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TRIP C-6

THE STRUCTURAL AND STRATIGRAPHIC DEVELOPMENT OF THE CASCO BAY GROUP AT HARPSWELL NECK, MAINE

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INTRODUCTION

This field trip provides the opportunity to examine in detail the lithologic, textural and structural variations within the Casco Bay Group formations at a single area, Harpswell Neck (Figure 1). Regional stratigraphic and structural relations throughout the Casco Bay are beyond the scope of this field trip guide. The overall structure and lithologies were originally described by Hussey (1971) as part of the geology of the Orrs Island quadrangle. Detailed structural and lithologic mapping within this original framework was conducted by Swanson and Pollock during summer field camp excercises 1983-86.

STRATIGRAPHY

The lithologies within the Harpswell Neck area include representatives from the entire stratigraphic sequence of the Casco Bay Group, exclusive of the Cushing Formation. Table 1 summarizes the representative lithologies and the stratigraphic sequence. The exposed anticlinal structure on Barnes Island is regionally important in establishing the stratigraphic sequence of the Casco Bay Group. All contacts are sharp and conformable. The Cape Elizabeth - Spring Point contact is locally gradational over distances of 30 - 40 cm. The lithologies observed here are typical of these formations elsewhere. However, the exposed thicknesses exhibit wider ranges than other areas in the Casco Bay due to textural and structural

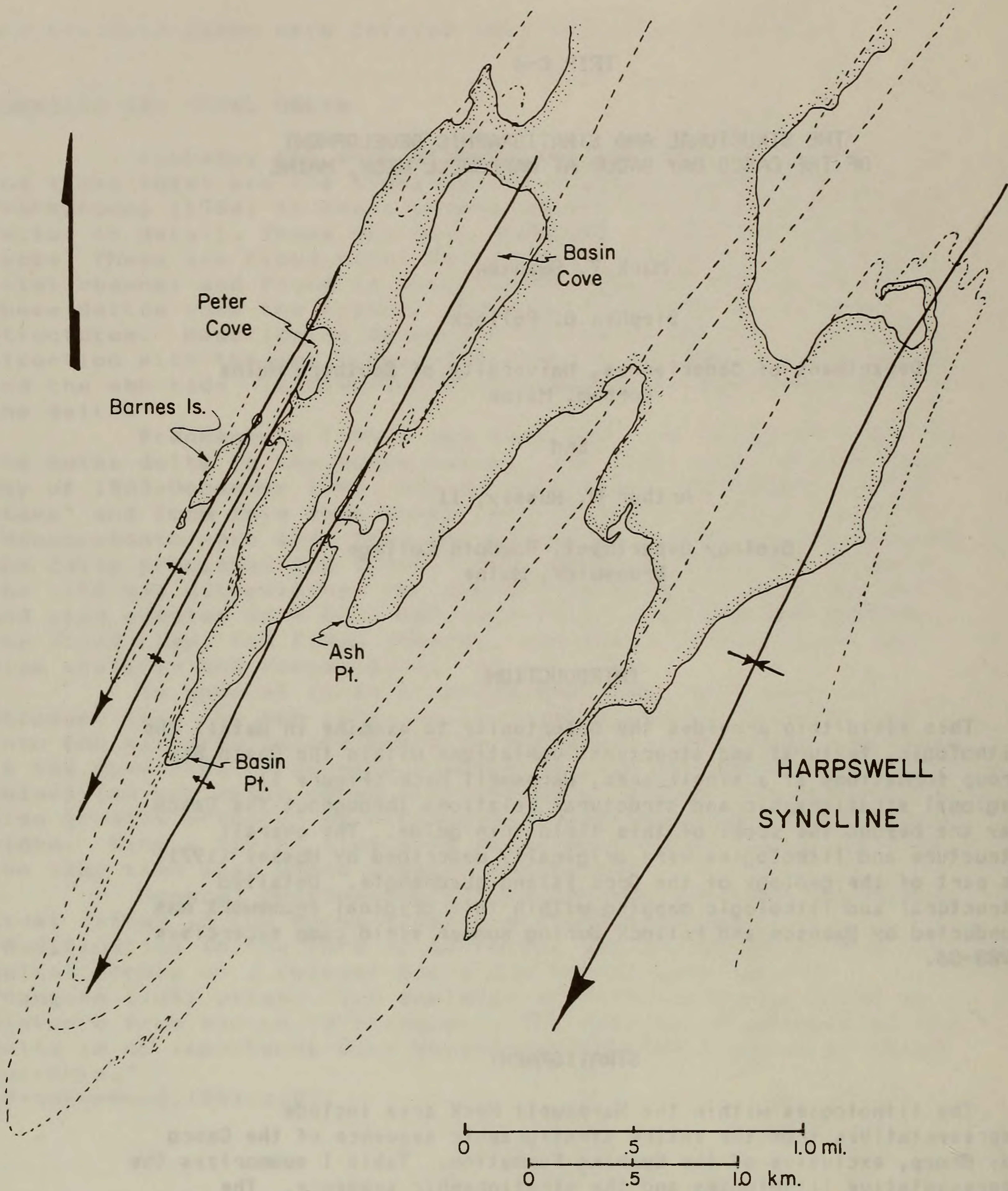

FIGURE 1: Regional structure of the Harpswell Neck area depicted as tight SW-plunging F2 folds. Field trip guide covers the NW shore of Harpswell Neck from Peter Cove to Basin Point and adjacent Barnes Island (after Hussey, 1971).

TABLE 1 - Summary of the stratigraphic relations and representative lithologies of the Casco Bay Group at Harpswell Neck

FORMATION	MAJOR LITHOLOGIES	MINOR LITHOLOGIES
JEWELL FORMATION	Muscovite biotite schist with abundant quartz vein boudins	
SPURWINK METALIMESTONE	Very fine grained medium dark gray, rusty weathering, biotite quartz pyrite chalcopyrite metalimestone	biotite quartzite calcareous biotite quartz schist calcsilicate quartzite
SCARBORO FORMATION	Fine grained medium dark gray to greenish gray muscovite biotite garnet quartz schist with thin discontinuous laminae and beds of muscovite biotite quartzite. Plagioclase quartz biotite magnetite schist.	amphibolite
DIAMOND ISLAND FORMATION	Very fine grained, dark gray to grayish black rusty, yellow and yellow-orange weathering, quartz graphite muscovite schist. Abundant thin (2mm) quartz veins parallel to schistosity.	
SPRING POINT FORMATION	Dark gray to grayish black, thin bedded, fine to coarse grained biotite garnet amphibolite Biotite garnet amphibole quartz plagioclase schist.	Fine grained, light gray quartz plagioclase biotite garnet amphibole gneiss and schist
CAPE ELIZABETH FORMATION	Very fine grained, light to dark gray, thin bedded muscovite biotite quartz feldspar +/- garnet schist. Very fine to fine grained light to dark gray, thin to medium bedded feldspathic muscovite biotite quartzite.	Calcsilicate gneiss and amphibolite.

modification and attenuation associated with the regional deformation.

The Casco Bay Group exposed at Harpswell Neck includes the Cape Elizabeth, Spring Point, Diamond Island, Scarboro, Spurwink and Jewell Formations. The units at Harpswell Neck exhibit very wide ranges in thicknesses, and in general, are much thinner than elsewhere in the Casco Bay area.

Jewell Formation - The Jewell is the most poorly exposed of the formations which crop out here. It is exposed at low tide within a small parasitic synclinal core between Barnes Island and the mainland. The Jewell, as observed here is a muscovite, biotite schist with abundant secondary quartz vein boudins.

Spurwink Metalimestone - The Spurwink is a fine-grained, medium dark gray quartz muscovite biotite metalimestone. Pyrite and chalcopyrite are locally important. Textures range from sugary granoblastic to schistose and gneissose. Layering is generally thin (< 10 cm). Fish-mouth boudin structures are common. Overlying the metalimestone lithologies are thin (10 cm) to medium (30 cm) bedded quartzites with biotite and calcsilicate minerals.

Scarboro Formation - The Scarboro is a lithologically complex unit. Two lithologies are predominant. These are: 1) a poorly bedded or layered, very fine grained to fine grained muscovite, biotite garnet quartz schist with thin discontinuous laminae and beds of muscovite biotite quartzite and 2) a plagioclase quartz biotite magnetite muscovite schist. The latter occurs on the west side of Barnes Island stratigraphically above the former. In addition to these two major lithologies, thin beds of amphibolite are present. Stratigraphically, these are most common between the two dominant rock types observed here. Macroscopic textures of the Scarboro are distinctive. Thin discontinuous laminae of quartz and feldspar are common. These are locally observed as the noses or hinges of very small scale limbless folds. The origin of these is uncertain, but they may be interpreted to represent felsic blastopyroclasts within a meta-lithic tuff.

Diamond Island Formation - The Diamond Island is a fine to medium grained, dark gray to grayish black quartz graphite muscovite schist. The unit is characterized by rusty, yellow and yellow-orange weathering. Textures are uniform. Foliation is well developed. Thin (< 2mm) discontinuous quartz lamellae are abundant and parallel regional schistosity. Bedding is not observed within the Diamond Island. This unit exhibits extreme variation in thickness here. At the type locality at Spring Point in Portland, it is 35 m thick. At Harpswell Neck thicknesses range from 1 m to an inferred stratigraphic thickness of approximately 62 m in a synclinal core at Peter Cove.

Spring Point Formation - At Harpswell Neck the Spring Point is easily recognized by its prominent, thin (2 - 15 cm), and compositionally distinctive bedding. The Spring Point exhibits a wide range of textures ranging from very fine to coarse grained. Rock types of individual beds range from amphibolites to schists and gneisses. Minerals and mineral proportions are variable, bed by bed. The amphibolite mineralogies may include, in varying proportions, anthophyllite, cummingtonite, hornblende, plagioclase, biotite, quartz and garnet. The schists and gneisses may include plagioclase, quartz, biotite, garnet, hornblende and muscovite.

Cape Elizabeth Formation - The Cape Elizabeth is the lowest formation in the Casco Bay sequence that will be observed today. The

Cape Elizabeth is predominantly thin bedded (2 - 30 cm). Bedding is variably developed. Outcrops may exhibit either poorly preserved or well preserved beds of alternating lithologies. Alternating lithologies include: 1) muscovite, biotite, plagioclase, quartz, +/- garnet schist and 2) feldspathic muscovite biotite quartzite. Additionally, the schistose beds contain chlorite porphyroblasts which cross cut the dominant S2 schistosity. Sizes of these porphyroblasts range from less than 1 x 3 mm to 3 x 8 mm. These appear to be randomly distributed on the S2 surface. However, careful observation may indicate that they are aligned within three separate, weakly developed lineations on the S2 surface. These three weak lineations are not always observable on the same schistosity surface. A third rock type observed within the Cape Elizabeth is granoblastic or gneissose calcsilicates. These occur as thin beds (< 30 cm) or boudins.

METAMORPHISM

The lithologies at Harpswell Neck have been subjected to two metamorphic events. The first is a regional prograde event of the low pressure facies series type. The second is a retrograde event. The first prograde event metamorphosed the lithologies at Harpswell Neck to the andalusite-staurolite zone. The retrograde event was to the chlorite zone. One of us (A.M.H., 1971) mapped the regional prograde isograds. The staurolite-andalusite isograd is to the southwest of the field trip area, while the staurolite-sillimanite isograd is to the northeast. Garnet is the only metamorphic index mineral from the first metamorphic event that has been observed, to date, in the exposures examined on this trip. Both staurolite and andalusite have been observed in appropriate lithologies elsewhere (Hussey, 1971). The second retrograde event produced chlorite porphyroblasts which cross cut the S1 schistosity. These are generally small, but porphyroblasts to 3 x 8 mm have been observed in schists of the Cape Elizabeth. The Cape Elizabeth Formation contains the best developed macroscopic evidence of this retrograde event. However, careful observation of the Spring Point and Scarboro Formations will disclose small chlorites which cross cut the S2 schistosity. This retrograde event may be related to the later phases of deformation. The chlorites have also grown across crenulations (F3) and their associated schistosity (S3). Undeformed chlorite porphyroblasts are also observed within sheared Cape Elizabeth lithologies at out-of-sequence contacts. This sheared, metamorphosed contact is between the Diamond Island and Cape Elizabeth lithologies along the NW shoreline of Harpswell Neck.

The age of the prograde metamorphism is interpreted to be Acadian (Osberg, Hussey and Boone, 1985). Thompson and Guidotti (1986) indicate that metamorphism of Carboniferous age affected much of southern Maine. It may be speculated that the retrograde metamorphism is related to the Carboniferous event. Conclusive documentation, is however, lacking at this time.

STRUCTURE

The overall structure of the Harpswell Neck area as illustrated

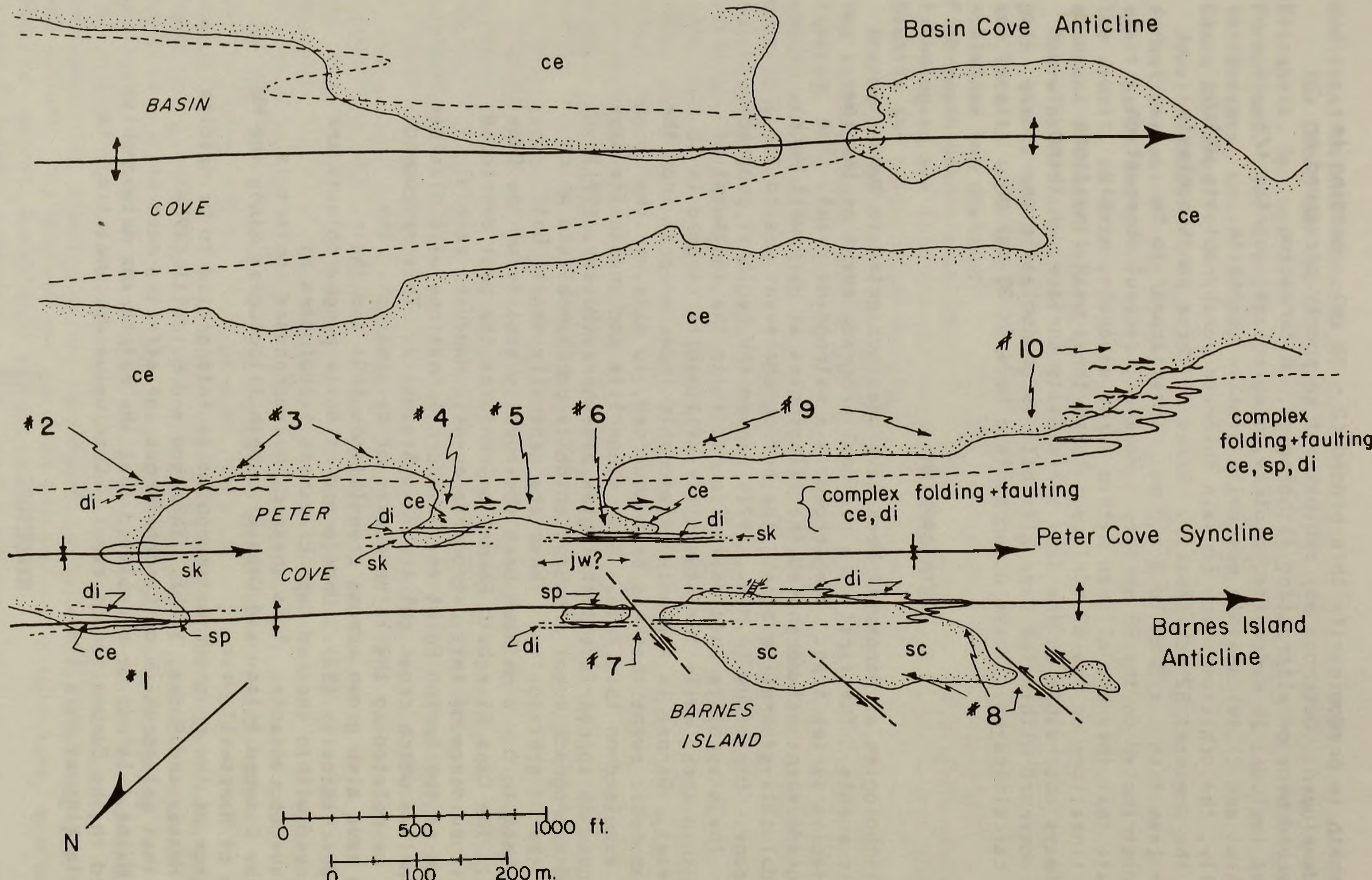

FIGURE 2: Geology and field trip localities for the NW coast of Harpswell Neck from Peter Cove to Barnes Island. All foliations and lithologic contacts are near-vertical and NE-trending.

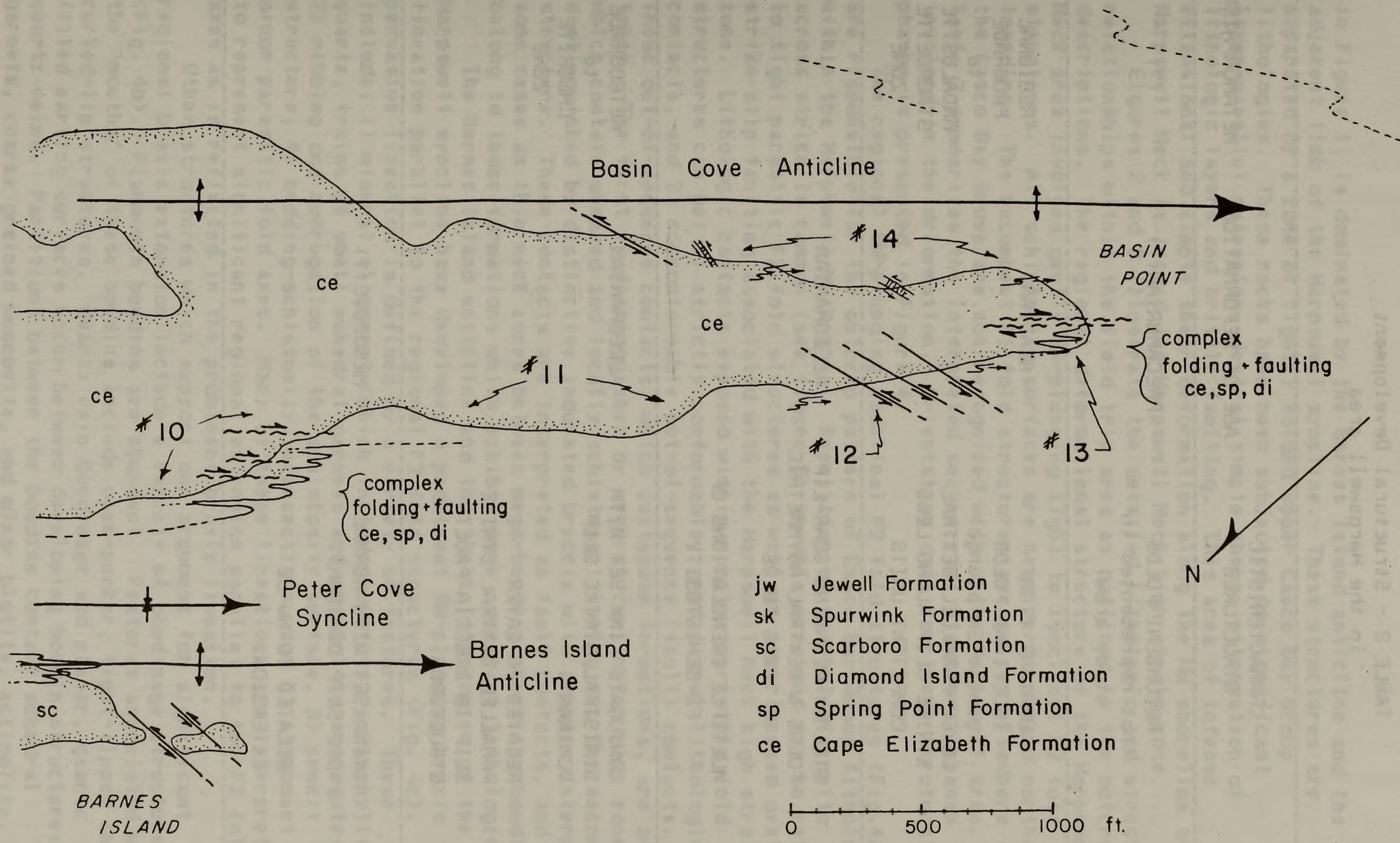

FIGURE 3: Geology and field trip localities for the NW coast of Harpswell Neck from Barnes Island to Basin Point. All foliations and lithologic contacts are near-vertical and NE-trending.

TABLE 2 - Structural Development in the Harpswell area

STRUCTURAL EVENT	CHARACTERISTIC STRUCTURES	AGE OF DEFORMATION	METAMORPHISM
F1	RECUMBENT FOLDS (not represented in study area)	PRECAMBRIAN(?)	(?)
F2	UPRIGHT TIGHT-ISOCLINAL FOLDS (gentle SW plunge) LAYER-PARALLEL DEXTRAL STRIKE SLIP ALONG LESS COMPETENT UNITS	ACADIAN	REGIONAL PROGRADE to ANDALUSITE STAUROLITE ZONE
F3	STEEPLY PLUNGING SCAR-LIP FOLDS & DEXTRAL ASYMMETRIC DRAG FOLDS MULTIPLE CRENULATIONS OF F2 SCHISTOSITY	ALLEGHANIAN	-
F4	CONJUGATE KINK SET WITH SINISTRAL STRIKE SLIP DOMINANT. RELATED TO LAYER PARALLEL DEXTRAL STRIKE SLIP IN BRECCIA FAULT STRUCTURES.	ALLEGHANIAN	RETROGRADE to CHLORITE ZONE
F5	KINK SET WITH NORMAL DIP SLIP DOMINANT. RELATED TO NW-SE EXTENSION.	MESOZOIC(?)	-

in Figure 1, is dominated by the Barnes Island anticline and the adjacent limb of the Harpswell syncline. These structures are separated by a zone of tightly folded upper Casco Bay Group lithologies. These rocks have been subjected to significant layer-parallel extension, dextral simple shear, attenuation of lithologic layers and brittle faulting. This area of intense extensional and simple shear deformation along the NW shoreline of Harpswell Neck is termed the Harpswell Neck high strain zone.

Figures 2 and 3 illustrate the detailed lithologic and structural relationships within the field trip area as outlined in the outcrop descriptions. The regional deformational structure of the Harpswell Neck area involves gently SW-plunging tight to isoclinal F2 fold structures. All schistosity surfaces are near vertical and northeast trending. The recumbent F1 fold structures recognized elsewhere in the Casco Bay Group are not recognized within the Harpswell area. Table 2 summarizes the interpreted sequence of structural phases involved in the deformation. Orientation data for these strutural phases is presented in Figure 4.

The regional SW-plunging isoclinal F2 fold structures (Fig.4a) are responsible for the outcrop pattern of Casco Bay Group lithologies within the Harpswell Neck area. Repetition of lithologic units across strike is common (see figure 5) in this area and can be related to tight parasitic F2 fold structures as well as superimposed dextral strike-slip faulting associated with the Harpswell Neck high strain zone. Lithologic contacts exposed within complex parasitic fold structures can be: 1) strictly conformable, gradational lithologic contacts, and 2) nonconformable out-of-sequence (fault) contacts. These out-of-sequence contacts, which juxtapose formations, are of two types. The first is distinguished by several centimeter wide zones which contain sheared and locally schistose lithologies. The second is distinguished by distinctive indurated breccia with complex internal structure. These contacts are interpreted as fault contacts, and in some cases as thin neck zones between mega-boudins where the boudins belong to those formations which exhibit more competent lithologies.

The Barnes Island anticline and the flank lithologies of the Harpswell syncline have developed a prominent SW-plunging b-axis lineation parallel to the regional F2 fold structures (Fig. 4c). This pervasive lineation is defined by a variety of features. These include: 1) mineral alignment (which includes biotite, anthophyllite, quartz, trains of small euhedral garnets and chert-like aggregates), 2) ribbing and corrugation of the schistosity surface, 3) pencil structure, 4) bedding-schistosity intersections, and 5) alignment of minor parasitic fold axes. Many of these lineations are interpreted to represent significant regional extension parallel to the F2 fold axes as is reflected in the prominent b-axis lineation.

Other structures which support our argument for significant regional b axis extension include a variety of boudinage structures (Fig. 4b). Fishmouth boudins are abundant. Features associated with the "mouths" of these boudins include open-pucker, tight-lipped and curled-lip structures. Quartz vein boudinage and planar, quartz filled parting surfaces occur between developing boudin structures and quartz veins. Partitions between the boudins contain euhedral garnets, coarse grained muscovite, and minor biotite, actinolite, quartz and calcite. These euhedral porphyroblasts as part of the

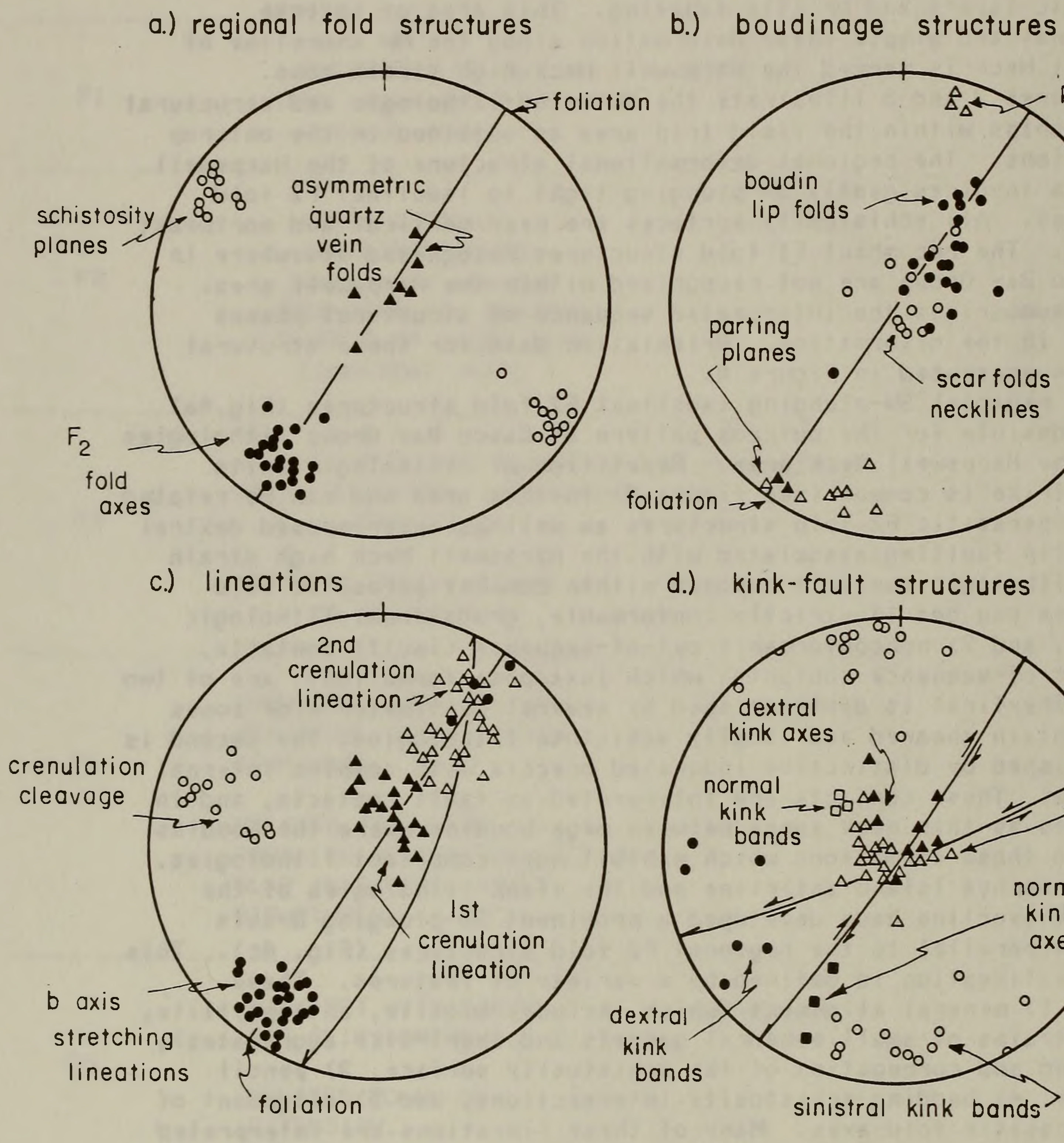

FIGURE 4: Stereographic projection (lower hemisphere) of structural data for the Harpswell Neck area. Structures plotted as planes (foliations, cleavage, faults), poles to planes (schistosity, crenulation cleavage, quartz veins, boudin parting planes, and kink bands) and lineations (fold axes, neck lines, kink axes and intersection lineations).

boudin partition mineralization suggests a temporal relationship between the regional prograde metamorphism and the development of the prominent b-axis lineations. The development of distinctly asymmetric foliation and quartz vein boudinage and segmented vein boudinage suggest strong layer-parallel dextral shear, a well as extension. This is particularly evident along the NW coast of Harpswell Neck through Peter Cove.

This zone of high extensional and dextral shear strain accommodation also contains both ductile (syn-metamorphic) and brittle faults. This assemblage of ductile and brittle structures represents a distinctive feature within this portion of Casco Bay, here termed the Harpswell Neck high strain zone. Brittle faults exhibit asymmetric shear zone fabrics and textures. Both types of faults document a long history of deformation. In addition to the faults, prominent dextral z-shaped quartz boudins, dextral offset quartz veins and structures within outcrop-scale brittle faults serve as the kinematic indicators which suggest that this was a broad zone of dextral shear strain.

The regional b-axis extension and layer-parallel ductile dextral shear produce steeply-plunging asymmetric folds (F3) and associated structures that clearly deform the F2 axial surfaces. These folds consist of lip folds and scar folds associated with the boudinage and asymmetric folded quartz veins and boudins as well as z-shaped asymmetric intrafolial folds many of which contain an oblique axial plane crenulation cleavage expressed as lineations on the schistosity surfaces. Exposures exhibit several possible sets of crenulations. These are expressed as multiple lineations on the S2 schistosity surfaces of the more micaceous units, particularly within the Cape Elizabeth Formation (Fig. 4c).

The F4 fold structures consist of brittle steeply-plunging kink folds and kink bands, of both dextral and sinistral sense, which have a direct spatial association with numerous EW-trending sinistral strike-slip faults and layer-parallel dextral strike slip faults that cut both the Barnes Island and Harpswell Neck exposures. These faults and kinks are interpreted to be a coherent structural assemblage associated with the later deformation history of the Harpswell Neck high strain zone.

The F5 structures include an additional set of kink bands with horizontal fold axes (Fig. 4d). These kink structures are interpreted to express a NW-SE extension most likely associated with Mesozoic tectonic events represented within the study area by a single basalt dike exposed along the NW shoreline of Harpswell Neck and minor NE-trending normal fault structures.

REGIONAL CORRELATIONS

The Barnes Island anticline illustrates the clear stratigraphic succession of the Cape Elizabeth, Spring Point, Diamond Island and Scarboro Formations within the Casco Bay Group. Significant shear and/or extensional strain has been superimposed on all lithologies as represented by asymmetric structures and fabrics and the prominent b-axis elongation lineation. There is a close spatial and temporal association between the SW-plunging regional F2 fold structures and the regional extension. These structures may be related to the deformational history of the Casco Bay formations within the regional Norumbega fault system as a series of originally en echelon fold structures. These F2 folds have been tightened to upright isoclinal structures and sheathed by regional extension and dextral shear strain associated with the Norumbega fault system.

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ITINERARY

ASSEMBLY POINT: Basin Point at Dolphin Marina, Harpswell Neck. From Brunswick, take Route 123 (Harpswell Road) south for approximately 12 miles. Turn right onto Ash Point Road at signs for Dolphin marina and an elementary school. Take next right onto Basin Point Road following signs to Dolphin Marina. Enter marina and proceed through boatyard to grassy area at Basin Point. Time : 8:00 A.M. The group will then proceed to the first outcrop. Access to the exposures is dependant on the tidal cycle. Because of this it may be necessary to visit the exposures in a sequence different from that listed below.

See Figures 2 and 3 for outcrop location. All schistosities are NE trending and near vertical within the field trip area.

LOCALITY 1: Anticlinal core axis at northwestern end of Peter Cove.

This exposure represents the deepest section of the gently SW-plunging Barnes Island anticline. Formations present here include

Cape Elizabeth, Spring Point and Diamond Island. The Cape Elizabeth consists of thin to medium beds of quartzite or quartz mica schist. These quartzites are exposed within the northernmost hinge zone of the Barnes Island anticline. Conformably overlying the Cape Elizabeth Formation is the Spring Point Formation. Spring Point lithologies include well bedded very fine to coarse grained, amphibolites, schists and gneisses. The more common lithologies include anthophyllite garnet plagioclase quartz amphibolites, biotite garnet plagioclase quartz schists, and plagioclase quartz biotite schists. Minor asymmetric folds, within the Spring Point, can be seen on both limbs of this well-defined SW-plunging anticlinal structure. Trains of euhedral garnets are locally observed to produce both "b" and "a" lineations. A conformable contact between the Spring Point formation and the overlying Diamond Island Formation is exposed on the SE limb of the anticline adjacent to Peters Cove. The Diamond Island is also exposed as a 30 cm wide layer within the core of a small parasitic syncline, also on the southeastern limb of the anticline.

Approximately 125 m of the Diamond Island Formation is linferred to be present under the beach at Peter Cove. A small outcrop of silicified metalimestone crops out in the middle of the beach area. This represents the Spurwink Metalimestone. The presence of Spurwink, combined with the unusual thickness of the Diamond Island suggest to us that the Peter Cove beach area, and Peter Cove is underlain by the thickened nose of a SW-plunging F2 syncline.

LOCALITY #2: Peter Cove fault zone-

Two types of faults are present here. One is interpreted as a pre or syn-metamorphic fault, the other is a post retrograde brittle fault.

The first fault produces an out-of-sequence contact between Diamond Island and Cape Elizabeth lithologies. Note that the Spring Point Formation which was well exposed on the opposite side of the beach is completely missing here. The contact between the Diamond Island and Cape Elizabeth is sharp and parallels the regional schistosity. There is no apparent gouge or breccia. Later today we will have the opportunity to examine this same fault where 20 cm thick boudins of Spring Point separate the Diamond Island from the Cape Elizabeth.

The post retrograde metamorphic fault is exposed as a meter-wide zone of indurated fault breccia. The breccia consists of Diamond Island lithologies. This fault zone is located near the base of the cliff at the northeastern end of Peter Cove. This NE-trending fault breccia zone is developed parallel to the foliation in the adjacent Cape Elizabeth and Diamond Island lithologies. Additional exposures of the same fault zone will be examined along strike to the SW. This fault represents a late brittle layer-parallel dextral strike-slip fault of limited displacement. This fault is within 2 m of the previously faulted out-of-sequence contact between the Cape Elizabeth and Diamond Island Formations. Kinematic indicators in this brittle fault exposure include subhorizontal slip lineations along breccia fragment surfaces, internal minor dextral strike slip surfaces, and small-scale drag folds and high-angle kink structures.

LOCALITY #3: Cliff exposures along shore of Peter Cove-

High-standing cliffs consisting of muscovite quartz schists, muscovite quartzites and calcsilicates of the Cape Elizabeth Formation are exposed along this traverse. The Cape Elizabeth exhibits a well-developed SW-plunging b-axis elliptical or ovoid lineation on the near-vertical axial plane (F2) schistosity. These chert-like ellipses or ovoids consist of very fine grained (cryptocrystalline) material which appears opaque in thin section.

Planar quartz veins, oblique-boudined quartz veins and puckered fishmouth foliation boudinage with accompanying asymmetric scar folding can be observed locally. Steeply-plunging crenulation lineations within the near-vertical schistosity are well developed as intersection lineations of an oblique crenulation cleavage associated with moderately NE-plunging z-shaped minor F3 folds.

Along this traverse the faulted contact between the Cape Elizabeth and Diamond Island Formations is again exposed. This interpreted fault structure consists of a broad zone of sheared lithologies and abundant boudined quartz veining. Sheared Cape Elizabeth lithologies contain fine-grained, blackish, chert-like, elliptical to rod-shaped features, as well as flattened garnet porphyroblasts. Spring Point lithologies may be preserved as minor remnants within the sheared contact zone.

LOCALITY #4: Silicified marble with sulfide mineralization-

This unusual lithology is interpreted to represent the Spurwink Metalimestone. Lithologies consist of a rusty-weathering silicified impure marble with abundant sulfide (pyrite and chalcopyrite) mineralization. The marble exhibits well-developed pucker and open-fishmouth foliation boudinage. The prominent sulfide mineralization occurs as a partition mineralization along with quartz and coarse grained muscovite. The sulfides also occur as cross-cutting veins and as a disseminated intergranular components within some horizons. This lithologic unit is flanked on both sides by the Diamond Island Formation. These out-of-sequence contacts between the Spurwink and the Diamond Island (Scarboro is missing) and between the Diamond Island and Cape Elizabeth formations (Spring Point missing) can be explained by faulting and/or large-scale boudinage to account for the missing Scarboro and Spring Point lithologies.

LOCALITY #5: Black graphitic and muscovite quartz garnet schists-

This series of outcrops consists of well-bedded muscovite quartz feldspar garnet schists of the Cape Elizabeth Formation and blackish quartz graphite muscovite schists of the Diamond Island Formation. These lithologies are interpreted as lithotectonic units in out-of-sequence formational contact. These contacts show significant layer-parallel extension and dextral shear which is represented by symmetric and asymmetric foliation and quartz vein boudinage. Some boudinage of the quartz vein material has produced flow folding (scar folding) of the schistose host into the separation zone between boudin segments. Several scar folds are Z-shaped and locally develop their own axial plane cleavage. Several steeply-plunging asymmetric Z-shaped quartz vein folds are exposed. These support a dextral, non-coaxial simple shear strain history for the Harpswell Neck high strain zone.

Contacts between the Cape Elizabeth and Diamond Island lithologies are interpreted as faults. These faults include abundant quartz veining, boudinage and distortion of schistosity surfaces. Younger brittle strain is localized along these contacts. These younger brittle fault breccia zones are represented by the along strike continuation of the fault breccia zone in locality #2. Subhorizontal slip lineations along the breccia fragment surfaces supports a strike-slip (dextral) interpretation for this fault structure.

LOCALITY #6: End of access road to Barnes Island-

Lithologies include the blackish quartz graphite muscovite schist of the Diamond Island Formation, muscovite quartz garnet schists and micaceous quartzites of the Cape Elizabeth Formation, and a thin ductilly deformed metalimestone remnant of the Spurwink. The Jewell Formation may be present in poorly exposed low tide outcrops just offshore toward Barnes Island.

These exposures contain abundant stringers of asymmetric quartz vein boudins which generally transgress through the schistosity, and compositional layering at a slight oblique angle. This relationship would be expected for the reorientation and extension of discordant quartz veins during subhorizontal layer-parallel dextral simple shear. Distinctly asymmetric foliation boudinage within the Spurwink is also indicative of dextral strike-slip shear strain. The texture of the Spurwink Metalimestone can also be related to grain size reduction processes during ductile flow or mylonitization. A considerable amount of dextral simple shear strain has been accommodated within these lithotectonic units.

A SW-plunging mineral smear lineation is prominently developed parallel to the regional fold axes. Scar folding of the host lithologies about the boudinage is common. A single mullion structure is also developed in these exposures.

Additional layer-parallel fault structures are evident. These bring the Diamond Island into contact with the Cape Elizabeth. One of these contacts is expressed as a foliated boudined fault zone. This fault appears to contain lithologic remnants suggestive of the Spring Point Formation. This out-of-sequence contact may be the result of large-scale boudinage of the more competent Spring Point lithologies. The Spurwink itself may represent an early ductile fault or thin boudined neck which removes the Scarboro and juxtaposes the Spurwink with the Diamond Island formation.

Exposures along the backside of this small peninsula at the adjacent cove beach represent the continuation of the brittle fault breccia zone seen in the previous locations. Dextral shear strain is localized along the margins of this meter-wide limited-displacement fault zone with little internal structural development or brecciation. A conjugate set of steeply-plunging F4 kink band structures is also exposed here.

Barnes Island exposures-

LOCALITY #7: Saddle exposures and small island at NE end of Barnes Island-

The Spring Point is the dominant formation in these exposures. Rock types consist of thin beds of biotite garnet plagioclase quartz schists, anthophyllite garnet plagioclase quartz amphibolite and quartz biotite garnet schist. Locally, the fibrous anthophyllite is aligned parallel to the prominent b-axis lineation. This is interpreted to represent grain growth during regional extension. Several exposures (NE end of Barnes Island) contain recognizable bedding in parasitic folds with an accompanying axial plane schistosity. These are easily observed on the SE limb of this SW-plunging anticline.

The axis of the main Barnes Island anticline trends along the SE side of Barnes Island. The Diamond Island is approximately 1 m thick on the west limb of the anticline, and substantially thicker on the east limb. The Scarboro Formation is in excess of 50 m thick, and crops out in the center and west side of the island. These exposures constitue the NW limb of the Barnes Island anticline.

Exposures in the saddle area between the two islands contain numerous EW-trending sinistral kink structures up to a meter in width. These sinistral kinks occur in association with discrete sinistral strike slip faults. Displacements along these faults are estimated to be less than 10 m. Smaller-scale dextral kinks are also present in conjunction with minor layer-parallel dextral strike-slip surfaces. A single 3 meter wide dextral kink structure is exposed to the south of the saddle area on the eastern side of the island. These structures may be correlated with the layer-parallel dextral strike-slip faults and fault breccia zones seen in previous outcrops. An additional layer-parallel dextral strike-slip fault is exposed along the SE shoreline within the Diamond Island and Spring Point Formations.

LOCALITY #8: SW end of Barnes Island-

Lithologies in these exposures consist dominantly of thin and poorly bedded and laminated muscovite biotite quartz garnet schist and minor amphibolite of the Scarboro Formation. Tight parasitic asymmetric folds with gentle SW plunge are well developed in these exposures. The repetition of Scarboro, Diamond Island and Spring Point lithologies along the very southern end of Barnes Island is interpreted as a series of tight isoclinal parasitic fold structures. All plunges are to the southwest.

Considerable alteration and actinolite mineralization is developed within the Scarboro Formation as part of the regional b-axis extension and boudinage. Partition mineralization associated with the boudinage consists of quartz, coarse grained muscovite and biotite, chlorite, actinolite and minor euhedral coarse grained garnet. A prominent b-axis extension is expressed as strongly lineated quartz sheets that define the schistosity within the Scarboro Formation. Flattened and distinctly asymmetric magnetite porphyroblasts are developed within plagioclase quartz biotite magnetite muscovite schists of the Scarboro along the NW shoreline of Barnes Island. These flattened porphyroblasts are evidence for dextral strike-slip shear strain associated with the prominent b-axis lineation.

These exposures of the Scarboro Formation particularly along the NW shoreline contain the best developed fishmouth boudinage structures in the area. These foliation boudin structures vary from mere puckers to tight-lipped closed-mouthed pseudo-fold structures and to dramatic curled-lip fishmouth structures with steeply-plunging lip folds.

Saddle exposures between the main portion of Barnes Island and the smaller SW end of the island contain sinistral strike-slip faults and sinistral kinks similar to those observed in previous exposures. These brittle structures have controlled the morphology of the island in creating the cross-cutting topographic saddles at either end of the main island.

Harpswell Neck Exposures

LOCALITY # 9: High cliff face exposures along the NW Harpswell Neck shoreline-

The high standing cliff exposures along the NW shoreline of Harpswell Neck consist dominantly of muscovite quartz biotite garnet schist, micaceous quartzite and minor calcsilicate of the Cape Elizabeth Formation. The axial plane schistosity is well developed here and contains a prominent b-axis lineation expressed as extremely elongated fine-grained chert-like inclusions up to 30 centimeters in length. The steeply NE-plunging crenulation lineations are absent while a gently NE-plunging crenulation lineation is locally present in association with Z-shaped asymmetric minor F3 folds. A large erratic boulder of syenite is present along the shore. A single 20 cm. wide Mesozoic basalt dike has also intruded parallel to the prominent schistosity.

LOCALITY #10: Repeated lithologic units and fault slice exposures at change in trend of shoreline-

As the trend of the shoreline changes toward the SW, exposures consist of several distinctive lithologies which include representatives of the Diamond Island, Spring Point and Cape Elizabeth Formations. These lithologies are repeated across strike by minor parasitic isoclinal folding and/or layer-parallel strike-slip faulting. Both conformable gradational contacts and sheared out-of-sequence contacts can be observed in these exposures. The conformable contacts and observed minor asymmetric folds help to recognize this section as a series of SW-plunging parasitic folds on the west flank of the Harpswell syncline (see Fig. 5).

Asymmetric sigmoidal quartz boudins are preserved in these exposures. These suggest a ductile phase of dextral simple shear and/or strike-slip faulting. Several larger boudins exhibit well-developed steeply-plunging asymmetric scar folds and steeply-plunging boudin neck lines. The northwesternmost exposure of the Spring Point may represent a large-scale boudin where out-of-sequence contacts have developed between the Cape Elizabeth and

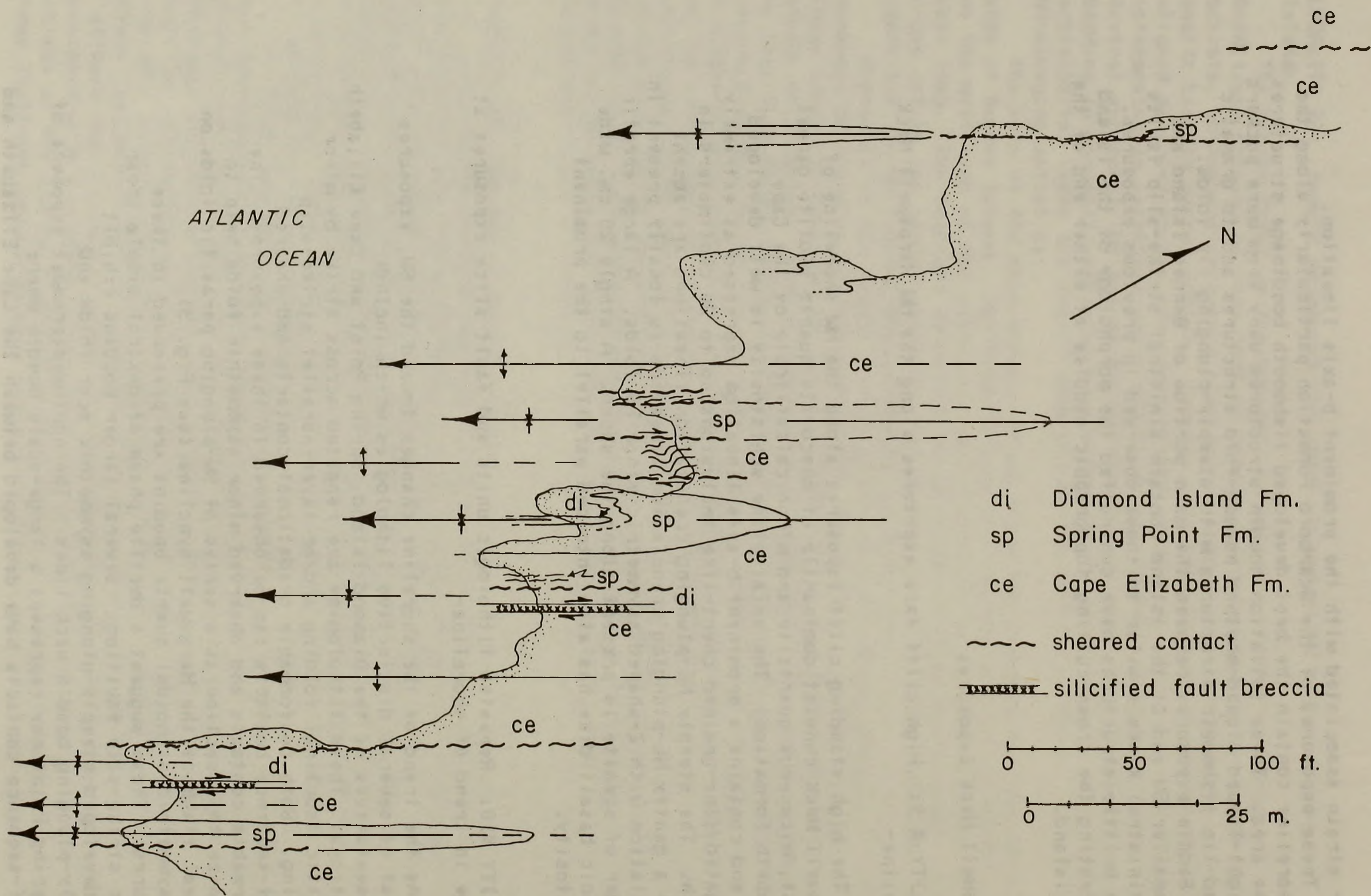

FIGURE 5: Detailed geologic map of a portion of the NW shoreline of Harpswell Neck between Peter Cove and Basin Point (Locality #10). All foliations and lithologic contacts are near-vertical and NE-trending.

the Diamond Island Formations within the neck areas of the boudins. Minor fibrous anthophyllite veins are preserved along with a distinct fibrous pull-apart texture. The aligned fibrous mineral growth and distinct dilational features are representative of the prominent b-axis extension. This extension is parallel to the regional SW-plunging F2 fold axes.

Schistose Cape Elizabeth lithologies contain abundant chlorite porphyroblasts up to 4 mm in length randomly oriented with respect to the regional F2 schistosity. Sheared Cape Elizabeth lithologies at out-of-sequence contacts with the Diamond Island Formation contain undeformed chlorite porphyroblasts. This indicates that layer-parallel faulting and/or large-scale boudin necking occurred prior to the retrograde chlorite metamorphic event.

Several out-of-sequence contacts in these exposures are marked by later layer-parallel breccia fault zones with indurated breccia, silicification, minor gouge development and complex, generally steeply-plunging internal fold structures. Quartz-filled en echelon feather fractures and steeply-plunging internal fold structures indicate dextral strike-slip faulting. One 2 meter-wide layer-parallel fault structure within the Cape Elizabeth lithologies contains steeply-plunging box fold structures similar to structures found at Basin Point.

Small centimeter-wide sinistral kinks with steeply-plunging rotation axes are developed in these exposures. A second set of kink structures with horizontal rotation axes are also represented. Minor normal faults of minimal displacement are present. These exhibit down-dip striations.

LOCALITY #11: Crenulations along the Harpswell Neck shoreline

The continuing coastal exposures along the NW Harpswell Neck shoreline consist exclusively of the Cape Elizabeth Formation. The exposed lithologies include thick-bedded quartzites, thin and poorly bedded, fine to very fine grained muscovite biotite quartz garnet schist and thin bedded calcsilicates. The quartzites exhibit well-developed S-shaped, SW-plunging F2 parasitic folds. The micaceous schists exhibit abundant boudined quartz veins and well developed crenulation lineations. These crenulation lineations occur in two sets. The dominant set is a steeply NE-plunging set that is cross-cut by the second set which plunges gently to the NE. The two sets of crenulations have developed prior to the retrograde chlorite metamorphic event. Chlorite porphyroblasts have grown across the crenulations. The crenulation lineations represent an intersection lineation that is caused by the intersection of an oblique crenulation cleavage and the F2 schistosity. The crenulation cleavage is developed axial planar to open NE-plunging Z-shaped minor F3 fold structures.

LOCALITY #12: Brittle fault exposures along NW Harpswell Neck shoreline-

The cliff exposures near Basin Point contain several well developed ENE-trending brittle sinistral strike-slip faults. These cut the Cape Elizabeth Formation. These faults appear to be preceeded by a phase of F4 sinistral kinking. Continued slip along the kink boundaries developed into discrete strike-slip faults. These faults display well developed steeply plunging drag folds, subhorizontal striations and polished surfaces. These fault zones have also been the site for gouge formation, and silicification resulting in a prominent rusty weathering appearance. Displacements along these faults are probably on the order of several meters. The cumulative displacements of these faults may substantially effect the outcrop pattern within the Harpswell Neck exposures.

Boudin structures are particularly well-developed in these exposures. Quartz vein boudinage has developed clear steeply-plunging neck lines and associated scar folds. Subhorizontal extension of some of the thicker quartzite beds relative to the more micaceous layers within the Cape Elizabeth Formation has developed rectilinear quartz partition mineralizations. Continued subhorizontal extension with an apparent ductility contrast between the more competent partition mineralization and the quartzite layers has resulted in necking of the quartzite layers about the partition. Several of these rectilinear quartz partitions appear to be arranged en echelon and can be interpreted to be segmented earlier quartz veins. These veins, up to 50 cm. in width, are disrupted by dextral layer-parallel shear. Dextral slip has been concentrated along the more ductile schistose layers producing the offset quartz pod patterns observed in these exposures.

A single large silicified boudin pod approximately 2 meters in width has also been isolated by this boudin-producing deformation. This silicified boudin pod has been necked abruptly. Similar lithologies are not present along strike in these exposures suggesting significant regional extension.

LOCALITY # 13: SW tip of Harpswell Neck at Basin Point-

At the SW tip of Basin Point a sharp axial crest of a minor anticlinal F2 fold appears to be gently folded about the steeply plunging axis of boudin related scar folds similar to those seen elsewhere on this trip.

At Basin Point, several lithologies are present. These represent the Cape Elizabeth, Spring Point and Diamond Island Formations. Several conformable contacts between the Cape Elizabeth and Spring Point lithologies are present within tight synclinal F2 folds. These SW-plunging synclines expose the younger Spring Point within the cores. The Diamond Island Formation is in apparent fault contact with the Cape Elizabeth. One of these faulted contacts is a 5 meter wide layer-parallel zone of contorted rock within the Cape Elizabeth Formation. The internal contortion involves steeply-plunging box and kink folds similar to those within fault zones at locality #10. This zone of faulted and parasitically folded lithologies may be correlated with similar structures and lithologies found farther to the NE along Harpswell Neck at locality #10 where they are now offset by the prominent sinistral strike-slip faulting described in locality #12.

LOCALITY #14: SE shoreline of Harpswell Neck-

The SE shoreline of Harpswell Neck consists exclusively of the Cape Elizabeth Formation. Lithologies are similar to those seen elsewhere in the Cape Elizabeth. These exposures exhibit well developed thin to thick beds. These lithologies exhibit well developed scar folding, quartz vein boudinage, and isolated steeply plunging quartz vein fold noses, often asymmetric and z-shaped. Large scale pencil structures are well developed here parallel to the regional SW-plunging F2 fold axes often a meter or more in length. Crenulation lineations are prominently developed in the thinner bedded units with the gentle NE-plunging set dominating. Garnet grains a observed to exhibit tails or pressure shadows of quartz. These tails or pressure shadows are commonly sigmoidal in shape suggesting crenulation or rotatation.

Dextral and sinistral centimeter-scale kinks are locally very prominent. These create distinctive chevron folds whose axes plunge subparallel to crenulation lineations. Larger-scale meter-sized kinks, planar quartz veins and sinistral strike-slip faults (one with over two meters of displacement) are also present in these exposures.