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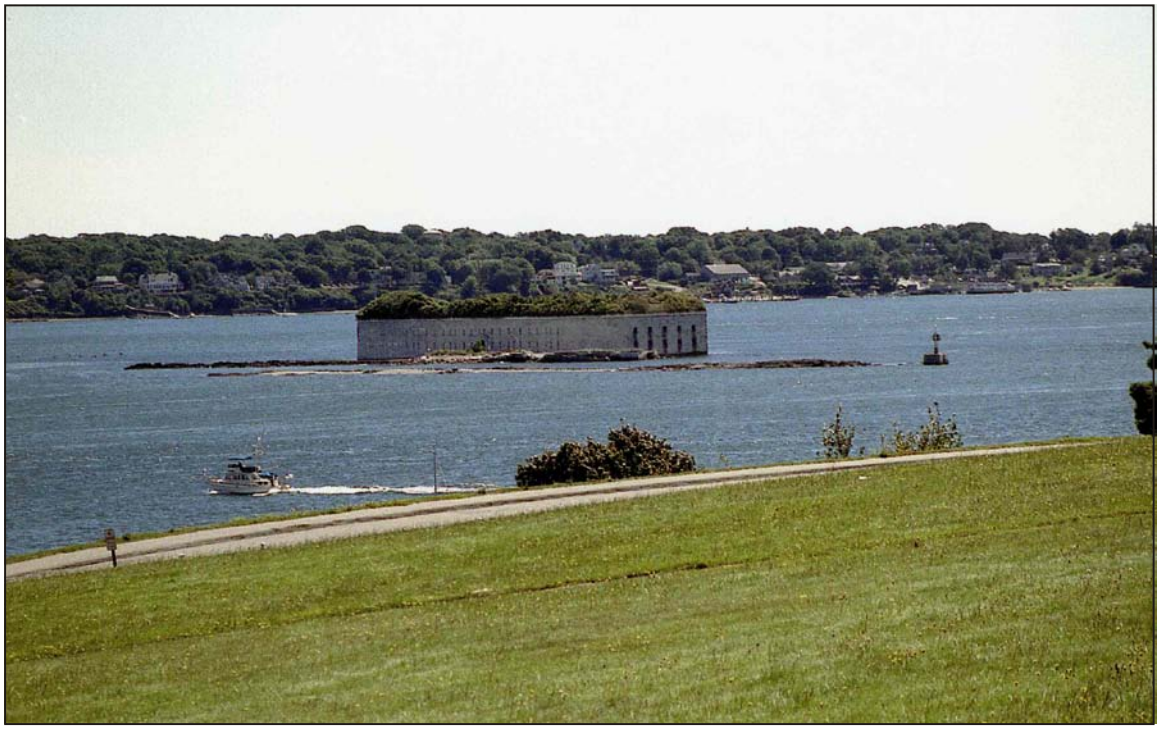

Inner Casco Bay with Fort Gorges in the middle ground and Little Diamond Island in the background as viewed from the Eastern Promenade, Portland.

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Bedrock Geology of the Portland East 7.5' Quadrangle, Cumberland County, Maine

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INTRODUCTION

The Portland East 7.5' quadrangle is located at the southwestern end of Casco Bay (Figure 1), and includes parts of the City of Portland and many of the larger islands within Casco Bay. This is essentially the southwest end of the highly indented Maine coast. Bedrock is well exposed along most of the shorelines, especially those facing toward the southeast, into the direction of prevailing winds and surf. Bedrock surfaces along the shore and some inland areas preserve glacial striations indicating a south-southeastward direction of ice movement. Sediments preserved above these bedrock surfaces include marine clay (locally fossiliferous) of the Presumpscot Formation and a variety of glacial gravels and sands (Bernotavicz, 1999).

Bedrock in the quadrangle is assigned to four major tectono-stratigraphic sequences: the Casco Bay Group and Falmouth-Brunswick sequence of probable Middle Ordovician age, and the Central Maine sequence and Merrimack Group of Late Ordovician to Early Silurian age. The rocks were highly folded during compressive phases of the Acadian orogeny in Devonian time. They were recrystallized in a low-pressure, high-temperature (Buchan-facies) metamorphism at the end of the Acadian deformation; grades of metamorphism range from greenschist to amphibolite facies. Pegmatite dikes and sills are abundant in rocks of the Falmouth-Brunswick and Central Maine sequences in the high-grade zones where the rocks are extensively migmatized. Rocks of the Casco Bay Group have also been intruded by dikes of intermediate to felsic composition which have been metamorphosed but not significantly deformed. Episodes of strike-slip and dip-slip faulting occurred from Devonian through Mesozoic time. All sequences are intruded by numerous undeformed dikes and sills of basalt and diabase of probable Jurassic age.

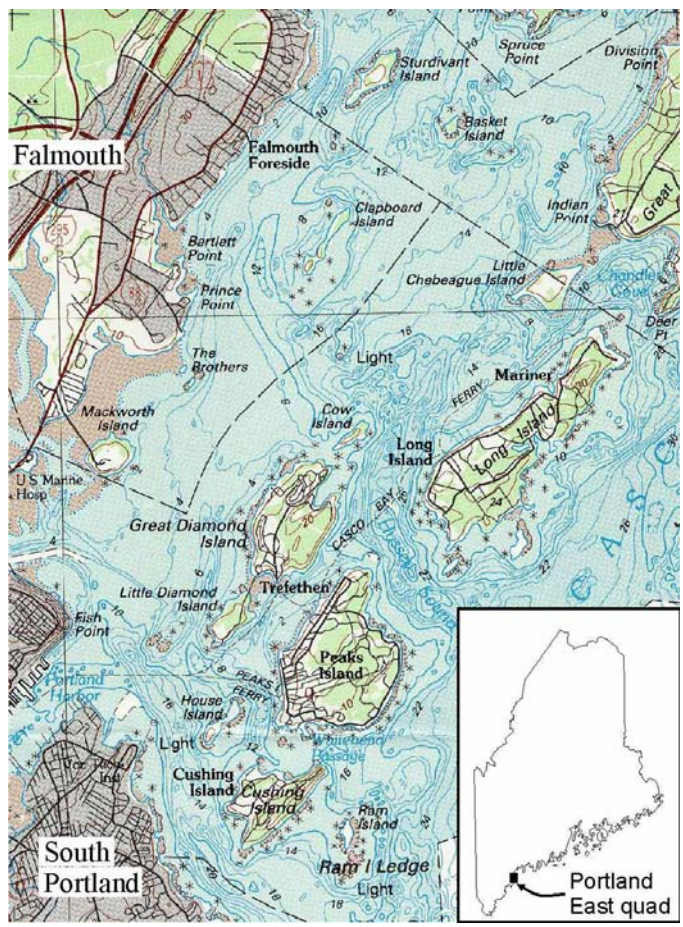

Figure 1. Location of the Portland East 7.5-minute quadrangle, southwestern Maine.

INTRUSIVE ROCKS

Mafic Intrusions

Numerous dikes and sills of basaltic composition, ranging from a few centimeters to 35 meters in thickness, intrude all tectonostratigraphic sequences. Thinner dikes and sills have basaltic textures, whereas thicker ones have diabasic texture and are predominantly non-porphyritic; porphyritic and non-prophyritic varieties are present. All mafic dikes and sills post-date compressional deformation and strike-slip faulting, and none show clear evidence of faulting by late high-angle normal faulting.

Pegmatite

Pegmatite dikes and sills, with one exception, are restricted to high-grade migmatized rocks of the Falmouth-Brunswick and Central Maine sequences in the northwestern part of the Portland East 7.5' quadrangle. The one exception is an exposure of sheared pegmatite of unknown dimension within the Spring Point Formation on Little Diamond Island. All of the pegmatites are of similar mineralogy, consisting of perthitic microcline, albite, muscovite, and biotite with minor garnet and black tourmaline. Sills ranging from a few centimeters to more than 15 meters in thickness generally show weak to moderate foliation and some are deformed in shallowly plunging strongly overturned folds of gneissic foliation of the host rocks. Pegmatite dikes ranging from 0.5 to 10 meters in thickness show no foliation and cross-cut migmatite foliation and foliated pegmatite sills at high angles. Foliated sills and non-foliated dikes are well exposed in the roadcuts along Interstate Route 295 between Falmouth and Portland. Figure 2 portrays stereographically the relatively consistent structural orientation of discordant dikes in the outcrop belt of the Hutchins Corner and Richmond Corner Formations in the northwest corner of the map. Strikes are north-northeast and dips range from vertical to 70 degrees southwest.

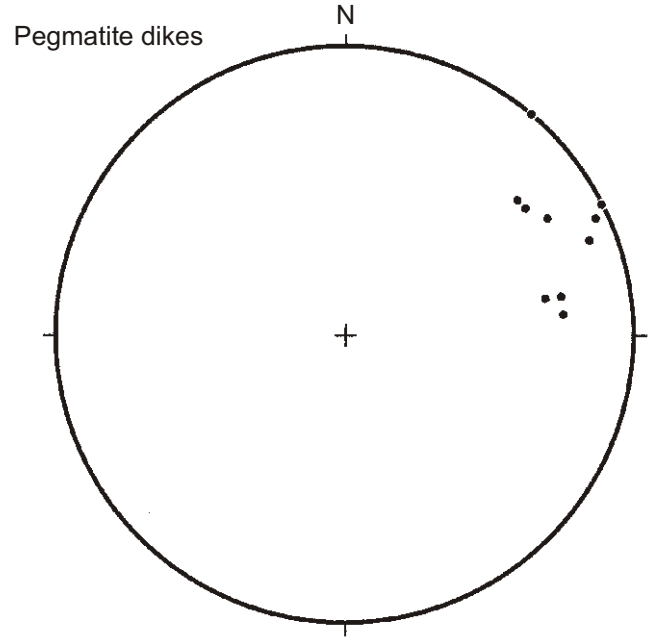

Figure 2. Stereogram of poles to discordant pegmatite dikes in the outcrop belt of the Falmouth-Brunswick sequence. All stereograms in this report are lower hemisphere, equal area projections.

TECTONOSTRATIGRAPHIC SEQUENCES

Central Maine Sequence

The Central Maine sequence crops out in the northwestern corner of the Portland East quadrangle. It is divided into the Hutchins Corner, Richmond Corner, and Torrey Hill Formations on the basis of differences in mineralogy. These rocks are extensively migmatized and injected by pegmatite and granite lenses and dikes. Concordant pegmatite and irregularly textured biotite-muscovite granite lenses are moderately foliated and folded. These are cut by slightly later discordant pegmatite dikes.

Hutchins Corner Formation (SOhc). The Hutchins Corner Formation consists of medium brownish gray salt-and pepper-textured quartz-plagioclase-biotite gneiss and granofels. Interbedded with rocks of this dominant lithology are thin compositional bands of medium greenish gray quartz-plagioclase-hornblende-diopside gneiss and granofels representing sheared calc-silicate interbeds. Conformable, even-walled slightly foliated pegmatite lenses intrude the Hutchins Corner Formation locally forming a lit-par-lit injection gneiss as seen in roadcuts on the eastern end of the Falmouth Connector between U. S. Route 1 and the Maine Turnpike.

Richmond Corner Formation (SOrc). The Richmond Corner Formation within the Portland East quadrangle occupies a 0.4 km-wide belt within the Hutchins Corner Formation. The Richmond Corner Formation is a medium brownish gray quartz-plagioclase-biotite-garnet-sillimanite gneiss. It is distinguished from the Hutchins Corner Formation by the absence of calc-silicate beds, the presence of minor amounts of sillimanite and xenoblastic irregular red garnet masses, and its slightly more foliated, locally schistose, fabric. The Richmond Corner Formation is more extensively migmatized than the Hutchins Corner Formation, and the pegmatite leucosomes are more abundant and irregular than those in the Hutchins Corner Formation. Good exposures of the Richmond Corner Formation are to be seen along and just west of U. S. Route 1 north of the I-95 exit to Route 1. To the north, in the Brunswick-Topsham area, the Richmond Corner Formation occupies a stratigraphic position between the Hutchins Corner and Torrey Hill Formations (Hussey and Berry, 2002; Hussey and Marvinney, 2002). The fact that the Richmond Corner belt crops out within the Hutchins Corner Formation in the Portland East quadrangle is probably an indication, that locally, the two formations interfinger.

Torrey Hill Formation (SOth). The Torrey Hill Formation is poorly exposed in the Portland East quadrangle. It consists of migmatized, very rusty-weathering quartz-muscovite-graphite-biotite schist and gneiss, rusty-weathering quartz-plagioclase gneiss with sparse muscovite, and rusty-weathering quartz-plagioclase-biotite-sillimanite schistose gneiss. Graphite and garnet, seen in exposures north of the map area, were not observed in the Portland East outcrops. The Torrey Hill Formation occupies a 0.25 km-wide belt between the Hutchins Corner and Nehumkeag Pond Formations.

Merrimack Group

To the south of the map sheet in the Kittery area, the Merrimack Group consists of the Kittery, Eliot, and Berwick Formations (Katz, 1917, Hussey, 1962). Within the Portland East quadrangle the group is represented only by the Eliot Formation.

Eliot Formation (SOe). Rocks here assigned to the Eliot Formation were originally mapped as the Mackworth Formation by Katz (1917), who included it with the Casco Bay Group, interpreting it to be the uppermost formation of that group. The writer recognized the strong lithic similarity of the Mackworth Island exposures with exposures of the Eliot Formation to the southwest (Hussey, in press, b). The Eliot Formation is confined to a 3 km-wide belt bounded by the Flying Point fault on the west and the Johns Point fault on the east.

The Eliot Formation consists predominantly of medium brownish gray very fine-grained calcareous phyllites and quartz-plagioclase-calcite phyllites with chlorite, biotite, or epidote + hornblende depending on grade of metamorphism. Fine laminae are common and may be effects of ductile faulting associated with the Norumbega fault zone (see below). Locally, the quartzo-feldspathic rock occurs as beds 2 to 10 cm thick alternating with the chlorite and mica-rich phyllites suggestive of relict primary sedimentary structures. These alternations are particularly well exposed in the gently-dipping exposures on Mackworth Island. Sporadically present within the formation are (1) thin layers (2-10 cm thick) of light-gray chalky weathering phyllite of possible volcanic origin, and (2) thin beds of phyllite (1-3 cm) with elongate 1x2 mm granules of chalky weathering material of uncertain affinity. Some of these have the appearance of volcanic lapilli. On the southeastern third of Mackworth Island, the rock types described above are interbedded with 2 to 10 meter-thick intervals of very rusty weathering phyllite. This variant is mapped as a separate member of the Eliot Formation (**SOer**) and may correlate with the Calef Member of the Eliot Formation mapped by Freedman (1950) in southeastern New Hampshire.

Falmouth-Brunswick Sequence

Within the Portland East quadrangle the Falmouth-Brunswick sequence is represented by the Nehumkeag Pond Formation. Within the Nehumkeag Pond Formation are several intervals of amphibolite that may represent fingers of the Mount Ararat Formation that crops out extensively in the Freeport to Topsham area to the north (Berry and Hussey, 1998; Hussey and Marvinney, 2002).

Nehumkeag Pond Formation (Onp). The Nehumkeag Pond Formation consists of medium light gray plagioclase-quartz-biotite gneiss with minor muscovite and garnet. Sporadically interlayered with this dominant rock type are 2-5 m intervals of moderately rusty-weathering gneiss of similar mineralogy and dark gray amphibolite. One narrow belt of rusty-weathering pyrrhotitic plagioclase-quartz-biotite gneiss is shown separately on the map (**Onpr**). The Nehumkeag Pond rocks are metamorphosed to upper amphibolite facies and are extensively migmatized and injected by both older concordant foliated sills and younger cross-cutting non-foliated dikes of pegmatite.

One amphibolite horizon (**Onpa**), informally referred to by Marc Bodine (personal communication, 1963) as the Bartlett Point amphibolite, crops out at Bartlett Point and the western edge of Sturdivant Island. The width of its outcrop belt, although not precisely constrained, is approximately 200 meters. It is quite variable in mineralogy and texture. At Bartlett Point, hornblende varies from 50 to 90% of the rock. This rock, although extensively sheared and microfaulted, locally preserves a relict medium-grained texture that suggests derivation from a premetamorphic diabase, gabbro, or diorite. However, other interlayered rocks include rusty weathering quartz-plagioclase-biotite-muscovite schist and gneiss and white, chalky weathering gneiss (possibly acid metavolcanic rocks). This association suggests a volcanic parentage for the amphibolite.

Stratigraphic Relations between the Falmouth-Brunswick and Central Maine Sequences. Outcrops in this quadrangle do not expose the contact between any of the formations and thus give no direct evidence of the stratigraphic or structural relations between the Falmouth-Brunswick and Central Maine sequences. Along strike to the northeast, Hussey and Berry (2002) and Hussey and Marvinney (2002) interpret that the Central Maine sequence unconformably overlies the Falmouth-Brunswick sequence but the evidence is not strong. In the Portland East quadrangle, however, formational contacts in the Falmouth-Brunswick and Central Maine sequences have uniform trends, the dips of foliation are similar, and grades of metamorphism and migmatization are identical, suggesting the two sequences may be conformable. It is possible that the Falmouth-Brunswick sequence represents the lower parts of the Central Maine sequence. Further study in the Yarmouth and Freeport 7.5' quadrangles north and northeast of the Portland East quadrangle may resolve these possibilities.

Casco Bay Group

The Casco Bay Group consists, in ascending order, of the Cushing Formation, Cape Elizabeth Formation, Spring Point

Formation, Diamond Island Formation, Scarboro Formation, Spurwink Metalimestone, and Jewell Formation. The Mackworth Formation, originally included by Katz (1917) as the upper-most unit of the group, is now interpreted as noted above, to be equivalent to the Eliot Formation of the Merrimack Group.

Cushing Formation (Oc). The Cushing Formation was originally mapped by Katz (1917) as a deformed granodiorite intrusive. Bodine (personal communication, 1961; 1965) from his mapping in the Casco Bay 15' quadrangle, recognized features that clearly indicate a fragmental volcanic origin of these rocks. This has been subsequently confirmed by my own mapping in the area. In addition, Levy and others (2003) have described apparent thick bedding units from exposures on the east side of Long Island (this quadrangle) that reinforce a volcanogenic origin. Members of the Cushing Formation, not present in this quadrangle, include the Wilson Cove and Merepoint Members (Hussey and Berry, 2002; Hussey and Marvinney, 2002; and Berry and Hussey, 1998).

The Cushing Formation typically is a light gray, fine- to medium-grained plagioclase-quartz-K-feldspar-biotite granofels with minor muscovite and garnet. It represents a metamorphosed volcanic rock of the composition ranging from rhyodacite to dacite. Fragmental structures are present locally, confirming the fragmental volcanic nature of the rock. At Danford Cove, 50 meters southeast of the Cushing/Cape Elizabeth contact (Figure 3), irregular fragments of light to medium gray metavolcanic rocks are present (Figure 4). These have angular boundaries and are extremely stretched. Similar fragmental material is present at localities on Peaks and Long Islands. In addition, much of the material lacking the angular breccia structure has a texture resembling relict crystal tuff (Figure 5). Slightly larger grains of either twinned plagioclase or quartz, and in some localities both, are set in a finer groundmass of plagioclase, quartz, biotite, and K-feldspar. In a few localities the larger quartz grains are light blue in color, probably due to the presence of minute grains of rutile (Figure 6).

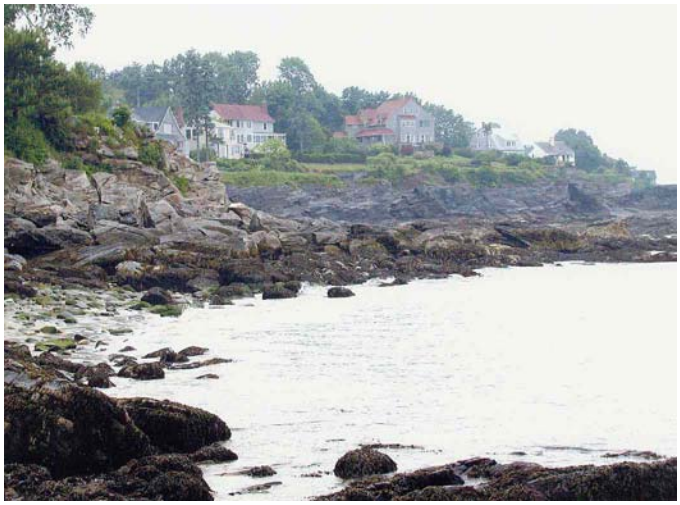

Figure 3. Danford Cove area, South Portland. The Cape Elizabeth Formation (darker gray rocks) forms the cliff in the background. The Cushing Formation (lighter, buff-colored rocks) crops out in the middle and foreground. The locality of the two radiometric ages of the Cushing is approximately 50 meters behind the lower edge of the photograph.

On Long Island, a narrow belt of rock (Ocw), 10 - 25 meters wide, of a very distinct and unusual lithology consists of white quartz-muscovite granulose schist (Figure 7); feldspar is rare, and dark minerals are very rare (mostly pyrite or pyrrhotite). This belt crops out within the Cushing about 25-30 meters east of outcrops of the overlying Cape Elizabeth Formation.

The protolith of this rock type is uncertain in view of its setting in a volcanic association. The fact that the granular minerals are comprised dominantly of quartz suggests a mature sedimen-

Figure 4. Stretched pyroclastic blocks of the Cushing Formation at Danford Cove, South Portland.

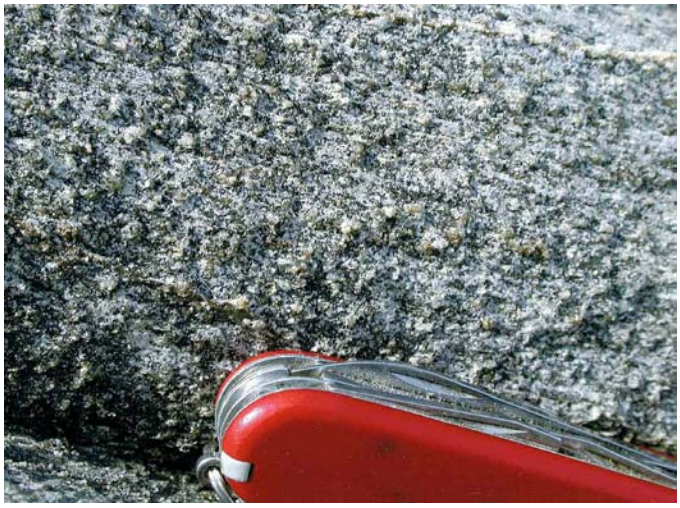

Figure 5. Relict crystal tuff texture in the Cushing Formation near Beach Cove on the east shore of Long Island.

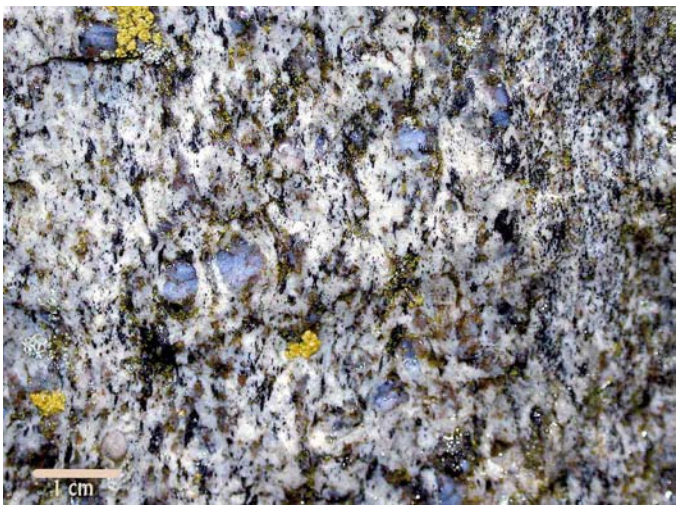

Figure 6. Relict crystal tuff with blue quartz fragments at Danford Cove. This is the rock unit from which the U/Pb zircon age reported by Tucker was obtained.

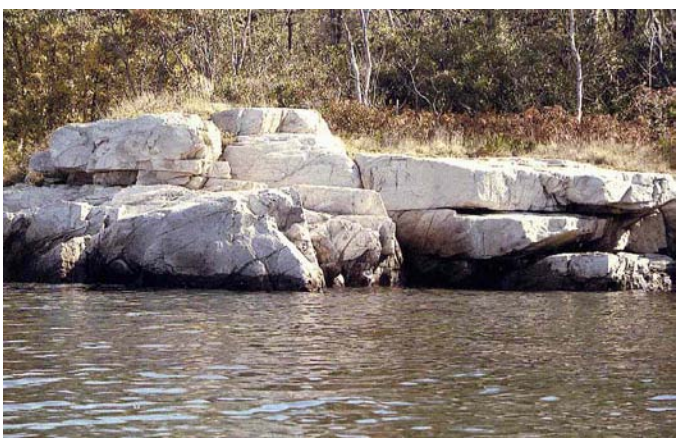

Figure 7. The white quartz-rich muscovite granofels member of the Cushing Formation just south of Great Ledge Cove, Long Island.

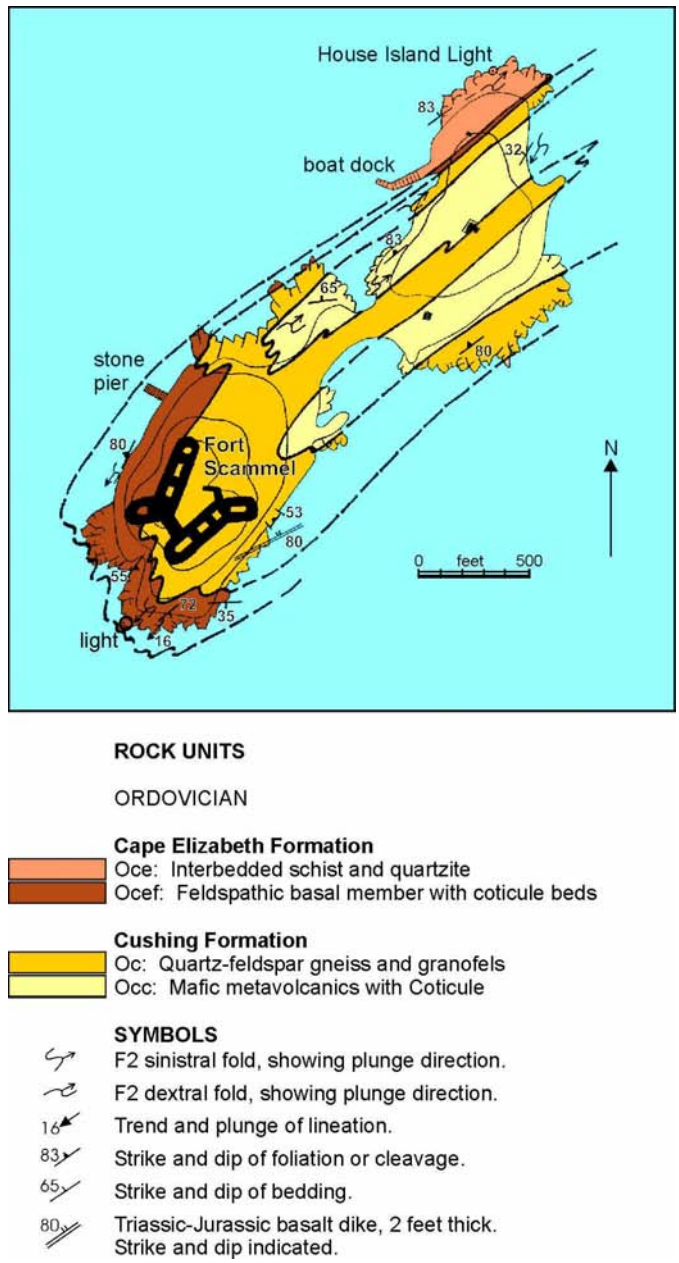

Figure 8. Detailed geologic map of House Island.

tary environment rather than volcanic. Another similar light-colored belt (**Ocr**) is mapped along the southeastern third of the island. The eastern belt crops out only on Long Island, but the western belt is also present on the western side of Peaks Island and on the mainland in Cape Elizabeth. The eastern belt is probably not a structural repetition of the western belt because of (1) the lack of any nearby exposures of the Cape Elizabeth Formation to the southeast, and (2) its slightly more feldspathic composition (Levy and others, 2003).

Two U/Pb ages have been obtained from zircons in metamorphosed rhyodacite tuff at Danford Cove, South Portland (this quadrangle). John F. Aleinikoff reported an age of 471 ± 3 Ma (Hussey and others, 1993; Aleinikoff, personal communicastion, 2002). Robert D. Tucker (personal communication, 1995) reported a closely similar age of 473 ± 3 Ma on metatuff with blue quartz phenoclasts. Both of these ages are from rocks near the top of the formation, about 200 meters southeast of the Cushing/Cape Elizabeth contact (Figure 3).

Cushing Formation on House Island. Figure 8 is a detailed geologic map of House Island. The Cushing Formation is exposed in the core of a compound southwest-plunging anticline. The contact with the Cape Elizabeth Formation is exposed on the southern end of the island near historic Fort Scammel. Metamorphosed rhyodacite tuff similar to that exposed on Peaks Island forms an upper unit. The lower unit is a heterogenous metavolcanic assemblage, mostly mafic to intermediate in composition. Included are dark greenish-gray chlorite phyllite, medium- to

Figure 9. Coticule beds (garnet-quartz granofels) in light-gray metarhyodacite tuff of the lower unit of the Cushing Formation exposed on House Island. The beds are deformed by gently-plunging F_2 (?) folds with axial planar cleavage.

Figure 10. Contact of the Cape Elizabeth Formation (darker rocks left of the white house) with the Cushing Formation (lighter colored rocks beneath the house and deck) at Long Cove, Long Island. White arrow marks the location of Figure 11. (*View toward the northeast.*)

coarse-grained medium greenish gray metamorphosed intermediate gneiss with pebble-sized volcanic clasts of light gray metamorphosed rhyodacite tuff, and thinly interbedded light gray metafelsite tuff and maroon to pink garnet-quartz granofels (Figure 9). The assemblage of the lower unit has not been observed elsewhere.

Rocks typical of the Cape Elizabeth Formation crop out at the northern end of House Island. They are medium-gray quartz-plagioclase-muscovite-chlorite-biotite phyllite with thin interbeds of lighter gray metamorphosed feldspathic wacke. These rocks are separated from the light gray metatuff of the Cushing by a transition sequence of dark gray quartz-plagioclase-biotite granofels with thin interbeds of fine-grained garnetiferous granofels and feldspathic quartzite. These are well-exposed around the south end of the island in the vicinity of Fort Scammel.

Cape Elizabeth Formation. The Cape Elizabeth Formation typically consists of medium dark gray quartz-plagioclase-muscovite-biotite-chlorite-garnet phyllite with thin interbeds of medium gray feldspathic quartzite with minor biotite, garnet, and chlorite. Andalusite and staurolite are present in the exposures on the northern end of Long Island and the southern tip of Great Chebeague Island. Graded bedding is occasionally developed.

Rocks exposed on Ram Island and Ram Island Ledge just east of Cushing Island are included with the Cape Elizabeth Formation, although the proportion of metapelite to quartzo-feldspathic granofels beds is considerably lower. Pelitic beds have muscovite, biotite, and pinkish garnet. Quartzo-feldspathic beds generally are somewhat more quartz-rich and harder than the thin quartzose rocks of the Cape Elizabeth Formation elsewhere. In addition, the quartzose beds have relict sedimentary concretions with distinct chemical zoning in which hornblende and grossularite are present. In many respects (more quartzose competent beds and zoned calcareous concretions) these rocks resemble the Kittery Formation exposed in Cape Elizabeth at Two Lights State Park except that their metamorphic grade is considerably higher.

Stratigraphic Relations between the Cushing Formation and the Cape Elizabeth Formation. A superior exposure of the contact between the Cushing Formation and the Cape Elizabeth Formation exists on the west shore of Long Island (Figure 10). There, the basal 20 meters of the Cape Elizabeth Formation includes several distinct lenses of metamorphosed rhyodacite tuff ranging in thickness from 5 to 20 cm and seldom exceeding a strike length greater than 20 meters. Some of these beds are graded, with feldspar- and quartz-rich bases grading upward into a more micaceous lithology (Figure 11). This clearly indicates that (1) the volcanogenic material of the Cushing Formation was unconsolidated at the time of deposition of the Cape Elizabeth Formation, and (2) that the two formations are conformable. A tentative interpretation of the conditions of deposition is that the Cape Elizabeth Formation was deposited on the flanks of a submarine pyroclastic volcanic pile (Levy and others, 2003). Episodically, local slumps of the unconsolidated pyroclasts occurred, sending turbidity flows of the material into the adjacent area where Cape Elizabeth muds and silts were being deposited. Slumping was favored where the slope of the volcanic pile was the highest and may have been the result of seismic unrest. The limited lateral extent of these volcanogenic layers in the basal Cape Elizabeth Formation argues against periods of recurrent volcanism. A corollary of this interpretation is that the Cape Elizabeth Formation, although generally on top, locally interfingers laterally with the Cushing Formation. This might

Figure 11. Five graded beds of feldspathic granofels in the lower part of the Cape Elizabeth Formation. These beds are interpreted to be derived from unstable submarine slopes by slumping of unconsolidated pyroclastic material of the Cushing Formation during initial stages of deposition of silts and muds of the Cape Elizabeth Formation. The location of this photograph is shown by the arrow in Figure 10.

Figure 12. Evenly textured metamorphosed andesitic to basaltic tuff of the Spring Point Formation at Fish Point on the northeastern shore of the Portland peninsula.

Figure 13. Spring Point Formation with well-preserved pyroclasts of light colored metatuff in matrix of medium greenish gray metamorphosed andesite to basalt ash. Southwest end of Great Diamond Island.

explain the presence of Cape Elizabeth lithologies within the Cushing as mapped on Little Whaleboat and Whaleboat Islands off Harpswell Neck (Hussey, 1971), northeast of the Portland East quadrangle.

On the southwestern end of House Island, as described above, the conformable-appearing unit between the Cape Elizabeth and Cushing rocks is exposed in the nose of prominent anticline near Fort Scammel (Figure 8). The lithology of this unit is transitional to both principal rock units, consisting of thin, rhythmically-bedded quartz-plagioclase-biotite-garnet schist, with thin pulled-apart medium reddish gray garnet-quartz granofels beds (coticule). The coticule beds may represent metamorphosed muddy chert. Near the base of the transition rocks is a 5-15 cm more feldspathic biotite-garnet schist, and immediately on top of the Cushing rocks is a 2-4 cm bed of coarse-grained garnet-biotite-quartz schist. The transitional rocks may represent a conformably deposited zone of current-reworked volcanic detritus from the Cushing mixed with the muds of the Cape Elizabeth Formation.

Spring Point Formation. The Spring Point Formation is medium greenish gray chlorite-actinolite-plagioclase-biotite schist and granofels. Compositional layering is rare. On the Portland peninsula at Fish Point the rock is essentially massive with no significant schistosity and may represent fine-grained andesitic to basaltic tuff (Figure 12). At other localities coarse fragmental textures are developed. These can be seen in the excellent shoreline exposures at Southern Maine Technical College (formerly Southern Maine Vocational Technical Institute as shown on the Portland East map sheet). Here, the clasts are highly stretched and flattened medium to light greenish gray metavolcanics. On Little and Great Diamond Islands angular to subrounded light gray and greenish-gray pyroclastic fragments up to 15 cm maximum dimension occur abundantly in a matrix of fine-grained chlorite-actinolite-biotite schist (Figure 13). Near the Casco Bay Lines ferry landing on the south end of Great Diamond Island some of the gray pyroclasts have abundant megacrysts of blue quartz up to 8 mm in maximum dimension. These pyroclasts resemble parts of the Cushing Formation suggesting the possibility that they may have been ripped off from the Cushing Formation during Spring Point eruptive activity.

Diamond Island Formation. The Diamond Island Formation is the most distinctive and easily identifiable rock unit of the Casco Bay Group. It is a dark gray to black quartz-graphite-muscovite phyllite, almost completely devoid of compositional layering. Pyrite, frequently in well-formed cubes, is common and imparts to the phyllite its conspicuous yellow and orange weathering color (Figure 14). Thin (~0.1 mm) short quartz partings along cleavage planes are abundant. The

Figure 14. Diamond Island Formation at Southern Maine Technical College in South Portland.

Figure 15. Buff-weathering interbedded calcite granofels and quartz-plagioclase-biotite phyllite. Cow Island.

Diamond Island Formation is distinguished from highly carbonaceous lithologies in the Scarboro and Jewell Formations by the dull black, sooty appearance when powdered. The formation is named from Great Diamond and Little Diamond islands (Katz, 1917), but exposures there are difficult to get to. The most accessible exposure, and one that is designated the type locality for the formation (Hussey, 1985) is along the shoreline at Southern Maine Technical College in South Portland. There its contact with the underlying Spring Point Formation is exposed, and its contact with the overlying Scarboro Formation occurs in an interval of 8 to 10 meters concealed by the sand and cobble beach. The contact between the Spring Point and Diamond Island Formations is sharp and apparently conformable. The contact with the Scarboro Formation is probably conformable.

Scarboro Formation[1]. The Scarboro Formation crops out on Little Chebeague, Great Chebeague, Cow, and Great Diamond Islands, and on the mainland at Southern Maine Technical College. Outcrop belts in South Portland at the southwestern corner of the quadrangle are inferred based on the distribution of outcrops of the different rock units above and below it in areas on strike in the Prouts Neck 7.5' quadrangle (Hussey, in press, a). The Scarboro Formation consists of rusty and non rusty weathering metapelites. The most common lithology in the Portland East quadrangle is nonrusty to slightly rusty-weathering muscovite-biotite-quartz phyllite with locally abundant euhedral garnets. Minor associated rock types include (1) light to medium greenish gray chlorite-biotite-quartz phyllite of intermediate volcanic affinity; (2) very rusty-weathering dark gray muscovite-biotite-garnet-graphite phyllite, and (3) very rusty-weathering light gray schist like (2) except no graphite is present. A thin (5 to 20-meter) ribbony-bedded medium-gray metalimestone, essentially identical to the Spurwink Metalimestone described below, is present locally near the base of the formation. Rare quartz-plagioclase granofels beds occur throughout the formation.

Spurwink Metalimestone. Conformably above the Scarboro Formation is the Spurwink Metalimestone. Katz (1917) proposed the lithic designation "limestone" for this formation, but to avoid confusion to geologists not acquainted with the fact that these rocks are metamorphosed, I have referred to the formation as "metalimestone." Why not marble? Simply, it does not look like marble. This formation consists of fine-grained medium brownish gray weathering, medium dark gray ribbony-textured calcite granofels with minor biotite (Figure 15). It includes 1 to 3 cm interbeds of medium brownish gray quartz-biotite-plagioclase phyllite. Its thickness does not exceed 100 meters.

Jewell Formation. The Jewell Formation is very similar to the Scarboro Formation. The dominant lithology is both rusty- and non-rusty weathering medium silvery-gray muscovite-biotite-garnet-quartz phyllite and schist, with occasional andalusite, staurolite, and chloritoid. Staurolite and andalusite are partially retrograded to micas and chlorite. Other lithologies include (1) non-rusty mostly greenish and purplish gray muscovite-chlorite-biotite-garnet-quartz phyllite and schist, (2) medium greenish-gray chlorite-biotite-muscovite-quartz-magnetite phyllite and schist (possibly intermediate metavolcanic tuffs), (3) non-rusty and very rusty weathering dark gray muscovite-graphite-quartz-biotite phyllite and schist with 1-4 mm-thick zones rich in pink garnet.

The outcrop belt of the Jewell Formation in South Portland is inferred from outcrops in the Prouts Neck 7.5' quadrangle to the southwest (Hussey, in press, c).

STRUCTURE

Figure 16 shows the distribution of faults and major folds in the Portland East 7.5' quadrangle. This area spans the Casco Bay shear zone described by Swanson (1999a, 1999b), an exten-

[1] The spelling adopted here for the name of the formation is that which was given by Katz (1917). Subsequently, the town adopted the spelling "Scarborough."

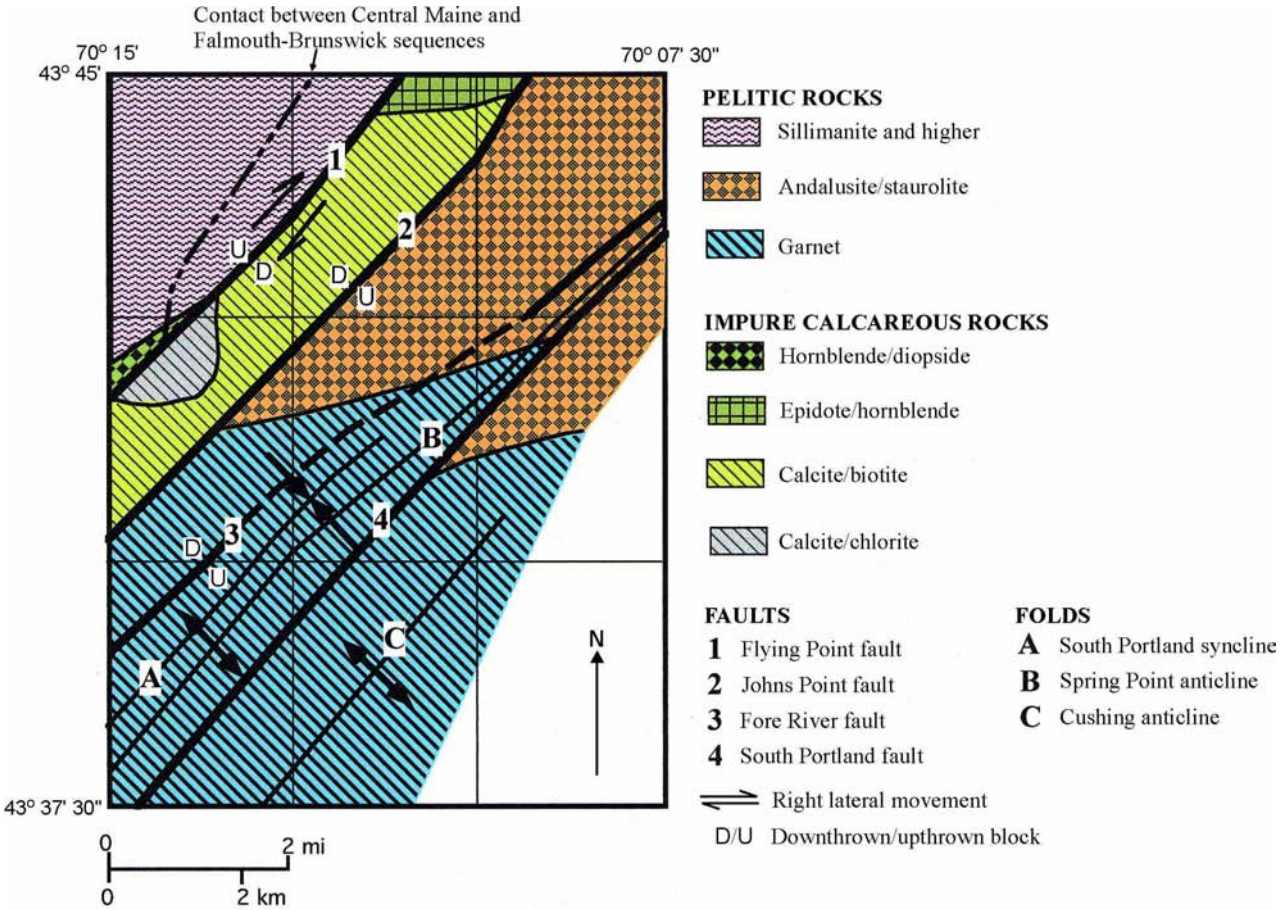

Figure 16. Generalized structure and metamorphic map of the Portland East 7.5-minute quadrangle.

sion of the Norumbega fault system to the northeast (Ludman and West, 1999). Most of this system is characterized by right-lateral strike slip movement as indicated mostly by small-scale kinematic indicators, such as rotated boudins, delta and sigma tails of porphyroblasts, shear bands, sheath folds, and others. This right-lateral ductile deformation took place in Late Paleozoic time.

Faults

Most of the major faults delineated in the Portland East quadrangle are interpreted to be related to brittle faulting in Mesozoic time (Hussey and Berry, 2002), associated with the breakup of Pangea. The Flying Point fault preserves evidence of both early ductile faulting (Swanson, 1999a, b) and later brittle down-to-the-east faulting (West and others, 1993). Estimates of approximately 4 km of normal faulting are suggested by West and others, 1993) to account for the metamorphic and structural contrasts of the rocks on either side of the fault. The Johns Point, Fore River, and South Portland faults show evidence of brittle deformation, including fault breccia, slickensides, gouge, and vuggy milky quartz veins. The South Portland fault was first recognized by Bodine in 1965. The Fore River fault was first recognized by Hussey (in press, c) from core samples taken along the alignment of the Casco Bay Bridge between South Portland and Portland in the Portland West quadrangle. This fault probably connects with the zone of silicification mapped on Little and Great Chebeague Islands (this quadrangle). Based primarily on distribution of the metamorphic isograds (Figure 16) and ages of juxtaposed formations, the Johns Point, Fore River, South Portland faults appear to be downthrown in a direction opposite to that of the Flying Point fault. It is tempting to regard them as antithetic faults to the major Flying Point fault, and that the Merrimack and Casco Bay Groups occupy a major Mesozoic-age half-graben system.

Folds

Major folds are mapped only for the Casco Bay Group, and their axial traces are shown in Figure 16. These folds are delineated solely on the basis of outcrop distribution of the formations that constitute the group. Minor asymmetric fold sets are present in outcrop, but do not to predict the major fold pattern; this may be due to insufficient examples, but also because they may repre-

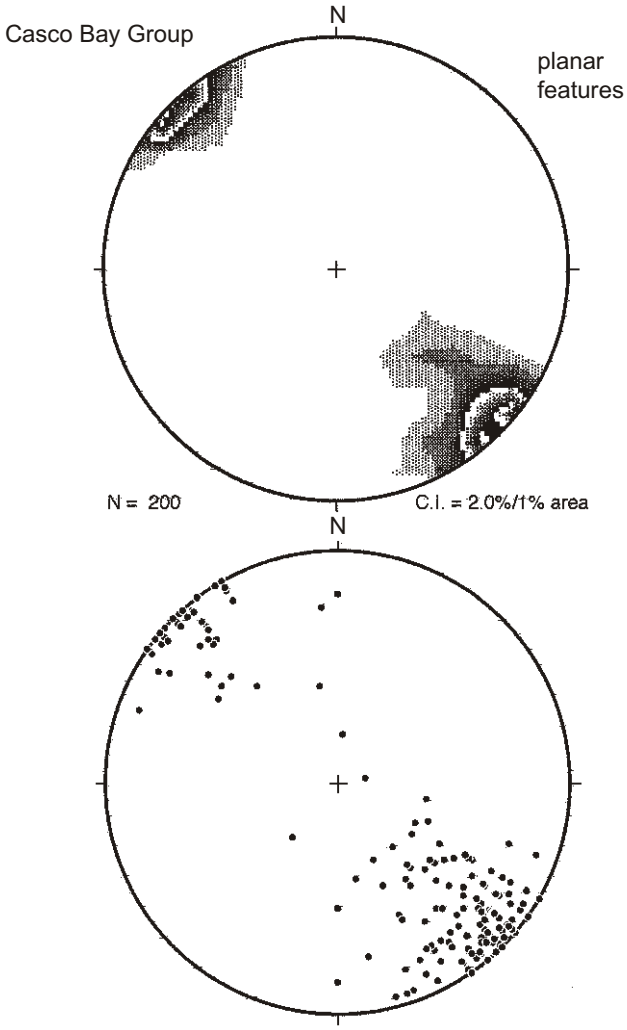

Figure 17. Stereogram showing poles to foliation, compositional layering, and schistosity, Casco Bay outcrop belt, Portland East quadrangle. The poles show a tendency toward steep to vertical dips and a N 45° E strike. N = number of data points. C.I. = contour interval.

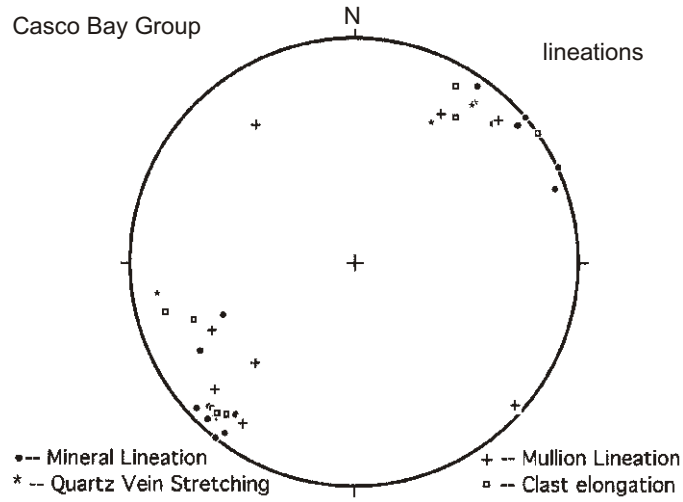

Figure 18. Stereogram of different lineations within the Casco Bay belt showing marked tendency for shallow plunges to the northeast and southwest.

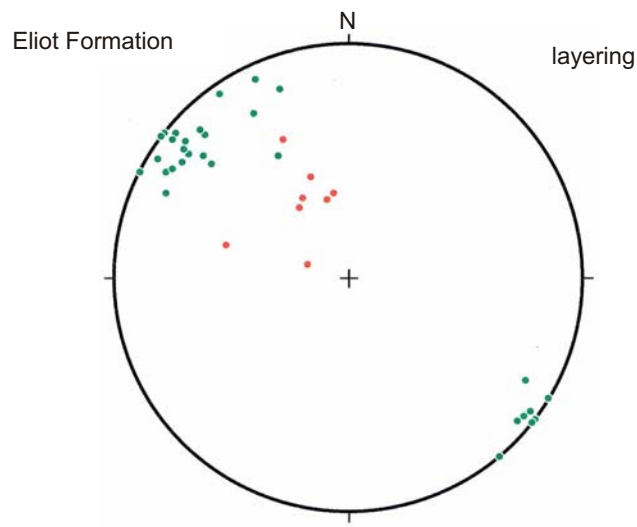

Figure 19. Stereogram of poles to compositional layering and lamination of the Eliot Formation within the Portland East quadrangle. Red poles are for the Eliot Formation exposed on Mackworth Island and green poles are for the Eliot Formation exposed elsewhere within its outcrop belt. Poles for Mackworth Island have a similar orientation to those for the Falmouth-Brunswick and Central Maine sequences (Figures 20 and 21); poles for exposures elsewhere have an orientation similar to those for the Casco Bay Group.

sent two or more stages of folding. Major folds of the Portland East quadrangle trace into fold systems in the northern part of the Casco Bay belt that are interpreted to be upright to very slightly overturned F_2-fold generation folds (Hussey and Berry, 2002). Earlier recumbent folds have not been identified in the Portland East quadrangle. Figure 17 is a stereogram of poles to planar structures in the Casco Bay Group showing a tendency toward vertical to steep northwest dips and strikes approximating 45 degrees. Figure 18 shows poles to various lineations indicating generally shallow plunges to the northeast and southwest, parallel to plunges of axes of minor folds seen in outcrop.

The belt of the Eliot Formation is characterized by tightly compressed minor folds of thin laminae. These are mostly observed where dips of the compositional layering and lamination are steep. Steep layering occurs throughout most of the Eliot belt except on Mackworth Island where dips are moderate to gentle to the southeast (Figure 19). In general, other than for the exposures on Mackworth Island, dips and strikes are similar to those of the Casco Bay Group. The shallower dips on Mackworth Island may be the result of fault rotation along the Johns Point fault on the southeast side of the island, and another as yet unrecognized late brittle fault on the northwest side of the island. Similar gentle dips are present in the Eliot Formation on strike to the southwest in the Portland West quadrangle (Hussey, in press, b).

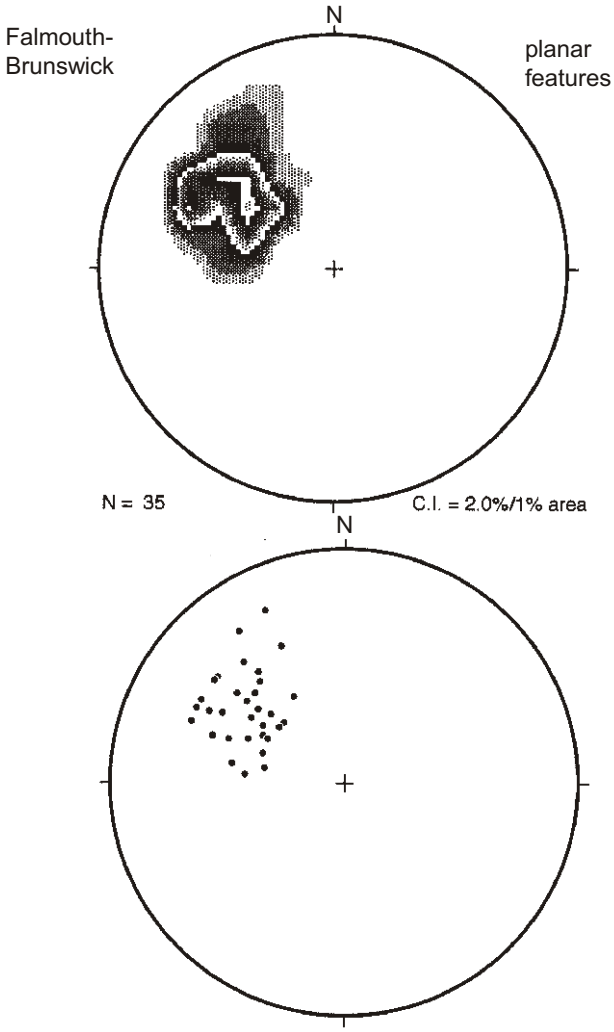

Figure 20. Poles to compositional layering and schistosity of the Falmouth-Brunswick sequence.

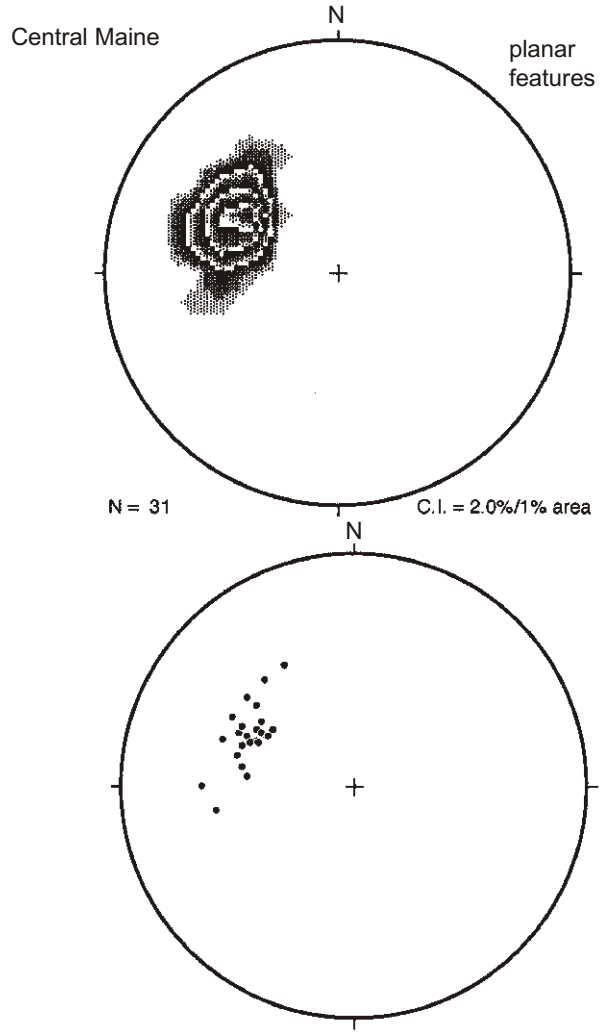

Figure 21. Poles to compositional layering and schistosity of the Central Maine sequence.

Gneissic layering, and schistosity in the Falmouth-Brunswick and Central Maine sequences are essentially parallel (Figures 20 and 21); strikes average around N 45 E, and dips are moderate to the southeast, much like on Mackworth Island. Major folds have not been mapped; those shown on the map sheet in cross-section A A' are conjectural. Minor asymmetric folds are rather uncommon in these sequences. Those observed are predominantly west verging and strongly overturned. They deform foliated conformable pegmatite lenses, migmatite stringers, gneissic foliation, and schistosity; thus they are late in the fold sequence. Their correlation with times of folding in the Casco Bay and Eliot belts is not yet known.

METAMORPHISM

The rocks of the Portland East quadrangle have been metamorphosed to varying grades ranging from garnet to andalusite zones in a Buchan facies series for the metapelites of the Casco Bay Group, to sillimanite (possibly sillimanite + K-feldspar) zone for metapelites in the Falmouth-Brunswick and Central Maine sequences, and from chlorite-calcite to hornblende-diopside zones for impure carbonate rocks in the Merrimack Group and Central Maine sequence. Isograds are shown in Figure 16. Within the Eliot Formation of the Merrimack Group and the rocks of the Casco Bay Group, the grade of metamorphism generally increases to the northeast. Metamorphic isograds have been offset by the major brittle Mesozoic faults.

Garnet is the highest-grade index mineral in the pelitic rocks of the Casco Bay Group in the southern half of the quadrangle. In the northern half, andalusite, staurolite, and chloritoid are present. Staurolite and andalusite are extensively retrograded to mica and chlorite. In the andalusite-staurolite zone large quartz veins commonly have anhedral masses of clear pink andalusite. Blue corundum grains less than a millimeter in maximum dimension occur rarely within the andalusite which isolates them from the quartz. Late retrograde chlorite is common

in the pelitic rocks of the Casco Bay rocks. Mafic rocks of the Spring Point Formation are metamorphosed only to garnet grade. The indicator minerals are actinolite and rarely epidote. Green chlorite is always present, probably as a prograde mineral.

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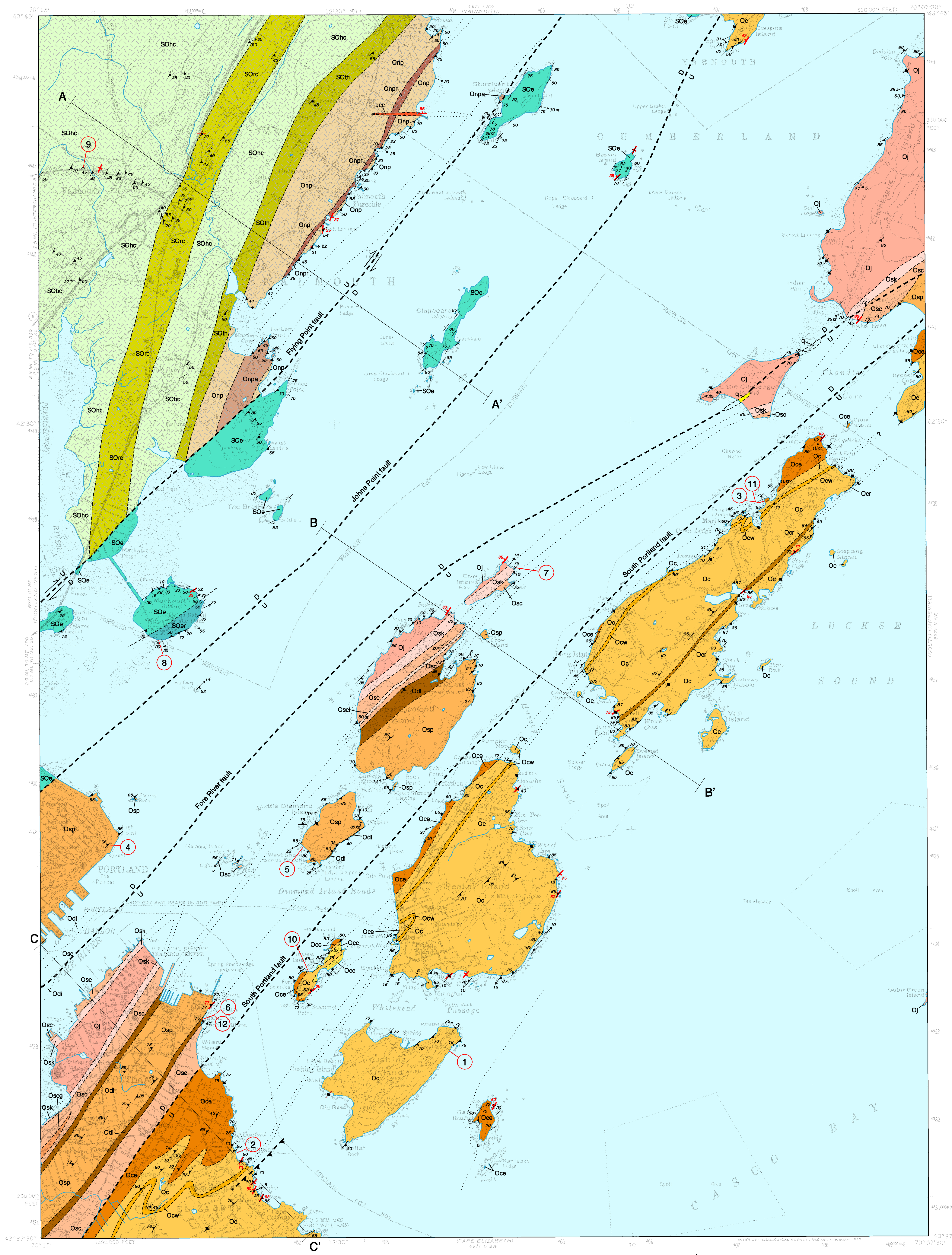
Bedrock Geology



SCALE 1 : 24,000

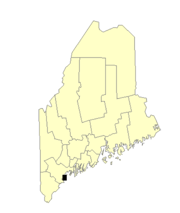
1 MILE; 1000 0 1000 2000 3000 4000 5000 6000 7000 FEET; 1 KILOMETER

CONTOUR INTERVAL 20 FEET

TRUE NORTH

SOURCES OF INFORMATION

Geologic mapping by A. M. Hussey II, 1970 - 2003.



Quadrangle Location

Topographic base from U.S. Geological Survey Portland East quadrangle, scale 1:24,000 using standard U.S. Geological Survey topographic map symbols.

The use of industry, firm, or local government names on this map is for location purposes only and does not impute responsibility for any present or potential effects on the natural resources.

Portland East Quadrangle, Maine

Bedrock geologic mapping by
Arthur M. Hussey II

Digital cartography by:
Susan S. Tolman
John B. Poisson

Robert G. Marvinney
State Geologist

Cartographic design and editing by:
Robert D. Tucker
Henry N. Berry IV

Funding for the preparation of this map was provided by the Maine Geological Survey.

Maine Geological Survey

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Home page: http://www.maine.gov/doc/nrimc/nrimc.htm

Open-File No. 03-90
2003

This map accompanied by a 12 p. report.

On the geologic map, different bedrock units are indicated by colors and identified by letter symbols that represent their assigned age and unit name. The Flying Point and Johns Point faults divide the map into three parts, each having a different set of rock units. The following description summarizes the major rock types of each unit, and gives a simplified geologic history by which they formed.

MAJOR ROCK TYPES

The stratified, or layered, rocks of the Portland East quadrangle are all metamorphic rocks, including schist, phyllite, gneiss, granofels, and amphibolite. Schist consists mostly of thin, flat flakes of mica which are arranged parallel to each other such that the rock splits into sheets. Phyllite has a similar mineral texture except the individual grains are very small and not readily seen without a microscope. Gneiss is a type of layered rock in which the different minerals are concentrated in separate, irregular streaks or layers. Granofels, made up primarily of the minerals quartz and feldspar, has a grainy texure somewhat like sugar. In contrast with schist and phyllite, gneiss and granofels tend to break into angular blocks or chunks. Amphibolite is a rock named for dark grains of the mineral amphibole, the principal constituent of the rock. Varieties of gneiss, schist, and granofels may be further distinguished by their particular mineral content, grain size, color, or other characteristics.

ORIGIN OF THE STRATIFIED ROCKS

The oldest rocks of the Portland East quadrangle, southeast of the Johns Point fault, belong to the Casco Bay Group, a diverse assortment of metamorphosed volcanic rocks, shales, and limestone, deposited during Ordovician time (see Geologic Time Scale, below). The oldest unit of the Casco Bay Group is the Cushing Formation, a thick pile of light gray volcanic material (Photo 1), composed of coarse angular blocks of volcanic breccia and fine volcanic ash with crystals of quartz and feldspar (Photo 2). These rocks formed as hot lava erupted on an ancient ocean floor and became fragmented on contact with the cold ocean water. As volcanic activity ended, shale and siltstone of the Cape Elizabeth Formation accumulated conformably on top of the volcanic pile. Near the base of the Cape Elizabeth Formation, beds of volcanic ash, similar in composition to the Cushing volcanic rocks, were deposited intermittently (Photo 3) when slopes of the volcanic pile slumped and were transported by currents to where the Cape Elizabeth shale and siltstone were being deposited. A period of renewed volcanism ensued, depositing basaltic ash and breccia of the Spring Point Formation (Photos 4 and 5). In places, dark shale of the Diamond Island Formation (Photo 6), rich in organic matter and iron sulfide, accumulated after cessation of the basaltic volcanism. This was followed by accumulation of more shale and siltstone, of the Scarboro and Jewell Formations, and shaly limestone of the Spurwink Metalimestone (Figure 7).

Rocks of the Falmouth-Brunswick sequence, along the Falmouth shore, are represented by the Nehumkeag Pond Formation which consists of a thick, heterogeneous pile of metamorphosed feldspar-rich sandstone, iron sulfide-rich shale, and sporadically-interbedded volcanic ash of basaltic composition. The age of these rocks is poorly constrained but is thought to be Ordovician. Their original relationship to the Casco Bay Group is uncertain because the two sequences are now separated by faults, and have distinctively different grades of metamorphism.

The Merrimack Group, much more extensive in the southwestern part of Maine, is represented in the Portland East quadrangle by a thin strip of Eliot Formation, between the Johns Point and Flying Point faults. Here it consists of slightly metamorphosed calcareous siltstone and shale with interbedded layers of very rusty weathering shale (Photo 8). These rocks are interpreted to be deep ocean sediments deposited during Late Ordovician to Early Silurian time.

The Central Maine sequence, in the northwest corner of the map, was deposited during Late Ordovician to Early Silurian time. It consists of highly metamorphosed calcareous and non-calcareous sandstone and siltstone (Hutchins Corner Formation) and slightly muddy sandstone and siltstone (Richmond Corner Formation), also deposited in a marine environment. These rocks were extensively injected by magma, now preserved as conformable layers of light-colored granitic pegmatite (Photo 9).

DEFORMATION, METAMORPHISM, FAULTING, AND IGNEOUS INTRUSION

Rocks of all the stratified sequences were complexly folded during a period of major regional deformation and mountain-building known as the Acadian orogeny, in Early to Middle Devonian time. Large-scale deformation of the Earth's crust is indicated by large folds in the map pattern and cross-sections; minor folds and other internal structural complexities can be seen in outcrop at many localities (Photos 10 and 11). During late stages of this active deformation period, the rocks were forced to deep levels in the Earth's crust where heat and pressure gradually transformed the sedimentary rocks into the metamorphic rocks that we see now. Shale was transformed into phyllite and schist; sandstones became granofels and gneiss; volcanic ash and breccia of basaltic composition became amphibolite. The intensity of metamorphism was not everywhere the same. Some rocks became hot enough to melt, yielding granitic magma that was injected as stringers into the metamorphic rocks to produce strikingly banded rocks (Photo 9). Some of the magma was injected into cross-cutting cracks and cooled to form dikes of a very coarse-grained granite known as pegmatite.

After the Acadian orogeny the rocks of the quadrangle were subjected to major faulting and shearing while still deep in the Earth's crust, forming part of the Norumbega fault zone. Shear bands, disrupted white quartz veins, and many similar small structures that formed during this event attest to the fact that rocks sheared past each other in a right-lateral sense; i.e., rocks on the east moved south and rocks on the west moved north. This ancient fault zone in some ways resembles the present-day San Andreas fault in California. Later faulting, with vertical rather than sideways motion, formed the major normal faults of the quadrangle, the Flying Point, Fore River, and South Portland faults.

The youngest rocks in the area are the numerous dark-colored basalt and diabase dikes. They formed when basaltic magma was injected into extensional fractures produced during continental rifting of the incipient Atlantic Ocean in Mesozoic time. These widely scattered dikes are typically a few inches to a few feet thick (Photo 12), but one, the Christmas Cove dike, is nearly 100 feet wide and has been traced 75 miles east-northeast to the Port Clyde area. The present landscape and ocean bathymetry are fundamentally controlled by uneven erosion of the complex underlying bedrock geology over great spans of time, modified by recent and ongoing surface processes.

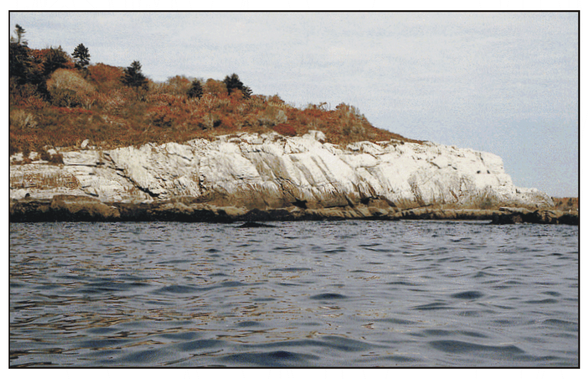


Photo 1. Cushing Formation. Light gray metamorphosed volcanic rocks. *(Cushing Island near Whitehead)*

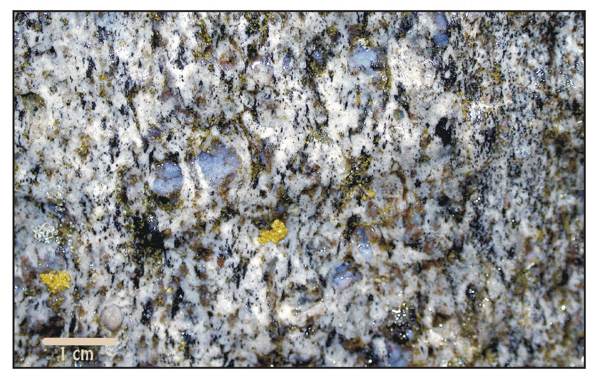


Photo 2. Cushing Formation. Gneiss derived from volcanic ash with conspicuous crystals of blue quartz. *(Danford Cove, South Portland)*

Photo 3. Cape Elizabeth Formation. Metamorphosed sedimentary beds in the lower part of the formation. The light gray beds of volcanic ash, similar to those in the Cushing Formation, were redeposited when slopes of the unconsolidated tuff failed repeatedly, producing bottom-hugging currents of turbid water. As the currents slowed, coarser grains of the ash settled first, followed by gradually finer-grained, dark-colored mud. *(Long Cove, Long Island)*

Photo 4. Spring Point Formation. Massive deposit of fine-grained, metamorphosed volcanic ash. *(Fish Point, Portland, beneath Fort Allen Park, next to narrow gauge railroad)*

Photo 5. Spring Point Formation. Coarse volcanic breccia. White chunks are rock fragments blown from a volcanic vent. *(Little Diamond Island)*

Photo 6. Diamond Island Formation. Rusty-weathering black phyllite (foreground) rests against greenish volcanic ash of the Spring Point Formation (background). Fort Prebble at far right. *(Southern Maine Technical College, South Portland)*

Photo 7. Spurwink Metalimestone. Thinly layered, buff-weathering metamorphosed muddy limestone. The steep inclination of the layering, a common feature of this map area, indicates the rocks have been deformed from their original flat-lying orientation. *(Cow Island)*

Photo 8. Eliot Formation. Gray calcareous metamorphosed siltstone, with very rusty-weathering, dark gray contorted phyllite in foreground. *(Southeastern side of Mackworth Island)*

Photo 9. Hutchins Corner Formation. Gray gneiss of the Hutchins Corner Formation here has been extensively injected by parallel layers and lenses of light-gray pegmatite. Thin beds of greenish gray gneiss, which were originally limy and muddy sandstone, are interbedded with the gray gneiss. *(Falmouth Connector between I-295 and the Maine Turnpike, Falmouth)*

Photo 10. Cushing Formation, coticule member. Beautifully folded layers of garnet-rich granofels. These folds formed as a result of compression of the Earth's crust during the Acadian orogeny. *(House Island)*

Photo 11. Cape Elizabeth Formation. Thinly bedded, metamorphosed feldspar-rich siltstone (lighter bands) and shale, 5 meters west of the contact with the Cushing Formation. The thin layers are folded very tightly, while the stout white quartz vein to the left has more open fold shapes. *(Long Cove, Long Island)*

Photo 12. Three-foot thick diabase dike cutting the Diamond Island Formation. Edges of the dike are highlighted by white lines. Margins of the dike are more blocky than its interior. *(Southern Maine Technical College, South Portland)*

EXPLANATION OF UNITS

DIKES AND FAULT-RELATED ROCKS

Jurassic (?)

- Porphyritic and non-porphyritic diabase and basalt dikes and sills, 5 cm to 3 m thick.
- **Jcc** — **Christmas Cove Dike**. Reddish-brown weathering, columnar-jointed, medium-dark gray generally non-porphyritic diabase, up to 30 m thick.
- **q** — Silicified zone related to fault. Massive veined white quartz rock.
- Overprint pattern indicates areas of extensive injection by granite pegmatite stringers, northwest of Flying Point fault.

STRATIFIED ROCKS

Early Silurian to Late Ordovician (?)

CENTRAL MAINE SEQUENCE

- **SOhc** — **Hutchins Corner Formation.** Medium-gray fine- to medium-grained quartz-plagioclase-biotite granofels or gneiss with or without 2 to 6 cm beds of medium greenish gray quartz-plagioclase-diopside-hornblende-sphene granofels or gneiss. Heavily injected by pegmatite.
- **SOrc** — **Richmond Corner Formation.** Medium brownish gray quartz-plagioclase-biotite gneiss locally with almanditic garnet and sillimanite. More strongly migmatized than SOhc.
- **SOth** — **Torrey Hill Formation.** Rusty-weathering schistose muscovite-biotite-quartz schist and gneiss, locally with abundant sillimanite.

MERRIMACK GROUP

- **SOe** — **Eliot Formation**. Fine-grained brownish-gray-weathering strongly sheared calcareous biotite-chlorite-muscovite phyllite, regularly alternating with thin interlayers of dark gray chlorite-muscovite phyllite.
  - **SOer** — Same as rest of formation, but with 2 to 30 m intervals of rusty phyllite.

Ordovician (?)

FALMOUTH - BRUNSWICK SEQUENCE

- **Onp** — **Nehumkeag Pond Formation.** Light- to medium-gray quartz-plagioclase-biotite-muscovite gneiss and schist, slightly to strongly migmatized.
  - **Onpr** — Rusty-weathering phyrrhotitic plagioclase-quartz-biotite gneiss with minor amphibolite.
  - **Onpa** — Amphibolite, locally with light- to medium-gray quartz-plagioclase-biotite-muscovite gneiss and schist. Possibly equivalent to Mount Ararat Formation to the north.

------(stratigraphic relations unknown)------

Ordovician (probably Middle)

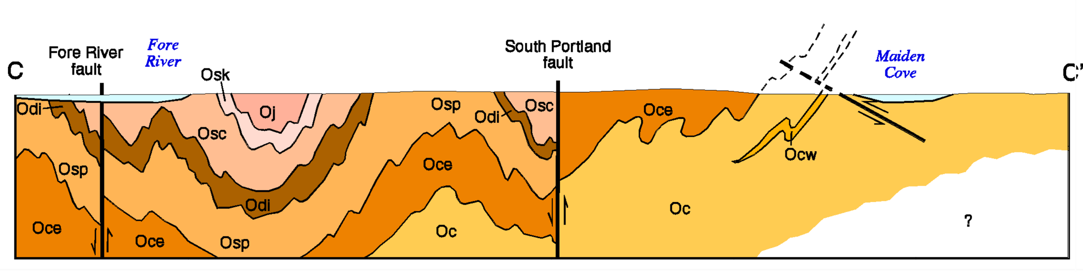
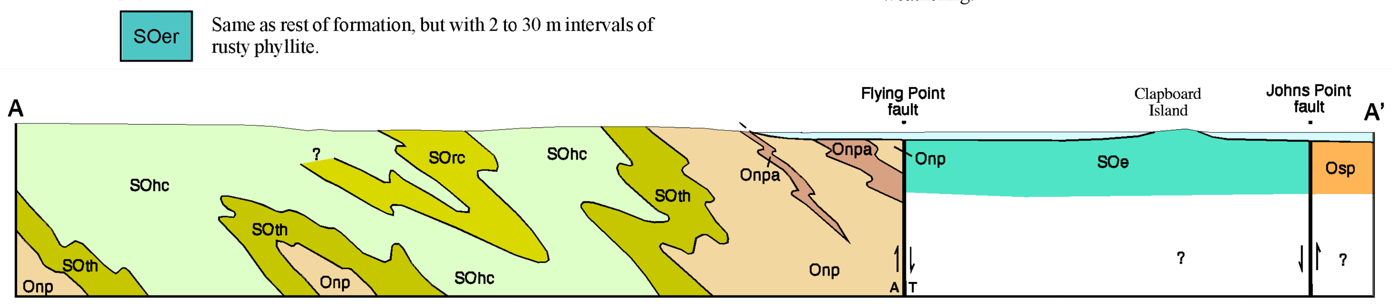
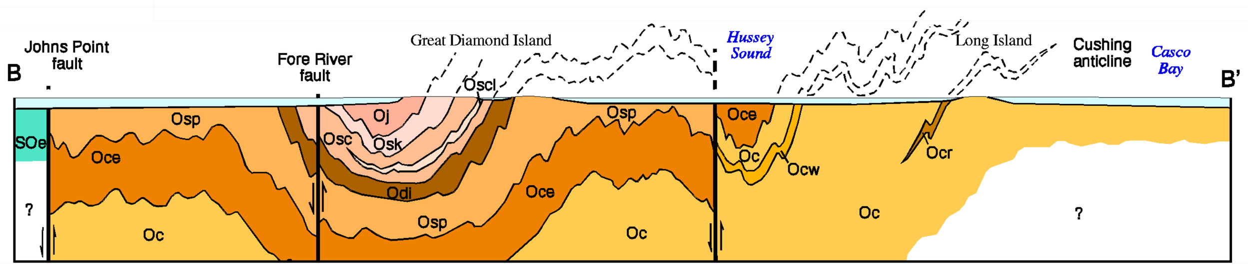
CASCO BAY GROUP

- **Oj** — **Jewell Formation**. Rusty and non-rusty, graphitic and non-graphitic brownish-weathering phyllite or schist with muscovite, biotite, and garnet in the garnet zone; muscovite, biotite, garnet, andalusite, staurolite, and chloritoid in the andalusite+staurolite zone. Includes zones of non-rusty green chlorite-rich phyllite not separately mapped. (See report for metamorphic zones.)
- **Osk** — **Spurwink Metalimestone**. Medium-gray ribbony-layered impure metalimestone with interbeds of biotite-chlorite phyllite.
- **Osc** — **Scarboro Formation**. Lithology indistinguishable from the Jewell Formation. Has rare beds of quartz-plagioclase-muscovite-biotite schist.
  - **Oscl** — Medium-gray ribbony-layered impure metalimestone with interbeds of biotite-chlorite phyllite.
  - **Oscg** — Unnamed volcanogenic member**.** Medium greenish gray chlorite-garnet-quartz phyllite, generally non-rusty weathering.
- **Odi** — **Diamond Island Formation**. Rusty-orange-weathering black quartz-muscovite-graphite phyllite.
- **Osp** — **Spring Point Formation**. Medium-dark greenish gray plagioclase-chlorite-actinolite amphibolite. Some zones preserve 2 to 25 cm ovoid blocks of light gray- to greenish-gray metavolcanic rocks.
- **Oce** — **Cape Elizabeth Formation**. Medium gray quartz-plagioclase-biotite-muscovite-chlorite-garnet phyllite to schist, with interbeds of more micaceous phyllite or schist.
- **Oc** — **Cushing Formation**. Light gray plagioclase-quartz-microcline-muscovite-biotite gneiss. Some zones have small (1 to 4 mm) megacrysts of blue quartz, plagioclase, and clear gray quartz. Some zones preserve 2 to 20 cm irregular blocks of light- and medium-gray gneiss similar to the main rock type, and dark gray fine-grained granofels. Volcanic samples from Danford Cove, South Portland have been dated at 471 ± 3 Ma (J. N. Aleinikoff) and 473 ± 3 Ma (R. D. Tucker). See report for details.
  - **Occ** — Heterogeneous metavolcanic assemblage including fine-grained pink coticule, amphibolite, and medium gray quartz-plagioclase-biotite gneiss.
  - **Ocw** — White schistose quartz-muscovite gneiss with minor garnet and plagioclase; locally rusty-weathering.
  - **Ocr** — Rusty-weathering white to very light gray quartz-feldspar-muscovite schist.

EXPLANATION OF SYMBOLS

- Outcrop of mapped unit.
- Strike and dip of bedding. (inclined, vertical)
- Strike and dip of gneissic foliation. (inclined, vertical)
- Direction and angle of inclination of lineations. (plunging, horizontal)
- Stratigraphic or intrusive contact.
- Fault. Arrows indicate sense of motion. U = upthrown block; D = downthrown block.
- Thrust fault. Teeth on overthrust block.
- Photo locality

GEOLOGIC TIME SCALE

Geologic Age		Absolute Age*
Cenozoic Era		0-65
Mesozoic Era	Cretaceous Period	65-145
	Jurassic Period	145-200
	Triassic Period	200-253
Paleozoic Era	Permian Period	253-300
	Carboniferous Period	300-360
	Devonian Period	360-418
	Silurian Period	418-443
	Ordovician Period	443-489
	Cambrian Period	489-544
Precambrian time		Older than 544

* In millions of years before present.