MERRIMACK GROUP. In Southwestern Maine the Merrimack Group consists of, in ascending stratigraphic order, the Kittery, Eliot, and Berwick Formations. The Formations are dominantly an assemblage of interbedded quartzofeldspathic schists or phyllites and calcareous metaquartzite and granulite with minor metapelites and calcareous metapelites.

In the Portland Quadrangle the Group is represented by the Berwick and Windham Formations, the latter being a new stratigraphic name proposed here for the first time, and tentatively correlated with the Eliot Formation. These two formations crop out over much of the northwestern half of the quadrangle.

Berwick Formation (DSb). The Berwick Formation has been mapped from the type locality in the Salmon Falls River in Berwick, Maine, northeast into the Portland Quadrangle.

Katz (1917) proposed the name Berwick Gneiss for this formation, and because he felt these rocks were more metamorphosed than surrounding rocks, he regarded them to be of Precambrian age. Freedman (1950) renamed the unit the Berwick Formation because of variability of texture and structure of the rock and alternation of lithic types. He clearly pointed out the probable Paleozoic age of the unit.

The principal part of the Formation (DSb) consists of thin-to medium-bedded, occasionally massive, biotite quartzite and quartz-biotite schist containing variable amounts of plagioclase. Locally interbedded with these rock types is quartz-biotite-muscovite schist with very rare garnet and staurolite. Thin calc-silicate beds and pods up to 6" thick, containing hornblende, and occasionally diopside and grossularite, occur sporadically throughout the section, but only locally constitute more than 15% of the sequence. Graded bedding is not common, and other geopetal sedimentary structures such as cross lamination or bedding, and small-scale cut-and-fill structure have not been observed.

The lens designated DSbv, just northwest of the Nonesuch River Fault, consists of poorly bedded calcareous plagioclase-quartz-biotite granofels which in thin section commonly shows randomly oriented elongate twinned plagioclase suggesting a relict volcanic texture. Some exposures consist
of granofels containing 1/8 inch porphyroblasts of twinned plagioclase which probably represent relict phenocrysts or grain fragments of crystal tuff. On the basis of the feldspathic composition and the relict igneous textures, the rocks of the DSbv lens were likely derived from flows and pyroclastic volcanic rocks of intermediate to acidic composition.

Through detailed and reconnaissance mapping (unpublished) the writer has traced the Berwick Formation from the Portland area into the Gardiner area 40 miles to the northeast. From there it has been traced by Barker (1961) and Osberg (1968) into the type Vassalboro Formation in the greater Waterville area. Osberg has assigned a Siluro-Devonian age to the Vassalboro Formation on the basis of its position above the Waterville Formation which has been paleontologically dated as Middle Silurian in age (Osberg, 1968). Thus the Berwick Formation is of probable Siluro-Devonian age.

Windham Formation (Sw). The name Windham Formation is proposed here for the first time for metapelites and associated ribbon limestone and quartzofeldspathic biotite granofels exposed in the northwest corner of the Portland quadrangle and in the Gray quadrangle to the north. The name is from the town of Windham, principally in the Gray quadrangle, where the Formation is best exposed. No type section can be given inasmuch as no continuous or nearly continuous exposures from the base to the top are present. However, the outcrops of pelite at Dundee Falls on the Presumpscot River in the Gray quadrangle (4.6 miles N41E of the northwest corner of the Portland quadrangle) are designated as type exposures.

In the Portland quadrangle, superior exposures are found along Douglas Brook (NW rectangle) and at several points along Little River, notably just northwest of the Route 114 and Route 22 highway bridges.

The principal lithology (Sw on the geologic map) of the Windham Formation is thin-bedded or massive muscovite-biotite quartz schist with garnet, staurolite, and kyanite common in some beds. Interbedded sporadically through the mica schist are thin to medium beds of muscovite-biotite quartzite.

The member designated Sw1 on the geologic map consists of gray limestone and very calcareous calc-silicate granofels thinly interbedded with quartz-biotite schist. This unit which characteristically weathers in a banded, ribbed fashion resembling ribbon candy, is exposed in the southeastern part of the two anticlinal belts of the Windham Formation in the Portland quadrangle. It is also present in the northwestern belt to the northeast in the Gray quadrangle.

The Swq unit exposed in the northwestern anticlinal belt of the Formation consists of thin bedded quartz-plagioclase-biotite schist and...
micaceous quartzite with subordinate calc-silicate beds, identical in lithology to the Berwick Formation. In the Gray quadrangle, these quartz-mica schists and quartzites are closely associated with the "ribbon" limestone, and the two may be facies equivalents.

The contact between the Berwick and Windham Formations was observed at two localities, 1) along the tributary to North Branch Little River (0.15 mi., S12E of BM 153 in the NW corner of the quadrangle), and 2) along Douglas Brook approximately 0.4 mile downstream from the crossing of Highway 114. Critical examination of both localities (which are on opposite limbs of the same anticline) failed to reveal primary sedimentary tops information as to sequence. At both localities, however, the two Formations are clearly conformable. A key locality that establishes sequence is found along U.S. Highway 202 at a point 2.60 mi. N26E of Fosters corner in North Windham (Gray 15' quadrangle). There both the lower and upper contacts of the "ribbon" limestone member with the pelites are exposed. At the western contact, 3 feet within the pelite is a distinct 2" graded bed facing southeast, away from the core of the structure and toward the outcrop belt of the Berwick Formation. At the eastern contact, four feet into the pelite is a sequence of crudely graded beds indicating tops southeast also. From these observations, and from the gross regional structural relationships, the Windham Formation is considered to lie conformably beneath the Berwick Formation, and is thus correlative with the Eliot Formation of Southwestern Maine and the Waterville Formation of Central Maine. The latter is dated paleontologically as Middle Silurian (Osberg, 1968), and through this correlation the Windham Formation is assigned a Middle Silurian age.

Because of its exposure in the cores of anticlines, only a minimum figure for the thickness of the Windham Formation can be given. It is estimated to be at least 2000 to 2500 feet thick. The ribbon limestone member is approximately 200-250 feet thick, and the Swq unit is estimated at 400 to 600 feet in thickness.

CASCO BAY GROUP. As redefined by Hussey (1968), the Casco Bay Group consists, in ascending stratigraphic order, of the Cushing Formation, Cape Elizabeth Formation, Spring Point Formation, Diamond Island Formation, Scarboro Formation, Spurwink Limestone and Jewell Formation. The name was proposed by Katz (1917) for the excellent exposures of the formations throughout the Casco Bay region. Katz, however, did not include the rocks now called the Cushing Formation in the Group because of his belief that they represented a highly deformed granodiorite rather than metavolcanics.

The Group consists of a combination of metamorphosed pelites, sub-pelites, volcanic rocks (both felsic and basic), and immaturely re-worked volcanics.
Cushing Formation (DOCu). This unit was named the Cushing Granodiorite by Katz (1917) from type exposures on Cushing Island in the Casco Bay quadrangle to the east. Remapping in the type area by Bodine (1965), and of rock units of the same stratigraphic interval in the Harpswell area by the writer, clearly demonstrates the stratified character of the unit, and that its predominant lithology consists of fragmental metafelsites and very feldspathic metasediments. Based on this more recent mapping, the unit has been renamed the Cushing Formation.

The Cushing Formation crops out in three areally limited belts in the southeastern part of the quadrangle. The largest of these is in the southwest-plunging nose of the Cushing anticline which, to the northeast in the Casco Bay quadrangle, includes the type locality of the Formation. The second belt lies to the southeast within, and on the northeast side of, the Cape Elizabeth Fault zone. The third belt is on Prouts Neck where the Formation crops out around the southwest plunging trough of the Prouts Neck syncline.

The Cushing Formation is divided into two contrasting units. The principal unit, DOCm on the map, is a sequence of chalky weathering light gray plagioclase-quartz biotite gneiss, locally containing distinctive blue quartz and twinned albite porphyroblasts probably representing relict mineral grains of a crystal tuff. These gneisses which were probably volcanics of dacitic composition, are massive to weakly thin bedded. Some beds are characterized by distinctive parallel elongate porphyroblastic clots of biotite forming a strong lineation parallel to axes of major folds. Feldspathic amphibolite in which hornblende forms lineated porphyroblastic clots has been observed in outcrops close to the contact with the Cape Elizabeth Formation in the Cushing anticlinal belt, but could not be separated as a distinctly mappable unit.

The member mapped as DOcu consists of a sequence of thin-bedded to massive very sulfidic, and hence rusty-weathering, garnet-biotite quartz schist, and amphibolite. It is absent in the outcrop belt in the nose of the Cushing Anticline, but crops out in the other two belts. The most extensive exposure is centered around the faulted southwest plunging nose of the Spurwink Hill anticline where it lies stratigraphically between the Cushing metafelsite and the Cape Elizabeth Formation. On Prouts Neck, however, the sulfidic unit is separated from the Cape Elizabeth by approximately 200 feet of Cushing metafelsite. The same relation is observed within the Cape Elizabeth Fault zone. These relations suggest rapid facies variations within the Cushing Formation.

The Cushing-Cape Elizabeth contact has been observed in the Cape Elizabeth Fault zone, and along shore at Prouts Neck on both the southeastern and northwestern limbs of the Prouts Neck anticline. On Prouts Neck graded beds 15 feet within the Cape Elizabeth Formation from the contact on the northwest flank indicate the beds face southeast, toward the axis of the syncline. On the southeast limb, graded beds in the
Cape Elizabeth within 20 feet of the contact indicate a facing toward the northwest, also toward the axis of the syncline. At the latter locality the graded beds occur in a zone of sinistral southwest-plunging parasitic folds which are in harmony with the major structure. The writer feels that the sedimentary facing data, although not observed precisely at the contact, nevertheless clearly suggest that the Cape Elizabeth Formation lies stratigraphically above the Cushing Formation.

On Prouts Neck and at several localities within the Casco Bay quadrangle, 10 to 30 foot stringers of Cushing metafelsite occur interbedded with metapelites of the Cape Elizabeth Formation in the lower 150 feet of that formation. This clearly indicates that the Cape Elizabeth-Cushing contact is not only conformable but also gradational. All observed contact of the sulfidic member are likewise conformable with surrounding units.

Cape Elizabeth Formation (DOce). The Cape Elizabeth Formation was named and described by Katz (1917) for the extensive exposures of quartzose metapelite exposed in the eastern-most part of Cape Elizabeth in the vicinity of Two Lights State Park (Casco Bay quadrangle.) Within the Portland quadrangle the broadest outcrop belts of the Cape Elizabeth Formation are located just east of the Nonesuch River fault and on the southeast limb of the Saco syncline. Narrower belts are found on the limbs of the Cushing anticline, west of the Spurwink Hill anticline, east of the Cape Elizabeth Fault zone, and in the trough of the Prouts Neck syncline. Varying widths of outcrop may reflect variations in thickness, but more likely indicate varying degrees of parasitic folding.

In the chlorite zone of metamorphism the Cape Elizabeth consists of massive to thin, well-bedded calcareous quartz-muscovite (chlorite) phyllite frequently interbedded with dark gray, strongly crenulated muscovite-chlorite-quartz phyllite. Slightly micaceous quartzite occurs sporadically as beds 2 to 5 inches thick. In the biotite zone the more quartzose beds take on a brownish appearance with the sparing development of biotite. In the garnet zone the typical lithology is thin bedded or massive quartz-muscovite-biotite-garnet schist commonly interbedded with very micaceous laminated quartzite. In general the rocks of the Cape Elizabeth were feldspathic siliceous shale and feldspathic argillaceous quartzite prior to metamorphism. Sulfidic or dominantly micaceous units as have been mapped by the writer in the Orrs Island quadrangle to the northeast (Hussey, 1965) are not present in the Portland quadrangle.

Along the northeast edge of the Cape Elizabeth outcrop belt, rocks somewhat similar to the Berwick Formation, but generally lacking the well developed bedding of that Formation, have been mapped as a member (DOceq on the map) of the Cape Elizabeth Formation. The rocks of this unit are very thinly bedded, laminated, or massive, consisting of quartz-plagioclase-
biotite-calcite schist and feldspathic biotite quartzite. No amphibole is present in the carbonaceous beds, suggesting that these rocks have not been metamorphosed beyond the biotite grade of regional metamorphism. This is in strong contrast to nearby exposures of the Berwick Formation on the opposite (west side of the Nonesuch River fault where hornblende, diopside, and grossularite garnet are frequently present indicating probable staurolite or higher grade of metamorphism.

The Cape Elizabeth-Cushing contact relations have already been discussed. The contact between the Cape Elizabeth and the Spring Point Formations is exposed in three places: 1) Slater Hill along U.S. Highway 1 approximately 1.5 miles north of Saco; 2) Scottow Hill approximately 1.3 miles northeast of West Scarboro, and 3) along the shore just east of the Cape Elizabeth fault zone. At the first and last localities the contact is very sharp and clearly conformable. No facing evidence which might establish sequence was found at the contact at either locality. At the Scottow Hill locality, the contact is exposed in the northwestern edge of a large borrow pit. The Cape Elizabeth Formation lies on the northwest and the Spring Point Formation on the southeast side of the contact. Approximately 4 feet into the Cape Elizabeth is a 6-inch graded bed—quartzite with quartz and plagioclase feldspar granules in the lower part grading into gray phyllite at the top, and facing northwest. This would suggest that the Cape Elizabeth lies on top of the Spring Point which is contrary to the sequence proposed by Katz and accepted by both Bodine (1965) and Hussey (1965). The contact was carefully shoveled off and swept clean of debris. Close examination revealed isoclinal folding in the Cape Elizabeth between the graded bed in question, and the Spring Point Formation. Furthermore the precise contact is occupied by vein quartz one to four inches wide, suggesting the possibility that the contact here might be a fault. Because of these structural complications the graded bed within the Cape Elizabeth cannot be used with any assurance to determine stratigraphic sequence.

Although critical facing evidence—that at or very close to the contact—is lacking at the Cape Elizabeth-Spring Point contact just east of the Cape Elizabeth fault zone, graded beds do occur throughout the upper part of the Cape Elizabeth Formation. This observation, combined with a very consistent parasitic fold pattern (see following discussion on structure) throughout the entire Casco Bay Group section exposed there, quite clearly suggests that the Spring Point Formation overlies the Cape Elizabeth Formation.

Estimates of the thickness of the Cape Elizabeth Formation are difficult to make because of the extensive parasitic folding observed in many outcrops. However, on the basis of widths of the outcrop belts in the southeastern part of the map, the Formation would appear not to exceed 2500 feet in thickness. If such a thickness prevails throughout the quadrangle, the width of the outcrop belt of the Formation just southeast of the Nonesuch River fault implies that the Formation is grossly
almost flat-lying, with only minor parasitic folds producing the steeply
dipping cleavage and bedding attitudes observed. A possibility exists
that the Cape Elizabeth and Cushing Formations exist, in part, in a
facies relationship to one another. It is thus possible that in the wide
outcrop belt southeast of the Nonesuch River where the Cushing is
apparently absent, the Cape Elizabeth may be thicker than in the region
southeast of the South Portland fault where the Cushing Formation is present.

Spring Point Formation (DOsp). The Spring Point Formation was originally
named the "Spring Point Greens tone" by Katz (1917). Both Bodine (1965)
and the writer (1965, '68) have demonstrated a significant variability of
the rocks of this unit, both in composition and grade of metamorphism, to
warrant the use of "Formation" rather than Katz's lithic designation.

The Spring Point Formation crops out extensively on the limbs of the
several anticlines and synclines in the southeastern third of the map, and
forms the core of the Spring Point anticline. The unit pinches out
southward in the Old Orchard-Saco area, and is thus absent around the nose
of the Saco syncline.

The Spring Point consists of a varied assemblage of green phyllite,
amphibolite, and quartz-feldspathic gneiss representing metavolcanic tuffs
and flows of intermediate and felsic composition. Within the Portland
quadrangle it is found in the chlorite, biotite and garnet zones of regional
metamorphism.

In the chlorite zone the mafic units of the Spring Point are mostly
greenish gray chloritic phyllite or slate. In the biotite zone, in addi-
tion to chlorite which is still abundant, small amounts of biotite and
minute spessartitic garnets are developed. In the upper part of the
biotite zone and in the garnet zone, actinolite is present.

The quartz-feldspathic gneiss (not separated as a member) of the
Spring Point is confined to the very eastern edge of the map area. The
typical lithology is light medium gray crudely thin-bedded quartz-plagioclase-
biotite gneiss with minor amounts of amphibole in some beds.

The thickness of the Spring Point ranges from 0 (around the nose of
the Saco syncline) to an estimated 500-600 feet in the South Portland area.
In the outcrop belt just east of the Cape Elizabeth fault zone, the Spring
Point is approximately 100 feet thick.

Diamond Island Formation (DOdi). Katz (1917) proposed the name Diamond
Island Slate for the distinctive black sulfidic and graphitic rocks that
typically crop out on the southeast shore of Great Diamond Island in Casco
Bay (Casco Bay Quadrangle). This area constitutes the type locality for the Formation. Nowhere are these rocks slaty in structure, and Bodine (1965) renamed the unit the Diamond Island Formation.

The Diamond Island crops out as a persistent thin band between the Scarboro and Spring Point Formations except around the Saco syncline where it is absent by stratigraphic pinchout. Two small lens-shaped outcrop belts of Diamond Island lithology have been mapped within the Spring Point Formation in the Spring Point anticline, and one within the Spring Point on the southeast flank of the Cushing anticline. These patches may represent either small doubly plunging infolds in the Spring Point, or separate lenses interbedded with the Spring Point lithology. Bodine (personal communication, 1965) reports that similar lenses are present within the Scarboro Formation in the Casco Bay quadrangle.

The Diamond Island Formation lithically is the most distinctive stratigraphic unit in the outcrop belt of the Casco Bay Group. It is a black, sooty, relatively hard graphite-quartz-muscovite-pyrite phyllite which is characteristically stained orange and yellow on weathered surfaces. Bedding is absent, but very thin, discontinuous vein-quartz laminae parallel to cleavage are pervasive throughout and impart a pin-striped appearance to the unit.

The Diamond Island Formation varies in thickness from 0 to an estimated 150-200 feet.

Scarboro Formation (DOsc). The type locality for the Scarboro Formation is the cliffed shoreline between Higgins and Scarboro Beaches just north of Prouts Neck in this quadrangle. Katz (1917) proposed the name Scarboro Phyllite, but the lithic term "Phyllite," although appropriate for the type area is not appropriate for some exposures of the unit in the northern part of Casco Bay. The unit is now referred to as the Scarboro Formation (Hussey, 1965, '68; Bodine, 1965).

The Scarboro Formation crops out extensively in the troughs of the Saco and Turner Island synclines, on the limbs of the Higgins Beach syncline, and east of the Cape Elizabeth fault zone.

In the chlorite and biotite zones the Scarboro consists of fine-grained, highly crenulated dark gray phyllite, both rusty and non-rusty weathering, with rare interbeds of micaceous and calcareous quartzite. In the chlorite zone the common mineralogy is muscovite, chlorite, quartz and opaque minerals which include both graphite and pyrite. The mineralogy in the biotite zone is quite similar to that in the chlorite zone, with the addition of biotite in sparing quantities. Biotite becomes more common in the garnet zone where the non-rusty Scarboro is commonly a greenish and purplish muscovite-biotite-chlorite-garnet-quartz phyllite or schist. The
The principal difference between the Scarboro Formation and the Cape Elizabeth is the much higher quartz and feldspar content of the Cape Elizabeth Formation.

In the vicinity of Turner Island in South Portland, the upper part of the Scarboro Formation consists of greenish gray plagioclase-chlorite-garnet-quartz schist (designated DOscg on the map), essentially identical to the mafic metavolcanics of the Spring Point Formation. The contact (conformable) of this member with the overlying Spurwink Limestone can be observed on low glacial pavement outcrops in the mudflats just east of Turner Island.

Based on the narrowest outcrop belt which lies in the northwest flank of the Higgins Beach syncline, the thickness of the Scarboro Formation would appear not to exceed 700'.

Spurwink Limestone (DOsk). The type outcrops for the Spurwink Limestone are found along the banks of the Spurwink River in this quadrangle, one at the locality in the northern nose of the Higgins Beach syncline indicated by the bedding symbol showing a 25° southwesterly dip, and the other on the west bank of the River approximately 1/2 mile south of the first at the point indicated by the bedding symbol showing a 60° southeasterly dip. At the latter locality the contact between the Scarboro Formation and the Spurwink is exposed, showing the conformability of the two formations, but giving no primary evidence for facing direction.

The Spurwink Limestone crops out in three separate belts: 1) a small elongate belt in the trough of the Saco syncline northwest of Oak Hill in Scarboro; 2) a narrow band near the trough of the Turner Island syncline; and 3) a narrow band which defines the limbs of the doubly plunging Higgins Beach syncline.

The Spurwink consists of medium gray thin-bedded, very fine-grained limestone with calcareous biotite-quartz phyllite interbeds. In hand specimen, the limestone beds lack the characteristic granoblastic texture of marble, hence the retention of the sedimentary lithic designation. Estimates of the thickness of this Formation are subject to considerable uncertainty because of the great amount of incompetent flowage and repetition indicated by the ubiquitous presence of flow-type folds. An estimate of 200 feet for maximum thickness is probably reasonable.

Jewell Formation (DOj). For those rocks lying above the Spurwink Limestone Katz (1917) proposed the name "Jewell Phyllite" from what he considered to be the type locality for this stratigraphic sequence, Jewell Island in Casco Bay (Casco Bay 15' quadrangle). The designation of Jewell Island as
the type locality for this unit is open to serious question. The Scarboro and Jewell Formations are so similar lithically that they can be separately mapped only if the intervening Spurwink Limestone is present. According to Bodine (personal communication), the Spurwink Limestone is not known to crop out on Jewell Island and can only be inferred to occupy a belt passing between Jewell Island and Cliff Island, 1/4 mile to the northwest where the Scarboro Formation crops out. There exists, therefore, the possibility that the rocks on Jewell Island may not lie above the Spurwink, but may be a continuation of the Scarboro Formation. Because the name "Jewell" has been extensively used in the literature, it is retained in this report, but for unequivocal purposes of establishing a reference section of the rock types of this unit, the exposures of metapelite above the Spurwink Limestone at Peables Point, and on the northwestern side of Great Chebeague Island (both in the Casco Bay 15' quadrangle) are suggested as typical localities.

In the Portland quadrangle, the Jewell Formation crops out only within the trough of the Higgins Beach syncline. The Formation is inferred to underlie a small area in the trough of the Turner Island syncline at the eastern edge of the map.

The Jewell Formation is lithically identical to the Scarboro Formation. In the Higgins Beach syncline, the rocks are mostly rusty-weathering non-bedded muscovite schist and phylite with sparing amounts of graphite and biotite or chlorite after biotite. Within the garnet zone, as defined on the mineralogy of the Cape Elizabeth metapelites, garnet has not been observed in the Jewell Formation.

Nowhere in the outcrop belt of the Casco Bay Group is the top of the Jewell present; the Formation is confined only to the troughs of the deeper synclines. A minimum thickness of 400-600 feet is probably sufficient to account for the widths of the exposed belts.

AGE OF THE CASCO BAY GROUP. The problem of the relative age of the Casco Bay Group has been discussed by the writer (Hussey, 1968, pp. 300-301) and will be reviewed here in light of some new observations in the Portland quadrangle.

Inferences as to the age of the Casco Bay Group are drawn from structural and stratigraphic relations extending from Saco to the area between Waterville and Rockland, Maine, and from gross lithic similarities to rocks throughout the high-grade metamorphic zones of New England. On the one hand there exists a strong lithic similarity between many units of the Casco Bay Group and rocks regarded as being of Ordovician age elsewhere in New England. In particular, the Cushing and Spring Point Formations closely resemble the Ammonoosuc Volcanics of New Hampshire; the
Jewell and Scarboro Formations, the Patridge; and the Cape Elizabeth, the Albee. The New Hampshire units are of Ordovician age. Very close similarities exist between the metavolcanics and metasediments of northeastern Massachusetts, regarded by Bell (1971) to be of Ordovician age. If the correlation suggested by gross lithic similarity should be correct the Casco Bay Group would then be of Ordovician age.

On the other hand, there is the problem of the major structural setting of the Casco Bay Group relative to the formations of the Merrimack Group. The Casco Bay Group occupies a synclinorial belt as is discussed in the following section. To the north in the Waterville area, formations of the Merrimack Group (lowest to highest, the Mayflower Hill, Waterville, and Vassalboro Formations) face eastward toward the outcrop belt of the Casco Bay Group as mapped to the east of the Augusta-Waterville area (Doyle and Warner, 1965). From these relations the Casco Bay Group in its synclinorial structural setting would appear to be in harmony with the structural setting of, and hence overlying, the Merrimack Group. Osberg (1968) assigns a Siluro-Devonian age to the Vassalboro Formation of the Merrimack Group. The Casco Bay Group would thus be of probable Devonian age. In the Portland quadrangle, the Nonesuch River fault separates the Casco Bay Group from the Merrimack Group, hence no information cogent to a resolution of the age of the Casco Bay Group can be obtained here. To the northeast in the Freeport-Yarmouth area, the extension of the Nonesuch River fault diverges away from the contact between the two Groups, and passes into the outcrop belt of the Casco Bay Group. In the Freeport area, and northeastward, no definitive evidence for a fault separating the groups has emerged, but detailed mapping has only begun there and the interpretation is subject to change.

A third alternative for the age of the Casco Bay Group was expressed by the writer (Hussey, 1968), based on lithic similarity of the metapelite-ribbon limestone-metapelite of the Scarboro-Spurwink-Jewell sequence, with the metapelite-ribbon limestone-metapelite sequence of the Windham Formation. This would suggest (via the correlation of the Windham Formation with the fossiliferous Waterville Formation) a middle Silurian age for the upper part of the Casco Bay Group. However, looking further down into the sequence, the units below the Scarboro, particularly the Cushing, Spring Point and Diamond Island Formations, bear little or no resemblance to any units of the Merrimack Group. For this reason the writer does not prefer this alternative.

Until more evidence emerges from detailed mapping to the northeast, on both limbs of the synclinorium, the Casco Bay Group will have to be regarded as of Ordovician to Devonian age.
GRANITE ROCKS (Dg). Granite rocks ranging in composition from granite to quartz-monzonite and granodiorite form the Westbrook pluton which crops out north of the City of Westbrook and extends into the Gray quadrangle adjacent to the Portland quadrangle to the north. Because the three rock types are intimately associated, they cannot be separately mapped. The dominant phase is medium light gray fine-grained moderately foliated muscovite-biotite quartz monzonite. The foliation is formed by parallel orientation of muscovite and biotite, and by biotite schlieren which are common throughout the pluton. Blocks of light gray granite within the quartz-monzonite phase have been observed at a few localities. At other localities medium-grained to pegmatitic light gray foliated biotite-muscovite-garnet granite occurs as stringers within fine-grained medium gray foliated biotite granodiorite. All phases of the pluton are moderately jointed, some joints being filled with vein quartz. Foliation commonly is intensified near these joints and swings into parallelism with them suggesting shearing during late stages of magma consolidation.

The Westbrook pluton is elongate in a north-south direction, and is concordant with the regional structure of the Berwick Formation. Schistosity and bedding strikes in the Berwick Formation show a strong deflection around the south nose of the pluton; on the east side, structural trends are northeast, whereas on the west side they are north to northwest.

Granitic rocks form three small elongate, strongly concordant lenses up to 1.5 miles in length in the Deering section of Portland. These plutons, which are more homogeneous than the Westbrook pluton, consist of fine-grained light gray well-foliated muscovite-biotite granite and quartz-monzonite. Foliation is marked by mica orientation and is parallel to the contacts and to structures of the enclosing Berwick Formation.

The granite rocks are correlated with syn-to late-tectonic granitic rocks of Middle to Late Devonian Age comprising the New Hampshire Plutonic Series of Billings (1956) on the basis that they are 1) calc-alkalic rocks, 2) well foliated, 3) concordant, and 4) distinctively elongate parallel to regional structural trends.

GABBRO AND DIORITE (Dd). Rocks ranging in composition between gabbro and diorite form two relatively small plutons within the quadrangle—the Saco pluton in the southwest corner of the map, and an unnamed body at the southern end of the Westbrook pluton. Both bodies are lithically similar. They are dark gray, medium to coarse-grained, strongly foliated and intensely sheared and saussuritized marginally. Minerals present are well-twinned, moderately zoned plagioclase of average composition An 45-52,
light green hornblende, and brown biotite (the latter two commonly altered to secondary chlorite). Quartz and augite are minor constituents.

The gabbro and diorite are considered to be older than the granitic rocks because of the greater degree of alteration and foliation, and are correlated with the basic members of the New Hampshire plutonic series.

**DIABASE AND BASALT DIKES.** Diabase and basalt dikes, varying from 5 inches to 30 feet wide are present throughout the quadrangle, being most abundant along the shore in the vicinity of the Cape Elizabeth Fault zone and in the east-central part of the Westbrook pluton. These dikes cut all other rock types, both igneous and metamorphic, and are thus the youngest bedrock units in the quadrangle. All are undeformed, and unaffected by regional metamorphism although deuteric alteration is locally quite strong. Most of the dikes examined are of tholeitic-type basalt with either minor amounts of quartz or minor amounts of olivine. Although no radiometric ages are available, for these rocks in southern Maine, they are probably related to Late Triassic intrusive activity that took place in the Connecticut River and Fundy basins.

**STRUCTURE**

**MAJOR FOLDS WITHIN THE CASCO BAY OUTCROP BELT.** The Casco Bay Group occupies the southwest end of the Casco Bay synclinorium (Hussey, 1968), which in this area has an overall plunge to the northeast. Many of the mapped folds (Fig. 1) have varying plunge directions, some, such as the Higgins Beach syncline, being typically doubly plunging structures. These folds have been delineated on the basis of map pattern of the various formations of the Group. The stratigraphic sequence of these formations, as previously discussed, forms the principal basis for recognizing which structures are anticlines and which are synclines. In addition, in the Higgins Beach and Prouts Neck synclines, bedding and cleavage/schistosity consistently dips toward the synclinal axes outlining a synformal configuration. This is in agreement with the synclinal nature of the structures as deduced from stratigraphic sequence. Across the other structures in the Casco Bay outcrop belt, the attitudes of bedding and cleavage/schistosity vary non-systematically, presumably due to minor folding and flexuring.
Most of the folds as shown on the cross sections are slightly overturned toward the southeast. Local variation of dips of foliation and bedding indicate extensive parasitic folding and flexing of the limbs of the folds. Although these minor folds are tight to isoclinal, the major folds are interpreted to be considerably more open to avoid unreasonable thickness variations of the different units. This is particularly true of the great widths of outcrop of the Cape Elizabeth and Spring Point Formations on the limbs of the Saco syncline as compared with their outcrop widths around the tighter structures at the eastern edge of the map. Barring complications due to possible repetitive faulting, the 5-mile wide outcrop width of the Cape Elizabeth Formation on the west limb of the Saco syncline must indicate a grossly gently dipping attitude for that limb.

MAJOR FOLDS WITHIN THE MERRIMACK GROUP OUTCROP BELT. In the northwest corner of the map are two anticlines which bring the Windham Formation to the surface. The West Gorham anticline is doubly-plunging structure; however the noses of the fold lie outside the limits of the Portland quadrangle. The Douglas Brook anticline within the quadrangle plunges southwest with a nose that lies just to the west in the Buxton quadrangle. Recognition of these belts as anticlines rests on the evidence for sedimentary sequence within the Windham Formation in the Gray quadrangle discussed above.

FAULTS. Four major faults have been inferred in the Portland quadrangle, the names of which are given in Figure 1. All are post-metamorphic in development and may be correlative with normal faults of Triassic age such as those bounding the Fundian, Connecticut River, and other similar basins throughout the Appalachian chain.

The Nonesuch River Fault is recognized on the basis of 1) the juxtaposition of garnet grade rocks on the west with chlorite and biotite zone rocks on the east; 2) the straight course of the Nonesuch River from the west edge of the map to the vicinity of Beech Ridge in Scarborough; 3) the silicified and sheared zones in and near the Nonesuch River; 4) the gentle dips of the Berwick Formation on the west as compared with the steep dips of the Cape Elizabeth Formation on the east (for that stretch of the fault between Berry Hill and Beech Ridge); and 5) the truncation of both the DSbv number of the Berwick Formation and the DOceq unit of the Cape Elizabeth Formation.

The South Portland fault is mapped on the basis of omission of units on the northwest limb of the Cushing anticline and truncation of the biotite garnet isograd.
The Cape Elizabeth fault zone, as clearly exposed along the shore in
the vicinity of Spurwink Hill and the Cod Rocks, consists of several faults,
most of which are of unknown but presumably minor displacement. Only one
of the observed faults in the zone juxtaposes different units of the Casco
Bay Group, and all but one are steeply dipping with normal type movement
as indicated by slickensides. The fault just northwest of the principal
outcrop belt of the Cape Elizabeth Formation southeast of Spurwink Hill has
a moderate northwesterly dip and a drag sense within the Cape Elizabeth
beds indicating thrust movement. The northwesternmost fault of the zone
shown on the map, separating DOcu from DOcur is not exposed along shore,
but on land is clearly suggested by 1) three aligned exposures of white
vein quartz up to 20 feet wide, and 2) by truncation of the Cushing
Formation in the Spurwink Hill anticline.

Although slickensides observed along exposed fault breaks indicate
mostly normal-type movement, one line of evidence suggest the possibilibty
that the Cape Elizabeth fault zone may be, in part, the result of strike­
slip movement amounting to several miles. This line of evidence
involves facies relations within the Cushing Formation. The DOcur unit
of the Cushing Formation is lithically identical to a unit mapped at the
top of the Cushing on Harpswell Neck 20 miles to the northeast. Exposures
on Harpswell Neck show that the unit fingers out southward into the
feldspathic Cushing metavolcanics, and in the Central Casco Bay area this
unit is absent. Significantly it is also absent in the principal outcrop
belt of the Cushing Formation in the Cushing anticline 2 miles to the north
of Spurwink Hill. If this is a valid indication of strike-slip motion,
bringing a northerly facies of the Cushing into the Portland area, an
additional fault, unrecognized in the current mapping and thus not figured
on the geologic map, must be postulated to place the Spurwink Hill ex­
posure of the DOcur unit in a fault slice separate from the Cushing
Formation in the Cushing anticline where DOcur is absent.

A fourth fault, the Broad Cove Fault (named from Broad Cove in the
Casco Bay quadrangle, in the area approximately 1 mile north of Two
Lights State Park) is inferred to pass between Prouts Neck and Bluff Island
at the southeast corner of the map on the basis of the steep metamorphic
gradient; the Bluff Island Cape Elizabeth exposures indicate chlorite
grade metamorphism whereas on Prouts Neck, as mentioned, the Cape Eliza­
beth is in the staurolite zone.

A topographic lineament herein referred to as the "Westbrook linea­
ment" is formed by the northeast trending valleys of the Stroudwater and
Presumpscot Rivers in the vicinity of the City of Westbrook. This linea­
ment which is an extension of the Nonesuch River Fault lies entirely
within the Berwick Formation, and the metamorphic grade on either side is
the same. However, because of poor exposures along the zone, no evidence
for faulting has been observed. For these reasons, the feature is referred
to as a lineament.
STRUCTURE IN THE VICINITY OF THE COD ROCKS. The thrust fault of the Cape Elizabeth fault zone separates rocks of distinctly contrasting fold style. On the west, bedding, schistosity, and axial planes of parasitic folds are vertical or steeply dipping. East of the thrust fault bedding and schistosity are gently dipping, and parasitic folds, mostly seen in the Cape Elizabeth Formation, are recumbent. Figure 2 is a cross-section sketch of the shore exposures from the thrust fault eastward to the Cod Rocks. Graded beds are common in the Cape Elizabeth Formation and consistently indicate that the beds are upright. Parasitic folds are also common and consistently indicate overturning of the beds. These two relationships suggest that the exposures in the area of The Cod Rocks form the upright limb of a major recumbent anticline, the axial plane of which lies well below the surface and has been rotated slightly more than 90° from the vertical (Fig. 3). These relationships also constitute strong support for the stratigraphic sequence within the Casco Bay Group as presented in this report. Superimposed on the tight recumbent parasitic folds is a younger set of very open, gentle, upright folds that deform the schistosity as well as bedding.

An interpretation of the general structural relations from the Higgins Beach syncline east to the edge of the map in the area of The Cod Rocks is given in Figure 3. In this interpretation, the Spurwink Hill anticline is indicated as a faulted parasitic anticline on the west limb of the major recumbent anticline. The amplitude of the fold may be augmented by drag along the thrust fault. The thrust fault was generated as an axial plane fault in the core of the major anticline, but cuts through the upright limb where it changes from a normal to a recumbent fold.
1. Douglas Brook Anticline
2. Gotham Hill Syncline
3. West Gorham Anticline
4. Saco Syncline
5. Thorton Heights Anticline
6. Turner Island Syncline
7. Spring Point Anticline
8. Cushing Anticline
9. Higgins Beach Syncline
10. Spurwink Hill Anticline
11. Prouts Neck Syncline

A. Nonesuch River fault
B. South Portland fault
C. Cape Elizabeth fault zone
D. Broad Cove fault
E. Westbrook lineament

Figure 1. Major folds and faults of the Portland quadrangle.

Figure 2. Cross section sketch of geologic relations exposed along the seacliff at Ram Island Farm, Cape Elizabeth, in vicinity of The Cod Rocks. Arrows indicate tops sense of graded beds.
Figure 3. Interpretation of major structure from the Higgins Beach syncline eastward to The Cod Rocks area, Scarboro and Cape Elizabeth. Minor offsets due to normal faults of the Cape Elizabeth fault zone have been omitted.
REFERENCES CITED


