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Bedrock Geology of the Cape Elizabeth 7.5' Quadrangle, Cumberland County, Maine

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INTRODUCTION

The Cape Elizabeth 7.5' quadrangle, located east of the Prouts Neck 7.5' quadrangle and south of the Portland East 7.5' quadrangle (Figure 1), is underlain by rocks of the Casco Bay (Middle to Late Ordovician) and Merrimack (Late Ordovician to Early Silurian) Groups. Exposures of bedrock are abundant along the bold, often cliffed, shoreline, but are much less frequent inland. Sand beaches are relatively limited, mostly confined to the Crescent Beach State Park area and a few small coves elsewhere along the shoreline. Two Lights and Crescent Beach State Parks are located in the southeastern corner of the town of Cape Elizabeth, providing public access to the shoreline within the boundaries of the parks; but the rest of the shoreline is private, requiring permission from landowners to visit.

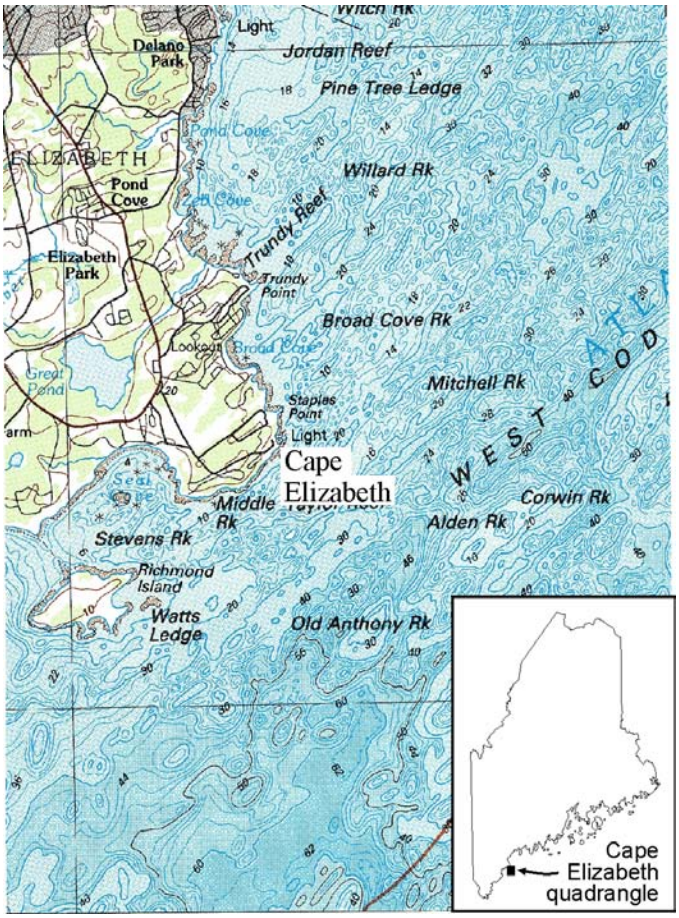

Figure 1. Location of the Cape Elizabeth 7.5-minute quadrangle, southwestern Maine.

STRATIFIED ROCKS

Merrimack Group

The Merrimack Group was originally mapped and named by F. J. Katz (1917) from his studies in southwestern Maine and southeastern New Hampshire. He included in this Group the Kittery, Eliot, and Berwick Formations. Only the Kittery Formation is present within the Cape Elizabeth quadrangle, exposed southeast of the Broad Cove fault. These rocks were originally mapped by Katz (1917) as part of the Cape Elizabeth Formation, and ironically he indicated that the exposures at High Head along the shore of Two Lights State Park were a reference locality for the Cape Elizabeth Formation. These rocks, however, are calcareous, not pelitic as are exposures of the Cape Elizabeth Formation along the shore between the Cape Elizabeth fault and Pond Cove. The calcareous composition, along with the primary sedimentary structures make these rocks correlate well with the Kittery Formation exposed further south in Maine (Hussey, 1962).

Kittery Formation. Rocks on Richmond Island and on the mainland southeast of the Broad Cove fault are variably bedded calcareous metawackes and phyllites, the former predominating. The metawacke beds vary from a few centimeters to a meter or so in thickness. They preserve primary structures, mostly graded bedding, but occasionally also cross-bedding and small-scale channel cuts, indicating deposition from turbidity currents. The metawackes are composed of quartz, plagioclase, calcite, ankerite, and minor white mica and chlorite. These rocks are bluish gray on fresh surfaces, but are buff-gray on weathered surfaces

resulting from alteration of ankerite (an iron-calcium carbonate) to limonite. Rare thin calcite-rich layers weather dark brown and are quite friable, making sampling difficult. In some of the thicker metawacke beds, primary granule or coarse sand-sized grains of quartz, plagioclase and dark unidentified material (possibly dark rock fragments) are present. The thin phyllite beds are dark gray, and are composed predominantly of a white mica and gray chlorite with minor fine-grained quartz. Metamorphic grade of these exposures is very low (ankerite zone of calcareous parageneses). In contrast, rocks northwest of the Broad Cove fault are at garnet grade, as represented by garnet-bearing rocks of the Cape Elizabeth Formation and actinolite-bearing rocks of the Spring Point Formation.

Casco Bay Group

The Casco Bay Group was originally mapped and named by F. J. Katz (1917). The formations that he assigned to the Group are, from oldest to youngest, the Cape Elizabeth, Spring Point, Diamond Island, Scarboro, Spurwink, Jewell, and Mackworth Formations. Katz's 1917 map did not show these formations, but descriptions were clear enough to allow subsequent investigators (Marc Bodine and myself) to delineate them through detailed mapping of 15' and 7.5' quadrangles of the area (Bodine, 1965; Hussey, 1985, 1988). The Cushing Formation is now included at the base of the Casco Bay Group, below the Cape Elizabeth Formation (Hussey, 1971a,b). The Mackworth Formation, which is not exposed in the Cape Elizabeth quadrangle, is now correlated with the Eliot Formation of the Merrimack Group, and is no longer considered part of the Casco Bay Group.

Cushing Formation. The Cushing Formation consists predominantly of fine-grained to medium-grained light gray plagioclase-quartz-biotite-muscovite K-feldspar granofels and gneiss. Compositional layering is weakly developed to absent, but a strong subhorizontal lineation represented by mineral streaks is ubiquitous. Katz (1917) interpreted these rocks as a deformed intrusion of granodiorite composition. Bodine (1965, and personal communications) and Hussey (1971a,b, 1988) have described relict layering and pyroclastic structures that suggest these rocks more likely originated as fragmental volcanic rocks of intermediate to felsic composition, probably deposited in an oceanic environment. The Cushing Formation crops out extensively along the shore in the northwestern part of the quadrangle (Figure 2), and in a small anticline west of Great Pond.

Wilson Cove Member. The Wilson Cove Member of the Cushing Formation is a rusty-weathering dark gray garnet-quartz-plagioclase-grunerite granofels and schist. In the Cape Elizabeth quadrangle, it crops out between the Cushing and Cape Elizabeth Formations only in the anticline west of Great Pond; it is absent between these formations in the northwestern corner of the map sheet. The Wilson Cove is considered part of the Cushing Formation rather than a member of the overlying Cape Elizabeth Formation on the basis of interfingering of Cushing and Wilson Cove lithologies on Harpswell Neck in the northern part of Casco Bay (Hussey, 1971b). The rocks of the Wilson Cove Member may represent metamorphosed iron- and manganese-rich argillaceous sediments. West and others (2008) interpreted the protoliths to be "mixtures of hydrothermal exhalatives and terrigenous clastic sediments deposited in a marine back-arc basin . . ."

The Cushing Formation and Wilson Cove Member have been metamorphosed to garnet grade based on presence of garnet and absence of higher grade index minerals in pelitic rocks of the overlying Cape Elizabeth Formation.

Cape Elizabeth Formation. The Cape Elizabeth Formation consists of medium gray thin-bedded to medium-bedded quartz-plagioclase-biotite ± muscovite granofels with interbeds of biotite-muscovite-quartz-plagioclase-garnet schist. Near the contact with the underlying Cushing Formation in the Maiden Cove area are thin to medium beds of light gray, mica-poor granofels, and a few layers of amphibolite 0.5-1 meter in thickness. The Cape Elizabeth Formation has been metamorphosed to garnet grade.

Spring Point Formation. The Spring Point Formation consists predominantly of medium greenish gray actinolite-chlorite-biotite-plagioclase schist and massive amphibolite, representing mafic volcanic rocks prior to metamorphism. Compositional layering (bedding?) is rare, but is present in a small exposure in Broad Cove (Figure 3). Intermediate to felsic metavolcanic rocks, such as have been observed in the Prouts Neck 7.5' quadrangle (Hussey, 2003b), are not present in outcrops of the Spring Point Formation in the Cape Elizabeth quadrangle.

Diamond Island Formation. The Diamond Island Formation contains strongly sheared black, quartz-muscovite-graphite phyllonite locally with cubes and irregular masses of pyrite that give the weathered surface a strong rusty stain. Outcrops of the formation are scarce, and the mapping of this unit within the quadrangle is mostly based on inferred position between the

Figure 2. Metamorphosed intermediate and felsic pyroclastic volcanics of the Cushing Formation exposed near the core of the Cushing anticline. Portland Head Lighthouse in the background.

Figure 3. Thinly banded, metamorphosed, intermediate to felsic volcanics of the Spring Point Formation at Broad Cove, Cape Elizabeth. Such banding is unusual in the Spring Point Formation, and probably represents waterlaid tuff.

Figure 4. Rusty phyllite of the Scarboro Formation exposed in road cut along Maine Route 77, 1 km northeast of Great Pond, Cape Elizabeth. The prominent spaced cleavage dipping moderately to the left (west) is probably related to a thrust fault that is well exposed in the Prouts Neck 7.5' quadrangle to the west along the shore in the Ram Island Farm area (Hussey, 2003b).

Scarboro and Spring Point Formations, and projection from outcrops in the adjacent Prouts Neck quadrangle (Hussey, 2003b).

Scarboro Formation. The Scarboro[1] Formation consists of very fine-grained, rusty (Figure 4) and non-rusty weathering muscovite-biotite-chlorite-garnet-quartz phyllite. Beds of quartz-muscovite phyllite are sparingly present, but otherwise the formation is non-bedded. Schistosity is strongly crenulated. Chlorite is gray in color, in contrast to the greenish color in the Spring Point Formation. Two lenticular belts of metalimestone are present within the outcrop belt of the Scarboro Formation, one near the junction of Route 77 and Two Lights Road, and the other at ledges on the southwest side of Crescent Beach. These lenses are probably equivalent to the thin exposure of metalimestone (Hussey, 1987, 2003b) along the shore at Southern Maine Community College (formerly known as SMVTI and later, SMTC) in South Portland. Their lithology is similar to that of the Spurwink Metalimestone described below.

Spurwink Metalimestone. The Spurwink Metalimestone is fine-grained ribbony-layered, medium gray metamorphosed limestone with calcite, biotite, and minor quartz. This is thinly interlayered with beds of rusty and non-rusty weathering muscovite-biotite-quartz phyllite. Exposures of this formation (Figure 5) show solutional etching. The formation is well exposed along Route 77 and along the shore between Trundy Point and Whale Back rock.

Jewell Formation. The Jewell Formation is lithologically identical to the Scarboro Formation. Without the intervening Spurwink Metalimestone, the two formations cannot be separately distinguished. The only exposure of the Jewell Formation in this quadrangle is in the core of the Peabbles Point syncline.

Figure 5. Road cut exposure of the Spurwink Metalimestone along Maine Route 77, approximately 500 meters southeast of Figure 4. Note solution etching and the dismembered quartz veins.

INTRUSIVE IGNEOUS ROCKS

Rhyolite in the Spring Point outcrop belt. There is an unusual occurrence of rhyolite, unlike any metafelsic portions of the Spring Point seen elsewhere, along the shore at Broad Cove. This occurrence is a buff-weathering porphyritic rhyolite with quartz phenocrysts in a fine-grained matrix of quartz, plagioclase and orthoclase with accessory carbonate and fluorite. This rock crops out in a distinct southwest-plunging anticline (Figure 6). The margins of the rhyolite are thinly and prominently banded, but the rhyolite in the core of the fold is only very weakly banded. The presence of fluorite as an accessory mineral suggests that the rock is not metamorphosed and therefore is not a part of the surrounding mafic volcanic pile of the Spring Point Formation.

[1] This is the spelling of the town (now known as Scarborough) at the time F.J. Katz (1917) completed his mapping and the naming of the formation.

Figure 6. Folded rhyolite sill exposed in the core of the Broad Cove anticline within intermediate metavolcanics of the Spring Point Formation. Because this felsite appears to be unmetamorphosed in contrast to actinolite-bearing mafic to intermediate Spring Point volcanics, it probably is not part of the Spring Point Formation. It is perhaps a sill intruded after F_1 folding, but before the F_2 fold event. View toward the southwest.

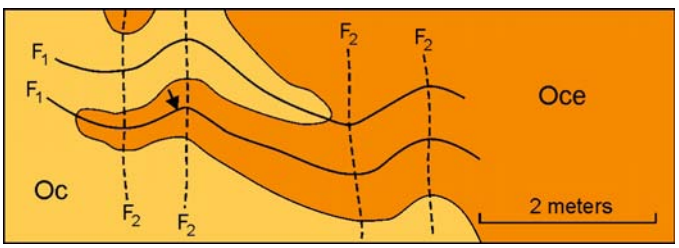

Figure 7. Sketch showing schematically the two stages of folding (recumbent F_1 refolded by upright F_2) at Chimney Rock, Cape Elizabeth, approximately 0.6 km north of Pond Cove. Arrow shows topping sense of a graded bed within the Cape Elizabeth Formation placing it stratigraphically above the Cushing Formation. Oc: Cushing Formation; Oce: Cape Elizabeth Formation. Vertical cross-section, viewed looking north.

Figure 8. Tight upright F_2 anticline folding the contact between the Cushing Formation (light rocks in the center) and the Cape Elizabeth Formation (darker rocks on the right side of the hinge, also exposed on the left side behind where the photo was taken). View looking southwest. Pond Cove, Cape Elizabeth.

The significance of this rhyolite in interpreting the timing of $F_1$and F_2 relative to metamorphism is discussed below.

Dikes. Other than the rhyolite porphyry within the Spring Point Formation described above, the only intrusive rocks in the quadrangle are diabase and basaltic dikes, ranging from 5 cm to 7 m in thickness. These dikes are seen in shoreline exposures of most of the Casco Bay and Merrimack Group rocks. They are unmetamorphosed and undeformed.

STRUCTURAL GEOLOGY

Faults

Three major faults are present in the Cape Elizabeth map area. At the very northwestern tip of the quadrangle, the **South Portland fault** separates the Scarboro and Cushing Formations. This fault was first recognized by Marc Bodine (unpublished mapping in the Portland area). Little is known of the geometry and movement direction of the fault due to lack of outcrops of the fault zone throughout Casco Bay. On the basis of regional mapping it offsets metamorphic isograds (Hussey, 2003a, b, c), and is probably a late high-angle normal fault of Mesozoic age, but this is very speculative. The **Cape Elizabeth fault** in the central part of the land area is also a late fault of probable Mesozoic age. From regional mapping it is known to be locally silicified with drusy quartz crystals, and offsets formational contacts and metamorphic isograds in a left-lateral sense (Hussey, 1971a). Silicified zones are not exposed in the Cape Elizabeth quadrangle, but are seen along the trace of the fault in the Prouts Neck quadrangle to the west where white bull quartz attains a width of outcrop in excess of 15 meters (Hussey, 2002b). The third fault, the **Broad Cove fault**, is traced between Broad Cove and Crescent Beach, without exposure of the fault zone proper. Swanson (1999) interpreted this as one of the major segments of the Norumbega fault zone, with major right-lateral sense of movement. It separates units of the Casco Bay Group from the Kittery Formation exposed in the southeastern tip of Cape Elizabeth.

Folds

The rocks of the Cape Elizabeth quadrangle have been deformed by two major folding events, an earlier recumbent folding (F_1) and a later upright folding (F_2). Evidence for the early recumbent folding is seen more clearly in the Ram Island Farm area of the Prouts Neck quadrangle (Hussey, 2003b) which adjoins the Cape Elizabeth quadrangle to the west, but is clearly developed at Chimney Rock 1.1 km south of Portland Head Lighthouse. Here, the Cushing Formation structurally overlies the Cape Elizabeth Formation, but well-developed graded bedding at the contact indicates that the Cape Elizabeth Formation stratigraphically overlies the Cushing Formation (Figure 7). Steep dips of bedding and foliation are the result of the later upright folding. Approximately 700 meters south on the shore of Pond Cove, the Cushing – Cape Elizabeth contact is tightly folded by the later upright folds (Figure 8).

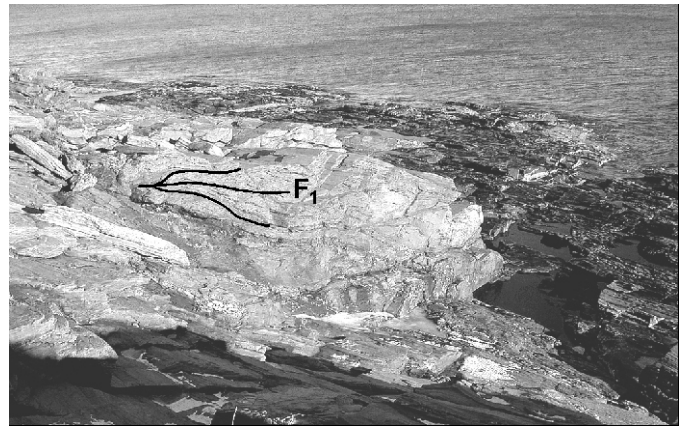

Figure 9. Exposure of the Kittery Formation at Two Lights State Park, Cape Elizabeth showing a recumbent fold opening to the east and possibly topping to the east. Open upright F_2 folds gently deform the axial plane of the recumbent fold. Photo at right highlights a folded bedding surface and the F_1 axial trace of the fold.

Major folds are indicated by the distribution of formations within the Casco Bay Group but the distinction between major recumbent F_1 and upright F_2 folds based on the map patterns is uncertain. The dips of bedding and foliation within the boundaries of a given formation are of little help in defining major folds because of frequent reversals, possibly due to the interference of minor, parasitic, F_1 and F_2 folds. For this reason, in the following discussion, the major folds are not categorized as F_1 or F_2. They are referred to simply as major anticlines and synclines. One exception to this is the Broad Cove anticline which is clearly upright based on the fold geometry of the unmetamorphosed rhyolite within the Spring Point Formation. This is clearly an F_2 fold.

The Cushing Formation in the northwest corner of the map is exposed in the core of the Cushing anticline. To the south, the Cape Elizabeth, Spring Point, Diamond Island and Scarboro Formations are exposed in a series of intermediate-scale synclines and anticlines that comprise the Spurwink River syncline. The map pattern, stratigraphic facing, and plunges of minor folds and lineations together indicate that this series of folds plunges southwest. A minor anticline just west of Great Pond in Cape Elizabeth exposes the Cushing Formation with its rusty Wilson Cove Member. This anticline is truncated on its northeastern end by the Cape Elizabeth fault. Just southeast of the Cape Elizabeth fault the Scarboro, Spurwink, and Jewell Formations are exposed in the Peabbles Point syncline, a complex northeast-plunging structure. On the northwest side of the Broad Cove fault, the Spring Point Formation crops out in a southwest-plunging anticline here referred to as the Broad Cove anticline. On the shore of Broad Cove, the core of this anticline is occupied by the well-exposed rhyolite described above (Figure 6). This anticline is truncated on the southeast by the Broad Cove fault. At the southwest edge of the map just north of Richmond Island the plunge of the Broad Cove anticline apparently reverses to the northeast.

Southeast of the Broad Cove fault, the Kittery Formation exhibits both isoclinal east-verging recumbent folds and gentle upright folds that deform both bedding and early cleavage associated with the recumbent folds (Figure 9).

Early recumbent folding and later upright folding are interpreted to be compressional events of the Early to Middle Devonian Acadian orogeny (Hussey and Berry, 2002). Swanson (1999) interprets the upright folds to be a consequence of dextral transpression related to a restraining bend in the greater Casco Bay area. He suggests that this folding may have begun as early as the Early Devonian, but may have persisted into the late Paleozoic (Swanson, 1999, p. 85).

The folded rhyolite dike in the core of the Broad Cove anticline described above may be a key to understanding the timing of metamorphism and the two stages of deformation. The presence of interstitial allotriomorphic fluorite in small amounts in the matrix suggests that the rock has not been metamorphosed. It has no fabric related to deformation, but is laminated (flow lamination?) parallel to the contacts with the host Spring Point intermediate volcanics which preserve well developed schistosity. The laminations die out within 0.5 meter of the contact, and in the core of the fold the rock is massive. These relationships suggests that the metamorphism of the Spring Point rocks is synchronous with F_1 folding, and that the F_2 event essentially was a non-metamorphic event. The F_2 folding of the rhyolite within the Spring Point volcanic pile suggests it is an intrusive rock injected slightly before or syntectonically with F_2 upright folding and after F_1 recumbent folding and metamorphism. An isotopic age of the felsite would be eminently useful in understanding the timing of these structural and metamorphic events.

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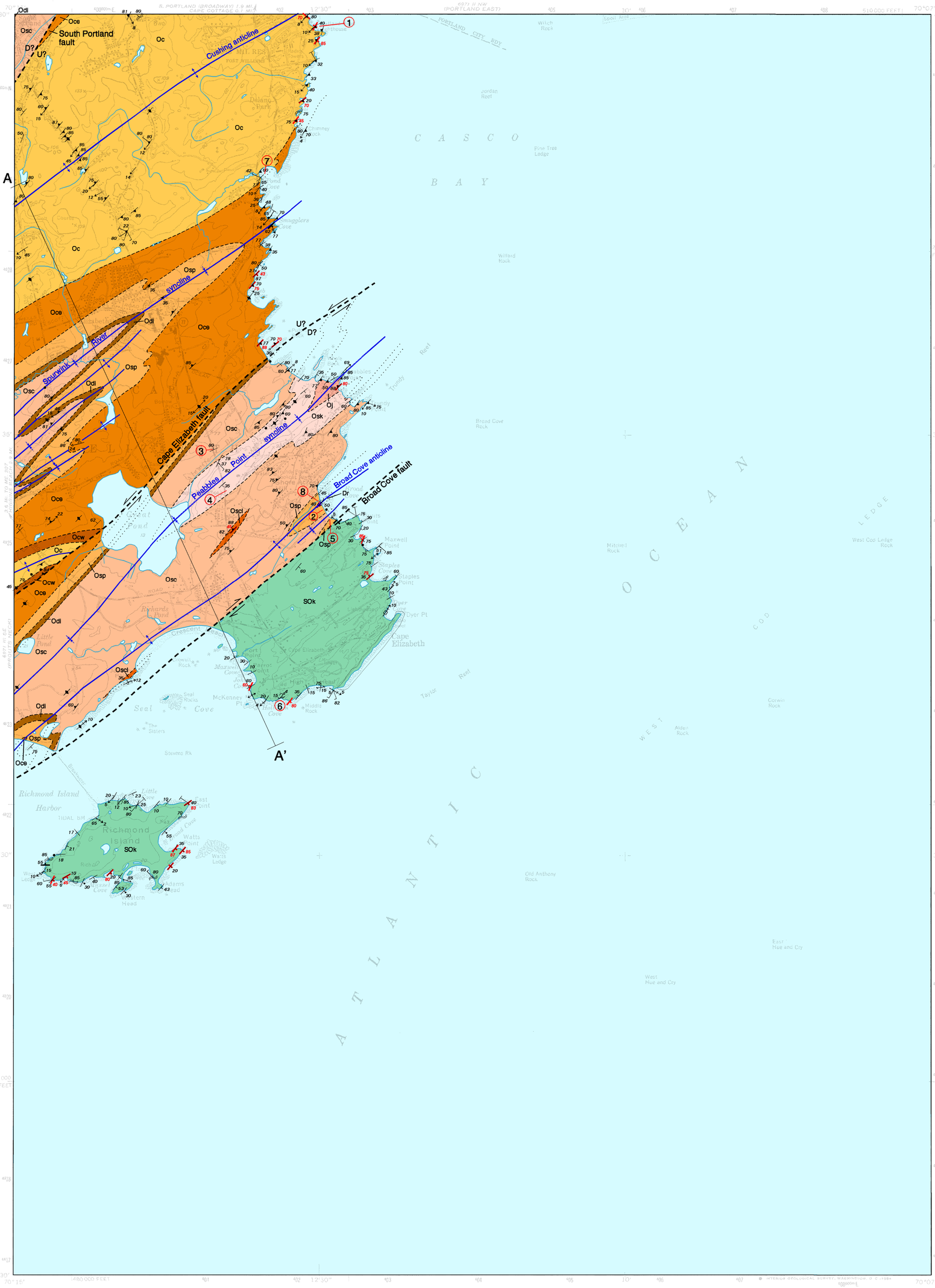
Bedrock Geology



SOURCES OF INFORMATION

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

Quadrangle Location

SCALE 1 : 24,000

1 — 0 — 1 MILE

1000 — 0 — 1000 — 2000 — 3000 — 4000 — 5000 — 6000 — 7000 FEET

1 — 0 — 1 KILOMETER

CONTOUR INTERVAL 20 FEET

TRUE NORTH

Topographic base from U.S. Geological Survey Cape Elizabeth 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.

Cape Elizabeth Quadrangle, Maine

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This map accompanied by a 6 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 following description summarizes the major rock types of each unit and gives a simplified geologic history by which they formed.

GEOGRAPHY

The topography of the Cape Elizabeth quadrangle is low and generally subdued. Areas underlain by the Cushing and Kittery Formation are the highest and hilliest, attaining elevations up to 140 feet above sea level. Areas underlain by the other formations of the Casco Bay Group are generally more subdued. The shoreline is characterized by low to bold sea cliffs with numerous small coves with pocket beaches. Most of the pocket beaches are cobbly. Crescent Beach, due south of Great Pond, is an exception, and is composed of fine quartz and feldspar sand. This beach has been included in Crescent Beach State Park, which provides public access to low cliff exposures of the Kittery Formation on the east end and of the Scarboro Formation on the west end. Other areas of public access in this quadrangle include Two Lights State Park and Fort Williams Park, the home of the Portland Head Lighthouse. Most of the shoreline exposures are on private land and require permission to visit. Outcrops are very extensive along the shore, and are numerous to sparse inland. Many of the roads provide good exposures that are available to the public, but extreme caution is urged when visiting these outcrops because of the frequent heavy traffic.

MAJOR ROCK TYPES

The oldest rocks of the Cape Elizabeth quadrangle belong to the Casco Bay Group, a diverse assortment of metamorphosed volcanic rocks, shale and limestone, deposited during Middle to Late 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 composed of fine metamorphosed massive to crudely layered volcanic ash (**Photo 1**). These rocks formed as hot lava erupted explosively on an ancient volcanic island chain. Airborne ash and hot ashflows may have been carried into an ancient ocean adjacent to the volcanic chain, accumulating as the Cushing Formation. As this volcanic activity waned, shale and siltstone of the Cape Elizabeth Formation accumulated in thin beds conformably on top of the volcanic pile. A period of renewed volcanism ensued, depositing basaltic ash of the Spring Point Formation (**Photo 2**). In places dark shale of the Diamond Island Formation, 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 (**Photo 3**) and Jewell Formations and shaly limestone of the Spurwink Metalimestone (**Photo 4**).

The Merrimack Group, much more extensively exposed in the southwestern part of Maine, is represented by the Kittery Formation, a sequence of slightly metamorphosed thin to thick bedded feldspathic sandstone and shale. These rocks are interpreted to be deep-water ocean sediments deposited during Late Ordovician to Early Silurian time. These rocks are exposed in the southeastern tip of Cape Elizabeth, southeast of the Broad Cove fault.

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. Major folds are indicated by the looping patterns of formations shown on the map and cross sections; minor folds and other internal structural complexities can be seen in outcrop (**Photo 5**). Early folds are recumbent, laying on their sides, so to speak (**Photo 6**) and are accompanied by thrust faulting (none seen in the Cape Elizabeth quadrangle, but see photos in the bedrock geology map of Prouts Neck quadrangle, Maine Geological Survey Open File 03-95). Gently to moderately west-dipping slip cleavage in rusty Scarboro Formation exposed along Maine Route 77 (**Photo 3**), may be related to this thrust that is not exposed in the Cape Elizabeth quadrangle. Late folds are upright to slightly overturned (**Photos 7, 8**) During the Acadian orogeny, the rocks were forced to deep levels in the Earth's crust where heat and pressure gradually transformed the sedimentary and volcanic rocks into the metamorphic rocks we see now. Shale was transformed into phyllite and schist; sandstone became granofels, volcanic ash of basaltic composition became amphibolite; the silica-rich volcanic ash of the Cushing Formation became granofels and gneiss; and limestone was transformed into fine-grained marble.

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 the Norumbega fault zone which, in this area, includes the Broad Cove fault with postulated right-lateral slip, an ancient fault somewhat like the San Andreas fault of today. Later faulting of possible Mesozoic age includes the Cape Elizabeth fault (possible left-lateral slip), and the South Portland fault (possible steep normal movement, down-dropped to the west). The youngest rocks in the area are the numerous dark-colored basalt and diabase dikes that were injected into extensional fractures produced during continental rifting that led to the formation of the Atlantic Ocean in Mesozoic time. These dikes range in thickness from a few centimeters to about seven meters in this quadrangle. The present landscape and near-shore bathymetry are fundamentally controlled by uneven erosion of the underlying complex rocks over a great span of geologic time, modified by recent and ongoing surface processes. These recent processes include glacial ice advance and retreat resulting in unconsolidated sediment deposition and significant sea level changes, and postglacial shoreline processes.

Photo 1. Light colored metamorphosed volcanic ash of the Cushing Formation exposed near the axial trace of the Cushing anticline, Fort Williams Park, Cape Elizabeth. Portland Head Lighthouse in the background is one of the oldest lighthouses in the United States and was commissioned by President George Washington in 1797.

Photo 2. Layered basaltic ash beds of the Spring Point Formation exposed in the core of the Broad Cove anticline, Broad Cove, Cape Elizabeth.

Photo 3. Rusty phyllite of the Scarboro Formation exposed in road cut along Maine Route 77, Cape Elizabeth. The prominent spaced cleavage dipping moderately to the left (west) is probably related to a thrust fault that is well exposed in the Prouts Neck quadrangle to the west in the Ram Island Farm area (Hussey, 2003, Bedrock geology of the Prouts Neck quadrangle: Maine Geological Survey, Open-File Report 03-95.)

Photo 4. Spurwink Metalimestone exposed along Maine Route 77, Cape Elizabeth, showing solutional etching and dismembered quartz veins.

Photo 5. Minor syncline dimpling the Broad Cove anticline, exposing rusty metamorphosed shale of the Scarboro Formation in the center, flanked with grayish green amphibolite of the Spring Point Formation.

Photo 6. Exposure of the Kittery Formation at Two Lights State Park, Cape Elizabeth showing a recumbent F1 fold opening to the east and possibly topping to the east. Open upright F2 folds gently deform the axial plane of the recumbent fold.

Photo 7. Tight upright F2 anticline folding the contact between the Cushing Formation (light rocks in the center) and the Cape Elizabeth Formation (darker rocks on the right side of the hinge, also exposed on the left side behind where the photo was taken). View looking southwest. Pond Cove, Cape Elizabeth.

Photo 8. Upright F2 fold of rhyolite sill exposed in the core of the Broad Cove anticline within intermediate metavolcanics of the Spring Point Formation. Because this felsite appears to be unmetamorphosed in contrast to actinolite-bearing mafic to intermediate Spring Point volcanics, it is probably not part of the Spring Point Formation. It is perhaps a sill intruded after the recumbent folding event, but before the later upright folding event.

EXPLANATION OF UNITS

INTRUSIVE ROCKS

Mesozoic

Dikes. Diabase and basaltic dikes, ranging from 5 cm to 7 m in thickness. (inclined, vertical)

Middle to Late Devonian (?)

Dr — **Rhyolite.** Buff-weathering porphyritic rhyolite with quartz phenocrysts in a fine-grained matrix of quartz, plagioclase and orthoclase with accessory carbonate and fluorite. Exposed in core of Broad Cove anticline.

STRATIFIED ROCKS

Early Silurian - Late Ordovician

MERRIMACK GROUP

SOk — **Kittery Formation.** Variably bedded calcareous metawackes and phyllites, the former predominating. The metawackes are composed of quartz, plagioclase, calcite, ankerite, and minor white mica and chlorite. These rocks are bluish gray on fresh surfaces, but are buff-gray on weathered surfaces. The thin phyllite beds are dark gray, and are composed predominantly of a white mica and gray chlorite with minor fine-grained quartz.

Middle - Late Ordovician

CASCO BAY GROUP

Oj — **Jewell Formation.** Very fine-grained, rusty and non-rusty weathering muscovite-biotite-chlorite-garnet-quartz phyllite.

Osk — **Spurwink Metalimestone.** Fine-grained ribbony-layered, medium gray metamorphosed limestone with calcite, biotite, and minor quartz. Thinly interlayered with beds of rusty and non-rusty weathering muscovite-biotite-quartz phyllite.

Osc — **Scarboro Formation.** Very fine-grained, rusty and non-rusty weathering muscovite-biotite-chlorite-garnet-quartz phyllite.

Oscl — Medium-gray ribbony-layered impure metalimestone with interbeds of biotite-chlorite phyllite.

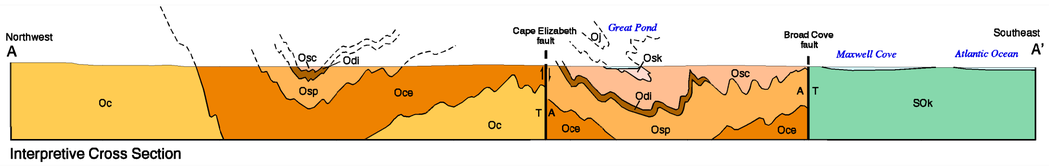
Odi — **Diamond Island Formation.** Strongly sheared black, quartz-muscovite-graphite phyllonite locally with cubes and irregular masses of pyrite.

Osp — **Spring Point Formation.** Medium greenish gray actinolite-chlorite-biotite-plagioclase schist and massive amphibolite, representing mafic volcanic rocks prior to metamorphism.

Oce — **Cape Elizabeth Formation.** Medium gray thin-bedded to medium-bedded quartz-plagioclase-biotite ± muscovite granofels with interbeds of biotite-muscovite-quartz-plagioclase-garnet schist.

Oc — **Cushing Formation.** Fine-grained to medium-grained light gray plagioclase-quartz-biotite-muscovite ± K-feldspar granofels and gneiss.

Ocw — **Wilson Cove Member.** Rusty-weathering dark gray garnet-quartz-plagioclase-grunerite granofels and schist.



Interpretive Cross Section

EXPLANATION OF SYMBOLS

- Outcrop
- Area of large outcrop
- Bedding, tops unknown (inclined)
- Bedding, tops known (upright, overturned)
- Metamorphic foliation or schistosity (inclined, vertical)
- Fracture cleavage (inclined, vertical)
- Intersection lineation or mullion structure (plunging, horizontal)
- Mineral lineation
- Axial plane of fold (inclined, vertical)
- Fold hinge (rotation unknown, counterclockwise, clockwise)
- Axis of anticline
- Shear zone (inclined)
- Minor fault with unknown displacement (inclined)
- Minor fault with right-lateral displacement (inclined)
- Slickenlines
- Joint set (inclined, vertical)
- Stratigraphic or intrusive contact.
- U D — High-angle fault. Arrows indicate sense of strike-slip motion. Dip-slip motion indicated by U = upthrown side, D = downthrown side. In cross section, A = motion away from the viewer, T = motion toward the viewer.
- Approximate trace of anticline
- Approximate trace of syncline
- A — A' Line of cross section
- 4 Photo locality

GEOLOGIC TIME SCALE

Geologic Age		Absolute Age*
Cenozoic Era		0-65
Mesozoic Era	Cretaceous Period	65-142
	Jurassic Period	142-200
	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	489-542
Precambrian time		Older than 542

* In millions of years before present. (Okulitch, A. V., 2004, Geological time chart, 2004: Geological Survey of Canada, Open File 3040 (National Earth Science Series, Geological Atlas) - REVISION.)