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

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INTRODUCTION

The Portland West 7.5' quadrangle lies at the southwest edge of Casco Bay (Figure 1) and encompasses the largest metropolitan district in the State of Maine, including major parts of the cities of Portland, South Portland, and Westbrook. Shoreline areas within the quadrangle are tidal mudflats and channels of Back Cove, Fore River and Presumpscot River. Topography is generally of low relief, the highest elevation being Leighton Hill (elevation between 480 and 500 feet) along the northern edge of the quadrangle. An extensive mantle of marine clay and glacial drift conceals much of the bedrock within the quadrangle. A significant amount of shore land on the east side of the Portland peninsula along Commercial Street, along the west side of the peninsula adjacent to Back Cove, and portions of the South Portland shoreline consist of artificial fill. Principal drainages in the area are the Presumpscot and Stroudwater Rivers. The Presumpscot River flows southeasterly into the quadrangle in the City of Wesbrook for a short distance before turning abruptly northeast to follow a prominent linear low that is on strike with the Nonesuch River fault southwest of the quadrangle. The Presumpscot River follows this northeasterly lineament for approximately 8.5 km and then abruptly turns to the southeast, parallel to its course at the western edge of the map. It empties into the Presumpscot estuary 4 miles north of Portland. The Stroudwater River flows easterly from just south of Westbrook and empties into the Fore River estuary on the south side of Portland.

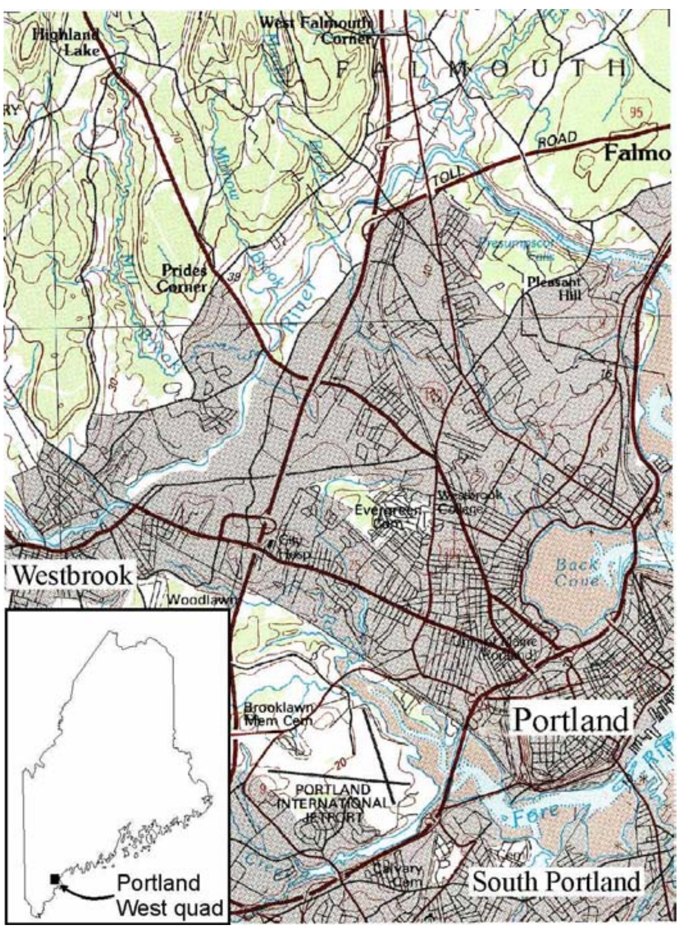


Figure 1. Location of the Portland West 7 1/2' quadrangle. Base map from Osberg and others 1985.

The generally hillier third of the quadrangle lying northwest of the Presumpscot River and East Branch of the Piscataqua River is underlain by granite, granite gneiss, and pegmatite of the Westbrook pluton of Devonian or younger age. The remainder of the quadrangle is underlain by metasedimentary and metavolcanic rocks assigned to three major lithotectonic sequences, the Merrimack Group, the Casco Bay Group, and the Central Maine sequence, ranging in age from Middle Ordovician to Early Silurian. In the northeastern part of the quadrangle, the metamorphic rocks are extensively migmatized, and narrow lenses of pegmatite and foliated granite are abundant.

Outcrops are locally abundant in low hills protruding through the surficial mantle such as in the Brighton area, and at

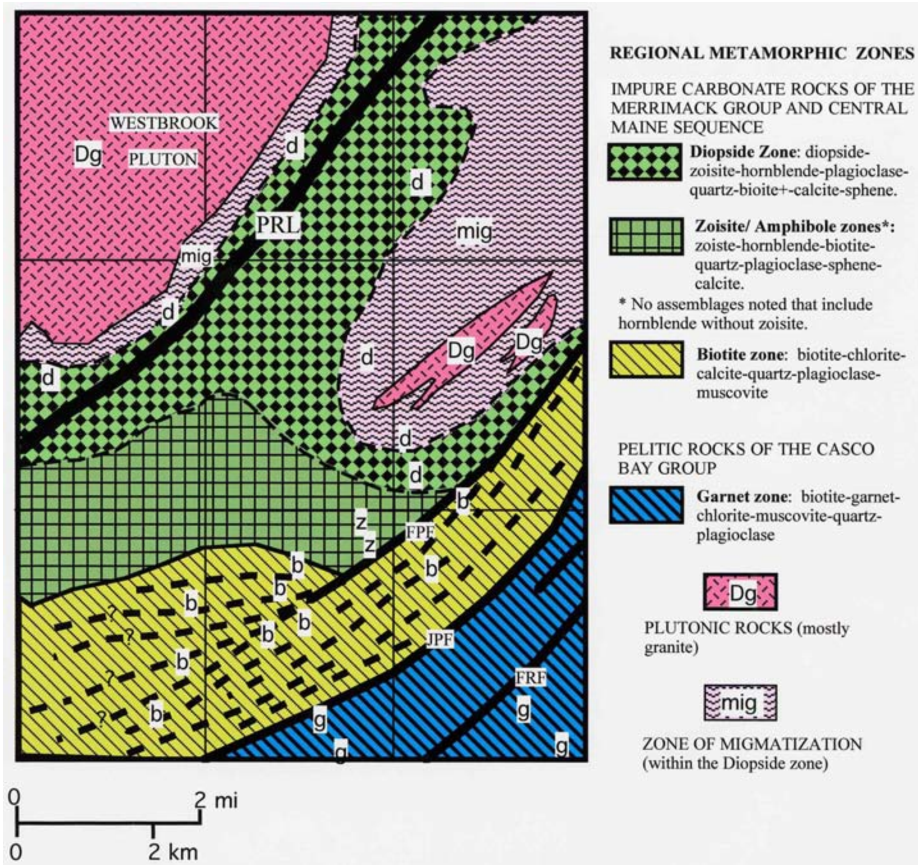


Figure 2. Map showing approximate distribution of zones of regional metamorphism and migmatization relative to major granitic plutons and faults. Letters **b**, **d**, and **z** indicate locations where diagnostic assemblages of the biotite, diopside, and zoisite/amphibole zones in the calcareous rocks of the Merrimack Group and Central Maine sequence have been confirmed by thin-section examination; letter g indicates the same for garnet zone assemblages of the pelitic rocks of the Casco Bay Group. **FPF**: Flying Point fault; **FRF**: Fore River fault; **JPF**: Johns Point fault; **PRL**: Presumpscot River lineament. Heavy dashed lines indicate schematically the zone of extensive shearing within low-grade Eliot Formation probably associated with the right-lateral Norumbega fault system.

Running Hill, Blueberry Hill, and Thompson Hill, and the area north and west of the Presumpscot River valley. Outcrops are very sparse along most of the distance of the northeast-trending Presumpscot River lineament (Figure 2). Shoreline outcrops are relatively sparse. Superior control on rock distribution in the Fore River estuary along the alignment of the new Casco Bay Bridge between Portland and South Portland near the southeast corner of the map comes from numerous core samples taken for evaluation of foundation characteristics for the bridge construction. Samples were taken every 100 feet or less between the mainlands of Portland and South Portland. The writer was fortunate to be able to obtain representative materials from these cores before they were disposed of.

INTRUSIVE ROCKS

Intrusive rocks in the Portland West 7.5' quadrangle include diabase and basalt dikes; granitic pegmatite sills, dikes, and lenses; foliated diorite; and intimately associated aluminous granite, granite gneiss, and intermediate rocks that compose the Westbrook pluton.

Basalt and related rocks

Unaltered diabase and basalt dikes intrude all other rock units in the quadrangle, and are thus the youngest bedrock features of the area. They range in thickness from a few centimeters to more than 5 meters. Strikes are moderately variable to the northeast, and dips are steep. In the area on the north side of the outlet of Back Cove, just north of the Portland peninsula, rocks of the Eliot Formation have been intruded by a series of gently-dipping sills of medium gray, fine-grained rock of possible intermediate composition (these have not yet been studied in thin section). These sills and associated structural features are discussed in detail below in the section on Structure.

Westbrook Granite

Granite and related rocks occupy the low hilly terrain northwest of the Presumpscot River lineament. Most of the pluton consists of fine-grained light gray massive (Figure 3A) to moderately foliated (Figure 3B) biotite-muscovite granite. Garnet, apatite, opaques, zircon, and monazite are common acces-

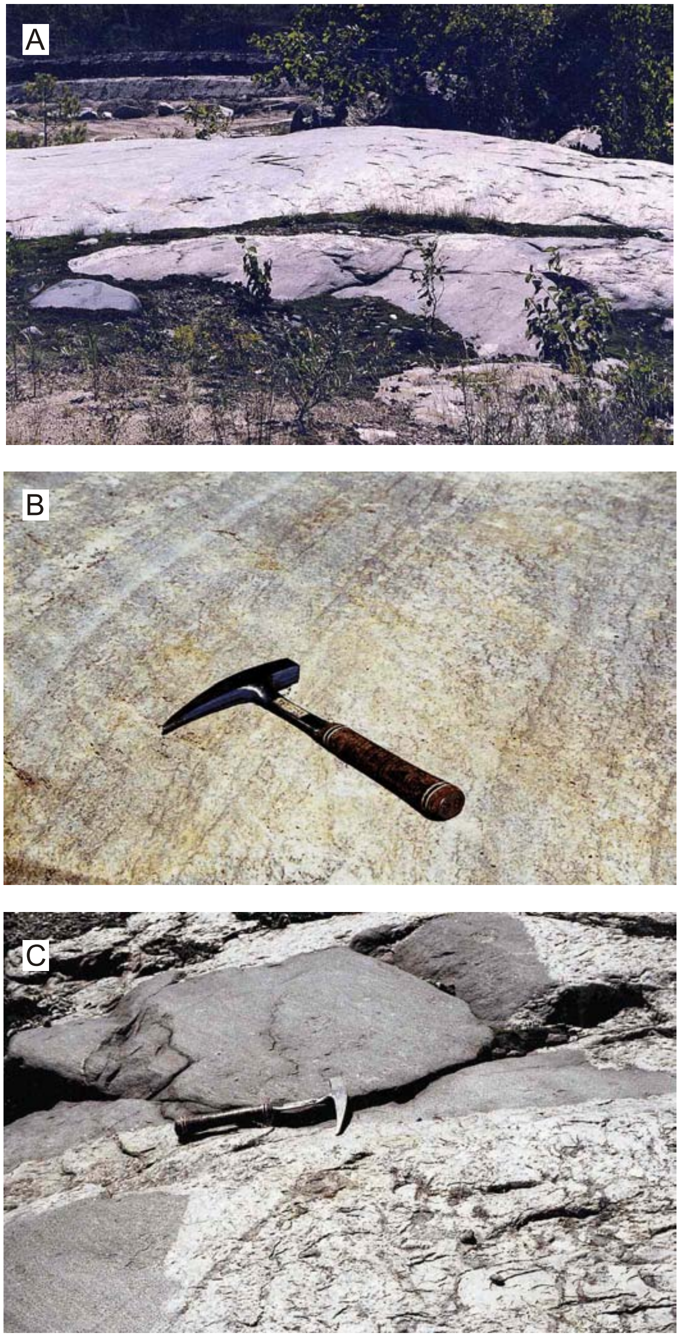


Figure 3. Glacially-polished surface of the Westbrook pluton at the Shaw Brothers Quarry along Methodist Road, 6 kms north of Westbrook. The quarry is presently active, producing crushed stone.
A. Light gray, weakly foliated biotite-muscovite granite; darker phase in foreground is fine-grained granodiorite or quartz diorite. B. Strongly foliated granite. C. Weakly foliated fine-grained medium gray granodiorite cut by dike and irregular mass of non-foliated granite pegmatite.

sory minerals. Included in the dominant two-mica granite phase are minor masses of medium gray foliated biotite granodiorite (Figure 3C). Both the granite and granodiorite are intruded by massive to slightly foliated dikes and irregular stringers of pegmatite containing black tourmaline, biotite, and muscovite (Figure 3C). Common throughout the pluton, are numerous blocks of Berwick-type granofels. The Presumpscot River lineament, mentioned briefly above does not form the boundary of the pluton. The contact of the granite with the Berwick Formation, although not well exposed, appears to be gradational over a distance of about a kilometer just northwest of the lineament. In this zone masses of the Berwick Formation become more numerous toward the mapped edge of the pluton, southeast of which the rock is mapped as migmatized Berwick Formation. The ages of the Westbrook plutonic phases have not been determined by radiometric dating. They are probably Devonian, related to the Acadian orogeny, but may be as young as the granites and pegmatite of the Topsham area for which Tomascak and Francis (1995) report Permian ages, relating them to thermal effects associated with the Alleghenian orogeny.

Two similar, unnamed, biotite-muscovite granite bodies crop out in the northern part of the City of Portland. Both are northeast-trending narrow lenses of irregularly textured foliated granite confined to the zone of migmatization. The larger of the two bodies has been extensively quarried at Rocky Hill in Portland (Figure 4). Some exposures of the granite in the Rocky Hill Quarry show shear-band-type foliation marked by concentrations of biotite (Figure 5) suggesting shearing during late-stage syntectonic crystallization of the magma.

Diorite

A small mass of diorite, approximately 1 by 1/2 km in size, occurs on the southeast side of Rocky Hill in Westbrook. This rock is medium- to fine-grained, medium gray massive to moderately foliated phanerite consisting of plagioclase, hornblende, and augite. Minor constituents include quartz, biotite, sphene, opaques (probably ilmenite because they are frequently mantled by sphene), and apatite. Where it is most strongly foliated, primary dark minerals are partially altered to finely fibrous opti-

Figure 4. Exposure of irregularly-textured granite gneiss and pegmatite at Rocky Hill Quarry, Deering area of Portland. Quarry is now inactive. Note steep west-dipping joints. Height of the exposure is approximately 35 feet.

Figure 5. Granite gneiss at Rocky Hill Quarry, Portland, showing prominent shear banding indicating shearing during late stage of consolidation of the granite.

cally unresolvable phases, and the plagioclase is partially altered to dusty clay materials. The diorite is intruded by numerous dikes and stringers of granitic pegmatite and two-mica granite akin to the principal phase of the Westbrook Granite. The absolute age of the diorite is unknown.

Pegmatite

In addition to those described above that are associated with the Westbrook pluton, pegmatite dikes, sills, and irregular bodies are seen throughout the area of migmatization of the rocks of the Merrimack Group and Central Maine sequence. Mineralogy is simple: quartz, perthitic potash feldspar, plagioclase, biotite, and muscovite with accessory garnet and black tourmaline. Sills and irregular bodies tend to be weakly to moderately foliated and folded along with the country rock, whereas the dikes are generally unfoliated and unfolded.

METAMORPHIC ROCKS

Metamorphic rocks in the Portland West 7.5' quadrangle are assigned to three lithotectonic sequences, the Merrimack and Casco Bay Groups and the Central Maine sequence. As a result of mapping in this quadrangle, two of these, the Merrimack Group and Central Maine sequence, are interpreted to be on-strike equivalents as will be discussed below.

Casco Bay Group

The Casco Bay Group consists, in structurally ascending order, of the Cushing Formation, Cape Elizabeth Formation, Spring Point Formation, Diamond Island Formation, Scarboro Formation, Spurwink Metalimestone, and Jewell Formation. The outcrop belt of the Cushing Formation does not pass through the Portland West quadrangle. The Jewell Formation does not crop out, but is completely covered by surficial sediments and artificial fill. Outcrops of the remaining formations occur in the very southeastern corner, defining the southeastern limb of a major syncline. The northwestern limb of the syncline is defined by the Spring Point through Scarboro outcrops on the Portland peninsula and southeast of Long Creek in South Portland; in addition, bedrock core samples taken along the alignment of the Casco Bay Bridge between Portland and South Portland confirm the existence of the Casco Bay formations under the Fore River.

The rocks of the Casco Bay Group are separated from the Merrimack and Central Maine rocks by the Johns Point fault (Figure 2). Internally, the Casco Bay formations appear to be separated from each other by conformable contacts.

Cape Elizabeth Formation. The Cape Elizabeth Formation crops out very sparingly in the quadrangle, in the area of Thornton Heights, South Portland (south edge of the map). It consists of non- to weakly bedded medium gray muscovite-chlorite-garnet-biotite-quartz phyllite (Figure 6). Until 2001, the best exposures were in a rock quarry 0.3 km N 60° E from the corner of Western Avenue and Westcott Road in the Thornton Heights area, but sometime between 2001 and June 2003, the quarry had been filled in and part of a housing development now occupies the site. (In urban areas such as Portland and South Portland, although the rocks endure, the exposures may be very fleeting!)

Spring Point Formation. The Spring Point Formation consists of medium greenish gray chlorite-actinolite-biotite-plagioclase schist and amphibolite, with minor medium gray plagioclase-quartz-chlorite-biotite-actinolite ± epidote granofels and schist (Figure 7). Included within the formation, but known only from borings for a building along Commercial Street in Portland and from the Casco Bay Bridge core samples is light gray plagioclase-quartz-muscovite granofels and schist, a

Figure 6. Medium gray nonbedded slightly iron-stained chlorite-biotite-garnet phyllite of the Cape Elizabeth Formation. Exposure is at the corner of Maine Route 9 and Wescott Street in the Thornton Heights area of South Portland.

Figure 7. Massive greenish gray amphibolite of the Spring Point Formation beneath the west-bound off ramp of the Casco Bay Bridge, Portland.

lithology very similar to some of the felsic phases of the Cushing Formation. The actinolite-bearing lithologies are interpreted to represent basaltic to andesitic pyroclastic volcanic rocks prior to metamorphism. The light gray quartzo-feldspathic rocks probably represent felsic tuffs prior to metamorphism. The Spring Point Formation crops out at scattered locations on the central and southeastern parts of the Portland peninsula, and in the southeastern corner of the quadrangle.

Diamond Island Formation. The Diamond Island Formation is the most distinctive and recognizable unit of the Casco Bay Group. It consists of compositionally unlayered dark gray to black quartz-muscovite-graphite phyllite. Pyrite, in the form of euhedral cubes and anhedral thin smears along phyllitic foliation planes, is common, and gives rise to local yellow and orange limonite staining on weathered surfaces. The Diamond Island lithology yields a sooty black powder when hammered or scratched, and this is the most reliable property by which this formation is distinguished from dark varieties of Scarboro Formation. The Diamond Island Formation is exposed at its proper stratigraphic position between the Spring Point and Scarboro Formations in the southeast corner of the map (Figure 8), and is present between the same lithologies in the core samples from the Fore River area.

Scarboro Formation. Two varieties of the Scarboro Formation have been mapped in the Portland West 7.5' quadrangle. The dominant lithology is non- to moderately rusty-weathering medium gray muscovite-chlorite-garnet-quartz-plagioclase phyllite with sparse thin interbeds of muscovite-quartz-plagioclase phyllite. The other lithology is medium greenish gray chlorite-muscovite-garnet-quartz phyllite. The greenish color makes it very similar in appearance to some portions of the Spring Point Formation. These greenish phyllites are interpreted to have been volcanogenic muds, representing either air-transported intermediate pyroclastic ash or fine mud eroded from terrains composed of intermediate volcanic rocks.

Spurwink Metalimestone. Katz (1917) originally referred to this unit as the Spurwink Limestone. However, the unit is metamorphosed to garnet and higher grades and therefore the appellation "limestone" seems inappropriate. In most localities where it is exposed, it does not have the appearance of a marble, so that name is not appropriate. I therefore, in my earliest mapping, preferred to refer to it as "metalimestone" (Hussey, 1971). Exposures within the quadrangle are limited to outcrops in the mudflats and shoreline on the southeast side of the Fore River in South Portland. However, several of the bridge borings encountered the unit, so it is well represented in the southeast corner of the quadrangle. It is typically thin ribbony-bedded medium gray very fine-grained rock composed mostly of calcite with minor biotite, quartz, and plagioclase, and thin interbeds of quartz-plagioclase-biotite phyllite. Fish-mouth-type boudinage is typical of most exposures of the formation. Within the quadrangle, the Spurwink Metalimestone is associated with pelitic rocks of the Scarboro Formation that have been metamorphosed only to garnet grade.

Jewell Formation. The lithology of the Jewell Formation in the Portland West quadrangle is not known; there are no exposures in the inferred outcrop belt. From outcrops nearby in the Cape Elizabeth (Hussey, in press), Portland East (Hussey, 2003a), and Prouts Neck 7.5' quadrangles (Hussey, 2003b), it is essentially identical to the Scarboro Formation — rusty and non-rusty light and dark gray muscovite-biotite-garnet-chlorite-quartz phyllite. Greenish gray phyllites similar to those mapped with the Scarboro Formation are also present in the Jewell Formation exposed on Jewell and Great Diamond Islands in the Portland East quadrangle.

Age of the Casco Bay Group. Bearing on the age of the Casco Bay Group are radiometric dates from two widely-separated localities. One of these is a few kilometers to the east along the shore at Danford Cove in South Portland. Felsic metamor-

Figure 8. Black graphitic phyllite of the Diamond Island Formation, exposed at the corner of Highland Avenue and Stillman Street, South Portland, at the southern edge of the Portland West quadrangle.

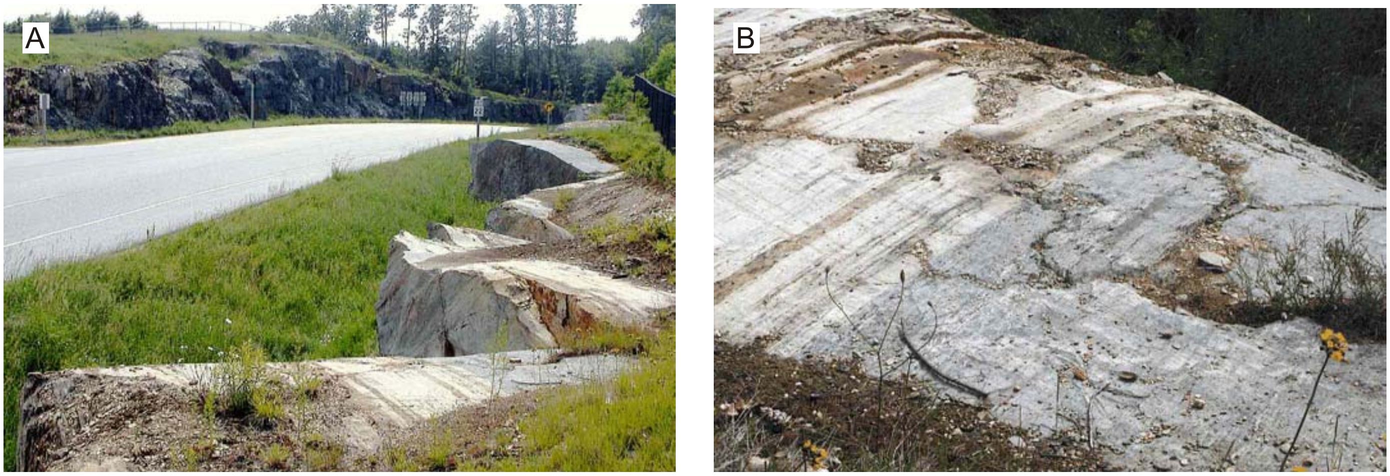


Figure 9. Eliot Formation at Exit 7A interchange of the Maine Turnpike, South Portland. A. General view of glaciated surface of the Eliot Formation, showing in the foreground thin compositional layering probably reflecting original sedimentary beds. B. Closeup, showing light buff-gray-weathering calcareous phyllite (metasiltstone) and dark gray chlorite-muscovite phyllite (metashale). Proportions and relative thickness of light vs. dark layers varies considerably in different parts of the exposure.

phosed volcanic rocks of the Cushing Formation have yielded U/Pb ages on zircons of 471 to 473 MA (John Aleinikoff and Robert Tucker, personal communications). The other is a 469 MA age on metavolcanics of the Spring Point Formation in the Liberty-Palermo area about 80 km to the north (Tucker and others, 1995). These ages suggest a Middle Ordovician (Llandeilo-Llanvirn) age for the Cushing, Cape Elizabeth, and Spring Point Formations. The Scarboro, Spurwink, and Jewell Formations are only slightly younger, probably also of Middle Ordovician age.

Merrimack Group

Rocks here assigned to the Merrimack Group include the Eliot and Berwick Formations. The Kittery Formation, also a part of the group, is not exposed in the Portland West 7.5' quadrangle. Within this area, the Berwick and Eliot Formations appear to be conformable, although critical exposures of contacts are lacking.

Eliot Formation. The Eliot Formation occupies a 3 -3.5 km wide belt extending from the southeastern corner of the quadrangle northeast through the Back Cove and Brighton areas of Portland. In the vicinity of Back Cove and northeastward, the rocks here assigned to the Eliot Formation were mapped as the Mackworth Formation by Katz (1917) and were included as the uppermost unit of the Casco Bay Group. Comparison of the lithology of these rocks, particularly the lower grade calcitic rocks in the southwestern corner of the Portland West quadrangle, with Merrimack Group rocks in southwestern Maine and southeastern New Hampshire indicates the close lithologic similarity of these rocks with the Eliot Formation to the southwest.

The Eliot Formation, at its lowest metamorphic grade (biotite zone), consists of thinly layered, thoroughly sheared alternations of medium gray, brown-weathering chlorite-calcite-biotite-muscovite-quartz-plagioclase phyllite, quartz-plagioclase-biotite-calcite phyllite and dark gray chlorite-muscovite-quartz phyllite (Figures 9A and 9B). At higher grades of metamorphism (amphibole through diopside zones) the rock is thinly layered brownish-gray weathering quartz-plagioclase-biotite-calc-silicate granofels and quartz-plagioclase-biotite granofels (Figure 10A). Zoisite, pale green hornblende, and sphene are the calc-silicate minerals of the intermediate (zoisite/amphibole zone) grade of metamorphism (Figure 10B), and hornblende, zoisite, diopside, sphene, and rarely grossular garnet, are the calc-silicate minerals of the highest (diopside zone) grade of metamorphism.

Amphibolite of Back Cove. One outcrop in the mud flats along the eastern side of Back Cove is the only observed exposure of dark green actinolite gneiss in the outcrop belt of the Eliot Formation. It is interpreted to be a metamorphosed mafic igneous rock, but whether intrusive or extrusive is not indicated by characteristics of this sole exposure. Its close proximity to the inferred trace of the Flying Point fault suggests that it may be an infaulted slice of one of the amphibolites mapped in the adjacent Portland East quadrangle such as the amphibolite of the Nehumkeag Pond Formation at Bartlett Point or the Spring Point Formation (Hussey, 2003a).

Berwick Formation. In the Portland West quadrangle the Berwick Formation occupies a 5 km wide belt between the Eliot Formation and the Westbrook pluton. Mineralogically these rocks are similar to the intermediate and high-grade zones of the Eliot Formation, but are distinguished by generally thicker compositional layering (3 to 10 centimeters) more quartz-

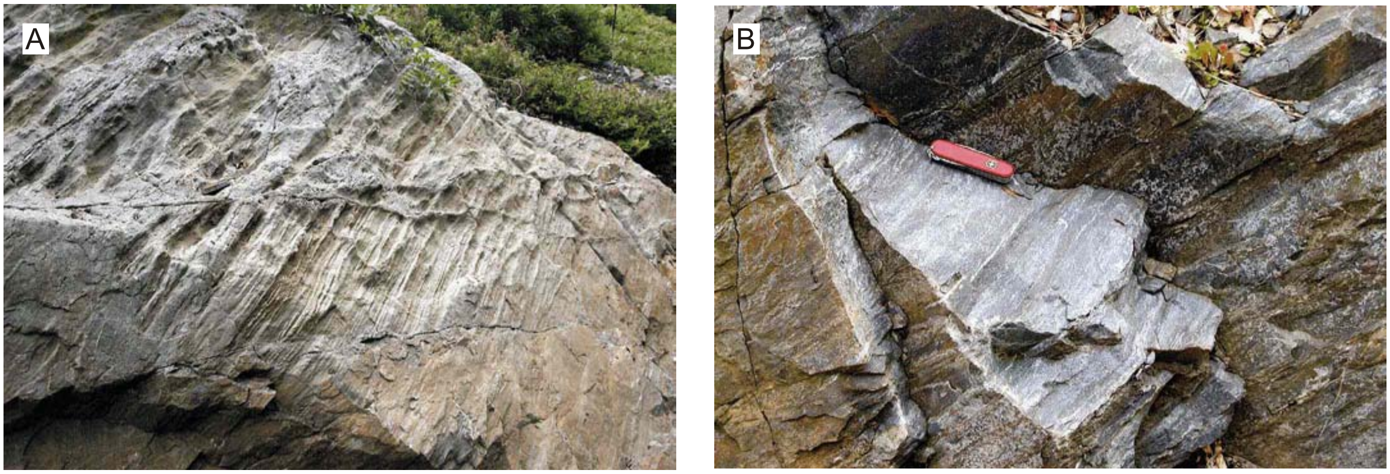


Figure 10. Eliot Formation at intermediate grade of metamorphism between Fore River and Brighton Avenue, Portland. A. Thinly banded brownish gray quartz-plagioclase-biotite gneiss with thin interlayers of greenish calc-silicate gneiss. B. Closeup showing green irregular streaks of the calc-silicate gneiss with hornblende and epidote. Exposure is in new housing development about 400 meters southwest of the corner of Brighton and Stevens Avenues, Portland.

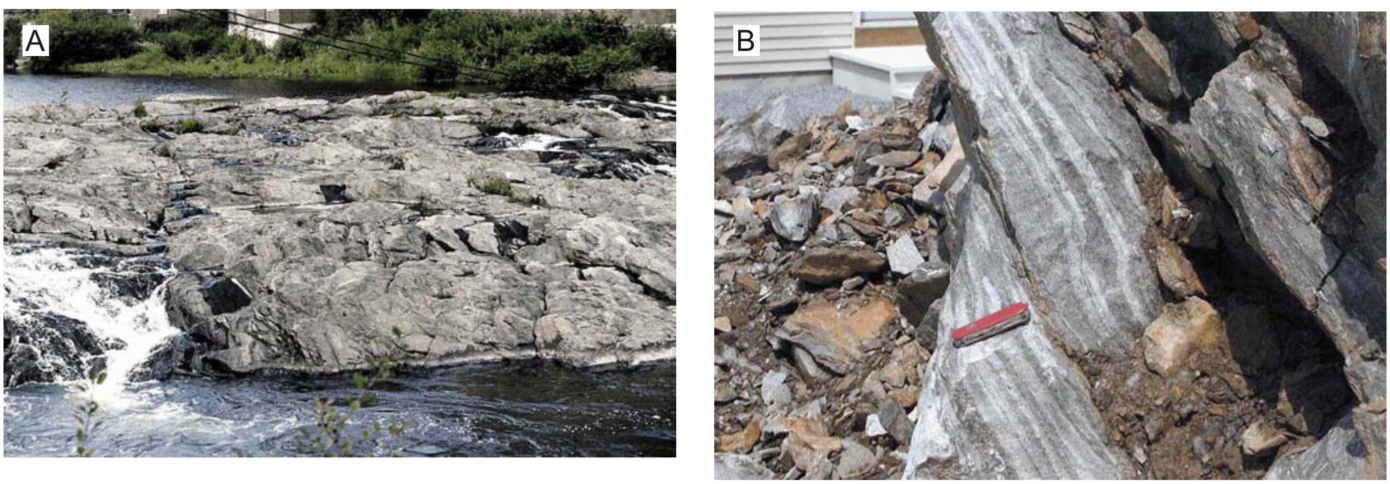


Figure 11. A. Exposure of medium-bedded Berwick Formation in the Presumpscot River, Westbrook. B. Thin to medium interlayered calc-silicate and biotite gneiss of the Berwick Formation near Morrills Corner, Portland.

plagioclase-biotite granofels and gneiss, more pronounced green calc-silicate layers, and less of the more micaceous interlayers (Figures 11A and B). The distinction between the Berwick and Eliot Formations in the northeast part of the map is much less certain because of the extensive migmatization.

Central Maine sequence

Rocks correlated with the Central Maine sequence in the Portland West quadrangle have been traced southward from the Topsham area into the Portland area (Hussey and Berry, 2002; Hussey and Marvinney, 2002; Berry and Hussey, 1998). The Central Maine sequence is represented by the Hutchins Corner Formation. The Richmond Corner and Torrey Hill Formations of that sequence are not recognized in the Portland West area, although they are present in the adjacent quadrangle to the east. The Hutchins Corner Formation consists of migmatized medium brownish gray salt-and- pepper-textured quartz-plagioclase-biotite gneiss and granofels with lesser amounts of medium to light greenish gray diopside-hornblende-zoisite-quartz-plagioclase-biotite granofels and gneiss.

The Hutchins Corner Formation is on strike with the Berwick and Eliot Formations, and as noted earlier, the distinction between the Eliot and Berwick is lost in the area of migmatization. This on-strike distribution of the Hutchins Corner Formation versus the Eliot and Berwick Formations is the principal reason for suggesting a correlation of the Central Maine sequence with the Merrimack Group as indicated in Fig-

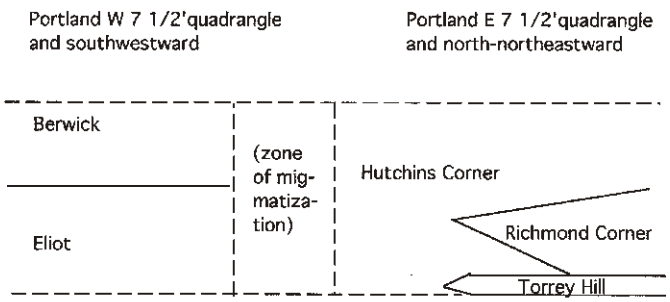


Figure 12. Proposed correlation between the Merrimack Group to the southwest and the Central Maine sequence to the northeast.

ure 12. The dotted line that separates them on the geologic map merely delimits the boundary where these two sequence names have been traditionally applied.

STRUCTURE

The inferred structure of the Portland West quadrangle is shown on cross-sections A-A' and B-B' on the map sheet. Major faults are shown on the metamorphic map (Figure 2).

Folds

The outcrop belt of the units of the Casco Bay Group in the southeastern part of the map is dominated by the South Portland syncline for which there is sufficient evidence in this quadrangle to delineate it. It includes the formations from Spring Point through Jewell. From distribution of outcrops of these formations in this quadrangle and the Prouts Neck 7.5' quadrangle immediately to the south, this syncline is inferred to plunge gently northeast.

The Cape Elizabeth Formation in the Thornton Heights area of South Portland occupies the core of an adjacent anticline which continues south into the Prouts Neck quadrangle. Outcrops at the head of tidewater along Long Creek south of the Portland airport define the northern end of a syncline which, again, is better understood from the outcrop distributions in the Prouts Neck quadrangle. These two structures are terminated northward in the vicinity of Long Creek by the inferred extension of the Johns Point fault.

Major fold structures in the Merrimack Group and Central Maine sequence are generally not indicated by either the map pattern or observed parasitic folds. Minor folds are suggested by the distribution of outcrops of the Eliot and Berwick Formations in the area just northwest of Back Cove, Portland, and south of Westbrook. Parasitic folding, as schematically shown on the cross sections A-A' and B-B', probably characterizes most of the sequences in this quadrangle inasmuch as it has been observed at many localities regionally.

No evidence in the Portland West quadrangle resolves the question of the relative stratigraphic position of the Berwick and Eliot Formations. In New Hampshire, Lyons and others (1997) have interpreted that, within the Merrimack Group, the Kittery Formation overlies the Eliot Formation. The stratigraphic relationship between the Eliot and Berwick Formations is complicated by the presence there of the Calef Member of the Eliot Formation. This member separates the Eliot lithology that is correlable with Eliot of the Portland area, from the Berwick Formation, and has been interpreted by Bothner and Hussey (1999) as a phyllonite possibly delineating a major segment of the Norumbega fault zone. No such lithology or structure has been observed in the Portland West quadrangle. There is no evidence to suggest that the contact between the two formations is anything other than conformable. In this report the Berwick Formation is regarded as a part of the Merrimack Group, but its stratigraphic position relative to other formations of the group remains unresolved.

Faults

Major faults within the Portland West quadrangle are the Flying Point, Johns Point, and Fore River faults (Figure 2). None of these fault zones have been observed in outcrop.

Evidence for the Fore River fault is three-fold. (1) Core samples from the alignment of the Casco Bay Bridge demonstrate a repetition of the Diamond Island and Spring Point lithologies under the channel of the Fore River. (2) Several of the cores in the area of this stratigraphic repetition preserve breccia with drusy quartz veins. (3) The thickness of the sedimentary fill in the western edge of the Fore River locally exceeds 100 meters (Maine Department of Transportation drill records), suggesting a deep preglacial gorge that may have been eroded along a zone of brecciation.

The Johns Point fault separates the Casco Bay Group from the Merrimack Group. It separates biotite-grade Eliot lithologies from garnet-grade pelites and actinolite-grade metabasites of the Casco Bay Group. It is probably one of the principal breaks within the Norumbega fault system.

The Flying Point fault separates biotite-grade Eliot lithologies from zoisite- and diopside-grade Eliot, Berwick, and Hutchins Corner lithologies. To the north, it separates rocks of the Falmouth-Brunswick sequence from the Casco Bay Group (Berry and Hussey, 1998; Hussey and Berry, 2002; Hussey and Marvinney, 2002), and is regarded as one of the segments of the right-lateral strike-slip Norumbega fault system (Swanson, 1999). In the Portland West quadrangle evidence for the continuation of the Flying Point fault appears to be lost within the Eliot Formation. However, the generally sheared appearance of the formation such as seen on glacially polished surfaces (Figure 13) at the 7A entrance to the Maine Turnpike suggests that motion on the Flying Point fault might be accommodated as distributive

Figure 13. Glacially polished horizontal surface of biotite-grade Eliot Formation at exit 7A of the Maine Turnpike, showing sheared appearance of the compositional layering. Blotchy appearance of the darker layers is due to extensive shear-band deformation in the more micaceous parts of the Eliot lithology. View is looking southwest.

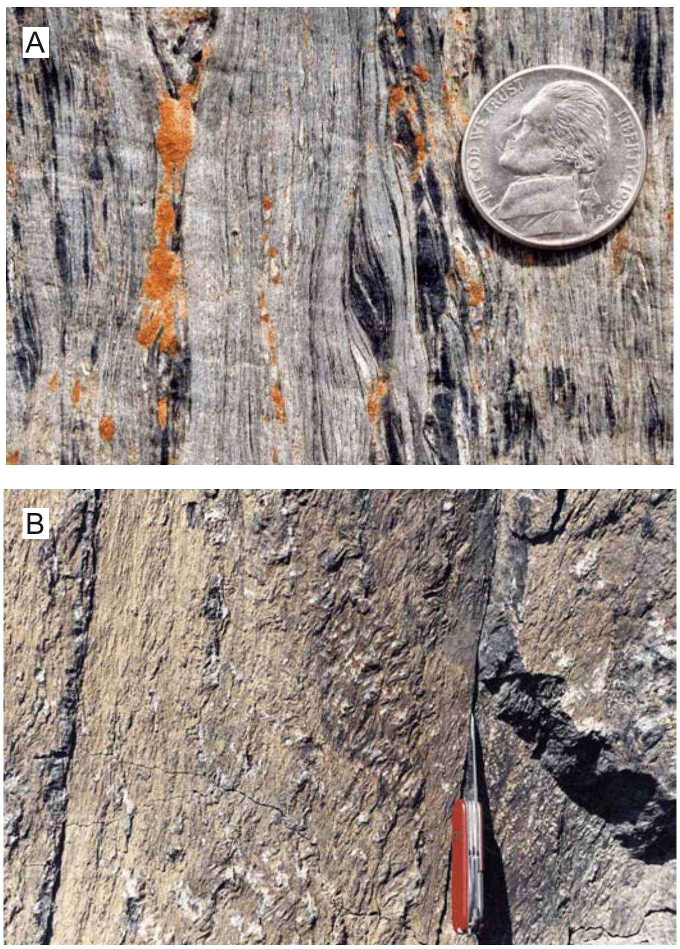


Figure 14. A. Closeup of the same exposure as Figure 13 showing shear-banding in the more micaceous layers, indicating right-lateral sense of shearing. B. Vertical surface of biotite-grade Eliot Formation at the same locality as Figure 13, showing small-scale shearing of beds indicating a down to the southeast (to the left) component of shearing.

shearing throughout the Eliot Formation Small-scale features at this locality indicate right-lateral shearing (Figure 14A), with a component of dip-slip motion down to the southeast (Figure 14B). This distributive shearing may be due to the abundance of carbonate in the lower-grade Eliot lithology.

The wide belt of the Spring Point Formation in the Portland peninsula area, as compared to other locations, may indicate the presence of numerous faults. Numerous high-angle brittle faults of unknown but presumably minor offset, and with generally dip-slip motion, can be seen in outcrops of the Spring Point Formation just east of the map area along a railroad cut at Fish Point on the northeast side of the peninsula.

Rock relations in the East Deering area. Unusually good exposures along shore in the East Deering area at the eastern edge of the map show some features of the structure of the Eliot Formation that are not observed elsewhere. These features may have significant, and possibly critical relevance, to interpreting the timing, spatial extent, mechanics, and relative direction of movement of splays of the Norumbega fault zone. The following observations will be accompanied by more questions than answers at the present level of investigation, but they hopefully will focus on additional work that needs to be done.

The general relations in the area are as follows:

Strike of compositional layering (bedding?) is relatively uniform: between N 25 E and N 60 E. Compositional layers vary from 1 to 20 cm (Figure 15).

Dip becomes progressively gentler eastward across strike to the end of the outcrops in the mudflats 100 meters east of the shoreline (60 degrees to almost horizontal as shown by the structural symbols on the map sheet).

Figure 15. Compositional layering (bedding) of thin- to medium-bedded biotite-grade Eliot Formation in shore exposures at East Deering just across the bay from the northwest end of the Portland peninsula. Layering dips about 10 degrees toward the east at this locality, and shows little evidence of disruption by shearing related to the Norumbega fault system.

Figure 16. Contact of intrusive sill with the Eliot Formation, same locality as Figure 15. Dark rock is chilled margin of the sill rock, and the light material is a thin selvage of the Eliot Formation that is welded to the intrusive.

Figure 18. Conjugate set of sub-vertical kink bands, same locality as Figure 15.

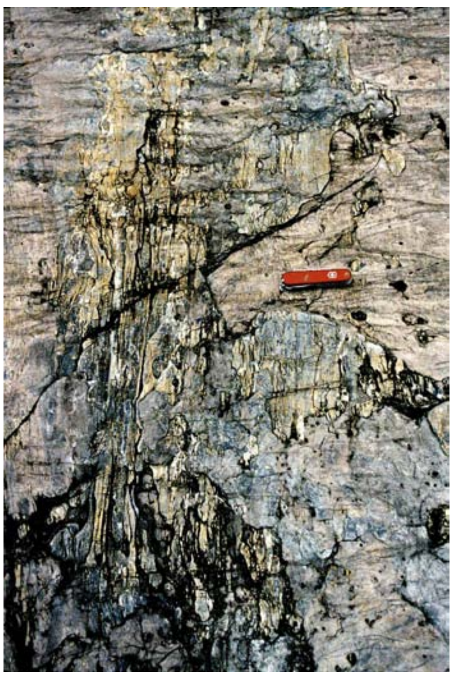


Figure 17. Highly stretched and rodded bedding-parallel quartz vein, same locality as Figure 15. Stretching direction is perpendicular to strike of bedding, and may relate to thrust-fault movement. Stretched quartz veins show slight deformation by gentle kink bands parallel to the pen knife.

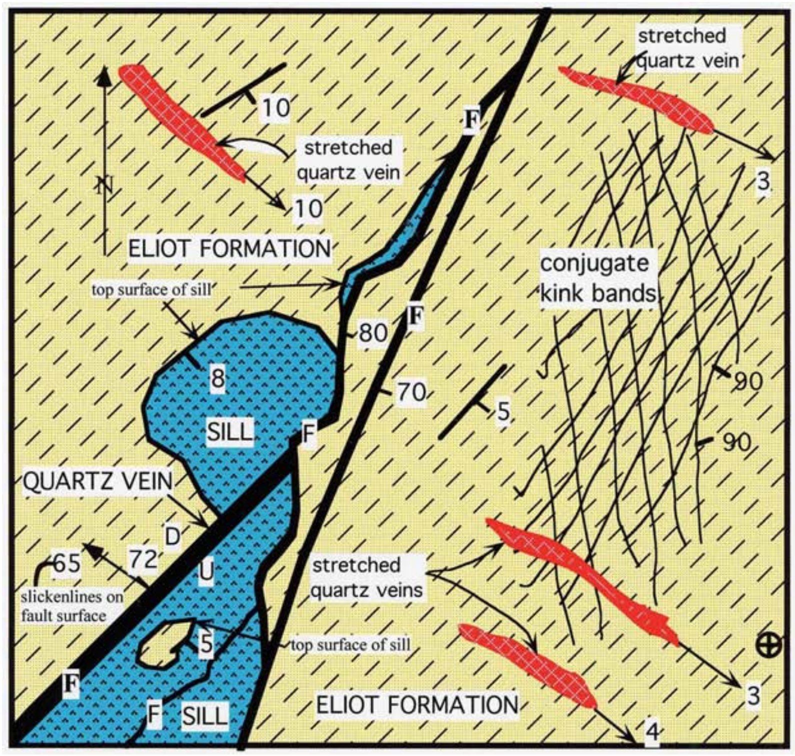
Several intrusive sills, possibly of diabase, basalt, or andesite, are present in the area and show the same progressive decline in angle of dip eastward as does the compositional layering. The texture of the sills in hand specimen has more the appearance of a metamorphically recrystallized rock than an original igneous texture. The contact zone is very fine-grained and black in color, and the metamorphic wall rock of the Eliot Formation is strongly welded to the sill such that in several places the metamorphic rocks form a thin patchy selvage on the surface exposures (Figure 16).

Lineation in the form of flattened and stretched, bedding-parallel quartz veins (Figure 17) are common on compositional layering surfaces and have a uniform down-dip, south-southeast, orientation. Such uniformity of down-dip quartz-vein lineation has not been observed elsewhere in the quadrangle.

Conjugate kink or shear bands (Figure 18) are locally, but not pervasively developed in the rocks of the Eliot Formation. They do not offset compositional layering to any significantly measurable extent (note that the more competent layers in Figure 15 are not affected by such bands).

Several high angle faults of different relative ages cut the Eliot rocks and the intrusive sills. Some of these faults have been injected by composite veins consisting of mostly milky quartz with lesser pale brownish weathering calcite and felted masses of black tourmaline prisms.

Figure 19 is a sketch map of the outcrop at the area of the 10 degree dip of compositional layering near the southeastern end of the exposures. Figure 20 is an oblique photo of the same locality. Three brittle fault generations are present. The oldest, occupied by the quartz vein, is high-angle normal, down to the northwest, based on drag of foliation. It has an approximate displacement of 15-20 cm based on the offset of the upper contact of the sill on opposite sides of the fault. This fault and the quartz vein that has formed along it are terminated against an undulatory fault dipping steeply east. Based on the irregularity of this fault, it is a dip-slip fault. This fault is, in turn, cut by a straighter fault dipping steeply southeast. Relative motion is not clear. All faults cut the sill. These faults may be Mesozoic in age and may be related to post-Norumbega normal faulting on the Flying Point segment of the Norumbega system as postulated by West and others (1993).



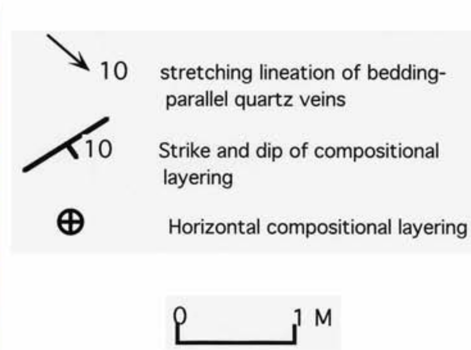


Figure 19. Detailed sketch map of outcrop relations along East Deering shoreline across the bay from the northwestern end of the Portland peninsula. This locality is just east of the B & M Baked Bean Plant in East Deering. Quartz-vein lineation and kink bands shown schematically. Quartz vein (with minor black tourmaline and calcite), shown by heaviest black line follows a minor high-angle normal fault with down-to-the-northwest motion as indicated by drag sense of foliation of the Eliot Formation and by offset of the contact of an intrusive sill.

The following sequence of events are inferred for this locality:

1) Early Silurian deposition of the Eliot Formation.
2) Initial folding of the Eliot Formation, probably to steeper angle than present. This is probably related to the Early Devonian Acadian orogeny.
3) Metamorphism of the Eliot Formation and injection of quartz veins parallel to bedding and foliation. This is also related to the Acadian orogeny.
4) Stretching and rodding of quartz veins parallel to dip, probably related to Acadian thrusting.
5) Intrusion of sill. (Question: Was this sill intruded at the present shallow angle, or at a higher angle before bedding was rotated to the present shallow angle? Steeper bedding might have provided a mechanically more advantageous path for injection of magma derived from depth.)
6) Rotation of bedding, sills, and quartz-ribbon lineation to present low angle of dip. Is this shallow dip the result of gentle open folding or is it the result of fault drag on a major offshore fault?
7) Small-scale normal faulting, down to the west, of bedding and sill.
8) Quartz-carbonate-tourmaline-vein injection along the fault plane of the earliest of these faults. Similar veins elsewhere in these exposures intrude along fractures.
9) Normal faulting (two relative generations).
10) Development of kink bands.

Figure 20. Oblique photograph of the locality of the sketch map (Figure 19).

The absence of extensive high-angle intensive right-lateral shearing such as is present in exposures of the steeply-dipping Eliot Formation at other localities (compare deformation of compositional layering shown in Figure 15 with Figures 11 and 13) begs the question of how the East Deering exposures relate to the distributive right-lateral shearing of the Norumbega fault system. This is an area where effects of the Norumbega shearing should be very extensively developed. It is possible (though not probable) that microscale layer-parallel features related to the Norumbega fault movement preserve a picture of such movement. Any Norumbega-related features would most likely have formed when compositional layering was vertical, prior to rotation to the present orientation. Events 6 to 10 above would then postdate the Norumbega faulting event. The quartz vein lineation cannot be related to Norumbega horizontal shearing, inasmuch as they have a down-dip orientation. Answers to the questions touched upon above and the timing of these events may be clearer when a radiometric age of the sill rock is available.

METAMORPHISM

Buchan-type metamorphism (low pressure, moderate to high temperature) of probable Acadian age characterizes the rocks in the Portland West quadrangle. The distribution of zones of regional metamorphism is shown in Figure 2.

Rocks of the Casco Bay Group in the Portland West quadrangle have been metamorphosed to garnet grade. The critical assemblages within pelitic rocks of the sequence include garnet, biotite, chlorite, white mica, quartz and plagioclase feldspar. In the metabasites of the Spring Point Formation, the critical assemblage is amphibole (probably actinolite), chlorite, biotite, plagioclase, and locally, epidote.

Zones of progressive regional metamorphism of the rocks of the Merrimack Group and Central Maine sequence are defined by changes in mineralogy of impure carbonates that characterize most of these sequences. These variations are essentially the same as observed in similar rocks of the Central Maine sequence in the Waterville area (Ferry, 1983). In the Portland West quadrangle the lowest grade of metamorphism is biotite zone, the critical assemblage being biotite, chlorite, calcite, muscovite, quartz, and plagioclase. An intermediate grade of metamorphism is characterized by the assemblage zoisite, hornblende, biotite, quartz, plagioclase, sphene , and occasionally calcite. This includes the zoisite and amphibole zones delineated by Ferry (1983) in the Waterville area. In the Portland area no separate amphibole zone (slightly lower grade than zoisite zone) appears to be present. No mineral assemblages with amphibole and without zoisite have been observed. The highest grade, diopside zone, is represented by the assemblage diopside, zoisite, hornblende, sphene, quartz, and plagioclase. Parts of this high grade zone have been extensively migmatized. The metamorphism of the Merrimack Group and Central Maine sequence may be of the same age as that of the Casco Bay Group, that is, related to the Acadian orogeny of Early Devonian age, but critical geobarometer and geothermometer criteria are not available at present to further refine these relationships.

ACKNOWLEDGMENTS

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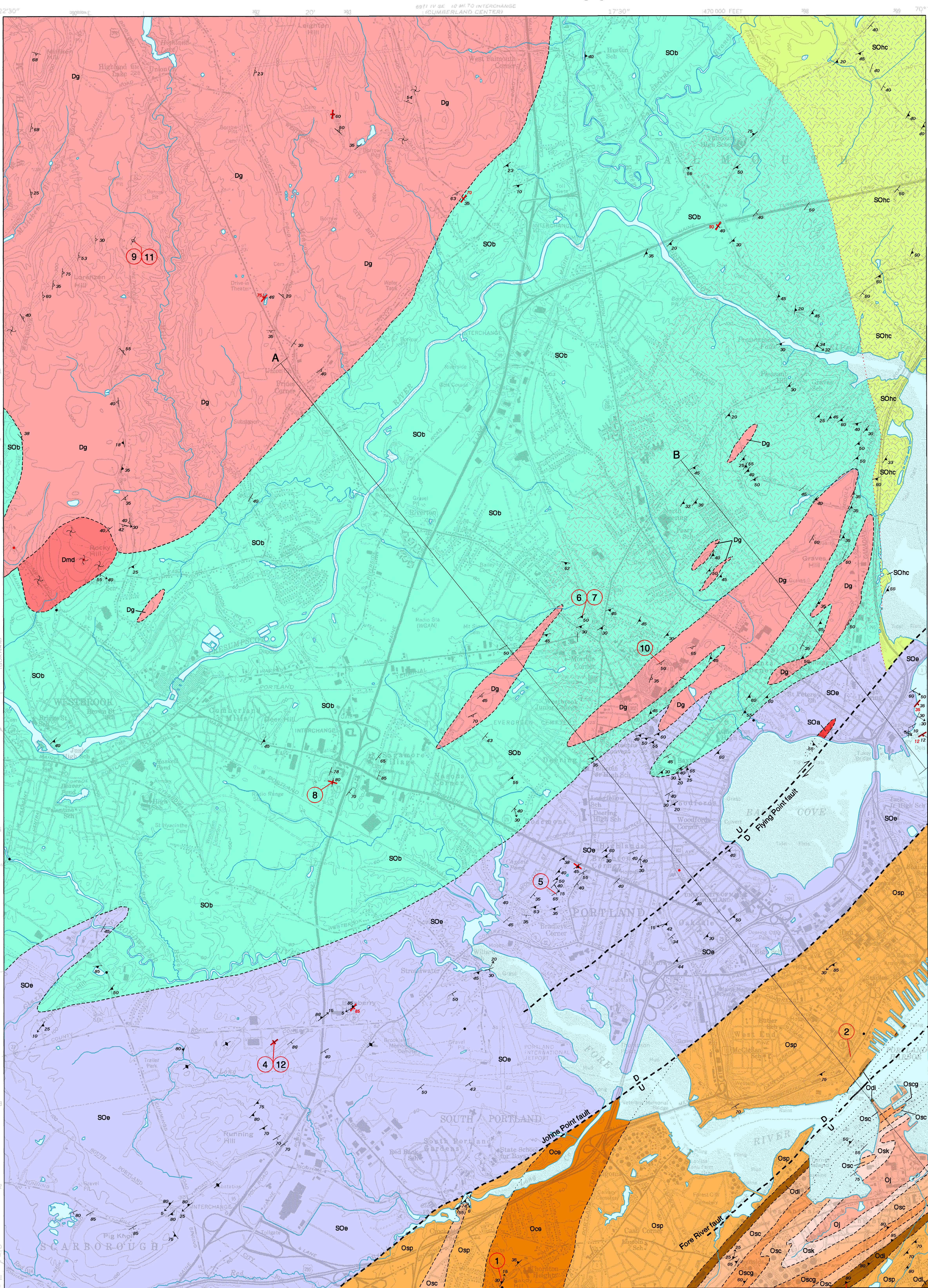
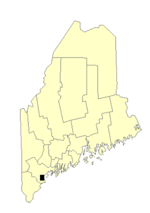
Bedrock Geology



SOURCES OF INFORMATION

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



Quadrangle Location

SCALE 1 : 24,000

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

CONTOUR INTERVAL 20 FEET

TRUE NORTH

Topographic base from U.S. Geological Survey Portland West 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.

INTRUSIVE ROCKS

Mesozoic (probably Jurassic)

Dark gray to black intrusive rocks. Diabase and basalt dikes.

Devonian (and/or younger)

Dg — Granite and granite gneiss. Fine- to medium-grained, massive to moderately foliated biotite-muscovite granite with minor garnet, and minor massive to slightly foliated pegmatite with biotite, muscovite, garnet, and locally schorl.

Devonian (or older)

Dmd — Strongly foliated hornblende-plagioclase-biotite metadiorite.

Silurian - Ordovician

SOa — Amphibolite (metamorphosed mafic dike?).

Overprint pattern indicates areas of extensive injection by granite pegmatite stringers, northwest of Flying Point fault.

STRATIFIED ROCKS

Silurian - Ordovician

CENTRAL MAINE SEQUENCE

SOhc — **Hutchins Corner Formation**. Fine-grained medium gray migmatized quartz-plagioclase-biotite gneiss with minor thin interlayers of medium light greenish gray calc-silicate granofels or gneiss.

MERRIMACK GROUP

SOb — **Berwick Formation**. Fine-grained medium gray migmatized and non-migmatized quartz-plagioclase biotite gneiss and granofels with minor light medium gray calc-silicate gneiss or granofels.

SOe — **Eliot Formation**: Fine-grained buff-weathering, medium-gray quartz-plagioclase-biotite phyllite with abundant carbonate at lowest grades, calc-silicate minerals (clinozoisite, sphene, diopside, and rarely grossular) at higher grades of metamorphism; with interlayered dark gray phyllite. Formation is strongly sheared throughout.

Middle Ordovician

CASCO BAY GROUP

Oj — **Jewell Formation.** Rusty- and non-rusty-weathering biotite-garnet muscovite phyllite. (No outcrop in this quadrangle; description from exposures in adjacent quadrangles).

Osk — **Spurwink Metalimestone.** Gray fine-grained, ribbony-bedded metamorphosed limestone (generally too fine-grained to be characterized as a marble in hand specimen) with interlayers of biotite-quartz-plagioclase phyllite.

Osc — **Scarboro Formation.** Rusty- and non-rusty weathering biotite-muscovite-garnet-quartz phyllite with rare quartz-plagioclase-biotite phyllite interbeds.

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

Odi — **Diamond Island Formation.** Distinctive strongly sheared dark gray to black, non-bedded quartz-muscovite-graphite-pyrite phyllite, usually showing thin veinlets of quartz. Pyrite occurs as euhedral cubes and as thin streaks parallel to foliation.

Osp — **Spring Point Formation.** Medium greenish gray actinolite-biotite-chlorite-plagioclase-quartz schist and amphibolite. Some light gray plagioclase-quartz-biotite granofels is known from borings, but is not presently exposed.

Oce — **Cape Elizabeth Formation.** Fine-grained medium gray quartz-plagioclase-muscovite-chlorite-biotite-garnet phyllite and dark gray muscovite-chlorite-biotite-garnet phyllite.

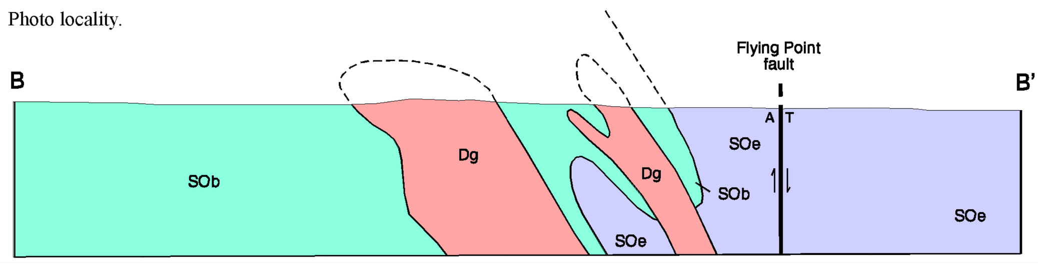
EXPLANATION OF SYMBOLS

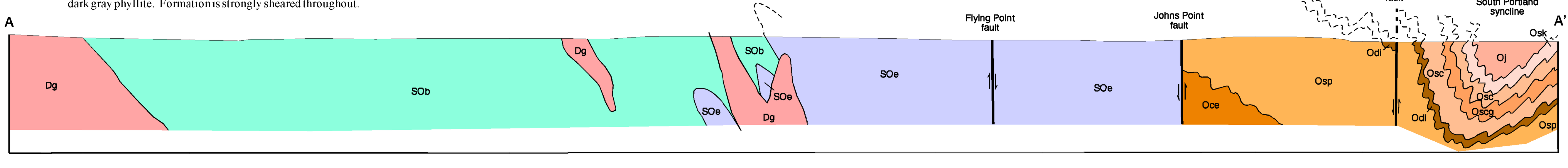
- Outcrop of metamorphic rock or non-foliated plutonic rock.
- Outcrop of foliated plutonic rock.
- Strike and dip of compositional layering. (inclined, vertical, horizontal)
- Strike and dip of gneissic foliation. (inclined, vertical)
- Foliation in granites. (inclined, vertical)
- Direction and angle of inclination of lineations. (plunging, horizontal)
- Stratigraphic or intrusive contact.
- Fault. Arrows indicate sense of motion. U = upthrown block; D = downthrown block.
- Nomenclature boundary between rocks assigned to the Merrimack Group and rocks assigned to the Central Maine sequence.
- 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.)





Portland West Quadrangle, Maine

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

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Open-File No. 03-94
2003
This map accompanied by a 13 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.

MAJOR ROCK TYPES

The stratified, or layered, rocks of the Portland West 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 texture 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 West 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, composed of coarse angular blocks of volcanic breccia and fine volcanic ash with crystals of quartz and feldspar. This formation is not exposed in the Portland West quadrangle, but is well exposed along the shore in the vicinity of Portland Head Light in the adjacent Portland East quadrangle. These rocks formed as hot lava erupted on an ancient ocean floor and became fragmented upon contact with the cold ocean water. As volcanic activity ended, shale and siltstone of the Cape Elizabeth Formation (Photo 1) accumulated conformably on top of the volcanic pile. A period of renewed submarine volcanism ensued, depositing basaltic and andesitic ash and breccia of the Spring Point Formation (Photo 2). In places, black shale of the Diamond Island Formation (Photo 3), 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.

The Merrimack Group is represented in the Portland West quadrangle by the Eliot and Berwick Formations, a sequence of metamorphosed calcareous siltstone and shale. The best exposures of the Eliot Formation occur in the area of Exit 7A of the Maine Turnpike in South Portland. Here the formation consists of thin-bedded, highly sheared alternations of light buff-gray calcareous metasiltstone and dark gray phyllite (Photo 4). Across the Fore River in Portland, these same rocks have been metamorphosed to higher temperature, producing green amphibole and epidote in the calcareous rocks (Photo 5). Rocks assigned to the Berwick Formation occupy the largest part of the Portland West quadrangle. These rocks are brownish gray granofels with interbeds of greenish gray gneiss and granofels (Photos 6 and 7). They are hard, making them suitable for durable rock aggregate such as is produced at the Blue Rock Quarry (Photo 8) between Portland and Westbrook. Rocks of both the Eliot and Berwick Formations are interpreted to be deep ocean sediments deposited during Late Ordovician to Early Silurian time.

The Central Maine sequence, deposited during Late Ordovician to Early Silurian time, consists of highly metamorphosed calcareous and non-calcareous sandstone and siltstone of the Hutchins Corner Formation. These rocks were extensively injected by magma, now preserved as conformable layers of light-colored granite and pegmatite. The Hutchins Corner Formation is correlated with the Berwick Formation of the Merrimack Group.

DEFORMATION, METAMORPHISM, FAULTING, AND IGNEOUS INTRUSION

Rocks of all the stratified sequences were complexly folded during a period of major regional deformation 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. 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; sandstone and siltstone 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 into the adjacent rocks forming the large body of granite in the northwestern quarter of the Portland West quadrangle (Photo 9) and lens-shaped bodies in the northern part of the City of Portland (Photo 10). Some of the magma was injected in cross-cutting cracks and cooled to form dikes of a very coarse-grained granite known as pegmatite (Photo 11).

After the Acadian orogeny the rocks of the quadrangle were subjected to major faulting and shearing while still deep in the Earth's crust (Photo 12), 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 Fore River, South Portland, and Flying Point 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. 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. Dark gray garnet phyllite of the Cape Elizabeth Formation, exposed in small rock quarry in the Thornton Heights area of South Portland, just south of Long Creek.

Photo 2. Metamorphosed andesitic ash of the Spring Point Formation exposed beneath the on-ramp for the Casco Bay Bridge, Portland.

Photo 3. Black phyllite of the Diamond Island Formation off Highland Avenue, South Portland.

Photo 4. Highly sheared interlayered light gray calcareous phyllite and dark gray phyllite of the Eliot Formation, exit 7A area of the Maine Turnpike, South Portland. Glacially scoured surface of the exposure shows well-preserved glacial striations of the last episode of glaciation, approximately 14,000 years ago.

Photo 5. Exposure of sheared Eliot Formation between Fore River and Brighton Avenue, Portland. These rocks are of intermediate grade of metamorphism in which green amphibole and epidote are present.

Photo 6. Exposure of the Berwick Formation, injected by granite and pegmatite, in the Morrills Corner area of Portland.

Photo 7. Close-up view of typical Berwick rock type at same locality as Photo 6. Purplish gray bands have quartz, plagioclase feldspar, and biotite. Green bands (originally calcareous beds) have quartz, feldspar, diopside, hornblende, and epidote.

Photo 8. Blue Rock quarry between Westbrook and Portland. Biotite granofels of the Berwick Formation is quarried here for crushed rock aggregate. The Maine Turnpike is just out of sight on the left side of the photograph.

Photo 9. Westbrook granite gneiss exposed in Shaw Brothers Quarry on the east side of Methodist Road near the northwest corner of the Portland West quadrangle. Note the well-developed glacially produced crescentic gouges.

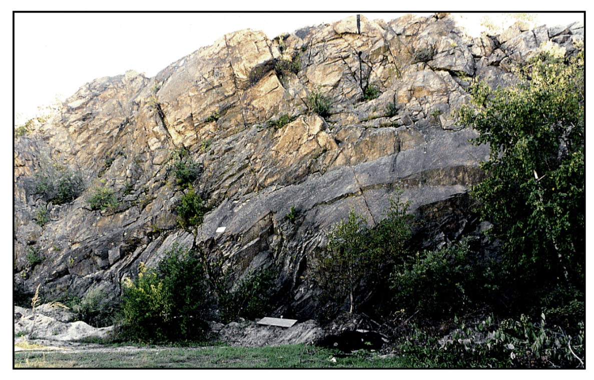

Photo 10. Granite gneiss and pegmatite exposed in Rocky Hill Quarry, Portland. Note the well-developed west-dipping joints.

Photo 11. Cross-cutting dike of granitic pegmatite cutting granodiorite of the Westbrook pluton, same locality as Photo 9.

Photo 12. Highly sheared rocks of the Eliot Formation near Exit 7A, Maine Turnpike. Asymmetric lens-shaped phyllite in center of photo indicates a component of right-lateral shearing associated with deep-seated faulting of the Norumbega fault zone in Late Carboniferous to Permian time.