshouse, where it is about twenty feet wide, and nearly vertical, with a trend S. 70° E. It crops at several points before reaching Holland Street, and in the vicinity of that street it is split up so as to reach the surface along several parallel lines. A few rods north of the Powder House, where a narrow excavation exists in the hillside, the large Powder-House dyke appears to be cut by a dyke of finer texture. This is precisely on the line of the Almshouse dyke; and, continuing in this direction, a large dyke forty to fifty feet wide, and dipping to the north nearly forty-five degrees, crops on both sides of the intersection of Main and Dexter Streets, in Medford; and beyond this it can be traced, without sensible change of course, nearly to Mystic Avenue, having an extreme length of more than two miles. The other long dyke is one-fourth to one-half mile north of the one just described. They are not quite parallel, but show an angular divergence toward the west of five to ten degrees. Number two, having the same width and general appearance as number one, first appears near the Mystic River, and for the first half mile it forms the well-marked escarpment which skirts the north side of Winter Hill, and overlooks the alluvial flats of the Mystic. It crops next immediately south of Professors' Row, in Somerville, and is seen for the last time near Curtis Street.

Many, if not all, of the local irregularities in the dip and strike of the slate are due to the disturbing action of the dykes. In some cases this connection is especially clear. The large Powder House dyke appears to send off a branch toward the west along the north side of Morrison Street, extending across Elm Street, and giving rise to lateral horizontal branches, which, forcing their way between the layers of slate, have lifted the overlying beds to a horizontal position.

One example of such an intrusive bed is now well exposed in the west side of the quarry. Another interesting phenomenon observable in this quarry is a north-south crevice, a foot wide, filled with small angular fragments of the slate, cemented by calcite. Toward the south-east the Powder House, or parent, dyke sends off a well-marked branch which extends to and across Willow Avenue, forming a small ridge. On the line of this ridge, on Cedar street, we find, not the diabase, but slate with an abnormal dip — S.E. 10° — as if it were exactly over the end of the dyke and tilted by the same. The action of intrusive beds in elevating and tilting the slates is very evident where the most southerly of the two long dykes described above crosses Main Street in Medford.

Assuming the average dip of the Somerville slates as thirty degrees, we have between the Mystic and the Fitchburg Railroad — nearly one and a half miles across the strike — an apparent thickness of not less than thirty-five hundred feet, and, if the Cambridge slate is included, very much greater. This fact alone is sufficient to render the existence of strike faults with the downthrow on the north exceedingly probable; but other general considerations point to the same conclusion, though the slates themselves are everywhere too homogeneous to show faulting through the repetition of particular strata. The principal elevations of Somerville form two well-marked, though discontinuous, ranges, which are nearly parallel with the strike of the slates. The more southerly of these includes Spring, Central, and Prospect Hills and the elevation occupied by the McLean Insane Asylum; while the northern range is composed of College and Winter Hills and Mt. Benedict, and appears to be continued by Bunker and Breed's Hills in Charlestown. Between these two is a much lower and less distinctly marked range, which, including the principal part of East Somerville, is recognizable at intervals to the western border of the city. The northern slopes of the two main ranges are sensibly the steepest, and in all respects the topography of the region is decidedly favorable to the fracture theory of its origin. The bases of the declivities, too, are marked at most points by extensive dykes parallel with their trends. On the north side of the more southern of the two long dykes in the north part of Somerville the slates show usually a gentle northerly dip, as if from the lifting power of the dyke; but toward the other dyke this changes rapidly, almost abruptly, to a high, and in some cases vertical, dip to the south.

The escarpment formed by the last-mentioned dyke, toward the east, is very suggestive of a fault. About two hundred feet north of, and parallel with, this escarpment is a second, less distinctly marked and about half as high, which shows no dyke, but indications of one, and slate dipping S.S.W. 40°–80°. The low island in the Mystic River crossed by the Eastern Railroad is on this line, and shows slate dipping south.

Slate east of Mystic Avenue, and ranging between the two long dykes, has a gentle northerly dip. In the cut on the Boston and Lowell Railroad, on the north side of College Hill, the slate dips south seventy degrees.

Although unable, as the foregoing résumé testifies, to cite evidence of an entirely irrefragable character, I am well satisfied that, to put the matter concisely, the series of synclinal and anticlinal folds probably characterizing this band of slates in Newton and Watertown is reduced to a single faulted monocline in Cambridge and Somerville; or to a single broken syncline, if we take into account the whole breadth of the formation from the Boston and Albany Railroad to the Mystic. The opinion has long been current among the geologists of this vicinity that the basin of the Charles River, in this part of its course, is a syncline; and I have simply suggested such a modification of this view as would bring it into more perfect harmony with the facts observed both here and elsewhere in the Boston basin. Before passing on I would call attention to the fact that this great slate syncline, as thus explained, matches, I might almost say exactly parallels, in extent and structure, the broad conglomerate anticline of Roxbury and Brookline.

North of the Mystic distinct slates are certainly known at only two points, both in Malden. One-fourth mile south-east of the Malden Station on the Saugus Branch of the Eastern Railroad, the slate is greatly disturbed by large intrusive masses, and shows high but irregular dips, with a north-easterly strike. One and a half miles to the eastward, on the Newburyport Turnpike and immediately south of the railroad at Maplewood Station, a compact gray slate, seemingly identical with that holding Paradoxides in Braintree, dips at a high angle to the north.

It is generally supposed that the conglomerate is not exposed north of the ledge in Watertown; but Mr. L. S. Burbank has recently called my attention to the existence of several outcrops of a distinct conglomerate on the extreme northern limits of the basin. The precise locality is in Medford, north of

Salem Street, and between Woburn and Purchase Streets. The fine-grained, euritic granite is extensively developed in the north-west part of Medford, and forms a prominent ledge on Purchase Street about one-fourth of a mile north-west of Salem Street. Going south from this we come first to outcrops of a hard, compact, felsitic rock, which is not distinctly stratified, and which closely resembles the rock that comes between the granite and conglomerate on the northern flank of the Blue Hills.

South of this felsite, or felsitic quartzite, but not seen in contact with it, comes the first of the conglomerate. This is mostly small-pebbled and slaty, containing some pinite, and showing a southerly dip of about forty-five degrees. The conglomerate has a breadth of at least three hundred or four hundred feet, and is represented by several ledges. It is interstratified with, and seems to pass gradually into, a firm, fine-grained, grayish to whitish sandstone, which is mainly a true quartzite, though sometimes feldspathic. This resembles the rock north of the conglomerate, but is, I think, more distinctly arenaceous and more evidently stratified. It certainly overlies the conglomerate; and yet I suspect that it may be continuous, across Salem Street, with the compact felsitic rock which I have marked on the map as forming a wedge-shaped area tapering toward the west, and referred to the Shawmut group. If this point were established, then the felsitic rock, which outcrops very prominently between Salem Street and the Mystic, would appear to be the equivalent of the slate formation.

Considered as a whole this section from the Medford granite southward is substantially similar to that on the opposite side of the basin from the Blue Hill granite northward, as exposed in the vicinity of Randolph Turnpike and farther west. The position of the conglomerate in Medford is an additional and plain confirmation of the statement on a preceding page that the outcrops of this rock occur normally between the crystallines and the slate along the margin of the basin.

With the exceptions just noted, the large area of smooth and, for the most part, low land, lying principally in Everett, Chelsea, and Revere, affords but a single clue to the nature of the underlying rocks; and this is the outcrop of rather nondescript exotics at the head of Washington Avenue in Chelsea, mentioned *ante*, p. 22, and referred to the Naugus Head Series. The variety of rocks exposed here — granite, a petrosilicious rock, and a basic rock, probably diabase — is favorable to the view that they form part of a considerable area of crystallines, — perhaps an extension of the rocks of Nahant or Saugus, — rather than a limited mass intersecting slate or conglomerate. In this hypothetical crystalline area, if admitted, we can find an adequate explanation of the south-easterly strike of the Somerville slates, which, it will be observed, show a marked divergence from the slates in Malden, as if this rock in its easterly extension divided to pass on opposite sides of a wedge-shaped crystalline area tapering toward the west; the Medford and Malden slate bounding it on the north and north-west and the Somerville slate on the south-west. It is less easy to question the validity of this explanation when we reflect that generally throughout the Boston basin the strike of both the conglomerate and slate is parallel with the adjacent crystalline border, and that the high and irregular S.S.W. dips of the slate along the north-east side of Somerville indicates their proximity to such a border.

Nahant. — The bold cliffs in the vicinity of East Point, Nahant, are composed of a very dark gray, almost black, compact slate, with a strike N. 60° E., and a nearly uniform northerly dip of about 40°. The general characters of this slate have been noticed on p. 195. The intersecting dykes are large and numerous, cutting the slate both with and across the strike. They are undoubtedly derived from, *i.e.*, are a part of, the extensive formation of coarse, exotic rock of the Naugus Head Series bounding the slate on the north-west. As explained on the page cited above, the slate, especially in the vicinity of the dykes, has suffered considerable change; the alteration consists in induration, much of the slate being of flinty hardness, and in the development along certain lines of large, elongated amygdules similar to those characterizing the slate at Mill Cove, in Weymouth. The comparatively thin layers possessing the amygdaloidal structure are mostly of a yellowish or greenish-white color. The calcareous beds are aggregated along two lines, near the middle of the slate; consisting of layers a few inches thick interstratified with the slate, and not always clearly distinguishable from it; they have a volume, taken collectively, of perhaps twenty feet. The color of the limestone is white to gray, and its texture varies from compact to finely crystalline or saccharoidal. Thin seams and strings of silicious material become evident on the weathered surface. A specimen selected as probably representing the purest of the limestone was analyzed by Miss Jennie M. Arms, with the following result: —

Insoluble residue (mostly $Si\,O_2$)	29.6
$Ca\,CO_3$	69.1
$Mg\,CO_3$	not determined
	98.7

I have already called attention to the plain indication which these calcareous beds in the eastern part of the Boston basin afford of deepening water, in ancient as well as in modern times, in this direction. It is instructive to compare these deposits formed in the open sea with the highly ferruginous, estuary strata in the vicinity of Charles River Village and South Natick.

The nature of the contact between the slate and the coarse pyroxenic rock which meets it on the north-west is uncertain. At several points the slate seems to dip beneath the crystallines, — a circumstance which would favor the theory that the slate is folded in a closed syncline with the axial plane inclined to the north-west. But the entire absence of arenaceous and conglomerate beds along the contact, as well as elsewhere in this vicinity; the undoubted exotic nature of most, at least, of the crystalline rock; and other important considerations, conspire to invalidate this view. And it seems most reasonable to suppose that the slate merely dips against an irregular crystalline wall; its beds having been broken off unevenly by the pyroxenic rock, during the elevation of the latter, in either a solid or plastic condition.

One structural feature of the slate, however, is sufficiently plain, viz., the faults by which most of the transverse dykes are accompanied. The downthrow appears to be sometimes to the south-west, but it is usually to the north-east. Several of these fractures are well marked; and, on account of the inclination of the strata, the outcrops of particular beds, as, for instance, the calcareous bands, experience considerable lateral displacement; the throw in some instances amounting to several hundred feet. In consequence of the transverse faulting, the limestone beds, in their south-westerly extension, lie beyond the present shore line, ending very abruptly on the land; and the north-west border of the slate is step-like, the beds on the north-east lying farthest to the north-west.

Marblehead Neck. — It is not generally known that this rocky peninsula, which may be regarded as lying on the extreme outskirt of the Boston basin, includes beds probably referable to the same horizon as the slate and conglomerate on the south and west. Briefly stated, the facts are as follows: near the middle of the north-west shore of the Neck, visible only at low tide, is a hard, whitish, fine-grained sandstone or arenaceous slate; it is evidently largely feldspathic, and turns yellowish on weathering. Porphyritically interspersed through the rock are clear, almost transparent, rhomboidal crystals, one-eighth to one-fourth of an inch long; these have been examined by Miss Hattie A. Walker, and proved to be orthoclase. In loose masses of the rock which were thoroughly weathered I have found these crystals changed to a green, soft, unctuous, and opaque mineral, probably pinite. The sandstone has a very gentle dip to the north-west, or toward the harbor; and it overlies unconformably the banded petrosilex forming the shore at this point. Interposed between the petrosilex and sandstone, and forming the base of the latter, is a thin stratum of conglomerate, composed of pebbles of the former rock. On the bank above, many fragments of the sandstone are scattered through the soil; and there are indications of its occurrence at other points on the Neck.

It is unquestionably hazardous to connect this sandstone with the other uncrystallines of the Boston basin, and I have done so only provisionally, and with hesitation. Lithological evidence of synchronism is almost entirely wanting, and stratigraphical there is none, save that the relations to the underlying crystallines are clearly the same in both cases. Neither the sandstone, nor the pebbly layer underlying it, bear any resemblance to the petrosilex breccia occurring so abundantly in the Marblehead region; but the conglomerate is much less firm, and in every way newer looking than any of the true breccia. The present position of the sandstone, its entirely undisturbed condition, and its occurrence in the form of loose masses in all parts of the Neck, indicate that it probably underlies Marblehead Harbor and the bar at the south-west end. And perhaps the numerous pebbles of precisely the same sandstone found on the beach on the east side of the Neck may be taken as an indication of a submarine deposit of this rock in that direction.

I have elsewhere[1] remarked upon the incontrovertible proof which this rock affords of the great antiquity of the depression in which it lies; for obviously Marblehead Harbor was excavated from the bordering Huronian diorite, petrosilex, and granite, before the deposition of the sandstone now lying unconformably and horizontally upon its crystalline floor. So that although the removal of the sand-rock from the harbor, which it doubtless once filled, may represent comparatively recent denudation; yet the harbor itself must have had substantially its present form in early Paleozoic times, having

[1] American Naturalist, xi., 585.

been since filled and re-excavated. It is scarcely necessary to point out the support which the fact here established lends to the doctrine of the comparative permanence of those topographical features fashioned from the crystalline formations.

Volume of the Conglomerate and Slate. — The volumes of both the slate and conglomerate vary greatly in different parts of the Boston basin; but I am satisfied that they nowhere reach the enormous thickness which some writers have assigned them. In the Roxbury and Brookline anticlinal, for example, the conglomerate has an apparent thickness of four or five thousand feet; and the slates of Somerville and Cambridge, taken as they lie, will scarcely measure less. But, since these results are entirely inconsistent with sections in the adjacent parts of the basin, where we have every reason to believe, not necessarily the maximum, but the entire, thickness of each rock is involved; and since, as I have shown in the preceding descriptions, proof is not entirely wanting that the broad folds mentioned are extensively faulted in a way to augment the apparent thickness of the strata, it is impossible to regard these large numbers as even approximations to the truth. At many points the structure, according to the interpretation proposed in the preceding pages, not only does not require, but will not allow, more than five hundred feet of conglomerate; and in some cases considerably less. Hence, when we pass almost abruptly from such a section to one where the same rock has an apparent volume ten times as great, it seems proper to seek for some other explanation than a natural thickening of the beds to that extent; and this is found in the plain indications of strike faults.

Several observers, overlooking, as it seems to me, the marked structural similarity of the conglomerate and slate, have assigned the former terrane a vastly greater thickness than the latter. Thus, Prof. N. S. Shaler, in speaking[1] of the conglomerate, especially that enclosing the Newton Upper Falls

[1] Proc. Bost. Soc. Nat. Hist., XIII., 175.

and Chestnut Hill band of slate, says: "The total thickness of the formation," referring evidently only to the conglomerate, "remains yet a matter of question; but it cannot be less than twelve hundred to two thousand feet, and may be twice the latter amount." While in the very next paragraph, relating to the slates of Cambridge and Somerville, which have an apparent volume, as just stated, fully equal to that of the conglomerate, — lying at an average angle of about twenty-five degrees for a horizontal distance across the strike of two miles or more, — we find the following: "The aggregate thickness disclosed in the Cambridge and Somerville sections is not far from two hundred feet." Prof. Shaler has evidently regarded the slates as faulted, and yet the proof is not clearer than in the case of the conglomerate.

In the light of my present knowledge I would assign the conglomerate a maximum volume not exceeding one thousand feet; and consider that the greatest thickness of the slate cannot be much less than that of the conglomerate, though in some cases certainly falling below five hundred feet. The extensive variations in lithological character and volume of these rocks is another proof that they were deposited in an irregular and limited basin, such as they now occupy.

Relations of the Slate and Conglomerate to the Crystallines.—Under this head I can only repeat, with, if possible, added emphasis, the general conclusion stated in the introduction. Nowhere in the Boston basin do we find a vestige of indisputable evidence pointing to the conclusion that there are crystalline rocks of Paleozoic age in this part of the State. Wherever the relations of the two great series, the crystallines and the uncrystallines (including the Shawmut group with the former), can be clearly observed, their entire unconformability is perfectly evident. Every crystalline rock in this region is represented in the pebbles of the conglomerate, and this rock certainly underlies the slate.

Only in a few limited localities, where the slate and conglomerate have been altered by contact with intrusives,— as at

Nantasket, Weymouth, Brighton, and Nahant,— is it possible to trace any lithological resemblance between these and any crystalline rocks; and in all such instances the fact, cause, and local nature of the alteration are clear beyond dispute; and, furthermore, the altered rocks bear no likeness to any known crystallines in this region, save where the conglomerate resembles uncrystalline (!) portions of the Shawmut breccia, or the sandstone has the hardness of quartzite (and induration is the simplest species of alteration), or slate and sandstone have the texture of amygdaloid. In this last case, however, there really is no resemblance, except, perhaps, with a small mass of sandstone at Nantasket; for the very large amygdules in the slate at Mill Cove, in Weymouth, and East Point, Nahant, are entirely unlike anything observed in the true amygdaloid of the Boston basin. With the exception of the orthoclase crystals in the sandrock of Marblehead Neck, crystalline characters are almost entirely wanting in the Primordial formation.

Basin of the River Parker.

The uncrystallines of this contracted basin are of limited extent, and comparatively little importance; and a few lines will suffice for their description. The only evidences of the Primordial age of these sediments are those afforded by (1) their relations to the crystallines, which are, in every essential respect, the same as in the Boston basin; and (2) their lithological resemblance to the Boston deposits, a resemblance that is conspicuous only in the case of the pinite conglomerate, and the red beds to be noticed presently. The conglomerate, with pinite pebbles, which is abundant on Kent's Island, is fine-grained and schistose, and indistinguishable from that between the Neponset River and Pine Tree Brook, in Milton, or in the vicinity of South Natick. At all points in the basin of the River Parker, the uncrystallines have an E.–W., varying to E.N.E., strike, and a high dip to the north; agreeing in these respects with the petrosilex and amygdaloid, and appearing to form, with them, small, closed synclinals, having the axial planes inclined to the north. It would be possible, however, to account for all the structural phenomena observed, by means of strike faults with the downthrow on the south; and in some respects this is the the more probable view.

Slate is the prevailing rock, and such conglomerate as occurs is invariably fine-grained and slaty, the formation including no coarse materials. It is practically impossible to make out in any of the numerous patches of these rocks any definite stratigraphical relation between the conglomerate and slate; in fact, this is essentially a slate formation.

I have seen no clear indications that any part of the amygdaloid is exotic, while the absence of special alteration in the slate points to the contrary conclusion. The slate makes its first appearance on the east bank of Little River, near its junction with the River Parker. It is here very fissile, and in part of a dark green color, and decidedly chloritic. The same slate forms both banks of this tributary at its mouth. On Kent's Island the rocks in question are confined mainly to the southern-central portion. The schistose conglomerate is well exposed on and near the railroad. West of Kent's Island these rocks are visible near the Newburyport Turnpike; but beyond this there are no actual outcrops, although we have abundant evidence, in the shape of erratics, of their farther extension in this direction for a mile and a half, or nearly to Byfield, following the general course of the river all the way. These erratics, which are very numerous along the road on the south side of the river, are all of a highly ferruginous, arenaceous slate; a plain indication that this basin has always been narrow and land-locked; and it is probable that the ancient shore line extended but little beyond the present limits of the deposits. The uncrystallines of this basin are almost identical with those in the vicinity of South Natick and Charles River Village, and were probably deposited under similar conditions; the adjoining crystallines, the sources of the sediment, are also the same in the two regions.

Mineralogical Notes.

Pinite. — The abundant occurrence of pinite in the pebbles and paste of some parts of our Primordial conglomerate, and the probable origin of this pinite débris in the Huronian petrosilex and felsite of this region, have been noticed on pages 89 and 220. It is proposed here to give (1.) a more detailed statement of the relations of this mineral (or rock, as it is perhaps more properly called) to the petrosilex, especially in Milton; (2.) chemical analyses of specimens taken from both the petrosilex and conglomerate, showing that this material is a true pinite, and that its composition is essentially similar in the two geological positions; (3.) further observations on its distribution in the conglomerate, together with a notice of its occurrence in the other fragmental rocks of Eastern Massachusetts.

(1.) Wherever occurring in the conglomerate, the pinite, as already observed, is always clearly an imported constituent; but in its association with the petrosilex and felsite it never presents this aspect; all the facts pointing to the conclusion that it is indigenous in this formation. In other words, the pinite, so far as the evidence allows us to judge, exists in the petrosilex only as a product of the superficial decomposition or alteration of that rock. Indications of this may be observed in many places. For instance, I have remarked on page 79 that the exceedingly homogeneous greenish and grayish elvanite, so extensively developed in Needham, very commonly presents a slaty appearance and yields to the knife; and this is probably a superficial phenomenon. Substantially the same language is repeated on the next page in describing the green petrosilex in West Dedham; also, on page 88, of the petrosilex exposed on River Street in Hyde Park, and on Blue Hill Avenue in Milton. And the greenish "toadstone" and other varieties of petrosilex in Newbury may be placed in the same category. In all these cases the rock is green, at least superficially. In Marblehead, Lynn, and other districts I have observed the brown, gray, black, and other colors of the petrosilex changing to green near the joints. In many cases, doubtless, the change is to kaolinite rather than pinite, but not always.

The clearest example of the formation of pinite from petrosilex which this region affords, so far as I have observed, is that already referred to on Central Avenue in Milton. The color of the unaltered petrosilex in this case is dark purple, and the pea-green pinite occurs in it in the form of irregular and ill-defined masses which seem to have their major axes normal to the surface of the ledge. Closer observation shows that they follow the jointing of the petrosilex; each joint being bordered on either side by pinite which shows a *gradual* passage into normal petrosilex at a distance of a few inches. The rather limited exposure is best in the vertical direction; and, tracing one of the pinite-bordered joints downward, it seems plain that the zone of this material is broadest and best marked near the surface, becoming narrower below, and almost entirely fading out at a depth of a few feet.

This peculiar disposition of the pinite in the petrosilex evidently leaves us no option but to believe that here at least it is a decomposition-product, and that percolating atmospheric water, for which the joints have afforded channels, has been the chief agent in its formation. The conglomerate cannot have been long removed from this part of the petrosilex; and hence this surface is clearly an ancient one; and I take it that we have here an example of pre-primordial decomposition.

(2.) The composition of a characteristic specimen of the pinite, taken from its original position in this ledge, is shown by the following analysis, made by Miss E. M. Walton: —

$Si\,O_2$	57.924
$Al_2\,O_3$	23.739
$Fe\,O$	2.826
$K_2\,O$	4,560
$Na_2\,O$	5.283
$H_2\,O$	3.142
$Mn\,O$	1.443
Cr and Mg	traces
	98.917

This pinite is unquestionably the source of that with which the slaty and schistose conglomerate overlying and surrounding the ledge of petrosilex is so replete (see page 220). The pinite pebbles are mostly quite small and well flattened; and hence considerable specimens are not easily secured. The portion submitted to analysis was obtained from perhaps a dozen pebbles from different parts of the ledge; great care being taken to prevent admixture with the slaty paste. This sample was analyzed by Mrs. Alice B. Crosby, with the following result:—

$Si\ O_2$	59.520
$Al_2\ O_3$	21.628
$Fe\ O$	5.840
$K_2\ O$	6.900
$Na_2\ O$	.804
$H_2\ O$	3.490
Cr, Mg, and Mn	not determined
	98.182

The formation of pinite by the alteration, and particularly by the hydration, of feldspathic rocks and minerals, which has been denied by some authorities, must apparently be conceded in some cases at least. Of course, where derived from a rock holding free quartz in an impalpable state, such as petrosilex, the pinite, though appearing quite pure, may, as the above analyses show, afford an abnormally high percentage of silica.

(3.) Pinite seems hardly ever to be entirely wanting in the Primordial conglomerate of this region, though there are comparatively few localities where, as on Kent's Island, in Newbury, and Central Avenue, in Milton, it occurs in such abundance as to give character to the rock, forming a distinct pinite conglomerate. It is interesting to observe, however, that these portions of the conglomerate marked by a predominance of pinite débris are found, with very few exceptions, in close proximity to ledges of petrosilex or felsite; and, in the exceptional cases, the underlying rocks are probably petrosilicious. This association is very significant.

The greenish sandstones and slates of this formation are also, probably, often rich in pinite, and the same may be said of the slaty beds in the Shawmut group. While in many places the petrosilex-breccia of the Shawmut group embraces, in both pebbles and paste, a large proportion of what appears to be more or less perfect pinite; *i.e.*, material of a light-green, or greenish-white color, which yields to the knife, and is somewhat unctuous, resembling serpentine in its external characters, and yet readily shown by its easy fusibility to be aluminous and not magnesian. Dr. Hunt has called my attention to the existence of pinite in the breccia in Saugus, and my own observations have convinced me that its occurrence in this way is a general fact.

To furnish all the pinite débris of these various fragmental rocks an extensive formation has been required. No vestiges of such a formation, distinct from the petrosilex, now exist in this region; and with the petrosilex we have the pinite, so far as the evidence allows us to judge, only as a product of the superficial decomposition of the former rock. The facts seem to warrant, or at least to forcibly suggest, the conclusion that, in pre-primordial times, the petrosilicious rocks, to a considerable depth, were changed by the action of atmospheric agents, not to kaolin, as generally at the present time, but to or toward pinite; and that subsequently this decomposition-product was for the most part swept away by the sea, in whieh were deposited the Shawmut breccia and Primordial conglomerate.

Kaolinite. — At the large quarry on Tremont Street, a short distance west of the Roxbury Station on the Boston and Providence Railroad, the conglomerate is traversed by several narrow veins and irregular cavities filled with a soft, white, kaolin-like substance, to which my attention was first called by Prof. W. R. Nichols; and I am indebted to him for the following notes and analyses made nearly nine years ago: —

"The mineral varies from a soft, powder-like kaolinite to a quite hard massive variety. From the appearance, and from the reaction before the blow-pipe, I judged it to be kaolinite;

and under the microscope it appeared to be made up of crystalline plates. In the softer varieties, which are easily reduced to powder, there appear crystals with well-defined edges which resemble those in the published descriptions of kaolinite; the majority of them, however, being elongated, and the hexagonal plates appearing more rarely. Analysis, however, shows a discrepancy between the composition of this mineral and that of kaolinite. Four samples were analyzed; I. and II. are a hard compact variety, and III. and IV. a compact, granular variety. In some cases the results given are the mean of several analyses." V. is the average composition of kaolinite.

	I.	II.	III.	IV.	V.
SiO_2	76.63	80.03	82.52	84.54	46.4
Al_2O_3	17.25	14.31	13.75	11.77	39.7
H_2O	5.89	5.13	4.24	3.48	13.9
Na_2O	.07				
K_2O	.66				
	100.50	99.47	100.51	99.79	100.00

The high silica ratio which these analyses show appears to be consistent only with the theory that this substance, notwithstanding its homogeneity, is a mixture of some hydrous aluminous silicate, such as kaolinite, with free silica. It is probably, like the pinite, a decomposition product; and I would suggest that such a chemical composition might result from the kaolinization of an acidic petrosilex.

DEVONIAN?

The rocks here referred doubtfully to the Devonian system are confined to the Naragansett basin, skirting the crystallines of north-eastern Rhode Island with a breadth of one to two miles and composing the principal part of the band of uncrystallines reaching from Rhode Island north-easterly to Braintree, where they nearly, perhaps actually, connect with the deposits of the Boston basin. The true stratigraphic relations of the two basins at this point cannot be observed on account of the drift; but their connection in either past or present time seems very improbable because of the unlikeness of the sediments. The rocks of the adjacent portion of the Boston basin, in Braintree and Weymouth, it will be remembered, are compact gray slates, including the Paradoxides bed; while the so-called Devonian strata are mainly of a red color, consisting to a large extent of highly ferruginous slate, sandstone, and conglomerate. The ferruginous character is maintained throughout nearly the entire extent of the formation; so that these rocks, and especially the slate, may be easily traced by reference to the color alone. The conglomerate is rarely coarse, and consists largely of pebbles of quartz and quartzite, though the other crystalline rocks of that region are also well represented. It is usually less deeply colored than the arenaceous and slaty beds; these more compact rocks, however, are also often light-colored — grayish or greenish. Thin layers of limestone are included in certain portions of the formation. Endogenous quartz is abundant, veins one to two feet wide sometimes occurring.

With the co-operation of Mr. George H. Barton, I am now (November, 1879) engaged in a systematic survey of this elongated arm of the Narragansett basin, which Mr. W. W. Dodge has appropriately designated the Norfolk County basin. Our work is only fairly begun; and, therefore, since my previous observations on these rocks have been few and casual, it seems wise not to attempt detailed descriptions of the lithology and stratigraphy of the belt here. For the best that has yet been done in this direction we are indebted to President Hitchcock[1] and Mr. Dodge.[2]

It is not difficult to conceive under what conditions the rocks of the Norfolk County basin were probably deposited. This geologic valley is narrow; and, judging by the present disposition of the uncrystallines of Rhode Island and Southern Massachusetts, it has always been well shut off from the open sea.

[1] Final report on the Geology of Massachusetts.
[2] Proc. Bost. Soc. Nat. Hist., XVII., 411 *et seq.*

These are facts that harmonize perfectly with the ferruginous character of the beds which, it will be observed, are very similar to the rocks lying in the estuary-like prolongations of the Boston basin.

The determination of the age of these so-called Devonian beds rests as yet on a very insufficient basis of facts. In reality this question remains about where President Hitchcock left it nearly forty years ago. This eminent observer considered the Norfolk County series older than the Carboniferous, and the red color suggested its equivalence to the Old Red Sandstone. I am not acquainted with a single characteristic of the red beds of Norfolk County and Rhode Island which proves, or even implies, their want of synchronism with the uncrystallines of the Boston basin, unless it be that they are less frequently and extensively cut by intrusives. The lithological differences observed are unimportant, and may be easily explained as matching the unlike physical conditions which obtained in the two basins during Primordial time. With respect to stratigraphy the Norfolk County basin is, apparently, exactly paralleled, on a smaller scale, by the Newton and Natick belt of conglomerate and slate; and here we find, as already pointed out, the most striking resemblance in lithology and the probable conditions of deposition.

CARBONIFEROUS.

Under this head I have nothing to add to what is already known; and will simply re-affirm my belief that the rocks of this age in Rhode Island and Massachusetts — chiefly gray and black, sometimes reddish, shales, sandstone, and conglomerate — were deposited in an arm of the Gulf of Maine, expanding and deepening toward the north-east, and having its head in the direction of Newport and Providence.

I have had no opportunity to study the supposed tertiary deposits in Marshfield and Duxbury, and hence these, although properly coming within the scope of this paper, must necessarily remain unnoticed here.

SUPPLEMENTARY NOTE.

Recent observations have convinced me that the isolated patch of slate lying upon and cut by the Blue Hill granite, near the common boundary of Quincy and Milton, is much larger than represented on the map, and that it belongs to the Primordial series instead of the Shawmut group. The new evidence consists of several ledges of a distinctly stratified gray argillite on Randolph turnpike, in Milton, about three-fourths of a mile north of the Quincy line. The dip is vertical and the strike E.N.E.; and the character of the rock is, in general, precisely the same as in the Paradoxides quarry in Braintree, but some layers are more pyritiferous. So far as exposed, the slate is not traversed by exotics, though a large mass of coarse diorite or diabase appears to come between it and the granite on the south. As compared with these ledges of slate, the small area of this rock, some three-fourths of a mile farther east, shows much greater disturbance, and is in every way more ancient-looking; and yet I judge that the two patches are, or have been, connected. They are both included in a broad, smooth valley, which divides the Blue Hills longitudinally, extending from the west boundary of Quincy, in a W.S.W. direction. Outcrops are very scarce in this well-marked intervale; but I think there are good reasons for believing that a considerable area of Primordial slate is probably concealed here.

INDEX.


B
BILLERICA
WILMINGTON
WILMINGTON
WEST VILLAGE
READING
READING
LYNNFIELD CENTER
LYNNFIELD
DANVERS PLAIN
EAST DANVERS
DANVERS CENTER
DANVERS PORT
LOCUST DALE
PROCTOR'S CORNER
PEABODY
LYNNFIELD
NEEDHAMS CORNER
SALE
WAKEFIELD
BURLINGTON
BURLINGTON
NORTH WOBURN
WOBURN
NORTH SAUGUS
SWAMPSC
CUMMINGSVILLE
EAST WOBURN
GREENWOOD
STONEHAM
STONEHAM
OAKLAND VALE
GRAVESEND
LYNN
SAUGUS
SWAMPSCOT
SAUGUS
LYNN
MELROSE
LEXINGTON
EAST SAUGUS
CLIFTON DALE
WINCHESTER
WINCHESTER
LEXINGTON
SWEETSER'S CORNER
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MAPLEWOOD
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EAST LEXINGTON
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WEST MEDFORD
MEDFORD
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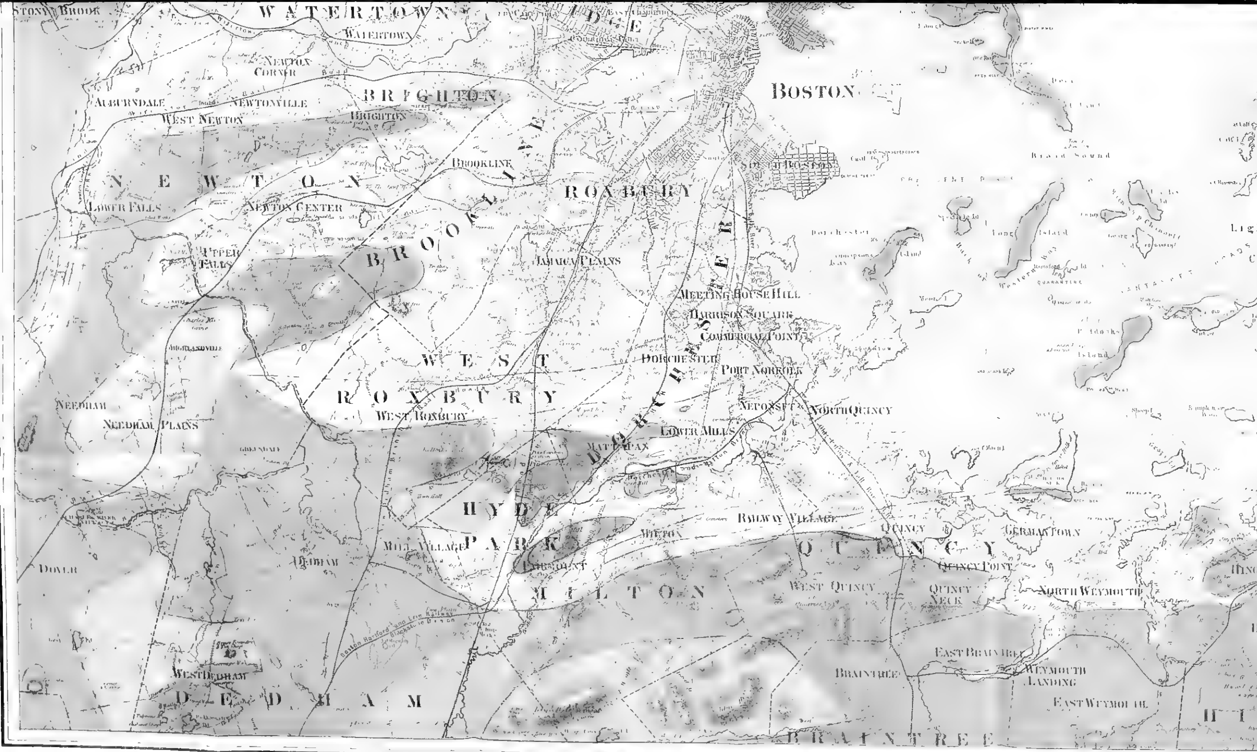
MALDEN
NAHANT
EAST MEDFORD
MEDFORD
REVERE
EVERETT
BELMONT
BELMONT
SOMERVILLE
WALTHAM
WALTHAM
WAVERLY
CHELSEA
CAMBRIDGE
MASSA
WINTHROP


Stony Brook
Watertown
Watertown
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Brighton
Auburndale
Newtonville
West Newton
Newton
Brookline
Brookline
Roxbury
South Boston
Lower Falls
Newton Center
Upper Falls
Jamaica Plains
Meeting House Hill
Harrison Square
Commercial Point
Dorchester
Dorchester
Port Norfolk
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Roxbury
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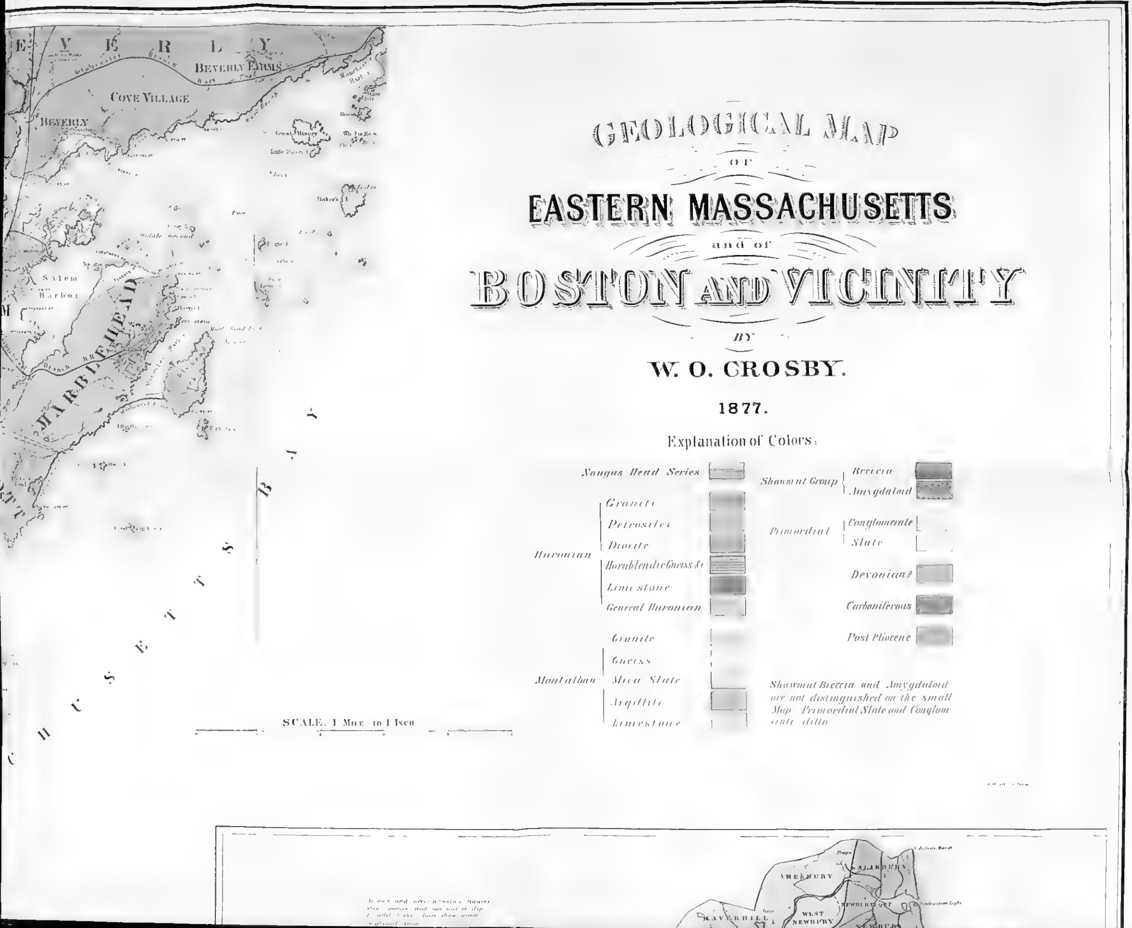
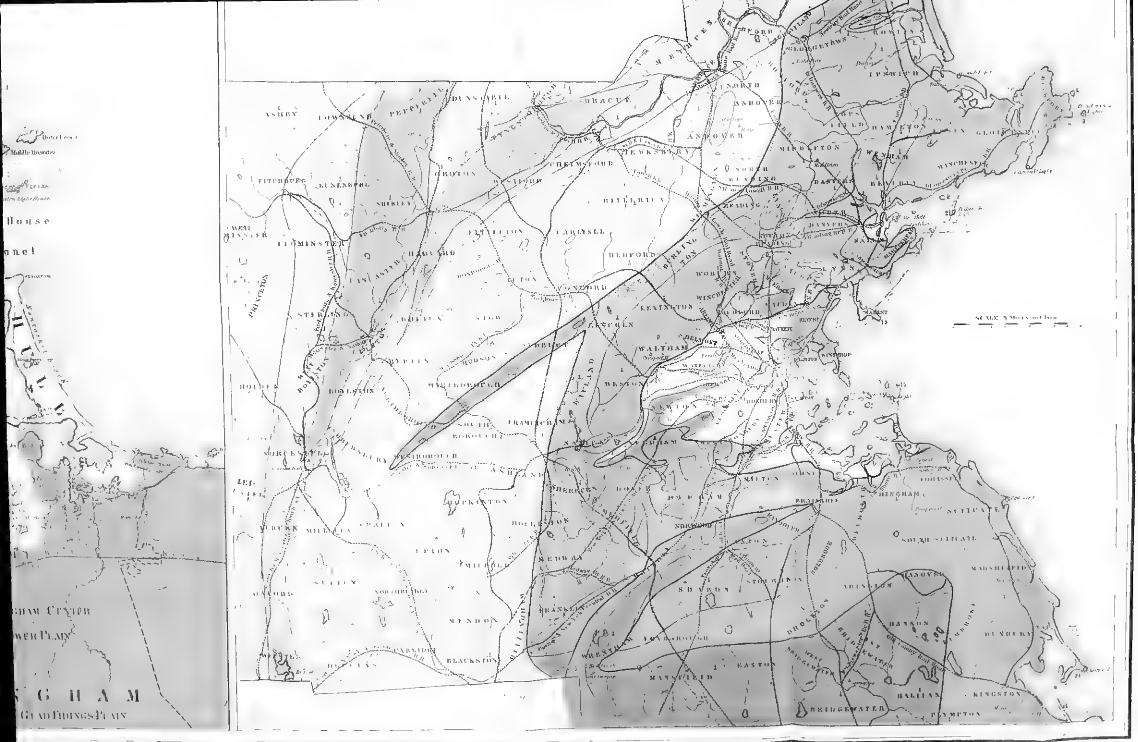
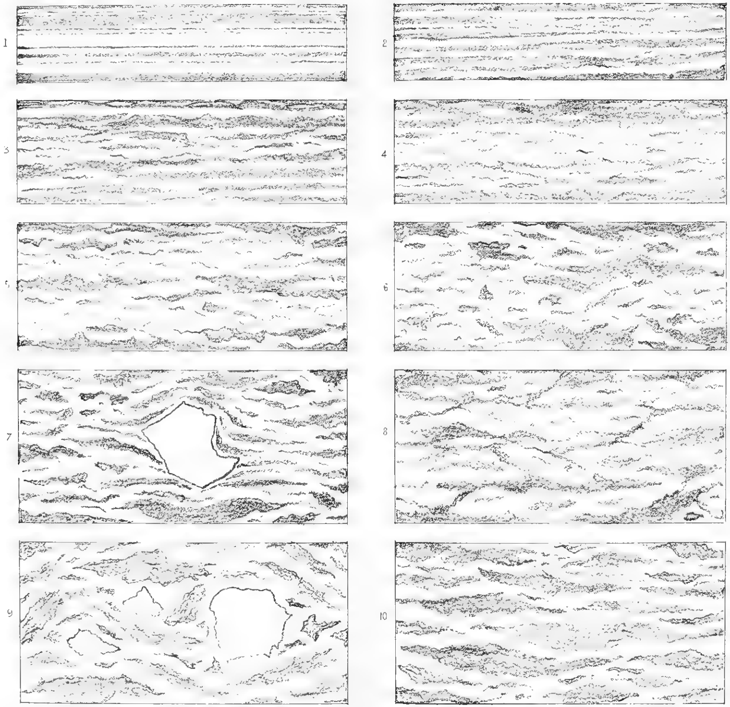
Braintree
Weymouth Landing
West Dedham
Dedham
East Weymouth
Braintree
Boston Hartford and Erie Railway
Long Island
Western Way
Light


GEOLOGICAL MAP
OF
EASTERN MASSACHUSETTS
and of
BOSTON AND VICINITY
BY
W. O. CROSBY.
1877.
Explanation of Colors:
Naugus Head Series
Huronian
Granite
Petrosilex
Diorite
Hornblendic Gneiss &c
Limestone
General Huronian
Montalban
Granite
Gneiss
Mica Slate
Argillite
Limestone
Shawmut Group
Breccia
Amygdaloid
Primordial
Conglomerate
Slate
Devonian?
Carboniferous
Post Pliocene
Shawmut Breccia and Amygdaloid are not distinguished on the small Map. Primordial Slate and Conglomerate ditto
SCALE, 1 Mile to 1 Inch
BEVERLY
BEVERLY FARMS
COVE VILLAGE
Salem Harbor
MARBLEHEAD
AMESBURY
WEST NEWBURY



ASHBY
TOWNSEND
PEPPERELL
DUNSTABLE
DRACUT
NORTH ANDOVER
ANDOVER
TEWKSBURY
CHELMSFORD
GEORGETOWN
ROWLEY
IPSWICH
MIDDLETON
WENHAM
BEVERLY
MANCHESTER
DANVERS
SALEM
MARBLEHEAD
LYNN
FITCHBURG
LUNENBURG
SHIRLEY
GROTON
WESTFORD
BILLERICA
READING
WEST MINSTER
LEOMINSTER
HARVARD
LITTLETON
CARLISLE
BEDFORD
BURLINGTON
WOBURN
LANCASTER
PRINCETON
STERLING
CONCORD
LEXINGTON
WINCHESTER
LINCOLN
WALTHAM
BELMONT
WINTHROP
HUDSON
SUDBURY
WESTON
BOYLSTON
MARLBOROUGH
NEWTON
ROXBURY
FRAMINGHAM
WESTBOROUGH
ASHLAND
MILTON
HOPKINTON
SHERBORN
DOVER
DEDHAM
BRAINTREE
HINGHAM
COHASSET
SCITUATE
SOUTH SCITUATE
NORWOOD
HOLLISTON
MEDWAY
MILFORD
UPTON
SHARON
STOUGHTON
HANOVER
MARSHFIELD
OXFORD
SUTTON
NORTHBRIDGE
MENDON
FRANKLIN
BROCKTON
HANSON
DUXBURY
WRENTHAM
BLACKSTONE
EASTON
WEST BRIDGEWATER
MANSFIELD
HALIFAX
KINGSTON
BRIDGEWATER
PLYMPTON
SCALE 5 Miles to 1 Inch



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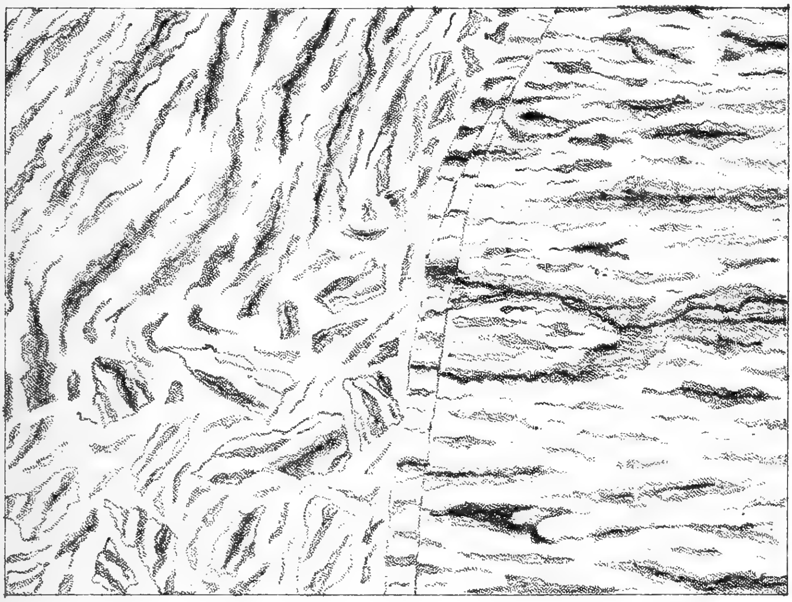

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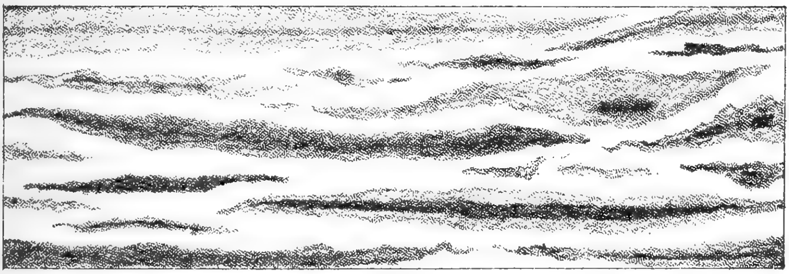

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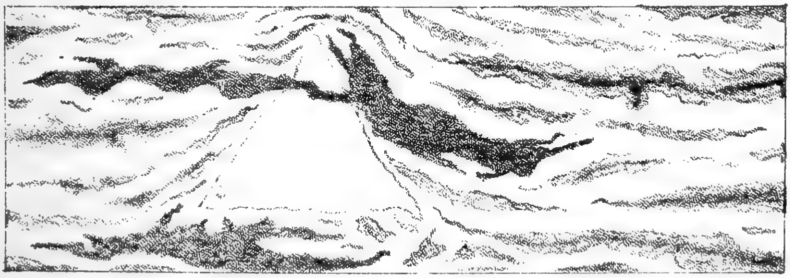

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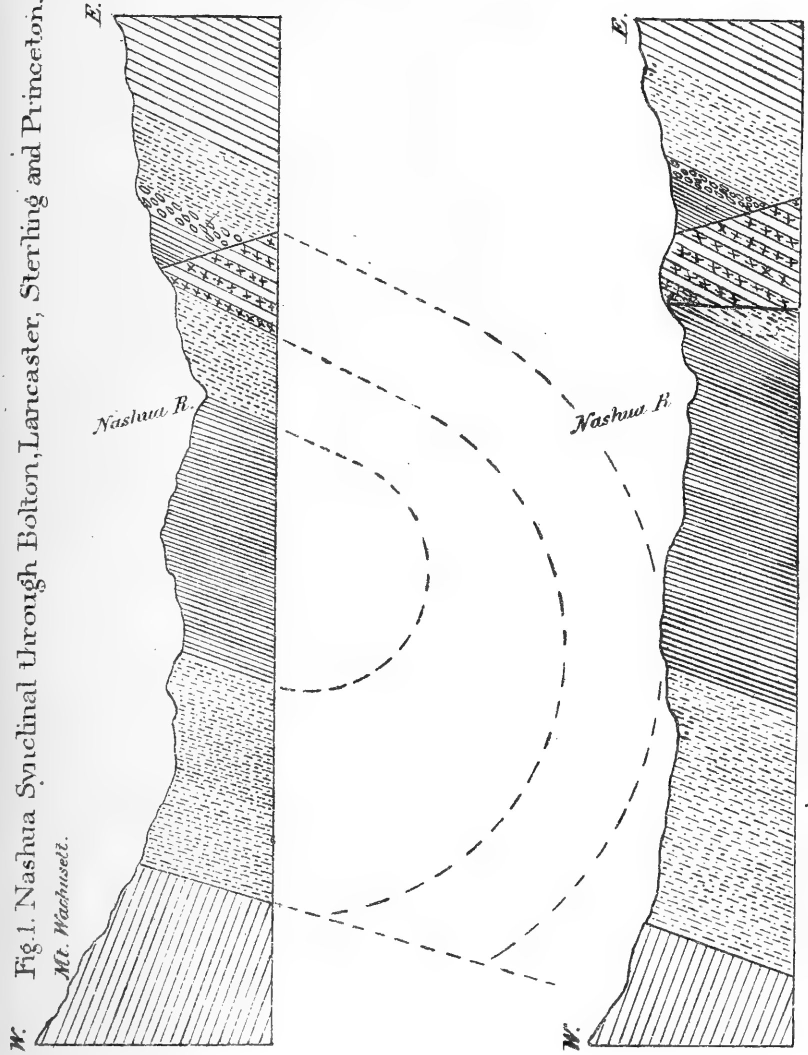

Fig.1. Nashua Synclinal through Bolton, Lancaster, Sterling and Princeton.

Fig.2. Nashua Synclinal through Harvard, Lancaster and Leominster.

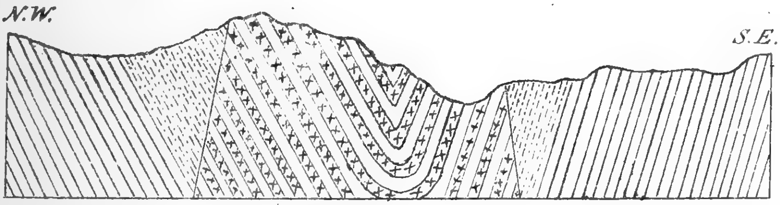

Fig. 3. Merrimac Synclinal from Westford to Dunstable.

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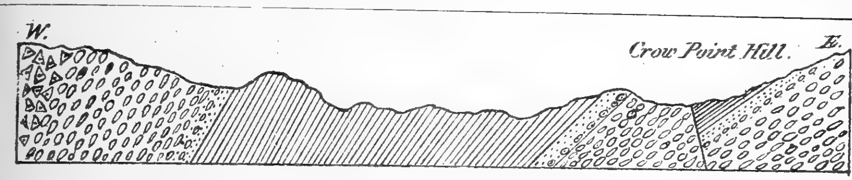

Fig. 1. Crow Point Hill toward Hewitt's Cove, Hingham.

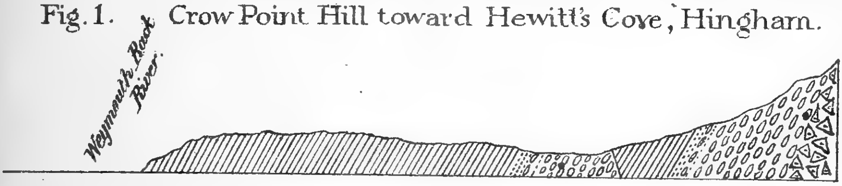

Fig. 2. North side of Hewitt's Cove.

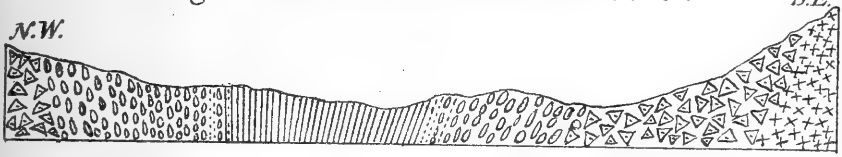

Fig 3. Baker's Hill, Hingham. N.W. across synclinal.

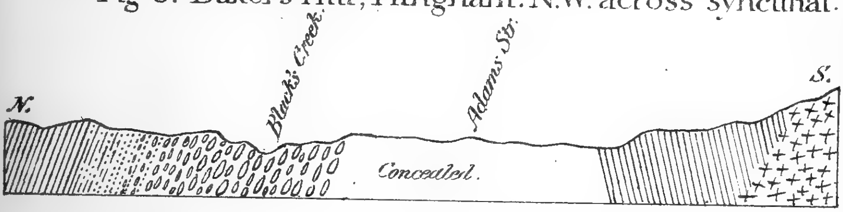

Fig. 4. Black's Creek and Rock Island Cove anticlinal, nearly ¼ m. W. of O.C.R.R., Quincy.

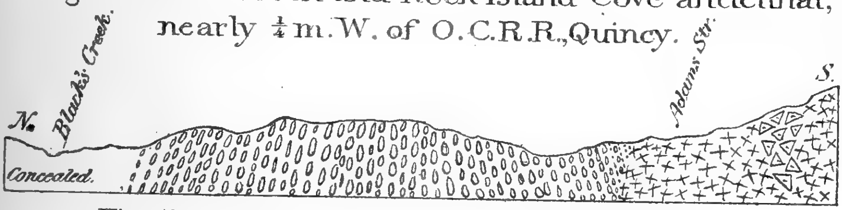

Fig. 5. Same as above 125 rods farther west.

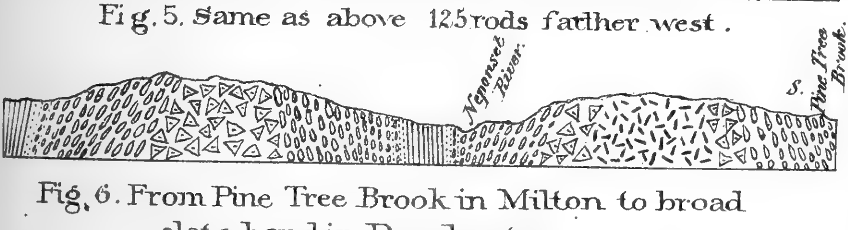

Fig. 6. From Pine Tree Brook in Milton to broad slate band in Dorchester.

Horizontal scale of Figs. 1, 2, 3, 4 and 5 = about 300 ft. to an inch; and of Fig. 6 = 1800 ft. to an inch.

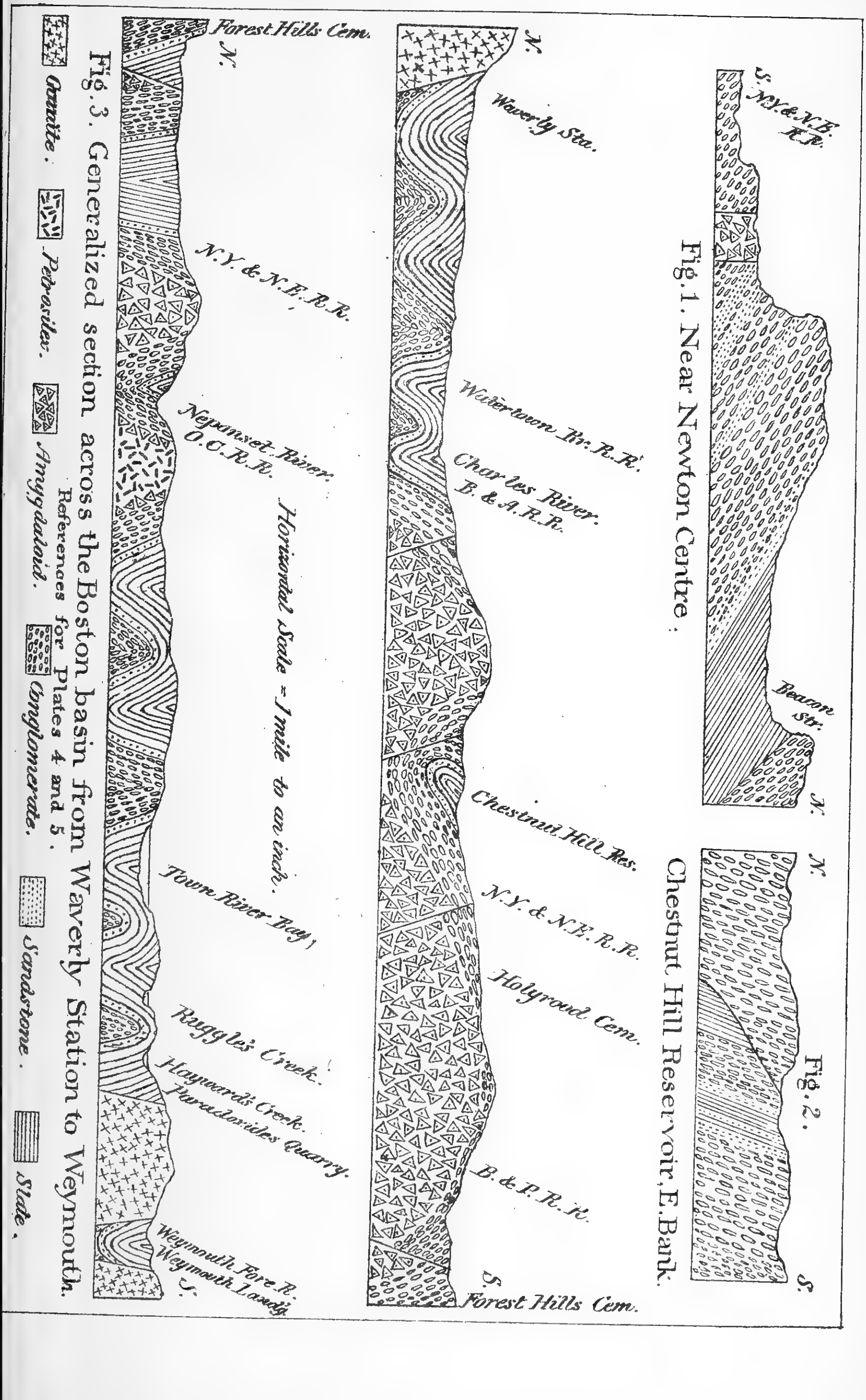
Fig. 1. Near Newton Centre;
S. N.Y. & N.E. R.R.
Beacon Str.
N.
Chestnut Hill Reservoir, E. Bank.
Fig. 2.
N.
S.
N.
Waverly Sta.
Watertown Br. R.R.
Charles River. B. & A. R.R.
Chestnut Hill Res.
N.Y. & N.E. R.R.
Holyrood Cem.
B. & P. R.R.
S. Forest Hills Cem.
Forest Hills Cem.
N.
N.Y. & N.E. R.R.
Neponset River. O.C.R.R.
Horizontal Scale = 1 mile to an inch.
Town River Bay;
Ruggles Creek.
Hayward's Creek.
Paradoxides Quarry.
Weymouth Fore R.
Weymouth Landg.
S.
Fig. 3. Generalized section across the Boston basin from Waverly Station to Weymouth.
References for Plates 4 and 5.
Granite; Petrosilex. Amygdaloid. Conglomerate. Sandstone. Slate.

Occasional Papers

OF THE

Boston Society of Natural History.

III.

CONTRIBUTIONS TO THE GEOLOGY OF EASTERN MASSACHUSETTS,

BY

WILLIAM O. CROSBY.

BOSTON:
BOSTON SOCIETY OF NATURAL HISTORY.
1880.

Books.

Prof. Jules Marcou.
42 Garden St.
Cambridge