DESCRIPTION OF THE PENOBSCOT BAY QUADRANGLE.

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INTRODUCTION.

LOCATION AND PRINCIPAL TOWNS.

The Penobscot Bay quadrangle lies between meridians 68° 30′ and 69° west longitude and parallels 44° and 44° 30′ north latitude. It includes one-fourth of a square degree of the earth's surface, and contains 857 square miles. The quadrangle embraces nearly the whole of Penobscot Bay, about one-half its area being water. It lies about midway between the eastern and western boundaries of Maine, and includes parts of Knox, Waldo, and Hancock counties. Of the land, about two-thirds belongs to the mainland and the remainder to islands, which are extremely numerous and of various sizes, the largest being North Haven, Vinalhaven, Deer Isle, Isle au Haut, and Islesboro. Belfast, the largest town, with a population of about 5000, is the county seat of Waldo County and the terminus of the Belfast branch of the Maine Central Railroad. Stockton Springs and Searsport, the only other railroad towns, are the southern termini of the Bangor and Aroostook Railroad. The Penobscot Bay region, because of its great beauty, its cool summer climate, and its many bays and inlets, which afford safe harbors and protected sailing, has come to be one of the most popular summer-resort regions in America. In the touring season most of the business and resort towns are easily reached by steamer from Boston, Portland, or Rockland. Castine receives, perhaps, the largest number of summer visitors, but Dark Harbor (Islesboro), North Haven, Bluehill, and many smaller places are popular resorts.

GENERAL GEOGRAPHY AND GEOLOGY OF THE PROVINCE.

The State of Maine belongs to a geographic and geologic province which includes the most of New England, together with Nova Scotia, New Brunswick, and the Eastern Townships of Quebec. Topographically the province is characterized by considerable diversity of forms, but for the most part it is an upland or plateau region, bordered on the one side by the great Atlantic Ocean depression and on the other by the great Canadian highland region. The higher portions of this upland country are deeply incised by the rivers and streams, so that they flow in deep valleys or canyons. Rising above the highest parts of the New England plateau are the White Mountains, the range of lower peaks in western Maine, and Mount Katahdin.

As a geologic province the region is characterized by the presence of great intrusive masses of granitic rocks of Paleozoic age. The metamorphic character of the slate, quartzite, marble, and schist in this province is due both to pre-Silurian dynamic action and to later igneous activity, so that the younger Paleozoic rocks may be highly metamorphosed, as well as the older formations. This contact metamorphism differentiates the province from the greater part of the Green Mountains, in which the later intrusives are not prominent except in the extreme southwestern portion of the range. The Green Mountains thus form a border zone between this region and the main Appalachian province. As in the Green Mountains, the rocks of the New England province exhibit a general parallelism in the trend of the main structural features.

It has been supposed that the highly metamorphic and nonfossiliferous rocks of the southern and northwestern parts of Maine are pre-Cambrian in age. The detailed geologic work within the Penobscot Bay quadrangle and the adjacent Rockland area supports the view that the metamorphosed sediments are of Cambrian or Cambro-Ordovician rather than of pre-Cambrian age. Reconnaissance work seems to extend this determination over large areas in the southern and western parts of the State. The assignment by the Canadian geologists of a Cambrian and Cambro-Ordovician age to metamorphosed sedimentary rocks near the Quebec-Maine boundary, as well as to metamorphic rocks in New Brunswick, further confirms this age determination.

Associated with the schists and slates, both on the Maine coast and in the northern part of the State, are fossiliferous sediments of Silurian and Devonian age, whose unmetamorphosed character shows that the principal epoch of folding occurred before their deposition and probably closed the Ordovician. To this date, therefore, is assigned the dynamic metamorphism which has affected all the pre-Silurian rocks and produced structures which differentiate them from the later formations. In the coastal region of Maine granitic intrusion on a large scale has resulted in some contact metamorphism of Silurian rocks, but this is readily distinguished from the dynamic metamorphism of earlier date.

The igneous activity which especially characterizes this province began with the volcanism of Cambrian time, volcanic rocks probably of this age being known both on the Maine coast and in eastern Massachusetts. In the Silurian the volcanic activity again prevailed and was followed probably in Devonian time by the intrusion of granitic rocks already referred to. It is this abundance of volcanic and plutonic rocks of Paleozoic age that characterizes both the area here described in detail and the whole province. It is noteworthy that these granites do not form a part of an Archean protaxis, as formerly held, but represent relatively late intrusions.

TOPOGRAPHY

The most striking features of the topography of this quadrangle are the large number of islands and the exceedingly irregular form of the coast line, features that are characteristic to a greater or less degree of the whole Maine coast. This irregularity can not be accounted for by the eroding action of the ocean, for it is as marked in the protected coves and estuaries as in the parts which are exposed to the full violence of the storm waves. A glance at the topographic map shows the presence of certain long, narrow channels which are largely free from islands. The most conspicuous of these is followed by the eastern boundary line of Waldo County; others are Bluehill Bay and Eggemoggin Reach. The Coast and Geodetic Survey chart of the same region, on which the depths of water are recorded, shows that these are deep-water channels and are therefore the principal paths of navigation.

The largest channel, the one passing on the east side of Islesboro, is a direct continuation of the present Penobscot River valley. This relation suggests an explanation of the irregular coast line, namely, that a subsidence of the coast has transformed the lower portions of the old river valleys into deep marine channels and the smaller valleys into tidal estuaries, thus changing a hilly land surface into an archipelago of small islands. A shore line showing these characteristics is termed a "drowned" coast. It is evident, however, that to produce the degree of coastal irregularity here observed the original contour of the land must also have been irregular. Its surface features were much like those found to-day on the lands bordering the coast. Thus, for example, if the portion of the mainland between Belfast Bay and Ducktrap Harbor were submerged to a depth of 200 or 250 feet, the result would be a similar archipelago of small, irregular, and diversified islands. This topography of the present land areas and of the land now submerged is the result in part of the normal processes of stream erosion, and in part of the eroding and depositing action of the glaciers which covered this region in Pleistocene time.

The region is characterized by a great variety of rocks distributed in a very irregular manner. Even within a single formation there are great variations in the texture and composition of the rock, differences which in some places are original and in others are produced in the processes of metamorphism. Weathering and stream erosion acting on these rocks before the advent of the glaciers sculptured them into a succession of hills of greatly varying size and slope and irregular form. There is a complete absence of plateaus, monadnocks, or any other features indicative of cycles of erosion.

The eroding and depositing action of the glaciers reduced to some extent the irregularities of the hills by planing off the more jagged prominences and filling some of the depressions, but the resulting contours were still very irregular.

The majority of the hills do not rise more than 200 to 300 feet above sea level. Higher elevations are usually called "mountains," though many of them are only 400 or 500 feet high, and the name is to some extent justified by the abruptness with which many of them rise from the shore and by a certain magnification due to the prevalent haziness of the atmosphere. The highest hill of the region is Blue Hill, near Bluehill village, which rises to an elevation of 940 feet.

The present drainage of the region is most irregular, partly as a result of the preglacial irregularities in the form and distribution of the hills and partly as an effect of the blocking of the preglacial stream courses by deposits of glacial drift. Most of the streams are brooks only a few miles in length, and their courses are in many places irregular and obstructed by ponds or marshes. Water power is available along some of them, but its importance is not great. All the so-called "rivers" of the quadrangle are in reality tidal estuaries. Bagaduce River, one of the largest estuaries, is remarkable for the northwestward trend of its upper portion as contrasted with the southwestward course of the lower portion. Through the portion called the Narrows the tide runs with a force capable of generating a large amount of power if means can be devised for its conversion. A similar water power is available near Bluehill Falls, at the outlet of Salt Pond.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

INTRODUCTORY STATEMENT.

The geological description of the Penobscot Bay quadrangle embraces a study of unmetamorphosed and metamorphosed representatives of both sedimentary and igneous rocks. The unmetamorphosed sediments have a very small areal distribution and include only the Silurian rocks of North Haven and Stimpson Island. Because of their fossiliferous character, however, these rocks furnish the basis of approximate age determinations for most of the other formations of the region and thus assume an importance out of all proportion to their areal extent. The class of unmetamorphosed igneous rocks includes only the granites and associated diorite, diabase, and gabbro, and a few dike rocks. These rocks are intrusive into all the other rocks of the region and thus present no difficult stratigraphic problems. The main geological problems center about the metamorphosed sedimentary and extrusive volcanic rocks, and their solution presents many difficulties and involves not only detailed and stratigraphic work in the field but also extensive microscopic studies.

The Ellsworth schist is the oldest formation in the region. It is of sedimentary origin and is presumably Cambrian or older in age. The sediments next younger are the Islesboro slate and the overlying Coombs limestone, with which the extrusive volcanics of the Castine formation and the North Haven greenstone are about contemporaneous. Next above the Coombs limestone comes the Battie quartzite, followed by the Penobscot slate. All the above-mentioned rocks are probably of Cambrian age and have been affected by dynamic metamorphism, being thus sharply differentiated from the later formations, a distinction indicative of a time interval of importance. The unmetamorphosed Silurian sediments lie unconformably upon the eroded surface of the North Haven greenstone, and are followed in apparent conformity by the Thorofare andesite, which in turn grades upward into the Vinalhaven rhyolite. All these rocks, from the oldest to the youngest, are cut by granite of probable Devonian age, with associated diorite, diabase, and gabbro.

SEDIMENTARY ROCKS.

ELLSWORTH SCHIST.

Definition.—The Ellsworth schist is composed of highly metamorphic argillaceous sedimentary rocks, prevailingly greenish gray in color and locally much injected with quartz. They are named from the city of Ellsworth, just beyond the northeast corner of the quadrangle, near which locality occur abundant exposures typical of the formation.

Distribution.—From the village of Surry, in the northeast corner of the quadrangle, the schists extend toward the west and southwest for 2 or 3 miles, until the Toddy Pond granite area is reached. The largest continuous area within the quadrangle has a width of about 2 miles, west of Toddy Pond, and from that locality extends southward to Bluehill, where its width increases to nearly 4 miles. The same belt continues along Bluehill Neck, widening southward until it occupies the whole width of the Brooklin peninsula. It is cut off by the granite just north of the village of Brooklin, but on the south side of Eggemoggin Reach, on Deer Isle, what appears to be a continuation of the schist belt is represented by two small schist areas, one on each side of the serpentine stock. Farther east the schist reappears on the northern part of Long Island and in small isolated areas along its western and southwestern shores. Several small masses occur within the granite area east and southeast of North Brooksville.

Structural relations.—The rocks of this formation are nearly everywhere highly schistose and show but slight lithologic variations in different parts of the region. They have suffered much more intense crumpling and shearing through regional metamorphism than any other rocks of the quadrangle. Distinct indications of bedding in the schist are wholly wanting within this quadrangle, but are found at one locality a few miles to the east. The general strike of the schistosity is rather constant, and trends north of east, N. 55°–60° E. being about the average. In some localities the strike varies from due east and west to almost north and south, and even within a few feet swings through wide angles. The dips vary from low angles to 90°, but may hold the same general direction over wide areas. In the southern portion of the main belt, on Long Island, and about Surry the dips are generally less than 30°, and in some areas the schist is horizontal. The flat-lying character of the schist for considerable distances between Surry and Ellsworth is a noteworthy feature.

Lithology.—Typical exposures of the schists are very numerous in the vicinity of Bluehill, especially along the shore and on the summit and western flanks of the 940-foot hill from which this village takes its name. The rock is very fine grained, dark purple to dark greenish gray in color, and finely foliated. Fresh surfaces show alternate light and dark bands, the darker bands being rich in micaceous minerals and the lighter bands being composed largely of quartz. On the weathered surfaces the more quartzose bands stand out in relief and serve to emphasize the foliation. Along the shore on the point just east of Bluehill village, where the schists are well exposed, they are dark, fine grained, and much crumpled, and contain large amounts of quartz in lenses, veins, and stringers. On Blue Hill and northwestward for several miles quartz is abundant but is distributed in masses so small as to give the rock the appearance of an augen-gneiss. Just southeast of North Bluehill, near the granite border, many of these "augen" are $1\frac{1}{2}$ inches across, and some 3 inches; they are in general somewhat elongate parallel to the foliation. To the north of North Bluehill the "augen" disappear and the schist is much finer grained, but quartz veins and stringers are abundant and in places are 3 to 6 inches wide. In the region west of Toddy Pond and near the northern border of the quadrangle the schistosity becomes less well defined and the weathering of the rocks to a rusty or metallic-looking surface denotes a great increase in the iron content. Locally sulphides of iron, lead, and copper are so abundant that shafts have been sunk in the hope of profitable development. On Long Island, where excellent exposures occur along the shore, the greenish-gray schists are more sericitic and freer from quartz veins than is usual on the mainland. The schist of Herriman Point is similar to that of Long Island. That occurring on the north end of Deer Isle is crumpled and much seamed with quartz, and closely resembles the rocks to the northeast on the other side of Eggemoggin Reach.

In the Mount Desert quadrangle, which lies just east of the Penobscot Bay quadrangle, clear evidence of the sedimentary origin of the Ellsworth schist is preserved at a single locality on the east shore of Skillings River. This evidence consists in the alternation of argillaceous beds with beds that are quartzitic and more massive. Within the Penobscot Bay quadrangle the metamorphism has everywhere obliterated all traces of bedding.

Under the microscope Ellsworth schist from Parker Point in Blue Hill Harbor shows as its principal minerals quartz and chlorite. The quartz shows evidence of much recrystallization in an interlocking of the borders of the grains and in the fact that many of them show a parallel elongation which aids in defining the schistosity. Chlorite occurs in small irregular plates aggregated most abundantly along certain thin subparallel layers which are the principal cause of the schistose structure. Muscovite in minute shreds is associated with the chlorite in a few places, as is also an opaque mineral, yellowish in reflected light, which may be leucoxene. Scattered somewhat sparingly among the quartzes are fresh, striated grains of albite and a larger number of grains of orthoclase. Since this specimen came from a point near the granite border, it is possible that the feldspar was largely developed as a result of contact metamorphism.

Schist from the northwestern shore of Long Island shows quartz, muscovite, and green biotite as its essential constituents. The quartz shows little sign of recrystallization, the grains being small, almost equidimensional, and not interlocking. The schistosity is due to the preponderance of small muscovite and green biotite plates along certain layers which are much less regular and well defined than those in the specimen from Parker Point described above. Much green chlorite has developed from the decomposition of biotite, and there are a few rather large, irregular aggregates of epidote. Magnetite is abundant in the micaceous layers. Feldspar is practically absent.

The schist occurring 2 miles west of Toddy Pond, in the extreme northern part of the quadrangle, weathers to a rusty surface. Microscopic examination shows its essential constituents to be quartz, muscovite, and brown biotite. The quartz grains are, for the most part, equidimensional. The mica is distributed more evenly throughout the rock than in the schist from Long Island, though there is some concentration along certain narrow and widely separated layers, which imparts to the rock a feeble schistosity. Here and there the muscovite develops larger crystals than any of the biotite. Ilmenite, largely altered to leucoxene, is present in small grains, as is also some micaceous hematite.

Contact relations.—The Ellsworth schist is in contact with the granite and diorite, with serpentine, and with the Castine volcanics, all of which are distinctly younger. In general the schist-granite contact is very sharp and the schist near it differs little in megascopic appearance from that farther away. Close to the contact dikes of granite in the schist are of common occurrence and may parallel or cut across the schistosity. The contact relations are well shown southeast of Closson Point, in Bluehill Harbor, and at the extreme north edge of the quadrangle three-fourths of a mile west of Toddy Pond. At the latter locality dikes of granite cut the schists, some being parallel to the foliation and others breaking across it; numerous angular schist fragments have been caught up in the intrusive granite. Two schist specimens collected at distances of 1 foot and 40 feet from the granite contact in the vicinity of Sedgwick differ little from each other microscopically. Both have been largely recrystallized and show the effects of the granite intrusion in the abundance of feldspar, in the development of irregular andalusite crystals, and in greater coarseness of grain than is usual in the normal schist. The contact relations will be further considered in the discussion of the granite.

Since the diorite is known to be practically contemporaneous with the granite, it also might be regarded as intrusive in the schist. Because of the scarcity of exposures, this relation was observed at only one locality.

The schists are associated with the Castine volcanics in a variety of ways. Along the contact near Sedgwick and on the north end of Deer Isle the volcanics, probably flows and breccias, seem to rest upon the schists, though the relations are not very clearly shown. On the east shore of Benjamin River and on Herriman Point a number of light-colored dikes of the volcanics cut the Ellsworth schist. On the north end of Deer Isle the Castine volcanics lie just to the west of the schist, and the rock composing certain dikes cutting the schist is seen under the microscope to be porphyritic rhyolite. Similar dikes of porphyritic rhyolite occur on Long Island, and some of them inclose schist fragments. All these dikes show schistosity, which is better defined in some than in others, but is nowhere as perfect as the schistosity of the rock that they invade.

The contact relations between the Ellsworth schist and the serpentine of Deer Isle are obscured, but the serpentine is probably intrusive in the Castine volcanics and hence must be related in a similar way to the much older Ellsworth schist.

Age.—The Ellsworth schist is believed to be older than any of the other rocks of the quadrangle, although positive proof can be adduced only in the case of the three formations mentioned above. The schist is regarded as considerably older than the Castine formation, the North Haven greenstone, the Penobscot formation, and the Islesboro formation because of the greater amount of crumpling and shearing which it shows. Dikes of the Castine formation which cut the schist appear much less metamorphosed than the schist itself. Within the Penobscot and the Islesboro formations distinct traces of bedding are observed at a great number of localities, whereas in the Ellsworth schist they have been obliterated except at the single locality already mentioned.

Since the Islesboro, Castine, and Penobscot formations and the North Haven greenstone are regarded as probably Cambrian or Cambro-Ordovician in age, the older Ellsworth schist is presumably early Cambrian or pre-Cambrian.

ISLESBORO FORMATION.

Definition.—The name Islesboro formation is applied to a series of somewhat metamorphosed rocks, mainly of sedimentary origin, which occupy the larger part of Islesboro and the neighboring smaller islands. The formation includes two members—the slate, which forms the larger part, and the overlying Coombs limestone. The slate member is made up of slates, schists, calcareous shales, impure quartzites, and small amounts of pyroclastics, but slate is by far the most abundant rock. The name Coombs limestone is taken from Coombs Point, on the northeastern shore of Islesboro. Near this point the limestone member is well exposed and its relations both to the Battie quartzite and to the slate member are well shown.

Distribution.—The rocks of the slate member cover about three-fourths of Islesboro and the adjacent islands, and outside of the Penobscot Bay quadrangle are known to occur only in one small area outcropping for a few hundred feet along the east shore of Rockport Harbor. Beginning at Turtle Head, at the north end of Islesboro, the slates extend uninterruptedly southward to Dark Harbor, where their continuity is broken by a belt of Coombs limestone. South of this belt they reappear and extend in an interrupted manner to Pendleton Point. They occupy the whole of Hog, Seal, and Flat islands, nearly all of Seven Hundred Acre and Warren islands, and considerable parts of the islands to the south. Their southernmost exposure is on Robinson Rock. The rocks mapped as the Calderwood formation and also a small mass of shaly and quartzose sediments exposed as an anticlinal arch beneath the Castine volcanics on the north side of Bradbury Island may belong to the Islesboro formation, but conclusive evidence for this correlation is absent.

The Coombs limestone member is represented by deposits of fairly pure limestone at three localities within the Penobscot Bay quadrangle—at Limekiln Landing, on the northeast shore of Islesboro; on the north shore of Seal Harbor; and on Lime Island, $1\frac{1}{2}$ miles southwest of Islesboro. In the main, however, the limestone is shaly or quartzitic. It occurs for the most part in long, narrow bands trending somewhat east of north. The most continuous of these extends across South Islesboro from Hewes Point to the village of Dark Harbor and reaches the western shore near Ames Cove; for much of this distance it outcrops along the shore. North of Dark Harbor this belt has a width of 500 to 800 feet, but in many places its width is less than 100 feet. Southeast of this belt and nearly parallel to it are two others, and small limestone areas occur on the shore near Pendleton Point. On the western side of Islesboro a belt of limestone that varies greatly in width extends with slight interruption from the west shore of Broad Cove to Crow Cove. Two narrow, nearly parallel belts cross the point between Seal Harbor and Sprague Cove. All of the limestone belts mentioned above, as well as some of less extent, are bordered by slates.

The Coombs limestone borders the Battie quartzite area north of Sprague Cove both on the east and on the west, and borders also the quartzite area extending northward from the shore of Seal Harbor. On Coombs Point and the next point to the south, along the northeast shore of Islesboro, the limestone occurs immediately west of the Battie quartzite. Small areas also occur on Hutchinson Island, off the eastern shore of North Islesboro; on Seven Hundred Acre Island; and on the neighboring Job, Spruce, and Warren islands. The small island between Job and Lime islands is also largely limestone.

On the mainland, limestone belonging to this horizon occurs within the Rockland quadrangle on Beauchamp Point near Rockport, and at a few other localities in this vicinity. It is extremely shaly and is not the limestone which is worked commercially.

Structure.—The rocks of the Islesboro formation are everywhere much folded. The general form and trend of some of the larger folds are shown on the map by the long, narrow belts of Coombs limestone, which is synclinally infolded with the slates. Superimposed upon the major folds are a great number of minor folds, in many places closely compressed and of nearly parallel trend, the resulting distribution of the rocks being too complicated to express on a map of this scale. The minor folding is shown particularly well along the shore from Turtle Head to Marshall Point and on the western shore of Seven Hundred Acre Island. The trend of the major folds in the central part of the island varies from nearly north and south to about N. 45° E., the average being about N. 25°–30° E., or about the average trend of the folds throughout the Penobscot Bay region. At the north end of the island, however, the trend becomes more easterly, as on the adjacent parts of the mainland, and in some places is due east and west.

Besides the intense folding, the rocks in many localities show a well-developed slaty cleavage which in general is nearly parallel to the trend of the folds. The cleavage planes are everywhere highly inclined and in many places intersect the bedding planes, the two being locally almost at right angles. Cleavage is well developed on the west shore of Islesboro about $1\frac{1}{2}$ miles south of Marshall Point, where it cuts the bedding planes at various angles up to 40°. It is also well shown at Turtle Head neck, where its strike is N. 50° E. and its dip about vertical, while the bedding planes strike N. 55° W. and dip at about 25°. Small quartz veins, few of them more than $1\frac{1}{2}$ inches through, are of common occurrence in the slate member, though in some localities they may be almost entirely absent. On the western shore of Seven Hundred Acre Island these veins are numerous and are intensely crumpled; their general trend is parallel to the bedding planes, but the axes of the crumplings lie in the plane of the cleavage, which in this case makes an angle of about 15° with the bedding.

Stratigraphy.—Stratigraphically the slates are known to underlie the Coombs limestone member, but this conclusion is reached by inference more than by direct field observation, for at none of the localities where these two members are in contact are their mutual relations clearly shown. Field observation shows, however, that the Battie quartzite lies immediately above the Coombs limestone, so that the slates which immediately adjoin the limestone on its opposite side must lie below it. The structural relations of these rocks are best shown near the point at the northern entrance to Parker Cove, on the eastern side of North Islesboro. Here the Coombs limestone, which is well exposed along the shore, seems to be overlain by thick and relatively little disturbed beds of Battie quartzite, which form a broad syncline pitching at an angle of about 50° down to water on the southeast. The exact contact is here obscured by glacial deposits, but it is well exposed just to the north, on the east side of Coombs Point. At the latter locality a belt of fairly pure limestone about 30 feet wide, appearing to occupy the crest of an eastward-pitching anticline, grades both to the south and to the north through shaly and quartzitic limestone into Battie quartzite, as is shown on the map. On the west this belt of Coombs limestone is bordered by slates, but the exact contact is nowhere exposed. There is no reason to believe that the beds at either of the localities above described have been overturned, and the present succession from slates below through Coombs limestone to Battie quartzite above seems to be the order in which they were deposited. These relations are shown in section B–B.

Further evidence confirmatory of this succession is found about the northern border of the limestone area which lies midway between Sabbathday Harbor and Sprague Cove, where the strikes and dips seem to indicate that the limestone overlies the slates.

In certain localities, on superficial examination, the Coombs limestone seems to be absent between the slates and the Battie quartzite. This is the case at the western border of the Sprague Cove area of Battie quartzite, but a more careful study of the continuous section from south to north along the shore shows the following succession:

Section along northwestern shore of Islesboro.

	Feet.
South, youngest.	
1. Typical massive Battie quartzite.	
2. Greenish slate containing numerous elongate quartzitic pebbles somewhat sheared and fractured, and all under $1\frac{1}{2}$ inches in diameter	3
3. Buff massive quartzite	2–3
4. Even-textured gray quartzose limestone, effervescing freely with dilute acid	7–8
5. Islesboro slates, greenish gray, highly fissile.	
North, oldest.	

The siliceous limestone (No. 4 of the section above) resembles the quartzite closely on the freshly fractured surfaces, but reveals its calcareous nature in the weathered surfaces, which are finely pitted and brownish yellow in color. The rock may easily be mistaken for pure quartzite. This narrow calcareous band seems to be the stratigraphic equivalent of the thicker beds of shaly limestone developed in other parts of the island. This is not remarkable when the known variable character of the Coombs limestone is considered, a variability manifest even in the siliceous limestone here mentioned, which shows, at the locality of the above section, a thickness of only 7 to 8 feet, but which appears one-half mile farther south along the shore with a thickness of about 20 feet. At the eastern border of this quartzite area at the head of Sprague Cove only the quartzite and the greenish Islesboro slate outcrop, but between these there is an interval of 150 feet, which allows abundant space for the intervening limestone horizon. Following the eastern border of the quartzite northward we find the quartzose limestone occurring between the slates and the quartzite near the turn in the road one-half mile north of Meadow Pond.

At the western border of the Battie quartzite area which extends northward from Seal Harbor the limestone horizon is represented by 12 feet of siliceous limestone exactly similar to that found at the border of the Sprague Cove quartzite area. This lies conformably between slates and typical quartzite. The exposures are so good that faulting, if present, could not remain undetected. East of the quartzite the limestone is developed in much greater thickness and purity and has been quarried to some extent. Limestone is also found bordering this quartzite tongue near its northern limit, but it is neither of the siliceous variety nor of the pure variety developed at the old quarries, but is thin bedded and shaly. We have here another striking example of the extreme variability of the limestone both in character and in thickness.

On the small island between Job and Lime islands, as well as on the southern part of Job

Island, the limestone is interbedded with dark-green layers which seem to be volcanic tuffs or muds of the North Haven greenstone. Within the slate member, also, as will be shown later, much volcanic material of the same age and origin occurs.

The thickness of the slate member of the Islesboro formation is unknown, the base being nowhere exposed. It is at least 300 to 400 feet and is probably considerably more. The thickness of the Coombs limestone member varies from 7 or 8 feet at the northern border of the Sprague Cove area of Battie quartzite to more than 100 feet at numerous other places. Its exact thickness is determinable at but few localities. At the abandoned limestone quarry on the north shore of Seal Harbor, between North and South Islesboro, the width of the limestone belt is considerable but is largely the result of repetition of the beds through folding, as indicated by the contortion of a darker-colored band within the limestone. The true thickness here is probably not over 50 feet.

Lithology.—Within the slate member there are two principal kinds of rock. One is a fine-grained rock showing very conspicuous and regular banding due to the alternation of bands of light-gray quartzose material with greenish-gray to blue-gray bands. Rock of this kind is well developed at Turtle Head, at the extreme north end of Islesboro; on the western shore of North Islesboro, about 1½ miles south of Marshall Point; on Flat and Seal islands; and along the western shore of Seven Hundred Acre Island. The second kind is much more massive, somewhat quartzitic, and light greenish gray in color. It is present through the central part of North Islesboro, and interruptedly through South Islesboro. In a few places the rocks of the slate member show abundant muscovite scales and develop a schistose character. Slightly schistose rocks occur on the narrow neck of land between North and South Islesboro, and a very perfect schist occurs on the north side of the easternmost point of Seven Hundred Acre Island. At this locality the rock shows a great abundance of muscovite in plates a few of which are one-fourth of an inch in diameter. At many localities minor crumpling has been intense.

In places the percentage of quartz increases so that the rock becomes a greenish to bluish-gray massive quartzite; this is particularly well developed at the north end of Seven Hundred Acre Island. Here and there the rock becomes a distinct quartzite conglomerate which shows small pebbles of quartz in a blue-gray quartzitic matrix. Rocks of this kind occur at the north and south ends of Seven Hundred Acre Island, on the southwestern shore of Job Island, on Ensign Islands, and at a number of other localities. The prevailing blue-gray color of both the fine-grained and the conglomeratic varieties of these quartzites is in strong contrast with the light-gray and buff colors of the Battie quartzite. This contrast is well brought out on Seven Hundred Acre Island, where, at the extreme north end, the blue-gray quartzite and quartzite conglomerate occur, while on the second point northwest of Cradle Cove there is a small outcrop of buff-colored Battie quartzite exactly like that of the large Battie quartzite area at Sprague Cove. The intraformational character of the blue-gray quartzite conglomerate is well shown at the southern point of Seven Hundred Acre Island, where it appears in a small anticline pitching 30° NE. On the limbs of this fold the conglomerate is seen to have a thickness of only 10 feet, and greenish slates exactly similar to each other in appearance occur both above and below.

Several rocks which have been mapped as part of the Islesboro slate bear a close resemblance to some forms of the North Haven greenstone. The 80-foot hill in the eastern part of Seven Hundred Acre Island is made up of rocks of dark-green color and fine grain which are feebly schistose. For the most part they are massive, but a few lighter colored bands occur which are continuous and of even thickness for considerable distances. Along the shore of the eastern point of this island the rocks are banded light and dark green in color and in some places have the appearance of tuffs, though in other places they seem plainly to be water-laid sediments. Sharp differentiation between the two is impracticable. The same characteristics are shown on the eastern and southeastern shores of Spruce Island. At its south end undoubted greenstones that appear to be tuffaceous are interbedded with somewhat quartzitic slates. On the north end of Lasells Island there seems to be a gradual transition from undoubted sediments to typical fragmental greenstones which show here and there some alternation of light and dark layers. In the southeastern part of Lasells Island occurs another patch of rocks whose distinct bedding indicates a sedimentary origin. Microscopic examination of the darker bands in this rock shows that the most abundant constituent is green pleochroic hornblende in very fresh grains elongated parallel to the well-defined schistosity of the rock. Some quartz in small crystals and a number of large augen of plagioclase feldspar occur between the grains of hornblende. Apparently this rock was originally of a dioritic or diabasic composition, but has been wholly recrystallized. The feldspar now shows some saussuritization, and secondary chlorite and epidote and muscovite are also present. On Mark Island also the sediments are not sharply differentiated from the greenstones. On the small island between Job and Lime islands, as will be discussed later, there is an apparent interbedding of the greenstones and the Coombs limestone.

The difficulty experienced in drawing a sharp line between these rocks that are apparently sedimentary and the tuffaceous varieties of the greenstones, their close areal association, the feldspathic and hornblendic character of some of the beds in the seemingly sedimentary deposits, as well as the prevailingly greenish tint of a large part of the slate member, all indicate that the rocks of the Islesboro formation contain much fragmental material of common age and origin with the North Haven greenstone. Some volcanic material is perhaps present throughout most of the formation, and certain parts seem originally to have been very pure volcanic muds, grading without break into tuffs.

Most of the limestone of the Islesboro formation, as previously stated, is exceedingly impure; indeed, a large part of the rock might be more correctly termed a calcareous shale. In the metamorphism which has affected the rocks of the whole island, the limestone has been wholly recrystallized and the shaly beds have in many places become schists. Even where outcrops are not found, the presence of the shaly limestone may usually be recognized by the reddish soil which results from its decomposition. The quartzose limestone lying next to the quartzite areas of the western part of the island and also on the eastern shore of Sabbathday Harbor was originally a sandy limestone. It is thick bedded, even textured, and fine grained, and is greenish gray in color on fresh surfaces. The purer limestone occurring at the old quarries north of Coombs Point and at Seal Harbor is blue-gray in color and crystalline, with grains usually under one-sixteenth of an inch in size. Even with the naked eye impurities, pyrite and muscovite, can usually be seen, and under the microscope some quartz in grains and as small veins is also recognized. The limestone from both of these quarries is only slightly magnesian.

The limestone of Lime Island and of the small island between it and Job Island differs from that of Islesboro in its greater purity, in being highly magnesian (it does not effervesce with dilute acid), and in the development of very conspicuous banding. The rock exhibits an alternation of bands of nearly white limestone with bands which are finer grained and blue-gray in color, and in places these are much contorted. Many of these bands, especially the broader ones, probably represent slight variations in the character of the limestone as it was deposited, but they have been modified and perhaps accentuated in the recrystallization to which this rock has been subjected. Many of the minor bandings seem to have originated in this metamorphic process.

The extreme variability of the limestone both in thickness and in purity indicates plainly that it was not deposited at abysmal depths but was laid down at depths well within the reach of ocean currents, in waters clearer than those in which the shaly member was deposited, but probably little if any deeper. Throughout most of the area over which limestone was forming the waters were occasionally muddy, so that in the resulting rock shaly layers alternate with layers of limestone; in some places fine sand was being brought in, so that a sandy limestone resulted; and in a few places, either because of slightly deeper water, more rapid growth of lime-secreting organisms, or unusual protection from land wash, limestone deposits of considerable purity were built up.

Age.—The age of the Islesboro formation is tentatively placed as Cambrian for reasons set forth in the section on "Historical geology," p. 12. Certain varieties of the North Haven greenstone are associated with the sediments of the Islesboro formation in such a way as to indicate that these two formations are practically contemporaneous.

BATTIE QUARTZITE.

Definition.—The Battie quartzite consists of massive buff quartzite and of clean, buff-colored quartzite conglomerate of very striking appearance. It is named from Mount Battie, a small mountain on the mainland near Camden, almost due west of the south end of Islesboro. This prominence is made up entirely of quartzite conglomerate, well exhibited in precipitous faces and broad glaciated surfaces.

Distribution.—Within the quadrangle the Battie quartzite is confined almost exclusively to the northern half of Islesboro, where it occurs in small isolated patches. In the largest area it outcrops along the west shore of North Islesboro for a little more than a mile, and from the shore extends inland in a northeasterly direction, constantly becoming narrower, until it tapers out about 1 mile southeast of Marshall Point. Northeast of this point several small outliers appear, one of which, as shown on the map, outcrops in the road. A similar but smaller quartzite area, with a maximum width of about one-eighth of a mile, extends northward for nearly a mile from the north shore of Seal Harbor. Quartzite in beautiful exposures occupies Coombs Point and the next point to the south, along the eastern shore of North Islesboro. The eastern half of Hutchinson Island, in Parker Cove, is made up of quartzite, the western half being occupied by the underlying Coombs limestone. A small area of quartzite occupying the point at the eastern entrance of Sabbathday Harbor is separated by a fault plane from the limestones which succeed it to the north. The quartzite outcrops along the northern side of this harbor and also forms most of the 140-foot hill to the northeast. The only other exposure of Battie quartzite within the quadrangle occurs on Seven Hundred Acre Island, on the second point northwest of Cradle Cove; its area is too small to map.

On the mainland just west of this quadrangle quartzites similar in every way to the massive and conglomeratic quartzites of Islesboro occupy very considerable areas in the vicinity of Camden and Rockport. In view of the striking and unusual character of the quartzite conglomerate, it seems highly improbable that two occurrences so closely adjacent as those of Islesboro and the mainland can be of different age. They are regarded as belonging to one formation and are named from their best and most extensive exposure on Mount Battie, near Camden.

Structure and stratigraphy.—The stratigraphic relations between the Battie quartzite and the rocks of the Islesboro formation are best exhibited on the point at the north entrance to Parker Cove and on Coombs Point in North Islesboro. These localities have been partially described in the section on the Islesboro formation. On the point north of Parker Cove the quartzite mass is broadly synclinal in form and pitches at an angle of about 50°. On Coombs Point the quartzite beds seem also to form a syncline which pitches to the east. There is no reason to suppose that the quartzite at either of these localities has been overturned. The rather gentle, open folding observed here is similar in kind and degree to that observed elsewhere within the quartzite formation both on the mainland and on Islesboro. Because of its relatively great rigidity minor crumplings such as were developed so abundantly within the Islesboro formation were seldom produced. It is highly probable, therefore, that the present position of the quartzite above the Islesboro formation represents the true order of deposition. These relations are shown in section B–B.

The structural and stratigraphic relations about Sabbathday Harbor are not clearly shown, but from analogy to the other occurrences the quartzite is believed to constitute a rather flat synclinal mass lying on top of the limestone.

The occurrence of the Coombs limestone about the borders of the Sprague Cove and Seal Harbor areas of Battie quartzite, between the quartzite and the slates, has already been described in the section on the Islesboro formation. This relation shows that the quartzite of these areas is infolded with the Islesboro sediments. Field observations on these areas do not show whether this infolding is anticlinal or synclinal, but the relations observed on the point north of Parker Cove indicate that the quartzite lies in synclines.

Lithology.—On the mainland (in the Rockland quadrangle) the most widespread variety of the Battie quartzite is the quartzite conglomerate. On Islesboro this variety is typically developed only on the point north of Parker Cove, where about 50 feet of conglomerate overlie massive quartzite. The conglomerate here is practically identical with that at Mount Battie, near Camden; it is light gray when freshly fractured and is composed of quartzite pebbles from 1 to 6 inches in diameter and more or less rounded, lying in a matrix of rather fine-grained gray quartzite. The pebbles show little deformation. In other places the pebbles in the conglomerate are smaller and not well rounded, and the color may be greenish gray rather than buff or light gray. On weathering the surface of the conglomerate assumes a buff to reddish-brown color. By far the larger part of the quartzite of Islesboro is massive and fine grained and only here and there shows conglomeratic bands. The rock along the western shore of the island from Sprague Cove northward may be taken as the type of this variety; it is a thick-bedded buff quartzite which weathers to a yellowish or reddish brown. On the point north of Parker Cove and at other places conglomeratic bands appear in the massive quartzite. Near the underlying Coombs limestone the quartzite in many places becomes shaly and here and there calcareous. The quartzite of the small area on Seven Hundred Acre Island is buff colored and massive. It is similar in appearance to that at Sprague Cove, but markedly different from certain gray to greenish quartzitic varieties of the Islesboro formation which occur on other parts of Seven Hundred Acre Island.

Microscopic examination shows, in most of the massive quartzite specimens, a filling of finely divided muscovite between the quartz grains; this represents an original clayey component and shows that most of the quartzite was somewhat argillaceous. Where this micaceous matrix is present, the original outlines of the quartz grains have in general been well preserved. The grains in most places are not well rounded. In specimens where there is little or no micaceous matrix, the quartz grains interlock in the irregular manner characteristic of recrystallized quartz rocks. Dynamic action is indicated in many of the slides by parallel elongation of the quartz grains, by undulatory extinction, and by granulation. In many localities hematite, magnetite, and pyrite are abundant constituents, and on weathering give the rock its rusty appearance. In a few specimens chlorite also is abundant.

Thickness.—The thickness of the Battie quartzite on Islesboro can not be determined, because its upper limit is nowhere exposed. On the point north of Parker Cove a thickness of about 100 feet is exposed, and in the Sprague Cove area its thickness may be considerably greater. On the mainland its thickness seems to be about 400 to 500 feet.

PENOBSCOT FORMATION.

Definition.—The Penobscot formation is composed of metamorphosed shaly sediments which are typically developed along nearly the whole length of the western shore of Penobscot Bay. They occupy large areas west of the Penobscot Bay quadrangle, between the ocean and Kennebec River.

Distribution.—Within this quadrangle this formation occupies almost all of the mainland west of Penobscot River, and occurs on the east side of the river as a strip from 1½ to 2 miles wide between West Penobscot and Pierce Pond. Between Little River and Ducktrap Harbor on the mainland the sediments are associated with considerable amounts of intrusive granite and diorite, which have produced notable contact effects. Beyond the limits of this quadrangle the same sediments extend up the Penobscot at least as far as Bucksport, and southward along the coast at least as far as Cushing. Inland they extend to Searsmont, in the southern part of Waldo County, and probably beyond.

Structure and stratigraphy.—The most typical exposures of this formation occur in the northwestern part of the quadrangle, between Belfast

Bay and Sandy Point. The sedimentary character of the rocks is shown by the presence of distinct bedding at many localities. Considered in its larger relations, the formation seems to be flat lying, but the rocks have been thrown into a large number of minor folds, so that the dips now vary from horizontal to vertical; in some areas the folding is isoclinal and the rocks over several square miles dip steeply in the same general direction. Between Belfast and Sandy Point the trend of the folds is in general N. 35°–50° E.; farther south, within the area of the Rockland quadrangle, the trend is N. 20°–30° E. Slaty cleavage, such as is developed at many places in the Islesboro slate, is of rare occurrence here, but a distinct and in many places very perfect schistosity is commonly present. In general the strike of the schistosity is nearly parallel to the trend of the folds.

The structural relations between the slates and the other sedimentary formations of the region are nowhere shown within this quadrangle. Evidence obtained elsewhere is discussed below in the paragraph on age and correlation.

Lithology.—In color the rocks of this formation vary from light gray through steel-gray and purplish gray to black, the darker grays being predominant. The weathered surfaces are usually rusty. In a few places, as at Fort Point, the rock exhibits a very perfect slaty cleavage which is highly inclined to the bedding planes. In most localities, however, the rock cleaves most readily along planes of schistosity, developed in varying degrees of perfection in different areas and in different beds. The most quartzose varieties exhibit little if any schistosity; less quartzose varieties show highly micaceous surfaces of easy parting, widely spaced; the more argillaceous varieties are highly micaceous throughout. The secondary mica developed in the process of metamorphism is as a rule present in very minute plates, and only in a few of the coarsest varieties do the plates reach megascopic proportions. Rarely the schist is conglomeratic, showing purplish quartzitic fragments between which there has been a large development of mica. "Knoten" schists are very common in nearly all parts of the formation, though somewhat more abundant in those portions which are associated with the intrusive granite and diorite. Certain bands, some of them only 6 inches or so in width, may be "knoten" schist, while the bordering layers on either side are ordinary phyllites or are quartzitic. The "knoten" seem to have developed in the more argillaceous strata, and their development tends to preserve or even to accentuate the original bedding.

The bedded character of the Penobscot slate is well shown just east of Searsport village, where are found alternate bands of dark fissile slate and of compact impure quartzite, some of the latter being 8 inches in thickness. In one place north of this village the somewhat crumpled rusty slates and schists show a schistosity which trends N. 50° E. and a series of gash veins of quartz which trend N. 25° E. All are about vertical.

When examined microscopically the more quartzitic varieties of the rock are seen to be fine-grained quartzites which show an abundant development of mica or chlorite in small plates. These generally have a more or less parallel arrangement, thus giving the rock a feeble schistosity. A purplish-gray, crinkly variety occurring near the village of West Penobscot is seen under the microscope to be a crumpled mica schist showing some finely divided quartz between the muscovite laminæ, and a large amount of magnetite in irregular masses, most of which are elongate parallel to the mica plates. The argillaceous varieties show in some places an abundance of minute garnets, and rarely andalusite.

Contact-metamorphic phases. — In the region between Little River and Ducktrap Harbor, where the slates are associated with intrusive granite and diorite, the bedding for the most part has been completely obscured in the development of notably coarser schists than are common elsewhere. In numerous places there has been an abundant crystallization of andalusite, staurolite, garnet, and similar secondary minerals. In many places a rock of gneissic texture is produced by the intrusion of the schist by granite. As a rule the schist is so mixed up with gneiss of this kind, with flow gneiss, and with pegmatitic granite that their separation on the map is wholly impracticable. The areas mapped as granite or diorite, in the region between Northport Camp Ground and Ducktrap Harbor, while generally free from other rocks, include small amounts of schist and gneiss. Outside the areas thus indicated, the schists are, in many localities, full of masses of intrusive granite or diorite in the form of dikes or irregular pegmatitic bodies too small to be indicated on the map.

Under the microscope the schists of this injected area show the same minerals that are characteristic of the normal varieties of the formation, but the grain of the rocks is in many specimens much coarser and andalusite and garnet are developed in larger, more numerous, and usually more perfect crystals. Some of the garnets reach megascopic proportions and the andalusite prisms attain a length of 1 to 1½ inches and a diameter of one-fourth inch.

In the neighborhood of Swanville, in the northwest corner of the quadrangle, some gneiss is associated with the granite border, and the contact effects on the pelites are noticeable. The granite contact from West Penobscot to Pierce Pond is sharply defined, and except that some granite dikes cut the slates and some slate fragments are caught up in the granite, the sedimentary rocks are but little affected so far as outward appearance goes. Microscopic examination, however, reveals some changes; thus on the southern slopes of Wallamatogus Mountain the schist next to the contact is full of small, more or less irregular prisms of brown tourmaline lying in a recrystallized mass of quartz, muscovite, and magnetite.

Age and correlation.—The relations between the Penobscot slate and rocks other than the granite and diorite are not shown within the limits of this quadrangle, but are well exhibited on the point east of Rockport Harbor, in the Rockland quadrangle. Here the Penobscot formation overlies directly and conformably the Battie quartzite.

Lithologically certain varieties of the Penobscot formation are identical in appearance with some of the slates of Islesboro. This similarity and the fact that less than 2 miles of water separates the two areas suggest that they belong to the same formation, but the stratigraphic sequence as determined in the Rockport area, with which the structural relations observed on Islesboro are in accord, makes it necessary to separate them.

CALDERWOOD FORMATION.

Definition.—The rocks of the Calderwood formation are metamorphosed argillaceous sediments similar in general appearance to the rocks of the Penobscot formation and of the Islesboro formation. They are named from the locality of their most extensive and typical development, Calderwood Neck, in the northern part of the island of Vinalhaven.

Distribution.—The Calderwood formation occupies the northern half of Calderwood Neck, with the exception of the narrow portion west of Carvers Cove. Disconnected from this larger area is a narrow strip of similar rocks along the western shore of Seal Cove, and another area occurs along the shore near the eastern entrance to Crockett Cove. Patches that are too small to be shown on the map occur on the extreme east end of Vinalhaven near Coombs Hill and at several places within the diabase area of Barley Hill and the volcanic area on the western side of the island. The formation is not known to occur on North Haven.

Structure.—The Calderwood in its principal development shows distinctly sedimentary characters. Bedding can be recognized even at some distance and seems fairly constant, the strike for the Calderwood Neck area being in the main within a few degrees of north and south and the dip 30°–40° W. On the shores of Seal Cove, however, the dips are more to the northwest. The formation has been folded somewhat and affected by dynamic metamorphism, which has given many of the more argillaceous beds a decided schistosity. In general this secondary structure has nearly the same strike as the bedding.

Lithology.—The Calderwood formation consists of dark quartzitic slates, banded schists, quartzose but varying in color and grain, and rather massive quartzites. Felsitic rocks occurring in close proximity to the granite and the volcanic rocks undoubtedly represent contact varieties of these sediments. These felsites are mottled and variegated, the general color being a light green. In the thin section the lighter bands in some of these rocks are seen to be composed of nearly pure epidote with some zoisite; the darker bands are nearly pure hornblende. The rocks along the western shore of Seal Cove are somewhat more massive than those on Calderwood Neck; in places they are slightly calcareous. Epidote is somewhat prominent along the bedding planes and gives a banded appearance in many places. Near Coombs Hill the schists are mainly actinolitic in appearance, but where cut by a granite dike they are bleached, as at several localities in Calderwood Neck.

Age and correlation.—At no point do these schists come into contact with the greenstones or the Ames Knob sediments. East of Seal Cove and north of Mill River the schists are interbedded with sheets of quartz porphyry which are apparently intrusive. On the western shore of Seal Cove, south of Perry Cove, diabase sheets and dikes mask the contact with the overlying volcanics. In their metamorphosed character and in the absence of all fossils these rocks are in marked contrast to the sediments of Niagara age, and plainly represent an earlier deposition. The contact relations prove that they are older than the granite and diorite which cut the slates and the Thorofare volcanics which overlie them. In general lithologic character and in the degree of metamorphism which has affected them they resemble both the Islesboro slate and the Penobscot slate of the mainland. For those reasons it is probable that the rocks of Calderwood Neck belong to one or the other of these two formations, but it has been thought best to describe them as a separate formation, since their isolated position prevents certain correlation.

AMES KNOB FORMATION.

Definition.—The rocks of the Ames Knob formation are limestones and red shales, which because of their fossiliferous character assume great importance in the age determination of the other rocks of the quadrangle. The formation is named from Ames Knob, one-half mile west of the village of North Haven, along whose northern flank good exposures occur. Although its fossils show it to be of Niagara age, the use of the name Niagara at this distance from the type area does not seem warranted.

Distribution.—The area occupied by these sedimentary rocks is smaller than that covered by any other formation in the Penobscot Bay quadrangle. The principal exposure is a wedgelike area extending eastward from the shore of Southern Harbor, where it is less than a quarter of a mile in width, across the Ames Knob peninsula, the apex of the wedge being east of the mud flat and near the road from North Haven village to Pulpit Harbor. Its full length is thus less than a mile, and the greatest width as exposed on the shore of Southern Harbor about one-eighth of a mile. Sediments of about the same age are found also in a narrow strip on the west end of Stimpson Island. Throughout both areas the surface is low and the rocks are mostly concealed, except on the shores.

Structure.—The structural features of the Ames Knob formation are in striking contrast with those of all the other sedimentary formations of the region. Its beds have been tilted and in places gently folded, but there is a complete absence of the closely compressed folds and minor crumplings so characteristic of the Penobscot, Calderwood, and Islesboro formations, the Castine formation, and the North Haven greenstone. Its bedding planes have not been obscured by the development of schistosity or of slaty cleavage and its fossils are perfectly preserved. It is apparent that it is separated in time from the formations mentioned above by a period of dynamic or regional metamorphism.

The general strike of the formation on the shore northward from Ames Knob varies from N. 85° E. near the base to N. 40° E. in the upper beds. Higher beds exposed on the north slope of Ames Knob, however, show a strike similar to that of the basal members. The dip is from 50° to 60° S., and even steeper at a few points. To the east, on the west shore of the mud flat, the lower beds of the series have much the same sequence and strike, but the upper portions show some slight folding and displacement.

On Stimpson Island the sediments strike N. 60° W. and dip about 30° NE.

Stratigraphy.—The best section of the Ames Knob sediments is found on the shore of Southern Harbor, just northwest of Ames Knob. Here the basal member is in immediate contact with the North Haven greenstone to the north. The upper members are about 70 feet from the overlying volcanics, but this interval is represented in part a short distance farther east by red shales with interbedded conglomerate. The section was measured at low tide and is much more complete than that exposed above high-water mark. In descending order the section is as follows:

Section of Ames Knob formation on the shore of Southern Harbor.

	Feet.
Sandy shale and quartzite	65
Concealed	70
Gray shale	49
Conglomerate and shale	12
Red shale	55
Conglomerate	1
Red shale	10
Gray shale	37
Concealed	17
Gray shale and limestone	71
Quartz porphyry, intrusive sheet	10
Concealed	16
Gray limestone, weathering brown, and shale	104
Grit, coral fragments	1
Sandy limestone	4
Concealed	42
Basal conglomerate	16
	580

The basal member is a conglomerate which includes in its lower part large, well-rounded masses of the subjacent North Haven greenstone, but in its upper part well-rounded pebbles of black and green slates, quartzite, and vein quartz, materials unlike the underlying rock. Such a basal member may be considered to have been deposited in a sea transgressing a land surface of more or less disintegrated rock which furnished the residual bowlders of greenstone. The limestone-shale series shows changing conditions, which were more constant, however, during the deposition of the hundred feet of limestone with slight amounts of shale, overlying the grit. This latter bed, from its evenness of grain, affords evidence of perfect sorting, and the presence of coral fragments may be considered to indicate breaker action. These calcareous deposits are very fossiliferous, showing that the conditions were favorable to lime-secreting organisms. Even within the shaly bands, nodules of limestone occur, some of which are plainly coralline.

An increase in the amount of silt contributed to the sea terminated the deposition of limestone, and the upper portions of the section are essentially argillaceous. In these shales the remains of the organisms are even better preserved than in the limestone. At one locality traces of ripple marks can be detected in the quartzite associated with the shales.

The red shales which occur as two important members in the shore section and also higher up in the formation as exposed a short distance to the east deserve special mention because of their close resemblance to certain fine-grained tuffs within the Thorofare volcanic series. This similarity is primarily one of color, for none of the tuffs possess quite the fineness of grain that characterizes these shales. The field relations suggest that the red color is due to fine ash from neighboring volcanic explosions. Microscopic examination also shows that the finer portions of the typical red tuffs of the Thorofare volcanics are very similar to the material of the shales. If this interpretation is correct the red shales would present the earliest evidence of that volcanic activity which later resulted in the red and gray lavas of the Thorofare andesite.

The sediments of Ames Knob grade upward in apparent conformity into the Thorofare andesite. The wedge shape of the Ames Knob area does not represent an unconformity between these rocks and the overlying Thorofare volcanics, but apparently is due to the nondeposition of the sediments. The west side of Waterman Cove may have marked the position of the shore line during the period of Niagara sedimentation, or possibly volcanic deposits may have been forming here while sedimentation was in progress to the westward.

On Stimpson Island a strip of limestones and quartzites less than 100 feet in width occurs within the area of the Thorofare andesite. These sediments are underlain by gray lavas and overlain by tuffs and breccias of the Thorofare andesite, so that they must be regarded as having been deposited during a time of cessation in the volcanic activity, a break not recorded so fully at any other locality of this region. The strike and dip of these sediments, N. 60° W. and 30° NE., and the thinness of the section prevent any exact correlation with the Ames Knob formation in North Haven, but the rocks very closely resemble the latter sediments, and the only fossils found, traces of brachiopod shells and a crinoid stem, are also similar in appearance to the more plentiful organic remains of the other area.

Fauna.—The fossils contained in the Ames Knob sediments have been carefully studied by C. E. Beecher, and the following conclusions reached (Am. Jour. Sci., 3d ser., vol. 43, 1892, pp. 416–418).

A large proportion of the species clearly points to a correlation with the Niagara of New York, and to this period they are here referred. The presence of quite a number of characteristic Clinton species is a disturbing element in any attempt to draw exact parallelisms with the New York subdivisions of the Upper Silurian. [For this reason the application of the local geographic name to this formation has been thought preferable to the use of the name Niagara, which carries a too definite time significance.]

The Clinton species are mostly confined to the lower half of the series, * * * but nearly all the typical Niagara forms are associated with them in abundance. Another fact to be noted is the conspicuous absence of some [Niagara] species from the entire series.

[The following is a revised list of the determined species:]

GRAPTOLITES.

Monograptus clintonensis Hall.

CORALS.

Streptelasma calyculum Hall.	Favosites favosus Hall.
Chonophyllum niagarense Hall.	Cœnites ramulosus Hall.
Favosites venustus Hall.	Halysites catenulatus Linné.
Favosites niagarensis Hall.	Heliolites spinoporus Hall.

CRINOIDS.

Ichthycrinus lævis.	Eucalyptocrinus cælatus.

TRILOBITES.

Encrinurus punctatus Wahl.	Dalmanites limulurus Green.
Calymene niagarensis Hall.	Ceraurus niagarensis Hall.
Homalonotus delphinocephalus Gr.	Illænus ioxus Hall.
	Proetus stokesi Hall.

BRACHIOPODS.

Lingula lamellosa Hall.	Chonetes cornutus Hall.
Orthis elegantula Dal.	Whitfieldella nitida Hall.
Orthis hybrida Sow.	Nucleospira pisum Hall.
Plectambonites transversalis Wahl.	Atrypina disparilis Hall.
Plectambonites (cf.) sericea Sow.	Spirifer crispus His.
Leptæna rhomboidalis Wilc.	Spirifer sulcatus His.
Stropheodonta profunda Hall.	Spirifer radiatus Sow.
Orthothetes subplanus Con.	Cyrtina pyramidalis Hall.
Pentamerus occidentalis Hall.	Atrypa reticularis Linné.
	Atrypa nodostriata Hall.
	Rhynchonella neglecta Hall.
	Rhynchonella obtusiplicata Hall.

PELECYPODS.

Avicula demissa Con.	Platyostoma niagarense Hall.

CEPHALOPODS.

Orthoceras annulatum Sow.	Orthoceras virgulatum Hall.
Orthoceras subcancellatum Hall.	Cytoceras subcancellatum Hall.

Nearly all the corals are confined to the lower beds, [being found in] a conglomerate of coral fragments together with pebbles of quartz and hydromica schist, [and in] a limestone. The greatest number of species is found near the middle of the series [on the shore northeast of Ames Knob] in a slightly indurated shale. The fauna was evidently a rich one, and several of the unidentified species are probably new to science.

Age.—The fossils found in these beds indicate that the strata are of early Niagara age. They are shown to be younger than the North Haven greenstone, not only by the lesser amount of deformation which they have suffered, but also by superposition and the presence of fragments of the greenstones in the conglomerate at the base of the Ames Knob sediments.

SURFICIAL DEPOSITS.

Glacial till.—All the land areas of the quadrangle are more or less covered by glacial deposits, which comprise till, sands, gravels, and clays. On account of their scattered distribution, it was considered inadvisable to map them. The till deposits are for the most part thin and occur in very interrupted and irregular areas. They are thickest in the valleys and depressions between the hills, but even here their depth in few places exceeds 40 or 50 feet and is in general much less. Most of the larger hills and many of the smaller ones are practically bare of glacial drift. The topography is controlled by the contour of the rock surface, and many of the characteristic features of drift topography, such as eskers and drumlins, are wholly wanting.

There are no continuous belts of drift showing a distinctly morainic topography, so that it is not possible to trace successive positions of the ice border. In perhaps half a dozen localities, however, small areas of drift were found which show the succession of low knobs and shallow kettles typical of a mild terminal moraine. One such morainic patch occurs just southeast of Ball Pond, near the road between Bluehill and Surry; besides showing knobs and kettles, it is characterized by an unusual abundance of bowlders of gray granite, some of which are 12 to 14 feet in diameter. This morainal area is bounded on the north by the swampy depression whose central portion is occupied by Ball Pond. Just southeast of Pierce Pond, near Penobscot, knobs and kettles may also be seen, with an unusual abundance of bowlders. Near this point, and just northeast of the road, a low, even-topped morainal crest, trending nearly N. 60° E., can be traced for about one-fourth of a mile. Pierce Pond itself is held in behind a dam of morainal material. A third morainic patch occurs 1 to 1½ miles northwest of Bluff Head, just east of the road; and about 1 mile east of South Penobscot, just north of the road, some kamelike deposits of gravel are associated with an unusual abundance of large granite bowlders.

Sands and gravels.—The most extensive and most abundant deposits of sands and gravels are on the mainland between Belfast and Sandy Point, and are well exposed just east of Belfast, along the railroad just north of Stockton Springs, and along the shore near Sandy Point. These deposits are in part well-stratified sands and gravels which are in the main cross-bedded, but there are also present unassorted materials showing great variations in coarseness. They are probably kamelike in origin, being deposited at the ice margin by waters flowing from the melting glacier. Throughout most of the quadrangle gravels are present in sufficient amounts to provide abundant material for road improvement.

Marine clays and fine sands.—The lowlands which border the coast of Maine are covered by a nearly horizontal mantle of clay of marine origin. Areally the clays are most extensive and reach farthest inland along the rivers and the tidal estuaries; along steeper parts of the coast they may be entirely absent. Along Penobscot River they are well developed as far inland as Bangor.

Vertically the bulk of the clay deposits is confined to the belt between sea level and the 125-foot contour, and though not all the land within this belt is occupied by these deposits it is probably safe to say that, on the mainland, they cover fully half of it. Above the 125-foot level marine clays are present here and there, the sea having stood for a time as much as 240 feet above its present level. These higher deposits are small in quantity and scattered in distribution. None were found within the Penobscot Bay quadrangle. Their thickness varies much; it is in general greatest on the lowlands and least on the adjacent hill slopes. Depths of 15 to 35 feet are very common, and some well records show a depth of 50 to 75 feet. In color the clays range from yellowish gray to blue gray, the former being by far the more common. For the most part they are exceedingly fine grained, and except in a few localities are very free from sand or pebbles, the material being so uniform that only here and there can distinct beds be recognized.

The clays are readily recognized where they have been exposed by the waves or streams and where they have been uncovered in excavations. Excellent natural exposures occur at many points along the shore, and artificial exposures may be seen in the cuts and ditches of wagon roads. Even where sections can not be found, the presence or absence of the clays may usually be recognized from the appearance of the land surface. Extensive flats or gently sloping plains occupying the lowlands and free from surface bowlders are nearly always found to be built of these clays. When roads traversing these flats have not been graded with materials brought in from other localities, the clayey character is revealed by the fine light-gray dust which develops in dry weather and the sticky gray mud which forms after a heavy rain, and also by the absence of pebbles or cobbles.

The distribution of these clays with respect to the present coast line at once suggests a marine origin, and this conclusion is sustained by the presence here and there within the clays of the shells of marine animals. The clays represent old mud flats formed at a time when the land was considerably lower and nearer sea level than it is at present. Their age is fixed by their relation to the deposits made by the glaciers which covered the State in the Pleistocene period. In several localities the clays overlie deposits of glacial bowlder clay, while they in turn are overlain by gravels deposited by streams flowing from the melting ice; they were deposited, therefore, during the glacial occupation. The streams flowing from the melting glaciers were heavily laden with sediment; the coarser portions, the gravels and sands, were deposited on the land surface or in the ocean close to the shore, but the finer portions were carried farther out and deposited as these beds of marine clay. They differ from the mud flats of to-day mainly in the greater rapidity with which the muds were deposited.

IGNEOUS ROCKS.

GENERAL FEATURES.

Fully two-thirds of the land area of the Penobscot Bay quadrangle is occupied by igneous rocks. These are of two general types—intrusive rocks and effusive surface volcanic rocks. The effusive rocks are represented by the North Haven greenstone, the Castine formation, the Thorofare andesite, and the Vinalhaven rhyolite, the first basic and the others acidic in composition. The North Haven greenstone and the Castine formation seem to have been deposited at about the same time as the sediments of the Islesboro formation, and, like these sediments, they have been much folded and altered in regional metamorphism. The Thorofare andesite and the Vinalhaven rhyolite are much younger rocks and have not been affected by regional metamorphism. Their relation to the Ames Knob formation shows them to be of Silurian age.

The principal intrusive rocks of the quadrangle are the granite and its associated diorite and diabase. These rocks cover a greater area than any other formation of the region. They are intrusive into the Silurian rocks and all the older formations and are probably of early Devonian age. The only other intrusive rocks of importance are basic dikes which cut the granite and all the other rocks of the region. They are believed to be probably of Triassic age.

CASTINE FORMATION.

Definition.—The Castine formation is made up of light-colored altered lavas and pyroclastics, including rhyolites, dacites, and andesites. These rocks are typically developed on the Castine peninsula, some of the best exposures occurring in the vicinity of the town of that name.

Distribution.—With the exception of the eastern part of Wardwell Point, the Castine volcanics occupy the whole of the peninsula lying between Penobscot and Bagaduce rivers. Southeast of this area they cover the region between West and South Brooksville and occupy almost the whole of the Cape Rosier peninsula. From South Brooksville they extend in a narrow band along the north shore of Eggemoggin Reach to Benjamin River. South of the Reach, on Little Deer Island, the northwestern part of Deer Isle, and the group of islands lying between these and North Haven, they are associated in varying proportions with the North Haven greenstone. Their southernmost observed occurrence is on Burnt Island, just off the northeast point of North Haven.

Varieties and mode of occurrence.—The rocks of the Castine formation are all surface volcanics and include the familiar types of flows, breccias, conglomerates, tuffs, and dike rocks. All belong to the group of acidic rocks, though ranging from rhyolites through dacites to andesites. In color they vary from light gray through yellowish and greenish gray to green and here and there to purple. The great bulk of these rocks are more or less schistose; some that are perfectly so must originally have been very fine and even textured and were probably volcanic muds, dust, or glassy flows. Schistose varieties are particularly well developed along the northern and western shores of Little Deer Island. Massive felsitic varieties are well shown on the 160-foot hill in the south-central part of Little Deer Island, where the rock is mottled greenish to purplish gray in color, and on the 200-foot hill in the east-central part of the same island, where the rock is gray to almost white in color. On the north end of Butter (Dirigo) Island the rock (an andesite) is felsitic in appearance, yellow-gray in color and speckled with red on the weathered surfaces. Occasionally banded varieties are found which are intermediate in character between the massive forms and those that are very markedly schistose.

Good exposures of the fragmental varieties of the Castine volcanics are very abundant, but of many of them it is impossible to say whether they are flow breccias, tuffs, or pyroclastics. One of the best exposures is at Goose Falls, about 2 miles south of Castine. Here the volcanic tuff or flow breccia shows angular or subangular altered fragments of light-yellow color in a finer grained matrix which is gray-green in color and somewhat sheared. One of the fragments was 2 feet long and 7 inches across, and many are 4 to 5 inches in diameter. In the small cove just north of Cape Rosier the volcanics are dark colored and highly fragmental. Many of the fragments and parts of the matrix are pumiceous. Fragmental rocks are well shown in the schoolhouse yard at North Castine, along the south shore of Wadsworth Cove, on the 120-foot hill just north of Hatchs Cove, and on the hill back of the lighthouse at Dice Head. On Little Deer Island they occur just southeast of the 200-foot hill in the east-central part of the island, and on the shore opposite Byard Point. Breccias occur on the northwest shore of Pickering Island and on the north side of Eaton Island; at the latter place the rock is an andesite porphyry.

On the southwest end of Bare Island the fragmentals are finely exposed in a steep cliff face. At the southeast end volcanics of andesitic composition show numerous fragments, some rounded and some angular, in a coarsely amygdaloidal matrix whose pores have been filled with quartz. The fragments are yellowish gray in color and the matrix is bluish gray. Some of the fragments have been fractured and are penetrated by veins of the matrix; a few show highly curved forms, assumed during their ejection from the volcano or as the result of movement of the inclosing lava before the fragments lost their plasticity. Some of the fragments at this locality are 6 to 7 inches in length and many of them only half an inch thick; there is little uniformity in orientation. The volcanics are amygdaloidal at a number of other localities.

At the extreme west end of Little Deer Island the Castine volcanics are cut by innumerable minute veins of quartz intersecting at every conceivable angle, and the rock has undergone a great amount of recrystallization. In a few places the content of iron in these rocks becomes great enough to give them a distinctly red color on either fresh or weathered surfaces. On the south end of Carney Island (between Deer Isle and Little Deer Island) the rock weathers to a yellow, red, or even black metallic-looking surface. On the southwest point of Little Deer Island, at the north and south ends of Birch Island, and in the cove on the west side of Hog Island the schistose volcanics are so full of finely divided hematite that on weathering they become dark purplish red in color.

A small patch of volcanic rocks on the west shore of Islesboro, about 1 mile south of Marshall Point, is probably to be correlated with the Castine volcanics. It is infolded with and probably overlies the Islesboro slate, though conclusive proof of this relation is lacking. These dark-greenish to purplish andesitic rocks extend for about 200 feet along the shore, but narrow and disappear within a short distance inland. They weather to a ragged surface which shows in places a distinctly fragmental character.

Stratigraphy.—The relations of the volcanic rocks of the Castine formation to the North Haven greenstone are such as to indicate that the two formations are nearly contemporaneous. On the shore of Deer Isle just north of Dunham Point, sheared dacite porphyry seems to be interbedded with altered greenstones. On the third of the Barred

Islands, reckoned from the south (between Spruce Head and Butter islands), the greenstones are in contact on the northwest point with a coarsely fragmental variety of the Castine volcanics. The layers of the greenstone next to the contact contain many angular, fresh-appearing fragments of the acidic rock; presumably these were caught up by the bottom layers of a basic lava mass as it flowed over a surface covered with fresh, unrounded fragments of the Castine volcanics. On the west side of Compass Island, also, diabase showing "bolster" structure and probably a surface flow rests upon acidic breccia, the greenstones becoming finer grained next to the contact. Dikes of the albite-pyroxene-syenite variety of the greenstones cut the Castine volcanics on Little Deer Island, on Deer Isle, and at many other places.

The contact relations between the Castine volcanics and the sediments of the Islesboro formation are nowhere very clearly shown. The small area of basic andesites on the western shore of North Islesboro is infolded with and presumably overlies the slates unconformably, but the relations are not clear and the correlation of these andesites with the Castine volcanics is more or less uncertain. Shaly sediments on Bradbury Island rising as an anticlinal fold from beneath Castine volcanics have already been described, but they can not certainly be correlated with the slates of Islesboro. The same is true of 100 feet of shaly sediments infolded with the volcanics of the Castine formation on Nautilus Island, south of Castine. The North Haven greenstone, however, has been shown in the section on the Islesboro formation to be about contemporaneous both with the Castine volcanics and with the Islesboro formation; some portions of the two latter formations must therefore be contemporaneous.

The contact between the Penobscot slate and the Castine volcanics is everywhere covered by drift. The eruption of acidic volcanic material which was in progress during the deposition of the Islesboro formation may or may not have continued into the period of deposition of the Penobscot formation.

The granite is plainly intrusive in the volcanics, and the relations are well shown in many places. Due east of Grays Point, near Bucks Harbor, the granite boundary cuts directly across the strike of the volcanics. On the north shore of Eggemoggin Reach, one-half mile west of Herricks, the volcanics are cut by a large number of flat-lying, forking, and intersecting granite dikes 8 inches to 2 feet in width. In general the contact-metamorphic effects of the granite are not noticeable to the eye.

Petrography.—The rocks making up the Castine formation are seen, on microscopic study, to include rhyolites, dacites, and andesites, which megascopically are usually indistinguishable from one another. These three varieties are found in almost all parts of the region and are associated with one another in a most irregular manner. The rhyolites and andesites seem to be about equally abundant; the dacites are very subordinate.

One of the freshest occurrences of rhyolite is on the shore just north of Cape Rosier village. The rock there is finely porphyritic, containing scattered phenocrysts and aggregates of fresh albite up to 2 or 3 mm. in diameter. These lie in a groundmass showing quartz in small, irregular grains and small laths of albite, many of which exhibit a slight parallel arrangement indicative of flowage. Between the quartz and feldspar crystals there is a little microfelsitic material which probably represents an originally glassy base. Scattered through the groundmass are small amounts of secondary muscovite and chlorite, and many minute crystals of magnetite.

Another rhyolite, occurring about 1 mile northeast of West Brooksville, shows, besides the phenocrysts of feldspar, a few of quartz. The groundmass differs from that of the preceding specimen in being finer grained and of microfelsitic texture throughout. It contains abundant minute muscovite flakes scattered evenly through it and much chlorite in irregular aggregates. Other specimens, such as that from the extreme northern part of Little Deer Island, are nonporphyritic, and show only a gray felsitic mass which bears scattered crystals of albite and quartz with definite boundaries. Secondary chlorite, calcite, and leucoxene are abundant in minute plates or grains.

One of the freshest of the dacites occurs along the north shore of Bagaduce River, 1½ miles northeast of North Castine. It is a finely porphyritic rock in which none of the phenocrysts exceed 1 mm. in diameter; most of them are orthoclase, though a few of the smaller ones are albite. The groundmass is finely microfelsitic, but contains a few recognizable quartz crystals. The rock is somewhat weathered and is feebly schistose. Along certain bands the original groundmass has been almost entirely replaced by an aggregate of epidote and chlorite, much of the latter showing vermicular forms. Other bands consist largely of muscovite in a finely divided state.

The arrangement of these secondary minerals in bands of varying width and purity gives the rock a certain amount of schistosity. In general the dacites differ but little in microscopic texture from the rhyolites.

Beautifully fresh specimens of andesite were collected at North Castine. Here much of the rock is fragmental, but the massive portions, when examined microscopically, show a fine gray microfelsitic groundmass containing scattered lath-shaped phenocrysts of fresh albite which in places attain a length of 1½ mm., but are mostly smaller. In certain parts of the thin section a number of these phenocrysts are loosely aggregated. Scattered through the groundmass are minute flakes of secondary muscovite and small cubes and octahedra of pyrite. Andesite from the north end of Bare Island, which lies about 2 miles north of the island of North Haven, differs from that at North Castine in being amygdaloidal and in the development of numerous feldspar laths in the groundmass. The amygdules are filled with a mixture of quartz and chlorite, and all the feldspar is albite. The groundmass is full of minute grains of secondary chlorite, epidote, calcite, and muscovite.

The features observed in these selected specimens of rhyolite, dacite, and andesite are characteristic of the bulk of the formation, though partially destroyed in most cases by weathering, shearing, or both.

The rocks of the small area of volcanics on the western shore of North Islesboro are found on microscopic study to be basic andesites in which the original ferromagnesian minerals are largely replaced by chlorite, calcite, and magnetite. Certain fragmental varieties show several kinds of pumiceous andesite, which may be very fresh or much weathered; some are light colored and some are almost black from the abundance of finely divided magnetite.

On the eastern side of Crow Island, a small island about 4 miles northwest of the village of Deer Isle, the rock is greenish gray and aphanitic, breaks up into sharp, angular fragments, and is similar in megascopic appearance to the more massive types of the Castine volcanics. Microscopically, however, it is seen to be an exceedingly fine-grained granite showing quartz, orthoclase, and microcline and large amounts of secondary calcite and chlorite. The quartz shows a tendency to form a poikilitic matrix for the feldspars. Magnetite has altered to leucoxene. This rock presumably represents a holocrystalline product of the same magma which elsewhere crystallized as a rhyolite.

The principal secondary minerals developed have already been mentioned. In one sheared rhyolite cordierite is an abundant secondary constituent. In the schistose porphyries the feldspar and quartz phenocrysts have as a rule been bent, fractured, or granulated, and many of the fragments have been dragged apart. The schistosity is mainly the result of the development of finely divided chlorite, muscovite, or biotite, one or all, in more or less irregular, subparallel layers. In many places the rocks are cut by a network of minute veins of secondary quartz.

Microscopic study of the Castine volcanics near the granite border shows in many places notable contact-metamorphic effects. A specimen of the volcanics taken 10 feet or so from the contact about east of Grays Point (in the vicinity of Bucks Harbor) shows complete recrystallization, which has wholly obliterated the original textures and has resulted in the abundant development of biotite in small plates and of pale-brown hornblende in brushlike and sheaflike aggregates. At the exact contact the hornblende is massive and occurs in large crystals, and the quartzes and feldspars also are much larger than is usual. The granite next to the contact is extremely fine grained, aplitic, and highly garnetiferous. At the head of Bucks Harbor the contact granite is beautifully micrographic.

Age.—The age of the Castine formation is tentatively placed as Cambrian, for reasons set forth in the section on "Historical geology," p. 12. It has been shown to be contemporaneous in a general way with the Islesboro formation and the North Haven greenstone.

NORTH HAVEN GREENSTONE.

Definition.—The North Haven greenstone is made up of altered basic igneous rocks which are typically and extensively developed on the island of North Haven. The rocks are prevailingly dark green in color and include diabases, basic trachytes, and albite-augite syenite. The different varieties are in many places indistinguishable from one another in the field and are associated in the most intimate and irregular manner. For these reasons and because the several kinds are believed to be practically contemporaneous, they have been grouped under the comprehensive title of greenstones.

Distribution.—The largest continuous area of greenstones is on the island of North Haven, where they occupy all but the extreme southern portion of the island. Northwestward from North Haven they are found on Mark, Saddle, Lasells, and Job islands and Islesboro; toward the northeast they occupy a considerable part of Eagle and neighboring islands and reach Deer Isle; to the north they are found on Spruce Head, Mark, Western, and a number of other islands, and reach the mainland near South Brooksville. They are thus distributed over an area of about 250 square miles, their continuity being interrupted by large areas of water.

Varieties and mode of occurrence.—The diabases of this formation in most of their occurrences are fine-grained, compact rocks of dark-green color. Some of the freshest specimens were obtained on the island of North Haven near the head of Southern Harbor, on Compass Island, and on Deer Isle in the cove between Northwest Harbor and Dunham Point. Distinctively surface volcanic structures are of common occurrence.

The trachytes are indistinguishable in the field from the diabases and from certain varieties of the albite-pyroxene syenite. The best exposure of trachyte is on the point at the west entrance to Bucks Harbor, where the rock is exceedingly fine grained, is light green in color, and shows the "bolster" structure described in another paragraph.

The albite-pyroxene syenite differs in general appearance from the diabases and trachytes mainly in its greater coarseness, the feldspar areas being readily distinguished by the naked eye from the basic constituents; the rocks thus present a somewhat mottled appearance. The syenite also differs from the diabases and trachytes in its mode of occurrence; structures indicating a surface volcanic character are usually absent and the typical forms are dikes, sills, and stocks. One of the least altered as well as one of the coarsest varieties of this rock is found near the head of Southern Harbor, on the island of North Haven; here feldspar phenocrysts one-half inch in length are locally developed. Other localities from which fairly fresh specimens of the syenite were collected are Hardhead Island and the south end of Spruce Head Island; on Little Deer Island it is especially well developed in the form of dikes and sills in the Castine acidic volcanics, and the 80-foot hill east of the steamboat wharf at Eggemoggin is a stock of somewhat serpentinized albite-pyroxene syenite. The western part of Crow Island is occupied by a variety of the syenite which to the naked eye shows numerous brown mottlings. Under the microscope these are seen to be caused by an unusual development of small brown biotite plates in irregular aggregates.

The greenstones have been involved in the general metamorphism which has affected many of the rocks of this region, and somewhat schistose forms are of common occurrence; most of them have also suffered severely from weathering.

The diabases and trachytes in particular, but here and there the syenites, show certain structures peculiar to surface volcanics; these will be briefly considered.

(1) Amygdaloids: These are lavas containing steam pores which have been wholly or partially filled with secondary minerals. Amygdaloidal diabases occur abundantly among the greenstones of the island of North Haven, just north of the narrow strip of Silurian rocks. They are grayish-green rocks which are pitted on the weathered surface, whereas a fresh fracture is spotted with shining calcite grains which represent the pore fillings. An amygdaloidal form of the albite-pyroxene syenite occurs at the southwest end of Bare Island, near the contact of the greenstones with the Castine formation. Here the pores have been filled with chlorite, and on the freshly fractured surface appear as nearly black shiny spots one-sixteenth to one-fourth inch in diameter.

(2) Fragmental varieties: Distinctly tuffaceous greenstones are developed on the island of North Haven near the head of Southern Harbor, and also at Crabtree Point and along the southwestern shore of the island. Among the islands to the north and east fragmental varieties are present in scant amount, but the greenstones of the islands south of Islesboro seem to be predominantly volcanic ash and dust deposits, which in places, as at the south point of Spruce Island, plainly reveal their fragmental character on the weathered surfaces.

(3) "Pillow" or "bolster" structure: This structure is produced by the parting of the rock before final solidification into more or less irregularly ellipsoidal bolster- or pillow-shaped blocks varying from a few inches to a yard or so in diameter. This structure seems to be confined to surface flows of rather basic composition. In some places the rocks are amygdaloidal. One of the best localities for the study of this structure is the point just west of Bucks Harbor, where the greenstones of the basic trachyte variety are well exposed on the shore. Another excellent exposure occurs on the northernmost of the Barred Islands, which lie between Butter and Spruce Head islands. The rocks are there seen in cross section and resemble a lot of pillows of varying sizes piled one on top of the other and then cut through. Other favorable localities are the head of Southern Harbor, North Haven, Scrag Island (southwest of Spruce Head Island), and Compass Island. On the latter the ellipsoidal greenstone is a true diabase and is found in contact with volcanics of the Castine formation. The greenstones here become finer grained next to the other volcanics; the contact plane is now almost vertical, but the fact that the longest axes of the ellipsoidal greenstone masses parallel this contact suggests that the acidic volcanics may represent the floor upon which the basic flow was laid down.

(4) Columnar structure: This structure is developed in basic volcanic rocks and consists in the division of the mass into approximately parallel prisms during the contraction and consolidation of the lava under essentially surface conditions. The contraction takes place chiefly in two directions and the hexagonal prism is the normal form, though the number of sides of the prism varies from three to nine. Its best development is in the diabase of the northwestern shore of the island of North Haven, about midway between North and Bartlett harbors. Here some of the columns show very sharp angular outlines, but the majority seem to have been modified by dynamic action, so that only cylindrical cores of massive rock remain, embedded in a schistose matrix of similar composition. On some of the weathered surfaces these massive cylinders project so as to remind one of the stumps of small trees.

Stratigraphy.—The relations between the North Haven greenstone and the Castine volcanics have already been mentioned in the discussion of the latter formation.

The North Haven greenstone lies unconformably below the Ames Knob formation, the contact being well exposed on the shore north of Ames Knob. At this place amygdaloidal diabase underlies the conglomerate, which dips to the south at an angle of about 60°. The extremely disintegrated character of this diabase and the apparent inclosing of large lenses of this rock by clastic material indicate superficial disintegration of the lava before deposition of the sediments; unconformity is also indicated by the fact that the North Haven greenstone has been affected by regional metamorphism, though the Ames Knob formation has not.

This unconformity is of the utmost importance in determining the age of several of the formations of the quadrangle. It indicates that the North Haven greenstone and its contemporaries, the Castine formation, the Islesboro formation, and the Penobscot formation, are not only pre-Niagara in age but are probably considerably older than the Niagara rocks, since the time interval represented by this unconformity includes an epoch marked by severe regional metamorphism and extensive erosion.

The relation between the greenstones and the rocks of the Islesboro formation is shown on the islands near Islesboro. In many localities the greenstone forms dikes and sills in the sediments. On the small island between Lime and Job islands what seems to be a fine fragmental variety of the greenstone is interbedded with limestone of the Islesboro formation, which makes up most of the island. On Seven Hundred Acre, Warren, and Spruce islands and on the southern part of Islesboro fine greenstone fragmentals, tuffs, and volcanic muds seem in a number of places to be interbedded with the shaly sediments of the Islesboro formation. The prevailingly green color of this series on Islesboro and the neighboring islands is thought to be due largely to an admixture of fine volcanic material of the greenstone series with the ordinary clastic materials. There can be no doubt that these two formations are essentially contemporaneous.

Petrography.—(1) Diabase: These rocks are for the most part aphanitic, though in places porphyritic. Under the microscope they show in the main an ophitic texture, small laths of plagioclase varying from andesine to labradorite in composition being inclosed in a matrix of pale pinkish to yellowish pyroxene. The pyroxene is feebly pleochroic and shows extinction angles up to 45°. Here and there somewhat larger feldspar laths occur either singly or in small groups. Magnetite is abundant in small, irregular angular grains. In most localities these rocks are so extensively weathered that no pyroxene remains. The alternations are similar to those described below for the albite-pyroxene syenites, except that the feldspar of the diabase, being calcic, alters much more readily than the albite of the syenites.

(2) Trachyte: Specimens showing the character of the trachyte were obtained from only one locality—the point just west of Bucks Harbor. Under the microscope it is seen to consist of a felt work of minute feldspar microlites, which are in many places arranged in flow structure; they seem to be unstriated and are below balsam in refractive index, hence are probably orthoclase. Between the feldspars a mineral appearing yellowish in reflected light and nearly opaque occurs in minute grains and is probably epidote. Calcite also occurs. Feldspar phenocrysts are sparingly scattered through the rock, but are extensively altered to an aggregate of calcite, muscovite, and albite (?).

(3) Albite-pyroxene syenite: This rock in most places, though not everywhere, shows a poikilitic texture. In some sections this is rendered obscure by the great variations in the size of the feldspar individuals; in others it has been obscured or destroyed in the development of schistose structure or by weathering. The feldspars are striated and as a rule form rather short prisms, which range from 0.5 to 1.5 mm. in length; in many of the slides they are remarkably fresh, and they are shown to be albite by their low extinction angles and by their

index of refraction, which is uniformly equal to or less than that of Canada balsam. The pyroxene normally forms a poikilitic matrix for the feldspar laths. The fact that the extinction angles approach but nowhere exceed 45° in the half-dozen or so slides studied indicates that the pyroxene is probably augite rather than diopside. Magnetite is the only other original constituent which plays an important rôle ; it occurs in irregularly angular grains, some of which assume skeleton forms and may partially inclose feldspar crystals. Even those occurrences which in the hand specimen appear most massive show, when examined microscopically, evidences of dynamic action in a fracturing and locally a bending of some of the feldspar laths. Distinctly schistose varieties are common, all of which show a considerable amount of alteration. In the more schistose varieties the ferromagnesian constituents are green hornblende, fibrous actinolite, and chlorite ; in some only chlorite remains. Most of the feldspar retains rather a fresh appearance even where the ferromagnesian minerals have all altered to chlorite. Many of the grains show fracturing, a pulling apart of the fragments, and their partial or complete rotation, so that their longer axis lies in the plane of schistosity. The latter two phenomena contribute to the development of the schistose structure, which, however, is due primarily to the distribution of chlorite in long irregular bands, to some parallelism among the shreds of fibrous hornblende, and to the distribution of secondary epidote grains in elongate and irregular aggregates parallel to the bands of chlorite. Here and there some muscovite is developed and helps to define the schistose structure. Titaniferous magnetite is in general altered largely to titanite or leucoxene. Similar secondary alterations to those described above for the schistose varieties are characteristic of all the albite-pyroxene-syenite rocks. Even the freshest show some hornblende with the pyroxene ; most of this hornblende is surely secondary, but some may be original. Micaceous plates which are probably paragonite are developed abundantly in the albite crystals. Zoisite, calcite, apatite, muscovite, biotite, and a chloritoid mineral are secondary constituents which are occasionally found. Rarely serpentine has been abundantly developed.

Age.—The stratigraphic relations already discussed show that the North Haven greenstone is much older than the Silurian sediments and is about contemporaneous with the Islesboro and the Castine formations. For reasons brought forth in the section on "Historical geology," its age is tentatively placed as Cambrian.

THOROFARE ANDESITE

Definition.—The Thorofare andesite consists of lavas and pyroclastic rocks of andesitic composition, and is extensively developed on both sides of the Fox Island Thorofare, which lies between North Haven and Vinalhaven. The lavas include massive porphyritic andesite and amygdaloid; the pyroclastics include tuff, flow breccia, and conglomerate.

Distribution.—On the island of North Haven this formation extends from Ames Point, at the eastern entrance of Southern Harbor, through the village of North Haven to Waterman Cove. Farther east it appears again on the peninsula ending in Indian Point and on Burnt, Stimpson, Calderwood, and Babbidge islands. On Vinalhaven it occupies the northwestern part of Calderwood Neck and occurs as a narrow strip along the western shore of the island from Browns Head northward for about a mile.

Structure.—The Thorofare volcanics show evidence of open folding and of some faulting. They have not been affected by the regional metamorphism which has altered the Islesboro and Calderwood formations and the North Haven greenstone, but in the degree of their disturbance are comparable to the sediments of the Ames Knob formation. The strike varies greatly in different localities. The dips locally become as steep as 80°, but in most places are under 60°. On the shore of Carvers Cove two parallel vertical faults can be seen in the shore cliff, with a strike of N. 45° W. The displacement, which is relatively downward on the southern side, amounts to somewhat more than 50 feet in one of the faults; the amount of throw in the other can not be measured, since the lavas and breccias, which overlie the bedded tuffs, afford no datum plane. The actual observation of displacement at this point strengthens the probability that unexposed faults exist toward the north.

Lithology.—Andesite is very prominently exposed on Ames Knob, the bold hill northwest of the village of North Haven. The rock is of a dark-gray color, much of it with a slight purple tinge. In striking contrast with the almost black groundmass are the well-defined phenocrysts of yellow to greenish-white feldspar about one-eighth of an inch in diameter. Typically it is compact, but amygdaloidal and even drusy varieties also occur. Contrasted with this rock is a compact dark-purplish andesite on the southern slopes of the hill just north of North Haven. This shows here and there reflections from small lath-shaped feldspars in the groundmass and contains a few small dark-green phenocrysts of pyroxene.

Other andesites are found which have a dark-red color, on both the weathered surface and fresh fractures. Feldspar phenocrysts are as a rule less numerous than in the andesites just described and are badly altered, in many places being tinged with red. One specimen of the red andesite, however, from the slopes of Ames Knob, shows large andesine phenocrysts which are quite unaltered. Within the North Haven area there also occurs a very little rhyolite porphyry, the quartz phenocrysts of which are plainly visible to the unaided eye. Some of these more acidic rocks are clearly intrusive dikes in the andesitic rocks, and there is some question whether any of them are really part of the Thorofare formation.

One of the most striking rocks in North Haven is an amygdaloid which occurs on the shore of the Thorofare, and much of which on weathered surfaces appears very vesicular. The groundmass of the rocks is gray and the elongated amygdules of white and pink quartz are very plentiful. A few phenocrysts of feldspar have characteristic crystal outlines but are largely decomposed. Pumiceous varieties occur with the gray andesite on Ames Knob, but their character is detected only with the microscope.

Associated with the lavas are the volcanic fragmental rocks, made up of the explosive fragments from volcanic eruptions. Although igneous in origin, these rocks are in general more or less distinctly bedded. Where this bedding is due to deposition under water, the rocks are intermediate in character between the lavas and ordinary sediments and are known as pyroclastics. Between the lavas and the pyroclastics on the one hand, and between the sediments and the pyroclastics on the other, it is often difficult and sometimes impossible to distinguish.

The most important of the pyroclastics represented on North Haven is the volcanic conglomerate on the slopes of Ames Knob. The more or less rounded fragments of the different andesites range in size from that of a bowlder several feet in diameter to that of coarse sand. The cementing material is small in amount and its character difficult of determination, but under the microscope this matrix is seen to be clastic. It consists of angular crystal fragments and particles of opaque material similar to that forming the groundmass of certain of the lavas. Slight traces of flowage seem to indicate that the cementing material was of the character of volcanic mud when it filled the spaces in this mass of coarser ejectamenta. The large fragments show andesitic structure in a marked degree.

A volcanic conglomerate somewhat finer grained than that just described occurs on Iron Point, and the fine dark-red cement of this rock again suggests an original volcanic mud. Both of these volcanic conglomerates grade into breccia, which has in the main the character of a lava including blocks of older lavas. Such a breccia is a flow breccia. In other places, however, the breccia seems to differ from the volcanic conglomerate only in the degree of rounding of the fragments, and may therefore be termed a tuff breccia.

A series of fragmental volcanic rocks of much finer grain than the breccias and conglomerates are the compact pink tuffs on Ames Point. The tuffaceous character is plainly revealed on the weathered surfaces.

Petrography.—The gray andesite of Ames Knob, when examined microscopically, shows phenocrysts and groundmass well differentiated. The feldspar crystals, with extinction angles of labradorite approaching andesine, are tabular and of good size, with albite twinning and zonal structure. Nearly all show considerable alteration, aggregates of epidote and pennine, with some clear grains of secondary feldspar, having replaced the original feldspar without affecting the crystal outlines. The ferromagnesian constituents have been completely altered, and phenocrysts that appear well defined in ordinary light are seen in polarized light to be composed of chlorite and calcite. The outlines of these phenocrysts suggest both hornblende and pyroxene, and their projection in certain places into the feldspar areas shows them to be, in part at least, older than the feldspars. The groundmass is composed of feldspar laths, with a noticeable felted texture, as well as a fluidal arrangement near some of the phenocrysts. The light-brown base is isotropic in places and much darker where included between several feldspar crystals. Magnetite occurs throughout the groundmass in small grains, and larger masses are associated with the ferromagnesian phenocrysts. In addition to the altered crystals of feldspar, there are roughly spherulitic areas of epidote with some zoisite and areas of chlorite. These may represent either irregular amygdules or merely an alteration which has extended beyond the outlines of the original crystals. This porphyritic rock presents the characters of an andesite, especially in the texture of its groundmass. The determination of the darker phenocrysts is uncertain, but from analogy with similar rocks in other parts of the region it was probably a pyroxene andesite.

The dark-purplish andesite exposed on the hill north of North Haven is of especial interest in the opportunity it affords for the study of the processes of alteration. The feldspar phenocrysts exhibit the albite lamellation, have the extinction angles of labradorite, and are beautifully zonal, being slightly more basic toward the center. Many of the crystals have an altered core, but are perfectly idiomorphic, showing that the clear outer zone is original. The light-green pyroxene phenocrysts have the high extinction angle of augite, and orthopinacoidal twinning is the rule, in many cases being repeated in the same crystal. The augite, in part, is altered to pennine. Both feldspar and augite phenocrysts have a zonal arrangement of inclusion, showing changing rates of crystallization in the later stages. The groundmass is less andesitic in character than that of the rock described above and is full of minute magnetite grains. Some interstitial areas of glass appear within groups of feldspar crystals, but elsewhere faint micropoikilitic areas are common in the groundmass.

The red andesites show a groundmass characterized by minute, irregular particles of red to brown opaque material. This groundmass now shows a micropoikilitic texture, but doubtless was originally very glassy. The feldspar phenocrysts are less numerous than in the other andesites and are badly altered, but from the amount of calcite present a rather basic character may be inferred. A few phenocrysts older than the feldspar as seen in ordinary light have the characteristics of olivine. Their association with magnetite, their dark border of iron oxide, their irregular transverse cracks, and their badly corroded prismatic outlines constitute the points of resemblance. In polarized light it is seen that none of the olivine remains, but that these phenocrysts consist of fibrous serpentine, with fibers normal to the transverse cracks, which are bordered by the opaque oxide. Small grains of quartz, plainly secondary, occur within the serpentine mass. Large hexagonal prisms of apatite, including much magnetite, form the oldest constituent of the rock. From the former presence of olivine as an original constituent this rock would naturally be considered the most basic of the North Haven volcanics. The olivine phenocrysts, however, are not very numerous and there is reason to regard this as simply an olivine-bearing variety of the andesite.

Another specimen of the red andesite, collected on the slope of Ames Knob, shows large feldspar phenocrysts which are quite unaltered and which show the extinction angles of basic andesine. The ferromagnesian constituent is not present except as well-defined prismatic areas, now composed of chlorite and calcite. There is much magnetite and some ilmenite, and apatite is associated with the magnetite as inclusions in the feldspars and also as long prisms in the groundmass. One crystal of titanite or sphene was observed, altered at the edges into calcite and an opaque iron oxide. The groundmass contains feldspar laths more acidic than the phenocrysts, as a rule simple, but here and there twinned, and in places irregularly terminated. There are also present laths and trichitic masses of a brown color. The flow structure is well developed near the phenocrysts, but elsewhere the parallelism of the elements of the groundmass is less apparent. Between crossed nicols a micropoikilitic structure can be seen in the groundmass, but this seems to be due to secondary crystallization.

Another of the dark-gray andesites is of much coarser texture, with larger phenocrysts of yellowish-white feldspar. In the thin section these feldspars are seen to have suffered the usual alteration to epidote and zoisite, and the porphyritic dark constituents are also wholly altered. They have opaque resorption borders and, therefore, probably represent either hornblende or mica ; some cross sections approximate the angles of hornblende. Magnetite is very abundant and apatite occurs in some of the more basic areas. The groundmass is lighter colored, although containing minute grains of magnetite. Microlitic laths of feldspar constitute a thin felt, and the clear base has a very slight effect on polarized light. It is probable that this rock is essentially a hornblende andesite, rather more acidic than many of the other lavas here described.

A dark-green rock associated with the typical andesites resembles them in many of its characters, both megascopic and microscopic, but approaches rather closely a diabase in texture and composition. The feldspar phenocrysts are almost wholly altered, but the twinned crystals of monoclinic pyroxene are very fresh, some chlorite being present as a product of the partial alteration. The pyroxene crystals are nearly colorless in the thin section and have the extinction angles of augite. The groundmass is holocrystalline, but is very fine grained and approaches the ophitic structure of diabase. The rock is therefore an andesite approaching diabase.

In the rhyolite porphyries associated in minor amounts with the andesites there are beautiful examples of well-defined phenocrysts, the sharp outlines of the bipyramids being interrupted only by the deep embayments. In some phenocrysts this effect of magmatic corrosion has been in part remedied by the subsequent addition of quartz, which seems to be of the same period of crystallization as the groundmass. The feldspar phenocrysts have altered to calcite and muscovite, and secondary muscovite also clouds the interlocking grains of the groundmass. In a few cases these grains are of twinned feldspar, and in others they have small areas of quartz at the center surrounded by micropegmatitic intergrowths. Similar intergrowths constitute a marked feature of another porphyry, the volcanic character of which is less certain. Here, however, the micropegmatitic areas envelop the quartz phenocrysts and are in crystalline continuity with them, forming wide borders which may reach from one crystal to another.

Microscopic examination of certain of the amygdaloids shows that the amygdules constitute one-fourth of the rock section. Their structure is concentric, quartz grains and chlorite forming the outer zone, from which quartz grains of perfect hexagonal prisms project inward. The central portion is filled with calcite or quartz, the latter, in a few cases, being in roughly spherulitic plumes. The rock is an amygdaloidal andesite.

Microscopic study of the finer tuffs from Ames Point shows them to consist of a mass of minute, angular, and almost colorless particles, with a few larger fragments of minerals or of lavas. These minute fragments seem to represent glass sherds, with concave triangular outlines for the most part, but many of them crescent- or sickle-shaped. The structure determined by this material is that generally described as the "aschen-structur" and considered to be characteristic for deposits of the most finely comminuted glass from a volcanic explosion. This ash structure somewhat resembles the rhyolitic or fluidal structure, but can be distinguished, as in the present case, by the fact that the angular areas are distinct from the matrix even in polarized light. The fragments, although originally glass, are now cryptocrystalline. One section exhibits an included fragment of a lava with a quartz phenocryst, associated with this typical ash structure. These fine tuffs are therefore to be considered as derived from a rhyolitic lava.

Sequence and occurrence.—A uniform succession, comparable with that of sedimentary rocks in a small area, is hardly to be expected in a volcanic series, but, though showing numerous local differences, a certain general sequence within the Thorofare volcanics is observable. The varying proportion of lavas and pyroclastics prevents any reliable estimate being given of the thickness of this series.

The lowest members of the series, the dark-gray pyroxene andesite and andesite porphyry, are most prominently exposed on Ames Knob, and to the south of this hill the sequence can be traced without difficulty. Above the andesitic lavas, which are locally very amygdaloidal, occurs the volcanic conglomerate, a well-defined deposit with a general strike of N. 65° E. and a southern dip. The included fragments of the dark-gray pyroxene andesite and porphyry which constitute the greater part of the volcanic conglomerate afford proof of the relative age of these two members of the series. Toward the south and west the conglomerate grades into breccias, which show both tuffaceous and flow characters. The red basaltic andesites overlie the conglomerate and breccia and are in turn followed by the more acidic hornblende andesite. At this point in the series the lavas become less prominent and on the shores of the Thorofare the tuffaceous rocks are exposed, acidic and basic tuffs being interbedded. The best bedded of these strike N. 85° W. and dip about 60° S. A short distance to the east the amygdaloidal flows, with amygdules giving a strike of N. 80° W., occur above the hornblende andesite and are in many places interbedded with the tuffs.

Just west of North Haven village occur the more acidic members, the rhyolite-porphyry tuffs and small amounts of the massive rhyolite porphyry, and on the shores of the Thorofare at the village the yellow porphyry is prominently exposed. This more acidic lava is not so widely distributed as the andesitic kinds.

In the eastern part of the main area of the volcanics, on the shores of Waterman Cove, much the same succession of red and gray andesites, andesite porphyry, and breccia is found, with some quartz porphyry, which here is probably intrusive. On Iron Point portions of the series are exposed which would overlie the rocks of the Ames Knob district. These are well-bedded tuffs, striking N. 80° E. and dipping about 60° S. With these tuffs occurs a medium-grained conglomerate with well-rounded pebbles. It is to be noted that throughout the principal area on North Haven the bedding of the pyroclastics is fairly constant.

Across the Thorofare, on the extreme northern portion of Calderwood Neck, the same sequence is found, the breccias being overlain by tuffs and the conglomerate, and the series striking N. 40° W. and dipping about 80° S. At this locality the section is continued even higher than on Iron Point, for breccias overlie these bedded rocks, and at the entrance of Seal Cove well-bedded tuffs occur above the breccias with approximately the same strike and a dip of about 50° S. This change in strike from that found toward the northwest on Iron Point must be accounted for by folding, with possibly some faulting. To the east, on the shore of Carvers Cove, the lower of the bedded tuffs and the conglomerate are found, striking N. 5°–25° E. and dipping about 35° W. Here also folding and faulting are necessary to explain the distribution of the beds.

On the western side of Vinalhaven Island the upper part of the series is again exposed, consisting of andesitic lavas, with tuffs and breccias. The well-bedded tuffs in this part of the area strike N. 18°–25° E. and dip 65° SE. At Browns Head the upper part of the series is in contact with the Vinalhaven acidic volcanics, which are discussed in the next section.

In the area of similar volcanics toward the east, along the shores of the Little Thorofare, the most prominent rock type is a flow breccia, with which occur tuffaceous rocks of varying character. There is nothing in the sequence, however, to warrant more than a correlation in general character with the rocks of the principal area.

Age.—The age of the Thorofare andesite can be determined only by its relation to the Ames Knob formation. In the Ames Knob locality the volcanic rocks overlie the upper members of the Ames Knob formation with about the same strike and dip. The lack of any marked unconformity must be considered as showing that the volcanic outbreaks followed the deposition of the Silurian sediments before the tilting of those sediments to their present position. The red shales of Ames Knob very probably represent old muds which received considerable amounts of volcanic dust, thus marking the beginning of the intermittent volcanic activity. On Stimpson Island, however, there is geologic evidence which bears more directly on the age problem. The fossiliferous limestones and quartzites there are interbedded with the volcanic rocks, so that it is apparent that the volcanic activity began in Niagara time.

VINALHAVEN RHYOLITE.

Definition.—The name Vinalhaven rhyolite is given to altered surface volcanic rocks of rhyolitic composition which are extensively developed and well exposed in the northwestern part of the island of Vinalhaven and which occur also in a number of other localities.

Distribution.—The Vinalhaven area of these rhyolites may be described as a rough circle about 2 miles in diameter, fitting into the western part of the area of Thorofare andesite. Extremely good sections are afforded by Perry and Crockett coves, which extend well toward the center of the area. The next largest area is in the northwestern part of Isle au Haut and extends as a band about three-fourths of a mile wide from Moore Head and Trial Point to the village of Isle au Haut. Similar rocks cover an area of somewhat more than 1 square mile in the southwest corner of the island, where they form a number of steep, rugged hills and high, precipitous sea cliffs. Saddleback Ledge, at the entrance to Isle au Haut Bay, and the Hay and Roberts islands, southeast of Vinalhaven, are composed of rocks of similar texture and composition.

General character and occurrence.—The volcanic rocks of this formation exhibit less variety than the Thorofare andesite, but such kinds as do occur are of special petrographic interest. They rank among the most beautiful of volcanic rocks and can not fail to attract attention as exposed in the weathered ledges and sea cliffs. Among them both lavas and pyroclastics are represented, and four kinds of rock will be described—the taxitic and the spherulitic aporhyolites, the flow breccias, and the tuffs.

The acidic lavas, which constitute the greater part of the formation as exposed on Vinalhaven, are very glassy in appearance and are characterized by flow structure. This texture is in many places beautifully exhibited on the weathered surfaces, the flowage lines being extremely delicate. Most of these taxitic aporhyolites are composed of light flesh-colored and dark-gray or purple layers of varying width, some of which are extremely irregular in form. Where the banding is regular the rock may show a parallel parting. No phenocrysts other than small magnetite and zircon crystals appear in any of the specimens examined from the island of Vinalhaven, but on Isle au Haut and on the Roberts Islands finely porphyritic varieties are very common. Outcrops showing flow structure occur abundantly along the shores of Perry and Crockett coves. On Isle au Haut the flow structure is commonly not recognizable on the weathered rock surfaces, but can be seen microscopically in many of the specimens.

The spherulitic aporhyolites are closely related to the taxitic, and gradations are found between the two kinds. The spherulites vary in abundance and size; in some places only a few small ones, the size of a pin head or of a pea, are disseminated through the variegated purple or dark-gray rock, but elsewhere they are in great abundance, in many places completely covering the exposed surfaces and attaining a diameter of several inches. Such a rock is so unusual in appearance that it would readily be noticed by even a casual observer. The spherulites vary greatly in form, some being perfect spheres, others ellipsoids, while in places several are united to form irregular nodules. They are as a rule compact and felsitic; more rarely they are hollow and lined with quartz, probably as a result of subsequent solution and deposition. Spherulitic aporhyolites are confined, so far as observed, to the Vinalhaven area, and are well developed on the shores of Perry and Crockett coves and especially along the shore south of Browns Head. The conditions determining this kind of crystallization are not clearly understood. The arrangement of the spherulitic growths in these old rhyolitic lavas indicates that, whatever agent determined the crystallization, its action was in many places confined to definite planes, and that in some localities the conditions favoring the process were not limited to a single period in the consolidation of the lava. The spherulites seem to have crystallized very rapidly in a glassy lava which had come to rest and become nearly solid; superheated water and steam were probably important factors.

Many of the aporhyolites present traces of brecciation. In some areas fragments of the Thorofare andesite are associated with those of the more acidic rock, the matrix being rhyolitic and showing flow structure. Most of these breccias can be identified only with the aid of the microscope. They appear to be developed locally within the central area of spherulitic aporhyolites. In part they probably originated as lava flows including fragments of older lavas, like the breccia so prominently developed in the Thorofare volcanics. In other places the brecciation seems to have been confined to the lava itself, certain strains within the cooling mass having been sufficient to break up those parts which had consolidated. This process seems to have been of a different character from the breaking up of lenticules of flow, which would give an ataxitic or rhyolitic structure, since here the brecciation took place when the cooling glass was sufficiently stiff to break into extremely angular fragments. This brecciation also followed the spherulitic crystallization and affords the best proof of the original nature of these spherulites, as well as of their development at a very early stage in the cooling of the lava.

The tuffs of this series are, in the main, much more compact than those of the Thorofare volcanics, but, like them, vary in color from dark purple or greenish to light pink or buff. In grain they present the same variation from a coarse assemblage of angular fragments to a rock composed of the finest particles and showing the ash structure. Within the Vinalhaven area the larger fragments are mostly of the banded and spherulitic lavas, but in some places andesite fragments are very plentiful. Crystal fragments also occur in the finer tuffs. Fragmental varieties of the volcanics occur at several points along the eastern shore of Isle au Haut Thorofare, where they form an agglomerate of angular fragments in a matrix of nearly the same composition. They are also particularly well developed at Western Head, Isle au Haut, where the fragments range up to 3 inches in size. Among the islands between Isle au Haut and Vinalhaven, they occur on the southernmost of the Hay Islands and on the Roberts Islands as distinctly bedded deposits showing an alternation of green, purple, and buff bands.

Petrography.—The lavas of the Vinalhaven formation are found on microscopic examination to be cryptocrystalline in part, but elsewhere to exhibit traces of glassy structure, now more or less obliterated by devitrification. Since the rocks are rhyolitic and were originally somewhat glassy, they have been termed aporhyolites. In those varieties in which the flow structure is best developed the darker lines are seen to owe their color to masses of black cumulitic grains, margarites, trichites, and minute crystallites, all of which probably have the composition of magnetite, being in many places connected with distinct grains of that mineral. The details of flow structure outlined by the arrangement of these crystallites is much more delicate than that seen megascopically. Locally the bands in which the trichitic flow lines are so prominent contain chains of minute spherulites, which are described with the other spherulites in another paragraph. More commonly, however, these bands are characterized by a peculiar weblike intergrowth of fine fibers of what seem to be quartz and feldspar, although the constituents are too minute to be certainly determined. In the lighter bands and lenses the crystallization is coarser and less definite in structure, although spherulitic in part. Some areas of quartz and epidote occur, and are probably of secondary origin.

On Isle au Haut most of the massive rhyolites are finely porphyritic, few of the phenocrysts exceeding one-eighth of an inch in diameter. In some places the groundmass is still in part isotropic, but in most of the rock it is completely devitrified. The devitrified groundmass may show an exceedingly fine and even texture throughout or great variations in coarseness from point to point, but in either case the crystal boundaries are in the main indefinite. When rotated between crossed nicols, certain irregular patches of the groundmass are seen to extinguish light at the same time, a phenomenon which probably indicates more or less parallel growth among the quartz and feldspar of these areas. In a few slides those areas which extinguish light at the same time assume narrow curved forms strongly suggestive of original perlitic cracking. In some of the rhyolites of the Vinalhaven area such cracking is very beautifully shown, the cracks being outlined in lighter lines in a groundmass of light-brown color; in polarized light they are seen to have been filled with quartz. The phenocrysts in the rhyolites of Isle au Haut are of all sizes up to three-sixteenths of an inch in diameter and are as a rule exceedingly fresh. They comprise angular, subangular, or rounded quartzes, many of which show embayments, also orthoclase and albite; the feldspars are in general more or less angular. Many feldspars show signs of fracturing and in places of a dragging apart of the fragments, apparently as a result of flow before complete solidification took place. Even in those porphyries which show distinct flow lines, what appear to be explosion fragments are here and there seen. They are usually small, highly strained quartzes of very angular outline, the borders in many places being concave, and they seem either to have been picked up by the flow from the underlying surface or to have fallen into the flow as volcanic dust or ash.

The spherulitic aporhyolites when examined microscopically are found to be characterized by an even more delicate arrangement of trichites and crystallites than that observed in the taxitic lavas. The spherulites, which may be described as complex intergrowths of crystal fibers, radially arranged, vary in outward form, the sections being circles, segments of circles, and plumes. Many of these, especially the smaller ones, are not to be seen in ordinary light, as they are wholly independent of the flow structure, the lines of trichites passing through the spherulites without interruption. Other spherulites may be readily seen because of a concentric arrangement of bands rich and poor in trichites, and still other spherulitic forms may be slightly different in color, the finely divided pigment being of a brown tint rather than black. The smaller spherulites are optically negative; in the larger ones the radiate structure can be resolved into more or less distinct fibers, the optical character of which could not be determined owing to the fact that several are commonly superimposed even in the thin section. In the best examples of large-scale spherulitic crystallization these radiating fibers are seen to be embedded in relatively large interlocking grains, and the radiate structure can be observed even in ordinary light owing to a slight difference in index of refraction and color between the fibers and the grains. These grains appear to be in part at least uniaxial, and most probably are quartz, while the arborescent fibers are feldspar. Such intergrowth is a form of micropegmatitic structure and is undoubtedly the original form in these larger spherulites. There are, however, indications that in some areas subsequent alteration has replaced the feldspar fibers with quartz, thus changing the micropegmatitic structure to a purely granular mosaic. Where the change has been complete, the spherulite is identified simply from the circular outline of the fine mosaic.

Different generations of the spherulitic crystallization are indicated in some of the sections examined. The spherulitic plumes, where they occur in connection with the more perfect spherulites, are of a darker color and appear to be older, being locally inclosed in the later spherulitic growth, or determining the outward form of the larger and lighter spherulite. In one section all of these plumes are seen to have grown in the same direction, parallel with the flow, and also to have determined sharp eddylike curves in the flow lines of trichites. One of the most beautiful of these spherulitic structures is formed by the abrupt spreading out of a long plume into three quadrants of a circle, as seen in cross section.

The matrix in which these larger spherulites occur is generally cryptocrystalline, although there are areas of coarser grains of quartz and feldspar, around which there seems to be some flowage. These areas may represent vesicles in the rock, subsequently filled. Allied to them are smaller miarolitic areas of quartz into which project fine laths, optically continuous with the fibers of small spherulites. That the rock was in part glassy is proved by the perlitic cracks which are beautifully shown in some of the sections. These are outlined as lighter lines in the light-brown groundmass, and in polarized light are seen to have been filled with quartz. In these portions of the rock the very delicate trichites do not appear to have been affected by the subsequent devitrification of the glass.

The flow breccias are megascopically similar to many of the spherulitic lavas, but on microscopic examination are seen to lack homogeneity. In some places fragments of the older andesitic lavas are included with those of the acidic glass, but the matrix is seen to have been a molten lava, thus making the rock a flow breccia. Under the microscope the mass of the breccia is seen to be characterized by a flow structure, much more irregular than in the taxitic aporhyolites. One specimen affords a beautiful example of the structures seen in obsidians, ribbons and filaments of the trichitic gauze being twisted into complex patterns. Traces of perlitic cracking also give evidence of the originally glassy state of the rock.

The fragments that are similar to the inclosing material as a rule appear to have been brecciated in place. Spherulitic plumes are broken across and the parts slightly displaced, and the spherulitic crystallization uniformly preceded the brecciation. Other fragments possess a flow structure sharply contrasted with that of the inclosing lava, and in one there has been a marked shearing without rupture. Devitrification has made these glassy rocks holocrystalline, but in the rock with the delicate obsidian structures the devitrification has been very slight.

In most of the specimens examined there has been some development of secondary minerals—muscovite, biotite, chlorite, calcite, epidote, and leucoxene. These occur in small grains, here and there grouped in irregular aggregates. Calcite was observed only in the tuffs containing andesitic fragments.

An analysis of one of the most typical and seemingly least altered of the spherulitic varieties of the Vinalhaven volcanics shows that the rock has the composition of a typical rhyolite.

Structure and sequence.—The structure on Vinalhaven is comparatively simple, the lavas and tuffs occupying a basinlike depression and overlying the tilted Thorofare volcanics. Where their structure can be determined the rhyolitic volcanics dip at angles of 45° or more toward the center of the area, except in the southwestern part, where the dip is more to the southeast. On the northwestern side of the area the lower members of the Vinalhaven series are found in contact with the Thorofare andesite, and the beds are seen to be wholly conformable. Tuffs constitute the basal members of the series, and their separation from the tuffs of the underlying andesitic series is in many places very difficult. Above these tuffs the general sequence is, taxitic aporhyolites, followed by spherulitic aporhyolites and flow breccias, with other tuffaceous beds as the highest member of the series represented. In the taxitic lavas the lamination has approximately the same strike and dip as the underlying tuffs. The larger spherulites first appear in the upper part of this taxitic aporhyolite, where they are confined to the lighter colored layers.

On Isle au Haut the volcanics are either massive, with little megascopic evidence of flow structure, or else irregular tuff deposits, in which no general structural relations are apparent. Like those on Vinalhaven, they apparently lie in nearly their original position, though somewhat disturbed by the granite. The latter is clearly intrusive, as shown by granite dikes which cut the volcanics here and there, and by the fact that the granite becomes finer grained and shows in many places micrographic structure next to the contact. This increase in fineness of the granite, together with a slight contact metamorphism of the volcanics, results locally in an apparent gradual transition of one series into the other, a feature which is well shown along the shore just north of Duck Harbor.

On the southernmost of the Hay Islands parts of the rhyolitic volcanics are distinctly bedded, the bands being green, purple, and buff in color and fine grained. Other parts are coarser and appear distinctly fragmental on the weathered surface. All are pyroclastic in origin. On the northernmost of the Roberts Islands similar pyroclastics occur, but they are associated with massive rhyolite porphyry that weathers to a pure white. Both are cut by dikes of granite.

Age and correlation.—The structural relations already outlined show that the extrusion of these acidic lavas and tuffs immediately succeeded that of the Thorofare volcanics. Indeed, it seems probable that the ejection of the more acidic lava began before that of the andesite closed. Within the Thorofare volcanics acidic members are found overlain by more basic varieties of lavas and pyroclastics, and again in the upper tuffaceous beds assigned to the Thorofare volcanics there is more or less mixture of rhyolitic and andesitic material. Thus at Browns Head a coarse tuff breccia composed of large fragments of andesites was found to contain a few angular pieces of the taxitic and spherulitic aporhyolites. On the other hand, the lower tuffaceous beds assigned to the Vinalhaven volcanics were found to contain fragments of the andesitic lavas. The tuffs of the upper portion of the Vinalhaven seem, however, to be wholly rhyolitic. It seems probable that the two kinds of lava were erupted from separate though neighboring vents, the rhyolitic eruptions beginning while the andesitic were in their later stages. The Vinalhaven volcanics, therefore, like the Thorofare andesite, are of post-Niagara age—probably late Silurian—and are older than the granite.

SERPENTINE.

Definition.—The name serpentine is applied to rocks in which the mineral serpentine occurs as the dominant constituent. This mineral is a hydrous silicate of iron, magnesium, and aluminum, and is usually formed through the decomposition of the minerals olivine, pyroxene, or amphibole. The serpentines of the Penobscot Bay quadrangle have resulted from the alteration of rocks composed largely of olivine and pyroxene or of olivine and amphibole.

Distribution.—The largest serpentine area in this region occurs on the northern part of Deer Isle, where it forms a single band extending nearly east and west from Eggemoggin Reach to Deer Isle Bay. Its eastern part has a width of about a mile, but it narrows on the west to less than one-fourth of a mile. This occurrence has resulted from the alteration of a stock of basic igneous rock intruded into the bordering Ellsworth schist and Castine formation.

In the east-central part of Little Deer Island a single prominent hill rising 125 feet above sea level and surrounded by acidic volcanic rocks is composed entirely of serpentine. This locality has long been known to geologists.[1] This mass also seems to be an intrusive stock cutting the Castine volcanics. Small serpentine dikes were found at South Brooksville on the grounds back of Gray's Inn, and at several points on Little Deer Island.

Description.—In general appearance the rock varies but little in the different localities; that from

[1]Jackson, C. T., Second Rept. on Geology of Maine, 1838, p. 45. Merrill, G. P., On a peridotite from Little Deer Isle, in Penobscot Bay, Maine: Proc. U. S. Nat. Mus., 1888, p. 191.

the old quarry on the northeast shore of Deer Isle is exceedingly fine grained, dimly mottled in dark green and black, and is crossed by irregular black bands of the mineral serpentine and by numerous minute veins of calcite. The rock from the Little Deer Island stock is somewhat more massive in appearance, coarser, and dark grayish green in color; it weathers on the immediate surface to a reddish or greenish brown, and breaks up into roughly quadrangular blocks of all sizes up to several feet in diameter.

Microscopic examination shows the rock from the old quarry in the northern part of Deer Isle to be made up almost entirely of the mineral serpentine, in part deep green and of very low double refraction, and in part light green with much higher double refraction. In certain parts of the rock the form of the serpentine network suggests the original presence of olivine, but none of this mineral remains. Serpentine is found to have developed from the alteration of a nearly colorless amphibole occurring in brush-shaped or sheaflike aggregates of large needles or elongate prisms which in the process of alteration have been broken up by cross bands of serpentine. This amphibole seems to be tremolite and at one time formed a large part of the rock; it may itself be secondary after some other mineral. At one side of the slide examined there appears to be a cavity that has been filled with a substance which for the most part is completely isotropic. The portion next to the normal rock is a homogeneous layer of light-green serpentine in botryoidal growths with radiating structure. This layer grades into a mass of very pale green isotropic material whose index of refraction is precisely the same as that of the undoubted serpentine, and which probably is serpentine, so finely divided as to behave optically like an isotropic body.

Two specimens collected from points close together on the northeastern shore of Deer Isle show considerable differences when examined microscopically. The first is a somewhat sheared rock showing abundant tremolite and olivine, both of which have been altered to nearly colorless serpentine that is blue-gray between crossed nicols. The rock also shows numerous grains of a blue-green, singly refracting mineral showing angular fractures, which is either spinel or garnet, and much magnetite in irregular grains of all sizes; several narrow, nearly parallel bands of almost isotropic serpentine cross the section. The other specimen is much less extensively serpentinized; its most abundant mineral is nearly colorless enstatite showing irregular prism terminations, an extinction everywhere parallel to the longitudinal cleavage cracks, and interference colors nowhere exceeding yellow of the first order. This mineral is in the main fairly fresh, but shows some decomposition to serpentine, mostly of the fibrous variety. Olivine is present in large grains and is much more serpentinized than the pyroxene. A micaceous variety of chlorite is abundant and is apparently of secondary origin. Some hornblende and muscovite are also secondarily developed. The serpentine is mainly concentrated along rather broad veins which cut the rock irregularly.

The microscopic structure of the serpentine from the Little Deer Island stock has been described very fully (Merrill, op. cit., p. 191) in an article which embodies the first published description of the secondary enlargement in pyroxene. The slides from other specimens exhibit the same features previously observed, but show in addition the presence of secondary hornblende. The singly refracting substance which occupies the interspaces between some of the olivine and pyroxene grains, and which was thought to be glassy base, appears to be serpentine so finely divided as to have the optical properties of an amorphous substance. By far the most abundant of the original minerals is olivine, occurring in rounded grains from 0.6 to 1.5 mm. in diameter, but averaging about 1 mm. Only small amounts of this mineral now remain, most of it having altered to transparent, colorless serpentine which between crossed nicols appears fibrous and blue-gray in color, but which still preserves the outlines of the parent olivine grains. Magnetite of very fresh appearance is abundantly developed in aggregates of minute grains and needles, following what were the cracks in the parent olivine grains; it is also scattered through the rock irregularly in ragged grains of larger size. Much of the space between the altered olivine grains is occupied by pink augite showing extinction angles up to 45°. Most of this pyroxene shows secondary enlargement, the secondary portions penetrating the olivine-serpentine areas as a jagged or netlike border about the original pyroxene. The boundaries of the original pyroxene are recognizable in ordinary light from the fact that its color is pink while its fringe of secondary pyroxene is nearly colorless. This difference in color as well as a very slight difference in extinction angle indicates some difference in composition, although both are of the augite variety. Small shreds that appear to be nearly colorless amphibole are abundant within some of the olivine-serpentine areas and seem to be a decomposition product of the olivine. The spaces between the olivine-serpentine areas, where not occupied by augite, are filled with a colorless to pale-green material which under crossed nicols usually behaves as an isotropic substance, but in some places shows feeble double refraction with faint gray to gray-blue colors. The fact that some of the boundaries between the augite and this substance were very sharp led Merrill (op. cit., p. 194) to conclude that the latter represented an original glassy base. It is to be noted, however, that just as sharp boundaries exist between the augite and undoubted serpentine. It seems improbable that glassy base should occur so abundantly in a rock in which so many of the minerals are developed in large and perfect crystals, and it also seems doubtful whether a glassy base would remain so largely unaltered in a rock which otherwise is much decomposed. The isotropic substance not only seems to grade into augite and undoubted serpentine, but also incloses serpentine, magnetite, and shreds of secondary amphibole. This, together with its local anisotropic properties and its index of refraction, which seems to be exactly the same as that of the typical serpentine, constitutes the reason for regarding it as a serpentine aggregate so finely divided as to behave optically like an amorphous substance. It seems to be essentially the same in character as the green isotropic material found in the serpentine rock from the old quarry on Deer Isle. As described above, this was observed to pass into undoubted serpentine developed in botryoidal forms. Some small apatite prisms occur, and by mechanical analysis the presence of chromic iron was recognized, while the chemical analysis (Merrill, op. cit., p. 195) shows by its percentages of sodium and calcium that the original rock probably contained some lime-soda feldspar. No feldspar is now recognizable, but some faint striation appearing in some of the nearly isotropic areas between the olivine grains may represent the albite twinning of original feldspars. The unaltered rock was a peridotite of the picrite variety.

Age.—The serpentine is known to be intrusive into the folded and metamorphosed Ellsworth schist and into the Castine formation, of probable Cambrian age, but in itself it shows no evidence of dynamic metamorphism other than the local shearing commonly found in serpentine. Its intrusion took place, therefore, subsequent to the period of general dynamic metamorphism which affected this region. Its contact with the granite is nowhere exposed, but the granite near the contact is somewhat porphyritic, indicating that the serpentine is probably the older rock. For these reasons an Ordovician age is perhaps the most reasonable to assign to the serpentine.

GRANITE.

Distribution.—The outlines of the areas occupied by granite are very irregular because of the general complexity of the coast line and because of the manner in which the granite intrudes the surrounding rocks. The belt crossing the northeastern part of the Penobscot Bay quadrangle extends for only a short distance east of the quadrangle, but just beyond the northern boundary it connects with the Sedgwick-Penobscot area and extends northeastward to Amherst and Aurora. There the belt is only 2 to 3 miles wide, but it widens again beyond and extends southward to Sullivan and Cherryfield. The whole area thus has somewhat the form of an immense horseshoe. A small isolated area occupies the southern part of Long Island, in Bluehill Bay. The granite areas of Deer Isle, Isle au Haut, and Vinalhaven form parts of a much interrupted belt whose general trend is about parallel with that of the coast. This belt includes the granite of Swan Island, Mount Desert, and Winter Harbor to the east, and that of Sprucehead and Clark Island to the west of this quadrangle. The small granite area in the northwest corner of the quadrangle forms part of a large area which extends eastward just beyond the northern boundary to the village of Sandy Point, and northward up Penobscot River to North Wintersport, where it includes the important quarries of Mount Waldo. Several small and irregular areas occur on the mainland in the town of Northport.

General description.—The great mass of the granite is gray to pinkish gray in color, nonporphyritic, and of medium grain, the feldspars averaging one-fourth to one-half inch in diameter and the other constituents occurring chiefly in smaller grains. There are, however, so many minor variations in texture, mineral composition, and color that it will be necessary to describe separately each of the areas mentioned above.

Bluehill-Toddy Pond area.—Because of the scarcity of exposures the northeastern boundary of the Bluehill-Toddy Pond granite belt can be drawn only with approximate accuracy. Exposures are very scarce also in the northern and central parts of the belt, but in the eastern and southern parts and along the western boundary they are very abundant.

Over the northeastern, eastern, and southern parts of the area the granite is moderately coarse and nonporphyritic. The feldspars average about one-fourth of an inch in length. The rock from the quarries at Bluehill, described in detail in the section on petrography, may be taken as the type of this medium-grained variety. The granite near Ball Pond and in the eastern part of the area is similar to it both in texture and in mineral composition. A coarsely porphyritic variety, some of which shows feldspar phenocrysts 2½ inches long, occupies the whole western part of the area from Bluehill to the northern edge of the quadrangle.

The contact between the granite and the Ellsworth schist is well exposed one-fourth of a mile northeast of Closson Point and on the shore one-half mile west of Woods Point. At the latter locality there is considerable intrusion of granite parallel to the foliation of the schists. The granite near the contact is closely jointed. Contact phenomena are also well shown due east of North Bluehill and near the northern edge of the quadrangle, one-half mile west of Toddy Pond. At the latter locality dikes of granite parallel the foliation of the schist and also break across it, and a number of angular fragments of schist have been caught up in the granite. Along this whole contact the granite has produced no change in the schist apparent to the eye, and even the microscope fails to show extensive recrystallization of the schist or abundant development of new minerals.

Long Island area.—The central part of Long Island, in Bluehill Bay, is a boss of granite of nearly circular outline. Its northern and northeastern contacts are well defined, but the southeastern contact is masked by surface deposits. The western boundary about parallels the western shore, as is shown by the small patches of schist found here and there along the shore and on some of the small off-lying ledges. In general texture and composition the granite of Long Island is similar to that of the southern and eastern parts of the Bluehill-Toddy Pond area.

Sedgwick-South Brooksville area.—Throughout the rudely circular granite area extending from Bluehill Falls to Sedgwick, Sargentville, and South Brooksville, and thence northward to Bear Head, the rock shows remarkable uniformity in texture, color, and mineral composition. Exposures are abundant, not only along the contacts with the surrounding schists and volcanics, but also throughout the central portion of the area. The granite is of medium grain and almost identical in appearance with that of the eastern and southern parts of the Bluehill-Toddy Pond area. The rock from the South Brooksville quarries may be taken as the type, and is described in the section on petrography.

The contact phenomena between the granite and the Ellsworth schist are well shown along the eastern and northern borders of this area. In general the contact is sharp and the schist has suffered no changes that are megascopically apparent. Dikes and irregular apophyses of granite penetrate the schist, but are not abundant, and the granite near the contact is of the same texture as in the central part of the area. The microscopic changes observed in the schist near the granite contact are discussed more fully in the section on the lithology of the Ellsworth schist.

The contact relations between the granite and the Castine volcanics are best shown between Billings Cove and South Brooksville. The contact is sharp in most places, and neither the schist nor the granite shows to the naked eye any very marked changes as the contact is approached. Dikes of granite are of rather common occurrence in the volcanics. In a few places the granite within a short distance of the contact is garnetiferous, and in other places it is exceedingly fine grained and shows micrographic structure. The microscopic characters of the contact phases of the granite and of the Castine volcanics are described in the sections on petrography under these two formations.

South Penobscot area.—The granite area extending from North Brooksville to Penobscot differs in many respects from that just described, its principal peculiarity being the possession of a border zone which is a complex of granite and diorite with smaller amounts of gabbro and flow gneiss. The central mass is rather pure granite, but there is no sharp division line between the granite and the basic zone, and in the latter some granite occurs even at the outer border. The characters of the basic belt are more fully discussed in the section on diorite, diabase, and gabbro. It is nearly contemporaneous with the central granite mass and probably represents a differentiation from the same magma. The roughly circular area of granite south of South Penobscot is made up mainly of gray biotite granite which is slightly coarser than that quarried at Bluehill or at South Brooksville, some of the feldspars being three-fourths of an inch to an inch and a half in length. It is probably somewhat inferior for building purposes and has not been much quarried. Near South Penobscot and to the north toward Penobscot and Wight Pond the granite becomes finer grained and more variable in texture and mineral composition, and small amounts of basic granite, quartz diorite, and diorite are associated with the true granite.

Wallamatogus Mountain area.—The granite of the Wallamatogus Mountain area is separated from that of South Penobscot by the belt of basic rock referred to above and is also distinctly different in mineral composition. In the South Penobscot area the rock is a biotite granite which shows only a small amount of muscovite, but that of the Wallamatogus Mountain area is rich in muscovite and contains little biotite. The granite of Wallamatogus and Montgomery mountains is mostly of medium grain, though showing some orthoclase laths three-fourths of an inch long, all similarly oriented. In places muscovite is the only mica developed. The rock in the vicinity of West Penobscot is a fine-grained gray muscovite granite whose weathered surfaces, unlike most of the granite, support an abundant lichenous growth. All of the muscovite granite weathers rapidly. The contact between the granite and the Penobscot slate is mainly covered by glacial deposits, but is well exposed on the southern slopes of Wallamatogus Mountain. There the contact effect of the granite on the slate is shown on the weathered surfaces by the more rusty appearance of the slate for a foot or so from the granite contact. Microscopic study shows that the slate within this narrow zone has undergone much recrystallization, in many places with the abundant development of small crystals of brown tourmaline.

Deer Isle and Isle au Haut areas.—The granite of Flye Point, Deer Isle, and the islands between Deer Isle and Isle au Haut is, for the most part, of medium grain, nonporphyritic, and free from the association of diorite, diabase, flow gneiss, etc., which characterizes many of the other areas. Pink granite is of common occurrence, the amount of pink orthoclase being much greater than in the other areas within the quadrangle. On Flye Point the rock is a coarse pink granite with porphyritic crystals of pink orthoclase which show zonal structure. Scattered "knots" or segregations are much finer grained and richer in ferromagnesian constituents. On Stinson Neck the rock is similar to that on Flye Point, but shows a well-defined horizontal sheeting. On Saddleback Island, 4 miles east of Stonington, and on some of the neighboring islands the granite is coarse grained and shows porphyritic crystals of orthoclase, many of which are 1 inch in length. The coarseness and the abundance of basic segregations render it unfit for ornamental purposes. The pink, coarse-grained granite from the quarry of Hagan & Wilcox in the northeastern part of the village of Stonington is typical of the granite on the south end of Deer Isle and on the neighboring islands. In general it is of even texture and fairly free from segregations ("knots"); it is described in detail in the section on petrography. The spacing of the joints varies greatly in different localities, but over considerable areas they are so far apart that large blocks may be quarried. Some of the most important quarries in Maine are in this vicinity.

The granite of Isle au Haut and Kimball Island is mainly pink and rather coarse grained, but near Moore Harbor it becomes finer grained and gray in color, so that on its weathered surfaces it is with difficulty distinguished from the neighboring rhyolites.

Vinalhaven area.—The northern boundary of the Vinalhaven granite area is a line running from a point about midway on the eastern shore of Calderwood Neck nearly due west to Seal Cove and thence southwest to the north point of Leadbetter Island. South of this contact of the granite with the quartzitic schists and acidic volcanics, Vinalhaven is composed wholly of granite, with the exception of two large areas of darker rock, the "black granite" of the quarrymen, which is described farther on. The principal type of the Vinalhaven granite is of a light-gray color, with a slight pink tint, and is comparatively free from the segregation patches of dark constituents, though cut by numerous aplite dikes. The rock quarried at Vinalhaven and on Hurricane Island may be taken as typical for the Vinalhaven area and is described in the section on petrography.

Spruce Island dike.—On the northeastern spur of Spruce Island, near Islesboro, occurs a single granite dike 10 feet wide, which trends parallel to the bedding of the shaly limestone. It is peculiar in its isolation from other granite masses and in its texture and composition. It is composed almost entirely of a coarse crystallization of orthoclase and muscovite, some plates of the latter being 1½ inches across. The muscovite plates are nearly all oriented parallel to the trend of the dike, so as to give the rock a coarsely schistose structure. If this structure is secondary and imposed by the same dynamic movements which folded and metamorphosed the neighboring sediments, then the dike must antedate the period of dynamic action, but more probably the schistose structure is primary and the result of differential flow during intrusion, the dike being of the same age as the other granites of the quadrangle.

Petrography.—The granite from the quarries near Bluehill may be taken as typical for the whole southern and eastern parts of the Bluehill-Toddy Pond granite belt. It is light gray on fresh surfaces, but becomes a pale pink on weathering. The largest crystals are the white feldspars, which average about one-fourth of an inch in length and a few of which show Carlsbad twinning. Gray quartz is almost equally abundant, but occurs in smaller grains. Dark-brown biotite is the only recognizable femic mineral and is subordinate to both feldspar and quartz. Here and there rounded segregations occur which are finer grained and slightly more basic than the normal granite but contain the same minerals. A few of these "knots," as they are called by the quarrymen, are 10 inches across. In some places in the eastern part of this area, the granite is a little coarser, and some of the feldspars reach a length of three-fourths of an inch.

Microscopic study of the rock from the Bluehill quarries shows that the feldspar is orthoclase and microcline with subordinate amounts of albite. The albite occurs in part as separate grains and in part in perthitic intergrowth with the potash feldspars. The biotite is dark brown and highly pleochroic; it is as a rule very fresh but shows some decomposition to chlorite through which are scattered small grains of hematite. In some slides the microscopic texture locally becomes uneven, some portions being much more finely granitic than others and even becoming micrographic.

Granite from the roadside just southeast of Ball Pond is similar in every way to that from the Bluehill quarries. The coarsely porphyritic variety characteristic of the western border of the belt is well exposed at many places along the road northwest of Blue Hill. The minerals are the same as in the medium-grained granite. Just southeast of North Bluehill this granite shows some feldspar phenocrysts 2½ inches long and three-fourths of an inch wide in a matrix which has about the coarseness of the normal granite, the quartzes seldom exceeding a quarter of an inch and the biotite plates an eighth of an inch in diameter. Some parts of the granite are made up largely of feldspar.

The granite from the quarries at South Brooksville may be taken as a type for the southern part of the Sedgwick-South Brooksville area. It is very similar to that quarried at Bluehill, being light gray in color when fresh, but becoming pale pink on weathered surfaces. The constituents visible megascopically are white feldspar, light-gray quartz, and dark-brown biotite. The feldspars average one-fourth to one-half an inch in length; the quartz occurs in small grains which are mostly aggregated in irregular masses few of which are more than one-fourth to one-half inch across; the biotite masses as a rule do not exceed one-eighth of an inch in diameter.

The granite from the quarry of Hagan & Wilcox, in the northeastern part of the village of Stonington, is typical of much of the granite of the south end of Deer Isle and vicinity. It differs principally from the granite of Bluehill and South Brooksville in the much greater amount of pink feldspar. This is the most abundant and coarsely crystallized mineral and gives the rock a general pinkish hue. Some of the crystals are an inch across. White feldspar is also present, but few of its crystals exceed half an inch in diameter. Here and there it forms a partial or complete envelope about a crystal of pink feldspar. Gray quartz in grains not exceeding one-fourth of an inch in diameter and mainly under one-eighth of an inch is about intermediate between the pink and white feldspar in abundance. Brown biotite, the only abundant femic mineral, occurs in plates which are mainly under one-eighth of an inch in size. The coarseness of the pink feldspars produces a texture that approaches the porphyritic.

When the granite from Stonington is examined under the microscope the pink feldspar is seen to be orthoclase and microcline and the white feldspar to be albite. Most of the albite shows a distinct zonal structure, the inner portions having a higher index of refraction than the outer; in many places the outer border shows a micrographic structure due to intergrowth with orthoclase. Microperthitic intergrowths of albite with both orthoclase and microcline also occur. Accessory minerals are magnetite, zircon, titanite, and apatite. Some decomposition of the feldspars has resulted in the development of minute shreds of muscovite and some calcite.

Age.—Contact relations show that the granite and its associated basic rocks and flow gneisses are younger than any of the other rocks in the quadrangle, with the single exception of some dikes of diabase and analcite basalt. The youngest of the rocks cut by the granite are younger than the sediments of Niagara age; the granite is therefore at least as young as Silurian.

More definite relations have, however, been observed in the Perry basin, in the extreme eastern part of the State, the granite there being an eastward continuation of that found on Deer Isle and Vinalhaven. In the Silurian rocks of the Perry region no granite pebbles are found, but they occur abundantly in the conglomerate at the base of the Perry formation, which is of late Devonian age (probably Catskill-Chemung). The granite intrusions of the Maine coast area therefore probably occurred in late Silurian or early Devonian time.

DIORITE, DIABASE, AND GABBRO.

General description.—One of the most striking features in connection with the granite areas of Maine is the great contrast in the sharpness of the granite border in different parts of the region and in the amount of basic rock and flow gneiss associated with the border. In some areas, such as that on Long Island and that between Bluehill Falls and South Brooksville, the granite is of even texture throughout and characterized by very sharp contacts. Very few dikes or apophyses penetrate the neighboring rocks, which as a rule show no megascopic evidences of metamorphism, even the microscopic evidences being confined to a narrow zone. Other granite areas, on the contrary, are characterized by very indefinite boundaries and by a more or less continuous border of diorite, diabase, gabbro, and flow gneiss.

The igneous rocks associated with the granites vary in composition from a quartz diorite, only slightly different from the granite itself, to a much more basic rock. These widely different kinds, however, constitute a group of intrusive rocks with apparently the same relations to the granite, and therefore the diorite, diabase, and gabbro are grouped together as a single cartographic unit. Their separation would be difficult in view of their close geologic association. Together they are believed to constitute the earlier differentiate of the magma from which later came the extensive intrusions of granite. Because of the greater extent of the granite in this area, that rock has been described first, although it is for the most part younger than the diorite, diabase, and gabbro.

Occurrence.—The South Penobscot granite area furnishes the best example of the basic border adjoining the granite. In the central part of this area the granite is very nearly pure, containing only in a few widely separated places small admixtures of more basic rock. The zone bordering the granite represents the area within which diorite, gabbro, flow gneiss, etc., are associated with the granite in varying quantity. Near the inner margins of this zone the amount of basic rock is in most places relatively small, but near the outer margins it dominates greatly over the granite. In the region northeast of West Brooksville several outliers of this peripheral basic zone cut the Castine formation in the form of broad dikes, which because of their superior resistance to erosion rise as low ridges above the bordering acidic volcanics.

The basic rocks are diorites and gabbros, for the most part much altered and of rusty appearance on the weathered surfaces. They vary from fine-grained rocks to those which show hornblende and pyroxene crystals three-fourths of an inch across. Within the main basic belt fine-grained diorite, locally quartz bearing, is the most abundant basic rock and is well exposed in many localities. The gabbros are much less abundant and occur in small patches which in general rise as low hills above the surrounding less resistant rocks. The best exposures occur on Grindle Point and south of Pierce Pond. The diorites are in many places of very fresh appearance but the gabbros are in general much altered and very rusty on the weathered surfaces. One-half mile east of Pierce Pond typical diorite of medium grain is found grading into a coarser rock which is a true gabbro; similar transitions may be observed in the northern part of Wardwell Point. On the shore of Bagaduce River opposite Pumpkin Island the diorite and gabbro are interbanded and grade into each other. The granite here is the later intrusive and is intercalated between the diorite on its peripheral side and the Castine volcanics.

Basic rocks are associated with the granite of the Vinalhaven area in a very irrregular manner and form four distinct areas. One of these areas includes the southern extremities of the main island as well as Lane Island and a part of Green Island. A second and larger area is on the eastern side of Vinalhaven and may be called the Barley Hill area, from the most prominent hill within its limits. A third area extends as a broad dikelike mass from a point near the south end of Seal Cove to Perry Cove and thence westward along the shore of the Thorofare. A fourth and much smaller area extends southeastward from the eastern shore of Crockett Cove.

The rock of the southernmost area is mainly an olivine diabase which in places becomes coarse and gabbrolike. In the Barley Hill area the most common rock has a slightly different character and shows a transition in texture and in mineral composition from a diabase to a diorite, both kinds of rock being present. Igneous or flow gneisses are developed here much more extensively and more beautifully than in any other part of the quadrangle. Along the shore north of The Reach the rock consists of alternate acidic and basic bands of varying width, so irregularly associated that the mixture has much the appearance of "marble cake." This gneiss is evidently the result of differentiation, within the cooling magma, of acidic from basic constituents while a differential flow was in progress. The diabase in this vicinity is also cut by sheets and dikes of granite in such numbers that the darker rock almost loses its continuity in the labyrinth. Some of the larger dikes of granite can be traced for a considerable distance into the diabase area, the granite at the contact being porphyritic but becoming more granular a short distance away. Igneous gneiss is also well exposed on the point south of Calderwood Point. At the head of Arey Cove the contact between the granite and diorite is well exposed. On Arey Neck the seamed diabase weathers to a pitted surface and is also somewhat schistose in places. The granite is plainly intrusive, dikes and veins penetrating and inclosing masses of the darker rock. The fine-grained diorite of the Brimstone Islands also probably belongs among the granite border rocks. The area of basic rocks extending from a point near the south end of Seal Cove to Perry Cove and thence westward along the shore of the Thorofare, is mainly diabase, though locally a quartz diorite. It is plainly intrusive in the neighboring sediments and volcanics. The area southeast of Crockett Cove is mainly diabase and diorite with some igneous gneiss.

The whole eastern side of Isle au Haut and all of York, Spoon, and Fog islands is composed of diorite, diabase, and gabbro. These rocks grade into each other and in general are intrusive in the granite, a relation only rarely observed in other parts of the quadrangle. Dikes of the basic rocks cutting the granite may be seen in many places on the north shore of Isle au Haut. On the west shore of Marshall Island the pink fine-grained granite is cut by several diorite dikes, one of which is 40 feet across. On the south shore of Kimball Island a dike of typical diorite 10 feet wide cuts the granite. On Green Ledge, between Isle au Haut and Marshall Island, it is found, on the other hand, that the coarse gabbro which constitutes most of the ledge is cut by a broad belt of fine-grained gray granite which is plainly intrusive and gives off a number of branches. These apparently discordant relations are discussed further in the section on age.

On the mainland, between Little River and Ducktrap Harbor, the relations are different from any that have been described above. Before the intrusion of the granite this area was occupied wholly by sedimentary rocks, similar in all respects to those now found between Belfast Bay and Sandy Point. At the time of the granite intrusion the rocks of this tract, together with a much larger area to the west and southwest, were thoroughly injected with granite, diorite, gabbro, and flow gneiss, while the sedimentary rocks suffered much recrystallization, in many places with the development of andalusite, staurolite, garnet, and tourmaline, and here and there with the formation of injection gneisses. The areas here mapped as granite or as diorite are areas within which these are the dominant though not the only rock, and granite and diorite also occur in hundreds of places outside of these areas, but in amounts too small to map.

Petrography.—The diorite associated with the granite varies in texture from an aphanitic rock, such as that of the Brimstone Islands southeast of Vinalhaven, to rocks in which the hornblende crystals have a diameter of one-fourth to one-half inch. The most abundant variety is an even-textured rock in which the feldspars and hornblendes average one-sixth to one-eighth of an inch in diameter. The coarser varieties tend to be uneven in texture. The color ranges from greenish black in the finer grained specimens to mottled white and dark green in the coarser varieties.

Under the microscope the texture is for the most part typically dioritic, but here and there, in the coarser varieties, borders on the ophitic, large hornblendes inclosing a number of feldspar laths. Nearly all of the feldspar is andesine and it is as a rule very fresh. The hornblende is mostly dark green in color, though in a few places pale green and more rarely still pale brown. In most specimens it is very fresh but locally shows some chloritization. In the fine-grained and medium-grained rock the hornblende and feldspar grains are approximately equal in size; in the coarsest varieties the hornblendes are in general much larger than the feldspars, which in many places they inclose. Dark-brown biotite is commonly present only in small amounts, though here and there equaling the hornblende in abundance. Quartz is wholly absent from many of these rocks but in some, both of the fine grained and the coarse grained, it is abundant, though in the main subordinate to feldspar. Magnetite, titanite, and apatite are present as accessory minerals and epidote, chlorite, and calcite as decomposition products. A moderately coarse diorite from the northeastern shore of Isle au Haut is peculiar in the dominance of brown biotite over hornblende and in the fact that the feldspars are much more coarsely crystallized than the femic constituents. The titaniferous magnetite in this rock is characterized by broad alteration borders of titanite.

Some diorites occur which in megascopic appearance are intermediate between the normal diorite and the normal granite. Microscopically most of these rocks are found to contain quartz, andesine, and biotite as their chief constituents, hornblende being almost entirely absent.

Most of the gabbros are coarse-grained rocks showing reflections of hornblende and pyroxene crystals up to one-fourth or even one-half inch in diameter. They are as a rule mottled dark green and white on fresh surfaces and very rusty on weathered surfaces. In general these rocks are so highly decomposed that no pyroxene remains, and the rocks are classed as gabbros only from their general resemblance in texture and mode of occurrence to a few moderately fresh gabbros. They occur associated with the borders of the granite areas of Isle au Haut, Vinalhaven, and South Penobscot. In the South Penobscot area they are especially common.

One of the freshest specimens of gabbro occurs on the shore of Bagaduce River just east of Pumpkin Island. It shows under the microscope a granitic texture, with enstatite and pale-green to brown hornblende as its most abundant and coarsely crystallized constituents. Pale-brown biotite is also abundant and some olivine occurs in widely scattered, irregular grains, in general partially or completely inclosed by enstatite. Magnetite is distributed in irregular grains and aggregates through the olivine and the decomposed portions of the enstatite and hornblende grains. The feldspar is labradorite and in amount is very subordinate to the femic constituents. In most of the gabbro occurrences the rock is so altered that the feldspar areas assume a greenish tint and are not sharply separated from the areas of femic minerals. The pyroxene is as a rule wholly replaced by hornblende, which in turn is in many places bleached and partially decomposed, with the development of chlorite. Serpentinization has also occurred in some localities.

The diabases of this group are best developed on Vinalhaven. The typical rock in the southern part of Vinalhaven is an olivine diabase, which in a few localities becomes coarse and almost gabbrolike, the plates of purple augite being equally prominent with the feldspars. For the most part, however, the diabase is fine grained, gray when fractured, but black on a polished surface. Laths of feldspar can be distinguished, though rather small.

Microscopically the rock is seen to have the characteristic diabase texture, though in some portions the lath-shaped feldspars make up so large a percentage of the rock that the pyroxene is confined to rather small and interrupted interstitial spaces. The pyroxene is a nearly colorless diopside which in some specimens is much altered to hornblende but in many other specimens is almost perfectly fresh. Olivine is abundant in colorless, rounded grains, only slightly altered, and is the oldest of the essential constituents. Magnetite occurs in irregular growth forms and aggregates of grains. Small amounts of biotite are found associated with the magnetite and olivine. The lath-shaped feldspars, which show Carlsbad, albite, and pericline twinning, are chiefly basic labradorite or anorthite.

In the Barley Hill area of the eastern side of Vinalhaven the rock shows a transition in texture and mineralogical composition from a diabase to a diorite. A variety which in the hand specimen resembles very closely the olivine diabase described above shows the diabase texture microscopically, but carries no olivine and has brown hornblende and biotite in equal abundance with the pyroxene. The hornblende and augite occur together in complex intergrowths and also in separate plates. They evidently crystallized together. Magnetite is more abundant than in the olivine diabase. Other rocks of this area are more feldspathic and thus lighter in color, while the texture is more granular than diabasic. The feldspar is more acidic than in the diabasic types and the pyroxene has become less abundant. Biotite is the most important of the femic constituents and much of it occurs in idiomorphic plates. Hornblende occurs in both massive and fibrous forms. Both hornblende and biotite are somewhat altered to chlorite. The total amount of quartz is small, although it is concentrated in large, irregular areas; it was the last mineral to crystallize. Apatite is plentiful in long, slender needles which in many places penetrate several different constituents. Titanite is found associated with biotite.

Age.—The diorites, diabases, and gabbros are in general somewhat older than the granite. In the South Penobscot area dikes of granite, many of them more or less aplitic, are abundant in the diorite and on the north end of Wardwell Point occur in the gabbro. In this part of the quadrangle dikes of diorite or gabbro cutting the granite were nowhere observed. In a number of localities the granite becomes finer grained next to the diorite contact, but no similar changes in the diorite were noticed. The presence here and there within the peripheral zone of small bodies of igneous or flow gneiss, composed of alternate bands of dioritic and granitic composition and grading on the one hand into granite and on the other hand into diorite, shows, however, that in some localities the granite and diorite are contemporaneous. On Vinalhaven the relations are similar to those in the South Penobscot area. On Isle au Haut and the neighboring islands, however, basic rocks occur which are for the most part intrusive in the granite, although on Green Ledge, between Isle au Haut and Marshall Island, a broad dike of granite cuts coarse gabbro. In the adjoining Rockland quadrangle diorites are found to grade through less basic forms into the main body of granite.

These relations show that the basic rocks, although in the main slightly older than the granite and in a few places younger or exactly contemporaneous, belong to the same general period of igneous intrusion. As suggested by the general form of the basic zone in the South Penobscot area the basic rocks there may represent in part a peripheral differentiation from the same magma from which came the intrusion of the central granite mass. Like the granite, which immediately followed, the diorite, diabase, and gabbro are therefore of late Silurian or early Devonian age.

BASIC DIKES.

General description.—One of the most striking features of the Penobscot Bay region is the large number of dikes, dark green to nearly black in color, which cut every formation of the district. They appear in general to be about equally abundant in all parts of the region, though most numerously exposed along the shores. No system could be recognized in their arrangement, but the strike is commonly between northeast and northwest. These rocks are in the main massive and aphanitic, though here and there phanerocrystalline, and even porphyritic; some are amygdaloidal. Diabase is the rock type generally represented. Although averaging only about 2 to 3 feet in width, the dikes in places reach 20 feet or more, as on the north shore of Little Deer Island, just east of Eggemoggin, where a vertical dike has a width of 30 feet.

In spite of their prevailing lithologic similarity, their relations to the other rocks of the region show that they are not all of the same age. In many localities there are diabase dikes which have been deformed in the regional metamorphism and, in some places, have been rendered schistose. The most striking examples of deformed dikes are found a short distance west of the Penobscot Bay quadrangle, in the limestone quarries near Rockland, where dikes of diabase have been fractured and in some places "pinched out" in the close folding of the limestone. Some of the diabase dikes are closely associated with the diorites and gabbros of the granite border, and, like them, seem to be a product of differentiation from the granite magma. Diabase of this origin was observed only on Vinalhaven. Dikes of similar character occur in the southern part of North Haven, but here are much narrower, the broadest being only 20 feet in width. Some dark-colored dikes, not all of which are of diabasic composition, cut the granite, and in some places similar dikes are themselves cut by aplitic granite. Other dikes are plainly much younger than the granite and may represent Mesozoic intrusions.

Petrography.—What appears to be one of the oldest basic dikes of the region cuts the Ellsworth schist along the east shore of Flye Point. This is a light greenish-gray rock showing a schistosity which parallels that of the Ellsworth schist, but is less pronounced. Under the microscope this rock is found to be a fine-grained hornblende schist. Green, strongly pleochroic hornblende makes up over two-thirds of the rock, the grains showing strong dimensional arrangement and some tendency toward crystallographic parallelism. The hornblende grains, which vary greatly in size, are developed along certain bands to the exclusion of almost all other minerals, but between these hornblende bands some quartz and plagioclase occur. Magnetite occurs in small irregular grains arranged in rows parallel to the schistosity.

At the same locality occurs what is probably one of the youngest rocks of the region. It is black and aphanitic and occurs as a vertical dike about 1 foot in width, which cuts the Ellsworth schist, the schistose dike described above, and the granite. On microscopic examination, its most abundant constituent is seen to be basaltic augite, in prisms of various sizes and showing in many places zonal and hourglass structure. The color of the augite is light reddish to purplish brown, the purplish tint suggesting a small titanium content. Brown hornblende occurs in irregular or elongate crystals; biotite shreds are common; apatite occurs in prisms many of which are extremely elongate; and magnetite is rather evenly distributed in small grains. All these constituents lie in an isotropic groundmass whose index of refraction is less than that of Canada balsam. In view of the moderately coarse crystallization of so many minerals in the rock, it is improbable that the groundmass represents a glassy base. It is more probably analcite, though proof of this must rest on chemical analysis, material for which was not available. The rock is probably an olivine-free analcite basalt (fourchite). The only other rock found which at all resembles it occurs as a dike 2 feet wide cutting the sedimentary schists of the northern shore of Rockland Harbor. The principal mineral here is basaltic augite, as in the Frye Point rock, but olivine is also present. Hornblende and biotite are not developed and the amount of isotropic base is much smaller than in the older rock. It seems to be a true analcite basalt (monchiquite).

By far the larger proportion of the basic dikes of the Penobscot Bay region appear to be diabases, which even in the much-altered specimens show typical diabase texture. The lath-shaped feldspars are labradorite, which in the freshest specimens lie in a poikilitic matrix of augite and secondary hornblende. Most of the pyroxene has entirely decomposed to hornblende and chlorite, and some of it to chlorite alone. Decomposition of the feldspars has caused the development of muscovite with epidote or calcite, and leucoxene and titanite result from the decomposition of magnetite.

Diabase from the southernmost of the Hay Islands and from a few other localities is distinctly phanerocrystalline, showing labradorite laths up to one-eighth of an inch in length. The Rockland Harbor dike of analcite basalt described above and a dike of altered diabase on the northern shore of Little Deer Island, both contain amygdaloidal cavities that are filled with calcite. Diabase occurring between Dunham Point and Northwest Harbor on Deer Isle contains feldspar phenocrysts one-fourth inch in diameter, and a similar dike near Owlshead in the Rockland quadrangle shows phenocrysts up to one-half inch in length. In both places extensive weathering has made it impossible to recognize the character of the feldspars.

Age.—Most of those dikes which have been deformed in the regional metamorphism are nearly vertical in position and trend about parallel to the axes of the folds, a relation which suggests that they were intruded subsequent to a part of the movement but previous to the final folding. It is possible, and indeed probable, that this folding was accomplished in several distinct stages which were not widely separated. The date of the folding is fixed tentatively as Ordovician or early Silurian or both. Those dikes which are associated with the granite border are, like the granite, of probable Devonian age, while the dikes which cut the granite are Devonian or later. The freshness of the analcite rocks would suggest that they may be Mesozoic, and, with some of the diabase, they might with considerable probability be correlated with the Triassic eruptions of Nova Scotia and southwestern New England.

STRUCTURE.

Geologic study does not reveal in this region any well-defined structural features of the larger kind, such as anticlinoria, synclinoria, large monoclinal folds, faulted blocks, etc., but the very considerable areal extent of many of the sedimentary and effusive volcanic formations whose thicknesses are moderate indicates that in a broad way these formations are flat lying or only slightly inclined. Minor structural features, anticlines and synclines, can be observed in the various bedded rocks, and the character of these structures differs somewhat with the kind and relative age of the formation. In the pre-Silurian sediments the minor folds are in general closely compressed and often overturned, so that anticlines and synclines are distinguished only with difficulty. In the Ames Knob sediments and the overlying volcanic rocks the structure is monoclinal with gentle warping and small local faults. At no place in the quadrangle have important faults been detected, though faults of limited extent and small displacement can be seen in the shore cliffs. Undoubtedly many of these extend inland but can not there be detected owing to insufficient exposures.

Rock metamorphism is connected with these structural features. A difference in degree of metamorphism is evident between the pre-Silurian rocks and the Silurian and post-Silurian rocks. The older rocks have suffered structural and textural changes which conceal to a large extent the original characters. The Ellsworth schist as exposed within this quadrangle is crumpled, its constituent minerals are thoroughly recrystallized, and quartz bands and lenses have been developed within the rock mass, with the result that there remain in most places no sure traces of the original character of the rock. In the Castine and North Haven volcanic series both lavas and pyroclastics have been rendered schistose in part, and in the schists thus developed few of the original constituents have escaped complete alteration. The sedimentary rocks included in the Calderwood, Islesboro, Battie, and Penobscot formations all show to some extent the results of metamorphism. Although the dynamic action has rarely been sufficient to obliterate the traces of the sedimentary character of these rocks, yet in many places it is difficult to distinguish between true stratification and schistosity. In all these rocks there has been a large amount of recrystallization, whereby the shale and sandstone have been converted into slate or schist and quartzite, and the limestone has become thoroughly crystalline.

In the Ames Knob shale and limestone the relative absence of metamorphism is at once noted. The fossils are well preserved and nowhere is the stratification obscured. The overlying lavas likewise show the absence of any dynamic action such as has affected the older rocks. Quartz phenocrysts exhibit not the least trace of peripheral granulation or even undulatory extinction, proving conclusively that these lavas have not suffered the same dynamic metamorphism as the North Haven greenstone. The mineralogical changes in these rocks and in the later intrusives, mentioned in the petrographic descriptions, are largely those of weathering. These changes are nowhere so complete as to conceal the original composition of the rock and even the serpentine contains abundant remnants of olivine and the other original minerals.

This contrast in both structure and metamorphism between the older and younger rocks of the region is important in fixing the date of the greater part of the dynamic movements as pre-Niagara. In the absence of contacts between many of the formations the relative degree of metamorphism and of complexity of structure are the more important data on which correlations may be based. It is largely on such evidence that the Ellsworth schist is considered the oldest rock within this area. However, the relations deduced from these structural and metamorphic characters in nowise conflict with what can be proved in places where the formations are in actual contact.

In the structure sections the structures and relations observed on the mainland have been continued across the intervening water-covered spaces. At best these sections must be somewhat diagrammatic, and it is believed that the portions of the sections representing wholly concealed areas should show structures similar to those inferred from the results of the geological study in the adjacent areas.

A noteworthy structural feature of the Ellsworth schist is its flat-lying character and common direction of dip over considerable areas, especially in the northeast corner of the quadrangle. Here the formation must lie in nearly its original attitude, which is an unexpected relation in view of the extreme metamorphism shown by this rock.

The undoubtedly sedimentary formations of Islesboro and the mainland toward the west and north show structural features which are similar throughout and are the result of the same series of dynamic movements. These rocks have been thrown into a succession of folds whose general trend is about N. 30° E. in the southern part of Islesboro but in northern Islesboro and near Searsport and Stockton Springs swings to about N. 45° E. Superimposed upon these major folds are a large number of minor folds in the main of similar trend but locally oblique to the major folds.

The prevailing uniformity of materials within the sedimentary series on the mainland and the schistosity which has been developed in most places make it difficult to trace the individual folds and quite impracticable to work out the structural details, but on Islesboro the limestone and quartzite beds which are associated with the shaly sediments serve as indices in the determination of the structure.

A study of the Islesboro rocks shows that among the sediments there developed the Islesboro slate is the oldest and is overlain by the Coombs limestone member and this by the Battie quartzite. The relation of the whole Islesboro succession to the Penobscot slate of the mainland is shown on the eastern shore of Rockport Harbor, within the area of the Rockland quadrangle, where the conformable Islesboro slate and limestone and Battie quartzite are found to be overlain conformably by the Penobscot slate. The massive Battie quartzite, although affected by the major foldings, has resisted minor folding to a much greater degree than the other formations, and only in its more shaly portions is schistosity developed.

On southern Islesboro and the islands south of Islesboro the North Haven greenstone is found to be interbedded with and intruded into the Islesboro slate. The greenstone is therefore about contemporaneous with the sediments of the Islesboro series and must have been involved with them in the general regional metamorphism. Although here and there developing fairly perfect schistosity the greenstones show but little evidence of folding. This is due mainly to the massive character of most of the rocks, which has enabled them to resist the folding movements better than other rocks of the region, but also to the fact that there is difficulty in recognizing folds in rocks which do not show a regular sequence of beds. Schistosity is best developed in the tuffaceous varieties but to some extent also in the dikes, sills, and flows.

The field relations indicate that the Castine volcanics were erupted about contemporaneously with the North Haven greenstone. In many places these Castine rocks were so massive that they were little affected by the dynamic movements, but the abundant pyroclastic beds have in most localities developed a very perfect schistosity. As in the greenstones the folding has been much less regular and the folds are less easily traced than in the sedimentary series. Both the basic and acidic volcanics are in a broad way flat lying, though they show many minor irregularities due to folding.

The Ames Knob sediments rest upon the eroded surface of the North Haven greenstone and have not shared at all in the regional metamorphism which has affected all of the older rocks, a fact highly important in that it fixes the age of the period of the most marked folding and metamorphism as pre-Niagara. They have, however, been tilted so as to show on the island of North Haven southerly dips of 50°, 60°, or even steeper, and on Stimpson Island 30°. In the latter locality they are interbedded with the Thorofare andesite, but on North Haven the andesites overlie the Ames Knob sediments in apparent conformity.

Like the Ames Knob rocks, the Thorofare andesite shows evidence of only broad tilting, the beds dipping at angles of 50° to 80° toward the area occupied by the Vinalhaven rhyolite. The relations are also complicated by minor faulting, much of which may date back to the time of the volcanic eruptions of these lavas. The andesitic lavas seem to have given place gradually to those of rhyolitic composition, so that the two formations are wholly conformable. In the Vinalhaven rhyolite open folding and faulting have also occurred and dips of 45° or more toward the center of the area are common. The dips within both of these acidic volcanic formations are such as to suggest a broad, irregular southward-pitching syncline with axis trending about northeast and southwest and passing through the central portion of the area occupied by the Vinalhaven rhyolite. These Silurian lavas rest upon both the Calderwood slate and the North Haven greenstone with relations that show the extent of the erosion unconformity between the Silurian and earlier rocks. This, together with the marked difference in degree of metamorphism of the Silurian and pre-Silurian rocks, indicates a considerable time interval between the deposition of the Penobscot sediments and that of the Ames Knob formation.

Most of these formations are cut by the granitic rocks. In a few localities, as near Flye Point and and on the west side of Long Island, the bedding of the older rocks appears to have determined to some extent the trend of the intrusive contact, but more generally the granite cuts across the sedimentary and volcanic rocks irrespective of structure.

HISTORICAL GEOLOGY.

INTRODUCTORY STATEMENT.

The geologic history of this area is recorded in the harder rocks, the surficial deposits, and the forms of the land and is interpreted through the study of their characters. In the descriptive portions of this text the various types of rocks, as well as the structures developed in them, have been described. So far as the rocks are concerned, the geologic record is one of sedimentation, volcanism, and igneous intrusion. These processes of rock formation were supplemented by dynamic activity which affected the rocks both by metamorphism of their physical characters and by changes in their attitude. The later chapters of the history are more easily read and the record can be more faithfully interpreted, since the glacial and alluvial deposits with their characteristic topography remain relatively unmodified.

PALEOZOIC HISTORY.

SEDIMENTATION.

The oldest rock of the Penobscot Bay region is the Ellsworth schist, which represents sediments probably of Cambrian or even pre-Cambrian age. The deposition of these arenaceous sediments was followed by dynamic action sufficient at least to inaugurate the changes of impure sand into a crystalline schist. This metamorphism is believed to have begun before the deposition of the next younger formation, inasmuch as the Ellsworth schist exhibits a much greater degree of alteration than any other rock in the quadrangle.

The next epoch probably began in Cambrian time with the deposition upon the ocean bottom of muds and impure sands that are now represented by the Islesboro slate, with which the Calderwood slate is possibly to be correlated. This deposition presumably took place in moderately shallow water and not far from shore, but the position of the land masses which furnished the sediments is wholly conjectural. Gradually conditions became favorable for the deposition of the beds now represented by the Coombs limestone. Such deposits are probably indicative of clearer waters, in which lime-secreting animals could exist in abundance, and may have resulted in several ways—through a slight deepening of the water by subsidence of the sea bottom, through a decrease in the amount of erosion on the neighboring land areas, through drainage changes on the land which carried the bulk of the argillaceous sediments to some other part of the coast, or through a combination of one or more of these processes. The considerable amount of argillaceous material associated with the limestone, as well as the great variations in the purity of the limestone from place to place, may be taken as indicating shallow water and somewhat shifting currents.

The changes which closed the period of limestone deposition were more rapid and of greater magnitude than those at its beginning, and resulted in the deposition above the limestone of sands and gravels of considerable purity which are now consolidated to form the Battie quartzite. The conglomerate beds of this quartzite show a somewhat impure quartzitic matrix in which are embedded pebbles of very pure quartzite. The fact that most of these pebbles are well rounded indicates that the rock from which they were derived was itself a well-indurated sandstone or possibly a quartzite. The massive quartzites have a composition about like that of the matrix in the conglomerates. Presumably these rocks represent shallow water or beach deposits which were subject to the sorting action of waves and currents. No quartzite beds which could have served as the source for such deposits are known in this part of the State, though they may occur buried beneath later formations.

The parent formation need not have been wholly or even largely of quartzite, for the assorting and disintegrating action of waves and currents would suffice to separate more resistant quartzitic portions from less resistant shaly or calcareous materials. Certain beds, however, must have been very pure quartzite in order to furnish the clean, pure pebbles characteristic of the conglomerate.

After the deposition of the Battie sands and gravels conditions for the deposition of muds were again restored and very extensive deposits were laid down, which are now represented by the Penobscot slate, the most widely outcropping and the thickest formation of the region. The change is probably indicative of slight but long-continued subsidence. Within the adjoining Rockland quadrangle these muds were succeeded conformably by thick deposits of limestone, which is now thoroughly crystalline and of great economic importance in the production of lime. The presence of beds of limestone conglomerate at various horizons within this limestone formation indicates a shallow-water origin.

VOLCANIC ERUPTIONS.

While the sedimentary formations mentioned in the foregoing paragraphs were being laid down, volcanic activity was also in progress and gave rise to the Castine volcanics and the North Haven greenstone. Erosion early destroyed, however, all traces of the volcanic craters from which the flows, tuffs, and dust of these deposits came. They may have formed small islands lying some distance off the coast or may have been features of a larger land area lying to the east of a bay or sound in which the above-described sedimentary deposits were laid down. The volcanoes from which the North Haven greenstone was erupted were active during the time when the Islesboro slate was being deposited. Volcanic dust and ash from these craters falling into the sea or washed down by streams became intermingled and interstratified with the muds derived from the neighboring lands. The eruptions seem to have ceased before the end of the deposition of the Coombs limestone, for the overlying quartzites and slates contain no traces of volcanic material.

While this extrusion of basic volcanic material was going on in the neighborhood of North Haven, rhyolitic and andesitic material was being erupted from centers lying farther to the north, probably in the vicinity of Castine, Cape Rosier peninsula, and Little Deer Island. Here also erosion has destroyed all traces of the original craters, but they were probably within or near the area where these rocks now outcrop.

DYNAMIC ACTION.

After these volcanic eruptions and the deposition of the Penobscot slate and the thick beds of limestone which occur on the mainland near Rockland and Rockport the whole region was affected by severe dynamic metamorphism. The trend of the folds indicates that the thrust which produced them was directed nearly at right angles to the trend of the present coast line; presumably it came from the southeast.

How long an interval elapsed between the close of the sedimentary deposition here recorded and the beginning of the period of metamorphism is unknown. It was probably long enough, however, to allow the sediments to become very well consolidated, for it seems probable, from the relatively small amount of deformation which the rocks of the Battie formation suffered, that they were already well-indurated quartzites before the folding began. The pelites seem to have been shales rather than clays at the time of the folding, and the limestones behaved as moderately rigid bodies within this area. Farther east the folding appears to have been more intense. The duration of the period of dynamic metamorphism is equally a matter of uncertainty. It may have been a single continuous period of crustal movement or a succession of shorter periods separated by intervals of quiescence.

NIAGARA SEDIMENTATION.

The period of metamorphism was followed, at least in the vicinity of North Haven, by an erosion interval of unknown duration, at the close of which the land sank and the beds of limestone bearing a rich Niagara fauna were laid down upon the eroded surface of the North Haven greenstone. These fossiliferous beds furnish almost the only basis for determining the age of the rocks of the Penobscot Bay quadrangle. The Penobscot slate, the sediments of Islesboro, the North Haven greenstone, and the Castine volcanics are all separated from the Ames Knob sediments by an erosion interval and a period of dynamic metamorphism of unknown duration. It follows, therefore, that these pre-Niagara rocks are at least as old as Ordovician and are probably still older.

RENEWED VOLCANIC ACTIVITY.

An increase in the amounts of silt contributed to the sea terminated the deposition of the Ames Knob limestone, and at the same time was initiated the series of volcanic eruptions that are recorded by the flows, tuffs, and breccias termed the Thorofare andesite.

In any attempt to picture the nature of the volcanism that characterized this area in Niagara time, the position of the volcanic center should be determined. It would be of interest to know the vent through which the lavas were poured forth and the fragmental material ejected. However, it is probable that the area of Thorofare volcanics described above is not more than a fragment of the original area, and that through the processes of erosion, many times repeated, the greater part of the volcano has been cut away. In the study of this small area no definite comparisons of the relative thicknesses of the volcanic series can be made, such as would point to the position of the volcanic center. The breccias so prominent among the Thorofare rocks are somewhat agglomeratic in character, but their distribution is too general to indicate accumulation within a crater. Topographically Ames Knob is suggestive of an old volcanic plug, but the relations of the rocks there do not justify such a view. Thus the evidence obtained in the study of these old volcanics does not warrant even conjectures as to the site of the vent.

The rock characters of these volcanics give some indication of the conditions under which they had their origin. The character of the crystallization in the andesites is expressive of consolidation at the surface and the flow structure shows that these lavas consolidated while in motion. The amygdaloidal character of several of the lava flows resulted from the expansion of escaping gases in the molten mass, while the intercalation of beds of tuffs with the amygdaloids shows that, at times, these gases became explosive and the eruption of lavas was interrupted by the ejection of lapilli and volcanic dust, which were deposited upon the flanks of the volcano. The flow breccias that have been described may be considered as having their origin in the mingling of two lava streams of different eruptions. In these flow breccias the included blocks and the matrix may be quite different in character, masses of the gray andesite being commonly embedded in the red andesite which in many places shows flowage around and between these included blocks. In other places the lava blocks have been cemented by tuff material or by volcanic mud. The volcanic conglomerate is composed of less angular fragments, and more varieties of lava are represented within a given mass of the conglomerate than in the breccia. These differences may result from the transportation of the fragments by running water for limited distances down the slopes of the volcano.

The absence of metamorphism in these volcanic rocks, other than a partial alteration of some mineral, not only permits fuller interpretation of the conditions of this formation than is possible in the case of the Castine and North Haven volcanic rocks, but it shows in a striking way the difference in age.

Just as the tuffs furnish indubitable criteria for establishing the volcanic nature of the series, so they also afford the best evidence with regard to the topographic features of this part, at least, of the volcano. Many of the tuffs seem to have originated simply as subaerial deposits upon the gentle slopes of older lava flows, but others may have been deposited in a body of water. In some the sorting of the different-sized grains and the banding of successive beds is as perfect as in any thin-bedded shale or sandstone. However, the fragments of minerals and lavas are as angular as in the subaerial deposits, showing the absence of long-continued wave action. On Iron Point, where the bedding of the tuffs is best exhibited, the beds of finer tuffs are in many places eroded on their upper surfaces, the succeeding beds showing slight local unconformities. Such erosion breaks in the beds are only a few feet in extent and have resulted probably from wave action along the tide flats. An overlying conglomerate has well-rounded pebbles and is thus an ordinary sediment, marking an interlude in volcanic activity. The conditions here, however, do not seem to have been favorable for marine life, as was the case when the sediments occurring within the volcanic rocks on Stimpson Island were deposited. The pyroclastics and other sediments show that this volcanic region was near sea level and oscillated more or less during the period of eruption.

The andesitic eruptions grew gradually less and less frequent, while at the same time, probably from neighboring vents, the rhyolitic lavas and pyroclastics of Vinalhaven and Isle au Haut began to be erupted. No one who is at all familiar with modern volcanic phenomena could fail to recognize, from general appearances alone, the volcanic origin of these deposits. The landscape at the time of this igneous activity was probably much like that of coastal regions in which volcanism of a mild type is to-day in progress.

GRANITIC INTRUSIONS.

It is probable that the volcanic activity ceased before the close of the Silurian, and perhaps it did not outlast Niagara time. After its close gentle folding and some faulting occurred which brought the Silurian sediments and volcanics into about their present attitudes. Then followed the great intrusions of diorite and granite. The transfer of these masses of molten rock from deeper portions of the earth's crust into these essentially surface formations was an event of great geologic importance. Not only were the intruded rocks metamorphosed somewhat by the hot vapors given off by the intrusive magma, but adjacent portions of the sedimentary strata or volcanic sheets were so widely displaced by the masses of igneous rock thus introduced that their subsequent position can not be determined. The amount of contact metamorphism, however, is less than might be expected.

The age of this intrusion is not known from phenomena observed within the Penobscot Bay quadrangle, but granites that are in all probability contemporaneous, in the Perry basin of eastern Maine and in New Brunswick, have been proved to be of Siluro-Devonian or early Devonian age. Together, the extensive granite intrusions constitute the most important geologic event in this region in Paleozoic time.

The scattered dikes of analcite and analcite basalt and some of the diabase dikes represent later intrusions than that of the granite. Locally some faulting has occurred which involves these later dikes; thus on the west shore of Bagaduce River opposite Johnson Point a basic dike in the granite is offset a dozen times by a series of small transverse faults.

QUATERNARY HISTORY.

The geologic record furnishes little clue to the events which took place in this region during the whole of Mesozoic and Tertiary time, but by the beginning of the Quaternary period the familiar processes of subaerial erosion had reduced the land surface to about its present topographic form. The record begins again with the effects produced by the great ice sheet which radiated in Pleistocene time from the region east of Hudson Bay. The evidences of its presence are found in the deposits of glacial till and gravel and in the polished and striated surfaces, which are abundant even in the outermost islands. The general trend of the striæ is about S. 20° E., though their direction may vary as much as 20° on either side of this average. The great ice sheet advanced slowly from the north until it covered the whole of the State; then, after an interval of unknown duration, it began a slow retreat. It can not be positively asserted that there was only one invasion of this region by the glaciers, but there is no evidence, either from divergent sets of striæ or from dissimilar drift sheets, to lead to the opposite conclusion.

The height of the land at the time when the region was completely covered by the ice is not certainly known, but during the retreat of the ice the land stood for a brief period about 240 to 250 feet below its present level. This is shown by the occurrence on Isle au Haut (Stone, G. H., Mon. U. S. Geol. Survey, vol. 34, 1899, p. 48) of beach gravels up to a height of about 225 feet, while between 250 feet and the highest point on the island (550 feet) not one water-washed stone was found. No cliffs of erosion were observed on Isle au Haut above the present beach, but on the projecting angles of the hills (which would be capes when the sea stood at high levels) the till was extensively denuded. Similar phenomena have been observed in other exposed localities on the coast.

From this submerged position the land rose to nearly its present elevation, some stages of the uplift being recorded in the marine terraces which are a characteristic feature of the coast. The lower terraces are well developed at nearly all parts of the coast, but the upper ones are developed, within this quadrangle, only at the south end of Sears Island. At this locality terraces occur at elevations of approximately 80, 60, 30, and 12 feet above present mean tide. The upper two are very narrow, the 30-foot level broader, and the 12-foot level the broadest of all. On Cape Jellison, one-half mile north of Squaw Point, the lowest terrace forms a sea cliff rising 13 to 15 feet above mean tide, and from this level slopes inland at an inclination of 2° to 3° for 200 yards, to a point where a steeper slope begins. The material is till, the upper portions being somewhat assorted by wave action.

Certain features of Ames Knob, at the west end of the island of North Haven, are noteworthy (Willis, B., Bull. Geol. Soc. America, vol. 14, 1903, pp. 201–206). These include a wave-built bar standing about 65 feet above the present sea level and composed of small pebbles some of which are thoroughly waterworn, while others preserve glacial striæ and thus prove the bar to have been of postglacial origin.

Throughout the Penobscot Bay region the best defined and most widely developed terrace has an elevation of 20 to 25 feet above the present sea level. In general the terraces are built terraces, whose materials are marine clays and sands; only in a few of the more exposed positions have wave-cut terraces been developed.

The history recorded by the facts outlined above may be summarized as follows: (1) On the withdrawal of the ice from the immediate vicinity of the coast the sea, for a short period, stood as much as 240 to 250 feet above its present level; (2) during the time when the ice was still not far removed from the coast, and was contributing to the sea large amounts of sands and clays, rather a rapid uplift was in progress; (3) this uplift was not regular but was interrupted by short periods of quiescence during which wave-cut and wave-built terraces were developed; (4) the better development of the lower terraces, indicates that in the later stages the uplift was slower than in the earlier; (5) the lowest terraces were probably developed after the ice had completely withdrawn from the region; (6) uplift may still be in progress.

From the considerations outlined above, it is apparent that the land has not stood at its present elevation for a very long time, although the present period of relative quiescence seems to have been much longer than any of the halts recorded by the marine terraces or related phenomena. Rock-cut cliffs, barrier beaches, spits, bars, and hooks are almost wholly absent at the higher levels but are common features of the present shore line. The net result of the development of such shore features is to straighten and simplify the coast line, but as yet the results of the process are insignificant.

On the land, post-Pleistocene erosion has been at work in removing the drift obstructions which gave rise to the multitude of lakes and marshes. Filling by sedimentation and by the growth of peat has conspired with a cutting down of outlets to convert the lakes into swamps, and similar processes have tended to convert the swamps into dry land. The abundance of lakes and swamps at the present time shows that these agents have as yet accomplished little.

ECONOMIC GEOLOGY.

GRANITE.

Output.—According to the statistics for 1906 compiled by the United States Geological Survey, Maine ranks third in the list of granite-producing States, Massachusetts being first and Vermont second. The output of the State, valued at $2,560,021 in 1906, is about one-ninth of the total granite production of the United States. Of the total Maine output nearly one-third is produced by the quarries of the Penobscot Bay quadrangle, so that the granite industry of this area is of considerable importance.

Of the production of this quadrangle for 1905 a little over one-half was in the form of dressed granite for building, about one-third was rough building stone, and about one-eighth was in the form of paving blocks; the remainder was for monumental purposes, curbing, "random" stone, "riprap," etc. The quadrangle produced over half of the rough building stone quarried in the State, over one-third of the paving, and over one-fourth of the dressed building stone.

The principal markets for the Penobscot Bay granite are Boston, New York, Philadelphia, and Washington. Each of the larger quarries has furnished the dressed granite for many large and well-known buildings in these cities, and a few buildings have been erected of this granite in Chicago, Milwaukee, St. Louis, and other western cities. Contracts that are now being worked on include the New York bridges, the custom-house in New York, and the Naval Academy at Annapolis.

The value of this industry to the community is not fully expressed by the mere statement of annual production. It is necessary to add that labor receives over 80 per cent of the value of the product of these quarries.

The general distribution of the granite is discussed in the section on descriptive geology. The most important belt, economically, extends from the southern part of Brooklin southwestward across Deer Isle to Vinalhaven and includes the Stonington, Crotch Island, Vinalhaven, and Hurricane Island quarries. Deep-water channels suitable for the largest coasting vessels extend to the very edge of the quarries, so that the largest blocks of granite can be loaded directly upon the vessels which are to take them to the large cities of the Atlantic coast. Thus the cost of transportation is reduced to a minimum.

Description.—The character of the granite in different parts of the region has already been described. The grain ranges from fine to coarse, although most of the rock quarried might be termed medium grained, the feldspars averaging from one-eighth to one-fourth of an inch in diameter. It is worthy of mention, as showing the uniformity of the granite in both color and grain, that often work on the same contract is done at quarries several miles apart. The dark segregations or "knots" and the aplite dikes which are present in the granite at some localities are as a rule not common enough to affect the amount of clear stone available in the quarries. The basic "knots" seem to be most abundant in those varieties of the granite which are somewhat too coarse grained for commercial use. The granite is remarkably free from pyrite and other mineral constituents which can produce stains on exposure, as is shown by the slight amount of discoloration in the weathered surfaces. The amount of weathered rock on the surface is very slight, so that very little work is necessary to open a quarry, even the surface blocks being used at many places.

Most important features affecting the granite industry are the distribution of joints in the rock mass and the direction of the rift or plane along which the granite splits most readily. In the vicinity of Stonington the direction of the rift varies through nearly every point of the compass, but the principal joints range from N. 50° W. to east and west. The "bottom" or nearly horizontal joints are conspicuous features in many of the quarries. The spacing of these parting planes in the rock determines the kind of work for which each quarry is especially adapted. In a few quarries in the Penobscot Bay district the joints are so close together that only material for curbing and paving blocks can be quarried, while in many other quarries exceptionally large blocks suitable for monoliths can easily be taken out. Examples of these are given in a later paragraph.

Equipment of quarries.—The largest of the granite quarries of the Penobscot Bay district are those in the vicinity of Stonington and Vinalhaven, including the Crotch Island and Hurricane Island quarries. Several of these quarries doubtless rank as the largest in the United States, the more extensive quarry openings including areas of 5 to 8 acres with an average depth of nearly 30 feet. The six largest quarries at Stonington and Vinalhaven have an aggregate area of more than 30 acres, with available stone covering many times that area.

These larger quarries are well equipped for a large output of both rough blocks and dressed granite. The plant of the Bodwell Granite Company at Sand Cove, on Vinalhaven, has an equipment comprising traveling cranes, lathes, pneumatic hand tools and plug drills, in addition to the usual number of derricks, hoisting engines, steam drill, and surfacers necessary for a large quarry. At this company's Palmer quarry, at the mouth of Long Cove on the same island, there is a giant lathe which will turn a monolithic column 70 feet in length and 7 feet in diameter. The columns for the Cathedral of St. John the Divine in New York City were turned in this lathe. The rough blocks for these columns measured 60 by 6 by 6 feet, and weighed about 185 tons. One of these huge blocks was successfully turned in the giant lathe, but split after being finished and removed from the lathe. On this account the columns were turned in two sections.

The Rodgers quarry on the east shore of Webb Cove, in Stonington, is also equipped with both steam and pneumatic drills, pneumatic surfacers, 9 hoisting engines, 10 derricks, a 10-ton crane, and a railway and locomotive. On Crotch Island the Ryan-Parker Construction Company operates a large quarry with extensive dressing sheds, full steam and pneumatic equipment, and a railway running to the two docks and through the entire length of the quarry. John S. Goss has a well-equipped quarry adjoining the Ryan-Parker quarry, and also one on Moose Island, on the opposite side of Deer Island Thorofare.

The topographic features of the granite coast of this region are such as to facilitate quarrying operations. Most of the quarries are opened on the slopes of hills rising directly from the shore, so that, although the older quarries have been operated for twenty-five to fifty years, the present conditions favor continued production without increase in expense. The larger part of the equipment of these quarries, therefore, is devoted to the finishing of the product rather than to the quarrying of the granite blocks.

For a more extended account of the granite resources of this quadrangle see Bulletin No. 313, U. S. Geol. Survey, by T. Nelson Dale.

LIMESTONE.

Limestone belonging to the Islesboro formation is not at present utilized, but in the past it has been quarried and burned for lime at two points on North Islesboro. At Limekiln Landing, on the northeastern shore of the island, an area about 100 feet in diameter has been excavated to a depth of about 30 feet. Much of the rock shows shaly bands and even the best rock obtainable contains some quartz, pyrite, and mica. The quantity of limestone is small, and the rock may be expected to decrease rather than to increase in purity with depth. No. 1 in the table below is a partial analysis of the best limestone obtainable at this quarry.

The second locality at which the limestone was formerly worked is on the northern shore of Seal Harbor. Here there is a hillside excavation about 40 feet in maximum depth and about 200 feet across. The limestone is practically the same as that at Limekiln Landing and in many places is shaly. Its total thickness does not appear to be much more than 50 feet, the rather considerable width of outcrop being the result of repetition through folding. As at the other quarry, the rock is a calcium limestone effervescing freely with dilute acid; its analysis is No. 2 of the table below. At neither of these two localities nor at any other place on Islesboro does there appear to be any warrant for further development of the limestones.

Partial analyses of limestone from Islesboro, Me.

	1.	2.
Calcium oxide	51.30	43.07
Magnesium oxide	1.16	7.82
Silica	3.76	2.76
Alumina	1.03	1.18
Iron oxides	.43	.55

1. Best quality of limestone from quarry of Limekiln Landing, Islesboro. W. T. Schaller, analyst, U. S. Geological Survey laboratory.

2. Best quality of limestone from quarry at Seal Harbor, Islesboro. W. T. Schaller, analyst, U. S. Geological Survey laboratory.

Lime Island, about 2 miles southwest of Islesboro, is made up largely of limestone. This is purer than any which occurs on Islesboro but is so highly magnesian that it does not effervesce at all with dilute acid. At present rock of this composition finds a market only for pulp-making purposes. Considerable amounts of greenstones are associated with the limestone here and would be a serious hindrance in quarrying. These facts and the absence of any protected harbor make it very doubtful whether the rock can be profitably worked.

SERPENTINE.

A considerable amount of serpentine has been obtained in the past from a quarry on the northeastern shore of Deer Isle, but for almost twenty years this quarry has remained unworked. The rock here is fine grained, massive, and dark green to almost black in color; in places it is cut by a multitude of minute veins of calcite. Its lithologic characters and mode of occurrence have already been described in the section on descriptive geology. The serpentine was sawed into slabs for window-sills, doorposts, doorsills, etc., but the work was soon abandoned because of the liability of these blocks to split along joint planes while in the shops or even after they were placed in position in a building. The color is too somber for ornamental uses, but the rock seems durable and well adapted for certain general building purposes in which large pieces are not required (Merrill, G. P., Stones for Building and Decoration, p. 60). In view, however, of the abundance of granite in the region it is doubtful whether the rock will ever be utilized in this way.

COPPER ORE.

Twenty-five or thirty years ago copper mines were operated in Bluehill and Brooksville. The ore extracted at that time appears to have been largely chalcopyrite, which occurs in association with quartz, muscovite, and pyrite, as well as galena and sphalerite. These mines were all abandoned later, but the ruins of shaft houses, mills, and smelters which remain mark the sites of this activity and indicate the scale on which the mining work was conducted. The shafts were all filled with water at the time the geologic field work was done, so that the present knowledge of the ore deposits of this area was obtained from observations on the material in the mine dumps and on rock exposures in the vicinity.

The Twin Lead, Bluehill, Bisbee, Phœnix, and Douglas mines are some of the old properties situated nearly 2 miles southwest of Bluehill village. The country rock is the crumpled Ellsworth schist, with the usual strike somewhat east of northeast and steep southerly dip. The sulphides occur in stringers and seams of quartz which parallel for the most part the schistosity of the inclosing rock. The proportion of quartz stringers at some points is such as to give the schist a gneissic appearance. At other places the sulphides impregnate the schist, and this material appears to have been mined at the Bluehill mine. The character of these deposits and their geologic relations suggest that their origin was connected with the intrusion of the granitic material, granite dikes occurring in the immediate vicinity and the contact with the large granite area being about a mile distant. At the Twin Lead mine the workings included a three-compartment incline; on the Bluehill property there are several abandoned shafts; and at the Douglas mine ore was mined in both shafts and open cut. Recent reports are to the effect that the underground workings of these mines will be pumped out and the attempt made to work these ores under modern metallurgical processes. Until such explorations and tests are made, no estimate as to the value of these deposits is justified.

At Brooksville work has recently been done on somewhat similar deposits from which it is reported shipments were made twenty-five years ago. The country rock here is the Castine formation, the deposits being near one of the dikes or intrusive masses of dioritic rock which are common in this vicinity.

Many other mining prospects were opened within the area of this quadrangle at the time the interest was at its height. Most of these were located in the towns of Bluehill, Penobscot, Brooksville, and Castine, and were usually described as showing copper ores. The Eggemoggin mine on Byard Point in Sedgwick and the Deer Isle mine on Dunham Point were reported as producing silver ore.

CLAY.

The only clays of commercial importance in this region are the marine clays, whose general appearance and mode of occurrence have already been described. Within the area of the Penobscot Bay quadrangle they are at present utilized in the manufacture of common brick at South Penobscot, Penobscot, and West Penobscot, though in the past they have been worked at a number of other localities on the mainland. At the works in South Penobscot, which are the largest in the quadrangle, the clays are gray in color and about 20 feet thick. The total output of common brick for the quadrangle in 1906 was valued at $11,902. At all three of these yards the clay is worked by the soft-mud process and burned in old-fashioned scove kilns, the product being a bright-red brick of good quality and appearance. Shipments are made mainly to Boston and vicinity, though a part of the product goes to other coast towns.

Several small works for the manufacture of common brick are located along the west shore of Penobscot River just north of this quadrangle, and farther down the coast at Thomaston, Damariscotta River, and other points. In the absence of analyses of clays from the Penobscot Bay quadrangle, the following from the adjacent Rockland quadrangle are inserted:

Analyses of clays from Rockland quadrangle, Maine.

	1.	2.	3.
Silica (SiO_2)	62.80	62.33	61.59
Titanium oxide (TiO_2)	.87	.79	
Alumina (Al_2O_3)	17.36	17.70	19.10
Ferric iron (Fe_2O_3)	4.40	5.19	7.53
Ferrous iron (FeO)	[1]2.00	[1]1.72	
Lime (CaO)	.88	1.00	1.68
Magnesia (MgO)	1.58	1.53	1.87
Soda (Na_2O)	1.48	2.38	
Potash (K_2O)	3.05	2.41	
Water (at 107° C.)	1.31	1.11	
Water (on ignition)	4.39	3.81	5.51
Carbon dioxide (CO_2)	None.	None.	
	100.12	99.97	97.28

[1] The values reported for ferrous iron are questionable on account of a small amount of organic matter.

1. Clay from brickyards at Thomaston, Me. W. T. Schaller, analyst, U. S. Geological Survey laboratory.
2. Clay from Hayden Point, near South Thomaston, Me. W. T. Schaller, analyst, U. S. Geological Survey laboratory.
3. Clay on the property of the Rockland-Rockport Lime Company, near Rockland, Me.

Although these three samples were taken at localities several miles distant from each other, their analyses are closely similar, a fact which suggests that throughout this region the clays possess a rather uniform composition. It is probable, therefore, that the clays of the Penobscot Bay quadrangle correspond very closely to these analyses. From the chemical analyses and also from a microscopic examination it is seen that these are not what could be called "sandy" clays, though the amount of sand is sufficient to obviate the necessity of adding any in mixing for brickmaking. In a comparison of several hundred analyses of brick clays (Ries, Heinrich, Final Rept. State Geologist of New Jersey, vol. 6, 1904, p. 55) the silica has been found to range from 34 to nearly 91 per cent, with an average of about 59 per cent. The Penobscot Bay specimens are only slightly above this average.

The percentage of iron is fairly constant and is sufficient to give to the burned bricks a bright-red color. The average for brick clays is about 5 per cent. The absence of calcium carbonate, shown by the absence of CO_2 in analyses 1 and 2, is a desirable feature, as is also the rather high percentage of alkalies. The latter are the most important fluxing constituents of the clay and on burning serve to bind the constituent grains together. If, as in this case, their quantity is large, the brick may be burned at a lower temperature than otherwise.

The clays, in common with the granite of this quadrangle, possess the commercial advantage of proximity to the coast, where the manufactured product can be easily and cheaply shipped by water. Their quality, their abundance, and their favorable situation seem to justify a more extensive commercial development.

SOIL.

The soils of the Penobscot Bay quadrangle are mainly of glacial origin, modified to some extent by postglacial accumulations of humus. Over much of the region the coating of surface materials is very thin. This is especially true on the islands, where very little of the land is suitable for agriculture, although much of it furnishes excellent pasturage. The most fertile areas are probably those covered by glacial till, but the abundance of bowlders in many places makes the original clearing of these areas a difficult task. The lowlands covered by marine clays are in general much less fertile, although they are extensively cultivated. Their surfaces are free from bowlders and the labor of clearing the land is much less than on the till-covered areas. The lesser fertility seems to be less a matter of chemical composition than of texture, for in wet seasons the crops on the clay areas are frequently much delayed because of the slowness with which the ground absorbs the excess of moisture.

WATER.

The present water supply of the Penobscot Bay region is derived almost exclusively from underground sources, the surface waters from lakes and streams being little used except for stock-watering purposes. The larger part of the supply, especially for domestic use on the farms, is obtained from ground water in the surficial deposits. Wells of this kind are commonly very shallow and many of them are located on low ground. The quality of the water obtained varies from excellent to very poor, such wells being liable to contamination from barnyard and other sources. Those located wholly within deposits of glacial till usually yield a moderate supply, but are in danger of failing during a dry summer. The same danger from drought is experienced in wells located wholly in deposits of marine clay. The best supply is in general obtained from the gravels or sands which may overlie the marine clays, the till, or solid rock, the principal flow usually being found near the bottom of the deposit. In a few localities gravels underlie marine clays, and a good water supply is obtained by penetrating the clays to the gravel. Some wells of this kind overflow when first dug.

Springs are rather abundant in this quadrangle and are most numerous on hill slopes, especially at the contact between gravel or sandy till and underlying clay or solid rock. Most of them are subject to much seasonal variation, and only a few survive a severe drought. One of the finest springs is located near North Bluehill and is owned by the Bluehill Mineral Water Company. An analysis of this water by W. P. Mason is given below. The flow averages about 6 gallons per minute.

Analysis of spring water from North Bluehill, Me.

	Parts per million.
Calcium carbonate	25.16
Magnesium carbonate	6.09
Ferrous carbonate	6.62
Manganous carbonate	.45
Calcium sulphate	5.61
Sodium sulphate	5.33
Sodium chloride	5.00
Sodium nitrate	.91
Potassium chloride	9.90
Alumina	1.89
Silica	20.56
	87.52

There is a growing tendency in this region to utilize the ground water stored in the solid rock, and a large number of wells have been drilled to various depths down to 675 feet. These are mostly located at elevations of less than 100 feet and their yield varies greatly; some are very successful and a few are failures. From most of them the supply can be obtained only by pumping, though the water usually rises in the well above the level at which it is first struck. A single well at Sabbathday Harbor is free flowing. Many of the islands occupied by summer residents are nearly free from lakes and streams and from surficial deposits, and in such localities the ground water in the rocks is practically the only source available. It becomes of vital importance, therefore, to know something of the conditions controlling this supply.

The prevailing rocks over much of the quadrangle are massive granites and diorites, and the rocks of the rest of the quadrangle are much folded and metamorphosed sediments and volcanics which are compact and well cemented. The physical character of these rocks and their structures are plainly quite different from those observed in typical artesian basins; in no strict sense can it be said that there is present a porous stratum between impervious strata, neither is there any approach to basin structure. However, that artesian water exists in this area is proved by the flowing well at Sabbathday Harbor and by other deep wells which do not flow but in which the water encountered is under static pressure, as evidenced by the rise within the well. Essentially, then, the water supply of these deep wells is of the artesian type—that is, the water rises within the drill hole for 20 feet or more above the level at which the drill tapped its flow.

In rocks so massive as the granites and diorites of this quadrangle and so thoroughly cemented as the sedimentary and volcanic rocks, the circulation of the ground water must take place largely along fracture planes rather than through pore spaces. The fractures may follow joint planes and planes of bedding and of schistosity, but in the granitic rocks the joints are practically the only openings. The development of artesian pressure in such rocks must be dependent on the distribution of the fracture planes and on differences in the readiness of water circulation along different sets of fractures. It involves (1) greater ease of circulation at considerable depths than near the surface, and (2) the existence of certain channels for the transfer of water from higher zones to the deeper circulation, thus producing a "head."

One of the simplest ways in which the above-named conditions may be fulfilled is where an inclined fracture zone in the rock serves both as the deep-seated zone of easier circulation and as the channel for the transfer of water from higher to lower horizons. The fracture zone becomes filled with ground water, and is tapped by a well that has passed through a considerable thickness of relatively impervious rock; the water then rises in the well nearly to the level at which it stands in the fracture zone.

A relatively impervious cover may result in at least two other ways—(1) by more complete cementing of the fracture planes in the upper horizons than in the lower, and (2) by greater ease of circulation along nearly horizontal fractures than along those which are highly inclined. Either of these conditions, if supplemented by the existence of a few inclined channels for the passage of water from higher to lower levels, may result in artesian conditions of water confined under "head." The study of ore deposits has shown that the filling of fractures by cementation or the deposition of minerals from water solutions goes on more rapidly in the upper part of the ground-water zone than in the lower part. Cementation of this kind is known to have taken place in the sedimentary and volcanic rocks of this quadrangle and may be an important factor in the production of artesian pressure. Greater ease of circulation along nearly horizontal fractures than along those which are highly inclined has not been proved for any of the rocks of this region but may be an important factor, especially in the granite, where flat-lying joints are very numerous. The weight of the rocks themselves would tend to close the flat-lying openings, but this effect may be offset by lateral pressure, as is explained in the next paragraph.

The water conditions throughout the granite-diorite areas are typified by those encountered in the vicinity of Stonington, where in drilled wells 5 to 6 inches in diameter sunk to depths of 50 to 150 feet the water rises within 10 to 20 feet of the surface, or even higher, and a steady supply of 1 to 3 gallons per minute can be procured by pumping. In the well of the Pine Rock Water Company, sunk to a depth of 183 feet, a flow of 28 gallons per per minute is reported. The depth at which the principal flow is obtained varies from 12 to 180 feet. The fact that in almost all wells drilled in granite the water is under a pressure which causes it to rise in the well hole when struck proves that that there are masses of the granite which are practically impervious to the flow. They are surrounded by fissures, more or less inclined, which are full of water; and when the drill, having passed through the impervious block, strikes a fissure, the water rises to its own level in the drill hole. If the level be above the top of the drill hole, the well becomes free flowing; if below, the water must be pumped. The fact that in some wells the drill drops several inches on reaching the water-bearing level shows that these channels are locally of considerable width. In many of the granite quarries the rock is found to be under very considerable lateral pressure, as indicated by the fact that a block once removed from between two granite walls can not, after the lapse of a short time, be replaced, the walls of the opening having in the meantime drawn closer together. Such lateral pressure would tend to close highly inclined joints and thus restrict the flow of water along them, while at the same time relieving to some extent the pressure due to the weight of the rock and making circulation along flat-lying fractures easier. How great an influence this has on the underground circulation is unknown, but it is probably not very great. It is to be expected that except at very elevated points within the granite-diorite areas a sufficient water supply for domestic purposes may be obtained at depths of 100 to 150 feet. The water is as a rule soft and of excellent purity.

On North Haven and Vinalhaven (Mr. Bailey Willis has furnished much information in regard to the wells of this locality), and probably in many other parts of the quadrangle, inclined fracture zones seem to be of considerable importance, many successful wells being located on nearly vertical fracture zones or tapping at some depth a fracture zone which descends at a rather steep angle from the surface. Some unsuccessful attempts to find water appear to have resulted from failure to strike such an inclined fracture zone, a failure which could in many instances have been avoided by a preliminary study of the position of the fracture planes at the surface and the inclination at which they descend into the earth. In the case of small cracks, however, it is not safe to depend much on their persistence in depth. Broad zones of fracturing, which are indicated at many localities by low belts between higher ledges, are more reliable. The depth of the drilled wells varies from 100 to 300 feet, the principal flow being obtained at depths ranging from 60 to 140 feet. The water rises within 10 to 35 feet of the surface and supplies of 4 to 20 gallons per minute are obtained by pumping.

On Islesboro the rocks are folded slates, schists, and limestones. The depth of the drilled wells varies from 50 to 265 feet, the principal flow being obtained at depths of 30 to 260 feet. In most wells the water rises within 15 feet of the surface and supplies of 1 to 20 gallons per minute are obtained by pumping. The flowing well at Sabbathday Harbor has already been mentioned. Because of the presence of limestone the water from many of these wells is hard.

The village of Castine is furnished with water for domestic and fire purposes by three drilled wells, situated at an elevation of 130 feet. In these the water was struck at a depth of 62½ feet below the surface, or 67½ feet above mean high-water mark. It rises naturally within 25 feet of the surface and is pumped by a windmill. These wells yield 40,000 gallons daily. A fourth well, 575 feet deep, not now used, is located at an elevation of 217 feet. Water was struck at a depth of 520 feet. The water level in this well is only 27 feet below the surface—that is, it is 190 feet above sea level and 85 feet higher than the water level in the three wells previously mentioned.

In general the distribution of fractures in the rocks in this quadrangle is such that a few failures among deep wells may be expected, since the water circulation is confined mainly to certain trunk channels rather than equally distributed throughout the water-bearing zone, but the percentage of failures should be very small if some judgment is used in the selection of the location for drilling. In most places an abundant flow may be expected at a depth of less than 100 feet, but in some localities the drill may reach a depth of 300 to 400 feet before water is encountered in good quantity. In general, the flow of ground water is from the land toward the sea, but wells located close to the seashore, especially in a highly fractured region, are liable to some inflow of salt water in case the volume of fresh water flowing out from the rocks under head is not sufficient to fill the fissures and keep the salt water out. In such wells active pumping is likely to increase the brackishness, for the fresh-water artesian pressure is thereby reduced, while the back pressure from the ocean waters remains practically unaffected.

April, 1907.