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Title: *Bedrock Geology of the Prouts Neck 7.5' Quadrangle, Cumberland and York Counties, Maine*

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Bedrock Geology of the Prouts Neck 7.5' Quadrangle, Cumberland and York Counties, Maine

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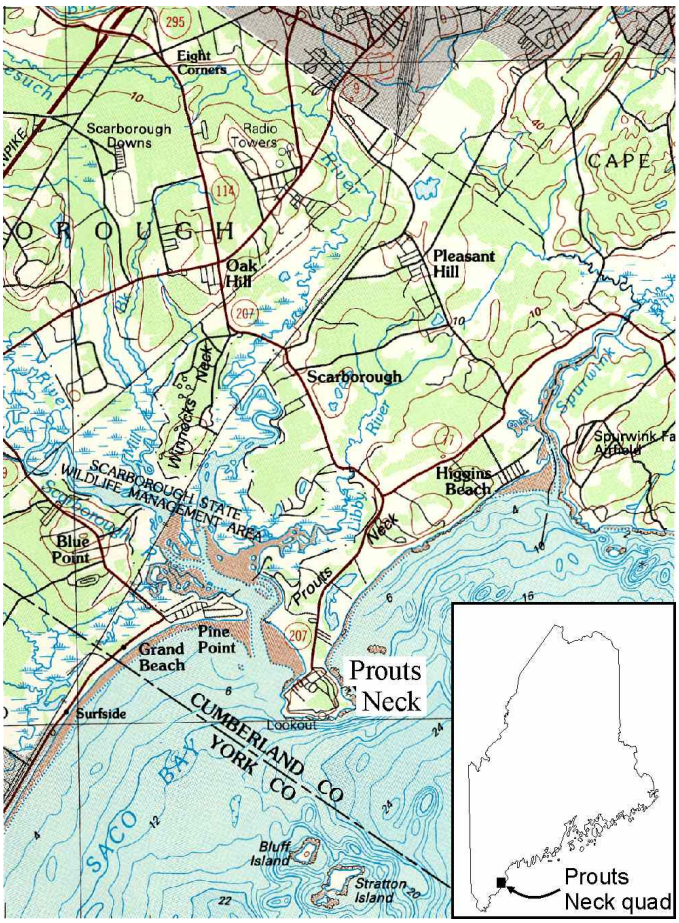

Figure 1. Location of the Prouts Neck 7.5-minute quadrangle, southwestern Maine.

INTRODUCTION

The Prouts Neck quadrangle lies just south of the cities of Portland and South Portland (Figure 1). The town of Cape Elizabeth is just to the east.

The northern two thirds of the quadrangle consists of low-lying land with extensive estuaries and salt water marshes (Scarborough, Nonesuch, and Spurwink Rivers). Extensive sand beaches (Figure 2) dominate the southwestern shoreline (Old Orchard, Western, and Scarborough Beaches, and Back Shore), whereas ledges dominate the northeastern shoreline. Prouts Neck whose shoreline is ledge-girded, is a prominent island tied to the mainland by an emergent tombolo made up of

Figure 2. Western Beach, located off the mouth of the Scarborough River, near the northeastern end of the extensive sand beaches of southwestern Maine.

Figure 3. Exposures of the Cape Elizabeth Formation just east of the Spurwink River, marking the beginning, northward, of the bold and embayed part of the Maine coast.

Figure 4. Thin- to heavy-bedded exposure of the Cushing Formation along the east shore of Prouts Neck, Scarborough. These beds lie just west of the core of the Prouts Neck syncline.

Figure 5. Thin- to medium-bedded alternations of garnet-quartz-plagioclase-biotite-grunerite granofels and garnet-biotite quartz schist, typical of the Wilson Cove Member of the Cushing Formation as exposed on the east shore of Prouts Neck.

Western Beach and the southwestern end of Scarborough Beach. Scarborough Beach marks the northeastern end of the southern coastal beach zone. Northeast of this is the beginning of the bold and indented coast of Maine (Figure 3).

Topography in the land area of the Prouts Neck quadrangle is low, never exceeding 150 feet in elevation. Much of the western half of the quadrangle is extensively covered by glacial and postglacial sediments, and outcrops are relatively rare. Bedrock exposures are quite abundant in the eastern half of the quadrangle, and in particular, in the area of the northeast and east-central parts of the map sheet.

STRATIFIED ROCK UNITS

The Prouts Neck 7.5' quadrangle is underlain by formations of the Middle to Late Ordovician age Casco Bay Group and the Late Ordovician to Early Silurian Merrimack Group. Faults separate these sequences. All formations are metamorphosed ranging from chlorite to staurolite grade in a Buchan-type metamorphic facies series.

Casco Bay Group

Rocks of the Casco Bay Group include, in ascending order of age, the Cushing Formation, Cape Elizabeth Formation, Spring Point Formation, Diamond Island Formation, Scarboro Formation, Spurwink Metalimestone, and Jewell Formation.

Cushing Formation. The Cushing Formation in the Prouts Neck quadrangle is a sequence of predominantly light gray plagioclase-quartz-muscovite-biotite ± k-feldspar granofels or gneiss, locally showing compositional layering (Figure 4). These rocks were originally interpreted by Katz (1917) to be a deformed granodiorite intrusion on the basis of their feldspar-rich composition. Bodine (1965) and Hussey (1971, 1988) have described relict pyroclastic structures (breccia, crude compositional layering, crystal tuff structure, and possible collapsed pumice fragments) that suggest that these rocks are more likely to be metamorphosed felsic- to intermediate-composition fragmental volcanic rocks.

The Wilson Cove Member of the Cushing Formation is rusty-weathering garnet-quartz-plagioclase-biotite-grunerite granofels and schist (Figure 5). The amphibole, grunerite, is identified on the basis of the extensive multiple twinning, negative optic sign, and pale brownish color. These rocks may represent iron- and manganese-rich, argillaceous chert with interlayered shale prior to metamorphism.

The Cushing Formation is exposed in three separate belts, one on Prouts Neck, another in the vicinity of Spurwink Hill in Cape Elizabeth, and the third in the northeastern corner of the map sheet in the core of the Cushing anticline. In the latter belt, the Wilson Cove Member is absent. In the Prouts Neck belt, the metamorphic grade is staurolite, based on the presence of relict staurolite in pelitic layers in the overlying Cape Elizabeth For-

mation (see below). The metamorphic grade in the other two belts is garnet, based on garnet in the overlying Cape Elizabeth Formation.

Cape Elizabeth Formation. The Cape Elizabeth Formation consists of thin- to medium-bedded medium gray quartz-plagioclase-biotite ± muscovite granofels with interbeds of biotite-muscovite-quartz-plagioclase-garnet schist (Figure 6). Relict staurolite in muscovite pseudomorphs, was observed on the southern side of Prouts Neck, but none has been observed either in hand specimen or thin section in the Spurwink Hill area.

Spring Point Formation. The Spring Point Formation is a lithologically heterogeneous assemblage of metavolcanic and metasedimentary rocks lying stratigraphically between the Cape Elizabeth and Diamond Island Formations. At chlorite and biotite grade it consists of medium greenish gray fine-grained chlorite-white mica-quartz ± biotite phyllite. Chlorite is distinctly greenish in color in contrast to its gray color in the overlying pelitic Scarboro Formation. Biotite is only sparingly present and is light brown in thin section. Small euhedral to subhedral garnets are common in the formation, but are not present in the pelitic assemblage of nearby exposures of the Scarboro Formation. This lower-grade occurrence of garnet may indicate a high manganese content. Chemical data are not available to confirm this.

In the northeastern part of the quadrangle, at garnet grade, the lower part of the formation consists mostly of intermediate to mafic composition metavolcanics (Figure 7) and the upper part is mostly quartzo-feldspathic metasedimentary rocks and possibly metafelsic volcanic rocks. The metabasites typically consist of green actinolite, biotite, plagioclase, and occasionally epidote. The upper part of the formation commonly consists of light gray granofels with quartz, plagioclase, biotite, garnet, and carbonate. The garnet is extremely irregular, commonly occurring as pinch and swell stringers and thin folded stringers. These rocks have been extensively sheared.

Diamond Island Formation. The Diamond Island Formation (Figure 8) is the most distinctive and lithologically uniform unit of the Casco Bay Group. It is a dark black, slightly to moderately rusty weathering, non- to very weakly-bedded quartz-muscovite-graphite phyllite, locally with abundant pyrite. Discontinuous thin stringers of vein quartz parallel to the cleavage are characteristic of almost all exposures of the formation.

Scarboro Formation. The Scarboro Formation is exposed in biotite and garnet metamorphic zones. At biotite grade it is a very fine-grained rusty and nonrusty weathering white mica-chlorite-biotite-quartz phyllite. Biotite is generally very sparse. The cleavage is commonly folded or irregularly contorted by shearing. Beds of quartz-white mica-chlorite phyllite are sparingly present. At garnet grade, the assemblage and appearance are quite similar to biotite grade occurrences with the appearance of garnet and the development of biotite in much greater abundance. In both grades of metamorphism, chlorite is gray in color in contrast to its green color in the Spring Point Formation. The exposures at the south end of Higgins Beach

Figure 6. Thin-bedded alternating quartz-plagioclase-biotite-muscovite-garnet schist (the evenly textured beds), and biotite-muscovite-garnet schist beds (the wavy-textured beds). These beds are exposed along the shore of Ram Island Farm in Cape Elizabeth, just east of the mouth of the Spurwink River. The one bed against which the upper part of the knife is leaning shows a hint of graded bedding, indicating that these beds are upright.

Figure 7. Amphibolite of the Spring Point Formation exposed in a rock quarry along Sawyer Road, Cape Elizabeth.

Figure 8. Black quartz-graphite-muscovite-pyrite phyllite of the Diamond Island Formation, off Highland Avenue, South Portland.

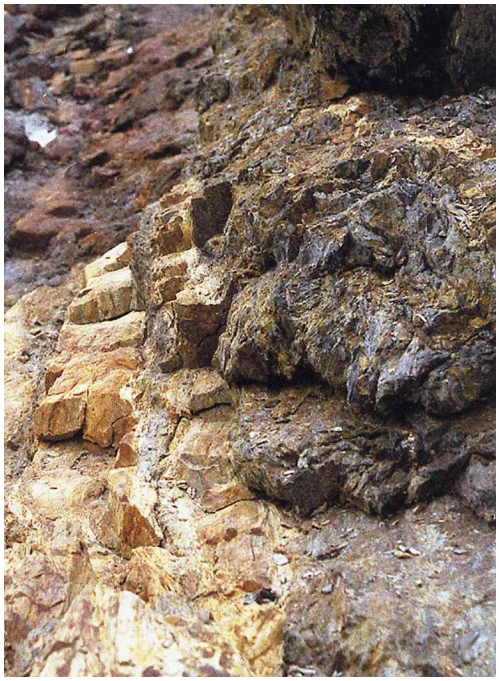

Figure 9. Type exposure of the rusty-weathering Scarboro Formation at Higgins Beach, Scarborough. The light colored rock on the left side of the photo is an argillaceous metasandstone bed within the rusty phyllite. [Note the different spellings of the formation and the town. At the time of mapping by F. J. Katz (1917), the official spelling of the town was "Scarboro," but this was later changed to "Scarborough."]

Figure 10. Close-up of the phyllite of the Scarboro Formation at Higgins Beach showing the highly sheared phyllite that comprises most of the formation.

Figure 11. Glacially-polished pavement outcrop at the edge of a gravel pit on the east side of Scottow Hill, Scarborough. The hammer handle lies olong the contact between the Spring Point Formation (lying toward the right) and the Scarboro Formation (to the left). The knife lies across a graded bed within the Scarboro Formation. The lower part of the bed consists of buff-weathering metasiltstone (the red handle of the knife), that grades up into dark phyllite that typifies the principal lithology of the Scarboro Formation. This graded bed, one meter into the Scarboro Formation, indicates that the Spring Point Formation lies below the Scarboro Formation.

(Figures 9 and 10) in Scarborough were designated as the type locality for the formation by Katz (1917).

A critical locality for determination of the stratigraphic sequence of the formations of the Casco Bay Group is in a gravel pit on the edge of Scottow Hill (NW portion). An outcrop at the edge of this gravel pit exposes the contact between the Spring Point Formation and the Scarboro Formation (Figure 11, along the hammer handle). One meter northwest of the contact, within the Scarboro Formation is a graded bed with tops toward the northwest (Figure 11, knife handle is on the lighter buff gray base of the bed, and knife blade points toward stratigraphic top), indicating that the Scarboro Formation lies on top of the Spring Point Formation.

Spurwink Metalimestone. The Spurwink Metalimestone is fine-grained ribbony-layered medium gray metamorphosed limestone with calcite, biotite, and minor quartz with interbeds of biotite-white mica-quartz phyllite. Exposed surfaces weather brownish and show characteristic solutional etching (Figure 12).

Jewell Formation. The Jewell Formation (Figure 13) is lithologically identical to the Scarboro Formation. Without the intervening Spurwink Metalimestone, the two formations cannot be separately distinguished.

Ledges at Black Rock, near the outlet of the Scarborough River, consist of contorted green chlorite phyllite and were originally correlated with the green phyllite of the Spring Point Formation (Hussey, 1971). Similar rocks occur on strike approximately a mile to the northeast in close proximity to outcrops of typical Jewell phyllite, and close to exposures of the Spurwink Metalimestone. A structurally simpler interpretation is that they are a belt of intermediate metavolcanics in the core of the Higgins Beach syncline. They are either a member within the Jewell Formation or are a separate unit above it. Similar rocks have been mapped within the Jewell Formation on the west shores of Great Diamond and Great Chebeague Islands.

Figure 12. The Spurwink Metalimestone along Highway 77, Scarborough, just northwest of Higgins Beach. This photo shows the thin, solutionally etched layering that typifies exposures of this formation.

Figure 13. Exposure of the dark gray but not particularly rusty-weathering phyllite of the Jewell Formation at the mouth of the Scarborough River.

Merrimack Group

The Merrimack Group is represented by the Kittery and Eliot Formations. These rocks, in the Prouts Neck quadrangle, were previously included with the Cape Elizabeth Formation of the Casco Bay Group (Katz, 1917; Hussey, 1971), but on the basis of the composition of these rocks (calcareous, and not pelitic) they are now correlated with the Merrimack Group (Hussey and others, 1999). They are interpreted to be in fault contact with Casco Bay rocks.

Kittery Formation. Rocks correlated with the Kittery Formation crop out on Bluff and Stratton Islands, southeast of the inferred extension of the Broad Cove fault. These rocks are thin to medium-bedded feldspathic and calcareous quartzose phyllite with interbeds of darker chlorite-white mica phyllite. These rocks are extensively sheared.

Eliot Formation. The Eliot Formation consists of thin bedded calcareous and ankeritic buff-weathering chlorite-muscovite-quartz-plagioclase phyllite and dark gray chlorite-muscovite phyllite. Chlorite is gray, imparting the gray color to the rock. The Eliot Formation is correlated with the Macworth Formation in the Portland area just north of the Prouts Neck quadrangle.

The stratigraphic position of the Eliot and Kittery Formation is uncertain. As originally interpreted by Billings (1956) in southeastern New Hampshire, the Kittery is beneath the Eliot, but reinterpretation by Lyons and others (1997) reverses the sequence. The cross sections on the geologic map reflect the Lyons interpretation.

INTRUSIVE IGNEOUS ROCKS

The only intrusive igneous rocks are diabase and basalt dikes of Mesozoic (probably Jurassic age). These range from 10 centimeters to 5 meters in thickness. They occur sparingly throughout most of the quadrangle, but along the shore just east of the Spurwink River they are locally numerous enough to constitute a dike swarm. Some with minor amounts of pyrite weather orangish brown, but most are gray weathering. Chilled margins against the country rock and older dikes are usually well developed, but no contact alteration of the intruded rocks has been observed. Figure14 shows a 1-meter wide basalt dike cutting the Cape Elizabeth Formation along the Cape Elizabeth shore just east of the mouth of the Spurwink River.

STRUCTURE

The rocks of the Prouts Neck quadrangle have been complexly deformed by two major folding events and by several stages of faulting. Outcrops, unfortunately, are too sparse in most areas to delineate critical aspects of fold hinges and limbs that would allow an objective, unbiased determination of which folds are large-scale refolded recumbent folds, and which are late upright folds. Similarly, lack of outcrops at critical areas precludes a resolution of relative age relations of the major faults mapped in the quadrangle. New information on the distribution of the various rock types, as it becomes available from excavations or drilling, may require significant revision to the map pattern, and hence the nature of deformation.

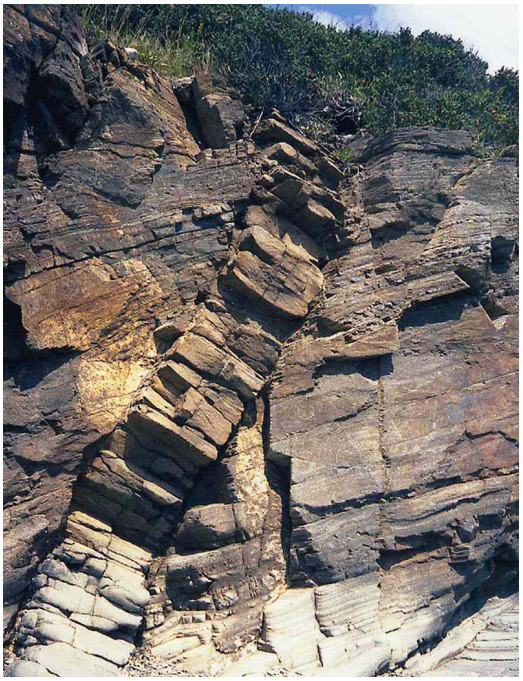

Figure 14. Basalt dike, 1 meter wide, exposed along the shore of Ram Island Farm, just east of the mouth of the Spurwink River. The basalt shows well developed columnar jointing perpendicular to its walls.

Figure 15. Tight, nearly isoclinal recumbent folds of bedding in the Cushing Formation at Prouts Neck, Scarborough.

Figure 16. East verging mesoscale folds of thin bedding of the Cape Elizabeth Formation, Ram Island Farm, Cape Elizabeth.

Figure 17. East-verging, gently dipping thrust fault of the Cape Elizabeth Formation at Ram Island Farm, Cape Elizabeth, just east of the mouth of the Spurwink River.

Folding

The earliest folds are meso-scale recumbent folds that are seen in both the Cushing Formation on Prouts Neck (Figure 15), and the Cape Elizabeth Formation at Ram Island Farm, Cape Elizabeth (Figure 16). At the Ram Island Farm locality, the folds verge to the east and are associated with a minor but conspicuous east-verging thrust fault (Figures 17 and 18). The beds of the upper plate have been strongly overturned as a result of thrust-fault drag.

Later upright folding is demonstrated by small-scale parasitic folds seen in outcrop (Figure 19). The nature of most of the macro-scale folds delineated by the map pattern remains uncertain; some are undoubtedly upright folds associated with the upright parasitic folds, but some may represent refolded recumbent fold hinges.

Field relations in the Prouts Neck quadrangle do not constrain the age of folding. Hussey (1988) has suggested that both stages of folding are related to the Acadian orogeny of Early to Middle Devonian age and are due to convergence and collision of the Avalonian Composite Terrane by means of subduction. Swanson (1999) argues for a transpressional origin of at least the later episode of upright folding. He argues that this is related to right-lateral movement at a constraining bend during the development of the Norumbega fault zone. This would indicate a late Devonian to Permian age for at least the later upright folding. $^{40}Ar/^{39}Ar$ closure ages of hornblende (see section on metamorphism below) of Casco Bay Group rocks to the northeast suggest

Figure 18. Another view of the thrust fault, looking along the fault surface.

Figure 19. Upright, east-verging asymmetric folds of quartz veins and laminations in the Spring Point Formation. These folds plunge gently to the northeast and indicate a larger-scale antiform lies to the right of the picture.

that metamorphism occurred during Middle Devonian time, thus during the Acadian orogeny and not later as suggested by Swanson (1999).

Faults

Four major faults are mapped or inferred on the basis of regional distribution of formations. They are the South Portland fault (first recognized by Bodine,1965), Cape Elizabeth fault zone, Johns Point fault, and Broad Cove fault (Figure 20). The Broad Cove fault is interpreted to be a splay of the Norumbega fault system (Bothner and Hussey, 1999). It separates the Merrimack Group on the south from the Casco Bay Group on the north, and is interpreted by Swanson (1999) to have predominantly right-lateral strike-slip motion of Late Devonian to Permian age. The Johns Point fault likewise separates rocks of the Merrimack Group from the Casco Bay Group, but here the Merrimack Group lies on the north side. It is interpreted to be a Mesozoic high-angle fault downthrown to the northwest. The South Portland fault is here inferred to be a high-angle normal to right oblique fault with the southeast side up and to the south. Swanson, however, considered this to be another splay of the Norumbega fault system. The writer's interpretation is that this is a later fault, of possible Mesozoic age, that offsets the Broad Cove fault. The Cape Elizabeth fault zone is a two-hundred-meter wide zone characterized by numerous high-angle faults marked by the presence of fault gouge and elongate milky quartz veins up to 15 meters wide (Figure 21). Based primarily on apparent displacement of metamorphic isograds in the northern extension of this fault in the upper Casco Bay area, the writer interprets this to be a high-angle fault with a large component of left-lateral movement.

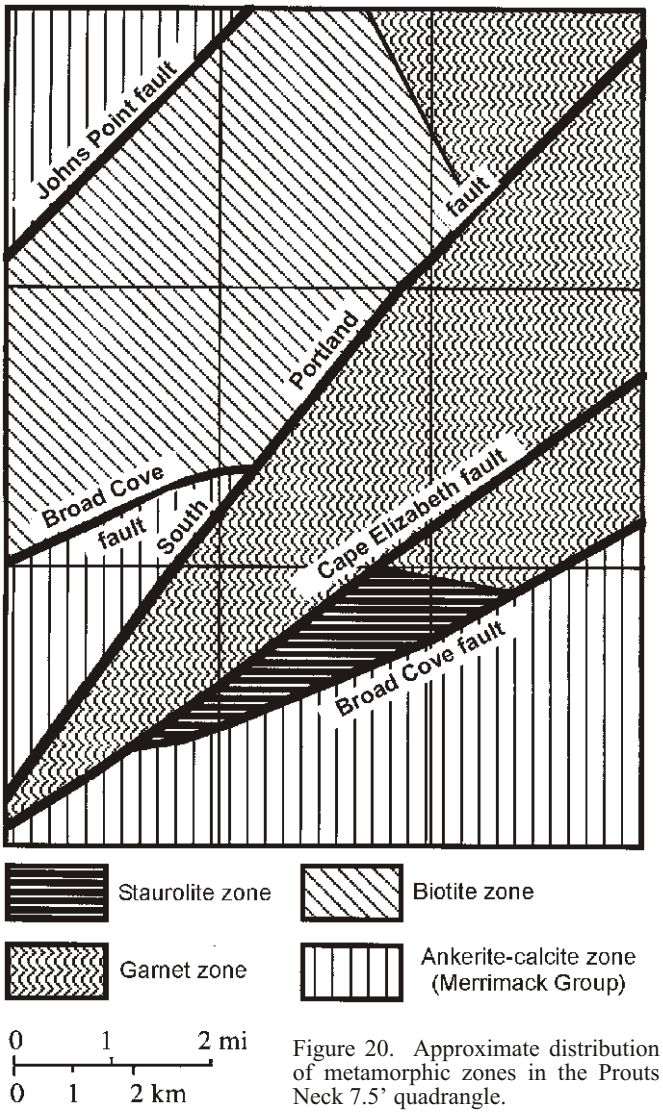

Figure 20. Approximate distribution of metamorphic zones in the Prouts Neck 7.5' quadrangle.

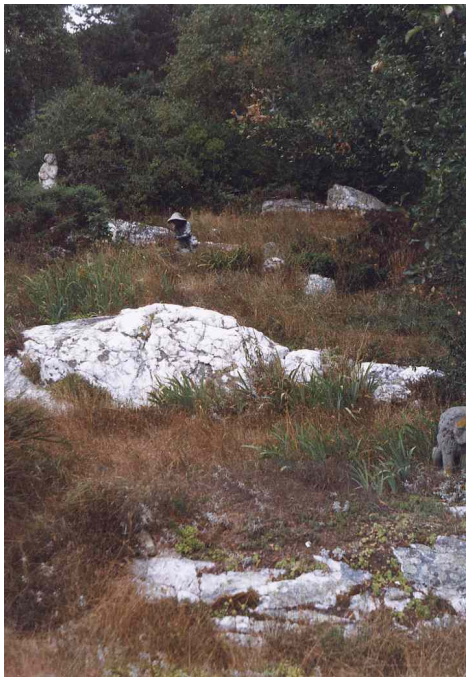

Figure 21. Rock-garden exposure of milky quartz vein along part of the Cape Elizabeth fault. Foreground, middle ground and background outcrops are all milky quartz.

METAMORPHISM

Distribution of the zones of regional metamorphism are shown in Figure 20. Rocks of the Merrimack Group have been metamorphosed only to lower greenschist facies. Carbonate-bearing rocks have ankerite, calcite, and chlorite as critical indicators, correlating with the ankerite zone of metamorphism as described for carbonate-bearing rocks of the Central Maine sequence in the Waterville area by Ferry (1983). Pelitic rocks of the Casco Bay Group have been metamorphosed from biotite to staurolite zones, and metabasites have been metamorphosed from middle greenschist to epidote amphibolite facies. Boundaries between metamorphic zones are mostly the major faults. The biotite-garnet isograd has been mapped in the sliver of the Casco Bay Group between the Johns Point and South Portland faults, and the staurolite-garnet isograd is mapped between the Cape Elizabeth and Broad Cove faults. The occurrence of the higher grade staurolite zone southwest of the garnet zone in the latter fault slice is anomalous. In the greater Casco Bay area the grade of metamorphism generally increases toward the northeast. The staurolite grade rocks in the Prouts Neck area suggest the presence of another major fault between Prouts Neck and the rocks of the Ram Island Farm area of Cape Elizabeth which are at garnet grade. The fault, if it exists, may coincide with the isograd boundary between Prouts Neck and Cape Elizabeth.

The age of metamorphism of the Casco Bay rocks is interpreted to be Middle to Late Devonian, related to the Acadian orogeny. This is based on the 370-380 Ma $^{40}Ar/^{39}Ar$ cooling ages of hornblende (West and others, 1988, 1993; West and Hubbard, 1997) from higher grade metamorphic zones in the upper Casco Bay area. The age of metamorphism of the Merrimack rocks in the Casco Bay region is not well constrained.

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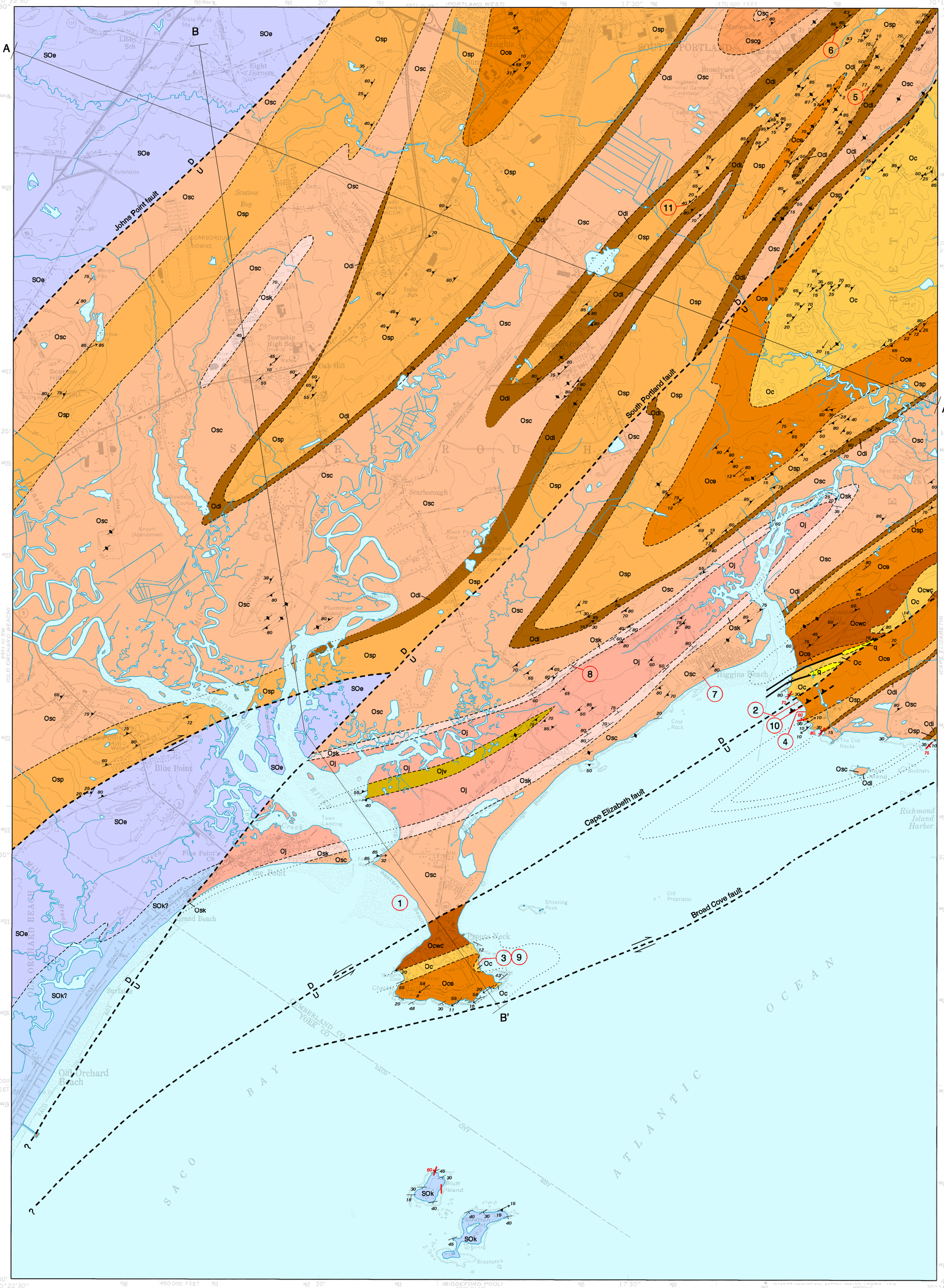
Bedrock Geology



SOURCES OF INFORMATION

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

Quadrangle Location

SCALE 1 : 24,000

1 — 0 — 1 MILE

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1 — 0 — 1 KILOMETER

CONTOUR INTERVAL 20 FEET

TRUE NORTH

Topographic base from U.S. Geological Survey Prouts Neck 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.

Prouts Neck Quadrangle, Maine

Bedrock geologic mapping by
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Cartographic design and editing by:
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This map accompanied by an 8 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 northern two thirds of the quadrangle consists of low-lying land with extensive estuaries and salt water marshes (Scarborough, Nonesuch, and Spurwink Rivers). Extensive sand beaches (Photo 1) dominate the southwestern shoreline (Old Orchard, Western, and Scarborough Beaches and Back Shore), whereas ledges dominate the northeastern shoreline. Prouts Neck, whose shoreline is ledge girded, is a former island tied to the mainland by an emergent tombolo made up of Western Beach and the southwestern end of Scarborough Beach. Scarborough Beach marks the northeastern end of the southern coastal beach zone. Northeast of this is the beginning of the bold and indented coast of Maine (Photo 2).

Topography in the land area of the Prouts Neck quadrangle is low, never exceeding 150 feet in elevation. Much of the western half of the quadrangle is extensively covered by glacial and postglacial sediments. Outcrops are relatively rare. Bedrock exposures are abundant in the eastern half of the quadrangle, and in particular, in the area of the northeast and east-central portions of the map sheet.

MAJOR ROCK TYPES

The stratified, or layered, rocks of the Prouts Neck 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 thin sheets. Phyllite has a similar mineral texture except the individual grains are very small and not readily seen without a microscope. 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 Prouts Neck quadrangle 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 composed of fine metamorphosed crudely to well-layered volcanic ash (Photo 3). 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 (Photo 4) accumulated in thin beds conformably on top of the volcanic pile. A period of renewed volcanism ensued, depositing basaltic ash (Photo 5) of the Spring Point Formation. 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 (Photo 7) and Jewell Formations and shaly limestone of the Spurwink Metalimestone (Photo 8).

The Merrimack Group, much more extensively exposed in the southwestern part of Maine, is represented in the Prouts Neck quadrangle by the Eliot Formation, a sequence of slightly metamorphosed calcareous siltstone and shale; and the Kittery Formation, consisting of thin to medium-bedded metamorphosed feldspathic sandstone and shale. These rocks are interpreted to be deep ocean sediments deposited during Late Ordovician to Early Silurian time.

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. Early folds are recumbent (Photo 9) and are accompanied by minor thrust faulting (Photo 10). Late folds are upright (Photo 11). During late stages of this deformation period, 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 that we see now. Shale was transformed into phyllite and schist; sandstone became granofels; volcanic ash of basaltic composition became amphibolite; 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. Shear bands associated with this faulting can be seen in Photo 7. This ancient fault zone 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 Johns Point and South Portland faults.

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 of the incipient Atlantic Ocean in Mesozoic time (Photo 4). These dikes range in thickness from a few inches to 15 feet in the Prouts Neck quadrangle. 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. Beach, dune, and lagoonal sediments of Western Beach at the mouth of the Scarborough River, Scarborough, Maine.

Photo 2. Beginning of the bold and indented rocky shore characteristic of much of the coast of Maine to the north. Ram Island Farm, Cape Elizabeth.

Photo 3. Light gray metamorphosed volcanic ash, in places weakly bedded, of the Cushing Formation, Prouts Neck, Scarborough, Maine.

Photo 4. Thin-bedded metamorphosed sandstone and shale of the Cape Elizabeth Formation intruded by a 1 meter Mesozoic-age basalt dike with prominent columnar cooling joints. Ram Island Farm shoreline, Cape Elizabeth.

Photo 5. Massive amphibolite of the Spring Point Formation. Rogers Brothers Quarry, Sawyer Road, Cape Elizabeth.

Photo 6. Black, pyrite-rich phyllite of the Diamond Island Formation. Small side lane off Highland Avenue, South Portland.

Photo 7. Rusty-weathering phyllite of the Scarboro Formation. Higgins Beach, Scarborough. Shear bands in the phyllite are interpreted to be the result of strike-slip movement during the development of the Norumbega fault zone.

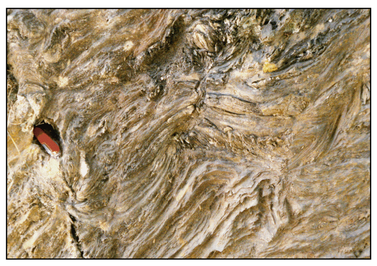


Photo 8. Thin-, ribbony-bedded Spurwink Metalimestone. Higgins Beach area, Scarborough.

Photo 9. Early recumbent folds of beds of metamorphosed volcanic ash within the Cushing Formation. Prouts Neck, Scarborough.

Photo 10. Thrust fault in the Cape Elizabeth Formation. The fault surface is inclined to the right (northwest), and the beds above the surface show drag folds indicating movement to the southeast over the beds below the surface.

Photo 11. Late upright folds of bedding and quartz veins in metamorphosed volcanic rocks of the Spring Point Formation, off Highland Avenue, South Portland.

EXPLANATION OF UNITS

INTRUSIVE ROCKS

Mesozoic

Diabase and basalt dikes.

q Silicified zone related to fault.

STRATIFIED ROCKS

Early Silurian or Late Ordovician

MERRIMACK GROUP

SOk **Kittery Formation**. Fine-grained thin to medium interlayered calcareous and ankeritic medium buff-gray weathering plagioclase-rich chlorite-muscovite-quartzose phyllite and dark gray chlorite-muscovite phyllite. (Where queried in southwest part of map, SOk is inferred to be present on the basis of outcrop distribution in Old Orchard Beach 7 1/2' quadrangle to the west.)

SOe **Eliot Formation**. Fine-grained medium buff gray calcareous and ankeritic chlorite-muscovite quartz phyllite, with thin regularly alternating interlayers of dark gray chlorite-muscovite phyllite.

Middle to Late Ordovician

CASCO BAY SEQUENCE

Oj **Jewell Formation**. Rusty and non-rusty medium gray muscovite-chlorite-biotite-garnet-quartz phyllite.

Ojv Fine-grained chlorite-white mica-biotite-garnet plagioclase schist (similar to Spring Point green phyllite).

Osk **Spurwink Formation**. Fine-grained medium gray metamorphosed limestone with biotite and minor quartz; interbeds of fine-grained biotite-white mica-quartz phyllite.

Osc **Scarboro Formation**. Generally similar to Jewell Formation: both rusty and non-rusty fine-grained muscovite-chlorite-garnet phyllite with minor quartz and plagioclase (garnet zone); rusty and non-rusty muscovite-biotite-chlorite phyllite (biotite zone); rusty and non-rusty muscovite-chlorite phyllite (chlorite zone). Graphite commonly present in minor amounts.

Oscg **Unnamed volcanogenic member.** Medium greenish gray chlorite-garnet-quartz phyllite, generally non-rusty weathering.

Odi **Diamond Island Formation**. Black muscovite-quartz graphite phyllite, locally with abundant pyrite.

Osp **Spring Point Formation**. Medium greenish gray chlorite-white mica-garnet-quartz-plagioclase phyllite (chlorite zone; same, with biotite in biotite zone); actinolite-biotite-chlorite-plagioclase ± epidote schist, biotite-garnet-muscovite-plagioclase-epidote schist (garnet zone). Upper part of the Spring Point Formation in the area of the Spurwink River (garnet zone) consists of fine-grained quartz-plagioclase-garnet-biotite chlorite-tremolite(?) granofels.

Oce **Cape Elizabeth Formation**. Fine-grained medium gray quartz-plagioclase-muscovite-biotite-garnet schist, quartz-plagioclase-biotite granofels (garnet zone); same with relict staurolite in muscovite and chlorite pseudomorphs (staurolite zone).

Oc **Cushing Formation**. Light gray plagioclase-quartz-biotite-muscovite ± microcline granofels and gneiss, strongly lineated; medium greenish gray plagioclase-hornblende-biotite gneiss.

Ocwc **Wilson Cove Member**. Rusty weathering garnet-quartz-plagioclase-biotite ± grunerite granofels; minor rusty weathering quartz-plagioclase muscovite schist.

EXPLANATION OF SYMBOLS

Strike and dip of bedding. (inclined, vertical)

Strike and dip of cleavage, schistosity, or foliation. (inclined, vertical)

Direction and angle of inclination of lineations. (plunging, horizontal)

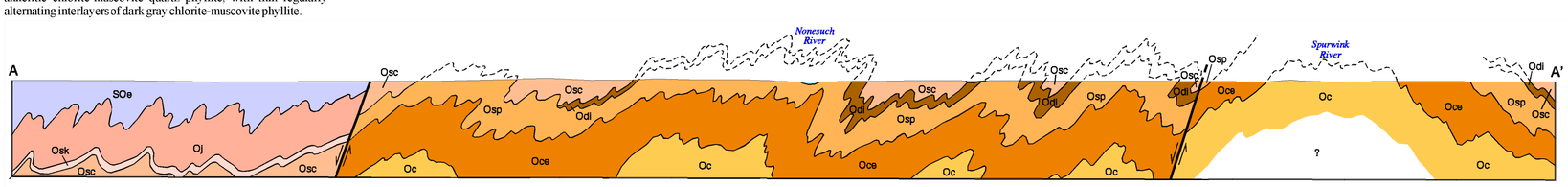
Stratigraphic or intrusive contact.

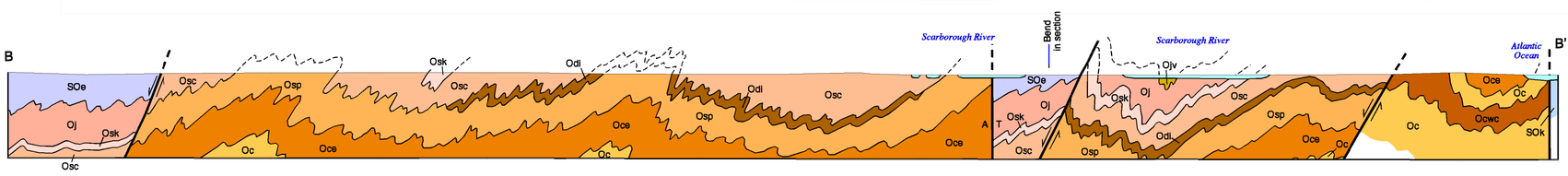
U D — High angle mostly dip-slip fault (U - upthrown block; D-downthrown block).

High-angle mostly strike-slip fault (arrows indicate sense of motion).

U D — High angle oblique-slip fault (arrows indicate sense of motion; U - upthrown block; D - downthrown block).

4 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. (Okulitch, A. V., 2002, Échelle des temps géologiques, 2002: Commission géologique du Canada, Dossier Public 3040 (Série nationale des sciences de la Terre, Atlas geologique) - RÉVISION.)