Geology of Southwestern Coastal Maine

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ABSTRACT

Southwestern Maine is underlain by 6 distinct sequences of metasedimentary and metavolcanic rocks ranging in age from Late Precambrian or Cambrian to Early Silurian. These sequences include 1) the Merrimack Group of Late Precambrian - Early Ordovician age; 2) the Casco Bay Group of Late Precambrian - Early Ordovician age; 3) the Falmouth - Brunswick sequence of Precambrian - Early Ordovician age; 4) the Kearsarge - Central Maine sequence of Early Silurian age in southwestern Maine, but ranging to Early Devonian age in the central part of the Kearsarge - Central Maine synclinorium; 5) the Cross River Formation of probable Ordovician age; and 6) the Rye Formation of Late Precambrian - Ordovician age. Rocks in the Boothbay area originally mapped as part of the Bucksport Formation are now correlated with, and mapped as part of the lithically similar Sebascodegan Formation of the Casco Bay Group (originally the Sebascodegan member of the Cushing Formation). The boundaries separating sequences 2 from 4, 2 from 3, and 2 from 5 are interpreted to be westward-dipping thrusts, and the notion of a synclinorially folded thrust originally proposed for the base of the Casco Bay Group must be abandoned. The boundary between the Rye Formation (6) and the Merrimack Group (1) is a zone of ultramylonite representing either a strike slip fault with dominantly right-lateral movement or a pseudo-wrench part of an east-dipping thrust. The west-dipping thrusts are probably related to the Acadian orogeny of Early Devonian age.

Intrusive igneous activity spans a time from Middle Ordovician to Cretaceous. Intermediate to basic plutons were intruded into the Merrimack Group in New Hampshire in middle to late Ordovician time. Large granitic plutons were intruded from Early Devonian time, immediately following Acadian deformation, to mid Carboniferous time. Anorogenic felsic alkalic intrusion began with the emplacement of members of the Agamenticus Complex in Late Permian time and continued on into the Cretaceous. Dike swarms, probably related to the onset of tensional rifting leading to the formation of the Atlantic Ocean, were emplaced in Late Triassic to Early Jurassic time, and basic plutonism and associated vulcanism occurred during the Cretaceous.

The Cape Elizabeth, Flying Point, and Nonesuch River faults are high angle faults which represent the extension of the Norumbega fault system into southwestern Maine. These faults underwent movement from mid-Devonian to as late as Jurassic time. Principal movement on these faults occurred after Acadian metamorphism but prior to emplacement of the Carboniferous plutons. Other high angle faults are interpreted to be normal faults, most of which are apparently down-dropped to the northwest. Movement on these may correlate with time of Juro-Triassic rifting. In southwestern Maine none of these faults are major boundaries between sequences. They merely offset major thrusts which are the true boundaries.

Major recumbent and upright folding and metamorphism of the Casco Bay, Falmouth - Brunswick, and Kearsarge Central Maine sequences are interpreted to be the result of the Acadian orogeny in Early Devonian time. The Merrimack Group was multiply deformed prior to the intrusion of the 473 ± 34 Ma Exeter pluton in southeastern New Hampshire during an orogenic episode prior to the time of the Taconic orogeny in western New England. Hercynian deformation and metamorphism is restricted to variably wide zones concentric to the Mississippian age Sebago and Lyman plutons.
INTRODUCTION

The purpose of this paper in a volume on neotectonics and seismicity of Coastal Maine is to provide an overview of the geological setting of southwestern Maine. The area included in this review extends from Kittery on the south to Pemaquid Point on the east, and inland to Lewiston and Sanford (Figure 1). This area is underlain by metamorphic rocks of Late Precambrian to Early Devonian age which have been intruded by plutonic rocks ranging from Middle Ordovician to Mesozoic in age. Six distinct stratigraphic sequences comprise the metamorphic rocks of the study area. They are 1) the Merrimack Group consisting of Late Precambrian - Early Ordovician easterly derived calcareous flysch; 2) the Casco Bay Group composed of felsic and mafic volcanic rocks, and pelitic, psammitic, and calcareous metasedimentary rocks of Late Precambrian - Ordovician age; 3) the Falmouth - Brunswick sequence consisting of mafic and felsic metavolcanic rocks and volcanogenic metasedimentary rocks of Late Precambrian age and originally correlated with the Cushing Formation; 4) the Kearsarge - Central Maine sequence of metamorphosed calcareous flysch, pelite, and ribbon limestone of Siluro-Devonian age; 5) the Cross River formation, migmatized very sulfidic and graphitic gneiss of probable Ordovician age, and 6) the Rye Formation, migmatized and blastomylonitized metasediments and amphibolite of Late Precambrian - Ordovician age.

This study is based on investigations by Pankiwskyj (1978a) and Creasy (1979) in the Gardiner, Vassalboro, Wiscasset and Palermo areas; Gilman (1977, 1978) in the Kezar Falls and Newfield quadrangles, Eusden (1984) in the Berwick quadrangle, and the writer in the Lewiston quadrangle (Hussey, 1981a,b), in the greater Casco Bay - Boothbay area (Hussey, 1971a,b; 1981b,c,d, 1986, and work in progress), and in Southern York County (Hussey, 1962). Figure 2, modified after the 1985 Bedrock Geologic Map of Maine (Osberg et al., 1985) shows the geology as it is interpreted from mapping done through the 1985 field season. Several problems of stratigraphic and structural interpretation exist, and the interpretation presented may be subject to extensive revision when further detailed mapping is completed in this and adjacent areas.

In the discussion that follows, formally defined and recognized stratigraphic units will be indicated by capitalization of the first letter of the lithology or stratigraphic rank (e.g., Macworth Formation, Spurwink Metamestone). Names of stratigraphic units used informally pending a formal definition in accepted publications will be indicated by lower case letter for the lithology or stratigraphic rank (e.g., Cross River formation, Wilson Cove member). All areal names have been cleared and reserved for future formal use.

Seldom can we as field geologists formulate unequivocal answers to the problems of interpreting the complex, multivariate systems we deal with. I feel we do a disservice in making positive statements that make complex problems seem simple and solved once and for all. What we likely are doing is impressing upon the unsuspecting reader our pet biases which too often are subsequently cited in derivative literature as fact. In order to avoid this, the words "possibly," "probably," "may," and other phrases or symbols indicating uncertainty will be used frequently and without apology in this discussion. Such is the state of the art.

PREVIOUS WORK

Katz (1917) conducted the first significant detailed mapping in the greater Casco Bay area, and is responsible for naming and describing the formations of the Casco Bay Group. Fisher (1941) carried out original detailed and reconnaissance mapping of the Lower Androscoggin Valley area, correlating the rocks of the Lewiston area with the fossiliferous sequence described by Perkins and Smith (1925) in the Waterville area. He was the first to recognize a Silurian age for at least part of the highly metamorphosed and migmatized sequence of the Lewiston area, previously regarded as Precambrian in age on the basis of degree of metamorphism (Keith, 1933).

STRATIGRAPHY

Casco Bay Group

Formations of the Casco Bay Group include, in decreasing order of age, the Cushing Formation, Sebascodegan Formation, Cape Elizabeth Formation, Spring Point Formation, Diamond Island Formation, Scarborough Formation, Spurwink Metamestone, Jewell Formation, and Macworth Formation. Lithologies of these units are summarized below. Further details are given in Hussey (1985).

The Cushing Formation is a complex and variable sequence of quartzo-feldspathic gneisses, feldspathic sillimanite gneiss, amphibolite, rusty-weathering sulfidic schist, coticule, marble, and well-bedded generally sulfidic manganiferous metachert. Rock units west of the Flying Point fault (Fig. 3) previously assigned to the Cushing Formation appear to form a separate stratigraphic sequence that cannot be readily correlated on lithologic grounds with the Cushing Formation east of the Flying Point fault. These two sequences may be independent of each other, possibly having been deposited in separate lithotectonic belts. The writer (Hussey, in press) refers to the sequence west of the Flying Point fault informally as the Falmouth - Brunswick sequence and this usage is followed here.

The Cushing Formation crops out in anticlinal belts and fault slivers southeast of the Flying Point Fault, and includes the Peaks Island, Wilson Cove, Bethel Point, Merenpoint, and York Island members (Hussey, 1985). Metavolcanic and
Figure 1. Location of the discussion area, showing the principal lithotectonic sequences of southwestern Maine.
Figure 2. Generalized geologic map of southwestern coastal Maine (modified after Osberg et al., 1985), and schematic cross section of the Brunswick - Boothbay Harbor area approximately along the line A-A'.
Geology of southwestern coastal Maine

INTRUSIVE ROCKS

Cretaceous
Ki
Basic ring complexes
Triassic
Tri
Agamenticus Complex
Carboniferous or younger
Ci
Gabbro, syenite, ultramafics
Carboniferous
Cg
2-mica granite and pegmatite
Carboniferous or older
Cgbd
Foliated gabbro-diorite
Early Devonian
Dg
2-mica granite
Dgd
Foliated granodiorite

High-angle post-metamorphic fault
Folded thrust (teeth on upper plate)
Sedimentary or intrusive contact

STRATIFIED ROCKS

Early Silurian
S
Ss
Rindgemere Formation of Shapleigh Group, Sangerville Formation
Ssp
Sangerville Formation; Ssp; Patch Mountain Member, Sangerville Formation
Sws
Waterville, Windham Formations, Anasagunticook Member, Sangerville Formation

Late Ordovician to Early Silurian
SOv
Vassalboro Formation
(fault contact)

Precambrian-Ordovician
ZObg
Berwick and Gonic Formations
ZOe
Eliot Formation
ZOk
Kittery Formation
(fault contact)

Precambrian-Ordovician
ZOm
Macworth Formation
ZOcbm
Jewel, Sparwink, Scarborough, Diamond Island, and Spring Point Formations
ZOce
Cape Elizabeth Formation
ZOce
Sebagocean Formations
ZOc
Cushing Formation
(fault contact)

Precambrian-Ordovician
ZOfb
Falmouth-Brunswick sequence
ZOdr
Rye Formation

Figure 2. Continued.

PLUTONS

AG- Agamenticus complex
AD- Alfred complex
AL- Androscoggin Lake pluton
LD- Leeds pluton
B- Biddeford pluton
C- Cape Neddick complex
H- Hedgehog Hill pluton
L- Lyman pluton
S- Sebago batholith
SO- Saco pluton
T- Tatic complex
W- Webhannet pluton
metasedimentary rocks above the Bethel Point member, originally included in the Cushing as the Sebascodegan member, are raised to formation rank (Hussey, 1988). The Cushing Formation exhibits the most distinctive volcanic characteristics, including volcanic breccia, crystal tuff texture, and very feldspathic mineralogy, in the belt extending from South Portland northward through Harpswell Neck. Amphibolites have been interpreted variously as metamorphosed basic flows and tuffs (Hussey, 1985), impure interlayered magnesian carbonate and shale (Hussey, 1971b, 1985), and as syntectonic premetamorphic sills (Newberg, 1981a; Hussey, 1985).

The Sebascodegan Formation (Hussey, 1988) consists of feldspathic biotite granofels with interbeds of calc-silicate gneiss and sillimanite gneiss, with significant metavolcanic breccia and crystal tuff in its western part. It is regarded as a facies of the upper part of the Cushing Formation. Rocks originally mapped as the Bucksport Formation in the Boothbay Harbor area (Fig. 1) are now correlated and included with the Sebascodegan Formation on the basis 1) of lithologic similarity, and 2) that they are overlain by the Cape Elizabeth Formation. The Cushing Formation is now interpreted to represent a facies proximal to an eruptive center lying to the west, and the Sebascodegan formation to be a more distal apron of reworked volcanic detritus to the east.

The correlation of the Sebascodegan with the Cushing raises a problem for future resolution: how do we separate the outcrop belt of these rocks in southwestern Maine from the supposedly younger (Late Ordovician to possibly Early Devonian) Bucksport Formation of south central Maine. It is conceivable that the age of the Bucksport should be reconsidered.

The Cape Elizabeth Formation has a variable lithology depending on the grade of metamorphism. At low grade (chlorite, biotite, and garnet) it is generally a thin-bedded alternation of fine-grained medium gray feldspathic and micaceous quartzite and medium dark gray phyllite, with small garnet porphyroblasts at garnet grade. The quartzose beds are characteristically finely laminated, and these laminae occasionally show fine-scale soft-sediment slump deformation. Minor lithologies of the Cape Elizabeth Formation at low grade include thin amphibolite and chlorite schist beds representing original feldspathic sandstones and felsic tuff beds. Minor lithologies include thin amphibolite and chlorite schist beds representing mafic tuffs prior to metamorphism.

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**Falmouth - Brunswick Sequence**

The Falmouth - Brunswick sequence crops out in a belt between the Vassalboro Formation of the Kearsarge - Central Maine sequence and the Flying Point fault extending from Falmouth toward the northeast beyond the mapped area. The sequence consists of four formations, Nehumkeag Pond, Mount Ararat, Torrey Hill and Richmond Corner, originally correlated as members of the Cushing Formation, but now interpreted to form a separate sequence. The Nehumkeag Pond formation, as defined by Newberg (1981), consists of buff to slightly rusty-weathering fine-grained quartz - K-feldspar - plagioclase - biotite - muscovite gneiss. Minor mappable lithologies include impure marble and associated rusty weathering mica schist. The Mount Ararat formation consists primarily of light gray quartz - plagioclase - biotite gneiss and granofels with subordinate amphibolite and biotite - hornblende - plagioclase granofels in beds ranging from 1 cm up to mappable lenses 200 m thick. Minor associated lithologies include rusty mica schist and hornblende-rich calc-silicate gneiss. The Torrey Hill formation consists of non-to poorly-bedded very sulfidic and rusty-weathering quartz - muscovite - biotite - graphite - sillimanite schist with minor sulfidic micaeous quartzite interbeds. The Richmond Corner formation is a heterogeneous assemblage of mostly metasedimentary rocks including 1) quartz - plagioclase - biotite - garnet granulose schist (the dominant lithology), 2) amphibolite with thin calc-silicate laminae, 3) pink coticule, and 4) rusty mica schist. The Falmouth - Brunswick sequence is no longer correlated with the Cushing Formation on the basis 1) that there is no correlation of lithic sequence from one side of the Flying Point fault (part of the Norumbega fault system) to the other, 2) that the Cushing sequence east of the Flying Point fault lacks the thin alternations of amphibolite and felsic granofels typical of the Mount Ararat formation.

**Formations of the Kearsarge - Central Maine Sequence**

Late Ordovician to Early Silurian formations in the study area comprising a cover to the pre-Silurian Falmouth - Brunswick sequence are the Vassalboro, Waterville, Windham, and Sangerville Formations. These formations are the lower part of a conformable sedimentary sequence ranging to Early Devonian age in the center of the Kearsarge - Central Maine synclinorium to the northwest of the study area. These formations are not considered part of the Merrimack Group as previously suggested by Billings (1956). As discussed below, the Merrimack is now regarded as a separate and older sequence of metasediments of pre-Silurian age (Gaudette et al., 1984). The lower part of the Rindgemere Formation of the Shapleigh Group, correlated with the Sangerville Formation, is included in this discussion. The Vassalboro Formation is a thick sequence of variably bedded medium gray quartz - plagioclase - biotite (-hornblende) granofels and calc-silicate granofels. Minor interbedded lithologies include biotite - quartz - plagioclase - muscovite - sillimanite schist, rusty-weathering biotite - quartz - graphite - muscovite schist, and impure marble. The principal lithology is very similar to that of the Berwick, Bucksport and Sebascodegan Formations.

The Waterville Formation consists of thin-bedded biotite - sillimanite - muscovite - garnet schist, and minor calc-silicate granofels. In the middle of the formation is a thin metalimestone member consisting of ribbony-bedded fine-grained marble with thin interbeds of quartz-biotite schist, and at the base is a discontinuous thin unit of rusty-weathering quartz - muscovite - graphite schist. Included as part of the Waterville Formation is the lithically similar and correlative Anasagunticook Member of the Sangerville Formation.

The Windham Formation, mapped only south of the Sebago pluton, is lithically similar to the Waterville Formation with which it is correlated. The principal lithology of the formation is thin to medium-bedded muscovite - biotite - garnet - quartz - plagioclase schist with staurolite, sillimanite, or kyanite (Thompson and Guidotti, 1986) at the appropriate grade. This is the only formation in the study area in which kyanite is part of the paragenesis. Interbedded with the schist are thin beds of micaceous quartzite. Toward the middle of the Windham Formation is a metalimestone member identical to that present in the Waterville Formation. A thin discontinuous zone of fine-grained purplish-gray quartz - plagioclase - biotite schist similar to the biotite granulate of the Vassalboro Formation occurs between the pelite and metalimestone.

The Sangerville Formation is traced on the southeast limb of the Currier Hill syncline of the Skowhegan area (Ludman, 1977) across the Livermore quadrangle to the northeast corner of the Lewiston 15' quadrangle by Pankiwskyj et al. (1976). As here mapped (Figure 2), the Sangerville Formation includes parts of the Sabattus, Taylor Pond, and Androscoggin Formations of Fisher (1941), the Turner Formation of Warner and Pankiwskyj (1965), and the Patch Mountain Formation of Guidotti (1965). The Sangerville Formation consists of a non-to slightly rusty-weathering association of variably bedded to massive metamorphosed pelite and quartz wacke that, in most areas, is very extensively migmatized. The dominant lithology is quartz - plagioclase - biotite granofels and schist. Sillimanite is common in the schist. In the area just north and east of Sabattus the formation is least migmatized and consists of thin to medium-bedded alternations of fine-grained medium gray quartz - plagioclase - biotite granofels and medium brownish-gray biotite - muscovite - sillimanite - garnet - quartz schist. Graded bedding is common here. These rocks are distinguished from the Waterville Formation by the relatively thicker granofels relative to pelite. They are very similar to the Mayflower Hill Formation of Osberg, (1968), and with the lower part of the Rindgemere Formation (Hussey, 1985) with which they are correlated.

The Patch Mountain Formation of Guidotti (1965) is now ranked as a member of the Sangerville Formation. It consists of
well-bedded alternations of light gray calc-silicate granofels, dark gray quartz - plagioclase - biotite (hornblende) granofels, and fine-grained granoblastic marble with abundant calc-silicate minerals. In places the member consists of massive marble, and locally, thick beds of quartz - plagioclase - biotite granofels. In the area just northeast of Sabbatus where the Sangerville is essentially unmetamorphized, the Patch Mountain Member consists of thin, ribbony-bedded metatuff very similar to the ribbon limestone members of both the Waterville and Windham Formations.

**Merrimack Group**

The Merrimack Group consists of the Kittery, Eliot, and Berwick Formations of southwestern Maine and adjacent New Hampshire. The group is limited in outcrop to an area southeast of the Nonesuch River fault, and southwest of the Casco Bay Group outcrop belt.

The Kittery Formation typically consists of a variably thin to thick-bedded association of calcareous and feldspathic quartzite and dark gray chlorite/biotite phyllite. Graded bedding, cross-bedding, flame structures and many other primary sedimentary structures are well preserved, and Rickerich (1983) interprets the environment of deposition of the formation to have been that of a deep-sea turbidite fan. From a statistical analysis of the orientation of small-scale cross bedding foresets, Rickerich determined a general east to west sediment transport for the turbidites of the Kittery Formation.

The Eliot Formation is inferred to lie conformably above the Kittery Formation. It consists of thin-bedded alternations of medium gray buff-weathering calcareous and ankeritic quartz-mica phyllite, and dark gray phyllite. In New Hampshire, Freedman (1950) mapped an upper member, the Calef Member, consisting of mostly dark graphitic phyllite. A similar lithology is present along the Mousam River (Fig. 2).

The Berwick Formation characteristically is an interbedded association of quartz - plagioclase - biotite - amphibole granofels and calc-silicate granofels. Calc-silicate minerals include zoisite, diopside, hornblende or actinolite, and grossularite (the latter essentially restricted to compositionally zoned concretions). Bedding thickness varies considerably, some parts of the formation being essentially massive biotite granofels. Although contacts with the underlying Eliot are not exposed, there is no indication of structural discordance between the two, and the contact is inferred to be conformable (Hussey, 1985).

**Cross River Formation**

The Cross River Formation (Hussey, 1985) is restricted in outcrop to the cores of two doubly-plunging antiformal windows in the Boothbay area. The upper part of the formation is a non-rusty variably-bedded quartz - plagioclase - biotite - garnet granofels. The lower part is moderately to extremely rusty-weathering sillimanite- and graphite-bearing nebulitic migmatite with rafts of biotite granofels and occasionally amphibolite. These rafts represent broken beds of lithologies resistant to migmatization and mobilization. The Bucksport-type rocks, now correlated with the Sebascodegan member of the Cushing Formation, structurally overlie the Cross River Formation and the contact is inferred to be a folded thrust fault.

**Rye Formation**

The principal lithology of the Rye Formation on Gerrish Island, Kittery, is an association of fine-grained, mylonitized dark chocolate-brown metapelite with muscovite, biotite, garnet, quartz, plagioclase, fibrolitic sillimanite, relic staurolite, and occasionally relic andalusite; and mylonitized fine-grained 1 to 2 cm alternations of chocolate-brown quartz - biotite - plagioclase gneiss and medium greenish-gray quartz - plagioclase - hornblende - biotite gneiss. Partially crushed and rolled porphyroclasts of plagioclase and microcline up to 4 cm in diameter are locally abundant giving the rocks a characteristic blastomylonitic fabric. Within this association are thin units of marble, sulfide black graphitic schist, and amphibolite. Locally the main lithic association has been reduced to ultramylonite with pseudotachylitic stringers through deep-seated ductile faulting (Hussey, 1980; Swanson, 1988). On Gerrish Island the rocks other than the pseudotachylite have been heavily migmatized and injected by sills of blastomylonitic granite, granodiorite and granite pegmatite ranging up to several meters in thickness. It is the regularity of these feldspathic layers that lead earlier investigators, including the writer, to interpret this sequence on Gerrish Island as metamorphic. Close examination reveals that these felsic layers occasionally cross-cut relic bedding at very low angles, and must be injected, not interbedded, material. Other than the amphibolite that may have been basaltic ash beds before metamorphism, there are no volcanics in the Rye Formation.

**STRATIGRAPHIC RELATIONS, AGE, AND CORRELATIONS**

**Casco Bay Group and Falmouth - Brunswick Sequence**

The writer now regards the Casco Bay Group to be of Late Precambrian (?) to early Ordovician (?) age rather than Devonian as earlier stated (Hussey, 1968). The principal basis for this reassignment is the Rb/Sr whole-rock dating (Table I) reported by Brookins and Hussey (1978).

Brookins and Hussey (1978) interpreted these ages to reflect time of formation of the different units. However many workers interpret such ages to reflect total or, as in this case, partial resetting during a metamorphic event. Assuming that the latest metamorphism of this sequence occurred as the result of the Acadian orogeny in Early Devonian time, these Cambro-Ordovician ages suggest deposition and vulcanism sometime prior.
The greater radiometric age reported by Brookins and Hussey (1978) for the Scarboro and Spring Point Formations probably reflects analytical uncertainty, inasmuch as primary structures clearly establish the stratigraphic sequence of these formations (Hussey, 1985).

The Macworth Formation, based on its lithic similarity, may correlate with either the Berwick or Vassalboro Formations. Its age may thus be anywhere from Late Precambrian to Late Ordovician.

The Falmouth - Brunswick sequence is interpreted to be a pre-Silurian basement terrane to the adjacent part of the Siluro-Devonian Kearsarge-Central Maine sequence. The Mount Ararat Formation is lithically similar to, and may correlate with, the metavolcanic phases of the Massabesic Gneiss in New Hampshire (Bothner et al., 1984), the Monson Gneiss in the Pelham Dome in Massachusetts (Robinson et al., 1986), core gneisses and Ammonoosuc volcanic cover in the Oliverian domes of western New Hampshire (Naylor, 1968), and pre-Silurian bimodal volcanics of the Miramichi anticlinorium in western New Brunswick (Fyffe, 1982). These correlations suggest a Late Precambrian - Ordovician age for the Falmouth - Brunswick sequence.

Merrimack Group

The Kittery Formation is in contact with the Rye Formation along a 30 to 50 m wide zone of unmetamorphosed ultramylonite (Hussey, 1980), representing a deep ductile fault zone which Swanson (1988) interprets to have significant right-lateral strike slip movement. The contact between the Merrimack Group and the Kearsarge - Central Maine Sequence is the Nonesuch River fault. The Berwick Formation is correlated with the Paxton and Oakdale Formations of Massachusetts, and with the Southbridge and Hebron Formations of southern Massachusetts and Connecticut (Barosh and Pease, 1981). Peck (1976) tentatively correlates the Kittery Formation with quartzose units of the Merrimack Group in the Clinton area of Massachusetts just west of the Clinton-Newbury fault.

On a lithic basis the Berwick Formation is identical to the Vassalboro and Bucksport Formations, and the Sebascodegan member of the Cushing Formation. Osberg (1980) regards the Vassalboro Formation to be of Late Ordovician to Early Silurian age and hence it has been held that the Merrimack Group may also be of Late Ordovician to Early Silurian age. However, the weight of accumulating radiometric ages of some of the plutons that cut the group (Exeter, and Newburyport) suggest a pre-Ordovician age for the group (Gaudette, et al., 1984; Zartman and Naylor, 1984). This seemingly would rule out a correlation of the Berwick and Vassalboro Formations, and reinforce the interpretation that these are separate terranes unrelated in time and space. Inasmuch as the strength of this notion of non-correlation rests with the single radiometric age reported for each of the above two plutons, it would be prudent to reserve final judgement of correlation or non-correlation until additional age determinations are made by other methods.

Cross River and Sebascodegan Formations

The Cross River Formation correlates either with the Penobscot Formation east of the Sennecoc Lake fault (Bickel’s [1976] St. George fault), or with the rusty schist of the Benner Hill sequence of Osberg and Guidotti (1974), also east of the Sennecoc Lake fault. Fossils in the Benner Hill sequence indicate an Ordovician age for that sequence (Boucot et al., 1972; Neuman, 1973). The Penobscot Formation is correlated with the Cookson Formation of eastern Maine (Osberg et al., 1985). Fossils in the Cookson indicate an early Ordovician age for the

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**TABLE I. RB/SR WHOLE-ROCK AGES FOR FALMOUTH-BRUNSWICK AND CASCO BAY SEQUENCES, AND PEGMATITES, PORTLAND-ORRS ISLAND AND RICHMOND AREAS.**

<table>
<thead>
<tr>
<th>Formation</th>
<th>Age (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cushing Formation</td>
<td>481 ± 40</td>
</tr>
<tr>
<td>Spring Point Formation</td>
<td>539 ± 50</td>
</tr>
<tr>
<td>Cape Elizabeth Formation</td>
<td>485 ± 40</td>
</tr>
<tr>
<td>Scarboro Formation</td>
<td>509 ± 45</td>
</tr>
<tr>
<td>Mount Ararat Fm.</td>
<td></td>
</tr>
<tr>
<td>Foliated pegmatite</td>
<td>385 Ma*</td>
</tr>
<tr>
<td>Non-foliated pegmatite</td>
<td>373 Ma**</td>
</tr>
</tbody>
</table>

(ages after Brookins and Hussey, 1978 [*], Brookins, personal communication [**], and Gaudette et al., 1983 [***]).
youngest part of that sequence. If the Cross River correlates with the Penobscot Formation its age would then be Cambrian to Early Ordovician. If it correlates with the Benner Hill sequence its age would be Ordovician but probably not Cambrian.

As indicated above, the Bucksport-like rocks in the Boothbay Harbor area are now included as part of the Sebascoedgan Formation which is interpreted to be a facies of the upper part of the Cushing Formation and not with the type Bucksport Formation to the north of the study area. The age of these rocks is thus probably Late Precambrian - Early Ordovician.

Kearsarge - Central Maine Sequence

The Kearsarge - Central Maine sequence including the Rindgemere Formation of the Shapleigh Group is in fault contact with the Merrimack and Casco Bay Groups. The Nonesuch River fault separates the Shapleigh Group from the Merrimack Group southwest of the Lyman pluton, and it juxtaposes the Cape Elizabeth Formation of the Casco Bay Group against the Vassalboro Formation of the Kearsarge - Central Maine sequence northeast of the Saco pluton. The Vassalboro Formation is separated from the Cape Elizabeth and Macworth Formations in the Portland area by the Flying Point fault. North of Portland the Falmouth - Brunswick sequence is separated from the Vassalboro Formation by the Hackmatack Pond fault (Fig. 2), a west-dipping thrust fault. Osberg et al. (1985) regard the contacts between units of the Kearsarge - Central Maine sequence to be conformable.

The Sangerville Formation is correlated with the Mayflower Hill Formation of the Waterville area, the Rangeley Formation of north central Maine, and lower parts of the Rindgemere Formation of southwestern Maine (Hussey, 1985). Graptolites in the Mayflower Hill Formation (Osberg, 1968), and a shelly fauna in the Rangeley Formation (Moench and Boudette, 1970) both support a Late Llandoverian age for these formations, hence also the lower part of the Rindgemere and the Sangerville Formations. Osberg (1980) correlates the Waterville Formation with the Greenvale Cove Formation of north central Maine and he assigns an early Silurian age for it on the basis of its position stratigraphically below the Sangerville, and poorly preserved graptolites. The Vassalboro Formation is correlated with the Quimby Formation of north central Maine, and is assigned an age of Late Ordovician to Early Silurian. This correlation of the Vassalboro Formation with the Quimby Formation introduces one major problem in stratigraphic interpretation and synthesis in southern Maine. As presently mapped, the Vassalboro Formation traces out on strike northeast into the Flume Ridge Formation which Ludman (1980) regards to be of Siluro-Devonian age. The Vassalboro is lithically identical to the Bucksport Formation with which it is correlated (Osberg et al., 1985). It is also lithically identical to the Berwick Formation, a correlation originally made by the writer (Hussey, 1968) but seriously questioned now in the light of Ordovician radiometric ages for the Newburyport and Exeter plutons and the extensive pre-plutonic recumbent and upright folding activity of the Merrimack Group discussed below. Future work must resolve this problem.

INTRUSIVE ROCKS

Intrusive rocks occupy approximately one third of the study area, collectively representing an intrusive history spanning the time from the Early Devonian to the Cretaceous.

The principal plutons of the area are the Sebago batholith, and the Lyman, Webhannet, Biddeford, Saco, Leeds, Lake Androscoggin, and Hedgehog Hill plutons; and the Agamenticus, Cape Neddiek, Alfred, and Tatnic complexes. In addition, many minor plutons, mostly composed of two-mica granite, occur throughout the area, principally in the outcrop belt of the Cape Elizabeth Formation between Bath and Georgetown.

The Biddeford pluton is composed of medium-grained non-foliated light gray biotite granite. The Webhannet pluton consists of three intrusive phases, foliated subporphyritic granodiorite, gray weakly foliated granite, and non-foliated pink biotite-muscovite granite (youngest). The Lyman, Leeds, and minor unnamed plutons are composed of weakly foliated biotite-muscovite granite, locally with accessory garnet. The Sebago batholith is composed of massive to moderately foliated biotite-muscovite granite. Creasy (1979) maps and describes two phases of the batholith, an outer phase which consists of 2-mica granite of great textural heterogeneity, and containing numerous xenoliths, and an inner phase much more homogeneous in texture and almost devoid of metasedimentary inclusions. Foliated granodiorite forms the arcuate Hedgehog Hill pluton just east of Lewiston.

Pegmatites of simple mineralogy (quartz, microcline, albite, biotite, muscovite, garnet, and schorl) are common throughout the study area in the sillimanite and sillimanite- K-feldspar zones of regional metamorphism, occurring as elongate pods and lenses, irregular stringers, and evenly-walled dikes. The irregular and discordant pegmatites tend to be foliated, and the thinner ones of these, folded. Pegmatite dikes are generally massive, unfolded, and unfoliated. Brookins (pers. comm., 1978) reports a Middle-Devonian age for both foliated and unfoliated pegmatites in the Falmouth - Yarmouth area (Table I).

The Saco pluton is composed of strongly lineated and weakly foliated diorite. Similar diorite, cut by and therefore older than the Sebago batholith, forms a small stock at the south end of the Westbrook tongue of the batholith. The original igneous mineralogy of these bodies has been changed almost completely either by regional metamorphism or deuteric alteration.

Gabbro, ultramafic rocks and syenite form an intrusive complex 7 km in diameter centered around Lake Androscoggin in Wayne. All phases are relatively younger than the 2-mica granite of the Leeds pluton and pegmatites. Noritic gabbro, monzodiorite, and porphyritic granodiorite form the Alfred complex in the town of Alfred. Noritic gabbro, quartz diorite, and olivine gabbro with included blocks of volcanic agglomerate
form the Tatic complex in South Berwick, North Berwick, and Wells. In York Beach cone sheets and funnel intrusions of gabbro, anorthositic gabbro, and cortlandtite gabbro comprise the Cape Neddick complex.

The Agamenticus complex is a roughly circular post-tectonic plutonic ring complex composed of four intrusive phases, alkaline syenite, alkaline quartz syenite, alkaline granite, and biotite granite (in the presumed order of injection). Reflective of the alkaline composition of the magmas from which these plutons formed are such minerals as hastingsite, ferrohastingsite, riebeckite, arfvedsonite, aegirine-augite, aegirine, and enigmatite.

Basic dikes, including basalt, diabase, camptonite, and monchique, are present throughout the area in greatly varying abundances. They range in thickness from less than a centimeter to greater than 30 m. They are undeformed and unmetamorphosed but frequently show markedly contrasting degrees of deuteric alteration. These dikes cut all metasedimentary units, pegmatites, and granitic plutons, and are younger than all other intrusive phases except the Cape Neddick, Tatic and Alfred complexes. The dikes form a swarm, locally accounting for 20% of the outcrop area in a relatively narrow belt that extends from southwest of the study area into the vicinity of Kennebunkport. The swarm either dies out or trends out to sea just south of the mouth of the Saco River, Biddeford. Another minor swarm is located in a crudely east-west trending belt through the city of Lewiston. These dikes individually have a general ENE trend.

Table II lists radiometric ages for plutons in the study area.

In the study area, biotite and biotite-muscovite granites (Webhannet, Biddeford, Lyman, Waldoboro, and Saco plutons) yield either Devonian or Carboniferous ages. The Webhannet pluton gives an early Devonian age indicating intrusion and cooling just after the peak of Acadian deformation (Gaudette et al., 1982). The Saco, Biddeford, Lyman, and Saco Plutons all give Carboniferous ages which correlate with ages obtained by Lux and Guidotti (1985) for metamorphic rocks north of the Sebago batholith. The 307 Ma age for the Saco pluton is perplexing in view of the strongly deformed and metamorphosed character of the pluton. Although the Nonesuch River fault cuts centrally through the pluton, the foliation, lineation, and metamorphic alteration are not restricted to the fault zone, but are pervasive throughout. This led the writer to regard the Saco pluton as a syn-Acadian intrusive older than the granite plutons of southwestern Maine. The anomalously young age of the Saco pluton may possibly represent resetting of the original syn-Acadian age by thermal effects of the intrusion of the Lyman pluton.

**STRUCTURE**

**Folds**

All of the stratified rocks of the southwestern Maine area have been multiply deformed. The Casco Bay Group, Mer-
Southwest-verging and deformation is chaotic, seldom with distinction of the different fold sequences seen northeast of the Sebago batholith. In the area southeast of Sanford, Eusden et al. (1987) describe a major northwest-facing, southeast verging recumbent $F_1$ fold, the Blue Hills Nappe, which has been refolded by overturned southeast-verging $F_2$ folds which largely control the map pattern. $F_3$ is a major deflection of $F_2$ fold axes from a northeast to a northwest trend (seen only to the west of the discussion area), probably related to the intrusion of the Sebago batholith.

In the Boothbay area, minor recumbent $F_1$ folds are indicated by the distribution of a thin amphibolite unit within the Cape Elizabeth Formation of that area. $F_2$ folds which control the major map distribution of the formations are upright to slightly overturned folds, with which most of the observed tight to nearly isoclinal mesoscopic-scale folds are associated. These $F_2$ folds correlate with the $F_2$ folds of the Bath - Brunswick - Portland area.

**Faults**

The major faults of the study area are shown in Figures 2 and 3. The names of the post-metamorphic faults are given in Figure 3.

**Thrust Faults.** The contact between the Vassalboro Formation and Falmouth - Brunswick sequence from Falmouth northward is the Hackmatuck Pond fault of Pankiwsky (1978b). It is interpreted to be a westward-dipping thrust fault on the basis of the USGS Quebec - Western Maine Seismic Reflection Profile to the northeast of the study area (Stewart et al., 1986). In the study area, this fault has been strongly folded (probably during the event that produced $F_3$ folds during migmatization). This folding has resulted in a southeasterly dip of bedding, foliation, and schistosity near the Portland-Brunswick segment of the fault (Fig. 2). A second west-dipping reflector east of this appears to coincide with the Beech Pond fault of Newberg (1985) which the writer interprets to be a thrust fault contact between the Falmouth - Brunswick sequence and the Cape Elizabeth Formation. The contact between the Sebascodegan member of the Cushing Formation of the Boothbay Harbor area and Cross River Formation is interpreted to be a third major thrust along which rocks of the Casco Bay sequence have overridden the Penobscot or Benner Hill sequences. This fault is indicated by a well-defined west-dipping reflector on the seismic line suggesting that in that area, the fault is unaffected by $F_2$ folds. However, in the Boothbay area this fault is clearly folded, and is exposed in two doubly-plunging antiforms. The boundary between the Sebascodegan Formation and the Benner Hill and Penobscot sequences to the east is an easterly dipping thrust originally named the St. George Fault by Bickel (1976). However, because this name is preempted for a major fault in coastal New Brunswick, this fault is here renamed the Sennec Lake fault after Sennec Lake which lies along the fault trace. This fault is clearly indicated on the USGS seismic reflection line (Stewart et al., 1986).

It is clear from the foregoing discussion that the earlier interpretation of the Casco Bay Group as klippe bounded by single synclinorally folded thrust fault (Hussey, 1985, Eusden et al., 1985) must be abandoned.

The contact between the Vassalboro and Rindgemere Formations southwest of Sebago Lake is inferred to be a folded
thrust on the basis of differences in relative ages of the sequences on either side of the contact.

**High-Angle Post-Metamorphic Faults.** The writer has mapped northeast-trending post-metamorphic faults extending through the Greater Casco Bay area (Hussey, 1971a,b; 1981b,c,d). Three of these, the Flying Point, Cape Elizabeth, and Nonesuch River faults (Fig. 3) are correlated with the Norumbega fault of Stewart and Wones (1974). These faults appear to involve a moderate amount (up to 30 km) of left-lateral slip and minor dip slip (Hussey, 1985). A fourth fault, the Back River fault (Fig. 3) with apparent left-lateral slip of approximately 1.5 km may be an independent fault or it may be part of the Norumbega system. Other post-metamorphic faults are interpreted to be normal faults, commonly down-dropped to the northwest.

The Nonesuch River fault has been traced southwestward into New Hampshire (Hussey and Newberg, 1978) where it joins with the Campbell Hill fault of Lyons et al. (1982). Evidence defining the Nonesuch River fault is as follows:

1) Juxtaposition of the Vassalboro and Cape Elizabeth Formations in the Saco-Portland area.

2) The marked topographic lineament formed by the Nonesuch River, the Presumpscot River northeast of Westbrook, and the short northeast course of the Saco River in the outcrop belt of the Saco pluton.

3) Truncation of metamorphic isograds in the Cape Elizabeth Formation, resulting in the juxtaposition of staurolite-grade Vassalboro Formation against chlorite to garnet-grade Cape Elizabeth.

4) Structural contortion and quartz veining (locally drussy) in the Nonesuch River bed south of Gorham.

Although positive evidence for the continuation of the fault northeast of Yarmouth is lacking, it may possibly extend northeast to join the Pleasant Pond fault of Newberg (1981a).

The Flying Point fault is traced from its junction with the Nonesuch River fault south of Gorham, through Brunswick to the Richmond area from which it may extend well beyond the discussion area to join with the main break of the Norumbega fault to the northeast. In the Portland area this fault juxtaposes non-migmatized gneiss schist facies to low amphibolite facies Macworth and Cape Elizabeth Formations on the southeast against pegmatite-injected, migmatized upper amphibolite facies Falmouth - Brunswick sequence and Vassalboro Formation on the northwest. Rocks of the Casco Bay Group of similar grade and degree of migmatization southeast of the fault are found only northeast of Merrymeeting Bay between Bowdoinham and Bath. If movement were strictly horizontal along this fault, this would suggest a displacement in excess of 50 km assuming that all sequences were metamorphosed at the same time, during the Acadian orogeny. Net movement might be considerably less if 1) net movement includes a significant component of dip slip, and 2) metamorphic isograd surfaces and migmatite fronts are very gently dipping, or if different terranes were independently metamorphosed at different times prior to accretion. Splays related to the Flying Point fault can be seen in shoreline exposures on the west side of Flying Point in Freeport. Here rocks of the Cushing Formation have been brecciated, and the foliation contorted and cut by numerous slickensided surfaces. Slickensides are generally steep, indicating that the latest movement was nearly dip slip.

Evidence for the South Portland fault is the omission of units of the Casco Bay Group from South Portland to Great Chebeague Island. This is probably a normal fault down-dropped on the northwest side. The amount of slip probably does not exceed a few hundred meters.

The Cape Elizabeth fault has been traced by Hussey (1971a,b) and Newberg (1981) from the Old Orchard Beach area to and beyond Dresden. Pankiwskyj (1978b) has traced this fault to the northeast into the Norumbega fault of Stewart and Wones (1974), and it may merge with the Flying Point fault north of the discussion area. The Cape Elizabeth Fault is well-exposed in a one-kilometer wide zone along the shoreline of Ram Island Farm in Cape Elizabeth. Here exposures of the Cape Elizabeth Formation show numerous variably-oriented high-angle faults that are locally filled with breccia or gouge. The zone includes a low-angle, west-dipping thrust fault of unknown but potentially significant throw. The major break of the Cape Elizabeth fault at Ram Island Farm is occupied by a 5 to 10 m-thick vein of milky quartz traceable approximately 2 km to the northeast, and along which different members of the Cushing Formation are juxtaposed against the Cape Elizabeth Formation. In the area of Harpswell Neck, Harpswell, the offset of the Cape Elizabeth-Cushing contact, and the sillimanite-andalusite metamorphic isograd suggest possible left-lateral slip movement of 4 to 5 km, but this may also be significantly less if there is a major component of dip-slip and if the overall dips of the formational contacts and the isograd are gentle.

The Back River fault follows Back River south of Wiscasset. It is indicated by 1) the Back River lineament, 2) offset of a granite orthogneiss and a thin amphibolite unit in the Cape Elizabeth Formation, and 3) strong retrograding of biotite to chloride close to the Back River lineament. Left-lateral strike slip motion of 1.5 km is suggested by the pattern of offset of the amphibolite and orthogneiss.

The Phippsburg fault has been mapped between Small Point and Phippsburg. Although net movement along the fault must be very minor, the lineament it forms is very conspicuous. The epicenter of the April 1979 earthquake is nearly on strike with this lineament. In addition, exposures of the Cape Elizabeth Formation along State Highway 127 just east of Bath show extensive slickensiding on strike with the lineament (J. Rand, pers. comm.).

The Cousins Island fault is inferred to form the eastern contact of the Macworth Formation. This is postulated on the basis that Casco Bay Group metapelites are at higher metamorphic grade to the east than the rocks of the Macworth Formation, and that the Macworth Formation truncates regional metamorphic isograds of these metapelites.
Hussey (1981a) and Newberg (1981a) map a high-angle fault extending along the linear lowland just west of Oak Hill in the Sabattus - Litchfield area. This fault, here named the Maxwell Swamp fault, is indicated by both the topographic lineament and by the omission of the Waterville Formation between the Sangerville and Vassalboro Formations just east of Sabattus.

In the Hebron area of the Poland Quadrangle Creasy (1979) maps a northeast-trending normal fault which he names the Ben Barrows fault. The fault is documented on the basis of offset of lithic contacts, and silicified and sheared zones within the granites of the Sebago batholith. He interprets the Ben Barrows fault to be a post-metamorphic normal fault down-dropped to the northwest and having a dip-slip movement of 1-2 km.

Twelve kilometers northwest of the Ben Barrows fault, Guidotti (1965) defined the Moll Ockett fault. It has a trend parallel to the Ben Barrows fault and is recognized on the basis of 1) a sharp topographic break; 2) sharp lithic and stratigraphic contrasts on either side of the fault; 3) contrasting structural styles and patterns; 4) presence of breccia at several places along the fault trace; and strong retrograde metamorphism. Guidotti regards the fault as a normal fault dipping 60 to 80 degrees to the northwest and down-dropped to the northwest.

Several minor unnamed faults are shown in Fig. 2. Many of these are silicified zones for which offset cannot be demonstrated. Many minor northwest trending faults in the Harpswell area are parallel to left-lateral kink bands (F₅) and may represent situations where deformation has exceeded the limits of kinking and passed into minor left-lateral strike-slip faults. Several intraformational bed-parallel gouge zones, breccia zones, slickensided surfaces, and silicified zones have been observed in the discussion area, particularly along coastal exposures, but are too small to be represented on Figure 2. Of notable mention is the concentration of faults along the shore at the southwest end of Harpswell Neck. Here faults of unknown throw and regional extent are indicated by intraformational bed-parallel breccia, a silicified and pyritized zone up to 10 m wide, and several northwest trending faults related to kinking.

Throughout the study area, minor indentations in the shoreline often can be shown to be related to minor brittle faulting where gouge or loosely cemented breccia has been removed by wave action.

SEISMICITY

Figure 3 shows the locations of earthquake epicenters between the years 1776 and 1986 (after Chiburis, 1981; and Johnston and Foley, 1987). Older epicenters are indicated by open circles. Younger epicenters, shown by the black-filled circles, are those for which Richter values are given, and for which epicenters have been determined instrumentally. Locations of older epicenters are those determined by felt effects, mostly reported in newspaper accounts, and are subject to considerable error in location.

The distribution of epicenters shows little relationship to major faults, except for an apparent cluster of older events between the Nonesuch River and Flying Point faults. More recent events form linear arrays of epicenters, generally northerly-trending, in the Lewiston area and just east of Sebago Lake. The Sebago Lake cluster is located within the limits of the Sebago batholith. The cluster near Lewiston extends from the edge of the Leeds pluton southward through the complexly folded belt of the Sangerville Formation, almost to the Sebago pluton. These two belts do not coincide with any mapped faults. It is noteworthy that recent events are concentrated mostly in the area northwest of a line extending from Waterville to the southern end of Sebago Lake. Relatively few recent events are found southeast of that line. The area northwest of that line approximately coincides with the area of Central Maine Gravity gradient (Kane and Bromery, 1966).

METAMORPHISM

The stratified rocks of the discussion area have been metamorphosed to a low-pressure-intermediate (Buchan type) facies series from lower greenschist facies to upper amphibolite facies. Pelitic rocks are characterized at intermediate grade by the presence of andalusite, cordierite, and staurolite, the latter overlapping the stability field of sillimanite. The presence of kyanite in the Gorham-Gray area suggests a higher pressure metamorphism there. Thomson and Guidotti (1986) postulate that the metamorphism that produced the kyanite occurred below the base of the sheetlike Sebago batholith. Subsequent regional tilting and differential erosion has exposed these deeper levels.

Pelitic rocks of the Small Point area, now at andalusite and sillimanite grades of metamorphism, preserve 2 to 4 cm long pseudomorphs of muscovite after chiastolite, suggesting an earlier intermediate-grade metamorphic event.

Retrograde metamorphism has variably affected the entire area, and is generally expressed in the partial to complete chloritization of biotite and sometimes garnet. Chloritization is particularly strong in the vicinity of high-angle post-metamorphic faults, suggesting a genetic relationship between faulting and retrograding.

TIME OF DEFORMATION AND METAMORPHISM

Deformation resulting in F₁ and F₂ folds of the Kearsarge Central Maine Sequence is clearly the result of the Acadian orogeny of Early Devonian time. These folds affect rocks of Late Ordovician and early Silurian age which are, in a broader regional basis, part of a conformable sequence of strata ranging up to early Devonian age (Osberg et al., 1985). F₃ folds of this sequence are restricted to the areas on the northeast margins of the Carboniferous age Lyman and Sebago plutons (Hussey, 1986). On the east side of the Lyman pluton the F₃ folds are minor folds with biotite schistosity and axial planes parallel to
Figure 3. Locations of earthquake epicenters (1776-1986) and post-metamorphic faults in southwestern coastal Maine. Earthquake data from Chiburis (1981) and Johnston and Foley (1987).
the contacts with the pluton. The schistosity which is nearly at right angles to the axial planes of \( F_2 \) folds dies out within a kilometer of the pluton. Clearly, the \( F_3 \) folds here are related to the forceful intrusion of the Lyman pluton. Similarly, the larger-scale northeast to north trending \( F_3 \) folds northeast of the Sebago batholith are interpreted to be structural effects related to the emplacement of that pluton. \( F_3 \) folds in both localities thus are of Carboniferous age and only locally developed around the upper contacts of the plutons and their country rock.

The time of \( F_1 \) and \( F_2 \) deformation of the Merrimack Group was pre-Middle Ordovician if the radiometric age of the Exeter pluton is correct. According to Gaudette et al. (1984) the Exeter pluton post-tectonically intrudes the Kittery and Eliot Formations and has resulted in a contact metamorphism that overprints an earlier low-grade regional metamorphism. The time of \( F_3 \) deformation is unknown.

The deformation of the Casco Bay Group may have occurred during a pre-Silurian event, or at the same time as the Kearsarge - Central Maine Sequence, during the Acadian orogeny in Early Devonian time. The answer to this question in part may lie in the association of a metamorphic event with the development of \( F_2 \) folds as described below.

Metamorphism of the Kearsarge - Central Maine sequence is a result of the Acadian orogeny except 1) the high-grade zone northeast of the Sebago batholith for which Lux and Guidotti (1985) report a Carboniferous age of metamorphism, 2) the Gray/Gorham area southwest of the Sebago batholith, which Thomson and Guidotti (1986) interpret to be related to emplacement of the Sebago batholith, and 3) the zone of reoriented biotite schistosity on the east side of the Lyman pluton. These three areas are essentially zones of metamorphism and migmatization spatially related to the contact areas of the Carboniferous plutons.

There appears to be no metamorphic discontinuity in the metamorphism of the Kearsarge - Central Maine Sequence, and the Casco Bay Group (except across the post-metamorphic Nonesuch River Fault). This suggests that the present prograde mineral assemblage developed during the Acadian orogeny. A well-developed biotite schistosity is associated with the \( F_2 \) folds of the Cape Elizabeth Formation suggesting that the folds developed during the Acadian orogeny also. The earlier metamorphism particularly as indicated by muscovite pseudomorphs in the Small Point area may be related to an early phase of metamorphism in the Acadian orogeny or to an earlier orogeny.

Major thrust faults and folded thrusts formed during the Acadian orogeny. The post-metamorphic Nonesuch River fault underwent principal movement, maybe strike slip, prior to emplacement of the Lyman and Saco plutons whose contacts with their country rock have not been appreciably offset. Reactivation of the fault after emplacement of the plutons is suggested by the topographic lineaments within the plutons (Hussey and Newberg, 1978). This later movement, probably normal, was not of sufficient magnitude to offset the contacts significantly.

Similarly the post-metamorphic Cape Elizabeth fault appears to follow a topographic lineament in the Biddeford pluton, but again, the Biddeford-Berwick contact is not offset appreciably. Major motion for this fault must then have predated Carboniferous time. Other faults in the study area that involve normal movement with downdropping to the northwest are the Ben Barrows and Moll Ockett faults. This normal faulting postdates the Carboniferous Sebago pluton and speculatively is correlated with Late Triassic rifting in other parts of the Appalachians.

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