Title: Bedrock Geology of the Camden Hills Area, Central Coastal Maine

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Contents: 30 page report and 2 maps
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Purpose</td>
<td>1</td>
</tr>
<tr>
<td>Geologic Setting and Previous Work</td>
<td>1</td>
</tr>
<tr>
<td>Economic Geology</td>
<td>3</td>
</tr>
<tr>
<td>STRATIGRAPHY OF THE LAYERED ROCKS</td>
<td>3</td>
</tr>
<tr>
<td>General Statement</td>
<td>3</td>
</tr>
<tr>
<td>The Megunticook Formation</td>
<td>5</td>
</tr>
<tr>
<td>Battle quartzite member</td>
<td>5</td>
</tr>
<tr>
<td>Gray quartz-mica schist</td>
<td>8</td>
</tr>
<tr>
<td>Tablelands schist member</td>
<td>9</td>
</tr>
<tr>
<td>Calc-silicate quartzite member</td>
<td>9</td>
</tr>
<tr>
<td>Chiastolite schist member</td>
<td>10</td>
</tr>
<tr>
<td>Summit quartzite lens</td>
<td>11</td>
</tr>
<tr>
<td>Sulfidic schist lens</td>
<td>11</td>
</tr>
<tr>
<td>Other Rocks</td>
<td>12</td>
</tr>
<tr>
<td>The Penobscot Formation</td>
<td>12</td>
</tr>
<tr>
<td>The Stratigraphic Column</td>
<td>13</td>
</tr>
<tr>
<td>Age</td>
<td>14</td>
</tr>
<tr>
<td>Correlation</td>
<td>15</td>
</tr>
<tr>
<td>IGNEOUS ROCKS</td>
<td>16</td>
</tr>
<tr>
<td>General Statement</td>
<td>16</td>
</tr>
<tr>
<td>Mafic Rocks</td>
<td>17</td>
</tr>
<tr>
<td>Rocks of Intermediate Composition</td>
<td>17</td>
</tr>
<tr>
<td>Muscovite-Biotite Granite</td>
<td>17</td>
</tr>
<tr>
<td>Composite Basalt-Granite Dikes</td>
<td>18</td>
</tr>
<tr>
<td>Unmapped Pegmatites</td>
<td>18</td>
</tr>
<tr>
<td>STRUCTURAL GEOLOGY</td>
<td>19</td>
</tr>
<tr>
<td>Introduction</td>
<td>19</td>
</tr>
<tr>
<td>Possible Early Structures</td>
<td>19</td>
</tr>
<tr>
<td>Isoclinal Fold Features</td>
<td>19</td>
</tr>
<tr>
<td>Northeast-Trending Features</td>
<td>21</td>
</tr>
<tr>
<td>Easterly Trending Features</td>
<td>21</td>
</tr>
<tr>
<td>Other Structural Features</td>
<td>22</td>
</tr>
<tr>
<td>Cross Section X-Y</td>
<td>22</td>
</tr>
<tr>
<td>METAMORPHISM</td>
<td>22</td>
</tr>
<tr>
<td>Introduction</td>
<td>22</td>
</tr>
<tr>
<td>Andalusite-Staurolite Event</td>
<td>22</td>
</tr>
<tr>
<td>Sillimanite-Pseudomorph Event</td>
<td>23</td>
</tr>
<tr>
<td>Retrograde Event</td>
<td>23</td>
</tr>
<tr>
<td>Timing of Metamorphism</td>
<td>24</td>
</tr>
<tr>
<td>BEDROCK GEOLOGIC HISTORY</td>
<td>24</td>
</tr>
<tr>
<td>REFERENCES CITED</td>
<td>27</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.</td>
<td>Location map of Penobscot Bay</td>
<td>2</td>
</tr>
<tr>
<td>Figure 2.</td>
<td>Stratigraphic column of the Camden Hills</td>
<td>4</td>
</tr>
<tr>
<td>Figure 3.</td>
<td>Local correlation chart</td>
<td>6</td>
</tr>
<tr>
<td>Figure 4.</td>
<td>Sketch of folds on Bald Rock Mountain</td>
<td>20</td>
</tr>
<tr>
<td>Figure 5.</td>
<td>Schematic cross sections illustrating geologic history</td>
<td>25</td>
</tr>
</tbody>
</table>

# LIST OF PLATES

<table>
<thead>
<tr>
<th>Plate</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate 1.</td>
<td>Geologic map of the Camden Hills</td>
</tr>
<tr>
<td>Plate 2.</td>
<td>Tectonic map and metamorphic map of the Camden Hills</td>
</tr>
</tbody>
</table>
The work and ideas presented in this report are based directly on my M.S. thesis at the University of Maine at Orono (Berry, 1986), which benefited from reviews by Bradford A. Hall, Daniel R. Lux, and Charles V. Guidotti as well as from the experience, criticism, and support of Philip H. Osberg, my thesis advisor.

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To all these people and institutions I extend my personal thanks. Each has made a direct contribution to my work in the Camden Hills, although the content of this report is ultimately my own responsibility.
INTRODUCTION

PURPOSE

The primary purpose of this study is to describe the stratigraphy and structural geology of the Camden Hills, Maine. This report presents a detailed map which demonstrates the lateral extent, continuity, and contact relationships of the various rock units. The contacts on the map together with field observations allow an interpretation of the structural geometry and deformational history of these rocks.

Also of interest is the complex recrystallization history of the metamorphic rocks and its relationships with deformational and plutonic episodes.

Finally, the geology of the Camden Hills can be compared with what is known about nearby and geologically related areas. It is hoped that this study will be a starting point for more extended stratigraphic and structural studies.

GEOLOGIC SETTING AND PREVIOUS WORK

The Camden Hills are located on the western shore of Penobscot Bay in central coastal Maine (Figure 1). This area is in the Cookson-Penobscot belt, part of the coastal lithotectonic belt as shown on the Bedrock Geologic Map of Maine (Osberg et al., 1985).

The first systematic studies which included the Camden area were those of Penobscot Bay by Smith, Bastin, and Brown (1907) and of the Rockland quadrangle by Bastin (1908) which included the first descriptions of the Battie Quartzite and Penobscot Slate which were inferred to be "probably of Cambrian age". The locations of these and several other studies are shown in Figure 1.

Allen (1951) worked on the structural geology of the Rockland-Thomaston limestone belt. He interpreted a northeast plunging anticlinal structure based on the orientation of several minor folds in the limestone. Cheney (1967) produced a map of the same Knox County marble belt and described evidence for two phases of folding.

Bickel (1971, 1974, 1976) studied the stratigraphy, structure, and metamorphism of the Belfast 15-minute quadrangle of which the Lincolnville 7.5-minute quadrangle is the southeastern quarter. He separated the Megunticook Formation from the Penobscot Formation. Structurally, he interpreted the southern part of the Belfast quadrangle as a northwest-dipping homoclinal sequence. He also interpreted the Jam Brook Formation within the homocline to be a transgressive sequence topping to the northwest. Thus, he inferred the Megunticook Formation to the southeast to be older than the Penobscot Formation. Bickel mapped all the stratified rocks in the Camden Hills portion of the Belfast quadrangle as belonging to the Penobscot Formation.

Osberg and Guidotti (1974) divided the rocks of the Camden-Rockland area into three stratigraphic sequences isolated from each other by faults.
Figure 1. Map showing locations of some geologic studies in Penobscot Bay, Maine. 1. Smith and others (1907); 2. Bastin (1908); 3. Cheney (1967); 4. Bickel (1971); 5. Osberg and Guidotti (1974); 6. Stewart (1974); 7. Stewart and Wones (1974); 8. Berry (1986), this study.
The three sequences are the Megunticook sequence, the Rockport sequence, and the Benner Hill sequence. The Camden Hills portion of the Camden quadrangle was mapped as entirely within the Megunticook sequence which includes rocks of both the Megunticook Formation and the Penobscot Formation of Bickel (1971). Osberg and Guidotti proposed a geologic history including three phases of folding, two generations of thrust faults, two generations of high-angle faults, three ages of intrusion, and two metamorphic events. Based on Caradocian age brachiopods from the Benner Hill sequence (Boucot et al., 1972) and tentative regional correlations, the three sequences were thought to be Lower Paleozoic or older.

Stewart (1974) described the geology of the island of Islesboro in Penobscot Bay and interpreted the presence of the Turtle Head fault zone to account for "so few similarities with the stratigraphic columns in adjacent structural blocks". One splay of this proposed fault zone separates the Camden Hills and adjoining mainland from Islesboro. Stewart and Wones (1974) presented evidence for faulting in northern Penobscot Bay. Wones (1974) described the various plutons in the same area.

Brookins (1976) published Rb-Sr whole rock dates on several samples from coastal Maine, including metamorphosed sedimentary rocks from the Battie Quartzite and the Penobscot Formation.

ECONOMIC GEOLOGY

While the Rockland-Camden region is locally known for its limestone quarries, there are none in the Camden Hills. There are a few small gravel pits along U.S. Route 1, and one on Route 52 south of Youngstown which are occasionally active. One granite quarry approximately 610 meters northwest of the intersection at Youngstown and one crushed rock quarry 800 meters S 79° E of Cameron Mountain are both inactive.

Morrill (1955) reports a prospect in a white quartz vein which produced lead and iron sulfides plus enough gold and silver to justify the formation of the Lincolnville Gold and Silver Company. The prospect is reported to have been located on the southeast side of Derry Mountain. It was active about 1875 and is more of historic than of geologic or economic interest.

STRATIGRAPHY OF THE LAYERED ROCKS

GENERAL STATEMENT

The rocks of the Camden Hills are divided into the Cambrian(?) Megunticook Formation and the Cambrian(?)–Ordovician(?) Penobscot Formation which are interpreted to be in a conformable stratigraphic sequence (Figure 2). Four horizons within the Megunticook Formation have been mapped as members. These are the Battie quartzite member, the Tablelands schist member, the calc-silicate quartzite member, and the chiastolite schist member. In addition, two horizons within the Megunticook Formation have been mapped as lenses. These are the summit quartzite lens, and the sulfidic schist lens. The areal distributions of these units are shown in
Figure 2. Stratigraphic column of the Camden Hills. Thicknesses are approximated from the map (Plate 1) and from cross section X-Y (Plate 3) for the area from Mount Battie across Mount Megunticook to the northeast.
THE MEGUNTICOOK FORMATION

Name. The name, Megunticook Formation, was proposed by Bickel (1971) to designate a rock unit exposed on the northern islands and shore of Megunticook Lake. It was described by him as consisting mostly of gray gneiss, quartz-mica schist, and lesser marble, with minor quartzite and calc-silicate granulite. The usage of Megunticook Formation in this paper is consistent with that of Bickel, but a more detailed internal stratigraphy is described here.

It should be emphasized that the Megunticook Formation as used here does not coincide with the Megunticook sequence of Osberg and Guidotti (1974). Only unit 1 and unit 2 of their Megunticook sequence belong to the Megunticook Formation; unit 3 of their Megunticook sequence belongs to the Penobscot Formation. It is proposed that unit 3 of their Rockport sequence might also be included in the Megunticook Formation (as shown by Osberg et al., 1985) (Figure 3).

Distribution. The Megunticook Formation underlies the southern and western part of the map area. This part of the area includes Mount Battie, Mount Megunticook except for the northern flank of Zekes Lookout, Millerite Ledges, Maiden Cliff, and the western side of Cameron Mountain (Plate 1). There are extensive, easily accessible exposures of light gray quartz-mica schist on Millerite Ledges and in the road cut on Route 52, 1400 meters N 89° W from the 1385 foot summit of Mount Megunticook.

Thickness. The lower contact of the Megunticook Formation is not exposed in the field area. The portion of the Battie quartzite member which is exposed is estimated to be 300 meters thick. The present thickness of the portion of the Megunticook Formation above the Battie quartzite member is estimated to be 570 meters thick. Repetition by minor folds presumably makes these present thicknesses somewhat greater than the original stratigraphic thicknesses, but the relationship between present thickness and stratigraphic thickness has not been estimated. The contact of the Megunticook Formation with the overlying Penobscot Formation is gradational over less than 5 meters.

Lithology. The predominant rock types of the Megunticook Formation are gray quartz-mica schist and schistose gneiss. Within these schists and gneisses are the Battie quartzite member, Tablelands schist member, calc-silicate quartzite member, chiastolite schist member, summit quartzite lens, and sulfidic schist lens (Figure 2). These units provide fundamental stratigraphic and structural control in a sea of massively bedded, structurally obscure gray schist and schistose gneiss.

Other rock types present within the Megunticook Formation, but in small amounts, include quartz-rich granulites, calc-silicate granulite, and garnet-rich granulites.

Battie quartzite member

The oldest unit in the study area is the Battie quartzite member of
Osberg et al. (1985) and this paper

<table>
<thead>
<tr>
<th>CAMDEN</th>
<th>LINCOLNVILLE</th>
<th>APPLETON</th>
</tr>
</thead>
<tbody>
<tr>
<td>PENOBSCOT FORMATION</td>
<td>PENOBSCOT FORMATION</td>
<td>PENOBSCOT FORMATION</td>
</tr>
<tr>
<td>MEGUNTICOOK FORMATION</td>
<td>MEGUNTICOOK FORMATION</td>
<td>MEGUNTICOOK FORMATION</td>
</tr>
<tr>
<td>ROCKPORT SEQUENCE</td>
<td>BATTLE FORMATION</td>
<td>POLYMICT CONGLOMERATE</td>
</tr>
<tr>
<td>UNIT 3</td>
<td>UNIT 1</td>
<td>UNIT 3</td>
</tr>
<tr>
<td>UNIT 2</td>
<td>UNIT 2</td>
<td></td>
</tr>
<tr>
<td>UNIT 2</td>
<td>UNIT 1</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. Correlation of units in the Camden Hills with units of previous workers.
the Megunticook Formation. The Battie quartzite member as presented here includes only some of the rocks assigned to the Battie Quartzite by Smith, et al. (1907) and by Bastin (1908). The Battie quartzite member consists of distinctive quartzite conglomerate such as that which is exposed on Mount Battle (Plate 1). Other quartzites in the area were included by Smith, et al. (1907) in their Battie Quartzite unit, but these correlations are now considered uncertain or incorrect. Also, the lithology of the Battie quartzite member is unique among the several quartzites in the area. Therefore, it is recommended that the broad usage of Battie Quartzite by Smith, et al. (1907) be dropped in favor of the more restricted Battie quartzite member of the Megunticook Formation as used here.

Bickel (1976) unfortunately assigned a variety of rocks northwest of the Camden Hills to the "Battie Formation". These same rocks he had earlier assigned to the Megunticook Formation (Bickel, 1971, 1974), which is the assignment preferred and followed in this paper. This allows the name Battie to be reserved only for the quartzite conglomerate unit within the Megunticook Formation. This nomenclature emphasizes the probability that those rocks northwest of the Camden Hills belong to part of the Megunticook Formation stratigraphically above the Battie quartzite member.

The Battie quartzite member as used here is the same as unit 1 of the Megunticook sequence of Osberg and Guidotti (1974). Osberg, et al. (1985) referred to these rocks as the Mt. Battie Formation.

The lithology of the Battie quartzite member is quite striking. It consists of quartzite conglomerate with clasts 2 to 8 centimeters in diameter, enclosed in a light gray to white, biotitic quartzite matrix. The clasts are generally spherical (see Paterson, 1981 for discussion), angular to subangular, and consist almost exclusively of white to light gray, clean to biotitic quartzite. Although clasts make up the major portion of the rock, they are matrix-supported, separated from each other by matrix quartzite. The even spacing and the size of the clasts are notably consistent from place to place; such primary features as bedding and clast imbrication are subtle or absent, except near the upper contact of the member as described below. Biotite in the matrix is fine grained, evenly distributed and has no obvious preferred orientation.

Near the upper contact of the member, lenses and beds of clean quartzite, typically 5 to 20 centimeters thick, are present within the quartzite conglomerate. This lithology grades upward into rock with a smaller ratio of conglomerate to quartzite, smaller clast-size conglomerates, and somewhat more regular bedding as the contact is approached. Just below the contact, conglomerate occurs only in lenses within bedded quartzite which also contains scattered lenses of muscovite-rich, schistose quartzite. This sequence is well displayed in roadside outcrops 800 meters N 50º E from the Mount Battie summit observatory. The upper contact of the Battie quartzite member is defined by the lowest continuous layer of schist interbedded with quartzite. The Battie quartzite member does include a small interval of relatively clean, bedded quartzite at its top. Cut and fill structures and sparse graded beds are present locally in this interval.
Gray quartz-mica schist

Massive, medium to light gray quartz-mica schist of the Megunticook Formation is present between the Battie quartzite member and the Tablelands schist member, between the chiastolite schist member and the summit quartzite lens, and above the sulfidic schist lens to the top of the formation (Figure 2). It is the characteristic rock which ties together the Megunticook Formation.

Most weathered surfaces are light gray, although a few cleavage surfaces have an orange-brown weathering stain. Commonly, grains of andalusite, garnet, and quartz stand out in relief causing nubby outcrop surfaces.

Most gray quartz-mica schist is massive, lacking pronounced bedding contacts. However, well developed bedding does exist in two places worth noting. One place is just above the Battie quartzite member, and the other is near the top of Mount Megunticook, just above the chiastolite schist member (Plate 1, Figure 2). At the location just above the Battie quartzite member, there are irregularly interbedded quartzite and more or less quartz-rich pelitic schist. Bedding thicknesses range from about 2 to 20 centimeters, with lateral as well as bed-to-bed variation. Both the thickness and amount of quartzite relative to schist gradually decrease with higher stratigraphic position away from the Battie quartzite member to a point where thin quartzite layers are lenticular to obscure within typically monotonous gray quartz-mica schist. This type of well bedded rock represents about 70 meters of section above the Battie quartzite member. It is well displayed on the abandoned carriage road 600 meters N 35° W from the observatory.

Gray quartz-mica schist of the Megunticook Formation is also well bedded just above the chiastolite schist member near the top of Mount Megunticook. There, silvery-gray quartz-mica schist with white-weathering chiastolite and andalusite is interbedded with chalky-weathering, feldspathic, quartz-rich granulite on a 1 to 5 centimeter scale with beds commonly graded. The bedding is regular and laterally continuous, with a ratio of pelite to granulite of about 2:1 to 5:1.

Fine to medium-fine grained quartz-rich layers are common in the Megunticook Formation, in addition to those described above. These are dark gray, biotitic quartzites and light gray quartz-biotite-muscovite granulites and schistose granulites. These various quartz-rich granulites typically occur as small pods or layers less than 5 centimeters thick within outcrops of gray quartz-mica schist. Some layers probably represent relict bedding, but some clearly cut bedding and are interpreted to be a metamorphic feature.

The typical mineralogy of the gray schist includes quartz, muscovite, biotite, garnet, and andalusite, all in medium to coarse grains identifiable in hand specimen. Many rocks, however, contain a variation of this assemblage. Specifically, one or more of the minerals fibrolitic sillimanite, chlorite, chloritoid, and sericite are present at many locations. Another variation is the presence of clots of coarse grained muscovite+quartz+biotite interpreted to be pseudomorphous after andalusite.
Pale red garnet is ubiquitous, occurring as 1 to 3 millimeter beads scattered throughout the rock. Small amounts of microscopic plagioclase, ilmenite, apatite, tourmaline, zircon, and allanite are commonly present in all these rocks.

Coticule-bearing rocks make up a distinctive group of rare rocks in the Megunticook Formation. These rocks have thin beds or pods rich in fine grained, pale salmon colored garnets. Coticule-bearing gray schists are exposed 260 meters southeast of the top of Garey Mountain, on the top and northeast side of Bald Rock Mountain, and in the road cut on Route 52, 1400 meters N 89° W from the 1385 foot summit of Mount Megunticook. The coticule occurs as thin, isolated pods and stringers, typically 1/2 centimeter thick, each mantled by a thin black biotite layer one millimeter thick. The amount of coticule within the schist ranges from less than 1% where isolated pods are present, to about 10% where stringy layers are more abundant. Continuous layers of coticule are rare; pinch and swell structure is common. In thin section, the coticule pods are seen to consist of more than 95% garnet and quartz. The relative proportion of garnet to quartz ranges from about 1:3 to 2:1.

Schistosity in the gray quartz-mica schist is defined by the parallel orientation of muscovite and biotite grains. Parallel to this foliation are thin quartz-rich pods or stringers, some of which may be remnants of quartzite beds but most of which are interpreted as metamorphic segregations. Many rocks are more properly called schistose gneisses, but they differ from gray quartz-mica schists only by their contorted structure.

Tablelands schist member

The Tablelands schist member of the Megunticook Formation is named for the broad, gently sloping area partway down the southern and southwestern side of Mount Megunticook, locally known as the Tablelands (Plate 1). There, it is about 100 meters thick. At the northwest end of the tablelands it thins dramatically. Farther northwest, the Tablelands schist member is traced to Maiden Cliff where it is somewhat thicker.

The characteristic rock of the Tablelands schist member is reddish-brown rusty weathering, massively bedded, quartz-muscovite-biotite-garnet-andalusite-graphite schist. The dull reddish-brown weathering, presumably due to iron sulfide in the rock, and the more homogeneous, even texture with few coarse pseudomorphs distinguish these rocks from the underlying gray quartz-mica schist. In general, these rocks contain somewhat more graphite and are less quartz-rich than the gray quartz-mica schist.

Calc-silicate quartzite member

The lower part of the cliff which rises above the tablelands on Mount Megunticook is composed of rocks of the calc-silicate quartzite member. The rocks of this member characteristically form large, steep-sided outcrops and loose, angular blocks. A talus pile covers the foot of the cliff, obscuring the contact between the calc-silicate quartzite member and the underlying Tablelands schist member there. The upper contact, with the chiastolite schist member is exposed partway up the cliff. The calc-
silicate quartzite member at this locality is estimated to be 30 meters thick.

The calc-silicate quartzite member of the Megunticook Formation includes a variety of quartz-rich granulites, the most distinctive of which is a white to greenish white quartzite that contains white needles of tremolite 2 to 5 millimeters long. Other calc-silicate minerals such as diopside, epidote, actinolite, garnet, and sphene are commonly present with a substantial amount of quartz. This unit is heterogeneous insofar as the amounts of these minor constituents differ from place to place; that is, the calc-silicate quartzite member includes rare yellowish-white to buff-weathering clean quartzite as well as green, actinolite-rich granulite. The most common rock type is between these extreme compositions, being an impure quartzite with less than half calc-silicate minerals. The "guide fossil" of the calc-silicate quartzite member is the white calcic amphibole, tremolite. It is commonly, though not everywhere, present in this unit and has not been found in calc-silicate rocks elsewhere in the Megunticook Formation.

Within this member is a thin lens of light gray, massive marble northeast of Maiden Cliff, shown on Plate 1.

Bedding in the calc-silicate quartzite member is generally poorly defined, but thin quartzite beds are locally present. In some rocks, especially ones richer in calc-silicate minerals, thin brown seams and pits weather out suggesting a carbonate mineral is present, perhaps in relict beds. At one place, silvery muscovite schist was observed irregularly interbedded with quartzite on a scale of 1/2 to 3 centimeters thick. Some of these beds are graded.

Chiastolite schist member

Immediately above the calc-silicate quartzite member is the chiastolite schist member of the Megunticook Formation. It is estimated to be 40 meters thick, being overlain by gray quartz-mica schist. Its map pattern parallels that of the calc-silicate quartzite member except where the chiastolite schist member reaches the crest of Mount Megunticook at the beginning of Spring Brook. From there, it can be traced for a distance down the northeastern slope of the mountain. Because this slope is nearly parallel to the dip of bedding, the breadth of outcrop of the chiastolite schist member here is unusually large even though its thickness is not significantly greater than elsewhere.

Rocks of the chiastolite schist member typically weather medium to steel gray, but are locally orange rusty weathering. The matrix is medium to fine grained and bluish black, consisting of biotite, graphite, quartz, muscovite, and plagioclase with very fine, disseminated graphite making up as much as 30% of the matrix. The small amount of muscovite and near absence of garnet distinguish this schist from others in the Megunticook Formation. Abundant chiastolite megacrysts typically 5 centimeters long, and ranging up to 12 centimeters long, characterize the unit.

West of the Mount Megunticook summit near the top of Spring Brook this unit contains graded beds near its upper contact. These beds are 2 to 5
centimeters thick with white, quartz-rich granulite overlain by black, chiastolite schist in proportional thicknesses of 1:4.

Summit quartzite lens

At the 1385 foot summit of Mount Megunticook, overlying gray quartz-mica schist, is the summit quartzite lens of the Megunticook Formation. At this summit it forms a thin cap whose upper contact has been largely eroded, except where a small area of the overlying sulfidic schist lens is preserved (Plate 1). Also assigned to the summit quartzite lens are rocks on the west-facing slope below Zekes Lookout. The summit quartzite lens is estimated to be commonly 40 to 65 meters thick, but thins laterally.

Quartzites of this unit are typically layered to laminated, although massive quartzite is locally present. Coticule beds and laminae are common, consisting of medium to fine grained, pale salmon colored garnet with subordinate minor amounts of quartz. The amount of coticule is different from place to place in that some outcrops contain only white, layered quartzite, others contain interlayered coticule and quartzite, and others are largely orange-pink coticule. The lamination which is commonly present in all these rocks consists of laterally continuous black pinstripes, largely of biotite. A few small pods of light green, fine grained calc-silicate granulite were found in this unit west of Zekes Lookout.

It should be interjected here that some outcrops of the calc-silicate quartzite member are similar to some outcrops of the summit quartzite lens, suggesting a possible correlation of these two units. Even though they are both heterogeneous units, the dominance of calc-silicate minerals and minor marble in the first case and of coticule-bearing and well layered quartzites in the second case argues against correlation. More convincingly, the units above and below the two quartzites are not the same. In this regard, the only doubt is raised by the lithologic similarity of the Tablelands schist member, below the calc-silicate quartzite member, to the sulfidic schist lens, above the summit quartzite lens. But the distinctive rocks of the chiastolite schist member are not found below the summit quartzite lens, where instead gray quartz-mica schist is present (Plate 1, Figure 2).

Sulfidic schist lens

A small patch of rock just east of the 1385 foot summit of Mount Megunticook and a thin belt of rock just west of Zekes Lookout are assigned to the sulfidic schist lens of the Megunticook Formation (Plate 1). This lens directly overlies the summit quartzite lens. Its upper contact is eroded at the Mount Megunticook summit, but west of Zekes Lookout it is overlain by gray quartz-mica schist. It is estimated to be 20 meters thick at most.

The rocks of this unit are orange- to brown-rusty weathering, silvery-gray to black, biotite-quartz-muscovite-graphite schist containing coarse andalusite crystals or pseudomorphs. In some places, where andalusite is less abundant, the rock is more evenly textured and smooth-weathering like rocks of the Tablelands schist member.
Other Rocks

Besides the units just described, two small areas of other rocks are present in the Megunticook Formation. These are a light green "grasshopper rock" and a light gray, coticule-bearing quartzite. These two units are separately mapped on Plate 1, north of Mount Battie and just east of Route 52.

The "grasshopper rock" consists of fine-grained, light green quartz-diopside-actinolite granulite with closely spaced, 1/4 to 1 millimeter thick quartzite laminae. In thin section, significant amounts of finer grained epidote and microcline can be seen, with accessory amounts of sphene and allanite(?). A few interbeds of slabby biotite granulite about 5 to 10 centimeters thick are also present. The whole calc-silicate horizon is about 10 meters thick. Light gray quartz-mica schist lies below it and above it. This "grasshopper rock" is similar to a minor lithology in the calc-silicate quartzite member on the southeastern slope of Mount Megunticook.

A small area of light gray, coticule-bearing quartzite is mapped west of the "grasshopper rock". The quartzites here are light gray to white with more or less fine grained biotite and are well laminated. Stringers and beds of 1 to 5 millimeter thick coticule are common, with coticule beds locally up to 5 centimeters thick. Minor amounts of quartz-muscovite granulite and light greenish gray calc-silicate granulite are interbedded with this quartzite. The mapped unit is about 15 meters thick, both over lain and under lain by light gray quartz-mica schist. This unit is lithologically similar to the summit quartzite lens.

THE PENOBSCOT FORMATION

Name. The name, Penobscot Formation, was first used by Smith, et al. (1907) and then by Bastin (1908). It was defined as consisting of "metamorphosed shaly sediments which are typically developed along nearly the whole length of the western shore of Penobscot Bay" (Smith et al., 1907, p. 3). As mapped by them, it included rocks of both the Penobscot Formation and Megunticook Formation of this paper.

Bickel (1971) restricted the name Penobscot Formation to apply to rusty-weathering pelitic schists, while separately mapping the Megunticook, Jam Brook, Appleton Ridge, and Bucksport Formations, all of which had been included in the Penobscot Formation by several workers at various times (e.g. Bastin, 1908; Perkins and Smith, 1925; and Doyle and Warner, 1965). The name Penobscot Formation as used in this report follows the usage of Bickel (1971), but not of Bickel (1976) who lumped rocks of the Megunticook Formation of the Camden Hills in the Penobscot Formation.

Distribution. The Penobscot Formation underlies the central and northeastern part of the Camden Hills as well as a narrow strip along the Penobscot Bay coast (Plate 1). The shore exposures are washed clean and display bedding well. There are many outcrops inland as well, the weathered surfaces of which tend to emphasize the schistosity and obscure bedding contrasts somewhat. There are good exposures on Cameron Mountain,
on Bald Rock Mountain, and in the abandoned quarry 800 meters S 79° E from the top of Cameron Mountain.

**Thickness.** The upper contact of the Penobscot Formation is not within the mapped field area. The portion of the unit which is present has an estimated thickness of 150 meters.

**Lithology.** The predominant and characteristic rock type of the Penobscot Formation is rusty-weathering, dark gray to black, biotite-muscovite-quartz-plagioclase-andalusite-graphite-pyrrhotite-pyrite-fibrolite schist. Weathered outcrop surfaces are dark orange-brown to purplish black. A rusty weathering stain penetrates along cleavage surfaces well into the rock. Garnet, which is ubiquitous in adjacent Megunticook Formation schist, is imperceptible in hand samples of the Penobscot Formation, although some microscopic blebs of anhedral garnet are present in small amounts.

Many outcrops consist exclusively of massive, rusty-weathering schist. However, widespread evidence of bedding exists, most commonly as quartzite interbedded with the schist. In some places, particularly near the lower contact of the formation, bedding is on the scale of 10 to 20 centimeters thick and fairly regular, with quartzite consistently subordinate to schist. Graded beds are rare. In other places, quartzite interbeds are less abundant but thicker, up to 1 meter thick. These quartzites are white on fresh surfaces and in clean shoreline exposures; weathered surfaces are a dull orange-brown rusty color. Most quartzites are clean except for common thin, biotite-rich laminations. These are interpreted as a tectonic foliation. Primary structures are rare.

A small amount of rusty-weathering calc-silicate granulite is present. It occurs in isolated beds up to 30 centimeters thick within schist typical of the Penobscot Formation. This rock is fine grained, dark greenish gray to black, and massive, containing quartz, plagioclase, actinolite, zoisite, sphene, and minor amounts of pyrrhotite specks. The rusty weathering rind is thin, below which the rock is generally fresh. These beds break into blocky, angular pieces and stand out from the rest of the outcrop in many cases.

THE STRATIGRAPHIC COLUMN

**Contact Relations.** A generalized summary of the stratigraphy is presented in Figure 2, the stratigraphic column. This particular column is based on the portion of the map from Mount Battie across the tablelands and over Mount Megunticook toward the northeast. The thicknesses are based on the constructed structure section X-Y (Plate 1).

The internal stratigraphy of the Megunticook Formation is mappable across the field area. The fact that the distinctive rocks mapped as members occur in a consistent sequence supports the contention that it is a continuous, one directional sequence.

An important question is which way this stratigraphic sequence faces. The sequence as presented in Figure 2 is supported by three key observations:
(1) The gradational nature of the contact at the top of the Battie quartzite member. The transition from coarse conglomerate, through finer-grained conglomerate, through bedded quartzite, to quartz-rich schist is a fining-upward sequence. In addition, the numerous cut and fill structures and the few graded beds observed at this horizon indicate stratigraphic tops to the north or northeast.

(2) In the calc-silicate quartzite member, a short but uncertain distance above the unexposed contact with the Tablelands schist member, graded beds indicate upward facing.

(3) At the top of the chiastolite schist member, a short distance northwest of the 1385 foot summit of Mount Megunticook, is a thin interval of graded beds indicating tops are up, into the gray schist above the chiastolite schist member.

The contact between the Megunticook Formation and the Penobscot Formation is interpreted to be a conformable stratigraphic contact. Rocks very near or containing this contact are exposed at several places in the Camden Hills area (Plate 1). The contact seems to be gradational over a small interval, commonly less than 2 meters and in all cases less than about 5 meters, in the following manner. Below the contact is light gray, quartz- and muscovite-rich, garnet-bearing schist of the Megunticook Formation. At the excellent exposures on Garey Mountain, the top of Bald Rock Mountain, and Zekes Lookout, thin, discontinuous coticule beds are present near but not restricted to near the contact. As the contact is approached, the schist becomes more orange-brown rusty weathering. The rusty weathering becomes more intense to where a dark brown to purplish-black crust covers the outcrop surface. Concomitantly, the schist becomes poorer in quartz and garnet, and richer in biotite and graphite to where black schist typical of the Penobscot Formation is present. At the locality east of Sherman Cove in Camden described as stop 9 of Osberg and Guidotti (1974, p. 59-60), a thin white marble unit occurs just above the base of the Penobscot Formation. Marble at this horizon was not observed elsewhere in the field area.

AGE

The Penobscot Formation is considered to be Upper Cambrian-Lower Ordovician (Tremadocian). This is based on its correlation with the Cookson Formation which contains graptolites on Cookson Island in Oak Bay, New Brunswick. This correlation has been suggested by several authors (Stewart and Wones, 1974; Osberg and Guidotti, 1974; Ruitenberg and Ludman, 1978) and is now generally accepted. Except for intervening plutons, the Penobscot Formation can be traced from the Camden Hills to Cookson Island (Osberg et al., 1985).

The fossils on Cookson Island were first described by Cumming (1957) who deduced an Arenigian (Early Ordovician) age. Ruitenberg and Ludman (1978) report that new collections suggest a somewhat older Ordovician age (Tremadocian). In addition, they interpret the thinly bedded graphitic slate at the fossil locality to be stratigraphically higher than massive quartzites in the Cookson Formation which may extend down into the
Cambrian. Therefore, a somewhat broad estimate of Upper Cambrian-Lower Ordovician for the Penobscot Formation is proposed.

The Megunticook Formation is considered to be of Cambrian age because it is conformably beneath the Penobscot Formation. Lower constraints for the Megunticook Formation are not certain, but if the schist at the top of the Rockport sequence belongs to the base of the Megunticook Formation, then the Megunticook Formation is probably all Cambrian and not Precambrian (see "CORRELATION", below).

CORRELATION

The Battie quartzite member of the Megunticook Formation is equivalent to unit 1 of the Megunticook sequence of Osberg and Guidotti (1974) (Figure 3). The part of the Megunticook Formation above the Battie quartzite member is equivalent to unit 2 of the Megunticook sequence. The Penobscot Formation is equivalent to unit 3 of the Megunticook sequence, and to the Owls Head Unit of Guidotti (1979). However, the Penobscot Formation is lithologically different and does not correlate with any part of the Benner Hill sequence as had been suggested by Stewart and Wones (1974). This is emphasized by the Middle Ordovician (Caradocian) brachiopods from the Benner Hill (Boucot et al., 1972) in contrast to the lowermost Ordovician age inferred for the Penobscot Formation.

In the western Penobscot Bay area, the Megunticook Formation may possibly correlate with rocks in the Rockport sequence or in the Jam Brook Formation. The uppermost unit in the Rockport sequence (Osberg and Guidotti, 1974; Osberg, unpub. data) consists of light gray andalusite schist with basal gritty quartzite and polymictic pebble conglomerate which rests with angular unconformity on older units of the Rockport sequence. It is suggested that this schist may represent the basal part of the Megunticook Formation, below the Battie quartzite member (Osberg et al., 1985). A westerly trending fault with associated brecciation, mineralization, and truncation of units separates the Megunticook Formation of the Camden Hills from the Rockport sequence on the south. The older units of the Rockport sequence are tentatively correlated by Osberg (pers. comm., 1986) with some rocks of the Islesboro Formation (Smith et al., 1979), which are considered "post-late Precambrian" because they are unconformably above rocks intruded by a 600 m.y. pegmatite dike (Stewart, 1974). If the older units of the Rockport sequence are "post-late Precambrian", then the andalusite schist at the top of the Rockport sequence is probably Cambrian, which is consistent with its being in the lower Megunticook Formation.

The Jam Brook Formation (Bickel, 1971) from west to east includes light gray marble, andalusite schist, polymictic pebble conglomerate, and andalusite schist. This eastern schist is in contact with and presumably older than the Penobscot Formation on the east. Because of its apparently analogous stratigraphic position below the Penobscot Formation, at least the upper andalusite schist of the Jam Brook Formation may correlate with andalusite schist of the Megunticook Formation (Figure 3). Interestingly, the distinctive polymictic pebble conglomerate of the Jam Brook Formation is lithologically similar to the one at the base of the andalusite schist in the Rockport sequence. If these two conglomerates are correlative, why
are the thick and varied strata of the Camden Hills Megunticook Formation absent from the Jam Brook Formation? Regional correlation of the Jam Brook Formation remains a problem.

In eastern Maine and western New Brunswick, the Cookson Formation, and by implication the Penobscot Formation, has been correlated with similar Tremadocian, graptolitic, black shales in the Miramichi anticlinorium to the northwest (Ruitenberg et al., 1977; Fyffe et al., 1983; Ludman, 1985; Fyffe and Pickerill, 1986), or alternatively, with those in the Navy Island and Suspension Bridge Formations of the Saint John Group to the southeast (Ruitenberg and Ludman, 1978; Ludman, 1986a, 1986b). Lithologically and faunally, these Lower Ordovician units are similar, but regional tectonic arguments seem to discourage correlation across all three belts (Fyffe and Pickerill, 1986; Ludman, 1986b). In the Big Lake quadrangle, the Cookson Formation and underlying Woodland Formation (Ludman, 1986b) together are probably equivalent to the Penobscot Formation.

In the Big Lake quadrangle (Ludman, 1986b), the Kendall Mountain and Pocomoonshine Lake Formations may correlate with the upper part of the Megunticook Formation. The Pocomoonshine Lake Formation may be an equivalent, at lower metamorphic grade, of the chiastolite schist member. Elsewhere, both the unnamed Cambrian-Ordovician unit of the southwest end of the Miramichi anticlinorium and the Cambrian part of the Saint John Group have assemblages of rock types similar to the Megunticook Formation, but neither can be correlated unit-for-unit with the Megunticook Formation. Ludman (1986b) and Fyffe and Pickerill (1986) agree that the rocks of the Saint John Group represent a shallower-water, shelf-type facies while the sediments of the Cookson Formation were deposited in deeper water, perhaps in a slope facies. The Megunticook Formation has an intermediate character, with thin units of quartzite and black shale such as the Saint John Group, but also with massive gray shales and some black shale-quartzite units with graded beds of perhaps deeper water. Similarly, the unnamed Cambrian-Ordovician unit of the Miramichi is not identical to, but may be a facies equivalent of the Megunticook Formation.

In southern New England, units which have quartz-rich gray shales and minor calc-silicate which might correlate with the Megunticook Formation include the Braintree Argillite and Hoppin Formation in Massachusetts (Bell and Alvord, 1976; Zen et al., 1983), and the Jamestown Formation and upper part of the Newport Formation in Rhode Island (Murray and Skehan, 1979).

**IGNEOUS ROCKS**

**GENERAL STATEMENT**

Variously metamorphosed to unmetamorphosed mafic rocks, intermediate compositional plagioclase granulite, muscovite-biotite granite, and composite basalt-granite dikes are mapped in the Camden Hills (Plate 1). Their ages are not known directly, but based on similarities to isotopically dated rocks in the region, they are presumed to be Silurian or Devonian. Unmapped pegmatite is also present.
MAFIC ROCKS

The large mafic plutonic body on Bald Rock Mountain and the surrounding smaller bodies (Plate 1) have been subdivided in a general way into coarse, medium, and fine grained varieties based on field observations. The petrologic distinction between these varieties and the nature of the contacts between them are uncertain.

The coarse and medium grained varieties consist largely of dark gray orthopyroxene-plagioclase norite. The grain size of the coarse grained rock is greater than 1 centimeter, and medium grained rocks have a grain size of about 0.2 to 1 centimeter. Texturally, these rocks are massive, with orthopyroxene phenocrysts or clusters of grains set in a somewhat less coarse orthopyroxene-plagioclase groundmass. Some of the medium grained rocks also contain hornblende.

Many of the fine grained and some of the medium grained mafic rocks are greenish-gray to dark green in color, and are presumed to be metamorphosed. The few thin sections examined from these rocks support this contention in that hornblende, variable amounts of biotite, and lesser amounts of chlorite constitute the mafic mineralogy.

Tentatively, it is suggested that some of the smaller bodies in the lower part of the Penobscot Formation may be metamorphosed mafic volcanics. In the Belfast quadrangle, Bickel (1971, 1976) has mapped a metamorphosed mafic volcanic unit, the Gushee Member, which seems to be at a similar horizon in the lower Penobscot Formation.

Most if not all of the contiguously mapped plutonic rocks on Bald Rock Mountain, together with the gabbro dike south of Cameron Mountain, are considered to be intrusive and coeval. These are similar to plutonic rocks to the west in the Union Igneous Complex (Rainville and Park, 1976; Talkington, 1983) which intrude the Megunticook Formation near the Penobscot Formation contact (Osberg et al., 1985). Zircons from a diorite of this complex yielded a U-Pb age of 410±7 Ma (Gaudette, 1981), which straddles the Silurian-Devonian boundary. By analogy, the pluton on Bald Rock Mountain is believed to be Late Silurian-Early Devonian. Some of the textural and mineralogical variation within the pluton may be due to different but related igneous phases such as described within the Union Igneous Complex.

ROCKS OF INTERMEDIATE COMPOSITION

Rocks of intermediate composition are rare in the Camden Hills. They are represented by a few small dikes of biotite-plagioclase granulite (Plate 1) which probably represent metamorphosed granodiorites. The origin and timing of these rocks are not well constrained.

MUSCOWITE-BIOTITE GRANITE

A large pluton on the northwest side of the study area and four smaller bodies nearby consist of biotite-muscovite granite (Plate 1). These rocks are evenly textured, massive to weakly foliated, medium to coarse grained, white granite. These granites are interpreted to be post-
tectonic based on sharp, crosscutting contacts and lack of deformational fabric.

Brookins (1983) gives the range of granite ages in the Penobscot Bay region to be 410 to 350 Ma, based on accumulated Rb-Sr whole rock data. The Bedrock Geologic Map of Maine (Osberg et al., 1985), based on these and other data, shows all granitic rocks of the Penobscot Bay area to be Devonian. The Wallamatogus pluton, mineralogically similar to the Camden Hills bodies, has yielded a $^{40}\text{Ar}~/^{39}\text{Ar}$ muscovite age of 397±2 Ma (D. R. Lux, unpub. data). The Camden Hills granites are therefore inferred to be Devonian, and perhaps Early Devonian.

Zartman, et al. (1970) obtained a K-Ar biotite age of 277±8 Ma for a sample of granite from the quarry northwest of Youngtown. They considered this to be a reset age. Alternatively, this may be a cooling age.

COMPOSITE BASALT-GRANITE DIKES

Between Maiden Cliff and Zekes Lookout, composite basalt-granite dikes have been mapped (Plate 1). These consist of biotite or biotite-hornblende granite containing enclaves of basalt, ranging from scattered, round, silver dollar-sized bodies enclosed in granite to larger, pillow-shaped bodies surrounded by granite matrix. The basalt-granite contacts are quite sharp with apparently little interaction of the two rock types. The basalt contains interlocking subhedral laths of plagioclase (estimated at An$_{57}$) with subhedral hornblende, suggesting a reasonably pristine igneous rock. Some biotite is present and contains a small amount of patchy chlorite which suggest some alteration, probably deuteric (Chapman, 1962).

Composite dikes of this type from eastern coastal Maine were described by Chapman (1962) who interpreted them to be intrusive breccias. They are typically in undeformed, unmetamorphosed dikes thought to have been emplaced along late- or post-Acadian brittle, extensional fractures.

Mitchell (1986) reports similar composite dikes on Vinalhaven Island in Penobscot Bay. Although he alternatively interprets them to have crystallized from commingling basaltic and granitic liquids, he similarly considers them to have originated and intruded in an extensional, late- or post-Acadian tectonic setting.

The composite dikes of the Camden Hills are considered coeval with those reported by Chapman and Mitchell and therefore are late- or post-Acadian.

UNMAPPED PEGMATITES

Many small pegmatites, considered locally derived, are present within outcrops of metamorphic rock. These pegmatites commonly contain muscovite, biotite, and garnet. Ductile deformation has affected them, indicating they are older than the muscovite-biotite granite described above.
INTRODUCTION

Deformational features in the Camden Hills have been divided into five groups: (1) possible early structures; (2) features associated with reclined isoclinal folds; (3) features associated with northeast-trending asymmetric folds; (4) features associated with easterly trending upright folds; and (5) other deformational features.

POSSIBLE EARLY STRUCTURES

Structural features which are tentatively believed to be the earliest are only locally developed and incompletely understood. These include segregation banding and outcrop-scale isoclinal folds.

Locally developed segregation banding in gray quartz-mica schist consists of 3 to 30 millimeter thick layers of alternating andalusite-mica schist and quartz-rich, biotite granulite. Over a few meters, these layers are not laterally continuous, but pinch out or become diffuse. In places, the rock has a mottled look where the two rock types are intermingled instead of well layered. In a few localities, coticule layers interpreted to be relict beds are not parallel to the segregation banding. These observations together suggest that this banding is some form of recrystallized spaced cleavage and not relict bedding, as first impressions might suggest.

On the northeast side of Bald Rock Mountain, a small isoclinal fold hinge in a coticule bed is transected by the schistosity-aged foliation. The hinge of this fold trends N 85° W, in contrast to adjacent schistosity-aged minor folds which trend slightly to the east of north (Figure 4). Based on the tentative interpretation of a cross-cutting foliation, this hinge is considered to be an early, that is pre-schistosity, hinge.

ISOCLINAL FOLD FEATURES

The structures described above are deformed by the predominant structures of the Camden Hills area which formed during a phase of reclined isoclinal folding. These structures include the schistosity or foliation, outcrop-scale isoclinal folds in bedding, and two orders of map-scale isoclinal folds.

The schistosity is defined by parallel biotite and muscovite grains. Commonly, quartz pods are elongated parallel to the schistosity. In quartz-rich, granular rocks the typical planar fabric of this age is a biotite lamination interpreted to be a pressure-solution cleavage, common in the coticule-bearing rocks and quartzites in the area.

Schistosity and bedding are practically parallel. This is consistent with the interpretation that the schistosity is axial planar to isoclinal folds in bedding, such as those shown in Figure 4a.

On Bald Rock Mountain (Plate 1) the contact at the base of the Penobscot Formation outlines an isoclinal stratigraphic anticline which has
Figure 4. Field sketch of isoclinal folds on Bald Rock Mountain. Black layers are coticule beds. Approximately actual size. A. Possible early foliation (1) is folded by north-trending isoclinal folds with axial plane foliation (2). B. From the same outcrop, 1 meter east of A. Isoclinal fold with N85°W hinge cut by later foliation (2 in part A).
a synclinal mate approximately 1 1/2 kilometers to the south in Great Brook, near Route 1. This anticline-syncline pair shows an asymmetry of east-over-west, more clearly shown on structure section X-Y (Plate 1).

A set of smaller scale, higher order folds in the same contact is mapped in the area extending 1 kilometer east from Zekes Lookout. These folds show an east-over-west asymmetry and are consistent with their position on the southwestern limb of the larger scale syncline just described.

The shape of the mafic rock body on Bald Rock Mountain suggests that it is deformed by the same isoclinal anticline which deforms the base of the Penobscot Formation (Plate 1).

The orientations of these structures are controlled by their positions on later structures, but over a large part of the area the axial plane schistosity dips gently to the northeast and the fold axis is inferred to plunge to the north or northeast.

NORTHEAST-TRENDING FEATURES

Northeast-trending folds and associated structures deform the reclined isoclinal fold features. The most common feature of this phase of deformation is a steeply southeast-dipping, northeast-striking crenulation or slip cleavage which deforms the schistosity, producing a locally strong intersection lineation. This cleavage is axial planar to outcrop-scale and map-scale asymmetric, open folds. These folds, on average, trend N 44° E and plunge 15° with an overall east-side-up asymmetry.

The overall geometry of the rocks in the Camden Hills area is controlled by two northeast-trending folds, an anticline whose axial trace runs from Mount Battie across Garey Mountain, and a syncline whose axial trace runs from the south end of Megunticook Lake past the west side of Zekes Lookout. These two folds form an east-side-up asymmetric fold set on the scale of the field area (Plate 1), with gentle dips in the center of the field area, and steep southerly dips on the flanks (Plate 1).

EASTERN TRENDING FEATURES

Another distinct set of structures has a more easterly trend. These structures include a crenulation cleavage which deforms schistosity, outcrop-scale minor folds, and map-scale folds on the west side of Cameron Mountain. These structures trend N 65° E to N 80° E, with shallowly plunging fold axes. Folds are open, cleavage is only locally developed, and map-scale features are rare, indicating this deformation was not intense.

The easterly trending structures are tentatively interpreted to be younger than the northeast-trending structures based on a few outcrops where the easterly trending cleavage seems to mildly deform the northeast-trending cleavage. Where exposed together, easterly trending folds interfere with northeast-trending folds, forming outcrop-scale dome and basin patterns.
OTHER STRUCTURAL FEATURES

The inferred fault at Zekes Lookout is believed to be younger than all folds described above. It cuts all structures present, is apparently not deformed itself, and is intruded by a non-foliated, unmetamorphosed composite basalt-granite dike. The motion on this fault is interpreted to be mostly dip-slip and of small magnitude, probably less than 25 meters. The southwestern side, on which more of the underlying Megunticook Formation is exposed, is presumed to be the upthrown side.

The folds mapped northeast of Maiden Cliff are of uncertain age (Plate 2). Their orientation appears to be different from the three sets of folds described above. These folds may represent a phase of deformation for which no minor structures have been recognized.

CROSS SECTION X-Y

A northwest-striking, vertical cross section is shown in Plate 1. The orientation of this section is perpendicular to the northeast-trending fold axis so that the contacts on the map can be projected onto the section parallel to this fold axis.

Early isoclinal folds outlined by the base of the Penobscot Formation are clearly portrayed. The smaller scale folds near Zekes Lookout are compatible with the larger scale east-over-west folds projected in the air from Bald Rock Mountain.

Northeast-trending asymmetric folds are broad, open folds overturned to the northwest. The large scale east-side-up fold which controls the broad shape of the contacts is of this age.

Easterly trending folds are not displayed on Plate 1 because they are oriented obliquely to the line of section.

The folds northeast of Maiden Cliff are projected underground to the western part of the cross section. Their west-over-east asymmetry is conspicuously opposed to the asymmetry of other isoclinal folds on this section.

METAMORPHISM

INTRODUCTION

Metamorphic mineral assemblages and textural relationships in pelitic schist indicate an early event which produced andalusite and staurolite, a second prograde event which produced sillimanite and pseudomorphs of older megacrysts, and a post-tectonic retrograde metamorphism.

ANDALUSITE-STAUROLITE EVENT

The earliest metamorphic event formed andalusite and staurolite megacrysts which are now largely pseudomorphed. These were presumably in equilibrium with a garnet-biotite-muscovite-quartz-plagioclase matrix,
Although these minerals in the present matrix have probably been more recently reconstituted and coarsened. Inclusion-rich garnet cores which preserve a fine-grained metamorphic foliation may have grown at this time.

Andalusite and staurolite pseudomorphs seem to cover the whole field area, so the metamorphic gradient of this early event is not evident. The consistent large, euhedral forms of the megacrysts and pseudomorphs suggests that this event was of sufficient duration for equilibrium to be approached. Some of the unmapped pegmatites (see p. 18) and quartz veins probably formed at this time.

**Sillimanite-Pseudomorph Event**

A second metamorphic event caused the prograde demise of the older andalusite and staurolite megacrysts, and the growth of fibrolite with coarsening of the matrix. The mechanism envisioned for the breakdown of andalusite to fibrolite is that of Carmichael (1969). In this model, the net chemical reaction is andalusite-sillimanite, but it is accomplished by the physical replacement of andalusite by coarse muscovite. Meanwhile, matrix muscovite is physically replaced by fibrolite. This cation exchange mechanism is supported in these rocks by (1) the location of fibrolite in the matrix just outside andalusite pseudomorphs and not in contact with relict andalusite; by (2) partial pseudomorphs in which poikilitic andalusite and muscovite are intergrown; and by (3) the smaller proportion of muscovite in the matrix of rocks with more fibrolite.

Foster (1983) proposed a similar prograde cation exchange reaction in which staurolite is physically replaced by laths of muscovite, biotite, and quartz. Abundant pseudomorphs in the Camden Hills similar in texture and composition to staurolite pseudomorphs reported by Guidotti (1968) are inferred to have replaced staurolite, although no relict staurolite was found. Staurolite is known from nearby rocks in the Belfast quadrangle (Bickel, 1974) and the Thomaston quadrangle (Boucot et al., 1972).

An isograd for this proposed regional prograde event is shown in Plate 2. Fibrolite occurs only in the central and northwestern part of the area where sufficient temperatures were attained. The increase in metamorphic grade is marked by a modal increase in fibrolite together with matrix coarsening to the northwest, away from the isograd.

During the prograde sillimanite-pseudomorph event, the matrix minerals were annealed to produce polygonal textures. Bent grains and undulatory extinction are rare.

**Retrograde Event**

The third metamorphic event was responsible for replacement of andalusite and sillimanite by sericitic muscovite and margarite, and replacement of biotite by chlorite. These replacements are complete in the southern and eastern parts of the area and affect the central part less intensely. A few samples from the northwest show none of these retrograde effects (Plate 2). Sample 124 contains chloritoid as well as sericite and chlorite, all of which formed during this event. The systematic variation of intensity across the map indicates this is a regional-scale retrograde
metamorphism.

Garnet is typically anhedral, but rarely rimmed by retrograde minerals, even in samples where biotite is totally replaced by chlorite. Possibly the retrograde event was at such a low temperature that garnet reactions were kinetically ineffective.

TIMING OF METAMORPHISM

Based on the general conformability of the schistosity to the porphyroblasts, the andalusite-staurolite event is thought to be the same age as the original matrix schistosity. This is somewhat tenuous in that both the megacrysts and matrix minerals have been subsequently recrystallized. It is also possible that this event is younger than the schistosity, but truncations of the schistosity and helicitic overprint textures are not present.

The sillimanite-pseudomorph event was later than crenulation cleavage and schistosity deformation. This is clearly indicated by undeformed pseudomorphs in rocks with crenulated schistosity.

And finally, the retrograde event overprints all structural fabrics and other metamorphic features.

The absolute age of the two prograde events is thought to be between the intrusion of the pre-tectonic mafic pluton at Bald Rock Mountain and the post-tectonic composite basalt-granite dikes. These are inferred to be Late Silurian and Middle Devonian, respectively. Therefore the two prograde events are considered to be Acadian. The retrograde event is only constrained to be younger than the prograde events, so may be Late Paleozoic as is some of the late-stage, static metamorphism in southwestern Maine (Lux and Guidotti, 1985; Thomson and Guidotti, 1986).

BEDROCK GEOLOGIC HISTORY

As a convenient way to synthesize all the geologic information from the Camden Hills, a chronological account of events and their effects is presented here. It is emphasized that this account is interpretive and therefore at the mercy of selectivity, incomplete data, and intuition. Alternative interpretations, many of which have been discussed in previous sections, are possible. Absolute ages proposed here are based on fossil or isotopic ages for rocks outside the field area except for the Permian granite cooling age.

(1) Deposition of the protoliths of the Megunticook Formation in the Middle to Late Cambrian. The association of conglomerate, quartz-rich rocks, and calcareous rocks, and rapid changes in rock type may indicate a continental shelf type of depositional environment.

(2) Conformable deposition of the Penobscot Formation protoliths in the latest Cambrian to earliest Ordovician. Black, graphitic, sulfidic schists and possibly minor mafic volcanics indicate an anoxic environment (Figure 5a).
Figure 5. Schematic cross sections illustrating the geologic history of the Camden Hills. Each section is about 3 kilometers across. Northwest is to the left. See text for discussion.
(3) Intrusion of the Bald Rock Mountain plutonic rocks, including norites and related gabbros and diorites in late Silurian to earliest Devonian time. This may be a precursor to the Acadian orogeny (Figure 5b).

(4) Formation of large-scale isoclinal folds with associated axial plane schistosity and minor deformational features. Large-scale asymmetry indicates southeast-over-northwest motion (Figure 5c). Acadian.

(5) Concurrent with or slightly after the isoclinal folds, recrystallization of schists to andalusite-staurolite grade. Acadian (Figure 5c).

(6) Formation of northeast-trending crenulation cleavage and folds with east-side-up asymmetry (Figure 5d). Accompanied by local recrystallization of the schistosity along the crenulation cleavage. Acadian.

(7) Deformation by easterly trending open folds and local cleavage. This deformation was not intense. Acadian.

(8) Intrusion of muscovite-biotite granite at Youngtown and other small bodies (Figure 5e). Late Acadian.

(9) Possibly concurrent with granite, prograde metamorphism causes the formation of sillimanite and of pseudomorphs after andalusite and staurolite. The grade of this metamorphism is higher toward the northwest (Figure 5e). Late Acadian.

(10) Emplacement of composite dikes and high-angle faulting near Zekes Lookout (Figure 5f). Post-Acadian/Middle to Late Devonian.

(11) Retrograde metamorphism at low grade. Its effects are strongest in the south and southeast (Figure 5g). The age of this event relative to composite dike emplacement and to the Permian argon age of the granite at Youngtown is not known.

(12) Cooling of the granite at Youngtown through the argon closure temperature of biotite. Early Permian.
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