ART. XIV.—*Intrusive Rocks of the Portsmouth Basin, Maine and New Hampshire*; by ALFRED WANDKE, Foxcroft House, Cambridge, Mass.

INTRODUCTION.

Location.—The portion of the Portsmouth Basin to be treated in this paper includes 500 square miles of territory that lies partly in the southwestern corner of Maine, and partly in the southeastern corner of New Hampshire. The area under consideration is easily accessible by rail being served by the Eastern and Western Divisions of the Boston and Maine Railroad. The Atlantic Shore Street Railway passes through much of the country not touched by the steam road and thus but little remains that is not easy of access.

The portion of this area in Maine, except for the immediate vicinity of the shore where a thriving business is done entertaining summer visitors, is sparsely settled; that in New Hampshire, traversed by several rivers upon which manufacturing industries have been established, although not densely populated, contains a number of prosperous communities.

Field Work.—This paper is based upon field work done during the years 1915, 1916 and 1917. During this time members of the United States Geological Survey were conducting an investigation of the geology of southwestern Maine and conferences with Dr. L. Laforge of the Survey aided greatly in deciphering the obscure geology.

Previous Work.—Except for the work of Jackson¹ of the Maine Survey in 1839, and of Hitchcock² of the New Hampshire Survey in 1868, but little had been done in this field. At various intervals since the publication of the reconnaissances of these two men, notes mentioning the area have appeared in several publications: the clays of South Berwick, Maine, which contain Pleistocene fossils, have been cited in papers dealing with the elevation of the coast of Maine; Kemp³ in 1890 described some of the dikes at Kennebunkport and Bald Head Cliffs,

¹ Geology of Maine, Augusta, Maine, 1839.

² Geology of New Hampshire, Concord, New Hampshire, 1878.

³ Amer. Geologist, vol. 5, 1890.

Maine, and mentioned similar occurrences at Portsmouth, New Hampshire; G. P. Merrill⁴ noted the Durham granite in his "Building Stones"; Dale⁵ briefly referred to the Berwick "black granite"; Powers⁶ in 1914 had occasion to visit Bald Head Cliffs while collecting material for his paper on the inclusions in dikes. Recently the U. S. Geological Survey began a systematic study of this region and two papers⁷ relating to the geology have appeared.

Acknowledgments.—In connection with this paper acknowledgments are due to Professor R. A. Daly of Harvard University under whose guidance the area was studied; to Professors John E. Wolff and Charles Palache, both of Harvard, for helpful aid in the microscopic investigation; to Dr. L. Laforge and Dr. Frank Katz of the U. S. Geological Survey for suggestions regarding the characteristics of the formations.

TOPOGRAPHY.

The Portsmouth Basin lies within the tilted and dissected Cretaceous peneplain of the Northern Appalachian Geological Province. The portion of this peneplain near the shore, spoken of as the coastal lowland, to which the area under consideration properly belongs, is a land surface of low relief and slight diversity. It rises gently toward the interior and its few hills, either monadnocks or morainal material left by the Pleistocene glaciers, rarely attain an elevation of more than 300 feet above sea level. Its valleys, except for those of the short coastal streams, are relatively broad and shallow depressions whose courses, determined largely during post-Cretaceous time, were but slightly affected by the glaciers of the Pleistocene period. The shore line is marked by a succession of bold rocky headlands between which are marshes fronted by excellent sand beaches. Wherever rivers enter the ocean they generally afford good harbors, this being one result of a recent drowning of the shore.

⁴ G. P. Merrill, *Stones for Building*, 1897.

⁵ T. N. Dale, *U. S. Geol. Survey, Bull.* 313, 1907.

⁶ S. Powers, *Jour. of Geol.*, vol. 23, 1915.

⁷ *U. S. Geol. Survey, Prof. Paper* 108, 1917.

AREAL GEOLOGY.

General Statement.—The Portsmouth Basin resembles in many respects the other fragmentary geological basins which have been recognized in the as yet imperfectly known area of the Northern Appalachians. The rocks consist of fine-grained steeply inclined sediments supposed to be of Upper Carboniferous age, of both intrusive and effusive igneous rocks, and of some thoroughly metamorphosed rocks of doubtful origin and unknown age which have been classified as gneisses and schists. The sediments and the metamorphic rocks have a general strike of N 45° E, but local departures from this general direction are numerous; the dikes of the region follow a northeasterly trend; and the batholiths are elongated in the same direction. The dip of the stratification of the sediments and of the schistosity of the metamorphics is, on the whole, to the northwest, but frequent departures from this direction indicate, perhaps, local folds and crumplings. The gneisses and schists occur both to the northwest and to the southeast of the sediments of Upper Carboniferous age, and since the highly metamorphosed rocks almost close in on the sediments to the southwest, a basin-like arrangement results.

Sedimentary Rocks.

General Statement.—Hitchcock^s in his survey made no attempt to separate the rocks of the Portsmouth Basin into groups or formations, as is indicated by the following quotation: "This name (Merrimack Group) was informally applied by my father to the mica schists, slates, and quartzites contained in the Merrimack River, in Massachusetts. They skirt the Exeter sienites in New Hampshire, lying in troughs in an anticlinal. They probably belong to the earliest Silurian." On purely lithologic grounds it seems possible to separate this Merrimack group of Hitchcock's into two groups. The first contains three formations which have been called the Gonic schist^a, the Berwick gneiss^b, and the Rye gneiss^c; the second con-

^s Geology of New Hampshire, Concord, New Hampshire, p. 27, 1878.

^a Correlated by Katz, as a part of the Eliot formation but lithologically different.

^b Is the same as the Berwick gneiss of Katz.

^c Is the Algonkian complex of Katz.

sists of two formations, the Kittery quartzite^d and the Eliot phyllite^e. No definite age has been assigned to the first group nor can correlations be made between the different members; the second group, it seems, can be traced to Worcester, Massachusetts, where fossil-bearing rocks,⁹ Upper Carboniferous in age, have been found. The writer, however, has been able to trace the Kittery formation only as far as Lowell, Mass. From there on to Worcester, Mass., a distance of 30 miles, glacial material makes it difficult to follow the strata. The rocks at Worcester from which the fossils have been reported are lithologically unlike those of the Portsmouth Basin. In the hand specimen the typical Kittery quartzite is almost identical in appearance with the Isleboro¹⁰ formation of Rockland, Maine, perhaps of Cambrian age. It would seem, therefore, that until fossils are found within the Kittery formation its age must remain a matter of inference. The Kittery and Eliot formations are however provisionally dated as Carboniferous, following the lead of the U. S. Geological Survey.

Metamorphic Rocks of Unknown Age.

General Statement.—This classification includes the Gonic schist and the Berwick gneiss which form the north-western boundary of the basin, and the Rye gneiss on the southeastern side. Limits have been assigned to the extent of these formations with the understanding that they are not to be regarded as fixed.

Gonic Schist.—The Gonic schist has been named from the typical exposures occurring in the falls of the Cocheco River at Gonic, New Hampshire. The rock is a biotite-garnet schist evidently produced by dynamic and contact metamorphism of argillaceous and arenaceous sediments. Cutting across the schistosity of the formation, although occasionally paralleling the same, are a great many stringers of coarse pegmatite and veins of quartz. It is entirely probable that these stringers and veins are genetically related to the intrusive pegmatitic

^d The same as the Katz's Kittery quartzite.

^e Is the Eliot slate of Katz.

⁹ David White, Jour. Wash. Acad. Sci., p. 115, 1914.

¹⁰ U. S. Geol. Survey, Folio 158, 1908.

granite which outcrops less than 2000 feet distant from the exposures of Gonic schist. The formation has, in general, a gentle northwesterly dip, but departures from the normal dip and strike are abundant. The thickness of the formation is unknown.

Berwick Gneiss.—This formation is typically developed at the falls of the Salmon Falls River in Berwick, Maine. Dynamic and static metamorphism have entirely obscured the original texture and composition of the rocks which now consist of thin bands of mica schist alternating with well banded paragneiss. The formation appears to have been derived from an argillaceous sandstone or a graywacke. Because of metamorphism some of the bands are now characterized by glaucophane. Associated with the amphibole are feldspar, quartz, biotite, chlorite, pyrite, and titanite. Quartz veins varying in width from mere stringers up to masses two feet in thickness frequently cut the formation. Although some of the veins are developed parallel to the foliation of the gneiss, the general tendency is for them to occur in cross-cutting relationships. The thickness could not be determined. Departures from the general northwesterly dip of the foliation, which in rather limited areas may undergo wide variations, suggest that the formation is compressed into several tight folds which have been overturned to the southeast. Little can be said of the position of this formation in relation to its neighbors.

Rye Gneiss.—The Rye gneiss has been so called from the typical exposures that occur along the Rye coast of New Hampshire. The most northerly outcrops of rock belonging to this formation are found on Gerrish's Island, Kittery, Maine. From this locality the rocks have been traced south and southwest into Portsmouth, Rye, North Hampton and Hampton, New Hampshire. At Hampton Falls the country becomes drift-covered and for a space of six miles westward across the towns of Kensington and East Kensington no outcrops are to be seen. In the town of Kingston gneisses outcrop at Rock Rimmon Hill.

At the type-locality the gneiss is well banded, consisting of alternations of light feldspathic layers, which become pegmatitic with dark-fine biotite-rich bands that

are schistose. On Gerrish's Island the rock is fine-grained, the banding characteristic of the typical gneiss being absent. As narrow stringers of feldspathic material penetrate the rock it loses its sedimentary habit. The feldspathic stringers may increase in size until they attain a width of fifteen feet. The entire occurrence is suggestive of the feldspathization described by Wherry¹¹ in the pre-Cambrian highlands of eastern Pennsylvania. On Newcastle Island the process of feldspathization is well marked, and the gneisses become distinctly granitized.

A number of dikes cut the gneisses, but in not a single instance in the good exposures along the coast has the metamorphism so characteristic of the gneisses affected a dike. Since some of these dikes are earlier than the batholiths (to be described later) the period of granitization and feldspathization must be earlier than the period of batholithic intrusion.

Grouped with these gneisses are some rocks which suggest altered basic volcanic flows. These have not been studied in detail.

Sedimentary Rocks Upper Carboniferous in Age.

General Statement.—The Upper Carboniferous rocks form a single group consisting of two formations. The Kittery quartzite is the older of these and the Eliot phyllite the younger. Boundary lines between the two cannot be drawn with any great degree of accuracy, and the lack of exposures and the prevalent glacial drift prevent a close correlation. The two formations appear to be conformable.

Kittery Quartzite.—The typical Kittery quartzite is found just north of the bridge of the York Harbor and Beach Railroad that crosses Spruce Creek in the town of Kittery, Maine. At this locality the formation consists of a series of thin beds of red phyllite that alternate with thicker strata of a dense fine-grained grayish green or bluish quartzite. Variations from the normal are, however, abundant, the differences being due in part to primary causes during the time of deposition and in part to secondary changes during and after the period of fold-

¹¹ Paper read before the Geol. Soc. of America, 1916.

ing. The thickness cannot be accurately stated. In a section from Godfrey's Cove northwest to the contact of the sediments with the granites, a distance of eight miles, the rocks dip almost invariably steeply to the northwest, and although several folds seem to be indicated, the covering of glacial drift obscures the structure. Along the coast where outcrops are more numerous a duplication of lithologically similar rocks appears at such intervals as to suggest that the formation has a thickness of about 2000 feet.

The lower limit of the Kittery could not be established: in the southeastern part of the area the formation is seemingly a faulted contact with the Rye gneiss; in the northwestern part it appears to stand in a faulted relationship to the Berwick gneiss. Multitudes of dikes cut this formation.

Eliot Phyllite.—This phyllite is typically developed in the town of Eliot, Maine. It is, as a rule, gray in color but red, brown, black, and buff phases are common. Slight variations in texture and composition are observed and in the formation calcareous and carbonaceous phyllites, true slates, and a light yellow to brown gray crumpled and easily eroded argillite have been included. Quartz veins and dikes are frequently seen cutting the formation. Because of the lack of exposures it becomes difficult to establish a standard section, and hence the thickness can at best merely be estimated. South of Eliot where exposures are most numerous the thickness would seem not to exceed 2500 feet. Since the passage from quartzite to phyllite is effected by transitional beds which gradually change from quartzite with thin beds of phyllite to homogeneous phyllite or shale, and because the prevalent dips are such as to carry the quartzite constantly beneath the shale or phyllite, it seems certain that the Eliot and Kittery formations are conformable and that the Eliot is the younger.

IGNEOUS ROCKS.

General Statement.—The igneous rocks of the area include a great many dikes, several subjacent bodies, a few effusives, and some mixed gneisses. The mixed gneisses are pre-Carboniferous in age and occur in the

Rye formation. The effusives, or at least rocks resembling metamorphosed effusives, occur in a narrow belt at Portsmouth, New Hampshire. No attempt was made to study them. The discussion will center upon the dikes and subjacent bodies which for the most part cut the Upper Carboniferous rocks.

Dikes.

The dikes, because of their number, their wide range in composition, and the manner and order of their intrusion form a group of rocks well deserving of more detailed study. Although every outcrop carries one or more of them, the best display of dikes occurs along the coastal section from Perkin's Cove to Brave Boat Harbor. In these eleven miles there are several hundred, perhaps a thousand, dikes and they vary in width from stringers hardly thicker than the blade of a case knife up to 200 feet. Multiple and composite examples abound. In several instances three or more dikes of the same or of contrasted compositions may occupy a single fissure. In composition they range from an olivine-bearing lamprophyre through diabase, diorite, and granite porphyry to paisanite and aplite. Some abound in inclusions, which being fragments either brought up from depth or torn from the adjacent walls, occur in various stages of assimilation. In short, the dikes of the area form a remarkable display and illustrate most of the phenomena associated with intrusions of this type. All of the observed dikes are later than both the period of folding and the period of granitization which produced the Rye gneisses, and for the most part appear younger than the quartz veins and the metamorphism which characterize the outcrops from Perkin's Cove to Brave Boat Harbor. In a broad way they may be separated into two groups,¹² (a) those earlier, and (b), those later than the stocks and batholiths. On the basis of composition each of these groups may be subdivided and such a sub-division is helpful in gaining a clearer conception of the changes in the magma from which the dikes were derived.

¹² A similar grouping was made by C. H. Clapp for the dike rocks of Essex County, Mass., U. S. Geol. Surv., Bull. 704, p. 107, 1921.

First Group.

Although this group has been divided into three subgroups,—diabases, diorites, and granite porphyries, no hard and fast line of division can be drawn, since the diabases grade into the diorites and the diorites show transition phases which suggest the granite porphyries.

Diabases.—For the most part the diabase dikes are the oldest of the region. In the batholiths other diabasic dikes are seen which indicate a second period of diabase intrusion as a late phase of igneous activity. This region illustrates therefore the initiation of a period of intrusion by a great development of diabase dikes and the recurrence of similar rocks at the close of the irruptive period.

Diorites.—As the rocks in the preceding class grow lighter in color they grade into the diorites. The lighter colored members of the group have a banded appearance due to the development of innumerable segregations of quartz and feldspar in subparallel lines that follow the contacts. The development of quartz in these rocks is worthy of note for it may indicate that the magma of which they are offshoots began to approach a quartz diorite in composition.

Granite Porphyries.—Under this heading have been placed all of the light-colored typically porphyritic dike rocks of which the phenocrysts are invariably quartz and feldspar. Some of these are characterized by resorbed quartz phenocrysts, by pyrrhotite instead of pyrite, and by a groundmass which consists almost entirely of myrmekite. The myrmekite may well have resulted from the escape of volatile components as has been suggested by Sederholm.¹³

Second Group.

General Statement.—This group consists of two subgroups of diaschistic dikes,—the one contains the paisanites, tinguaites, and camptonites; the other the aplites and the late diabases. The first sub-group is generally associated with rocks that belong to the alkaline clan; the second with those which belong to the sub-alkaline clan.

¹³ Bulletin de la Commission Geologique de Finland, No. 48, p. 81, 1916.

First Sub-group.

Tinguaites.—The tinguaite dikes vary from a deep blue to a light gray in color. The feldspar is anorthoclase. The aegerite needles which dominate the ground-mass give the rock its characteristic color.

Camptonites.—The camptonites are poorly exposed, but wherever found they are characteristically developed. They are full of inclusions and contain large porphyritic crystals of glistening poikilitic hornblende. The hornblende is full of feldspar and apatite.

Paisanite.—A single example of this type of dike was found near the crest of a hill just north of "Scotland," York, Maine. The minerals present are quartz, albite, microcline, micropertite, aegerite, riebeckite, arfvedsonite, zoisite, and an undetermined titaniferous mineral, brown in color and platy in habit. Both zoisite and the feldspars are poikilitically intergrown..

Second Sub-group.

Aplites.—The aplites, present in each of the subjacent intrusives, are composed essentially of feldspar and quartz, the darker minerals being sparingly developed. Their composition and texture present no unusual features.

Diabases.—The diabases of the second generation differ but little from those of the earlier period. They are found cross cutting all of the other types of rock.

Stocks and Batholiths.

General Statement.—Large intrusive bodies occupy a considerable part of the Portsmouth Basin. They are of especial interest because of their contrasted compositions, their contact actions, and their method of emplacement. For purposes of easy reference these bodies have been named the Rochester biotite granite; Durham quartz diorite; Hampton granodiorite; Agamenticus complex, which consists of biotite granite, gabbro, syenite, and alkaline granite; Cape Neddick gabbro; York Harbor biotite granite; and the Brave Boat Harbor biotite granite.

The New England province seems to have been affected by two periods¹⁴ of batholithic intrusion. The first is usually dated as Devonian (?) and is characterized by granites, granodiorites, and quartz diorites; the second, or Carboniferous, is characterized by alkaline granites of which the Quincy granite is the typical example. It is probable that the subjacent rocks of the Portsmouth Basin fall into these two groups. In (1) may be placed the Rochester granite; in (2), the Durham, Hampton, Agamenticus, Cape Neddick, and York Harbor occurrences. The granite at Brave Boat Harbor is much more sheared than are the other nearby intrusives. It is doubtfully classified as a Carboniferous intrusive.

Rochester Biotite-Granite.—This body has no unusual features of mineralogical composition. Outcrops are not numerous, the best exposures occurring in a few small quarries. The rock cuts the Gonic schist and may be a pre-Carboniferous intrusive. Pegmatite veins cut the granite and as a rule carry quartz, perthitic feldspar, and muscovite.

Durham Quartz-Diorite.—The Durham quartz diorite batholith is an elongated body that extends from two miles southwest of Exeter, N. H., to within one fourth mile of Rollingsford, N. H. It occupies about one third of the Dover quadrangle, has an extreme length of twenty miles, and a maximum width of four and one half miles. Outcrops showing the crosscutting relationships of the body are abundant and the boundaries as shown on the map will need but slight revision. The elongation corresponds to the dominant strike of the invaded sediments. In places inclusions of the Kittery formation occur in various stages of assimilation.

Although the composition has been indicated as quartz diorite this term merely covers the dominant phase. A distinct gradation from a basic margin to an acidic interior is one of the features of this body. In a section taken across the batholith in a southeasterly direction through the town of Durham, the following variations in composition have been noted: a marginal phase of gabbro, quartz norite, quartz gabbro, quartz augite gabbro; an intermediate phase of quartz augite diorite,

¹⁴ B. K. Emerson, *Geology of Massachusetts and Rhode Island*, U. S. Geol. Survey, Bull. 597, p. 172, 1917.

quartz diorite, quartz biotite diorite; and a central phase of granodiorite, granite, and granite aplite.

Volumetric composition of two phases of the Durham quartz diorite:

	I	II
Plagioclase (Ab_3An_7 — Ab_6An_4)	63.15	....
Microperthite to oligoclase .....	....	56.06
Quartz	10.03	17.10
Biotite	16.21	15.92
Pyroxene	8.91	....
Amphibole	1.68	10.10
Apatite .....	....	.01
Totals	99.98	99.19

- I. Quartz diorite 300 feet from the contact.
- II. Granite from the central portion.

Other bodies related to the quartz diorite.—Two other bodies within the area resemble the Durham batholith, not only in composition, but also in a similar gradation from basic margins to a more acidic central phase. One of these, a small stock, occurs about two miles east of North Berwick; the other, also stock-like in habit, occurs at the intersection of the North Hampton, Exeter and Newington boundaries.

Cape Neddick Gabbro.—The Cape Neddick gabbro forms a small oval stock measuring about one-half by three-fourths of a mile. It is well exposed and shows particularly fine contact phenomena as well as variations in composition. This stock shows four phases: (a) the contact phase, a medium to fine-grained rock rich in olivine, myrmekite, and apatite, and contains abundant inclusions of the invaded quartzites; (b) a dark coarse-grained phase (phenocrysts may show a diameter up to 2 cm.) having about equal amounts of the light and dark minerals which are poikilitically intergrown and characterized furthermore by a vertical banding parallel to the contacts; (c) a very dark, almost black phase, medium to coarse in grain, containing olivine embedded in large poikilitic crystals of hornblende, biotite, and titaniferous pyroxene; and (d) a light colored central phase composed largely of plagioclase feldspar accompanied by small amounts of quartz and orthoclase.

Volumetric composition of the four phases of the Cape Neddick gabbro:

	I	II	III	IV
Olivine	17.89	1.50	6.76	....
Plagioclase	45.50	45.60	51.85	87.10
Alkaline feldspar	1.17	....	....	.16
Pyroxene	23.53	25.00	8.23	9.43
Hornblende .....	....	10.01	21.42	.68
Biotite	3.77	3.26	4.76	1.21
Hypersthene	2.33	....	....	....
Magnetite	3.62	13.82	6.79	1.55
Apatite	2.97	....	....	....
Totals	100.78	99.19	99.81	100.13

- I. Contact phase of the gabbro.
- II. Pyroxene-rich phase.
- III. Hornblende-rich phase.
- IV. Central feldspathic phase.

Agamenticus Complex.

This complex, so-called to signify that it consists of more than one kind of rock, is situated in York County, Maine, and has been named from Mount Agamenticus upon whose slopes three of the dominant rock types are to be found.

Biotite Granite.—This rock forms the dominant phase of the batholith. The texture and composition vary from place to place, but on the whole the rock is light colored, has a slightly cataclastic structure, and a porphyritic habit. Near the Jewett station, York, Maine, a narrow vein carrying pyrite and molybdenum was found. This vein is the only evidence of ore mineralization seen in the entire area.

Alkaline Granite.—This rock forms an irregular, roughly U-shaped body, the limb of the U enclosing biotite granite and the syenite stock. The typical granite is characterized by euhedral and anhedral perthitic feldspar, allotriomorphic to poikilitic arfvedsonite and aegerite-augite. Quartz-rich phases, aplitic tendencies and peculiar orbicular fine-grained contact phases are some of the departures from the normal. Although the usual amphibole is arfvedsonite, riebeckite is common; aegerite and aegerite-augite are the usual pyroxenes; orthite is seen in almost every section.

Syenite.—The syenite forms an irregular stock-like mass measuring three and one-half by four miles. The field habit of the rock is varied, all gradations being seen from a fine-grained grayish-green quartz-free syenite to a coarsely pegmatitic rock consisting essentially of perthitic feldspar, quartz, and arfvedsonite. The olivine, fayalite, occurs rather abundantly in the contact phases; in some of the central phases, arfvedsonite, riebeckite, orthite, aegerite, and zircon become locally abundant.

Contacts of this rock against the alkaline granite are rather poor so that age relations cannot be established with certainty. Along the northwestern margin of the syenite this rock appears to dike the alkaline granite. The syenite, usually a quartz syenite (nordmarkite) in composition, is in turn cut by the lenticular masses of rather coarse-grained pegmatic quartz syenite, thus indicating an additional concentration of volatile components in the later stages of this intrusive.

Volumetric composition of two phases of the Agamenticus complex:

	I	II
Alkaline feldspar	87.90	76.02
Fayalite	3.76	....
Aegerite augite	3.35	2.61
Quartz	2.43	17.46
Arfvedsonite	.49	3.55
Biotite	.61	....
Magnetite	.73	....
Allanite .....	....	.19
Zircon .....	....	.09
Totals	99.27	99.92

- I. Border phase of the syenite.
- II. Typical alkaline granite from Mt. Agamenticus.

Berwick Quartz Diorite.—Apparently later than the main biotite granite is the small stock of quartz diorite situated about two miles east of Berwick. The contact phase is essentially a gabbro, but the central mass is a typical quartz diorite. This body may possibly be correlated with the Cape Neddick gabbro.

Other Granitic Bodies.—In addition to the above mentioned occurrences of granite there are other small bodies

such as those along the South side of York Harbor and along the northeastern side of Brave Boat Harbor. The Brave Boat Harbor granite is highly cataclastic. Neither body presents unusual characteristics.

Emplacement of the Intrusives.

Elongation.—The map shows that each of the larger intrusive bodies is distinctly elongated in a northeasterly direction, which corresponds in a general way to the dominant direction of folding for this region. In this respect they conform to one of the characteristics of batholiths as postulated by Daly,¹⁵ that they should be elongated in the direction of the orogenic axes.

Method of Emplacement.—The contacts of each of the large intrusive bodies have been traced as carefully as the exposures would admit. The mapping has shown that they are distinctly cross-cutting. Contact breccias are decidedly common and within each of the intrusive bodies are "islands" of the invaded sediments whose strike and dip corresponds with that of the nearby country rock. These inliers are unquestionably roof pendants. The map on an earlier page will better show the relationships. The question of the isolation of the roof pendants becomes vital in considering the emplacement of the intrusives. Without going into the details as to how this emplacement was effected, the following table is offered in support of the method that seems to have played an important part:

*Specific Gravities.*¹⁶

Temp. in Centi- grade	Solid				Molten		
	20	1000	1100	1200	1000	1100	1200
Sediment	2.71	2.67	2.66	2.65	....	....	....
Gabbro	2.92	2.85	2.84	2.83	2.67	2.66	2.65
Quartz diorite.	2.81	2.77	2.76	2.75	2.58	2.57	2.56
Alkaline granite	2.67	2.63	2.62	2.61	2.38	2.37	2.36

The tabulated specific gravities indicate that a fragment of sedimentary rock similar to the Kittery quartzite in composition would tend to sink in a magma having

¹⁵ Igneous Rocks and Their Origin, 1914.

¹⁶ Day, Sosman and Hostetter, this Journal, vol. 37, 1914.

the composition of a quartz diorite or an alkaline granite if the magma in question were molten at a temperature even less than 1000° C. The stoping hypothesis¹⁷ may thus account for a large measure of the final emplacement,

Although assimilation in place may have removed a part of the invaded sediments, and although block-faulting or differential lateral movement may account for a part of the width of these batholiths, nevertheless, the areas of contact breccias, the roof pendants, and the relative specific gravities of molten rock and engulfed fragments all seem to indicate that the intrusives of the Portsmouth Basin in their later stages have been emplaced to a large degree by magmatic stoping.

Slightly different in its method of emplacement is the Cape Neddick gabbro. Excellent exposures of this body are to be had, the northwestern contact being particularly illuminating. Here the waves have cut a marine bench about 100 feet wide and at low tide the rocks can be studied in detail. Basic and granitic dikes cut the Kittery quartzite which forms the country rock. Close to the intrusive the dikes and sediments are mixed by contact brecciation and contact metamorphism has almost obliterated the original lithologic differences. A short distance from the contact the sediments are seen to be crumpled, simple folds, overturned folds and overthrust faults all being present on a miniature scale. The crumpling gives way 75 feet distant from the contact to gentle folding and this in turn grades into the characteristic steep dip and NE-SW strike of the sediments. The intrusive was apparently emplaced in part by bodily forcing its containing walls apart and crumpling and mashing them. As shown by the peculiar quartz-rich contact phases a part of this shattered rock was assimilated; a part seems also to have been removed by being floated away. This latter condition is well illustrated by frozen-in isolated blocks of quartzite weighing several tons now removed a short distance from the contact. The figures dealing with specific gravities indicate that these blocks may have sunk in gabbroid magma, there to be slowly digested and assimilated at depth.

¹⁷ For a detailed presentation of this hypothesis, see R. A. Daly, *Igneous Rocks and Their Origin*, p. 194, 1914.

DIFFERENTIATION.

The stocks and batholiths of the Portsmouth Basin, although not remarkable for an assemblage of rare rock types, nevertheless exhibit contrasted mineralogical compositions. In the descriptions of the igneous bodies it was mentioned that the composition of the Durham quartz diorite varied from a basic marginal phase to an acidic central one; that the Agamenticus complex seems to show a march of progress from calcic to alkalic types; that the dikes in their cross-cutting relationships indicate a change in composition of the parent magma from a basic to an acidic type. The foregoing statements appear to be the field facts; their bearing upon the problem of rock origin seems worthy of consideration.

Of the two contrasting types of rock—the calcic and the alkalic—the former appear to have been developed by the simpler processes. The quartz-rich calcic contact phases of the Durham quartz diorite seem quite clearly the result of the assimilation of Kittery quartzite by the gabbroid magma. The study of a number of selected specimens in which fragments of a quartzite were seen in various stages of alteration seems to prove this point. The abundance of apatite, indicating the presence of plenty of mineralizer, would, moreover, appear to show that the assimilation was aided by the action of the rock's volatile components. But the gradation from a gabbroid margin to a granitic center seems hardly the result of assimilation as no granite was seen in the marginal phase. The formation of granite might in part result from a process of fractional crystallization under gravitative control as the laboratory work of Bowen¹⁸ indicates may take place experimentally. But such a simple setting is hardly the entire story. In studying by means of thin sections several suites of specimens taken across the Durham body, two facts stand out rather clearly: (1) the gradual disappearance of pyroxene and the development of hornblende and biotite, both minerals that all experimental work indicates can only be formed in the wet way; (2) the partial disappearance of calcic feldspar and the development of sodic and potassic feldspar, the latter again, judging

¹⁸ Jour. Geology, vol. 23, No. 8, suppl., 1915.

from experimental evidence, only to be produced in the wet way. Thus to the theory of fractional crystallization under gravitative control a necessary addition would seem to be the influence of mineralizing solutions in furthering changes in composition. It is entirely probable that for a given locality either of these agencies may have been chiefly responsible for a given rock type. In the case of the Durham body, since it shows marked contact effects, it would seem necessary to assign an important role to the action of the volatile components in producing the granite.

The alkaline rocks offer a more complex problem. In this case a biotite granite is succeeded by alkaline granite which in turn is apparently followed by alkaline rocks carrying less and less quartz but rich (10-13%) in such elements as soda and potash. Here and there in these alkaline rocks are found coarse pegmatitic phases in which the crystals of feldspar measure up to 10 centimeters in length and the alkaline hornblende 5 to 6 centimeters. The development of soda—and potash—rich minerals and the presence of pegmatitic phases are both interpreted as indicating that mineralizers were active agents in producing these peculiar rock types. There are, however, other factors, which must be reckoned with. The experimental work of Bowen indicates that fractional crystallization under gravitative control may largely influence the process of differentiation. The contacts of the subjacent bodies against the sedimentaries certainly indicate that magmatic stoping was one of the means of emplacement. The figures dealing with specific gravities appear to show that much of the stoped material would sink. With stoping a factor of emplacement, then the assimilation of the stoped blocks would seem necessary since the contact actions show that the process actually takes place. Such stoped and assimilated material ought to make itself felt as the process of differentiation continues. Both of these aforementioned processes have evidently exerted a control upon the differentiates, but to the writer it seems that their effects were furthered by volatile components which not only aided assimilation but also were active in producing the upward transfer of the alkaline constituents so necessary in producing the alkaline rock types.

CORRELATION OF THE INTRUSIVES.

Alkaline rocks were at one time regarded as rare in New England, but little by little new localities for the occurrence of these types are being reported. The subjoined table notes some of the localities in New England from which alkaline rocks have been reported and also shows the approximate ages of the intrusives.

<i>Locality.</i>	<i>Types of Intrusives.</i>	<i>Age.</i>
Mt. Ascutney, ¹⁹ Vermont.	Biotite granite, nordmarkite, pulaskite, diorite, essexite, gabbro, paisanite.	Post Carboniferous and pre-Cretaceous.
Cuttingsville, ²⁰ Vermont.	Essexite and nepheline syenites.	Age unknown.
Litchfield, ²¹ Maine.	Syenites and nepheline syenites.	Age unknown.
Belknap Mountain, ²² New Hampshire.	Syenite and aplite.	No age given.
Tripyramid Mountain, ²³ New Hampshire.	Monsonite and syenite.	No age given.
Blue Hills, ²⁴ Massachusetts.	Alkali-granite.	Upper Carboniferous.
Copper Mine Hill, ²⁵ Rhode Island.	Quartz diorite and biotite granite. Riebeckite-aegerite granite.	Middle Devonian. Middle Pennsylvanian.
Essex County, ²⁶ Massachusetts.	Diorite, calci-alkaline granite, grano-diorite, gabbro diorite. Alkaline syenites, Cape Ann and Peabody granites, Andover alkaline granite.	Post-Ordovician and pre-Silurian? Mississippian or Pennsylvanian.
Portsmouth Basin, Maine and New Hampshire.	Biotite granite. Quartz diorite, biotite granite, gabbro, grano-diorite, alkaline granite, alkaline syenite, gabbro?	Pre-Carboniferous. Post Upper Carboniferous.

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¹⁹ R. A. Daly, U. S. Geol. Survey, Bull. 209, 1903.

²⁰ J. W. Eggleston, this Journal, vol. 45, 1918.

²¹ R. A. Daly, Bull. Geol. Soc. Amer., vol. 29, p. 463, 1918.

²² L. V. Pirsson, this Journal, vol. 22, 1906.

²³ L. V. Pirsson and W. N. Rice, this Journal, vol. 31, 1911.

²⁴ C. H. Warren and S. Powers, Bull. Geol. Soc. of Amer., vol. 25, p. 463.

²⁵ C. H. Warren and S. Powers, *ibid.* pp. 452 and 463.

²⁶ C. H. Clapp, U. S. Geol. Survey, Bull. 704, 1921.