Maine Geological Survey
Robert G. Doyle, State Geologist

THE GEOLOGY OF SOUTHERN YORK COUNTY, MAINE

by

Arthur M. Hussey II

Special Geologic Studies Series
No. 4

Department of Economic Development
Augusta, Maine
December 1962

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TABLE OF CONTENTS

	Page
Introduction	7
Previous work in the area	9
Topography and drainage	10
Metamorphic rocks	
General statement	13
Rye formation	14
Introductory statement	14
Lithology	15
Kittery formation	19
Introductory statement	19
Lithology	20
Stratigraphic relations and distribution	23
Eliot formation	23
Introductory statement	23
Lithology	23
Stratigraphic relations and distribution	24
Berwick formation	24
Introductory statement	24
Lithology	25
Stratigraphic relations and distribution	26
Gonic formation	26
Introductory statement	26
Lithology	26
Stratigraphic relations and distribution	26
Rindgemere formation	27
Introductory statement	27
Lithology	28
Stratigraphic relations and distribution	28
Towow formation	29
Introductory statement	29
Lithology	29
Stratigraphic relations and distribution	29
Thickness of the stratigraphic units	30
Igneous rocks	
General statement	32
Major elongate plutons	34
Lyman pluton	34
Biddeford pluton	35

TABLE OF CONTENTS—Continued

	Page
Webhannet pluton	36
Porphyritic biotite quartz monzonite	36
Biotite granite	37
Granodiorite	38
Age relations of the granodiorite, quartz monzonite, and biotite granite	39
Other small biotite-muscovite granite bodies	39
Agamenticus complex	40
General statement	40
Alkaline syenite	40
Alkaline granite	40
Contaminated alkaline granite	41
Porphyritic pink biotite granite	41
Small basic complexes	42
General statement	42
Cape Neddick complex	42
Tatnic complex	48
Alfred complex	51
Lebanon diorite	53
Dikes	53
Age relationships of the major intrusive groups	55
General statement	55
Elongate plutons	55
Agamenticus complex	56
Basic complexes	56
Dikes	57
Structure of the metasediments	57
Economic geology	61
Geological history	
Geosynclinal stage	62
Tectonic stage	63
Post-tectonic stage	64
Acknowledgments	65
References cited	66

LIST OF ILLUSTRATIONS

		Page
Figure 1.	Index map showing location of the southern York County area	8
Figure 2.	View of Mount Agamenticus and the Seaboard Lowlands section looking southwest from Kennebunkport	10
Figure 3.	General view across the Seaboard Lowlands in the northwestern part of Wells	11
Figure 4.	Details of coarsely porphyritic biotite-feldspar gneiss of the upper metavolcanic member of the Rye formation, southwestern Gerrish Island, Kittery	15
Figure 5.	Typical exposure of acid volcanics of the Rye formation, southwestern Gerrish Island, Kittery	16
Figure 6.	Thinly laminated amphibolites, representing metamorphosed equivalents of basic pyroclastics, southeastern Gerrish Island, Kittery	17
Figure 7.	Breccia at the southeastern end, Gerrish Island, Kittery	19
Figure 8.	Very thin, rhythmically bedded, almost varved Kittery formation between Perkins Cove in Ogunquit, and Bald Head Cliff in York	20
Figure 9.	Excellent graded bedding in medium-bedded Kittery formation, between Perkins Cove, Ogunquit, and Bald Head Cliff, York	21
Figure 10.	Two zoned concretions in Kittery formation, Israels Head, Ogunquit	22
Figure 11.	Sketch map of southwestern Maine showing major folds and igneous bodies	33

LIST OF ILLUSTRATIONS—Continued

Page

Figure 12. Outer (eastern) tip of Cape Neddick as seen from Nubble Lighthouse tower 43

Figure 13. Volcanic agglomerate exposed on the outer side of Nubble Island, Cape Neddick 44

Figure 14. Graded rhythmic layering in normal gabbro phase of the Cape Neddick complex 47

Figure 15. Uniform ungraded rhythmic layering in anorthositic gabbro, northeast edge of Cape Neddick peninsula 48

Figure 16. Block of anorthositic gabbro in cortlandtitic gabbro, Cape Neddick complex 49

Figure 17. Thin-bedded Kittery formation near Bald Head Cliff, York, cut by three basaltic dikes 54

Figure 18. Minor folds in thin-bedded Kittery formation, near Bald Head Cliff, York 60

Plate I. Geologic map of southern York County, Maine.

Plate II. Geologic map of the Cape Neddick complex.

Plate III. Geologic map of the Tatnic complex.

Plate IV. Geologic map of the Alfred complex.

All plates are in pocket inside back cover.

GEOLOGY OF SOUTHERN YORK COUNTY, MAINE

Arthur M. Hussey II

INTRODUCTION

This investigation was undertaken to provide a better understanding of the bedrock geology of southwestern Maine, giving special attention to the northeast extension of the mid-lower Paleozoic sequence developed in New Hampshire. The area discussed in this report includes approximately 450 square miles of the southern half of York County extending from Acton, Sanford, Alfred, Lyman, and Saco on the north to Kittery and Eliot on the south (Figure 1). The area is covered by the Dover, York, Berwick, Kennebunk, and Biddeford 15′ topographic quadrangles. This report is based on three seasons of field work. The first season, during the summer of 1958, involved a reconnaissance of the whole area with the purpose of outlining the broad geologic features. The second season during the summer of 1959 was spent in detailed investigation of two small basic igneous complexes at Cape Neddick in York, and the Tatnic Hills in Wells and South Berwick. General mapping was also done to outline more clearly the areal distribution and structure of the metasedimentary formations. In 1960 detailed investigations were conducted on a third basic complex in the town of Alfred, and the geology of parts of the general map area not visited during the previous field seasons was completed. In addition, the regional field mapping was extended into the Portland and Buxton quadrangles, north of the Biddeford and Kennebunk quadrangles respectively. This part of the investigation is not complete and will be continued in future field seasons.

Because of the large area covered, much of the geology of the metasediments is generalized. Future field seasons will be devoted to detailed investigations in the area discussed in this report. Although such detailed investigations may result in revision or even rejection of some of the relationships and ideas presented here, it is felt that the information obtained to date should be reported.

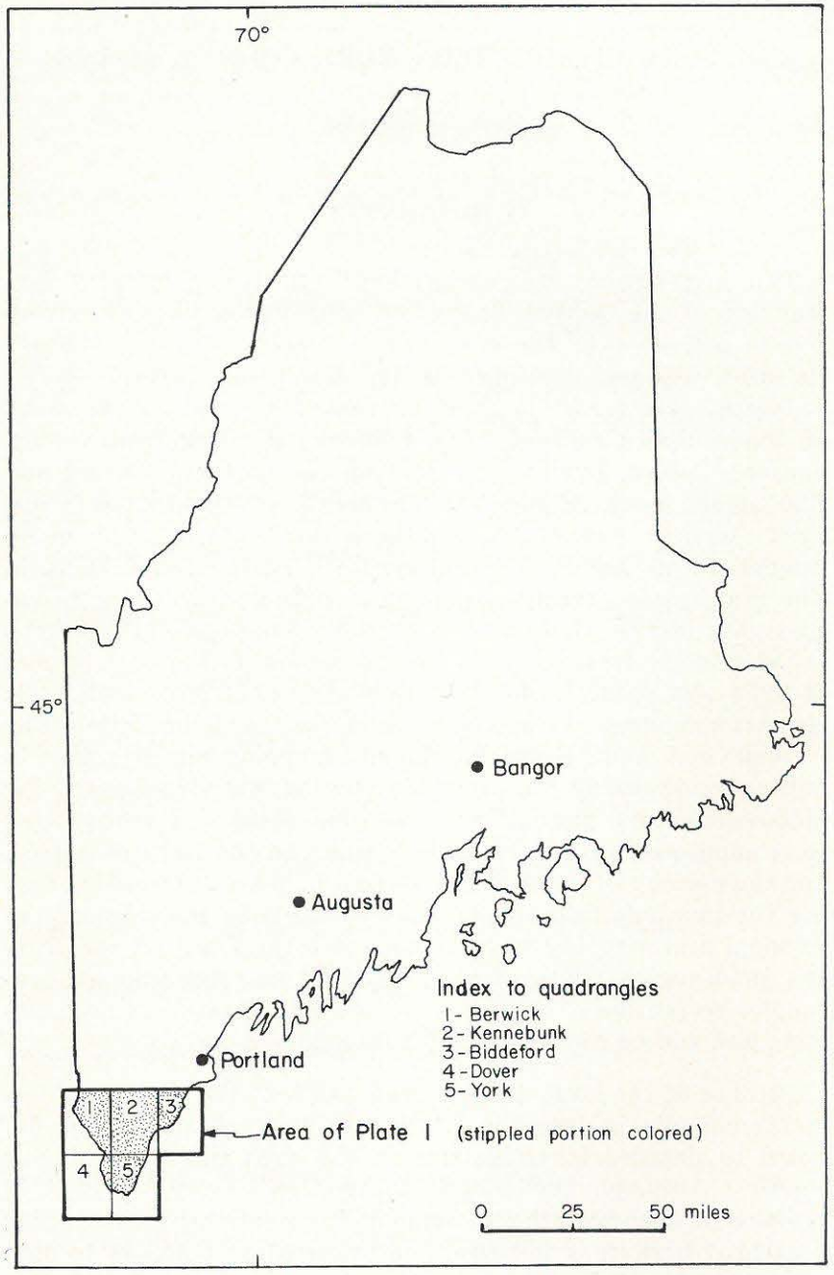

FIGURE 1. Index map of southern York County, Maine.

Previous Work in the Area. The earliest investigation of the geology of this area was made in brief reconnaissance in 1836 by C. T. Jackson. In his Report on the Geology of Maine (Jackson, 1836), he made brief notations of the igneous rocks and metasediments in southern York County.

C. H. Hitchcock (1861) made brief references to "ranges of mica schist" in York County, which, according to his descriptions of the locations, must be correlative with the Berwick, Kittery, and Eliot formations. He commented briefly on granites at Biddeford and Kennebunk (presumably Kennebunkport or Arundel); and on a syenite at Wells, Mt. Agamenticus, and Cape Neddick (which according to his definition is a hornblende granite rather than micaceous granite). He commented on the abundance of trap dikes associated with the metamorphosed slates and mica schists, in particular on the relationships of the dikes at Bald Head Cliff in York where he recognized three different ages based on cutting relationships. In general his observations, along with those of Jackson, can be used only as very rough guides to the geology of this area and no further mention of these earlier studies will be made.

Katz (1917) made a reconnaissance investigation of the stratigraphy of southwestern Maine and adjacent parts of southeastern New Hampshire, and commented briefly on the igneous rocks of the region. Discussion of his work will be presented later. Wandke (1922 a, b) described the petrology and general geologic setting of the igneous rocks of the Portsmouth basin, including the Cape Neddick gabbro complex, biotite granite of the Wells-South Berwick area, and the alkaline complex at York. Haff (1939, 1941, and 1943) described the relationships of solitary and multiple dikes of the Cape Neddick area and presented certain observations on the alkaline granite at York Beach and the gabbro at Cape Neddick. Keeley (1914, 1923) published brief notes on the petrographic character of certain dikes near Ogunquit. Powers (1915), in his studies on the origin of inclusions in dikes, described one prominent inclusion-bearing dike between Perkins Cove, Ogunquit, and Bald Head Cliff, York. Woodard (1957) described the petrographic relations of inclusion-bearing members of the York alkaline complex and presented observations on the general bedrock geology of this area.

Investigations of the glacial and post-glacial geology have been made by Stone (1899), Clapp (1907), Katz and Keith (1917), Katz (1918), Antevs (1928), Perkins (1930), Leavitt and Perkins (1934, 1935), Lougee (1950), Hussey (1959) and Bloom (1960).

Topography and Drainage. The southern York County area lies partly in the Seaboard Lowlands section and partly in the New England Uplands section (Fenneman, 1938). The Seaboard Lowlands section is characterized by low relief and altitudes that range from sea level to about 300 feet at its northwestern edge. The surface of this section slopes uniformly toward the ocean with the exception of the areas underlain by the Tatnic complex, the York alkaline complex, and parts of the quartz monzonite of the Wells-South Berwick area. These igneous rock complexes underlie areas of distinctly higher elevation than the flanking metasediments. Mount Agamenticus and the attendant Second and Third Hills to the northwest are conspicuous hills rising above the general surface (Figure 2). Between Sanford and the Bald Hill area in Wells the surface has an average slope less than 20 feet per mile and is underlain by outwash sand.

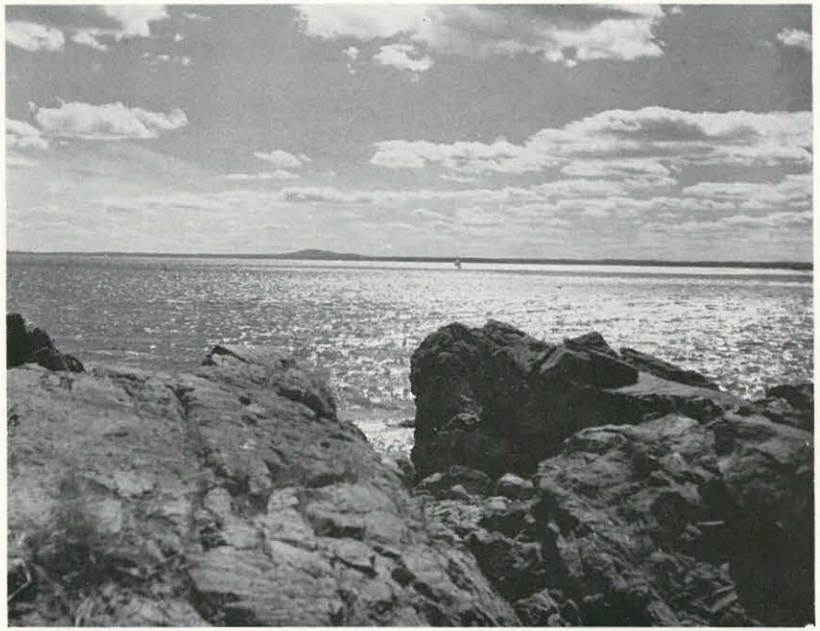

FIGURE 2. View of Mount Agamenticus and the Seaboard Lowlands section looking southwest from Kennebunkport.

FIGURE 3. General view across the Seaboard Lowland in the northwestern part of Wells, looking northwestward toward the higher areas of the New England Upland, dominated by Bauneg Beg Mountain in the center background.

The New England Uplands section is characterized by a generally hilly, maturely-dissected topography ranging in elevation from about 300 feet to 900 feet. Slopes of the hills are locally steep and in some instances cliffed. The most prominent hill in this section is Bauneg Beg Mountain (elevation 866 feet) close to the margin of the Uplands section (Figure 3).

The transition between the two physiographic sections is rather abrupt and distinct from the vicinity of Bauneg Beg Mountain northeastward through Sanford to the Alfred area. North of Alfred there is no marked distinction between the two, the Lowlands section giving way gradually to the Uplands section.

Both sections have been glaciated, resulting in the deposition of an extensive cover of glacial drift. After the retreat of Wisconsin ice, the Lowlands section and deeper valleys of the Uplands section experienced a period of submergence as a conse-

quence of which marine silts and clays were deposited and added to the surficial cover of the bedrock. Because of the glacial and post-glacial deposition, exposures of bedrock are rather limited throughout much of the area. The best exposures are found near the coast where much of the clay and drift was apparently swept away in the late stages of post-glacial submergence. The surficial geology of this area has been extensively studied by Bloom (1960) and further discussion will not be given here.

The major rivers of the area are the Saco River, which heads in the Presidential Range in New Hampshire; the Mousam River heading in the Shapleigh, Maine, area; and the Salmon Falls-Piscataqua River system, heading in the Sanbornville, New Hampshire, area. These three rivers all flow southeasterly.

Two of the three major plutonic bodies form effective barriers to through flowing drainage. In the area underlain by the Webhannet pluton and Agamenticus complex (Figure 11), there are no major through-flowing streams with the exception of Merriland River in Wells. Streams on the east side of the pluton are generally short and empty directly into the Atlantic Ocean. Those on the west side all drain into the Great Works River, a tributary to the Salmon Falls River. Very little of the drainage of the west side is carried around the northern end of the pluton.

The Biddeford pluton appears also to have exerted an important influence on the evolution of the drainage in the area that surrounds it. As with the Webhannet pluton, no through-flowing streams cross the Biddeford pluton. Northwest of Biddeford, the Saco River follows a southerly course heading directly toward the pluton, but within 1/3 of a mile of the contact it abruptly changes its course to the southeast and flows parallel to the edge of the pluton until it empties into the ocean at Biddeford Pool. In general, the drainage pattern of streams heading within the pluton is radial.

In contrast, the Lyman pluton does not appear to have exerted much control on the major drainage. Both the Main Branch Mousam River and Middle Branch Mousam River cut directly across the pluton as do two other streams north of the map area. The Middle Branch Mousam River also cuts directly across the noritic gabbro member of the Alfred complex.

METAMORPHIC ROCKS

General Statement

The metamorphic rocks of southern York County, Maine, and adjacent parts of southeastern New Hampshire are divided into the Rye, Kittery, Eliot, Berwick, Gonic, Rindgemere, and Towow formations. All of these metamorphic rocks are of sedimentary origin with the exception of the upper part of the Rye formation which is in part of volcanic origin. These seven formations form what is tentatively regarded as a conformable sequence with the Rye formation at the base and Towow formation at the top of the column. They occupy slightly more than half of the mapped area.

The first attempt to subdivide these metamorphic rocks and to determine their stratigraphic relationships and distributions was made by F. J. Katz (1917). He established the names "Kittery quartzite," "Eliot slate," and "Berwick gneiss" which are now referred to as formations rather than by lithology; and he established the names "Gonic formation" "Rindgemere formation," and "Towow formation" which are used in this report. He distinguished another formation which he called the "Algonkian complex." He assumed that this was of a greater age than the surrounding formations with the exception of the Berwick gneiss because of a greater degree of metamorphism. Wandke later referred to this as the "Rye gneiss," and it is now called the "Rye formation" by Billings (1956) and other workers in New Hampshire.

Katz regarded the Berwick gneiss and Algonkian complex as Precambrian in age on the basis of the presumed greater degree of metamorphism. He assigned an age of Pennsylvanian(?) to the Kittery and Eliot formations on the basis of correlations with rocks supposedly of Carboniferous age near Worcester, Massachusetts. He regarded the Gonic, Rindgemere, and Towow formations as equivalent to the Eliot formation.

As a result of recent investigations in New Hampshire, Billings (1956) assigns an age of Ordovician (?) to the Rye forma-

tion, Silurian to the Kittery, Eliot, and Berwick formations, and Early Devonian to the Littleton formation, which is the equivalent of the Gonic, Rindgemere, and possibly Towow formations of this report. The reader is referred to Billings (1956, pp. 99-105) for a discussion of the correlations.

At the northern edge of the map (Plate I) in the vicinity of the Biddeford pluton, the position of the Eliot formation is occupied by formations which Katz assigned to the Casco Bay group. He regarded the Eliot formation as equivalent, at least in part, to the Casco Bay group. Although the Casco Bay group is present at the edge of the map area, the limited areal extent of the formations of that group does not warrant discussion in this report.

In the following section, discussions of the lithologies of the formations are based on megascopic hand specimen examination. Only a few samples were sectioned for microscopic examination, and consequently, complete tabulations of the mineralogy of the formations cannot be given at the present. The writer feels that the metasediments are most reliably divided into formations on the basis of gross lithologic appearances and general appearance of primary sedimentary structures and secondary metamorphic structures as seen in outcrop and in hand specimen. Since problems of the regional metamorphism were not a primary goal of this study, microscopic examination of the different rock types was not undertaken.

Rye Formation

Introductory Statement. The rocks assigned to the Rye formation by Billings (1956) are essentially the same as those assigned by Katz (1917) to the Algonkian complex, and by Wandke (1922a) to the Rye gneiss. They crop out typically in the town of Rye, New Hampshire. Katz's map shows a continuation of these rocks onto Gerrish Island in the very southern tip of Maine.

Billings (1956) distinguishes two members of the Rye formation in New Hampshire — a lower metasedimentary member and an upper metavolcanic member. The lower metasedimentary member is a feldspathic mica schist with garnet or sillimanite depending on the particular metamorphic zone, and is exposed in a belt about 2 miles wide and 12 miles long along the coast of

New Hampshire. The upper metavolcanic member lies in the garnet zone and consists of medium-grained amphibolite and fine-grained biotite gneiss. This member crops out in a belt approximately 2 miles wide northwest of the metasedimentary belt. The amphibolite is interpreted by Billings as representing metamorphosed andesites or basalts and the biotite gneiss as representing metamorphosed soda rhyolite.

From the present field work it was determined that the upper metavolcanic member of the Rye formation occurs in the southern ¾ of Gerrish Island in Kittery, but that the lower metasedimentary member is not present. Most of the rocks of the metavolcanic member on Gerrish Island belong to what Billings has referred to as biotite gneiss. Amphibolite occurs only on the south-southeastern tip of the Island.

Lithology. The acidic portion of the metavolcanic member on Gerrish Island is variable. The most characteristic phase is a very leucocratic, finely to coarsely porphyroblastic gneiss com-

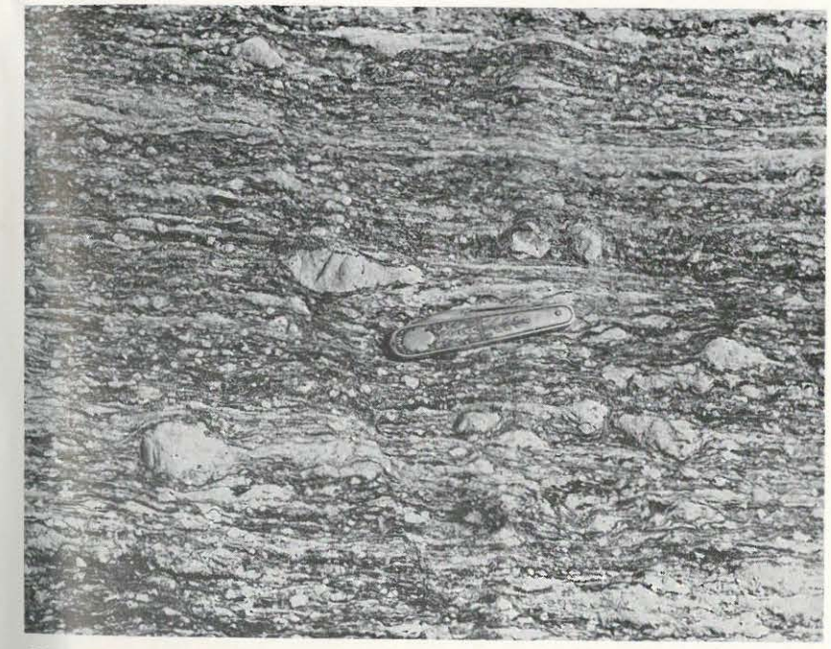

FIGURE 4. Details of coarsely porphyroblastic biotite-feldspar gneiss of the upper metavolcanic member of the Rye formation, southwestern Gerrish Island, Kittery. The largest porphyroblast beside the pen knife is approximately 2″ long.

posed mostly of potash feldspar set in a fine-grained to aphanitic groundmass. Figure 4 shows the typical development of porphyroblasts, some up to 2″ long, in one of the coarsely porphyroblastic, biotite-rich layers. Interbedded with the gneisses are

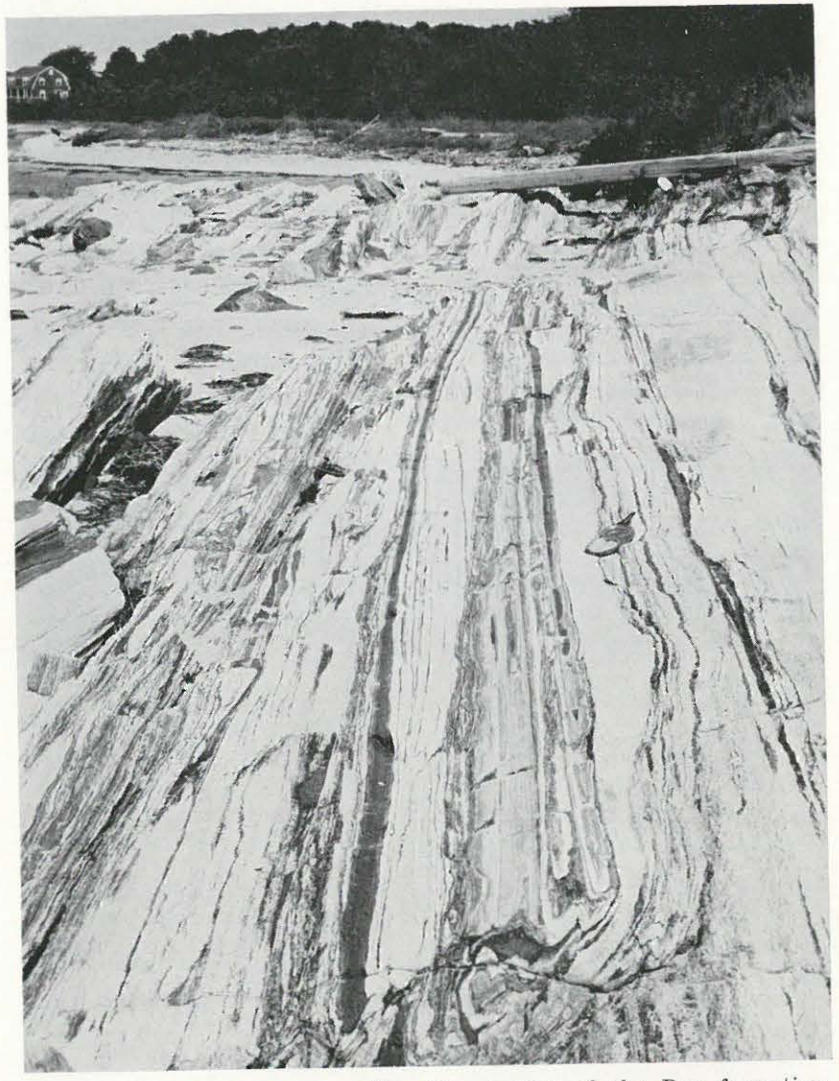

FIGURE 5. Typical exposure of acid volcanics of the Rye formation, southwestern Gerrish Island, Kittery. Lighter bands are porphyroblastic biotite-feldspar gneisses representing metamorphosed rhyolitic pyroclastics. Darker bands are mostly feldspathic biotite schists and some feldspathic biotitic quartzites.

thin units of fine-grained biotite quartz phyllite and schist and feldspathic biotite quartzite. The thin, interbedded nature of these phases such as is shown in Figure 5 suggests that the sequence before metamorphism consisted mostly of tuffaceous, waterlaid acid volcanics interbedded with submature land-washed sediments, probably derived from volcanic terrains.

At the very south-southeastern tip of Gerrish Island, and presumably underlying the acidic volcanics is a very limited exposure of fine-grained, strongly banded to laminated, feldspathic amphibolite, which is probably the equivalent of the medium-grained amphibolite of New Hampshire. Numerous pegmatite lenses occur in this amphibolite. They are generally concordant to, but locally transect the laminations as shown in Figure 6.

In addition to these rock types which have their counterparts in New Hampshire, two additional minor units, not previously noted, are exposed on Gerrish Island. At the southwestern tip

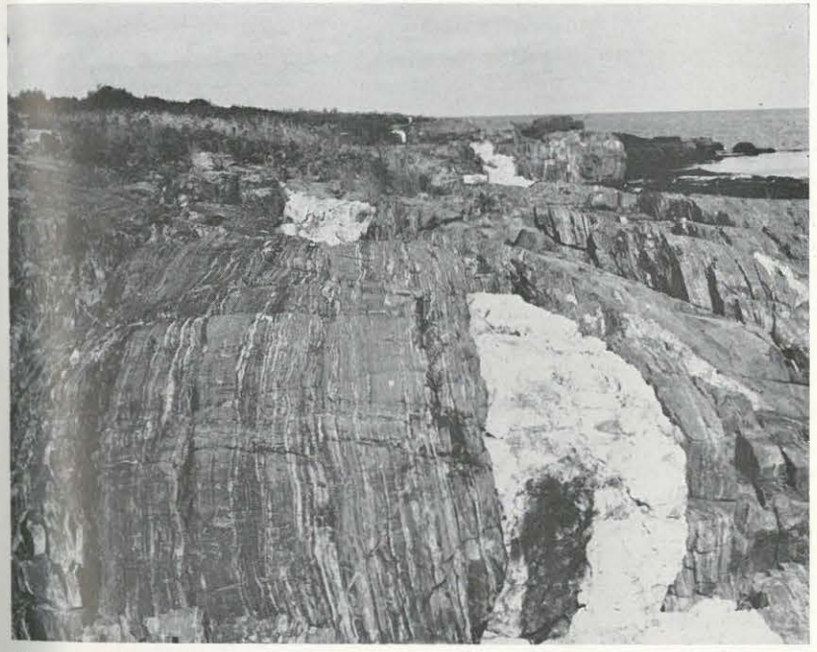

FIGURE 6. Thinly laminated amphibolites, representing metamorphosed equivalents of basic pyroclastics, southeastern Gerrish Island, Kittery. Numerous lens-shaped pegmatites within the amphibolite are generally parallel to the lamination, but locally transgress it as shown in the lower edge of the photograph.

of the island, thinly laminated, very fine-grained marble about 10-15 feet thick and dark gray pyritiferous, carbonaceous biotite schist of unknown thickness are exposed. The limited exposures of these two units suggest that they occupy the crest of a minor anticline within the Rye metavolcanic member, with the marble overlying the carbonaceous biotite schist. The marble is overlain by the acid volcanics. The marble and graphitic biotite schist must also be underlain by the acid volcanics, because, further to the southeast and presumably up dip, acid volcanics are in contact with the amphibolite. Unfortunately, the only exposure of these two minor units is separated from outcrops of the acid volcanics by rather long expanses of sand along shore, and swamp or glacial drift inland. A minor syncline southeast of the anticline is inferred in order to bring these two units above the present erosion surface before the next exposures of the acid volcanics about 800 feet to the southeast.

The acid volcanics appear to grade upward into less feldspathic and porphyroblastic gneisses and eventually into biotitic quartzites, actinolitic quartzites, and biotite phyllites typical of the Kittery formation. However, along the western portion of the contact there is a zone which appears to be highly sheared but not noticeably brecciated. This zone, approximately 15-20 feet thick, is parallel to the bedding and is found only on the western side of the island. From field evidence, it appears that this shear zone does not represent a major fault contact between the Kittery and Rye formations. The gradual change in character of the acid volcanics toward more Kittery-like sediments stratigraphically upward, and the apparent absence of the shear zone on the eastern side of the island rule against a fault of major proportions. The shear zone is probably one of the many minor faults and shear zones which can be observed in the Kittery and other formations elsewhere along the coast.

Two oval-shaped breccia bodies are present within the Rye formation along the eastern shore of Gerrish Island. The larger body has a width of about 800 feet, but its length is not known. The smaller body, ¾ mile to the north is about 300 feet long. In both these areas the breccia includes fragments of the Rye metavolcanics and diabase which is probably related to the earlier group of diabase dikes noted in the Bald Head Cliff-Ogunquit area (see p. 53). These breccias are cut by irregular stringers

and dikes of light buff felsite porphyry which are in turn cut by a set of diabase dikes possibly related to the later group of diabase dikes in the Bald Head Cliff-Ogunquit area. The general character of the larger breccia is shown in Figure 7. Nowhere

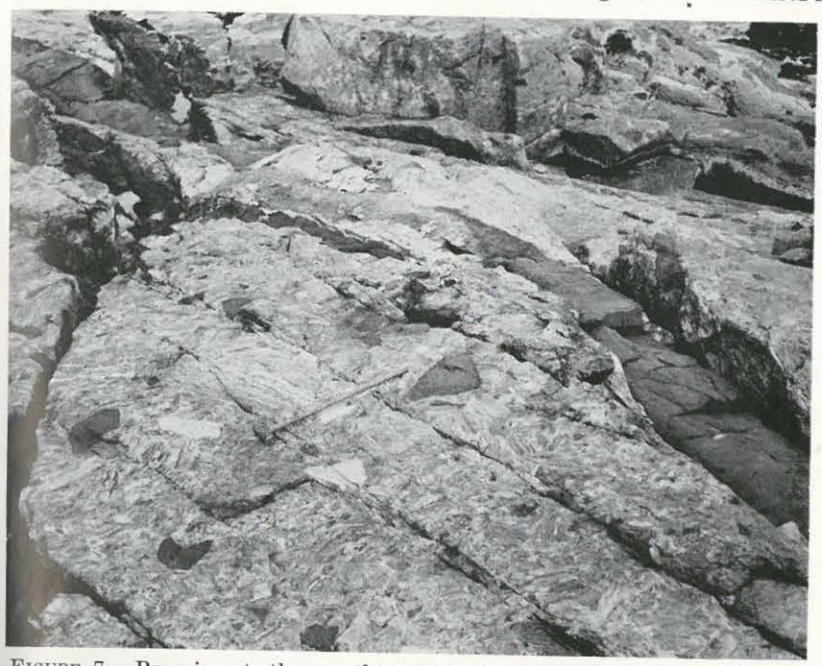

FIGURE 7. Breccia at the southeastern end, Gerrish Island, Kittery. The breccia is composed mostly of fragments of the acid volcanics of the Rye formation and basic dikes which cut the volcanics. A later diabase dike can be seen cutting the breccia.

was there any structure such as bedding of the breccia observed. These bodies are tentatively considered to represent explosion breccias, and may be correlative with the volcanic activity associated with the Cape Neddick and Tatnic Complexes.

Kittery Formation

Introductory Statement. The Kittery formation was originally referred to by Katz (1917) as the "Kittery quartzite." However, because of the abundance of interbedded argillaceous material, recent investigators (Billings, 1956) have preferred to call it the "Kittery formation," a nomenclature to be followed here. The type locality as mentioned by Katz is the southern part of the town of Kittery.

Lithology. The Kittery formation in the map area is confined to the lower grades of metamorphism, mostly the biotite zone. The most common and characteristic lithology is a medium purplish gray, hard, brittle, fine-grained quartzite which breaks with a hackly to rough conchoidal fracture. Calcite or dolomite in small amounts is present in most exposures, but the rock is in general too fine-grained to determine megascopically the other minerals present. The quartzite is rarely porphyroblastic. The second most common lithology is a dark gray to dark purplish gray slightly siliceous phyllite grading to very fine-grained, lustrous, non-porphyroblastic biotite-quartz schist. The phyllite possesses a cleavage which is generally uniform and nearly planar; only occasionally is it crenulated or crumpled. In the schists, the schistosity is correspondingly uniform and non-deformed. Other lithologies of minor importance encountered in the formation include thin beds of light tan calcite marble, dark purplish-gray siliceous and biotitic calcite marble, and light gray clean quartzite. None of these minor lithologies appears to form a distinctive sequence that would serve as a mappable unit.

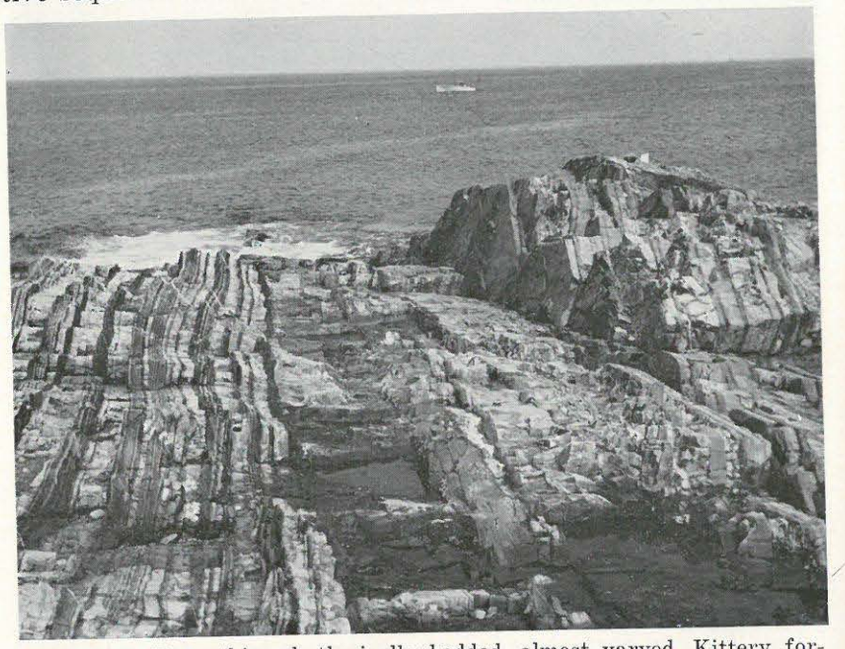

FIGURE 8. Very thin, rhythmically bedded, almost varved, Kittery formation, between Perkins Cove in Ogunquit, and Bald Head Cliff in York. Graded bedding, although not conspicuous in the photograph is typical of the sequence here.

In places, quartzite is the dominant lithology occurring in medium to thick (1-4 foot) beds with only minor thin interbeds of phyllite or schist. Many of the quartzite beds are thinly laminated with the lamination planes marked by concentrations of biotite. Locally, as along the coast in the vicinity of Ogunquit and York, the Kittery formation is a thin-bedded (¼ to 6 inch) sequence of alternating quartzites or laminated quartzites and phyllites, in some places closely resembling lake varves. Figure 8 shows a typical example of this thin-bedded alternating lithology near Bald Head Cliff in York. This thin-bedded sequence commonly shows very well developed graded bedding — quartzite grading upward into phyllite or schist (Figure 9). Much use has been made of this feature in working out structure, particu-

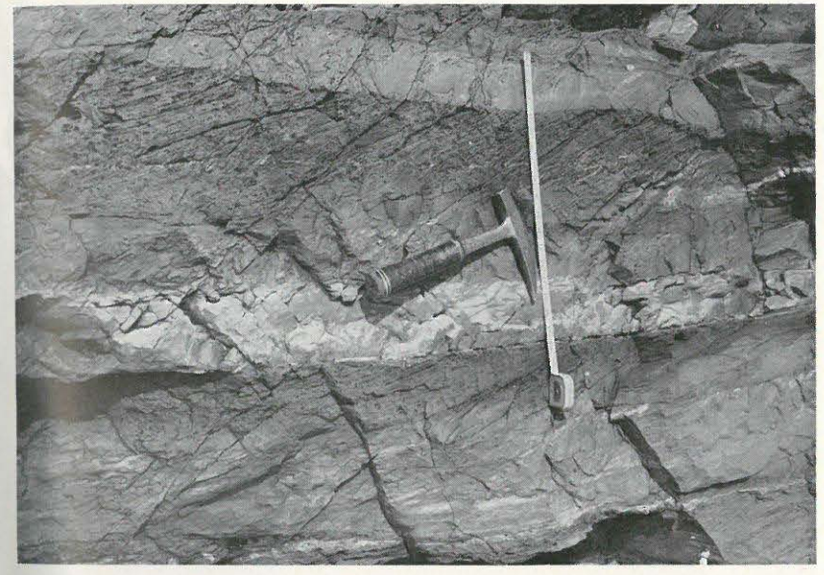

FIGURE 9. Excellent graded bedding in medium-bedded Kittery formation, between Perkins Cove, Ogunquit, and Bald Head Cliff, York. Quartzitic uncleaved units grade to the top of the picture into well-cleaved slaty units with an abrupt change to the next quartzitic unit.

larly along the coast where the formation is excellently exposed. In addition, cross-bedding on a small scale has been noted at two localities — Long Sands Beach in York, and near the junction of the Great Works River and the Salmon Falls River. In both places, tops of beds as indicated by graded bedding and cross-bedding are in agreement. A third example noted in outcrops of

the Kittery formation in the southern part of Wells Township was later determined to be a cross-bedding form simulated by small-scale drag folding in very thinly laminated quartzite.

Numerous ellipsoidal concretionary masses of calcite, dolomite, lime silicates, and quartz are very common in the Kittery formation. These concretionary masses range from about 2 inches to 1½ feet long, and each is contained within the limits of a single bed. They are commonly zoned, with either calcitic or dolomitic centers. A typical example is shown in Figure 10, in which two adjacent concretions are restricted to a single, slightly limy quartzite bed. Similar concretions have been noted in other formations, principally the Eliot and Berwick, but are rare.

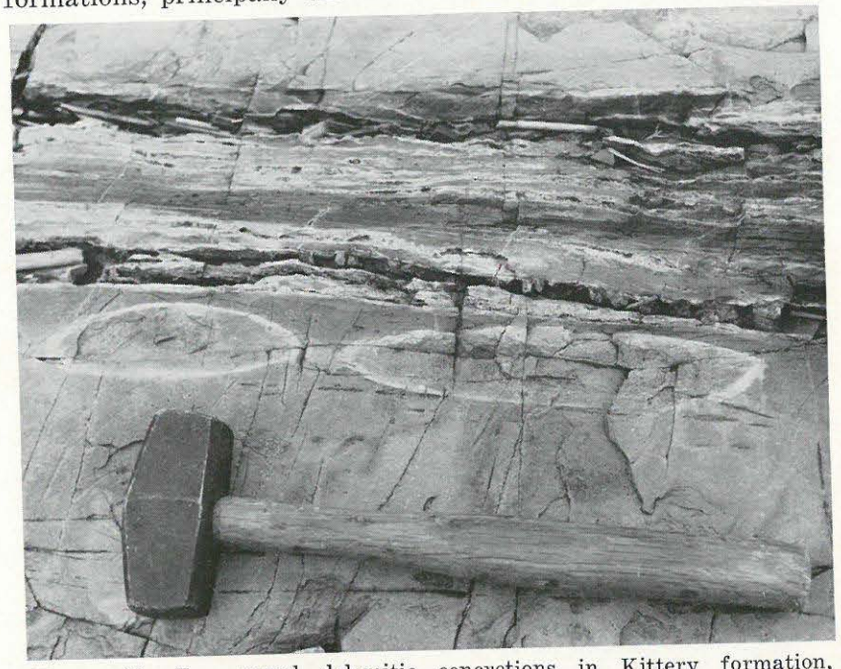

FIGURE 10. Two zoned dolomitic concretions in Kittery formation, Israel's Head, Ogunquit. Both concretions are contained within a slightly limy quartzite bed.

Although no fossils have been found in the Kittery formation, it is considered to be of marine origin. The predominance of graded bedding and the even stratification of the individual beds suggest similarities to many graywacke sequences believed to be due to deposition from turbidity currents (for example, see Kuenen, 1953 and 1956).

Stratigraphic Relations and Distribution. The Kittery formation probably overlies the upper Rye acid volcanics conformably, although the transition beds are complicated by the shear zone discussed above. The Eliot formation conformably overlies the Kittery formation. Exposures of the contact zone between the two formations suggest a gradual transition from Kittery type lithology into the typical siliceous phyllites of the lower part of the Eliot formation.

The Kittery formation is exposed in a broad belt 3 to 9 miles wide, parallel to the coast from Kittery north-northeast to the Biddeford-Saco area at the northern end of the map. Beyond this point, the distribution of the formation has not yet been determined.

Eliot Formation

Introductory Statement. The Eliot formation was originally called the "Eliot slate" by Katz (1917), but recent investigators (Freedman, 1950, and Billings, 1956) prefer to call it the "Eliot formation" on the basis that true slates are not universally present. The type locality is in the town of Eliot on the northeastern side of the Piscataqua River.

Lithology. The Eliot formation in the type locality consists of two distinct units. The lower unit, transitional from the Kittery formation, consists of rather uniform, thin-bedded, medium gray, slightly siliceous chloritic slates and phyllites characterized by relatively uniform cleavage. It differs from the Kittery formation in lacking either the thick quartzite beds or the clear-cut alternations of quartzitic and argillaceous beds. Furthermore, cleavage is universally developed throughout the lower unit of the Eliot, but only in the argillaceous interbeds of the Kittery formation.

The upper unit of the Eliot formation consists of thinly interbedded, medium gray, moderately to slightly crumpled chloritic phyllite with occasional interbeds of chloritic quartzite. Katz (1917) reported the presence of thin laminae of light bluish limestone, but this lithology was not observed during the present investigations.

Pyritiferous and slightly carbonaceous phyllites were observed along the Mousam River in the vicinity of West Kennebunk, in

a position stratigraphically between the Kittery and Berwick formations. These phyllites may be equivalent to the Calef member of the Eliot formation described by Freedman (1950). The Calef member is exposed only in a band extending from Lee to Epping, New Hampshire, and occupies a position stratigraphically at the top of the Eliot.

Stratigraphic Relations and Distribution. The Eliot formation conformably overlies the Kittery formation through the transition zone described above. It is believed to be overlain conformably by the Berwick formation, but the contact between the two is nowhere exposed. The opinion has been expressed by Billings (1956, pp. 41-42) that much of the difference between the Eliot and Berwick metasediments is due to the grade of metamorphism, that the original sediments were much the same. In southern Maine, however, the Eliot sediments were found to be distinctly more argillaceous than Berwick sediments. Furthermore, the Berwick formation has greater amounts of what were probably rather limy or dolomitic quartzites than the Eliot formation.

The outcrop belt of the Eliot formation is irregular, reflecting the major structure of the area. The formation extends from the northern corner of Arundel Township through Kennebunk Township to the Wells-Kennebunk town line in a belt ranging from ¼ to ¾ of a mile in width, complicated by several small folds. From the Kennebunk-Wells town line to a point 3 miles northeast of North Berwick Village, the belt is interrupted by the Webhannet pluton, but continues from the western side of the pluton south-southwest to the Berwick-South Berwick area and thence into New Hampshire. The Eliot formation also underlies much of Eliot Township in a synclinal belt extending from the Piscataqua River northeastward into York Township. The formation has been mapped as far south as the Exeter area, beyond which it has been included in the Merrimack group without separate distinction.

Berwick Formation

Introductory Statement. The Berwick formation was originally referred to by Katz (1917) as the "Berwick gneiss" which he considered to be Precambrian in age. However, throughout most of the area where these rocks are exposed, even at the type locality in the channel of the Salmon Falls River at Berwick, they are not characterized by distinctive gneissic structure, and bedding is usually well preserved. It seems more appropriate to refer to this sequence as the "Berwick formation" as suggested by Freedman (1950).

Lithology. The rocks of the Berwick formation are very similar in lithology to those of the Kittery formation, and some of the difference in appearance of the two formations in outcrop may be a function of the generally higher grade of metamorphism (biotite and garnet ? zone) of the Berwick formation. In general, the Berwick formation consists of a more heterogeneous array of rock types than either the Kittery or Eliot formations. The following rock types are characteristic, but none may be said to be dominant:

(1) Fine-grained mottled green and purplish gray quartzite with abundant dark green actinolite porphyroblasts; (2) dense, conchoidal fracturing greenish gray quartzite with abundant actinolite; (3) mottled light green and purplish gray quartzo-feldspathic actinolite-biotite granulite with a slight tendency toward gneissic structure, and containing abundant thin actinolite-feldspar veins; (4) medium purplish gray, rather granular quartz-biotite schist, locally containing elongate biotite porphyroblasts which give a slight gneissic structure and lineation to the fabric; (5) gray quartzo-feldspathic biotite-actinolite gneiss marked by conspicuous streaks and bands of biotite, and (6) greenish gray quartzo-feldspathic actinolite gneiss occurring as thin interbeds in association with the other types. Close to the contacts with the Lyman pluton the lithology is a medium gray, granular, medium grained quartz biotite schist with occasional thin interbeds of actinolite gneiss. Hard brittle purplish gray quartzite which is the dominant lithology of the Kittery formation is also common in the Berwick formation.

The Berwick formation is characteristically medium to thin bedded, and in general there is less contrast between adjacent beds than in the Kittery formation. The characteristic alternation of quartzite and phyllite found in parts of the Kittery formation is lacking in the Berwick formation, and hard brittle purplish gray Kittery-type quartzites are not a dominant lithology in the Berwick formation.

The lithologies of the Berwick formation as a whole are much less argillaceous than those of the two units of the Eliot formation, and there is little difficulty in distinguishing the two formations in the field.

Stratigraphic Relations and Distribution. By inference, the Berwick formation overlies the upper unit of the Eliot formation although the contact has not been observed. The contact between the two is probably gradational. Conformably above the Berwick is the Gonic formation, and again the contact has not been observed.

The Berwick formation crops out northwest of the Eliot formation and extends from the Maine-New Hampshire border in the vicinity of Berwick, Maine, north-northeastward to Lyman and Arundel Townships. The width of the outcrop belt varies from 2 miles in the Berwick area to 4 miles in the vicinity of North Berwick.

Gonic Formation

Introductory Statement. The Gonic formation takes its name from the village of Gonic in Rochester Township, New Hampshire, where it is exposed in the channel of the Cocheco River. The name was first given to these rocks by Katz (1917) and he used the exposures here as the type locality for the formation.

From recent work done in New Hampshire, Billings (1956) has included the Gonic formation as well as the Rindgemere formation as part of his Littleton formation on the basis of general lithologic similarities. Although the Gonic and Rindgemere formations may be lithologic equivalents of the Littleton formation, the writer feels that the names Gonic and Rindgemere take precedence in this area.

Lithology. The Gonic formation consists of a sequence of fine-grained silvery gray muscovite-biotite-garnet-staurolite schists and minor muscovitic quartzites. The formation lies completely in the staurolite zone of metamorphism in the area mapped. Porphyroblasts of biotite, garnet, and staurolite are very abundant and well developed.

Stratigraphic Relations and Distribution. The Gonic formation is inferred to overlie the Berwick formation conformably; although the contact of the two formations is nowhere exposed, the dips and strikes of bedding or schistosity are usually parallel in both formations. About one mile south of Bauneg Beg Mountain, outcrops of typical Berwick have been found within about 100 feet of typical Gonic. This represents one of the most abrupt changes in character of the original sediments between any of the formations studied in the map area.

It should be pointed out that the Kittery and Berwick formations lack the aluminous character of the Gonic, Rindgemere, and Towow formations. The Eliot formation in areas of medium grade of metamorphism is intermediate, in places being rather muscovitic, and in other places biotitic. The muscovitic character of the Gonic, Rindgemere, and possibly Towow formations forms the basis of Billings' (1956) correlation of these two formations with the Littleton formation in New Hampshire.

The Gonic formation is conformably overlain by the Rindgemere formation. Field evidence suggests that the contact is gradational; in some areas near the contact it is sometimes difficult to decide to which formation an outcrop belongs.

The Gonic formation extends from the margin of the Lyman pluton in Sanford in a belt approximately 1½ miles wide southwest to the limits of the map area. Katz (1917) states that it extends southwest into New Hampshire to the vicinity of Barrington. His map shows the formation both on the northwest and southeast sides of the Fitchburg pluton. Billings (1956), however, has assigned the metasediments on the southeast side of the pluton to the Berwick formation on the basis that aluminous minerals characteristic of the Littleton formation are not abundant. As determined during the present investigation, the Gonic formation trends toward, and is apparently separated from the type locality by the Fitchburg pluton. The formation does not appear to wrap around the nose of the pluton. The distribution of the formation north of the Lyman pluton has not yet been determined.

Rindgemere Formation

Introductory Statement. The name "Rindgemere formation" was proposed by Katz (1917) for a sequence of schists, quartzites and gneisses including those exposed in the Salmon Falls River

near Rindgemere Station, East Rochester, New Hampshire. In New Hampshire, these rocks are included in the Littleton formation by Billings (1956).

Lithology. The Rindgemere formation consists of several rock types, the proportions of which vary considerably from one locality to another. Included are: (1) fine to medium-grained muscovite-biotite-garnet schist with variable amounts of sillimanite; (2) quartz-mica schist and micaceous quartzite; and (3) irregularly-textured schistose feldspathic biotite-muscovite-quartz gneiss which is usually associated with the masses of pegmatite or binary granite that are common throughout the formation. Where bedding is discernible, these rocks are characteristically thin-bedded. Schistosity is commonly crenulated on a minute scale by small folds that may represent a later period of deformation. The formation lies mostly in the sillimanite zone of regional metamorphism with only the lowest portion, which is transitional to Gonic lithology, in the staurolite zone. At one place in this transitional zone, located one mile south of the summit of Bauneg Beg Mountain in North Berwick, clear brown euhedral crystals of staurolite and irregular fibrous masses of sillimanite occur in the same outcrop.

The upper part of the formation in the Lebanon-Acton area is generally finer grained and more uniformly schistose. Pegmatites are rare and the rocks are generally non-feldspathic and rather well-bedded. Masses of muscovite up to 2 inches long are common and may represent retrogressive pseudomorphs after andalusite. Although these rocks may constitute a mappable unit separate from the normal Rindgemere, further field work is needed to define and delineate them. Massive, slightly phyllitic quartzites have been observed within this upper unit, but exposures are not numerous enough to determine whether these are observations of one stratigraphic unit or several interstratified units of minor thickness.

Stratigraphic Relations and Distribution. The Rindgemere formation overlies the Gonic formation conformably. The field data suggest that the transition from one to the other is gradual rather than abrupt. The Rindgemere formation is overlain conformably by the Towow formation through a contact which also appears to be transitional, but nowhere has the actual contact been observed.

The Rindgemere formation extends from the margin of the Lyman pluton and the Alfred complex in a broad belt southwest to the New Hampshire-Maine state line, and from there, an undetermined distance southeast. The northwestern limit of the formation was not determined during the present field work. It apparently extends beyond the map area.

Towow Formation

Introductory Statement. The Towow formation takes its name from the original name of the town of Lebanon, Maine, and was proposed by Katz (1917) for a sequence of what he termed "carbonaceous" metasediments typically exposed throughout parts of the township. These metasediments appear to be restricted to the town of Lebanon; equivalents of the Towow formation have not been described in the adjacent parts of New Hampshire, nor are they present elsewhere in the map area.

Lithology. The Towow formation is composed of fine-grained muscovite schist and phyllite, with interbeds of dark silvery gray phyllite, pyrite and/or pyrrhotite-rich, dull-gray earthy phyllite and fine-grained quartzose muscovite schist. Katz concluded that the gray phyllites were graphitic. Although carbonaceous matter may be a major coloring agent, it does not appear to be one of the major mineral constituents of the phyllites. Because of the high concentration of sulfides, these rocks weather very rapidly, and at one place in a road cut along U. S. Highway 202, bright orange incrustations and stalactites of iron sulfate are developed. The glacial drift derived from this formation is distinctively orange due to limonite staining and very commonly till or even stratified drift is cemented into a conglomerate by limonite derived from the weathering of the pyrite.

Stratigraphic Relations and Distribution. The Rindgemere formation grades conformably upwards into the Towow formation, and the base of the latter has been placed arbitrarily at the stratigraphic position where the dark gray phyllites begin to appear. From structural considerations, the Towow formation appears to be preserved in a syncline, and thus represents the highest stratigraphic unit in the map area. Billings (personal communication) suggests that these rocks may not be the equivalents of portions of the Littleton formation in New Hampshire, but may lie stratigraphically above the Littleton formation.

The Towow formation crops out in a belt 2 to 3 miles wide extending from the northern part of Lebanon southwest to the Salmon Falls River, a distance of approximately 8 miles. Rocks of the Towow type have not been found across the river in New Hampshire.

Thickness of the Stratigraphic Units

The thicknesses of the formations in southwestern Maine and southeastern New Hampshire are difficult to determine. Because of the lack of exposures in key areas, no reliable idea of the amount of repetition due to minor folding can be determined, nor can the general dips of homoclinal belts be accurately determined. Local dips throughout the area are vertical or steep, but the general dips of the homoclinal belts are certainly more gentle.

The original thicknesses suggested by Katz (1917) and the more recent figures given by Billings (1956) are summarized in Table 1. The figure of 6500 feet suggested by Billings for the Eliot formation appears high for most of southern York County, although it may be a reasonable approximation for the New Hampshire area. In the vicinity of North Berwick, and between the Webhannet and Biddeford plutons, the width of outcrop of the Eliot formation is commonly less than 0.4 of a mile; thus, unless it has been locally thinned tectonically, this formation in southern York County would appear to be less than 2000 feet thick. On the other hand, the Kittery formation is probably much thicker than 1500 feet. Its width of outcrop is greater than that of the Berwick formation for which Billings gives a thickness of 7000 to 10,000 feet. No field evidence has been found to indicate that the Berwick formation shows less repetition due to folding than the Kittery formation, and it seems likely that the thicknesses of the two formations are of the same order of magnitude.

The reader is cautioned from attaching significance to the thicknesses of the formation as can be measured from the cross-sections of Plate I. The average dips of the formations may be steeper or gentler than shown on the sections, and consequently the formations may be thicker or thinner than shown.

TABLE 1

Thickness of formations in southwestern Maine and southeastern New Hampshire after Katz (1917) and Billings (1956)

Formation	Thickness according to: Katz (1917)	Billings (1956)
Towow	Unknown (top missing)	Not represented (?)
Rindgemere	1,000 feet	Rocks equivalent to these included in the Littleton formation (total thickness possibly as high as 15,000 feet).
Gonic	300-500 feet	
Berwick	Unknown	7,000-10,000 feet (quoting Freedman)
Eliot	Unknown (top missing)	6,500 feet (quoting Freedman)
Kittery	1,500 feet	1,500 feet (citing Katz)
Rye	(not given)	4,000 feet

IGNEOUS ROCKS

General Statement

Four contrasting groups of igneous rocks, differing markedly in age, general composition, and shape or structure are present in southern York County. They include (1) large granite, quartz monzonite, and granodiorite plutons that are elongated parallel to the structural trend of the surrounding metasediments; (2) an alkaline complex similar to those of the White Mountain plutonic-volcanic series in New Hampshire; (3) small circular to elliptical basic complexes, and associated volcanics; and (4) numerous basaltic to rhyolitic dikes. These igneous rocks occupy slightly less than half of the total area in southern York County. Excluding the dikes, which occur chiefly in the metamorphic rocks, these igneous bodies underlie higher, more hilly areas than the metasediments and metavolcanics and consequently are better exposed and more clearly understood.

It has been found convenient to refer to the bodies of the first group of igneous rocks as "plutons." The three major plutons of this group in southern York County are the Lyman pluton, the Webhannet pluton, and the Biddeford pluton (Figure 11). Two plutons of similar character in New Hampshire, the Fitchburg and Exeter plutons, are shown on Plate I and Figure 11. They are shown on Plate I only as an aid in understanding and interpreting the geology of southern York County, and no attempt will be made to describe them. The reader is referred to Billings' (1956) report on the bedrock geology of New Hampshire for such descriptions. Another body, the Saco pluton, shown in Figure 11 will not be described in this report because it lies mostly in the Buxton and Portland quadrangles north of the area of Plate I.

The single alkaline complex in this area is referred to as the "Agamenticus Complex" following the usage of Woodard (1957). Wandke (1922 a) originally proposed the term to apply to the composite igneous mass composed of the Webhannet pluton, the alkaline rocks in York Township, and the Tatnic complex. It seems appropriate to amend Wandke's usage and to retain the name "Agamenticus complex" for only the alkaline portion of the composite mass.

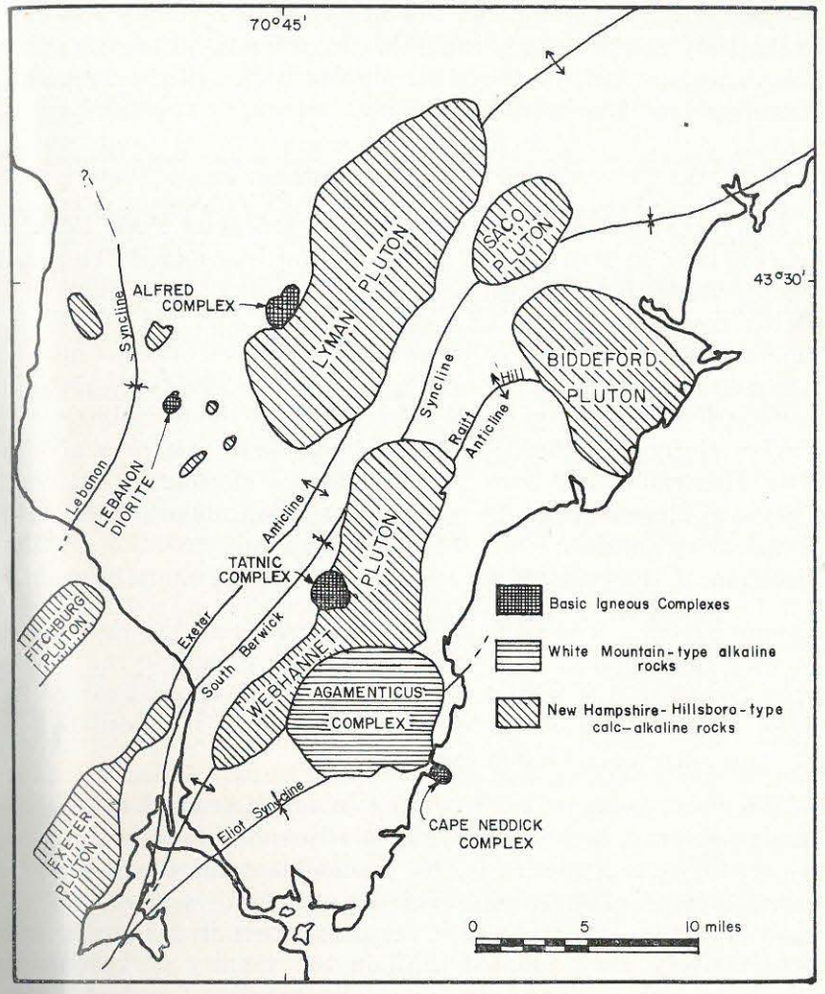

FIGURE 11. Sketch map of southwestern Maine showing major folds and igneous bodies.

Wandke originally applied the name "Berwick quartz diorite" to the rocks which in this report are called the "Tatnic complex." The complex is not situated in the town of Berwick but occupies that part of Wells and South Berwick called Tatnic. The dominant phase appears to be gabbro rather than quartz diorite. For these reasons it is more appropriate to refer to the body as the "Tatnic complex."

Wandke originally applied the name "Cape Neddick gabbro" to the body at the locality in York. In order to harmonize with the names adopted for the other similar bodies in the area, the term "gabbro" has been dropped and "complex" appended.

Major Elongate Plutons

The three major elongate plutons in southern York County are (1) the Lyman pluton in the Sanford-Lyman-Hollis area, composed mostly of biotite-muscovite granite; (2) the Biddeford pluton composed mostly of biotite granite; and (3) the Webhannet pluton composed of three associated rock types — quartz monzonite, biotite granite, and granodiorite. The three plutons are considered to be generally equivalent to the Fitchburg and Exeter plutons in New Hampshire which are members of the New Hampshire-Hillsboro plutonic series of Billings (1956). They are characterized by generally similar mineralogical and chemical composition, and by elongation and foliation in the direction of the regional structural trend of the metasediments.

Lyman Pluton. The Lyman pluton extends from the vicinity of Bauneg Beg Pond in Sanford north-northeastward to the Hollis area (north of the map area). The mass is approximately 20 miles long and 5 miles wide, and about 2/3 of it is situated in the southern York County map area.

The pluton is composed of a fine to medium-grained, light-gray to pinkish-gray, locally porphyritic biotite-muscovite granite. At its southern end, biotite is the predominant mica with only a minor amount of muscovite, and the granite here shows only a slight foliation. Northward it becomes richer in muscovite and progressively more foliated until in the vicinity of Lyman, it closely resembles the biotite-muscovite granites found at Freeport and Hallowell, Maine, and Concord, New Hampshire.

The foliation in general parallels the inferred contacts of the body and in the central part is parallel to the regional structural trend of the metasediments. North of the map area in Hollis Township, at the northern end of the body, the foliation is nearly east-west, parallel to the inferred northern contact of the granite. Near the southern end of Lyman Township, accessory magnetite grains up to ¼ inch in diameter are conspicuously scattered through the granite.

Small pegmatite and aplite stringers, similar in mineralogy to the main mass, are found in almost every outcrop of the Lyman pluton, but appear to be more abundant toward the margins of the body. In addition to the ubiquitous stringers, there are several large massive pegmatites that form relatively steep, bald knolls and hills. These pegmatites appear to be more common in the northern end of the pluton outside of the map area and are found both within the granite and outside in the surrounding metasediments. Small quantities of beryl have been found in some of the pegmatites, but no other rare or unusual minerals have been observed.

Biddeford Pluton. The Biddeford pluton, composed of a medium to coarse-grained, evenly-textured, light-gray to slightly pinkish biotite granite transitional to quartz monzonite, is considerably more homogeneous in texture, color, and composition than the other two major plutons. In the vicinity of Biddeford, the granite is essentially unfoliated, but near the coast it commonly shows moderate to strong foliation. The quartz in the coarser phases has a darker, more smoky appearance than that of the other granites.

Along the coast from Biddeford Pool to Kennebunkport, the continuity of the metamorphic rocks is interrupted by countless stringers of the Biddeford granite, varying from a few feet to several hundred feet in width. In some places the metamorphic rocks constitute only a minor part of the exposures. However, from a consideration of the attitude of bedding it would appear that the great majority of the isolated masses of metamorphic rocks have not been significantly rotated from their original attitude and hence represent roof pendants rather than stoped blocks.

A small exposure of medium gray, slightly porphyritic, fine-grained biotite-hornblende quartz diorite or granodiorite was noted close to the contact of the granite and the metasediments in the northeast part of the pluton. Time has not permitted further investigation of this body, but it would appear to be quite limited in size.

The Biddeford pluton is elongate in a northwest-southeast direction in contrast to the other two major biotite granites. The reason for this orientation will be discussed later under "STRUCTURE."

Several small pegmatites have been observed in the Biddeford pluton, northwest of Gooserock Beach, close to the southeast margin of the body.

Webhannet Pluton. The third major elongate body is a composite mass consisting of three closely related intrusive phases, biotite-hornblende granodiorite, porphyritic biotite-quartz monzonite, and non-porphyritic biotite granite. For this composite mass the writer proposes the name Webhannet pluton, derived from an old name for Wells Township. The Webhannet pluton extends from the northern corner of Eliot Township north-northeastward to the Wells-Kennebunk town line. The southern part of the mass is intruded and partially cut out by the alkaline complex in York Township.

Numerous blocks of the Kittery formation, the larger of which are shown on Plate I, are present in the three phases of the Webhannet pluton. The dips and strikes of bedding in the larger blocks are generally parallel to the regional structural trend suggesting roof pendants. Most of the smaller blocks, which are not shown on the map, appear to have been rotated from their original attitude. At a locality about 1½ miles south of Tatnic Hill, near the North Berwick-Ogunquit road, several outcrops over an area of about 2 acres expose fifteen to twenty small blocks of the Kittery formation with apparently random orientation of bedding. It is safe to infer that many more such blocks are actually present, but buried by the surficial cover. The abundance of blocks of the Kittery formation within the members of the Webhannet pluton suggests stoping as a possible mechanism of emplacement of these units although other evidence to be discussed under structure of the southern York County area suggests some form of more forceful injection.

Porphyritic Biotite Quartz Monzonite. The porphyritic biotite quartz monzonite member of the Webhannet pluton extends from Eliot Township northeastward into the Wells area where it is intimately associated with the granodiorite and the biotite granite. The quartz monzonite is characteristically medium to coarse-grained, light gray, strongly porphyritic, and locally foliated. The foliation is only weakly and locally developed, and for the most part the quartz monzonite is massive. The minerals present are quartz, microcline, plagioclase of composition about

An_{25}, biotite, and minor amounts of hornblende, with accessory sphene, magnetite, and apatite. In some parts of the quartz monzonite sphene is very abundant and occurs in idiomorphic grains up to 2 millimeters long, readily recognizable in hand specimen. The phenocrysts are composed of zoned plagioclase and range up to 2 inches in length but average about ½ to ¾ of an inch. The ratio of potash to plagioclase feldspar ranges considerably from one part of the body to another, but generally falls in the range between 1:1 to 2:1 placing it in the quartz monzonite field; in some places the amount of potash feldspar is great enough to place it in the granite field.

In the area where the town lines of York, South Berwick, and Wells meet, the quartz monzonite is coarse-grained, only slightly porphyritic, and pink, resembling to some extent the pink biotite granite member of the pluton. Although the pink material appears fresh a few inches beneath the surface, the color changes to the usual gray at depths of 4 to 6 feet beneath the surface (Swenson Granite Company, personal communication). As a consequence this pink material was considered to be only a local variant of the quartz monzonite and was not mapped separately. The color change from pink to gray seems to be gradational and not abrupt. One observation that may be significant is that the pink surficial color is developed only within ¼ to ½ a mile from the alkaline granite of the York complex. This might indicate that feeble contact metamorphic effects have caused some type of a change which allows the pink color to develop upon incipient weathering.

In a narrow zone along the eastern contact from a point one mile west-northwest of Ogunquit Village, northward to the Webhannet River in Wells, the rock is essentially an alaskite — very light colored, mafic-poor, and slightly more quartz-rich than the normal quartz monzonite. This rock type is not distinguished from the quartz monzonite on Plate I, but future studies may show it to be a separate phase.

Biotite Granite. Biotite granite occupies a crudely crescent-shaped area at the northern end of the quartz monzonite. It is well exposed on Bald Hill in Wells, where the granite has been extensively quarried. It is typically a uniform-textured, medium to coarse-grained, non-porphyritic pink biotite granite with no observed foliation. The minerals present are microcline, quartz

without undulatory extinction, plagioclase of composition An_{15-20}, biotite, and a minor amount of muscovite. Accessories include sphene, zircon, apatite, and opaques. In the few sections examined, the ratio of potash feldspar to plagioclase is consistently greater than 2:1, placing it well in the granite field.

In some areas, notably in the northeastern and southeastern ends of the body, the granite lacks the typical pink color, but its texture is distinctively like that at Bald Hill. Where it is pink, the color does not appear to give way at depth to gray as does that of the quartz monzonite mentioned above. At the Bald Hill quarry in Wells, both the color and texture are uniform to the bottom of the quarry, a depth of nearly 85 feet.

A small outcrop in a gravel pit at the southeastern corner of Merriland Ridge, 2 miles north-northwest of Tatnic Hill, exposes both the biotite granite and the quartz monzonite in intimate association with neither type chilled against the other. The intimate association suggests that both types are closely related as to time of emplacement. No other contacts between these two rock types have been observed inasmuch as the surficial cover is essentially complete over the inferred contact.

Granodiorite. Several bodies of intermediate composition ranging from basic quartz monzonite through quartz diorite are present within the limits of both the biotite granite and the quartz monzonite. They are grouped lithologically under the term granodiorite as this appears to be the average composition. The largest of these bodies lies on the northeastern and eastern sides of the Tatnic complex (see Plate I). The other bodies lie in the northern end of the biotite granite and quartz monzonite from the vicinity of Bald Hill eastward. Poor exposures in the latter area make it impossible to determine the true extent and relations of these granodiorite masses.

The granodiorite is typically fine-grained, medium gray, porphyritic, and slightly foliated. A local variant is an even-textured, non-porphyritic granodiorite. The minerals present are quartz, plagioclase of composition An_{35-40}, microcline, biotite, and hornblende, with accessory sphene, apatite, and opaques. Sphene is locally very abundant and readily recognizable in hand specimen. The phenocrysts are universally composed of plagioclase. The potash to plagioclase feldspar ratio is quite variable

from one body to another, and within a single body; for the most part it is usually about 1:2, on the border between quartz monzonite and granodiorite.

Fragments of the Kittery formation are locally very common. They average about 3 to 4 inches in length and appear to be randomly oriented.

Age Relations of the Granodiorite, Quartz Monzonite, and Biotite Granite. On the basis of general mineralogic similarity, and intimately associated nature, the quartz monzonite and granite are inferred to be closely related in age. It is tentatively felt that the granite is the younger of the two on the basis of the exposure at the gravel pit on Merriland Ridge.

The largest granodiorite body east of the Tatnic complex is unequivocally older than the quartz monzonite, and by inference, older than the biotite granite. At several localities southeast of Tatnic Hill, stringers and small dikes of quartz monzonite cut the granodiorite. At one locality ¾ of a mile south of Tatnic Hill where an isolated mass of the quartz monzonite has invaded the granodiorite, dikes of slightly chilled quartz monzonite can be seen in the granodiorite. The isolated masses of granodiorite within the biotite granite are probably equivalent to the larger mass. It is believed that the granodiorite masses are the remnants of an older more extensive and more basic pluton which was the forerunner of the quartz monzonite and biotite granite. It was in large part removed when the quartz monzonite and, slightly later, the biotite granite were emplaced.

Other Small Biotite-Muscovite Granite Bodies. Small masses of biotite-muscovite granite, mostly less than ½ mile in maximum dimension, are common throughout the outcrop area of the Rindgemere formation. Most of these are shown on Plate I. These minor bodies are extremely irregular in texture, some being almost pegmatitic; others, very fine-grained; some are highly foliated and might better be called granite gneiss, while others are essentially non-foliated.

Within the mapped area, these bodies are restricted to the Rindgemere formation, but north of the area they may be present in other formations of different lithology as well. The presence of these bodies may be related to the grade of metamorphism of the metasediments.

The following relations suggest a metasomatic origin for at least some of these minor bodies: (1) the metasediments surrounding them are characteristically feldspathized, sometimes grading into the biotite-muscovite granite body proper. (2) In many cases, the surrounding metasediments take on the appearance of a coarse-grained foliated pegmatitic gneiss. (3) The foliation of these bodies is continuous with and parallel to the general structural trends of the metasediments.

Agamenticus Complex

General Statement. Most of York Township and small parts of Wells and South Berwick Townships are underlain by moderately alkaline igneous rocks forming a roughly circular complex about 5½ miles in diameter, in marked contrast to the major plutons discussed above. Contacts are markedly discordant to the structure of the flanking metasediments. The complex was first mapped by Wandke (1922 a).

It should be emphasized that the Agamenticus complex has not been studied in detail during the present investigation. The relations described here have been obtained as a result of reconnaissance studies and may be revised with further investigation.

Four units of the Agamenticus complex are distinguished on Plate I. They are (1) alkaline syenite, (2) alkaline granite, (3) contaminated alkaline granite, and (4) porphyritic biotite granite.

Alkaline Syenite. The alkaline syenite is typically a medium to coarse-grained, even-textured, rather dark greenish gray, essentially non-porphyritic syenite containing such soda-rich dark minerals as arfvedsonite, riebeckite, aegirine, and aegirine-augite. Quartz is present, but usually in amounts less than 2%. Small amounts of accessory fayalite, sphene, and apatite are present. The feldspar is a microperthite and locally microantiperthite. In places the syenite contains appreciable amounts of biotite. The syenite is cut by numerous stringers and dikes of fine-grained, buff, aplitic material, and coarse greenish alkaline pegmatite.

Alkaline Granite. The alkaline granite is typically light buff-gray to light neutral gray, medium to fine-grained and relatively

even-textured. It contains the same soda-rich dark minerals as the alkaline syenite. It is characterized by euhedral to subhedral grains of microperthite, ranging to microantiperthite, between which occur quartz and the dark minerals. Alkaline granite is the dominant phase of the complex, underlying nearly ½ of the area on the northern, western, and southwestern sides of the complex.

Contaminated Alkaline Granite. Contaminated alkaline granite forms an irregular, ring-shaped zone which is located in places between alkaline granite and alkaline syenite, in places within the alkaline syenite, and at still other places, between the alkaline syenite and the flanking metasediments. In some areas the textures and colors are variable — resembling to some degree both the syenite and the granite. In such areas the amount of quartz varies moderately, with an average which is generally equivalent to a quartz syenite. In other areas, principally in the southeastern portion, blocks of fine-grained dark greenish-gray rock similar to the alkaline syenite are intimately associated with stringers of buff to salmon-gray, slightly quartz-poor alkaline granite.

These relations suggest that this zone was formed as a result of contamination of an alkaline granite magma by blocks of invaded, slightly older alkaline syenite. In part of the zone where evidence of two phases is lacking, and where the amount of quartz is intermediate between that of the alkaline granite and alkaline syenite, it would appear that assimilation of syenite blocks by alkaline granite magma proceeded further.

Porphyritic Pink Biotite Granite. The central part of the alkaline complex is occupied by a stock of biotite granite measuring approximately 3 miles by 2½ miles and elongate in a general northwest-southeast direction. This body is a fine- to medium-grained, porphyritic, light pinkish-gray biotite granite, with phenocrysts up to ½ inch long. It is non-foliated and the phenocrysts show no marked perferred orientation. As a general rule, this unit is more uniform in composition than the other members of the alkaline complex.

The minerals present are orthoclase, plagioclase of composition An_{20}, quartz, and biotite with minor amounts of zircon, apatite, and magnetite as accessories. The ratio of alkali to

plagioclase feldspar is greater than 2:1, placing it well in the granite range.

Actual contacts of this granite with the alkaline granite and alkaline syenite have not been observed, but because of the finer grain size as the contact with the other two units is approached, suggesting a chilled marginal phase, it is inferred to be younger than the alkaline units.

A small mass of similar granite of finer grain size, and not as markedly porphyritic crops out just east of the Maine Turnpike at a point about 2 miles north-northeast of Groundnut Hill in York Township.

Small Basic Complexes

General Statement. In southern York County three similar, internally complex, circular to elliptical basic bodies have been mapped. They are (1) the Cape Neddick complex in York, (2) the Tatnic complex on the western edge of the quartz monzonite of the Webhannet pluton in Wells and South Berwick, and (3) the Alfred complex on the western side of the Lyman pluton in Alfred. All three are characterized by generally similar basic rock types and strongly discordant cross-cutting contacts. A fourth body of this general type was located during the last field season on which this report is based. Preliminary examination of this body, which has been named the Lebanon diorite for convenience of reference, suggests that it is much simpler in structure and number of phases than the other three bodies.

Detailed structural and petrologic discussion of the Alfred, Tatnic, and Cape Neddick complexes is given by Hussey (1961) and consequently, only the general petrologic and structural features will be presented here.

Cape Neddick Complex. The Cape Neddick complex forms a generally elliptical body occupying the outer half of Cape Neddick peninsula in York Township. The complex is responsible for the position and prominence of the peninsula. Figure 12 shows the excellent exposures along the shore at the eastern tip of the Cape, which afford a chance for detailed study seldom available inland.

FIGURE 12. Outer (eastern) tip of Cape Neddick as seen from Nubble Lighthouse tower. Structure in the gabbro is roughly parallel to the lower edge of the photograph. Mount Agamenticus, Second Hill, and Third Hill appear in the right background.

The complex was previously studied by Wandke (1922 b) and to a limited extent by Haff (1939) in connection with his studies of the multiple dikes in the Kittery formation flanking the complex. Recently, students at the University of New Hampshire have made structural and petrologic studies in connection with senior projects. Wandke originally applied the name Cape Neddick gabbro to the complex. He distinguished three major lithologic units, (1) gabbro, (2) anorthosite, and (3) cortlandite. Haff did not map the internal phases of the complex, but recognized the breccia and the gabbroic pegmatite on the outer part of the Nubble, an island just off the eastern tip of the peninsula. He indicated that the breccia was composed of fragments of the Kittery formation.

As a result of the present investigation, five lithologic units have been distinguished and represented on the detailed map of the complex (Plate II). These are (1) medium to dark gray,

relatively uniform-textured, distinctly-layered, medium-grained gabbro, referred to for clarity in this report as "the normal gabbro," (2) a medium-grained, light gray, moderately to weakly layered, relatively uniformly-textured anorthositic gabbro, (3) medium-grained, very dark gray, weakly layered cortlandtitic gabbro, (4) a gabbroic pegmatite of extremely variable composition, texture, and grain size, probably closely related to the cortlandtitic gabbro, and (5) an agglomerate consisting of fragments of the Kittery formation, dikes within the Kittery formation, and possibly near surface volcanics (Figure 13).

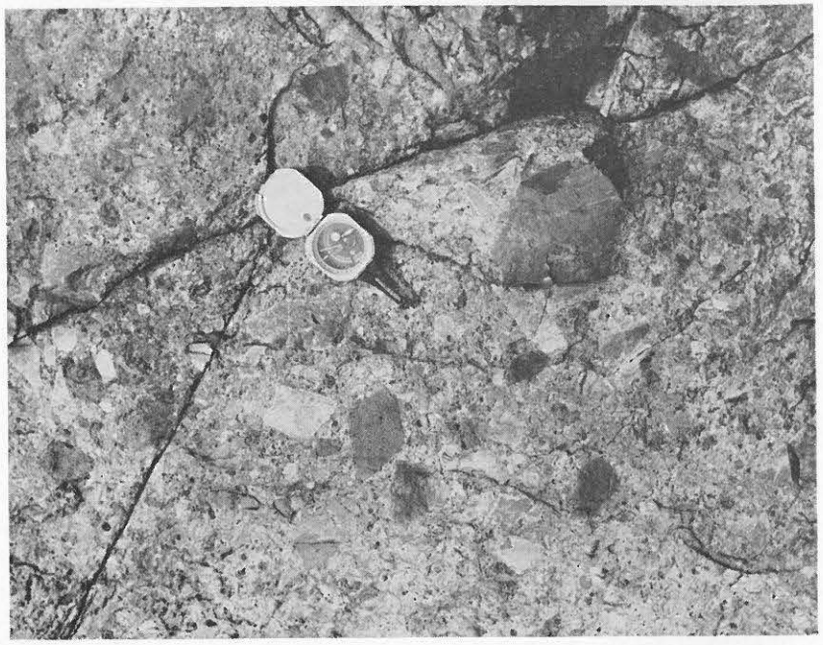

FIGURE 13. Volcanic agglomerate exposed on the outer side of Nubble Island, Cape Neddick, composed mostly of Kittery formation and dikes cutting it, but surface volcanics of varying types may also be represented.

The normal gabbro occupies a belt approximately 500 to 1000 feet wide along the outer portion of the complex. It is in contact on its outer side with the agglomerate on the Nubble and for a short distance on the southern side of the Cape, and with the Kittery formation on the northern side of the complex on the Cape. At nearly all places where observed, the contact of the normal gabbro with the country rock dips steeply inward.

The western and most of the southern parts of the contact are buried beneath a cover of glacial drift. On its inner side the normal gabbro is in contact with the anorthositic gabbro. The contact between the normal and anorthositic gabbros seems to be transitional in some places, but in others, especially the northeastern part, the contact is complicated by a zone of anomalous layering on one side of which is normal gabbro and on the other side of which is typical anorthositic gabbro.

The anorthositic gabbro occupies a generally concentric zone inward from the normal gabbro, but its continuity is interrupted by several apophyses of the cortlandtitic gabbro, the largest of which is exposed near the eastern edge of the Cape.

The cortlandtitic gabbro occupies the central portion of the complex. It also crops out as a crescent-shaped belt on the northern edge of the normal gabbro, and as two apophyses within the anorthositic gabbro (Plate II). Close to the contact with the anorthositic gabbro, it is essentially ultramafic in composition, with olivine, augite, hornblende, and ore minerals constituting nearly 80% of the rock. However, toward the center, it becomes considerably more feldspathic, but it still retains its poikilitic character throughout and fresh olivine is always present. The contact of the major mass of the cortlandtitic gabbro with the anorthositic gabbro is not exposed, but good exposures of the contacts of the largest of the apophyses of mafic gabbro with the anorthositic gabbro can be seen on the eastern end of the Cape. Here the outer contact is sharp, but the inner contact with the anorthositic gabbro is gradational over a distance of about 6 feet and is layered. Both contacts dip toward the center of the complex at about 50 degrees. This apophysis of the main body lacks the marginal concentrations of mafic minerals. Wandke (1922 b) originally mapped the apophyses and marginal ultramafic portions of this body as cortlandite, and considered the central part of the body as a part of the normal gabbro. This interpretation does not harmonize with the presently known distribution of the typical normal and anorthositic gabbros.

The gabbroic pegmatite is present only on the Nubble where it occupies a concentric band approximately 50 feet wide and 70 feet from the contact of the normal gabbro with the breccia. The pegmatite is surrounded by normal gabbro and both contacts dip steeply inward.

The agglomerate which contains fragments of the country rock and possibly of surface volcanics is exposed on the Nubble and on the southeastern tip of the Cape (Plate II). At other places the normal gabbro is in contact with the Kittery formation which may be locally brecciated in place, but the typical agglomerate of the Nubble is absent. The outer margin of the agglomerate is in contact with the Kittery formation. The contact appears to dip vertically and is transitional into undisturbed Kittery formation. The contact with the normal gabbro is locally sharp, but more commonly is gradational over a distance of about one foot, and the normal gabbro is only slightly chilled against the agglomerate. The agglomerate is interpreted as the remnant of a formerly more extensive explosion breccia, most of which was removed at the time the gabbro was emplaced.

All units of the complex except the agglomerate are layered to some degree. Toward the outer parts of the complex the layering is steep, but tends to become less steep toward the inner margin of the anorthositic gabbro. In the mafic gabbro, layering at the margins of the mass is relatively steep but becomes progessively gentler toward the general center of the mass. The layering of all units taken together describes a consistent concentric pattern with inward dips as shown in Plate II.

On the outer portion of the normal gabbro on the Nubble, and at places along parts of the contact between the anorthositic gabbro and normal gabbro, the layering shows patterns which resemble cross-bedded or channel-cut-and-fill forms except that they are oriented so that the tops of the forms point toward the outside of the complex. If these were produced as the result of convection currents as commonly hypothesized, it would be expected that the tops would be oriented toward the center of the complex, and in addition, that the layering would be relatively gentle and not steep as is the case for most of the Cape Neddick layering. The origin of these zones of anomalous layering is presently under evaluation and analysis and will be discussed in a later publication.

In various areas within both the normal and anorthositic gabbros, but not in the mafic gabbro, graded layering is present (Figure 14). In all cases the graded layers show concentrations of the mafic minerals toward the outside of the complex, indicating tops of the forms pointing toward the center. At every

FIGURE 14. Graded rhythmic layering in normal gabbro of the Cape Neddick gabbro complex. Mafic concentrations lie toward the outer side of the complex in each layer. This occurrence of graded layering is close to the contact with anorthositic gabbro on the northeast edge of Cape Neddick.

place observed, these graded layers dip at angles greater than 70 degrees. In addition, rhythmic, non-graded layering is present and is best developed in the anorthositic gabbro. Figure 15 shows very uniform, non-graded rhythmic layering exposed in the anorthositic gabbro along the eastern shore of the Cape.

The normal and anorthositic gabbros appear to have formed from the same magma, probably by a process of crystal sorting as suggested by the gradation from normal gabbro into progessively more anorthositic gabbro inward and "stratigraphically" upward. The cortlandtitic gabbro, however, is definitely a younger unit; at one locality along Cycad Avenue (location 1, Plate II) an angular fragment of the anorthositic gabbro is included in the cortlandtitic gabbro (Figure 16), and at different localities the anorthositic gabbro is cut by apophyses of the cortlandtitic gabbro. Because of the inward dip of the contacts and the arcuate pattern of the various units, the intrusive units of

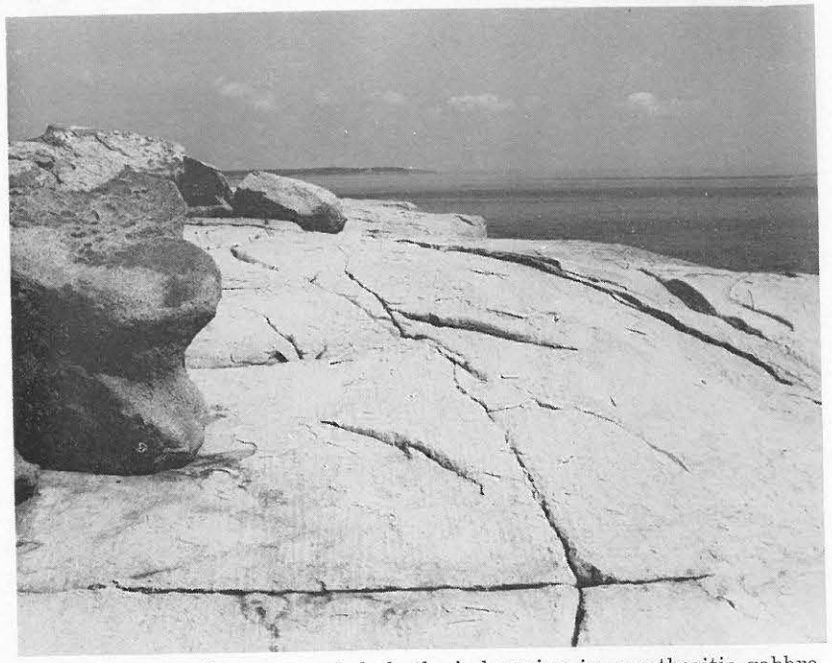

FIGURE 15. Uniform ungraded rhythmic layering in anorthositic gabbro, northeast edge of Cape Neddick peninsula.

the Cape Neddick complex are believed to have been emplaced by a process of cone-fracturing and upward displacement of the country rock. Two periods of cone-fracturing were involved — during the first period, the magma from which the normal and anorthositic gabbros formed was emplaced, and during the second, the cortlandtitic gabbro magma was emplaced. The apophyses of cortlandtitic gabbro represent portions of an inner cone sheet, and the belt of cortlandtitic gabbro in the northeast part of the normal gabbro is part of an outer cone sheet. The pegmatitic gabbro is believed to be due to alteration of normal gabbro by emanations arising along this outer cone-fracture.

Tatnic Complex. The Tatnic complex is a body approximately 1¼ miles in diameter located at the northwestern edge of the quartz monzonite of the Webhannet pluton in the towns of Wells and South Berwick. This complex was studied only briefly by Wandke (1922 a).

The following rock types have been delineated and are represented on the detailed map of the complex (Plate III): (1) gab-

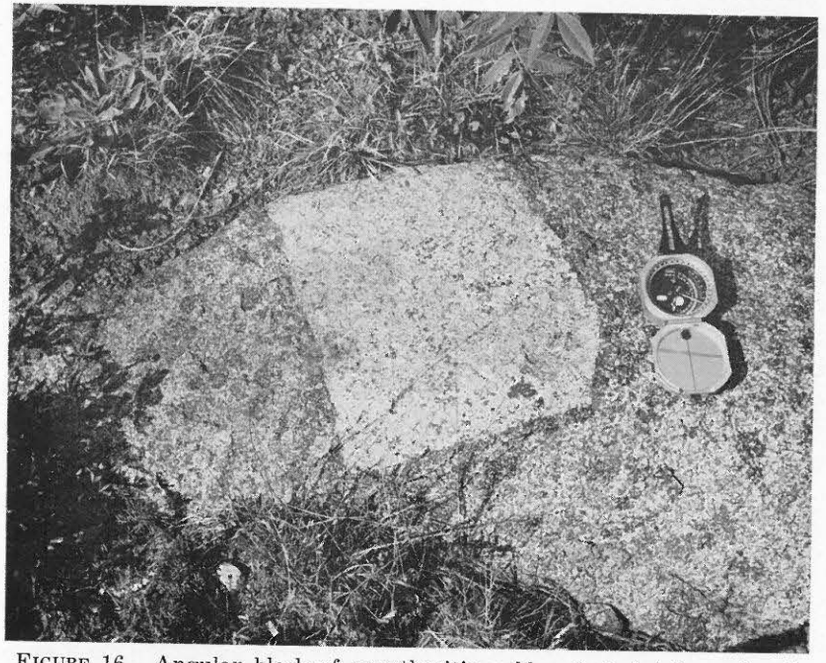

FIGURE 16. Angular block of anorthositic gabbro included in cortlandtitic gabbro, Cycad Avenue, Cape Neddick. Note the large poikilocrysts of hornblende in the cortlandtitic gabbro.

bro with dioritic tendencies, (2) anorthositic gabbro, (3) olivine gabbro, (4) poikilitic gabbro, (5) quartz diorite, and (6) undifferentiated volcanics. These units are complexly and intimately associated.

The gabbro is a dark to medium brownish-gray, fine-grained rock containing augite, biotite, hornblende and orthopyroxene for dark minerals. It is locally layered, but individual layers tend to be weak in comparison to Cape Neddick layering. Igneous lamination involving parallelism of tabular plagioclase plates is strongly developed throughout most of the body, and forms a centripetally dipping pattern toward the center of the complex. The gabbro is exposed around the margins of the complex except where cut out by olivine gabbro and quartz diorite.

Anorthositic gabbro is dark gray, medium to coarse-grained and essentially unlaminated and non-layered. It is probably comagmatic with the gabbro and is believed to form the crystal cumulate "stratigraphically" above that unit. The mineralogy

of the anorthositic gabbro is similar to that of the gabbro except for the relative quantities of the mineral species, and the more calcic composition of the plagioclase. It is exposed principally on the northwest side of the complex, inward from the gabbro.

The olivine gabbro is a very dark gray, fine-grained, relatively uniformly textured rock, feebly layered to non-layered. It is exposed in the southwestern part of the complex and throughout parts of the central portion where it has not been completely removed by the quartz diorite. Contacts of the olivine gabbro with the other phases of the complex have not been observed. However, considering the outcrop pattern of the different units, the olivine gabbro is older than the quartz diorite, but younger than the volcanics and normal gabbro, and possibly of the same age as the poikilitic gabbro.

The poikilitic gabbro, which may be a phase of the olivine gabbro, is exposed in two arcuate zones within the normal gabbro — one extending from Tatnic Hill northward for approximately one mile and the other extending along the top of Welch Hill in the northwestern part of the complex for a distance of about 1/3 of a mile. This unit is characterized by large poikilocrysts of hornblende up to 3 inches in diameter. In many places layering is present, but differs from that in the other gabbros. In this unit the layering is produced by the streaking-out of the hornblende poikilocrysts.

Patches of volcanics of various types, not differentiated on the map, are common throughout much of the southern 2/3 of the complex. Both flows and pyroclastics are represented and consist of such types as andesite porphyry, basalt porphyry, felsite porphyry, agglomerate and possibly some tuff. On the top of Brown Hill, on the western side of the complex, agglomerate resting on slightly rotated blocks of the Kittery formation is excellently exposed. It consists of fragments, ranging from a fraction of an inch up to one foot in diameter, of the rock types mentioned above plus fragments of the Kittery formation.

Quartz diorite has intimately intruded all other rock units of this complex. It is a light buff-gray, medium-grained biotite hornblende quartz diorite which weathers quite rapidly. Locally where it contains numerous digested fragments of volcanics or Kittery formation, it has been markedly contaminated forming a

hybrid of intermediate composition and color. In areas where relatively undigested, tabular fragments are common, they have a rather uniform concentric arrangement, with dips ranging from 60-70 degrees inward at the outer margin of the body to horizontal near the center. The orientation of these inclusions is shown in Plate III.

Alfred Complex. The Alfred complex underlies a series of arcuate hills on the northwestern side of the Lyman pluton near Alfred village. To the writer's knowledge, the geology of this complex has never before been studied.

The Alfred complex consists of four units: (1) noritic gabbro with dioritic tendencies, (2) anorthositic gabbro (not shown separately), (3) monzodiorite, and (4) porphyritic granodiorite (Plate IV). In addition, there are numerous blocks of the surrounding metasediments included in the marginal parts of the noritic gabbro.

The noritic gabbro is exposed as a crescent-shaped mass about 2 miles long by 1½ miles wide. It is fine to medium grained, relatively even-textured and consists of plagioclase of composition An_{45-55}, augite, hypersthene, biotite, hornblende, and opaque oxides with minor amounts of quartz, alkali feldspar, and apatite. Throughout all but the border portions of the body, the noritic gabbro possesses a very strong igneous lamination involving not only plagioclase, but also the dark minerals hypersthene and augite. Layering is present locally, but is generally non-graded and non-rhythmic. It commonly takes the form of short, discontinuous bands delineated by concentrations of mafic minerals and in some cases by concentrations of plagioclase. More layering would probably be observed were it not for the fact that the exposures have their greatest development parallel to the layers rather than across them. The igneous lamination describes a generally concentric pattern with gentle dips toward the center of the noritic gabbro as shown on the map of the complex (Plate IV). Layering where present, is parallel to the igneous lamination.

Anorthositic gabbro has been observed at several localities and appears to form a single layer, or possibly two layers, within the noritic gabbro. It is light gray, medium-grained, locally layered, essentially unlaminated, and is composed of plagioclase

of composition An_{65-75}, augite, hypersthene, and opaque oxides, with minor amounts of biotite, hornblende, quartz, alkali feldspar and apatite.

Monzodiorite and porphyritic granodiorite form a composite body approximately 1½ by 2½ miles, elongate in a northwest-southeast direction. This body has cut out part of the noritic gabbro. Monzodiorite forms an outer ring of the composite body and varies in width from ⅛ to ¼ mile; it also crops out as three isolated masses within the porphyritic granodiorite. The monzodiorite is medium grained, light gray and generally unstructured, but locally it shows a crude igneous lamination like that of the noritic gabbro. Minerals present are plagioclase, biotite, hornblende, quartz, and alkali feldspar with minor amounts of apatite, augite, hypersthene, and zircon. Inclusions of metasediments ranging from ½ to 8 inches and averaging about 3 inches are common throughout many parts of the quartz diorite. Due to the lichen cover of most outcrops it was not determined whether orientation of these inclusions exists.

Porphyritic granodiorite occupies the central part of the composite body. It is typically fine-grained, with phenocrysts of plagioclase up to ¼ inch in length. In thin section, quartz and alkali feldspar are a little more abundant than in the non-porphyritic monzodiorite. The porphyritic granodiorite contains few if any inclusions.

The monzodiorite is older than the porphyritic granodiorite. At one point where the contact between the two is exposed, the latter is chilled against the former. The monzodiorite is definitely younger than the noritic gabbro based on areal distribution of both rock units, and the presence of numerous noritic gabbro inclusions in the quartz diorite near the Bennett Quarry at the southeastern end of the body. Although the age relations of the anorthositic gabbro to the laminated noritic gabbro are not clear, it appears that they are essentially of the same age.

The metasediments surrounding the Alfred complex are not well exposed. Some of the inclusion of the metasedimentary rocks in the noritic gabbro are composed to a large extent of sillimanite-cordierite gneiss. Similar gneisses have been observed outside the complex close to the contact but have not been found elsewhere. Granular lime silicate gneisses are present on the

northern margin of the complex on Yeaton Hill, but have not been observed elsewhere around the complex. On the northwestern side of the complex, the metasediments are mostly of the Rindgemere type with occasional masses of gneissic muscovite-biotite granite.

Lebanon Diorite. The Lebanon diorite crops out as an irregularly shaped body in the northwestern end of Lebanon Township. Inasmuch as it is largely covered by glacial drift and swamp deposits, little is known about lithologic variations or structure within this body. From what has been seen, it appears to be a relatively simple diorite with no appreciable lamination or layering. In one exposure in a rotten rock pit, fresh diorite is overlain by 15+ feet of weathered diorite and this is in turn overlain by about 3 feet of glacial drift. Other exposures ⅛ mile away show fresh diorite to the surface, with the exception of a thin weathering selvage about 3 inches thick.

Dikes

The fourth major group of igneous rocks is composed of numerous dikes ranging in composition from diabase and basalt to rhyolite. They are most abundant in the coastal areas and tend to become scarcer inland; in the vicinity of Berwick and Sanford, they are rare.

These dikes have not been studied in thin section by the writer, but from published accounts of previous investigators (Keeley, 1914, 23; Powers, 1915; Wandke, 1922a; and Haff, 1939, 41, 43) the following types among others are represented: basalt, olivine basalt, rhyolite, diabase, trachyte, bostonite, tinguaite, camptonite, paisanite, granophyre, and aplite.

Along the coast from Bald Head Cliff, York, to Perkins Cove, Ogunquit, the writer has distinguished two general age groups of dikes. Dikes of the older group are the more numerous, range in thickness from 6 inches to 50 feet, and tend to be intruded parallel to the bedding or nearly so. Only a few of them cut across the bedding of the metasediments at large angles. Dikes of the older group are more diversified as to type and texture, and they commonly show strong textural and compositional layering parallel to their contacts. Occasional multiple dikes with granitic centers are present. Within the older group, several

subgroups based on cutting relationships, can be recognized locally.

The younger group of dikes consists of rather narrow dikes that transect the bedding and the dikes of the older group at nearly right angles. Only one rock type appears to be represented — basalt — which characteristically weathers to a deep rusty color. Dikes of the younger group do not enter into multiple relationships with other dikes.

Inclusions of various rock types, principally granite, and the host metasediments are common, especially in the dikes of the older group. They commonly are restricted to a zone in the center of the dike. In one small dike halfway between Bald Head Cliff and Perkins Cove, a central zone carries numerous fragments of garnet gneiss, granulite, and graphitic gneiss, which are unlike any of the metasediments in the general vicinity. This dike and two others adjacent to it are shown in Figure 17.

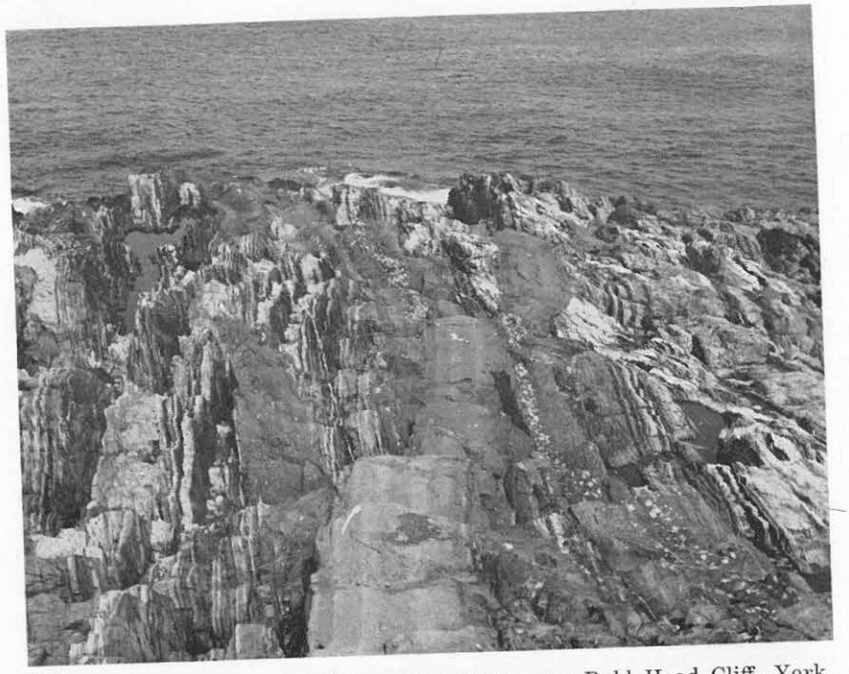

FIGURE 17. Thin bedded Kittery formation near Bald Head Cliff, York, cut by three basaltic dikes, one of which has central zone of inclusions of coarse garnet gneiss, graphite schist, and actinolite granulite. Note the zonation in the dike in the center foreground.

Approximately 1.2 miles east-southeast of Tatnic Hill a dike nearly 100 feet wide cuts the quartz monzonite. It has a medium grained diabasic texture in the central portion and has developed a contact metamorphic zone in the quartz monzonite approximately one foot wide.

A prominent diabase dike cuts the breccia zone in the Rye volcanics near the southeastern tip of Gerrish Island. This dike is approximately 100 feet wide, and can be followed along strike for a distance of approximately 1000 feet before it disappears beneath a surficial cover. By the fact that it is younger than the breccia which involves older dikes, this dike may possibly be correlative with one of the phases of the Cape Neddick complex.

Approximately one mile due west of Moody Point in Wells there is a diabase dike approximately 100 feet wide, striking about N 20°E, generally parallel to the local structural trend. This dike, which is choked with inclusions of vein quartz up to one foot in length and occasionally fragments of granite and the Kittery formation, can be followed along strike for over 2000 feet.

In the part of Wells Township referred to as Wells Branch, there is a poorly exposed mass of dark gray, fine to medium grained diabasic-textured gabbro which intrudes the biotite granite of the Webhannet pluton. From the known distribution of outcrops, this body is at least 300 feet wide and 1000 feet long. Like the Lebanon diorite, it is deeply weathered with one rotten-rock pit showing 8+ feet of residually weathered gabbro which preserves the textures and structures of the fresh rock. Although this body is represented on Plate I by the symbol for the basic complexes, it may be correlative with the group of dikes.

Age Relationships of the Major Intrusive Groups

General Statement. Relative ages of the major intrusive groups may be determined in the following ways: (1) cutting relationships seen in actual outcrops, (2) outcrop pattern of rock types such as would indicate that one type cuts another, (3) similarity of sequence of intrusive types, (4) similarity of structural characteristics, (5) gross lithologic similarities, and (6) cutting relationships involving the older group of dikes.

Elongate Plutons. The Webhannet, Lyman, and Biddeford plutons are believed to be generally equivalent in age, based on the

following lines of evidence: (1) the general textural and compositional similarity, and (2) elongation of these bodies parallel to the regional structural trends of the flanking metasediments. These bodies are regarded as late tectonic masses, correlative with the New Hampshire-Hillsboro plutonic series of Devonian age. A date of 300 million years obtained by Lyons, et al (1957) for the Biddeford pluton, lends strength to this belief.

Agamenticus Complex. The Agamenticus complex is a post-tectonic intrusive association clearly younger than the elongate plutons. In the South Berwick area, the alkaline granite member of this association intrudes and cuts out a considerable portion of the quartz monzonite of the Webhannet pluton. Actual contacts of the two rock types observed along the northeastern edge of the alkaline granite show alkaline granite slightly chilled against the pink-weathering quartz monzonite. Because of the alkaline nature of these rocks and their sharply discordant structure, the Agamenticus complex is considered to be equivalent to the White Mountain plutonic-volcanic series of New Hampshire, of Permian or later age (Toulmin, 1961).

Basic Complexes. The Cape Neddick, Tatnic, and Alfred complexes and the Lebanon diorite are believed to be closely related in age and genesis on the basis of (1) similarity of the intrusive rock types — gabbros and diorites, (2) generally circular to elliptical outlines, (3) strongly discordant, cross cutting contacts, and (4) lack of post-intrusion deformation.

The Tatnic and Alfred bodies are clearly younger than the calc-alkaline plutons based on their areal distribution with respect to the quartz monzonite of the Webhannet pluton and to the Lyman pluton respectively. By association, the Cape Neddick complex is also younger than these masses.

There remains the question of the ages of these bodies with respect to the Agamenticus complex. Here the cutting relationships of the major group of dikes with respect to the Cape Neddick complex and alkaline granite are of paramount importance. At York Beach in the vicinity of the mouth of the Cape Neddick River, numerous diabase dikes cut the alkaline granite or apophyses of the alkaline granite and nowhere is the reverse — diabase dikes cut by alkaline granite — observed. However, on Cape Neddick peninsula, all diabase dikes are cut by the normal

gabbro of the Cape Neddick complex. There is no reason to suspect that these dikes on the Cape belong to another group than those in the vicinity of Cape Neddick River; on the contrary, they are similar in structural habit, abundance, and general rock types. Thus it is concluded that the Cape Neddick complex and, by association, the Tatnic and Alfred complexes are younger than the Agamenticus complex.

Toulmin (1961) has recently reviewed the radiometric ages of the alkalic rocks of New England and suggests that at least two groups of alkalic rocks exist with ages of about 185 and 270 million years. If this distinction is real, it may be that the rocks of the Agamenticus complex belong to the older group, and the rocks of the basic complexes are members of the younger group.

Dikes. The major group of dikes which are so abundant in the metasedimentary formations in the coastal portions of the map area are believed to be generally of the same age, intermediate between that of the York alkaline complex and that of the gabbro complexes. Dikes of this group are known to cut all the metasedimentary formations and all the igneous rock bodies with the exception of the gabbro complexes. There are minor dikes within all the units of the basic complexes, but these are believed to be related to the complexes and not to be part of the major group of dikes. At present no age can be assigned to this major group of dikes.

STRUCTURE OF THE METASEDIMENTS

The structure of southern York County is relatively clear and is shown in Figure 11 and on section A-A′ and B-B′ of Plate I. The area lies on the northwest limb of the Rockingham anticlinorium, the axis of which is located in the Rye Beach area, New Hampshire, and on the southeastern limb of a synclinorium, the axis of which is the Lebanon syncline occupied by the Towow formation. The formations progress from the Rye on the east, through the Kittery, Eliot, Berwick, Gonic, and Rindgemere to the Towow on the west.

In the southern half of the map area (Plate I) the following major folds are present, delineated principally by the map pattern of the formations involved, particularly the Eliot formation:

(1) The Eliot syncline, plunging southwest and extending northeastward through the town of Eliot to the margin of the Agamenticus complex. The Eliot syncline is a branch of the Great Bay syncline in New Hampshire (Billings, 1956).

(2) The Raitt Hill anticline, a broad southwest-plunging flexure separating the two branches of the Great Bay syncline. In Maine this anticline is largely occupied by the southern prong of the Webhannet pluton and may be due to doming by forceful injection of the quartz monzonite of the pluton. In New Hampshire, the anticline dies out in the vicinity of Great Bay.

(3) The South Berwick syncline, a doubly plunging structure culminating in the vicinity of Dover, New Hampshire. In the South Berwick area this fold plunges to the northeast, but south of Dover, New Hampshire, it plunges south-southwest, merging with the Eliot syncline to form the Great Bay syncline where the Raitt Hill anticline dies out.

(4) The Exeter anticline, plunging to the northeast and extending northeastward between Berwick and South Berwick. In New Hampshire the core of the anticline is largely occupied by the Exeter pluton.

(5) The Lebanon syncline, a doubling plunging structure in which the Towow formation is preserved. This syncline is complicated by two small satellite anticlines and synclines.

Only general dips of the limbs of these structures are shown on section A-A′ Plate I. Local dips, however, are steep due to the superposition of minor, nearly isoclinal, folds on the major folds.

Folds in the northern half of the map are not so clearly indicated because of the lack of outcrops in key areas. However, from work now in progress by the writer in the Buxton and Portland quadrangles to the north of the map area, a syncline plunging southwest must be the major structure between the northern end of the Biddeford pluton and the Lyman pluton. This would represent the northern extension of the South Berwick syncline.

The southeastern limb of the syncline in the vicinity of West Kennebunk appears to be complicated by a series of minor anticlines and synclines. The Exeter anticline appears to be occupied by the Lyman pluton. The Raitt Hill anticline, sharply overturned to the northwest (section B-B′, Plate I) extends in an arc convex to the northwest from the Webhannet pluton to the Biddeford pluton. The Eliot syncline apparently passes out to sea, probably in the vicinity of Ogunquit, Maine.

General structural trends are quite uniform in the southern half of the map area, ranging from N 60° E in the Kittery-Eliot-York area to N 20° E in the Wells area. Between Wells and Kennebunkport the structure trends change from N 20° E to east-west, and finally to nearly north-south at the edge of the Biddeford pluton. The Biddeford pluton is elongate generally parallel to this divergent trend. It is probable that the pluton was not the cause of the divergence but was merely emplaced along a favorable structural site afforded by this divergence. On the northern side of the pluton the trend is approximately N 70° W but gradually becomes a more normal northeasterly trend just north of the map area. In the Lebanon-Acton area, the structural trend is variable but there is a tendency for a swing to the northwest.

Dips of cleavage, bedding, and gneissic foliation are usually steep to the northwest. Between Kennebunk and West Kennebunk, however, bedding in the Kittery formation on the southeast limb of the Raitt Hill anticline dips very gently southeast (10 to 20°).

Minor folds with vertical to steeply-dipping axial planes are very common in the Kittery formation and can best be observed in coastal exposures from Kittery to Biddeford Pool. Figure 18 shows minor folds typical of the Kittery formation in the vicinity of Bald Head Cliff in York. Inland, crests or troughs of minor folds are seldom seen in any of the metasediments, but the folds are inferred to be present in a similar manner. In places, they can be inferred from such evidences as local changes in dip and strike, minor drag folding, and graded bedding.

Minor faults and shear zones are commonly observed along the coastline, but none was observed with apparent displacement of more than a few feet. Many of the faults are marked by deep

FIGURE 18. Minor folds in thin-bedded Kittery formation near Bald Head Cliff, York. Note how the light colored competent beds have been broken into tablets parallel to the cleavage and "intruded" by the darker-colored incompetent units.

iron staining, resulting from the weathering of minute pyrite grains, and coarsely crystalline calcite is commonly present along the fault surfaces. Many of these faults cut both the metasediments and the older set of diabasic dikes in the metasediments.

On Israel's Head in Ogunquit, there is a minor structure of marked divergence from the normal northeast trend of the area. Details of this structure are extremely confusing. In general, the dips and strikes are nearly at right angles to the regional trend and would seem to represent plunge rather than dip of a limb of a major fold. This may represent the northeastern extension of the trough of the Eliot syncline. Part of this structure resembles a small-scale nappe. Graded bedding indicates that many of the beds are inverted, and a few major recumbent drag folds show long inverted limbs and short upright limbs.

ECONOMIC GEOLOGY

Relatively little mineral production comes from southern York County at the present time. The mineral industry of the area, excluding the use of water and the stripping of sand and gravel, is restricted to granite quarrying and brick manufacture. Granite is quarried from two openings operated by the Swenson Granite Company of Concord, New Hampshire. The oldest of these is the Bald Hill Quarry in Wells, where uniform-textured pink biotite granite of the Webhannet pluton has been produced for over 35 years. The other opening is the Pine Hill Quarry in York, Maine, which was opened by the company in 1958 in the typical green phase of the alkaline syenite of the York alkaline complex. Bricks are manufactured by the Morin Brothers Company of Eliot, Maine. The raw material is obtained from a local pit developed in post-glacial marine clay.

Early in this century, granite was actively quarried throughout southern York County. There were several quarries in Alfred, Biddeford, Wells, South Berwick, and Arundel, locations and additional information on which are given by Austin and Hussey (1958).

During the 1870's and early 1880's, a series of adjacent prospects along Little River in Acton and Lebanon Townships were opened for silver, lead, and zinc. Sphalerite, galena, and some chalcopyrite are associated with vein quartz, arsenopyrite, pyrite, and pyrrhotite for a considerable distance along the stream. This vein quartz may represent a silicified fault zone in the upper part of the Rindgemere formation. Mining activity was short-lived due to low grade and narrowness of the ore veins. Further details on the individual prospects and mines of the Acton silver district are given by Hussey and Austin (1958).

Southern York County is an area worthy of future exploration for mineralization. Lack of interest in the past in the mineral potential of the area has largely been a result of scarceness of outcrops, particularly of the metamorphic rocks that might well be host rocks of mineralization. Few traces of mineralization have been seen in the existing outcrops. However, with the various geophysical and geochemical prospecting techniques available today, we are able to obtain some idea of the mineral potential of areas where bedrock is concealed by surficial cover. It

might be rewarding to employ such methods in southern York County. An airborne magnetometer survey of the Berwick quadrangle already has been prepared by the U. S. Geological Survey (Bromery, et al., 1956) and shows several moderate magnetic anomalies in Lebanon and Acton Townships which, in general, are related to the sulfide-rich and carbonaceous (?) rocks of the Towow and upper Rindgemere formations. Another anomaly of moderate intensity extends along the inferred northwestern contact of the Gonic formation with the Rindgemere formation. No information has been obtained to date to shed light on the possible cause of this anomaly. Both areas are worthy of further geophysical and geochemical study.

GEOLOGICAL HISTORY

General Statement. The first events of the geologic record in southern York County involved deposition of the sediments of the Rye, Kittery, Eliot, Berwick, Gonic, Rindgemere, and Towow formations during the geosynclinal phase of the geologic history. Major breaks in this sedimentary sequence are believed not to be present, but without paleontologic evidence, this is an inference rather than an established fact. As mentioned previously, the ages of the different formations are tenuously, and tentatively, established on the basis of long range lithologic correlations to fossiliferous areas.

Geosynclinal Stage. The geologic record of the area begins with the deposition of interbedded volcanics and sediments of the Rye formation during some part of Ordovician (?) time. The volcanic activity appears to have been more in the form of eruption of pyroclastics than of flows. The earliest of the volcanics were of rather basic character — probably andesitic — but rapidly changed with time to rhyolitic types. The sediments deposited contemporaneously with the volcanics were generally of an argillaceous nature, although fine-grained sandy materials are represented. At one stage in the sedimentation, deposition of the acid volcanics ceased and carbonaceous argillaceous sediments accumulated, followed by a period in which a thin limestone unit formed. After this event, deposition of acid volcanics and argillaceous sediments resumed and continued until sedimentation of the Kittery type began.

In early Silurian (?) time, pyroclastic volcanic activity ceased and the Kittery sediments were deposited. The well developed graded bedding of the Kittery sediments suggests that deposition may have been brought about by the action of turbidity currents. The thickness of sediments deposited during Kittery time is not known but was considerable.

Later in Silurian (?) time, Kittery sedimentation gave way to Eliot type sedimentation, differing from the former in the paucity of quartz supplied to the basin of deposition, and consisting of rather chloritic and aluminous argillaceous materials. Deposition of Eliot sediments may also have been brought about by turbidity current action.

Toward the end of Silurian (?) time, Berwick type sedimentation appeared. It differed from Eliot type in that quartz again became more abundant, and limy or dolomitic beds were more commonly formed, and aluminous materials were lacking. Chloritic materials were still dominant and gave rise later to biotite-rich metasediments.

In early Devonian (?) time, Berwick-type sedimentation abruptly gave way to deposition of alumina-rich argillaceous materials which through metamorphism gave rise to the present muscovite phyllites and schists of the Gonic, Rindgemere, and in part, the Towow formation. Such argillaceous sediments characterized the remaining history of sedimentation.

Post-Towow sedimentation is not recognized.

Tectonic Stage. No field evidence seen during the period of investigation indicates any tectonic activity related to the Taconic disturbance of Late Ordovician time, although the volcanic activity associated with the Rye formation may be a side effect (assuming that the formation is of Ordovician age). It has been concluded that the deformation of the area is related to the Acadian revolution which took place during Middle or Late Devonian time. The sedimentary rocks were first deformed into relatively broad, open major folds. As the tectonic intensity increased, minor folds and drag folds were superimposed on the larger folds and the sedimentary rocks were metamorphosed. Toward the close of the tectonic stage, after the forces had largely subsided, large masses of calc-alkaline granitic material

were emplaced to form the various plutons of the New Hampshire-Hillsboro plutonic series. These were late tectonic rather than syntectonic masses on the basis that they show only slight foliation. Some of the minor granitic bodies which are restricted to the Rindgemere formation may have formed at a slightly earlier time during or shortly after the peak of metamorphic activity.

Post-Tectonic Stage. The next events took place in the final phase of the geologic history — the post-tectonic stage. The members of the Agamenticus complex were emplaced some time after the Late Devonian, possibly during Permian or Triassic time.

The ages of the remaining post orogenic events are speculative. Following the emplacement of the alkaline complex, the great majority of the basaltic to rhyolitic dikes were probably injected within a relatively short period of time. Previous investigators have suggested a Triassic age for similar dikes elsewhere, but this deserves further study.

After an unknown lapse of time, volcanic activity was resumed. The breccia zones on Gerrish Island, the volcanic breccia associated with the Cape Neddick complex and the volcanics associated with the Tatnic complex are believed to have been formed at this time. As the volcanic activity became more intense, basic magmas were injected and through processes of crystallization differentiation gave rise to the different phases in the various basic complexes. The Lebanon diorite probably belongs to this period of magmatic activity. The age of this activity is unknown. The intrusion of the basic magmas and their subsequent solidification brought to a close the bedrock history of the area. Since that time, the southern York County area has undergone extensive denudation and, recently, glaciation and post-glacial marine sedimentation.

ACKNOWLEDGMENTS

This investigation was sponsored by the Maine Geological Survey. In addition, that part dealing with the Cape Neddick, Tatnic, and Alfred complexes was undertaken as a Ph.D. dissertation at the University of Illinois. The writer sincerely acknowledges the suggestions made by the following visitors in the field: Robert G. Doyle, State Geologist; John R. Rand, former State Geologist; Professor Carleton Chapman, University of Illinois; Professor Marland P. Billings, Harvard University; Professor Marc Bodine, Bowdoin College; Professor Wakefield Dort, Jr., University of Kansas; and Webster F. Stickney, Maine Geological Survey. The writer is indebted to Nathaniel Sage, chairman of the Department of Geology at the University of New Hampshire, and to Henry Gaudette, William Eldridge, William Perkins, and Richard Smith for many stimulating discussions on the geology of this area and adjacent parts of New Hampshire. Mr. Doyle and Mr. Stickney offered many helpful suggestions and rendered assistance in the preparation of the manuscript and map. Professor Philip H. Osberg, University of Maine, Mr. Doyle, Professor Billings, and Professor Chapman have kindly read and criticized the manuscript.

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GEOLOGIC MAP OF SOUTHERN YORK COUNTY, MAINE

by Arthur M. Hussey II

MAINE GEOLOGICAL SURVEY
DEPARTMENT OF ECONOMIC DEVELOPMENT
Robert G. Doyle, State Geologist

APPROXIMATE MEAN DECLINATION, 1958

SCALE 1:62 500

Geology of adjacent parts of New Hampshire shown without color, modified after M. P. Billings (1956, Report on the bedrock geology of New Hampshire.

EXPLANATION OF SYMBOLS

IGNEOUS ROCKS

Permian (?) and later

- g — Gabbro and associated basic rocks. — Post-White Mountain plutonic-volcanic series (Cape Neddick, Tatnic, and Alfred complexes, Lebanon diorite and gabbro at Wells Branch.)
- pbg — Pink porphyritic biotite granite
- cag — Contaminated alkaline granite
- ag — Alkaline granite
- as — Alkaline syenite
- — White Mountain plutonic-volcanic series (Agamenticus complex)

Late Devonian

- bg — Biotite and biotite-muscovite granite and associated pegmatites
- qm — Quartz monzonite
- gd — Granodiorite
- — New Hampshire-Hillsboro plutonic series (Lyman, Biddeford, and Webhannet plutons, and small bodies in Southern York County, Fitchburg and Exeter plutons in New Hampshire.)

METAMORPHIC ROCKS

Early Devonian?

- Dt — Towow formation
- Dr — Rindgemere formation
- Dg — Gonic formation

Silurian?

- Sb — Berwick formation
- Se — Eliot formation
- Sk — Kittery formation

Ordovician?

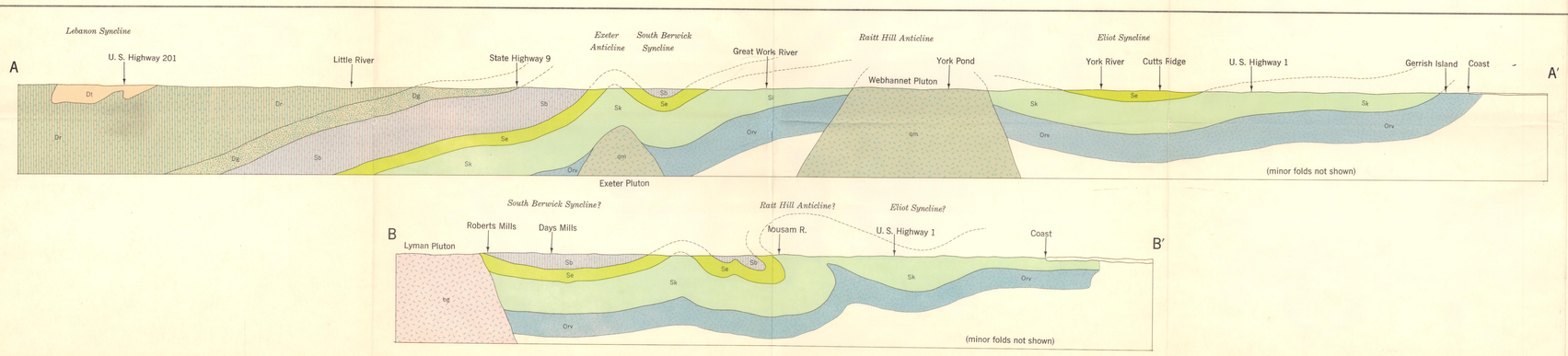
- Orv — Rye formation metavolcanic member

- Strike and dip of bedding
- Strike and dip of overturned bedding
- Strike of vertical bedding
- Strike and dip of cleavage or schistosity
- Strike of vertical cleavage or schistosity
- Contact accurately located
- Contact approximately located
- Contact gradational
- Quarry

(Note: Only a few of the field readings of structure are represented on the map.)

Base map from U.S. Geological Survey 15' series; York, Me-NH (1956), Berwick, Me-NH (1958), Dover, NH-Me (1916), Kennebunk, Me (1956), and Biddeford, Me (1956).
Compiled (1961) by James W. Sewall Company, Old Town, Maine.

Williams & Heintz Map Corporation, Washington 27, D.C.



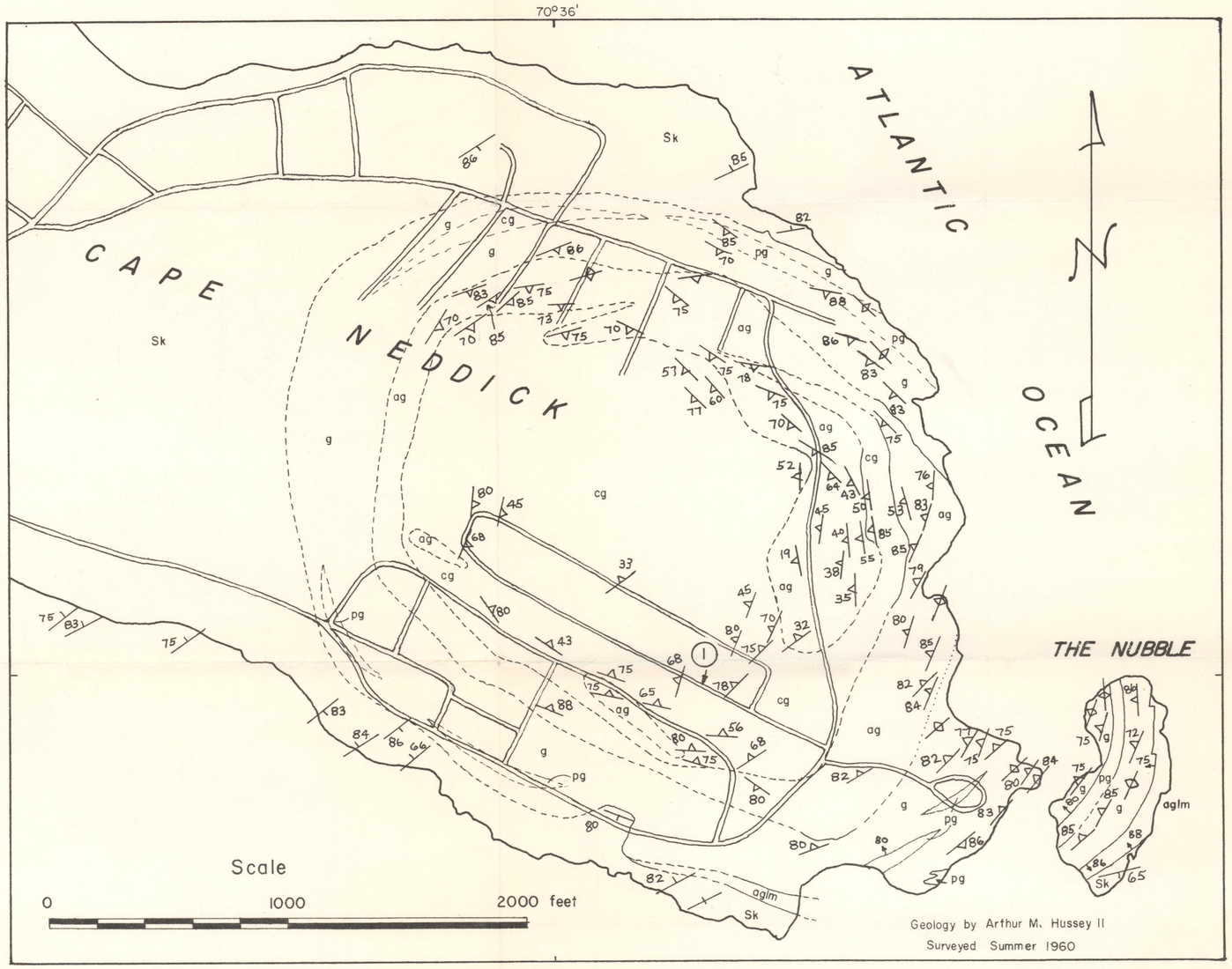
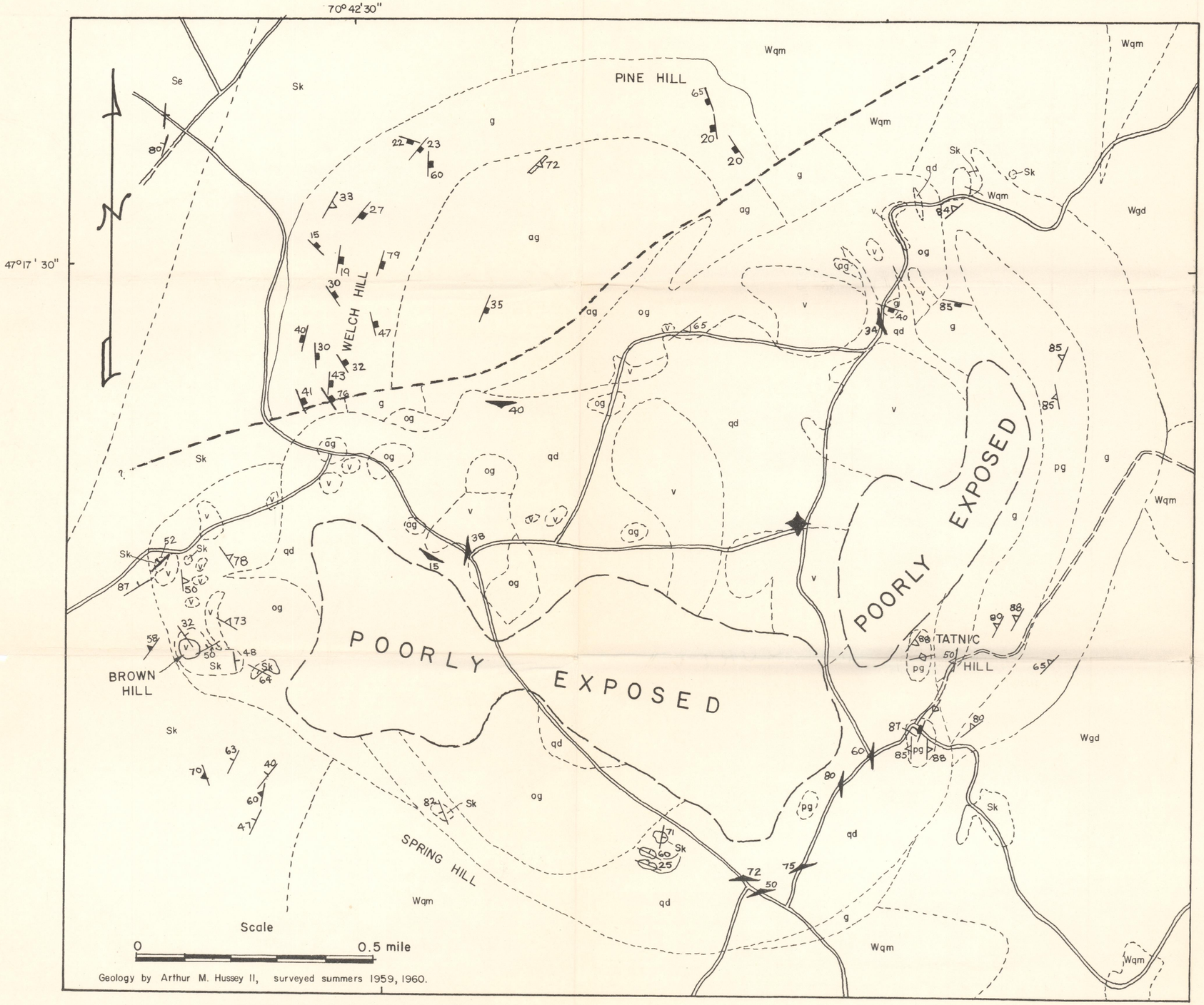


PLATE II. GEOLOGIC MAP OF THE CAPE NEDDICK COMPLEX, YORK, MAINE.

EXPLANATION OF SYMBOLS

cg	Cortlandtitic gabbro	CAPE NEDDICK COMPLEX	Triassic (?)
pg	Pegmatitic gabbro		
ag	Anorthositic gabbro		
g	Gabbro		
aglm	Agglomerate		
Sk	Kittery formation		Silurian (?)

- 80 — Dip and strike of bedding } of the Kittery formation
- Strike of vertical bedding } of the Kittery formation
- 70 — Dip and strike of layering } of the Cape Neddick complex
- Strike of vertical layering } of the Cape Neddick complex
- 80 — Contact accurately located, and dip
- Contact approximately located
- Gradational contact
- (1) Location of outcrop shown in Fig. 17



EXPLANATION OF SYMBOLS

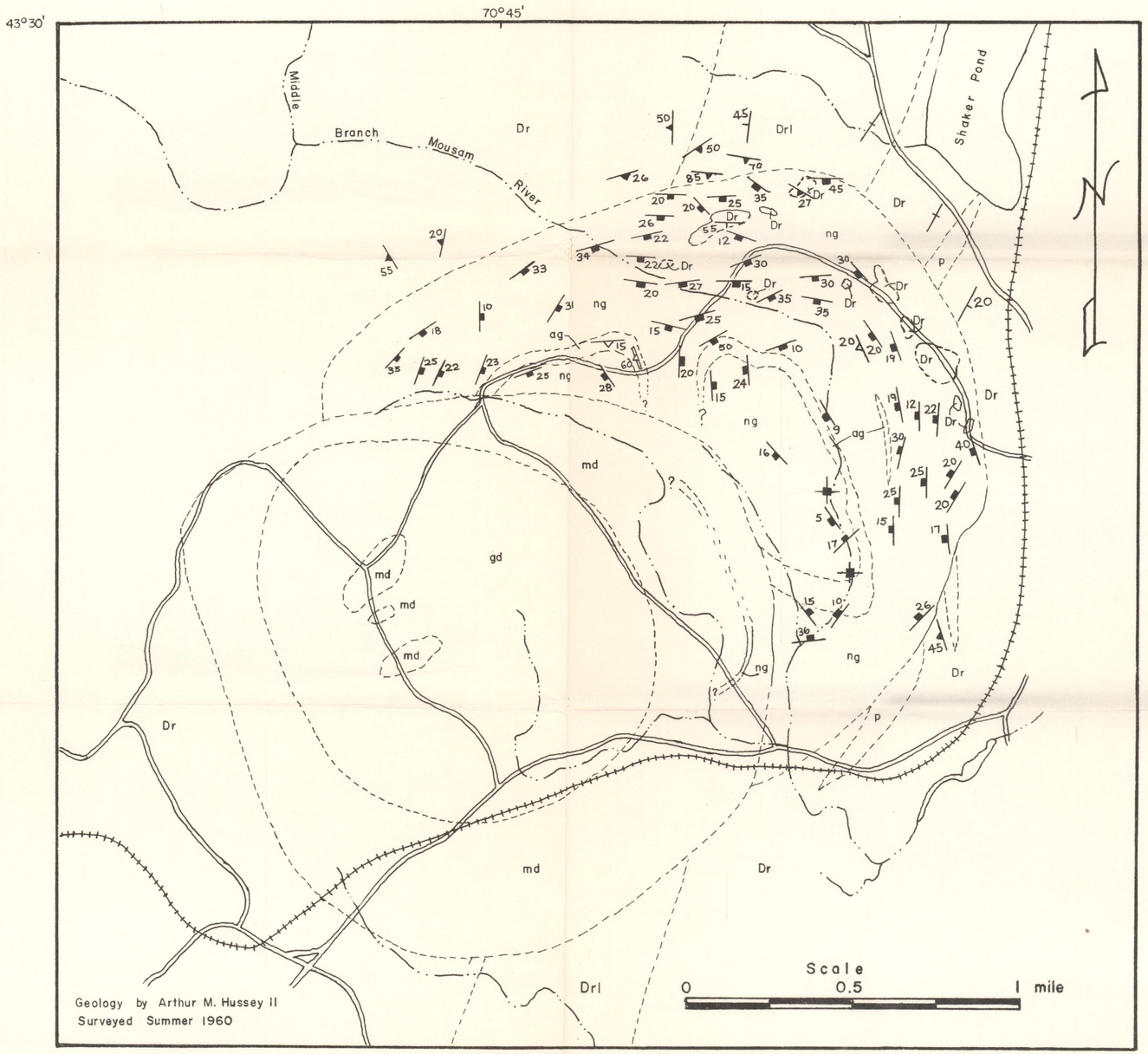
qd	quartz diorite	TATNIC COMPLEX	Triassic (?)
og	olivine gabbro		
pg	poikilitic gabbro		
ag	anorthositic gabbro		
g	gabbro		
v	volcanics, undivided		
Wqm	quartz monzonite	WEBHANNET PLUTON	Late Devonian (?)
Wgd	granodiorite		
Se	Eliot formation		Silurian (?)
Sk	Kittery formation		

Structures of the metasediments:
- 70 Strike and dip of bedding
- Strike of vertical bedding
- 60 Strike and of cleavage or schistosity

Structures of the Tatnic complex:
- 35 Strike and dip of igneous lamination
- 60 Strike and dip of non-graded layering
- Strike of vertical non-graded layering
- 72 Strike and dip of upright graded layering
- Strike and dip of small tabular inclusions
- Horizontal tabular inclusions

- Contact accurately located
- Contact approximately located
- Inferred fault

PLATE III. GEOLOGIC MAP OF THE TATNIC COMPLEX, WELLS AND SOUTH BERWICK, MAINE.



EXPLANATION OF SYMBOLS

gd	porphyritic granodiorite	ALFRED COMPLEX — Triassic (?)
md	monzodiorite	
ag	anorthositic gabbro	
ng	noritic gabbro	
p	pegmatite	Late Devonian (?)
Dr / Drl	Rindgemere formation (Drl--lime-silicate member)	Early Devonian (?)

Structures of the metasediments:

- Strike and dip of bedding
- Strike of vertical bedding
- Strike and dip of schistosity or foliation

Structures of the intrusives of the Alfred complex:

- Strike and dip of igneous lamination
- Horizontal igneous lamination
- Strike and dip of non-graded layering
- Strike and dip of upright graded layering

Contacts accurately located

Contacts approximately located

PLATE IV. GEOLOGIC MAP OF THE ALFRED COMPLEX, ALFRED, MAINE