Preliminary Compilation of the Bedrock Geology of the land area of the Boston 2° sheet, Massachusetts, Connecticut, Rhode Island and New Hampshire

by

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PRELIMINARY COMPILATION OF THE BEDROCK GEOLOGY OF THE LAND AREA OF THE BOSTON 2° SHEET, MASSACHUSETTS, CONNECTICUT, RHODE ISLAND AND NEW HAMPSHIRE

Description of rock units

Introduction

The bedrock geology of the Boston 2° sheet comprises tens of thousands of metres of clastic and volcanogenic, mostly eugeosynclinal stratified rock most of which has been deeply buried and intruded by a wide variety of plutonic and hypibyssal rock. These rocks range in age from Precambrian to Jurassic. Deformation of these rocks which includes folding, faulting, and metamorphism, was begun in the Precambrian and appears to have continued sporadically, both in time and place, throughout the Paleozoic and Mesozoic.

The symbols for geologic units on this map do not include an age designation unless the paleontologic age has been verified by fossil evidence. Fossils have been collected from the Weymouth and Braintree Formations of Cambrian age, the Newbury Volcanics of Silurian age, and the Pondville Conglomerate of Pennsylvanian age. In the absence of fossils, interpretation of the stratigraphy is based on superposition and tenuous regional correlation with distant strata.

The dating of rocks by various radiometric methods has become inreasingly more reliable in recent years. We now have a considerable collection of such dates, but these are obtained almost exclusively from intrusive rocks. Dating of clastic rocks, particularly with zircons, is considered unreliable because of the possibility that the radiogenic material has retained a "memory" of an older terrane. Dates of plutonic rocks, however, are useful. They provide maximum or minimum ages of rocks that respectively unconformably overlie or are intruded by the dated pluton; they are not much use for detailed stratigraphic correlation.

There is also a limit to the degree of analytical accuracy possible in dating these rocks radiometrically. This varies with the method used and with the sample. The possible range of analytical error in years, furthermore, increases with the age of the rock examined because the degree of analytical error is a proportion of the total age. A range of ± 5 my in rocks 500 my old, for example, is only 1 percent, but for a 50 my old rock it is 100 percent.

¶ L. R. Page (1968) assigned almost all of the plutonic rocks in the area of the Boston 2° sheet to one of 3 plutonic series and related these to the Acadian orogeny of Middle Devonian age. It has since become apparent that most of the rocks southeast of the Bloody Bluff fault were not affected by the Acadian orogeny. Radiometric ages, furthermore, have demonstrated almost without doubt, that there is a large body of intrusive rock south of Boston that is Precambrian in age. These include most of the Rhode Island ~~Complex, the Dedham, the Westwood, and others.~~

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Page's separation of the plutonic rocks to the north and west, however, into pretectonic, syntectonic, and early post-tectonic Acadian would appear to be a useful concept although it has not been followed in most recently published work. Radiometric ages, however, range from about 400 to 450 my, considerable older than the Middle Devonian age generally assigned to the Acadian orogeny. L. R. Page (1976, p. 12-14) discusses this problem of radiometric ages.

The northeast trending regional fabric that is a conspicuous feature of the map is the result of orientation of stratigraphic trends and foliation subparallel to major northeast trending faults. Three tectonically distinct geologic blocks are separated by two principal northeast trending fault zones, the Bloody Bluff and Clinton-Newbury, across neither of which can any stratigraphic or intrusive units be positively correlated. Time and grade of metamorphism differ markedly between these blocks.

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South and east of the Bloody Bluff fault zone the rocks have a distinct two-fold deformational history. Gneisses and schists of Precambrian age that occur as roof pendants in Precambrian, 620 ± 15 my old, plutonic rocks are the only strata that have undergone a tectonic history of deep-seated metamorphism and deformation. These plutonic rocks, which underlie more than half of the land area southeast of the Bloody Bluff have not been regionally metamorphosed nor have the younger intruded strata, which are for the most part at chlorite grade of metamorphism and non-foliated except by cataclastic or protoclastic deformation. These younger stratified rocks range in age from Cambrian to possibly Carboniferous; they are folded but only weakly foliated. Plutonic rocks younger than the Precambrian basement have a radiometric age range of 380 to 460 my.

Most of the stratified rocks between the Clinton-Newbury and Bloody Bluff fault zones are strongly foliated and deformed gneisses and schists of andalusite to sillimanite metamorphic grade. The Newbury Volcanics, exposed in a faulted horst between the two major fault zones, however, have been folded but show no evidence of deep-seated deformation. The only plutonic rocks are foliated syntectonic granite to diorite that intertongue with the stratified gneisses and schists, and occur only in fault contact with the Newbury Volcanics. Samples of the plutonic rock (Andover Granite) yield a radiometric age of 460 ± my.

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North and west of the Clinton-Newbury zone the stratified rocks consist of schist and gneiss mostly of chlorite to biotite grade of metamorphism near the fault, increasing gradually to reach sillimanite-orthoclase grade in the northwest corner of the map area. The plutonic rocks are generally Middle Paleozoic and considered to be related to the Acadian Orogeny. Radiometric ages, however, are spread over a relatively broad time interval from about 460 my to 380 my similar to the time space of the younger plutonic rocks south and east of the Bloody Bluff fault zone. Also exposed west of the Clinton-Newbury zone is the Massabesic pegmatitic granite gneiss, a sample from which has yielded a 620 ± my radiometric age that is not in accord with the present stratigraphic and structural interpretation.

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Rocks south and east of the Bloody Bluff fault zone

Intrusive Rocks

rhi

Intrusive Complex of Rhode Island

Most of the plutonic rocks exposed in the southwest corner of the map area have been assigned to the Intrusive Complex of Rhode Island. They underlie most of the Uxbridge quadrangle and much of the Oxford, Grafton, Milford, and Blackstone quadrangles.

The rock is pinkish medium-gray to medium-gray moderately to well foliated granitic gneiss with a composition approximating quartz monzonite. Weathering does not appreciably change its color. The rock is locally hydrothermally altered, with chloritized mafic minerals and pink stained feldspar. The rock commonly is strongly foliated and muscovitic, but the core may be only slightly foliated, Emerson (1917, p. 155-156). It includes the Ponaganset gneiss of Rhode Island (Quinn, 1971), and the Northbridge granite gneiss of Emerson, (1917). The foliation of the gneiss parallels the bedding of the intruded Plainfield Formation in the Oxford quadrangle suggesting syntectonic intrusion of the gneiss. The unit may also include some Hope Valley Alaskite Gneiss and Scituate Granite Gneiss. No radiometric age dates have been reported for these intrusive rocks. The Northbridge is cut by the Milford Granite (Emerson, 1917), that has been assigned an age of 620 ± 15 my by Naylor (personal commun.). The Intrusive Complex of Rhode Island is, therefore, considered to be Precambrian although it is entirely possible that small bodies of much younger rock may be present but not recognized in this Complex.

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mg

Milford Granite

The Milford Granite underlies much of the south-central part of the map area east of the Rhode Island Complex, mostly in the Blackstone, Franklin, Milford, and Holliston quadrangles. The rock is light-pinkish-gray to medium-gray, fine- to coarse-grained equigranular to locally porphyritic, chiefly quartz monzonite, but ranging from granite to granodiorite (Nelson, 1975). It weathers very light buff to buff. Foliation is quite variable; ranging from none to well foliated, commonly with closely spaced jointing parallel to the foliation. Principal minerals are quartz, perthite and microcline, oligoclase, albite, biotite, and muscovite; accessory minerals are magnetite, apatite, garnet, fluorite, sphene, and zircon; secondary minerals include sericite, epidote, chlorite and calcite (Nelson, 1975).

The Milford Granite was originally named by Emerson and Perry (1907) for the "pink granite" quarries in the town of Milford and vicinity. According to Naylor (personal commun.) samples of the Milford Granite from the Milford quadrangle, Massachusetts, yielded a 620 $\pm$ 15 my, Precambrian, zircon age. The Milford intrudes and contains as roof pendants quartzites and gneisses including parts of the Westborough Quartzite and the Blackstone Series. The Milford is overlain unconformably by the Bellingham Conglomerate of probable Carboniferous age.

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Volckmann (1973a), in the Holliston quadrangle, found that most of the Milford exhibited a strong "internal granular deformation" and mapped separately the less common exposures of Milford that lacked internal deformation. The distinction was not practicable on this regional map. Volckmann also mapped separately many small bodies of gabbro and diorite, ugd, from the main mass of Milford. Most of these probably are co-magmatic with the Milford and also Precambrian in age.

dg

Dedham Granodiorite

The Dedham Granodiorite was named by W. O. Crosby (1880) for typical exposures about Dedham, Mass. according to Emerson (1917, p. 172). The rock is pinkish-light-gray, pinkish-medium-gray and medium-gray fine- to coarse-grained plutonic rock that is mostly granodiorite but ranges from granite to quartz diorite (Hansen, 1956, Nelson, 1975). Weathering does not significantly change the colors. It is a massive rock with a slight primary foliation (Hansen, 1956), except near fault zones, where it may be very strongly foliated; it is equigranular to slightly porphyritic in places. Principal minerals are quartz, microcline, perthite and plagioclase, mostly oligoclase, and includes some albite, biotite, minor hornblende and muscovite and accessory magnetite, sphene, apatite, zircon, monazite and a trace of garnet (Nelson, 1975). In the quartz diorite facies the biotite and hornblende together compose as much as 25 percent of the rock (Hansen, 1956). Hydrothermal alteration has affected much of this rock in the Worcester area coloring the feldspars pink, chloritizing the mafic minerals and forming some epidote and sericite. The Dedham is cut by aplitic, basaltic and diabasic dikes, small bodies of fine-grained gabbro, it includes pendents and xenoliths of metasedimentary rocks.

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According to Emerson (1917, p. 172) "Much the greater part of the igneous rocks of probable Devonian age in eastern Massachusetts is comprised in a great group of intrusive rocks including many varieties.........Most of the rocks have been grouped for convenience in mapping and description under 3 names: Salem gabbro diorite, Newburyport quartz diorite, and Dedham granodiorite". R. E. Zartman (person commun.), however, obtained a late Precambrian zircon age date of 620 ± my for the Dedham, a middle Paleozoic Rb/Sr age of 460-490 ± my for the Salem gabbro diorite in the vicinity of Lexington, and a middle Paleozoic Rb/Sr age of 430-460 for the Newburyport Quartz Diorite in its type locality in Newburyport. The Dedham is clearly older than the Salem and Newburyport.

At Hoppin Hill near Attleboro, Massachusetts, just south of the map area, fossiliferous rocks of Cambrian age are in contact with the Dedham Granodiorite. The contact relation has been described as intrusive by some, but Dowse (1950) describes an unconformable contact with fossiliferous rocks of Cambrian age resting on the Dedham, thus supporting a Precambrian age for the Dedham.

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wg

Westwood Granite

The Westwood Granite underlies much of the northwest corner of the Norwood quadrangle and extends northeast and southeast into adjacent quadrangles. The rock is light-gray to pinkish-gray, medium- to fine-grained granite composed of quartz, orthoclase or microperthite, albite or sodic oligoclase, microcline, and small amounts of magnetite, sphene, apatite and chloritized biotite (Chute, 1966). Chute also mapped a porphyritic phase not distinguished on this map. The Westwood was named by Chute (1966) for exposures near the Westwood-Norwood town line; it is almost entirely contained within the Dedham. Chute (1966) stated that the Westwood intrudes the Dedham with sharp contacts and contains inclusions of the Dedham. Many workers, however, do not distinguish the Westwood from the Dedham. Fairbairn and others (1967), in their investigation of the age of the Dedham, obtained Rb-Sr whole rock ages of 562 my and 548 my for samples of Westwood Granite. According to Naylor (personal commun.), it is quite possible that present methods of analysis, particularly with the use of zircon, would yield an older date, suggesting that the Westwood may be consanguinous with the Dedham.

ugd

Uncorrelated gabbro and diorite

Includes several bodies of gabbro and diorite mapped south of the Boston Basin. Some of these had been mapped originally as Salem Gabbro Diorite (Chute, 1966), but there is no evidence to demonstrate that these gabbroic bodies are equivalent in age to the Salem north of the basin. Furthermore, Chute (1969) states that the Dedham is intrusive into the gabbro in the Blue Hills quadrangle, but radiometric ages obtained since Chute's publication have shown that the Salem Gabbro-Diorite in its type area is younger than the Dedham. Until further evidence is obtained it has seemed best not to correlate with the Salem Gabbro-Diorite the mafic plutonic rocks south of the Natick quadrangle, as they are possibly Precambrian in age and co-magmatic with the Milford and Dedham. Included with these uncorrelated rocks are exposures of quartz diorite correlated by Chute (1966) with the Newburyport Intrusive Complex and the Noon Hill and Bald Hill Gabbros of Volckmann (1973) in the Holliston quadrangle.

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ug

Uncorrelated granite

Several fault slivers of granite mapped by Volckmann (1973a) in the northern part of the Holliston quadrangle and extending north into the Natick and west into the Milford quadrangles. They probably are part of the Milford Granite; blue quartz is a characteristic of one of these bodies; this has been thought by many geologists in New England to be diagnostic of a Precambrian terraine.

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dgu

Dedham and gabbro undivided

Exposures of Dedham with remnants and inclusions of gabbro. At several localities south of Boston, Dedham Granodiorite and gabbro are so intimately mixed and exposures are so poor that the two rock types could not be mapped separately.

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dpz

hybrid Dedham and Middlesex Fells Volcanic rock

Exposured in the Lexington and Boston North quadrangles is a hybrid rock with the composition of quartz diorite. LaForge (1932) originally correlated these rocks with the Newburyport Quartz Diorite, but the rock probably is Dedham Granodiorite hybridized to a more mafic rock by assimilation of mafic constituents from the metavolcanic terraine it has intruded. A characteristic of these rocks is an orange staining of the feldspar, probably as a result of contact hydrothermal alteration.

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tg

Topsfield Granodiorite

The Topsfield granodiorite is exposed mostly in two fault blocks, in the northwest corner of the Ipswich quadrangle and vicinity, and in the southern part of the Georgetown quadrangle extending southwest into the Salem quadrangle; the name was proposed by Priestley Toulmin, III, (1964) for excellent exposures of a distinctive porphyritic granodiorite in the village of Topsfield. "The Topsfield is medium- to coarse-grained granodiorite composed of grayish-orange-pink feldspar, translucent light-gray quartz, grayish-yellow-green epidote and dark-greenish-gray to greenish-black aggregates of chlorite and epidote" (Shride, 1976). According to Shride, the rock has undergone extensive hydrothermal alteration and commonly is foliated as a consequence of widespread cataclasis. In the foliated rock, quartz lenses commonly have a bluish cast and are notable coarser than plagioclase; potassium feldspar is almost everywhere absent.

No radiometric ages have been obtained from the Topsfield. Toulmin (1964) considers that the Topsfield intrudes the Newbury Formation of Silurian age, but his evidence is inconclusive. Bell, Shride, and Cuppels (1977) include the Topsfield with a co-magmatic series of diorite, quartz diorite, and granodiorite that they consider to be Precambrian in age. They state that "these rocks are consideredto be of probably Precambrian age although no conclusive evidence confirms such an assignment. They intrude only the mafic

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metavolcanic rocks, tentatively correlated with the Blackstone Series. These rocks have been altered and their appearance changed during a complex history of hydrothermal alteration." Furthermore, "the rocks of this series are characterized by blue weathering quartz", a feature that many workers in New England consider to be found exclusively in Precambrian rocks.

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rd

Diorite of Rowley

A nearly circular body of diorite is centered in the town of Rowley, Georgetown quadrangle, for which it was informally named by Bell et al (1977). According to Bell, the diorite is intrusive into the Topsfield and almost entirely surrounded by an aureole of intrusive breccia. He considers it to be a mafic facies essentially cogmagmatic with the Topsfield and of probable Precambrian age.

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sgd

Salem Gabbro-Diorite

The Salem Gabbro-Diorite is extensively exposed between the Bloody Bluff and North Boundary faults north and west of Boston. It was named by C. H. Clapp (1910) for exposures of gabbro-diorite "typically developed in the towns of Salem, Marblehead, Lynnfield, and Wakefield (Clapp, 1921). According to Clapp, "The normal rock is dark fine to medium grained and consists of plagioclase, hornblende and biotite. In many specimens accessory pyrite and magnetite are abundant".

A. E. Nelson (1975a,b) describes the Salem Gabbro Diorite in the Natick and Framingham quadrangles as greenish-gray to medium- and dark-gray fine- to medium-grained generally massive hornblende gabbro, with lesser amounts of pyroxene gabbro and hornblende diorite. The principal minerals are hornblende, plagioclase (andesine to labradorite), pyroxene, biotite, and magnetite with some epidote, sphene, chlorite, sericite, and pyrite; pyroxene altered to hornblende and hornblende altered to biotite (Nelson, 1975a,b). For reason described previously in this report, some of the rock mapped as Salem by Nelson may be older and more closely related to the Dedham of Precambrian age. The Salem in the type area has a radiometric age of about 450 my ± 10, (Zartman, person commun.), Late Middle Ordovician, but geologic field relations suggests a younger, perhaps Devonian age (Dennen, 1976, p. 271).

ng

Gabbro at Nahant

The gabbro exposed on the peninsula of Nahant in the Lynn quadrangle was first mentioned in the literature by C. H. Clapp (1910). It is also exposed on Castle Rock in Marblehead and on Cat and Baker's Islands. According to Emerson (1917) most geologists consider this gabbro a phase of the Salem; Clapp (1921, p. 100) states, however, that the gabbro is "one very different from the gabbro and gabbro diorite of the Salem type". K. G. Bell (1948) describes the gabbro as consisting of 5.5 percent labradorite, 30 percent monoclinic pyroxene, 5 percent magnetite and minor amounts of biotite, olivine, pyrite, and zircon. He concludes on the basis of mineralogical evidence that "The Nahant gabbro and Salem gabbro-diorite are probably closely related in age and origin" (Bell, 1948, p. 78). C. A. Kaye (1965) has shown that the Nahant is clearly intrusive into the Weymouth Formation of Cambrian age. According to R. E. Zartman and R. F. Marvin (1971) phlogopitic biotite from samples of the gabbro of Nahant yielded Rb-Sr and K-Ar ages in the range of 400 to 490 my or Early Ordovician to Early Cambrian, perhaps slightly older than the Middle Ordovician age for the Salem, but within the range of possible analytical overlap.

cag

Cape Ann Granite

The Cape Ann Granite (Clapp, 1910, 1921, Warren and McKinstrey, 1924) underlies almost all of Cape Ann and extends southwestward in a triangular shaped fault block into the Reading quadrangle. Rocks of the Cape Ann Granite "..... are generally unfoliated, medium coarse-grained and compositionally variable from alkali-feldspar granite through alkali-feldspar quartz-syenite to alkali-feldspar syenite. The compositional variation is most easily seen in the modal quartz content of the rock as measured on outcrop, and mapping shows the different phases to occur in bands, probably reflecting rude primary layering within the unit. Cumulate textures are occasionally present and suggest that settling of microcline microperthite is the mechanism of differentiation" (Dennen, 1976, a).

The alkalic granitic rocks of Cape Ann have been equated by early workers (Clapp, 1921, Emerson, 1917) with the Quincy and Peabody alkalic rocks and considered younger than the Salem Gabbro-Diorite. Bell and Dennen (1972), however, consider on the basis of petrographic and spectrochemical analysis (Norton, 1974), that the Cape Ann and Salem Gabbro Diorite belong to the same plutonic series. The two co-magmatic facies apparently were emplaced in rapid succession; the gabbro-diorite was first as it is known to intrude the granite. A radiometric age of 450 $\pm$ 25 my for the Cape Ann and 460 $\pm$ 15 my for the Salem is given by Zartman and Marvin (1971). Those ages are

9.1267

appreciably older than ages for the Quincy and Peabody plutons although they are within the margin of analytical uncertainty (Naylor, personal commun.). Rocks mapped as Beverly syenite by Emerson (1917) are considered a facies of the Cape Ann by Dennen (1975, a, b, c).

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cagd

Gabbro-diorite in Cape Ann pluton

Occurs mostly in north-northeast trending fault slices in the Gloucester quadrangle. Medium- to medium coarse-grained, texturally variable mottled black and greenish-white ferro-hornblende-biotite diorite. Dennen (1975, c) mapped this as Salem Gabbro-Diorite.

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9.1267

qg

Quincy Granite

The Quincy Granite (Crosby, 1876) crops out in a 2-mile wide band across the northern part of the Blue Hills quadrangle and eastward into the Weymouth and Hull quadrangles. According to Chute (1969), "The Quincy Granite is a massive, medium- to coarse-grained, non-porphyritic gray to dark bluish gray granite, locally dark red or dark green due to hydrothermal alteration. Average unaltered granite contains about 60 percent microcline microperthite, 30 percent quartz and 10 percent reibeckite and aegerine". This alkalic granite has been variously correlated with the Cape Ann, Peabody, and Blue Hills porphyry. The Quincy apparently intrudes the Braintree Argillite of Cambrian age and according to Chute (1969) it intrudes the Sharon Syenite and is intruded by the Blue Hills porphyry. Naylor and Sayer (1976) showed that radiometric age dating by various methods yielded conflicting results and concluded that a radiometric age of 420 ± my was the most probable. This Silurian age agrees well with their interpretation that the Quincy is part of an igneous complex that includes the Blue Hills porphyry and the Mattapan Volcanics. The Mattapan has been equated by most workers with the Newbury Volcanics that contain Silurian fossils. Zartman (personal commun.) has more recently stated that a 450 my age is more reasonable for the Quincy and that the Quincy is equivalent in age to the Cape Ann.

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Pg

Peabody Granite

The Peabody Granite (Clapp, 1910) occurs in a rhomboid fault bounded block mostly in the southwest corner of the Salem quadrangle. The Peabody is a "medium- to coarse-grained, very uniform gray to light-green, cream weathering, massive granite composed essentially of quartz, microperthite, and ferrohornblende, with smaller amounts of aegeritic pyroxene and biotite", (Toulmin, 1964). Toulmin included the Peabody in his "alkalic" series and related it to the Cape Ann pluton, assigning to both an Upper(?) Paleozoic age. Zartman (personal commun.) assigns a 390 my radiometric age to the Peabody; and Lyons and Krueger (1976) would equate this with their Rattlesnake Pluton of 366 ± 9 m.y., both of which yield slightly younger radiometric ages than the Quincy and Cape Ann.

bqp

Blue Hills Porphyry

The Blue Hills Porphyry (Naylor and Sayer, 1976) is exposed in the hills just south of the band of Quincy in the Blue Hills quadrangle and extends westward into the Norwood quadrangle. Chute (1969) who called these rocks the Blue Hill Granite Porphyry describes the rock as "massive gray to bluish-gray porphyry with 40 - 80 percent phenocrysts and zenocrysts of perthite, quartz, and reibeckite, .5-8 mm long in a fine grained groundmass .... The matrix consists of fine grained quartz, perthite and needles and poikilitic grains of reibeckite". Chute also states that the porphyry intrudes the Mattapan Volcanic Complex and the Quincy Granite. Naylor and Sayer (1976, p. 136) conclude that "the close similarity of the Blue Hills Porphyry and the Quincy Granite in so many distinctive features strongly suggests that they are co-magmatic and hence should be similar in age". They go on to show that the broad spectrum of young 280-385 my Rb/Sr radiometric dates for the Quincy and the Blue Hills may not be reliable because of the propensity for Sr^{87} to migrate in these alkalic rocks. They conclude that 420 my is probably the best date.

rp

Rattlesnake Pluton

An alkalic granite in the northeast corner of the Mansfield quadrangle was named the Rattlesnake Hill Granite by Whitehead (1913). P. C. Lyons and H. W. Krueger (1976) studied the petrology, chemistry and age of this granite and associated rock which they termed the Rattlesnake Pluton. They concluded that the crystallization histories and minor element content of the Cape Ann, Peabody, Quincy and Rattlesnake plutons suggest that these alkalic granites essentially are consanguinous. The Cape Ann is very similar petrologically to the Peabody and the Rattlesnake to the Quincy (P. C. Lyons personal commun.). They stated that "K-Ar determination on reibeckite from rocks of the Rattlesnake Pluton are so consistent that we believe the average of 366 ± 9 my is significant even though it differs from the age of 450 ± 25 my proposed by Zartman and Marvin (1971) for other alkalic granites in eastern Massachusetts". A re-evaluation of the radiometric data from other alkalic granites in eastern Massachusetts indicated to Lyons and Krueger that the age of the Peabody is probably 370 my, the same as the Rattlesnake, and that the Quincy and Cape Ann dates are older, 400 to 450 my. They concluded, however, that the two different ages are inconsistent with chemical, petrologic, and spacial data that indicate a common age.

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SS

Sharon Syenite

The Sharon Syenite (Emerson, 1917) occurs in a broad lens along the south side of the Norfolk Basin in the Wrentham, Mansfield and Norwood quadrangles and in a few small bodies to the northeast. According to Chute (1966) the Sharon is "medium grained syenite composed of perthite, orthoclase, hornblende, and subordinate microcline, perthite, oligoclase and quartz, contains secondary epidote, clay minerals, and chlorite". He further states (1969) that the Sharon intrudes gabbro, which he mapped as Salem and is intruded by the Quincy Granite. No radiometric ages have been obtained for the Sharon.

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gdu

gabbro and diabase undivided

Exposures mapped by Nelson (1975) of gabbro interlaced by numerous younger diabase dikes in so complex a manner that they cannot be separated on the map.

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Stratified Rocks

P€b

Blackstone Series Undivided

The name Blackstone Series originally was used by Woodworth (in Shaler and others, 1899), but was dropped by Emerson in 1917. The name was later revived by Quinn and others (1949) and used for the extensive exposures along the valley of the Blackstone River in the Pawtucket quadrangle that extend northward into south-central Massachusetts and southward into Rhode Island west of the Narragansett Basin. This series includes quartzite, chlorite-quartz schist, quartz-mica schist, marble and mafic metavolcanic rock. The sequence was subdivided into a lowermost Mussey Brook Schist, approximately 450 metres thick, a middle massive quartzite 1,000 to 1,500 metres thick, which in the Milford quadrangle has been named the Hopedale Quartzite by Shaw (1967), the overlying Sneech Pond Schist, and the uppermost Hunting Hill Greenstone metavolcanic rocks. The total thickness of the Blackstone Series is at least 4,600 metres, and it may be more than 6,000 metres (Quinn, 1971).

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Pzbq

Hopedale Quartzite Member

The middle massive quartzite member of the Blackstone Series mapped by Shaw (1967) in the Milford quadrangle, Massachusetts. It is a fine- to medium-grained, sugary, white to buff, massive quartzite. Locally the member grades into feldspathic and biotite quartzite which contains lenses of muscovite-biotite-garnet schist. Bedding is discernible only where the biotite quartzite, amphibolite, or schist is interlayered with the quartzite, which gives the quartzite a conspicuously ribbed weathered surface.

Pz

Quartzites and gneissoid metavolcanics

These rocks occur in fault slivers and roof pendants within the Dedham Granodiorite in the area surrounding the Boston Basin and southeast of the Bloody Bluff Fault. The map unit includes the following formations: Cherry Brook, Clay Pit Hill, and Rice Gneiss of Nelson (1975) and the Burlington and Greenleaf Mountain of Bell (1976). It also includes the Middlesex Fells Volcanics Complex of Bell (1976), the Hollis Hill metamorphic rocks of Volckmann (1973) and metavolcanic rocks that lie between the Bloody Bluff Fault and the Clinton-Newbury Fault Zone in the Newburyport West quadrangle (Shride, 1976) and the Ipswich quadrangle (Dennen, 1975).

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These rocks apparently are all of Precambrian age, intruded by the Dedham Granodiorite from which late Precambrian radiometric dates have been obtained (Zartman, personal commun.). They are of biotite-amphibolite metamorphic grade as contrasted with the younger Newbury and Mattapan Volcanic Complexes which are of the green schist grade of metamorphism. Descriptions of specific formations within this map unit are given below.

The Cherry Brook formation crops out in the Natick and Framingham quadrangles (Nelson, 1975 a) and is composed of four members; an upper and lower amphibolite member separated by felsic tuff member, and a basal biotite gneiss member. The metavolcanic members are greenish gray to dark gray, fine to coarse grained, thin to thickly layered well-foliated amphibolite. The thinly layered amphibolite has fine alternations of felsic and mafic material giving the unit a characteristic pinstripe appearance. Locally the amphibolite is intercalated with subordinate amounts of light-gray, biotite-muscovite schist and thin layers of fine- to medium-grained feldspathie quartzite. The felsic member is a massive light-gray to purplish gray, fine- to medium-grained crystal mafic tuff intercalated with thin beds of medium-grained hornblende-biotite-plagioclase-quartz schist and gneiss, and also interlayered with light gray biotite-quartz-feldspar-muscovite schist and dark gray thin-bedded amphibolite. Thickness of the formation is approximately 1,350 metres.

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The Claypit Hill Formation was mapped by A. E. Nelson in the Natick (1975-b) quadrangle. The formation is chiefly a dark-greenish-gray, fine-grained hornblende-plagioclase-quartz-epidote gneiss interleaved with medium gray, fine-grained muscovite-sillimanite-garnet schist, with minor amounts of dark gray equigranular biotite-plagioclase-quartz-microcline gneiss and dark gray, fine to medium grained amphibolite. The formation is estimated to be 460 - 610 metres thick.

"The Kendall Green Formation is composed of light-tan to light-gray, very fine-grained, distinctively, thinly laminated tuff consisting of quartz-feldspar-sericite-calcite interlayered with dark greenish-gray, fine-grained tuff interleaved with discontinuous thin layers of fine-grained light gray quartzite. The formation is approximately 215 metres thick in the Natick quadrangle" (Nelson, 1975-b).

"The Rice Gneiss is a medium to dark gray, fine- to medium-grained, variably layered and textured biotite-plagioclase-quartz gneiss; biotite-plagioclase-quartz-microcline gneiss; biotite-plagioclase-quartz-muscovite gneiss and schist interlayered with minor thin beds of quartzite. The maximum thickness of the unit is 760 metres thick" (Nelson, 1975-b).

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The Burlington Formation comprises the meta-sedimentary rocks between the Greenleaf Mountain Formation and the Bloody Bluff Fault (Bell and Alvord, 1974, 1976). The unit includes massive fine-grained, white quartzite fine-grained, light-gray quartz-feldspar gneiss and micaceous quartz-feldspar gneiss. Amphibolite and plagioclase-hornblende gneiss are interleaved through the lighter colored quartzites and gneisses. The lower contact appears gradational and is placed above the first thick amphibolite assigned to the Greenleaf Mountain Formation.

The Greenleaf Mountain Formation is an amphibolite unit, defined by Bell and Alvord (1976), that crops out immediately south of the Bloody Bluff Fault extending from the south-central part of the Wilmington quadrangle to the northwest edge of the Lexington quadrangle. The formation is chiefly fine-grained, thinly laminated, dark-greenish-gray to dark-gray oligoclase-hornblende amphibolite with some minor zones of thinly layered, light green calc-silicate bearing rock.

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According to Bell and Alvord (1976), the Middlesex Fells Volcanic Complex of mafic metavolcanic rocks conformably overlies the Westboro Formation. It consists chiefly of dark colored amphibolite, hornblende-plagioclase gneiss and biotite-hornblende-plagioclase gneiss. The complex has been regionally metamorphosed to biotite-amphibolite facies, but locally parts of the complex have been retrograded to chloritic rock during an episode of hydrothermal alteration. Relict features are moderately to well preserved. Some lentils are composed of fine-grained, dark colored, massive virtually featureless amphibole gneiss. Lentils of dark, fine-grained quartzite, calc-silicate rock and marble constitute less than one percent of the complex. The maximum aggregate thickness of the complex is approximately 1,500 metres.

The Hollis Hill metamorphic rocks are fine to coarse-grained, light gray to black, foliated rocks showing strong mineral banding in a lenticular pattern. This unit crops out only in the north-central part of the Holliston quadrangle (Volckmann, 1973a).

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pw

Plainfield Formation and Westboro Quartzite

The Plainfield Quartz schist of Gregory (Rice and Gregory, 1906; Gregory and Robinson, 1907) was named the Plainfield Formation by Lundgren (1962) from exposures in eastern Connecticut. It consists of medium-grained quartzite interbedded with fine- to medium-grained biotite-muscovite schist. Where quartzite predominates in this formation, it occurs as light gray to buff, medium to thin beds; where the quartzite is interbedded with pelitic schist, the formation is thin bedded and medium gray with greenish and purplish cast. Both types weather slightly lighter in color. The pelitic interbeds are silvery medium gray and vary in thickness from about 2 cm to thin laminae. They predominate in the lower part of the exposed section. The Westboro Quartzite, named from exposures in Westboro, Massachusetts, by Emerson (1917), is similar in appearance to the upper part of the Plainfield and apparently occurs in a similar stratigraphic position. The Plainfield has a maximum exposed thickness of 1,000 m in the area of Oxford, Massachusetts. The Plainfield has been considered Cambrian in age (Goldsmith, 1966) but the Westboro is intruded by rock, dated as Precambrian (Nelson, 1975b).

6w

Weymouth Formation. Formation named by Laurence LaForge, 1909. It consists of thick to medium bedded somewhat siliceous argillites, black to greenish in color where close to the contact of the Quincy granite and Nahant gabbro. Siliceous light green to cream nodules are commonly found in the rock and suggest chert nodules or silicified algal bodies. Lenticular beds of limestone occur sparsely. Away from igneous contacts the rock is a red to gray mudstone with thin white limey beds. Lower Cambrian fossils occur sparsely.

6b

Braintree Argillite. Named by N. S. Shaler, 1871. This is a black to light gray, massive to obscurely bedded argillite. Adjacent to its contact with the Quincy Granite, which intrudes it, it is somewhat hornfelsed and contains much pyrite. Adjacent to larger faults, it has been converted to slate. The formation is along the margins of Weymouth Fore River. These rocks have yielded a Middle Cambrian fauna dominated by the large trilobite *Paradoxides harlanni*.

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mvu

Mattapan Volcanic Complex undivided

The Mattapan Volcanic Complex was defined by ~~LaForge~~ Emerson (1917) and later redefined by Billings (1929) to include all of the volcanic rocks that lie below the Roxbury conglomerate; LaForge (1932) described these volcanic rocks as an early extrusive phase related to the Quincy granite.

These volcanic rocks are exposed at numerous localities south of Boston extending from the Natick quadrangle on the west to the Nantasket quadrangle on the east. According to C. A. Kaye (personal commun.) they are an heterogeneous accumulation of lava, breccia and pyroclastic debris of composition ranging from basalt to rhyolite that are intimately intertongued with one another and with the Roxbury Conglomerate; they rest unconformably on the Dedham Granodiorite, and at least in part appear to intertongue with the Weymouth Formation of Cambrian age.

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The age of the complex is still uncertain. Billings (1929, 1976) assigned a Pennsylvanian or Mississippian age to the Mattapan volcanic rocks based on inconclusive fossil evidence and because they underlie with apparent conformity the Roxbury Conglomerate that has been correlated with the Pondville Conglomerate that is known to contain Pennsylvanian plant fossils (Shaler and others, 1899); Bell (1948) assigns an Upper Silurian to Lower Devonian age to both the Mattapan and Lynn Volcanics supported by lithologic similarities to the Newbury Volcanics of known Silurian age. Kaye suggests that because similar volcanogenic rocks intertongue with both the Roxbury Conglomerate and the Weymouth Formation, the Roxbury Conglomerate and Cambridge Argillite of the Boston Basin and the Mattapan may all represent a continuous sequence. It may be entirely Cambrian in age or it may range from Cambrian to Silurian, or even to Carboniferous.

Lithologic units have been tentatively separated from the undivided Mattapan in the Norwood, Natick, and Medfield quadrangles based on descriptions by Chute (1966), Nelson, (1975, b), and Volckmann (1973b). The intertonguing of lithologies is undoubtedly more complex than is implied by those subdivisions.

mvp

porphyritic intrusive rhyolite

Intrusive "Pink porphyritic intrusive rhyolite containing albite and quartz phenocrysts in a fine grained matrix of quartz and feldspar" (Chute, 1966).

mvf

extrusive felsite

Light gray to dark gray or purplish gray porphyritic extrusive felsite containing 5% albite phenocrysts 1.5 mm in diameter. The matrix is composed of anhedral grains of quartz or feldspar in which flow banding is commonly distinguishable but is predominately massive (Nelson, 1975-b).

mva

intermediate volcanic rock

This is 'bluish- to greenish-gray fine-grained andesite with small phenocrysts of sericitized plagioclase in an aphanitic to very fine grained groundmass of tiny plagioclase laths; bluish gray to reddish brown volcanic breccia in which fragments vary from 2 - 30 cm in length and consist of a variety of volcanic rock types in a matrix of quartz and feldspar. Greenish to bluish-gray lapilli and fine-grained crystal tuffs; deep red to purple-red color with heterogeneous mixture of poorly sorted volcanic rock fragments. The unit is approximately 850 metres thick"(Nelson, 1975-b).

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mvg

Siliceous pyroclastic

"Light-gray to pinkish-gray to greenish-gray siliceous pyroclastic rock that is mostly crystal tuff and some highly fragmented lapilli tuff, characterized by crystals of quartz, some of which are resorbed, and plagioclase embedded in a fine-grained matrix of seriticized plagioclase, quartz, chlorite and epidote; contains some pale-reddish purple lava fragments. In places, rock is fragmental, elsewhere it appears massive; rarely faint flow lines are observed"(Nelson, 1975). Includes volcanic rocks mapped as Powissett Peak and Noonet Peak volcanics in the Medfield quadrangle by Volckmann (1973-b).

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9.1267

mdu

Undivided Mattapan, Dedham, and Westwood

An area of poor exposures in the northeast corner of the Norwood quadrangle mapped as undivided, mdu, except where exposures are sufficient to designate the rock type.

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Lv

Lynn Volcanic Complex

The volcanic complex was first named by Clapp (1910) for exposures of volcanic rock that crop out north of Boston in the Boston North and Lynn quadrangles. The Lynn Volcanics rest unconformably upon an erosional surface of Precambrian Dedham Granodiorite and metavolcanic rock (Bell, 1977). A crude stratification is apparent in most exposures. Welded tuff and flow banded rhyolite are interstratified with lenses of massive volcanic conglomerate; massive porphyry encloses, in minor amounts, lenses of welded tuff, agglomerate, and basaltic lava; agglomerate and lithic tuff in turn envelope masses of welded tuff (Bell, 1977).

bc

Bellingham Conglomerate

The Bellingham Conglomerate was named by Mansfield (1906) for exposures of conglomerate in North Bellingham, Massachusetts. The conglomerate was later redescribed by Richmond (1951), to include exposures of conglomerate contained in two structural basins in the Georgiaville quadrangle, Rhode Island. The unit is composed of gray to greenish-gray conglomerate; sandstone, lithic greywacke and phyllite irregularly interlayered in beds of varied thickness.

Pebbles in the conglomerate are greatly elongated and are mostly quartzite. The matrix is a granular arkosic aggregate of quartz, albite and chlorite. Beds of medium to fine-grained quartzite, feldspathic quartz-biotite schist and chlorite-talc schist are interbedded with the conglomerate. The age and thickness of the Bellingham Conglomerate is unknown but a tentative correlation with the Narragansett Basin is suggested by Quinn (1971) supported by lithologic and structural similarities to the Rhode Island Formation in the Narragansett Basin.

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rc

<u>Roxbury Conglomerate</u>. This formation, named by Edward Hitchcock in 1861, is exposed chiefly in the Newton and Boston South quadrangles. It consists of massive to thick bedded conglomerate, mudflow, interbedded sandstone, arkose, argillite and tuffaceous beds. Color ranges from red to maroon to gray. Isolated lenticular masses of conglomerate occur within the finer-grained basin sediments with which it interfingers. It constitutes the coarser grained facies of the Boston Basin sediments and is most prominent in the western part of the basin. Age is generally given as Devonian or Carboniferous but recent work raises the possibility it is older (Kaye, personal commun.).

The name Squantum Tillite was used by LaForge (1932) to designate a poorly sorted coarse conglomerate that is stratigraphically at the top of or above the main mass of Roxbury conglomerate. Its tillite origin is now strongly questioned (Dott, 1961). It is more probably a mudflow, laharic, or turbidite deposit and is not differentiated here.

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Cambridge Argillite. This formation was first named Cambridge Slate by N. S. Shaler, 1871, for the argillites and slates of the Boston Basin. It consists of rythmically thin bedded to thick bedded, generally medium-to dark-gray to bluish-gray argillite, in places interbedded with siltstone and fine sandstone. Where it contains abundant volcanic ash the color is greenish to reddish. The formation grades laterally into the Roxbury Conglomerate and is dominant in the upper part of the section and eastern part of Boston Basin. Its age is considered to be Devonian or Carboniferous but may be older (Kaye, personal commun.).

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$\mathbb{P}_{pc}$

Lower Member, Pondville Conglomerate

J. B. Woodworth (in Shaler and others, 1899) first named the Pondville Conglomerate. The most extensive exposures of the conglomerate are found on the flanks of the Norfolk Basin in the Norwood and Blue Hills quadrangles where Chute (1966) has subdivided the conglomerate into a lower cobble conglomerate and an overlying pebble conglomerate. The lower member is a very coarse cobble and boulder conglomerate. Cobbles range from 15 cm to 25 cm; the greatest number of boulders vary from .3 to 2 m in length (Chute, 1966). The pebbles and cobbles are composed of felsite, quartzite and sandstone, but in the lower part of the conglomerate the cobbles and small boulders are predominately Blue Hills Quartz Porphyry. The lower member grades upward to the upper member through an interval of 7 metres and is approximately 300 to 500 metres thick in the Norwood quadrangle (Chute, 1966). Plant fossils Calamites and Sigillerria found within the conglomerate are Pennsylvanian in age.

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PP pp

Upper Member, Pondville Conglomerate

The upper member is light-greenish gray, poorly sorted, crossbedded granule and pebble conglomerate with a few small lenses of fine grained red sandstone similar to the sandstone of the Wamsutta Formation. The sandstone lenses are most numerous in the upper part of the member where they contain light gray impure calcareous concretions. The pebbles are red, purple, and gray felsite, quartzite and granite. Matrix consists of quartz, feldspar and small rock fragments with a small amount of calcite cement (Chute, 1969). The upper member varies from 180 metres to 300 metres (Chute, 1966) in the Norwood quadrangle and has a gradational contact with the underlying cobble conglomerate.

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IP Pw

Wamsutta Formation

The Wamsutta Formatin was first defined by Woodworth (in Shaler and others, 1899) for exposures of Pennsylvanian rocks in the Norfolk Basin and those bordering the northern boundary of the Narragansett Basin in southeastern Massachusetts and Rhode Island. It consists predominately of fine-grained sandstone and interbedded with appreciable red slate; subordinate amounts of gray granule and pebble conglomerate are also present. Grains of carbonate are disseminated unevenly through the sandstone; numerous light gray lentils of carbonate .3 metres to 2.5 metres thick are common in the red shale (Chute, 1966). The most extensive exposures of the Formation are in the Norfolk Basin, where it appears to be over 900 metres thick, and gradational into the underlying Pondville Conglomerate (Chute, 1966), where gray beds typical of the Pondville are interbedded with the characteristic red beds of the Wamsutta. It is also partly equivalent to the Rhode Island Formation according to Quinn (1971).

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IPr

Rhode Island Formation

The Rhode Island Formation was first named by Woodworth (in Shaler and others, 1899) for the group of Pennsylvanian rocks that underlie the largest part of the Narragansett Basin in southeastern Massachusetts and Rhode Island. "The formation consists of granule to boulder conglomerate, sandstone, greywacke, arkose, and shale, and a small amount of meta-anthracite. Most of the rock is gray to dark gray, and greenish, but some is black, especially the shale and the meta-anthracite. These are interbedded in a most irregular way; cross-bedding is common" (Quinn, 1971). The coal, chiefly anthracite, is not exposed within the map area. Conglomerate layers are gray to greenish-gray and are interbedded with sandstone and greywacke. They range up to coarse boulder conglomerate with clasts up to 1 metre in diameter. The formation is approximately 3,060 metres thick and conformably overlies the Pondville Conglomerate with a gradational contact; it is partly equivalent to the Wamsutta Formation and partly younger than coarse conglomerate in the Wamsutta Formation.

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Tcs

Tertiary coastal plain sedimentary

Gray clayey silts containing abundant Tertiary pollen crop out in the lower part of a landslide in the sea cliff at Third Cliff, Scituate. The same silts underlie parts of the Marshfield Hills. Just west of Marshfield patches of fossiliferous Miocene glaucovite sands (greensand) overlie hummocky bedrock and are covered by glacial drift. All these Tertiary déposits give evidence of having been glacially dislocated.

Qd

Large dunes up to 70 ft. in height consisting of uniform fine sand and some medium sand; shown only on the tip of Cape Cod.

Qm

Saltmarsh deposits are found to elevations of about mean high tide and consist of fibrous peat and organic-rich silts and fine sand varying very much in thickness from 1 ft. to 30 ft; shown only on the tip of Cape Cod.

Qp

Outwash depósits consisting of stratified fine to medium sand. Some pebbly layers and sparse boulders up to 6 ft., that occur mostly on the surface; shown only on the tip of Cape Cod.

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Rocks between Clinton-Newbury and Bloody Bluff fault zones

Intrusive rocks

ag

Andover Granite

The Andover Granite (Clapp, 1910) underlies more than a third of the area between the Clinton-Newbury and Bloody Bluff fault zones. According to Castle the "Andover Granite comprises a group of leucoratic peraluminous alkali - to calc alkali-feldspar, generally highly siliceous plutonic rocks ranging from alaskite to sodic tonalite or trendjhemite" (1964, p. 253-254). In his detailed study of the Andover Granite, Castle divided these rocks into six "separate but transitional facies" herein lumped as a single map unit. D. C. Alvord (1975) described the Andover Granite in the Westford and Billerica quadrangles as light- to medium-gray, slightly- to well-foliated, mostly medium-coarse to coarse-grained equigranular quartz monzonite in which quartz, plagioclase, and potassium feldspars occur in nearly equal proportions and constitute 85 to 95 percent of most specimens. Mica ranges from about 3 to 12 percent with biotite exceeding muscovite at most localities. Simple granitic pegmatite bodies, both conformable and cross-cutting to the foliation are very common in this rock.

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The Andover Granite intrudes the Nashoba Formation and associated metamorphosed stratified rocks that lie between the Clinton-Newbury and Bloody Bluff fault zone. The stratigraphic position of these rocks is not known, but regional considerations suggest that they vary from Precambrian to Early Paleozoic. According to Zartman (1976, personal commun.) the best radiometric date for the Andover at the present time is a Rb/Sr whole rock date of 460 ± my, Late Ordovician.

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aqd

Assabet Quartz Diorite

The Assabet Quartz Diorite was named by W. R. Hansen (1956) for exposures near the Assabet River in the town of Maynard. The quartz diorite forms a northeast trending elongate body between rocks of the Nashoba Formation and the southwesternmost exposure of the main body of the Andover Granite. The Assabet widens northeastward in the Concord quadrangle where it intertongues abruptly with the Shawsheen Gneiss. According to Hansen (1956) the rock is medium- to dark-gray medium grained slightly to moderately foliated quartz diorite composed of andesine, hornblende, quartz and biotite; it contains considerable accessory apatite and some sphene and hematite. The Straw Hollow Diorite of Hansen (1956), which is exposed near the southern border of the Hudson quadrangle extending southwestward into the Marlborough quadrangle, is lumped with the Assabet for this map. This diorite is mostly medium grained, medium gray, composed of andesine, hornblende, biotite, and minor amounts of apatite and sulfides and veinlets of quartz. According to K. G. Bell (personal commun.) the Assabet and Straw Hollow are mafic equivalents of the Andover. No radiometric dates have been obtained from the Assabet.

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dac

Acton Granite

The Acton Granite (Hansen, 1956) occurs chiefly in the Westford quadrangle, mostly as relatively small intruded sheets trending northeast subparallel to the regional structural trend, but also as cross cutting dikes and irregular bodies too small to map. This granite is a hard fresh fine-grained light-gray weakly foliated rock composed chiefly of quartz, orthoclase, microcline and oligoclase with the ratio of potash feldspar to oligoclase more than 2 to 1. Biotite and muscovite are the chief accessory minerals; apatite, zircon, garnet, and epidote are minor constituents (Hansen, 1956). R. O. Castle (1965a, p. C-79) considers the Acton to be equivalent to his massive facies of the Andover. According to Alvord (personal commun.), however, foliated Andover is cut by very weakly foliated Acton in the Maynard quadrangle, suggesting that the Andover is syntectonic and the Acton, slightly younger and unrelated to the main period of deformation of the Nashoba and related country rock. Perhaps Castle's massive Andover is the Acton and slightly younger than the foliated Andover. No radiometric dates have been obtained from the Acton.

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sd

Sharpeners Pond Diorite

Plutonic rocks assigned to the Sharpeners Pond Diorite are extensively exposed east of the Andover Granite and west and north of the graben containing Newbury Volcanics. The boundary between the Andover and Sharpners Pond is gradational and small bodies of each rock type occur in the other; the contact as drawn is generalized. R. O. Castle (1965b) adopted the name Sharpners Pond Tonalite for exposures of those generally melanocratic plutonic rocks, selecting as the type area exposures at Sharpners Pond in the southwest corner of the South Groveland quadrangle about 7 km west of the town of Topsfield. A. F. Shride (1976) extended the mapping of these rocks northwestward into the Newburyport West and East quadrangles. He prefers the more general term of Sharpners Pond Diorite for the entire body of rock. The Sharpners Pond in the type locality and vicinity consists ... "chiefly of massive to somewhat foliated, generally medium grained and equigranular intrusive rocks. They range in color from dark greenish gray or black to light gray. Their modal compositions fall generally in the tonalite-diorite range" (Castle, ~~1976~~ 1965a, p. C77). Shride (1976) describes the Sharpners Pond Diorite further northeast in the Newburyport quadrangles as fine-grained, medium- to dark-gray, biotite-hornblende diorite with a variable quartz, content commonly 2-8 percent. Castle (1965a, p. C78) states that the Andover Granite and the Sharpners Pond Tonalite belong to a continuous plutonic series". He considers the Sharpners Pond to be the same melanocratic facies of the Andover as the Assabet. This is in agreement with the interpretation of K. G. Bell (personal commun.) and of A. E. Shride (personal commun.). No radiometric dates have been obtained from the Sharpners Pond.

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qm

pink quartz monzonite

A body of quartz monzonite that is exposed between the east-trending fault that forms the north end of the graben of Newbury Volcanics and the body of Sharpners Pond Diorite in this area was mapped by A. F. Shride (1976). He states that "the rock is pinkish-gray to grayish-orange-pink, rusty-weathering, medium- to coarse-grained seriate-textured rock, characterized by grayish-orange-pink translucent perthitic microcline of very irregular outline, clear gray quartz, and minute (1 mm) ragged flakes of bright biotite. Quartz and milky white oligoclase each compose about one-third of the rock, microcline somewhat less, and biotite about 5 percent. The characteristic inequigranular texture varies with size of the microcline grains; as these progressively increase in size the texture becomes, first, subtly porphyritic, then obviously porphyritic with phenocrysts as much as 20 mm in length. Phases most nearly equigranular are dominant and are mostly quartz monzonite; the distinctly porphyritic phases are granodiorite." According to Shride this pink quartz monzonite intrudes the Andover and the Sharpners Pond. No radiometric ages have been obtained.

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Stratified rocks

m

Marlboro Formation

The Marlboro Formation, named by Emerson (1917), consists of an upper Sandy Pond Member and an undivided lower part (Bell and Alvord, 1976). The lower part is generally medium to dark gray and composed of calc-silicate-bearing gneiss, quartzo-feldspathic mica gneiss, alluminous mica schist, quartzite, marble and calc-silicate fels complexly interstratified with both layered and massive amphibolite. The area of the lower part also includes much medium to dark-gray intrusive quartz diorite, diorite and gabbro and possibly younger dark gray volcanic rocks. The overlying Sandy Pond member, msa, is chiefly dark gray to nearly black thinly layered fine-grained amphibolite interlayered with massive medium to coarse-grained amphibolite; other rock types amount to less than 20 percent (Bell and Alvord, 1976).

The base of the Marlboro is faulted. The top is conformable and gradational into the Shawsheen Gneiss. The contact is placed where muscovite-biotite gneiss and schist greatly exceeds amphibolite. The Marlboro has a maximum thickness of 2,140 m in the Shrewsbury quadrangle (Bell and Alvord, 1976). The Marlboro is believed equivalent to the Quinebaug Formation of Dixon (1964 and 1974) in the Thompson quadrangle, Connecticut.

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sh

Shawsheen Gneiss

The Shawsheen Gneiss consists of light to medium gray medium-grained locally sillimantic muscovite-biotite-oligoclase-quartz gneiss with some lenticular bodies of bedded and massive amphibolite. Sulfidic sillimanite-mica schist is present near the base. The principal rock type is identical to the most common rock type in the Nashoba Formation, but Bell and Alvord (1976) have separated the formation from the Nashoba by the Fish Brook Gneiss. The upper contact of the Shawsheen is conformable with the Fish Brook. The Shawsheen has a maximum thickness of 2,600 m.

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f

Fishbrook Gneiss

The Fishbrook Gneiss, named by Castle (1965) and redefined by Bell and Alvord (1976) is chiefly very light-gray to light-gray fine- to medium-grained plagioclase quartz biotite gneiss. It characteristically weathers pale yellow. A distinctive feature of the formation is the paucity of mafic constituents, mostly less than 10 percent. Relic bedding is characteristically faint but locally shows planar to rippled compositional layering, possibly cross-stratified. Thin lenticular lenses of amphibolite and plagioclase hornblende biotite granular schist and gneiss are sparsely distributed throughout the formation. The upper contact of the Fishbrook is gradational into amphibolite rocks at the base of the Nashoba (Bell and Alvord, 1976); it has a maximum thickness of 1,520 m.

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n

Nashoba Formation undivided

The Nashoba Formation was defined by Hansen (1956) to include all the stratified rocks between the Marlboro Formation and the Tadmuck Brook Schist. The formation has subsequently been restricted (Bell and Alvord, 1976) by separating the distinctive Fishbrook Gneiss and underlying Shawsheen Gneiss from its base. Alvord (1975) also divided the restricted Nashoba into 10 members. The Nashoba, n, is used in its original manner after Hansen (1956) where the members are not delineated. The Nashoba Formation of Hansen correlates with the Tatnic Hill Formation of Connecticut. Where members are mapped, chiefly in the Westford and Billerica quadrangles, the Nashoba Formation consists of relatively homogeneous members composed chiefly of medium-grained muscovite biotite-oligoclase-quartz gneiss alternating with members of more heterogeneous lithology including fine-grained amphibole-biotite gneiss and schist, amphibolite, mica schist locally sulfidic, calc-silicate-bearing gneiss and a few lenses of marble.

The Nashoba Formation is intruded by the Andover Granite of Late Ordovician radiometric age. Furthermore, this complex of regionally metamorphosed and deformed rocks is in fault contact with the Newbury Volcanics, a sequence of essentially unmetamorphosed volcanogenic rocks containing Silurian-Devonian fossils (Shride, 1976). The Nashoba is thus Early Paleozoic or possibly Precambrian in age. The Nashoba has a maximum thickness of 15,010 m (Bell and Alvord, 1976).

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nbx

Boxford Member

The Boxford is composed of varieties of thinly bedded amphibolite, massive amphibolite, and biotite-amphibole gneiss and schist interlayered with variable and at many places subsidiary amounts of biotite gneiss, calc-silicate bearing fels and gneiss and rare lenses of marble. Locally, particularly at its type locality and in the vicinity of Nutting Lake in the town of Billerica, the lower part of the Boxford is made up almost entirely of amphibolite and amphibole bearing gneiss and schist. Regionally, however, the member has been found similar to many of the overlying complexly interstratified members of the Nashoba. The upper contact is not exposed, but appears to be conformable. The Boxford has a maximum thickness of 1,520 m.

nbh

Bellows Hill Member

The Bellows Hill Member is almost entirely medium-grained sillimanitic muscovite-biotite gneiss that typifies the Nashoba. Subsidiary fine-grained amphibole-biotite gneiss and amphibolite, and thin lenticular beds of marble and related diopside-tremolite-calc-silicate fels occur discontinuously in the upper half. The upper contact with the Billerica Schist Member is not exposed, but is presumed conformable and gradational, however, evidence for faulting is found at many localities. The member has a maximum thickness of 1,100 m.

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nbs

Billerica Schist Member

The Billerica Schist Member consists chiefly of varieties of sulfidic sillimanite-muscovite-biotite schist and subsidiary lenticular bodies of amphibole schist and hornblende-biotite schist and gneiss.

This member everywhere is separated from the overlying member either by a concealed interval at least 100 m wide or by a tongue of Andover Granite. The contact is presumed to be conformable. It has a maximum thickness of 270 m.

ns

Spencer Brook Member

The Spencer Brook Member consists of complexly interstratified thin-bedded amphibole-biotite gneiss, thinly bedded amphibolite, and massive amphibolite, with notable amounts of amphibole-diopside calc-silicate fels and gneiss, biotite gneiss, and some thin lenses of marble. Its upper boundary is conformable and gradational. It has a maximum thickness of 580 m.

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nt

Tophet Swamp Gneiss Member

The Tophet Swamp Gneiss Member is chiefly the medium-grained sillimanitic muscovite-biotite-oligoclase-quartz gneiss characteristic of the Nashoba with a few lenticular bodies of thinly bedded amphibolite and massive amphibolite.

Its upper contact is conformable and gradational. It has a maximum thickness of 920 m.

nnb

Nashoba Brook Member

The Nashoba Brook Member is a heterogeneous assortment of amphibole-biotite gneiss, diopsidic calc-silicate bearing gneiss and fels with amphibolite in the upper and lower parts. The middle part is chiefly sulfidic sillimanite-biotite-muscovite schist and gneiss with subordinate amounts of amphibolite and biotite gneiss. The upper contact is conformable and gradational. Its maximum thickness is 920 m.

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nn

Nagog Pond Gneiss Member

The Nagog Pond Gneiss Member is chiefly the medium-grained muscovite-biotite-oligoclase-quartz gneiss that characterizes the Nashoba Formation interstratified with some amphibole-biotite gneiss and lenticular bodies of thinly bedded amphibolite and massive amphibolite. The upper contact is concealed, but is considered conformable. The maximum thickness of the member is 1,370 m.

nf

Fort Pond Member

The Fort Pond is another member with varied lithology. The lower part is made up mostly of fine-grained amphibole-biotite gneiss, calc-silicate (diopside-tremolite) bearing gneiss or fels, and amphibolite. The upper part consists chiefly of the same rock as the lower part but includes in addition, some sulfidic sillimanite-mica schist and discontinuous beds of marble. The upper contact with the Long Pond Gneiss Member is believed to be conformable, but at many localities the contact is faulted. The member has a maximum thickness of 1,470 m.

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nl

Long Pond Gneiss Member

The Long Pond Gneiss Member consists mostly of the characteristic medium-gray-medium-grained thin- to medium-bedded, well foliated sillimanitic muscovite-biotite-oligoclase-quartz gneiss of the Nashoba interstratified with a few lenticular bodies of thin- to medium-bedded dark green amphibolite and massive amphibolite. Pegmatite and granitic gneiss form as much as 25 percent of the rock. Relict bedding and, in some localities, cross laminations are present (Peck, 1975). The upper contact is covered, but mapping indicates it is conformable and gradational. It has a maximum thickness of 1,160 m.

nb

Beaver Brook Member

The uppermost member of the Nashoba is the Beaver Brook Member which is also composed of a heterogeneous variety of rock type. It is chiefly medium to dark gray amphibole-biotite gneiss, calc-silicate (tremolite-diopside) bearing gneiss and fels, and amphibolite. Discontinuous beds of limestone in the lowermost 400-500 m have been mapped (Peck, 1975) but are not shown separately. The remainder above include medium-grained sillimanitic muscovite-oligoclase-quartz gneiss complexly interstratified with sulfidic sillimanite-muscovite-biotite-oligoclase-quartz schist, both thin bedded and massive amphibolite, and amphibole-biotite gneiss. The upper contact with the Tadmuck Brook Schist appears conformable locally, but the regional overlap of the Tadmuck Brook on to successively lower members of the Nashoba Formation suggests an unconformity. The member has a maximum thickness of 1,580 m.

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tb

Tadmuck Brook Schist

The Tadmuck Brook Schist was originally mapped as Brimfield Schist by Emerson, 1917, and renamed the Tadmuck Brook by Bell and Alvord (1976). The Tadmuck Brook Schist is chiefly phyllite in the upper part, sericite-staurolite-andalusite phyllitic schist in the middle part, and sillimanite-quartz-mica schist in the lower part, all interstratified with some lenticular bodies of thin-bedded amphibolite, non-bedded or massive amphibolites and a few quartzite beds locally at the top of the schist. Much of the formation contains sulfide-rich layers that slake on weathering and stain large outcrops conspicuously rusty brown and sulfur yellow. Elsewhere, where sulfides are rare to absent the rocks weather light to medium gray or greenish gray.

The Tadmuck Brook Schist is best exposed in its northern area of outcrop particularly on Oak Hill crossing State Highway 2 and along Interstate Highway I-290. In much of the area to the south its presence is inferred; it is again exposed in Auburn.

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Newbury Volcanic Complex

Dsn

The Newbury Volcanic Complex (Shride, ~~1970~~ 1976) is a thick sequence (greater than 4,400 m) of relatively unmetamorphosed volcanic rocks. It was assigned an Upper Silurian to Lower Devonian age by Emerson (1917). This age has been confirmed by fossil evidence found in the northeast corner of the Salem quadrangle (Toulmin, 1964).

The following descriptions of units within the complex are by Shride (1976):

Dsni

Micrographic rhyolite intrusions

"Podlike bodies of brownish-grey to orange-pink, aphanitic to sugary-textured massive felsite. Characterized by micrographic and spherulitic intergrowths; spherulites are visible in some outcrops. 100-600 metres in thickness and as much as 1,600 m in length."

Dsnc

Calcareous Mudstone Member

"Laminated grey limestone and mudstone, very thinly interbedded. Large ostracodes characteristic, at least 90 m; possibly 300 + m in thickness."

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DSnm

Red mudstone Member

"Greyish-red, friable, micaceous sandy mudstone. Boundaries are indeterminate; combined thickness with the siliceous siltstone member and the calcareous mudstone member total 1,500 m."

DSns

Siliceous siltstone Member

"Dusky yellow green to olive black, dense, flinty rock; parallel stratification is conspicuous."

DSnp

Porphyritic Andesite Member

"Propylitized greyish-green to dark-grey andesite, typified by plagioclase phenocrysts. Non-stratified volcanoclastic layers, ranging from fine-grained tuffs to boulder breccias, are much more voluminous than intercalated flows; stratified greywacke is subordinate. Sparsely fossiliferous. 1,650 + m thick."

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DSnr

Flow Banded Rhyolite Vitrophyre Member

"Dense, lithoidal vitrophyre, mostly greyish red and conspicuously laminated; large parts not porphyritic; includes sparse lenses of vitric tuff; locally basal 120 m is pumiceous tuff. 580-670 m thick."

DSnl

Vitric Rhyolite Lapilli Tuff Member

"Greyish-green, friable, hackly fracturing tuff, in which flattened pumice fragments are abundant in shard-rich matrix. 0-52 m thick."

DSnb

Basalt Flow Member

"Uniformly fine-grained propylitized flows, devoid of fragmented materials; each 30 m or more thick and separated by thin lithified soil(?) zones. 250-300 m thick."

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DSna

Fine-grained Andesite Member

"Thoroughly propylitized, very fine-grained, olive to olive-brown rock; part conspicuously to vaguely laminated, part massive and amygdoloidal (?). 275 m interval between the andesite member and the rhyolite tuff member, with only 80 m of strata exposed."

DSnt

Rhyolite Tuff Member

"Flinty yellow-brown to brownish-grey vitroclastic rock, studded with darker fragments that are felted in texture."

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Rocks north and west of the Clinton-Newbury fault zone

Intrusive rocks

pgd

Pegmatitic granite complex

A broad belt 6 - 7 km wide herein loosely termed pegmatitic granite gneiss extends northeastward from the southern parts of the Ashby and Townsend quadrangles in Massachusetts to the northern border of the map area in New Hampshire. This belt of rocks was named the Massabesic Gneiss by Sriramadas (1966, p. 32) for exposures around Lake Massabesic, New Hampshire.

Sriramadas (1966) describes the rocks as pink microcline gneiss with minor oligoclase gneiss and amphibolite. Road cuts along the newly constructed part of highway I-93 east of Manchester have exposed a nearly complete cross section of the complex. It consists mainly of pegmatitic granite and associated intrusive rock with abundant pendants and xenoliths of metasedimentary rock. The pegmatitic granite is non-foliated, but, in places, it is migmatitic, which causes it to have a layered gneissic appearance. The layering can be seen to extend from and parallel bedding in pendants, locally at contacts. It represents relic bedding and demonstrates the metasomatic origin of the pegmatitic granite.

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The pegmatitic granite varies from pink to light-gray microcline and oligoclase pegmatite that grades to medium-grained granite in many places. It contains abundant biotite and is medium-gray where migmatitic, but elsewhere contains only a minor to moderate amount of biotite. Coarse magnetite, -.5 to 2 cm in diameter, is distributed in zones subparallel to the layering chiefly near the southern boundary of the complex. The magnetite and also much of the pink coloration of the feldspars appears to be due to deuteric alteration. Light gray fine to medium-grained binary granite sills and dikes are offshoots of the pegmatite granite.

The intruded metasedimentary rocks in the northern portion of the complex consist of sillimanite muscovite schist and gneiss in part sulfidic and containing minor amphibolite interlayers, intruded by sills a few centemeters to tens of meters wide of very light-gray, weakly foliated, medium- to fine-grained binary granite subparallel to foliation. The binary granite is cut in several directions by pink potassium feldspar pegmatite dikes. The northern boundary is not exposed, but the country rock can be traced along strike southwestward through the Peterborough quadrangle, New Hampshire, into rocks of very similar lithology and metamorphic grade, the Bigelow Brook Formation of the Brimfield Group, in eastern Connecticut (Peper, Pease, and Seiders, 1975). Schistose granulite typical of the "Paxton Group" occurs as xenoliths and pendants locally along the southeastern edge of the complex.

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J. R. Besancon collected a sample of the magnetite bearing migmatitic gneiss from a road cut on highway 101 several kilometers east of the I-93 road cuts before these exposures had been opened up. The sample yielded a very reliable zircon date of 600-620 my (Besancon, Gaudette and Naylor, 1977). This date is not in accord with the Middle Paleozoic age that has been assigned to the Bigelow Brook Formation, (Peper, Pease, Seiders, 1975). There are several possible alternatives for this inconsistency: 1) The Massabesic is isolated from the surrounding country rock by faults. This does not appear to be the case because schist and gneiss of the country rock clearly interfinger with the pegmatitic granite along Interstate I-93. 2) The country rock immediately surrounding the Massabesic is not the Bigelow Brook or "Paxton Group" but older rocks of Precambrian age. The rocks that intertongue with the pegmatitic granite, however, are lithologically similar to and appear to be contiguous with the Bigelow Brook Formation. Lithologic evidence for a major fault within the country rock to north or south has not been observed. 3) The entire "Paxton Group" and Brimfield Group sequences are Precambrian. If so, where is the major fault that separates Precambrian from Paleozoic to the southeast and how does this thick Precambrian section reconcile with presumed Middle Paleozoic age of the Littleton and Berwick of New Hampshire and Maine that are on strike to the northeast?
4) The analytical data are erroneous. According to Naylor (personal commun., 1976), the concordia, derived from 5 fractionations of the same sample, is exceptionally good. 5) The zircons are older than

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the rock in which they occur, either as Precambrian xenoliths that have been migmatized by the pegmatitic granite or as detrital zircons in Paleozoic xenoliths migmatized by the granite.

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This last alternative does not require any major remodeling of the regional structural and stratigraphic picture. Possibly the Paleozoic Brimfield or "Paxton Group" rocks contain detrital zircons of Precambrian age, but it appears more likely that the hybrid rock itself consists of Precambrian xenoliths brought up by the intruding granite pegmatite magma. The pegmatitic granite shows no evidence of regional metamorphism and almost certainly is younger than Precambrian. Samples have been collected, but not yet dated, of the granite, the pegmatite, the migmatitic rock and the pelitic schist from the new road cuts on Interstate highway I-93 where distinctions between rock types are clear. Dates from these samples should identify more specifically which rocks of the Massabesic complex are Precambrian in age; the pelitic schist should yield at least a maximum possible age for the country rock intruded by the pegmatitic granite.

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nqm

Newburyport Intrusive Complex - quartz monzonite

The name Newburyport Quartz Diorite was introduced by Emerson (1917) for rocks exposed in northeastern Essex County where quartz diorite and tonalite predominate over the granitic rocks he called Dedham and the gabbroic rocks he called Salem Gabbro-Diorite. Shride (1976) restricted the name Newburyport to the pluton exposed mostly in the Newburyport East and West quadrangles. He divided the pluton into a quartz monzonite, nqm, core and a porphyritic granodiorite border, nqp. The quartz monzonite core is medium-grained, greenish-gray to light-olive-green equigranular rock that ranges compositionally from quartz monzonite in southern outcrops to mafic granodiorite in northern exposures. Hornblende may occur in equal proportions to biotite in the more mafic phases. Reddish-brown sphene commonly is apparent to the unaided eye. Ubiquitous pyrite is the cause of rust-stained outcrops.

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nqp

porphyritic granodiorite

The porphyritic granodiorite border phase is similar to the least mafic parts of the core rock except that orthoclase is confined almost wholly to phenocrysts, which are as much as 6 by 9 cm in dimensions, and hornblende is entirely absent. Locally, two or more sets of thin aplite dikes abundantly rib the porphyritic granodiorite. Greenish-black, medium-grained, hornblendic segregation, in which hornblende plus biotite compose 45 to 75 percent of the rock and orthoclase plus sericitized plagioclase, quite variable in their proportions, is also common. Sphene is ubiquitous (Shride, 1976). Samples of the Newburyport yield a radiometric date of 430 my for the porphyritic and 460 my for the non-porphyritic phase. These dates correlate well with the Salem Gabbro-Diorite, Cape Ann, Quincy, and Andover Granites. This age is anomalously old to relate to the Acadian orogeny according to Zartman.

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fg

foliated granitic rock

Light- to medium-gray, medium-grained, moderately to well foliated biotite granitic rock exposed in the west-central part of the map extending from the Fitchburg quadrangle to the northeast corner of the Leicester quadrangle. It contains abundant xenoliths and screens of biotite and biotite-garnet schist and other rock types from the "Paxton" and Brimfield Groups. The granitic rock is variable, being in part migmatitic and cut by numerous pegmatites. No radiometric dates have been obtained from these rocks; they are known to cut strata of the Bigelow Brook Formation. It is more strongly foliated than adjacent muscovite quartz monzonite and possibly older, but the nature of the contact between these two igneous rocks is uncertain.

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ay

Ayer intrusive complex - undivided

The Ayer plutonic rocks are extensively exposed in the area northeast of the Clinton-Newbury fault in elongate bodies tens of kilometers long mostly subparallel to the regional trend of foliation and structure. The name Ayer Granite was originally assigned to granite that "occurs in several detached areas in a belt extending from Hampstead, N. H., through Ayer and Worcester, Mass. into Connecticut" by B. K. Emerson (1917, p. 223). Currier (1952), Jahns (1952), Hansen (1956), and Grew (1970) variously subdivided the Ayer in local areas. The most recent comprehensive study of the Ayer Intrusive Complex has been made by R. Z. Gore and it is his subdivision somewhat modified by ourselves that has been used for this map (Gore, 1973, 1976, and personal commun.). The Ayer is mostly of quartz monzonite composition; it consists of a coarse porphyry that is intruded by a medium grained muscovite-bearing intrusive, which in turn is cut by a medium grained biotite intrusive with a coarse porphyritic phase. The subdivisions are mapped locally, chiefly in the Ayer quadrangle. Zartman (personal commun.) states that samples from both the porphyritic and non-porphyritic Ayer have yielded a radiometric date of 425 ± my - Silurian.

ape

Early porphyritic quartz monzonite of Ayer Complex

Light- to medium-gray, coarse-grained well foliated chiefly biotite quartz monzonite, that may range in composition from granite to quartz diorite. Locally the rock appears layered due to compositional variations that probably reflect flow banding. The feldspar phenocrysts commonly are 10 cm long and generally are strongly fractured. The quartz generally is granulated. This rock type is intimately intruded by muscovite quartz monzonite and cannot be readily separated from it in mapping. In many areas the designated rock type is only indicative of the major rock type. Included with this rock is the Devens phase of Gore (1973). This rock generally is strongly foliated where sheared and mylonitized in fault zones.

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am

Muscovite quartz monzonite of Ayer Complex

This intrusive is formed of light gray fine- to medium-grained slightly to well foliated muscovite or muscovite-biotite-quartz monzonite. Locally, as near the Connecticut border, it forms a lit-par-lit complex with the early porphyritic quartz monzonite. In part it cuts the porphyry and is clearly younger, but a part may overlap the porphyry in age. It is similar in appearance to the Chelmsford Granite in the Westford and Billerica quadrangles (Alvord, 1975).

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aqm

Biotite quartz monzonite of Ayer Complex

This rock is light- to medium-gray, medium-grained, generally slightly to moderately foliated biotite quartz monzonite. It may be strongly foliated adjacent to fault zones with the biotite replaced by muscovite. It appears much less deformed and younger than the adjacent early porphyry.

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apl

Late porphyritic quartz monzonite of Ayer Complex

Light gray, coarse-grained, slightly to moderately well foliated porphyritic biotite quartz monzonite. It constitutes a local porphyritic phase of the biotite quartz monzonite. It can be easily mistaken for the early porphyritic quartz monzonite. This porphyry is also strongly chloritized where it is sheared and mylonitized in fault zones.

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t

tonalite

This is a dark border phase exposed around the north end of a body of Ayer Granite mapped by R. H. Jahns (1952) in the Lowell quadrangle. According to Jahns it is distinct from the adjacent Dracut Diorite.

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mqm

Muscovite quartz monzonite

Light-gray, fine- to medium-grained, slightly to well foliated muscovite-biotite quartz monzonite. It is mostly a binary granite but locally muscovite or biotite may be absent. It includes such rocks as the Eastford Gneiss and the Fitchburg and Chelmsford Granites. It appears to be the same as the muscovite quartz monzonite in the Ayer Intrusive Complex and is provisionally equated with it, but according to Zartman (personal commun.), the best radiometric age for the Eastford is about 400 my and for the Chelmsford about 380 my. This is slightly younger than the Ayer radiometric age.

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kqm

Kinsman quartz monzonite

The Kinsman quartz monzonite, named Kinsman Granodiorite by C. ~~M.~~ R. Williams (1934) and described as quartz monzonite by M. P. Billings (1937), forms the large Cardigan pluton, the southern part of which is exposed in the northwest corner of the map area. R. C. Greene (1970) describes the Kinsman as a "coarse grained gray rock with white microcline phenocrysts, one to two inches long that are parallel to one another; it has a coarse gray groundmass composed of quartz, plagioclase, microcline, biotite and muscovite." The Kinsman intrudes rocks of the Hamilton Reservoir Formation previously mapped as the Littleton by Billings (1956) and Greene (1970). Naylor assigns a radiometric date of 396 my to this rock; this is slightly younger than the Ayer, but most workers in the area equate it with the Ayer largely because it so closely resembles the porphyritic phase of the Ayer.

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sqd

Spaulding Quartz Diorite

The Spaulding Quartz Diorite (Fowler-Billings, 1949) is a dark gray medium-grained massive to foliated spotted rock composed of plagioclase, quartz, and biotite. Locally small bodies of light-colored granodiorite and quartz monzonite are present (Greene, 1970). It is exposed in a large amoeba shaped pluton in the east-central Peterborough quadrangle, New Hampshire, extending into the Milford quadrangle. A few small bodies of quartz diorite to the south have also been equated with the Spaulding by Greene (1970). The Spaulding intrudes rocks of the Hamilton Reservoir Formation - the Littleton Formation according to Billings (1956) and Greene (1970). No radiometric dates have been obtained from the Spaulding.

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dp

diorite plutons

The Dracut (Emerson, 1917) and Exeter (Hitchcock, 1870) diorite plutons and several small bodies of diorite are exposed between the Lowell quadrangle, Massachusetts, and the Exeter quadrangle, New Hampshire. These rocks are generally moderately to well foliated and range from granodiorite through quartz diorite to diorite with minor amounts of gabbro and according to Emerson (1917) subordinate augite or hypersthene and hornblende are commonly present. They generally are believed to represent more mafic phases of the Ayer Granite, and probably are correlatives of the Spaulding.

qd

quartz diorite

Medium-gray, medium-grained, very slightly to moderately well foliated biotite quartz diorite. Dark-gray to nearly black biotitic inclusions elongated parallel to the foliation are common and distinctive. The quartz diorite occurs southeast of Millstone Hill in Worcester and as a small body within the Ayer intrusive complex near the south edge of the Webster quadrangle.

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mh

Millstone Hill Granite

The Millstone Hill Granite is a small pluton exposed in the southeast corner of the Worcester North quadrangle. The rock is very light- to light-gray medium-grained equigranular, nonfoliated, granite to granodiorite. It weathers light buff to rusty brown. The granite contains smoky quartz that alters to blue upon weathering (Perry and Emerson, 1903, p. 53), and minor biotite, muscovite, and fluorite. According to Zartman (personal commun.) the Millstone Hill yields a 385 my radiometric age.

g

gabbro

Two small bodies of medium-to dark-gray, medium-grained nonfoliated to slightly foliated gabbro to diorite are exposed in the southwest corner of the Worcester South quadrangle and the northwest corner of the Shrewsbury quadrangle.

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d

Diabase

Diabase dikes are rarely exposed in the region, but their characteristic magnetic expression demonstrates a series of dikes trending northeast across the Worcester region. This is part of a line of dikes extending from Long Island Sound northeast to Maine (Barosh, 1976). A dike exposed in the Quabbin Tunnel near the southwest corner of the Sterling quadrangle is about 65 m wide.

A 13 m wide columnar jointed dike in the Clinton quadrangle is described by Peck (1975) as a dark greenish gray to dark-gray diabase that weathers brownish gray. It is fine-grained porphyritic near the border and medium-grained even-textured towards the center; composed of labradiorite, augite and biotite with accessory magnetite, calcite and quartz.

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Stratified rocks

sm

Metasiltstone

This unit consists of light-brownish-gray to light-gray metasiltstone and calcareous metasiltstone with some beds of dark-gray phyllite. Most of the metasiltstone is thin-bedded, laminated and contains very fine granular quartz, plagioclase, brown biotite, and chlorite with locally significant amounts of calcite (Peck, 1975). It weathers light brown. The unit forms large folded roof pendents in the Fitchburg Granite near the southern boundary of the Clinton quadrangle, along Interstate highway 290; it also is a bedded sequence in a fault block near Reubens Hill in the Clinton quadrangle. Granulated quartz with possibly some other quartz-like mineral (cordierite?) form knots in the phyllite (Peck, 1975). The metasiltstone is interlayered in the lower part of the Reubens Hill igneous complex in the Wachusetts-Marlboro tunnel (Skehan, 1968), but this relationship is not seen at the surface (Peck, 1975).

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rh

Reubens Hill Igneous Complex

The Reubens Hill Igneous Complex is a heterogeneous unit consisting of greenish-gray chlorite hornblende schist, dark-greenish-gray amphibolite, medium-gray to brownish-gray plagioclase, biotite, quartz schist, greenish-gray diorite, and plagioclase-hornblende-biotite-chlorite schist (Peck, 1975). The complex is only known to occur in the Clinton quadrangle and the discussion below is from Peck (1975). The rock types forming the unit were derived originally from mafic to intermediate flows, tuffaceous sediments, tuffs, hypabyssal intrusive rocks, intrusion breccias and some intrusive diorite. Most of the more northerly body in the Clinton quadrangle seems to have been diorite which is intruded irregularly by the Ayer Granite. The diorite is fine- to medium-grained and consists mostly of saussuritized plagioclase (andesine?) hornblende and biotite. The medium- to coarse-grained schist at Carville Basin and on Reubens Hill was originally a submarine basalt flow as indicated by structures resembling pillows and a chemical analysis that indicates the schist probably was an olivine rich oceanic basalt. Much of the rock in this unit is bedded and apparently is andesitic crystal tuff or aquagene crystal lithic tuff. Other bedded rocks are apparently basaltic tuffs with very fine laminations still preserved.

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rm, rv

Rye Formation

The Algonkian (?) complex of Katz (1917) was named the Rye Gneiss by Wandke (1922) after exposures in Rye township in coastal New Hampshire. It was referred to as the Rye Formation by Billings (1952 and 1956). The formation is divided into an Upper Metavolcanic Member and a Lower Metasedimentary Member with a total thickness estimated at 1,350 m (4,000 feet) (Billings, 1956). It conformably underlies the Kittery Formation and is considered Ordovician (?) in age as it underlies a probable Silurian sequence (Billings, 1956). The base of the formation is not exposed. The Rye extends from Gerrish Island in southernmost Maine southward along the coast to the Clinton-Newbury fault zone (Katz, 1917, Hussey, 1962, and Novotny, 1968).

rm

The Lower Metasedimentary Member consists of fine to coarse-grained, light to dark gray and black mica schist and quartzo-feldspacific schist, commonly containing garnet and sillimanite; fine to medium-grained, thin-bedded to massive gray quartzite, commonly feldspathic and garnetiferous and fine to coarse-grained dark-green to black amphibolite, commonly containing diopside and garnet (Novotny, 1968).

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The Upper Volcanic Member is composed of dark-gray medium- to coarse-grained, foliated quartz-biotite-plagioclase gneiss; finely interlaminated fine-grained, maroon feldspathic quartz-biotite schist and fine-grained gray-green feldspathic quartz-actinolite schist; medium to coarse-grained, dark gray biotite or hornblendic gneiss; dark-green to black, fine- to coarse-grained amphibolite and hornblende schist; and minor fine-grained gray quartzite (Novotny, 1968). The amphibolite is interpreted by Billings (1952) as representing metamorphosed andesites or basalts and the biotite gneiss as metamorphosed soda rhyolite. The member is thin to medium-bedded, and some units are laminated. The most characteristic phase is a very light-gray finely to coarsely porphyroblastic gneiss, Interbedded with the gneiss are thin units of fine-grained biotite quartz phyllite and schist and feldspathic biotite quartzite. These interbedded rocks probably represent tuffaceous waterlaid acid volcanics and land derived sediments probably derived from volcanic terrains. A 3 - 5 m thick thinly laminated fine-grained marble, some graphitic schist and also oval-shaped breccia bodies are present on Gerrish Island (Hussey, 1962).

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The Upper Volcanic Member is similar to the Reubens Hill Igneous Complex of the Clinton quadrangle, in being composed of a wide variety of volcanically derived rocks, and is tentatively correlated with it. The porphyroblastic gneiss, however, is very similar in appearance to some rock in the Nashoba Group. A metasiltstone unit underlying the Reubens Hill could correlate with the Lower Meta-sedimentary Member.

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k

Kittery Formation

A unit of fine-grained silicic rock exposed in Kittery, York County, Maine was named the Kittery Quartzite by Katz (1917) and changed to the Kittery Formation by Woodward (1957). The Kittery Formation extends from southern Maine southward, near the coast, to the Clinton-Newbury fault zone.

The formation as described by Hussey (1962) is composed of generally very well bedded thin-bedded fine-grained quartzite, silicic mudstone, silicic phyllite and some thin beds of marble. The quartzite and silicic mudstone are various tones of light to dark gray, bluish gray, purplish gray, chocolate brown and black, which is strikingly interbanded locally in thin bedded, 0.5 to 15 cm beds, that are also laminated. Graded bedding is present locally. In places quartzite is dominant, occuring in medium, .3 to 1.3 m, beds with only minor thin interbeds of phyllite on schist. The phyllite grades to biotite-quartz schist and is dark gray to dark purplish gray. The marble is silicic and biotitic in part and is light tan and dark purplish-gray. Much of the Kittery is probably tuffaceous. Katz (1917) considered the Kittery to be about 500 m (1,500 feet) thick.

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The Kittery is considered to be Silurian in age by correlation with fossiliferous rocks to the north.

The Kittery probably correlates with the quartzite, metamudstone and metasiltstone unit, qms, to the west in the Haverhill quadrangle and the quartzite and phyllite unit, qp, in the Clinton quadrangle. These units have a general lithologic similarity with Kittery although the thin bedded color banded laminated aspect of the Kittery has not been found in them.

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e

Eliot Formation

The Eliot Formation was first named the Eliot Slate by Katz (1917) for exposures in Eliot, in southern Maine, for rocks overlying the Kittery Formation and beneath the Berwick Formation. The Eliot was termed a formation by Freedman (1950). The Eliot Formation consists of two units in its type locality north of the map area according to Hussey (1962). The lower unit is transitional from the Kittery and consists of thin-bedded medium-gray, slightly siliceous chloritic slates and phyllites. The upper unit consists of thinly interbedded medium-gray moderately to slightly crumpled chloritic phyllite with interbeds of chloritic metasiltstone. Another member, the Calef, also north of the map area is described by Freedman (1950) as consisting of chiefly black with some green quartz-chlorite phyllite. The Calef Member is exposed only in a band extending from Lee to Epping, New Hampshire, and occupies a position stratigraphically at the top of the Eliot. The Eliot Formation is commonly ankeritic.

The Eliot conformably overlies the Kittery and probably is conformably overlain by the Berwick, but the contact is nowhere exposed and could be faulted (Hussey, 1962, Katz, 1917).

The Eliot is considered Silurian in age by correlation with fossiliferous units to the north (Billings, 1956, Hussey, personal commun.).

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The Eliot Formation forms two bands in its type area. The eastern band extends southward to the Clinton-Newbury fault zone, whereas the western band is terminated near Epping, New Hampshire, just north of the northeastern part of the Haverhill 15' quadrangle.

The Eliot Formation correlates with rocks in the Clinton and Shirley quadrangles on the basis of similar lithology and position in a stratigraphic sequence. The metasiltstone and phyllite unit (sp) is equivalent to at least the lower part of the Eliot, the phyllite unit (P) may correlate with the Calef Member and the overlying phyllite and metagraywacke (pg) and metagraywacke and chiastolite schist (gs) units may not be present to the north. Possibly the phyllite unit undergoes slight facies change and is equivalent to the upper unit of the type area and another higher phyllitic unit correlates with the Calef Member.

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qms

Quartzite, metamudstone and metasiltstone

A poorly defined unit of silicic rock lies between the southeastern belt of "Paxton Group" undifferentiated and the Eliot Formation in southern New Hampshire. A unit which is cut out to the south, in Massachusetts, agsinst the Clinton-Newbury fault zone. Much of the unit was included in the Merrimack Group of Hitchcock (1870) and the Merrimack Quartzite of Emerson (1917).

The unit consists of medium to dark gray thin to thick-bedded silicic metamudstone, metasiltstone, metagraywacke and some quartzite, plus a few beds of light-gray to light greenish gray calc-silicate bearing rocks. Some beds are slightly schistose and a few are sulphidic and weather rusty. The beds generally range in thickness from 15 cm to 1 m, and a few appear thicker. Some beds are laminated.

The eastern part of the unit extends northward into the Kittery Formation that flanks the Exeter diorite (Novotny, 1968) and the unit is probably equivalent to the Kittery Formation. Most of the unit has been designated Eliot Formation by Sundeen (1971) and Freedman (1950), but rocks typical of the type Eliot were not seen. Rocks typical of the Eliot Formation strike southwest towards the unit from west of Exeter, New Hampshire, but are apparently faulted; they are not known to extend into the map area.

The unit appears very thick, but may have fault repetion and could contain slivers of different formations. The northwest boundary is poorly defined.

A well bedded silicic metamudstone and metasiltstone unit in the Pepperell quadrangle is very similar to parts of this unit and is included with it.

qmss

muscovite schist within qms

A large lens and scattered small lenses and partings of dark gray to silvery gray muscovite schist to phyllite in the Haverhill quadrangle (Sundeen, 1971). The schist and phyllite is slightly rusty weathering and contains knots of quartz.

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qp

Quartzite and phyllite

This unit, which crops out in the Clinton, Shrewsbury and Worcester North quadrangles, is composed of light-gray to medium-gray very fine-grained quartzite interlayered with dark-gray to silver-gray phyllite. The proportions of quartzite and phyllite vary considerably within the unit. The interlayered sequence grades laterally into, and in places underlies, parts of this unit that consists almost entirely of quartzite. Phyllite makes up more than 50 percent of the outcrop at some places. The interlayered quartzite and phyllite sequence is mostly very thin- to thin-bedded; where the unit is predominantly quartzite, it is well-bedded, thin- to thick-bedded with some internal laminations. Quartzite pebble to cobble conglomerate with a phyllite matrix occurs locally in the quartzitic portion in the Worcester North quadrangle. The interlayered sequence forms very poor outcrop and is generally seen only near contacts with more resistant rock, but the quartzite portion forms resistant outcrop especially along the contact with the Ayer Granodiorite which intrudes it. The quartzite portion is probably a submarine channel filling or winnowed shoal deposit; it is not persistent along strike. This quartzite and phyllite unit conformably underlies the metasiltstone and phyllite. The above description of this unit is derived mostly from Peck (1975, and 1976). The interlayered quartzite and phyllite lithology is similar to the top of the Tadmuck Brook Schist exposed in the Clinton quadrangle but the Tadmuck Brook Schist lies south of the Clinton-Newbury fault and is not associated with thick quartzites.

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Beds included in the interlayered quartzite and phyllite were mapped in the Hudson quadrangle by Hansen (1956) as Worcester Formation and/or Vaughan Hills Member of the Worcester Formation. It is not described separately by Peck (1976). The quartzitic portion is included in the Oakdale Quartzite of Emerson (1917), forms the Tower Hill Quartzite Member of the Boylston Formation of Grew (1973), and constitutes Unit 1 of Peck (1976). This unit may be partially equivalent to the Kittery Formation in New Hampshire. This unit is as much as 100 m thick in the Clinton quadrangle (Peck, 1976).

sp

Metasiltstone and phyllite

This unit consists of interbedded laminated gray metasiltstone and phyllite with a minor amount of calcareous metasiltstone. It has been studied mainly by Peck (1975, 1976) in the Clinton area and most of the description is from his work. The metasiltsone is brownish gray to light-gray, fine grained, mostly well sorted, and consists dominantly of quartz with minor feldspar and ankerite. Weathering of ankerite to limonite gives exposures of the rock a distinctive spotted brown appearance. The phyllite is very fine-grained, dark-greenish-gray, medium-gray or locally light-greenish-gray and is composed mostly of quartz, sericite and chlorite. The phyllite weathers to greenish-gray or black. Metasiltstone and phyllite is well bedded in thin to thick beds. The unit has persistent laminations, very little cross lamination and is interpreted to be a deep water marine deposit.

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Graded beds are rarely present. The phyllite is characterized by small chevron folds with sub-horizontal axial planes accentuated by the thin laminae of the rock. This gives the rock a characteristic crinkled appearance. The unit is assumed to be conformable with rocks above, but the contact is not exposed. The unit crops out poorly.

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The unit was mapped previously as Oakdale Quartzite or Worcester Phyllite by Emerson, 1917. It comprises Unit 2 of Peck (1976). This unit is approximately 1,300 - 2,300 m thick in the Clinton area (Peck, 1976). The unit is equivalent to the Eliot formation of Maine and New Hampshire. The unit is especially similar to the lower part of the Eliot (Hussey, personal commun.). The Eliot Formation and the Berwick and Kittery Formations which overlie and underlie the Eliot have been correlated with fossiliferous Silurian rocks further north in Maine (Hussey, 1962) making this metasiltstone and phyllite unit probably Silurian in age also.

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P

Phyllite

This unit is composed of medium to dark gray, very fine-grained even textured phyllite,and it weathers dark gray with some rusty spots from oxidation of pyrite (Peck, 1975). This unit was defined in the Clinton quadrangle by Peck (1975, 1976). The rock consists of mainly quartz, sericite, chlorite and carbonaceous material, with accessory pyrite, feldspar, epidote, zircon, and calcite. Some outcrops can be classified as slate, others as phyllite only by the development of sericite flakes along the cleavage. The phyllite is thin- to medium-bedded, but the bedding is usually obscure due to the lack of compositional differences between beds and to the presence of strong slaty cleavage in the rock. Some graded beds have very thin metasiltstone or metagraywacke layers at the base, but most graded beds in this unit have less than 10 percent silt size constituents.

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According to Peck (1976) the unit probably was formed originally as extreme distal turbidites with only the very finest detritus transported to the site. It contains thin impure graphite layers in outcrops along Rt. 110 near the southwestern border of the Clinton quadrangle. The unit forms locally prominent outcrops and is apparently somewhat more resistant to erosion than rocks above and below. This unit is thickest in the Clinton quadrangle; it is cut out to the south against the Clinton-Newbury fault zone; occuring farther south only as lenses in the fault zone. It is not known to occur in Connecticut. The combined thickness of this unit and the overlying phyllite and metagraywacke is roughly 2,000 to 2,600 m. The unit was mapped previously as Worcester Phyllite by Emerson, 1917. It constitutes the lower part of Unit 3 of Peck (1976). This unit is provisionally correlated with the upper part of the Eliot Formation (Hussey, 1962) in southern Maine as the underlying metasiltstone and phyllite is correlative with the lower Eliot Formation. If so, the metasiltstone interbeds in the upper Eliot of Hussey have lensed out to the southwest. Another possibility is that this unit overlies the Eliot, but is not exposed in southern Maine.

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Phyllite and Metagraywacke

Dark gray phyllite with layers of medium gray metagraywacke compose this unit (Peck, 1975). As described by Peck (1975 and 1976) the phyllite weathers medium to dark gray;and the metagraywacke weathers medium to light gray. The phyllite is very fine grained and consists of quartz, sericite, chlorite, and carbonaceous matter with accessory minerals including tourmaline, garnet, pyrite, plagioclase, muscovite and rarely calcite. The metagraywacke is mostly silt size quartz and plagioclase with muscovite, biotite and chlorite and accessory pyrite, zircon, and calcite. The phyllite and metagraywacke are well bedded in graded beds; usually thin to medium bedded. The percentage of phyllite in each graded bed is 10 to 40 percent greater than that of metagraywacke. A few lenses of calc-silicate-bearing metasiltstone occur within this unit a short distance southwest of the Clinton quadrangle along the shore of Wachusett Reservoir. Cross laminations are common in the metagraywacke parts of the graded beds. Rocks of this unit show strong slaty cleavage,which is often refracted at the phyllite-metagraywacke boundary. The unit forms poor outcrop, and contacts with the overlying or underlying units are not exposed; presumably these rocks are gradational and conformable with units above and below. This unit occurs mainly in the Clinton quadrangle and to the north in the Shirley quadrangle, and is cut out against faults to the north and south.

This unit was previously mapped as Worcester Phyllite by Emerson, 1917. It constitutes the upper part of Unit 3 of Peck (1976).

pgu

undivided phyllite and metagraywacke

Exposures north and south of the Clinton quadrangle area where the lower phyllite, unit P of Peck (1975) has not been separated from the general belt of interlayered phyllite and metagraywacke.

gs

Metagraywacke and chiastolite schist

This unit crops out mainly in the Clinton quadrangle and pinches out both to north and south against a north trending fault that forms its western boundary. The following description is from the work of Peck (1975 and 1976) in the Clinton area.

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This unit is composed of medium- to dark-gray metagraywacke, medium-to dark-gray chiastolite schist and medium- to dark-gray phyllite with or without chiastolite porphyroblasts. The schist and phyllite weather dark gray, the more granular layers weather lighter gray. The unit is well bedded in thin to very thick graded beds with cross lamination in the metagraywacke common. The metagraywacke is composed chiefly of quartz, plagioclase, biotite, chlorite, muscovite and some carbonaceous material. The schist and phyllite are composed mostly of quartz, sericite, carbonaceous material, and large porphyroblasts of chiastolite and andalusite. The porphyroblasts, many of which are altered to muscovite, are as much as 1.5 cm. in diameter and 16 cm. long although most are about 1/2 cm. across and 3 or 4 cm. long. Small 1 mm or less porphyroblasts of garnet, many showing retrograde alteration to chlorite are abundant in fresh rock below the zone of weathering but are not seen in weathered outcrop. The graded beds consist generally of greater than 50 percent sand to silt size granular metagraywacke grading upward to dark-gray very fine-grained, quartz sericite schist or phyllite containing randomly oriented porphyroblasts of chiastolite or pink andalusite.

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Cross laminations in the metagraywacke indicate current transport from a westerly direction. The upper contact of the unit is faulted and its relation with the Oakdale Formation to the west is unknown. This unit corresponds to the "Chiastolite schist facies of the Worcester Phyllite" of Emerson, 1917, and unit 4 of Peck (1976); it is about 1,330 to 2,000 m thick in the Clinton region (Peck, 1976).

o

Oakdale Formation

The Oakdale Formation, originally the Oakedale Quartzite of Emerson (1917), extends from the southwest corner of the map area almost continuously in north and northeast trending fault blocks to the northern boundary of the map area in the northeast corner of the Manchester quadrangle. The Oakdale consists of medium- to dark-gray, greenish-gray and purplish-gray metasiltstone that weathers light to medium gray or greenish or brownish gray. It consists of granulose silt-size quartz, plagioclase (oligoclase-andesine) and brown biotite, with minor amounts of chlorite, actinolite, garnet, staurolite, muscovite and calcite (Peck, 1975). It also contains thin beds, lenses and pods of light greenish-gray calc-silicate-bearing rock, some calcite lamelli and, in the Clinton area, thin-beds of dark gray quartz, biotite, garnet, staurolite schist (Peck, 1975). Lenticular quartz fracture fillings, 1-2 cm wide are locally common. The calc-silicate-bearing rock consists mainly of quartz, epidote and actinolite with some also containing calcite and grossularite garnet (Peck, 1975).

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The metasiltstone is well-bedded in thin- to medium-beds commonly laminated or cross laminated with a few graded beds only in exposures near the base. The rock may locally appear phyllitic where weathered or altered. Foliation is not conspicuous and the rock has a very granulose texture.

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The metasiltstone is more silicic in exposures near the base and locally near the top and the rock was previously called "quartzite" or "feldspathic quartzite". The silicic metasiltstone near the base weathers a distinctive medium greenish gray with laminations etched out.

The metasiltstone characteristically has a lavender greenish tint in fresh rock owing to variations in the proportions of biotite and garnet to chlorite and actinolite respectively. Bedding is thin to laminated rather than graded and the texture is evenly granular like a coarse micaceous siltstone.

One or more pelitic zones occur in the upper part of the formation. These zones contain partings or beds, some at least 2 m thick, of muscovite schist interbedded with thin-bedded silicic metasiltstone. These zones as much as 100 m thick are delineated in Massachusetts by Emerson (1917) as narrow bands of Worcester Phyllite within the Oakedale Quartzite and by Dixon (1976) in the Putnam quadrangle, Connecticut, both as the Scotland Schist and as lenses of schist within the Hebron Formation.

The Oakdale Formation is one of the more easily eroded formations in the region and crops out poorly.

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The base of the Oakdale is everywhere cut out by a fault or by an intrusive; its relation to stratigraphic units to the east is not definitely known. The few graded-beds near the base suggests that the contact may be gradational into the metagraywacke and chiastolite schist unit. The contact with the overlying "Lower Paxton" is faulted in the Webster-Oxford area but appears conformable and gradational farther north. The Oakdale has an apparent maximum exposed thickness of approximately 2,000 m.

Silicic metasiltstone in the eastern Pepperell quadrangle is mapped as Oakdale by Robinson (1976), on the basis of similar lithology with rocks to the west, which are part of the Oakdale Formation. This eastern unit is nearly faulted out just north of the State Line, but reappears again crossing the Manchester quadrangle, New Hampshire in a northeast direction. Light- to medium-greenish-gray well laminated silicic metasiltstone, typical of the lower part of the Oakdale to the south, occurs locally in this band. More commonly the rock is only partially laminated very well bedded silic metasiltstone, with some slightly sulphidic layers, in 2 to 50 cm thick beds, which are generally less than 30 cm in thickness, such as that well exposed in the northwestern part of the Derry Interchage on Interstate Highway 93. This formation is approximately the same as the Lower Member of the Berwick Formation as mapped by Sriramadas (1966). The formation is overlain, with an apparent gradational contact, by thin bedded laminated schistose granulite mapped as Paxton Group undifferentiated; the base appears faulted against rock also mapped as "Paxton Group" undifferentiated.

The Oakdale is correlative with the lower part of the Berwick Formation of Hussey (1962) in Maine and with parts of the Hebron Formation and Scotland Schist of Dixon (1976) in Connecticut. The Oakdale Formation is considered Silurian (?) or Devonian (?) in age as it probably overlies the Silurian Eliot Formation as does the equivalent basal Berwick Formation in Maine.

oms

muscovite schist in Oakdale

Muscovite schist lenses in the Fitchburg, Townsend and Pepperell quadrangles have been tentatively correlated with the Oakdale Formation because of their similarity to the muscovite schist lenses in the upper part of the Oakdale and close field relationships to the Oakdale. They may form part of a series of lenses at the top of the Oakdale. A similar lens of muscovite schist designated the Gove member of the Littleton Formation by Freedman (1950) lies at the top of rocks correlated with the Oakdale in the southwestern part of the Mount Pawtuckaway Quadrangle, just north of the Haverhill 15' quadrangle. The Gove member consists of about 1 m thick muscovite schist layers interbedded with 1 to 3 cm beds of silicic metasiltstone. The lens in the Fitchburg quadrangle is similarly composed of muscovite schist interbedded at places with 2 to 20 cm thick silic metasiltstone beds. Metasiltstone is not noticeable in the other lenses.

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px

"PAXTON GROUP" undifferentiated

The Paxton Schist of Perry and Emerson (1903), referred to as the Paxton Quartz Schist by Emerson (1917), forms a stratigraphic unit underlying the Brimfield Group in its type area in southern Massachusetts, but elsewhere in Massachusetts rocks mapped as Paxton include some that are part of the Brimfield Group. Rocks of the Brimfield Group are excluded from the Paxton in this report. The Paxton has been subdivided southwest of the Leicester quadrangle and informally raised to status group. The upper part of the Paxton has been separated as the Southbridge Formation (Moore, personal commun., and Pease, 1972). The lower part is mapped separately, but has not yet been formally described as a formation and is informally referred to as "Lower Paxton". The undivided Paxton consists of medium-gray, thin- to medium-bedded, fine- to coarse-grained metagraywacke which weathers the same color or slightly darker with a brownish cast. The beds have a schistose to granulose structure and are composed mainly of quartz, biotite, and feldspar, which gives them a salt and pepper appearance. Calc-silicate-bearing beds occur at many horizons throughout the section. The general composition of the Paxton is similar to the Oakdale Formation but is coarser grained, less conspicuously granulose and lacks the silicic siltstone and muscovite schist interbeds of the Oakdale. Pegmatite is common in the Paxton and commonly forms 15 percent of the section.

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The "Paxton Group" forms a northeast trending belt across Massachusetts and in New Hampshire rocks tentatively correlated with the Paxton form two belts.

The rocks in both belts in New Hampshire are generally similar to those in the Paxton in Massachusetts; the northwestern belt lies between units similar to those bordering the Paxton in Massachusetts. Both belts top to the northwest, and the southeastern belt appears to be a repetition by faulting. Stratigraphic repetition by faulting may also occur within each belt. A difference from the Paxton in Massachusetts is the presence of very thin-bedded meta-graywacke in beds 1 to 10 cm thick with .5 to 1 cm thick calc-silicate-bearing beds that occur locally within both belts. These beds are generally also well laminated and present a pin-striped appearance. The pin-striped beds form much of the southeast side of the northwestern belt and are more limited in extent in the south-eastern belt. They probably represent a slight facies change.

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The upper part of the "Paxton Group", the Southbridge Formation, resembles closely the lithology of the Hebron Formation in its type area in Connecticut. The "Paxton Group" along with the underlying Oakdale correlates with the Berwick Formation of Hussey (1962) in southern Maine. The presence of two belts in New Hampshire has caused confusion as to what is Berwick. Sriramadas (1966) and Sundeen (1971) referred the northwest belt to the Berwick and the southeast one to the Eliot Formation whereas Freedman (1950) considered the southeast belt Berwick and the northwest one Littleton Formation.

pxm

muscovite schist in "Paxton Group"

This is a layer of muscovite schist near the top of the "Paxton Group" undifferentiated at the Massachusetts border in the Pepperell and Ayer quadrangles.

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lp

"Lower Paxton"

The lower part of the "Paxton" is equivalent to the Hebron Formation as mapped in the Eastford quadrangle, Connecticut (Pease, 1972), but not necessarily the Hebron elsewhere, where the Hebron may contain equivalents of the Southbridge or Oakdale Formations. The lower part of the '"Paxton" is uniformly fine-grained sand size and has generally thinner and more uniform beds than the Southbridge. The contact between the two is gradational. The "lower Paxton" is on the order of 1,000 m in thickness. It is separated from the Southbridge on the map only in the area southwest of Worcester.

s

Southbridge Formation

The upper part of the "Paxton" has been designated the Southbridge Formation by Moore (personal commun.) and Pease (1972) for the well-exposed section in the town of Southbridge, Massachusetts. The formation contains fine- to coarse-grained sand-size rock in thin to medium beds. The Southbridge overlies the "lower Paxton" with a gradational contact 30 - 50 m wide. The fault contact at the top of the formation in Connecticut appears to displace an originally gradational sedimentary contact (Peper, Pease and Seiders, 1975, p. 6). The maximum exposed thickness of the Southbridge is approximately 3,000 m. It is included with the "Paxton undifferentiated" northeast of Worcester.

bb

Bigelow Brook Formation

The name Bigelow Brook Formation was assigned by Pease (1972) for the sequence of rocks that lie at the base of the Brimfield Group (Peper, Pease, and Seiders, 1975) in north-central eastern Connecticut. In the type area, the Formation was divided into a lower gneiss member of predominantly grayish brown-weathering schistose gneiss and an upper gneiss member of mostly rusty-orange-weathering granular gneiss separated by a thin calc-silicate bearing gneiss member.

The formation extends from the southwest corner of the map area in the Leicester quadrangle, Massachusetts, northeastward across the southeast corner of the Peterborough 15-minute quadrangle, New Hampshire, and into the Milford quadrangle. In most of this area it is only poorly exposed, and was not divided into members. The sparse outcrops characteristically consist of gray-to rusty-yellow and brown-weathering, thin- to thick-layered, fine- to medium-grained sillimanite-garnet-rich schist with or without sulfide and graphite alternating with gray- to rusty orange-weathering, medium grained quartz-feldspar-rich biotite garnet granulite with a conspicuous lavender tint to the fresh rock.

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The Bigelow Brook Formation occurs mostly in roof pendants and inclusions in plutonic rocks that underlie much of the Sterling and Fitchburg quadrangles on strike to the north. A thin north trending band of the Bigelow Brook is mapped between the Oakdale and a large body of muscovite biotite quartz monzonite in the Sterling quadrangle. This unit consists chiefly of gray to brownish-gray weathering medium- to fine-grained granular biotite muscovite schist locally containing staurolite, andalusite, sillimanite or garnet. J. C. Hepburn (1976) named this unit the Bee Hill Formation and tentatively correlated it with the Worcester Phyllite. The regional stratigraphic and structural position and the overall lithology, however, favor correlation with the Bigelow Brook at a slightly lower metamorphic grade than in Connecticut.

The Bigelow Brook Formation is correlated with rocks in the Peterborough quadrangle, New Hampshire, mapped as the Souhegan Member of the Littleton Formation by R. C. Greene (1970). These rocks are mostly brown weathering, in part rusty weathering, evenly layered biotite muscovite schist interstratified with numerous thin layers of calc-silicate bearing granular schist and quartz-feldspar biotite schist and granulite.

Gray to rusty weathering biotite, muscovite, sillimanite schist and gneiss with or without garnet and sulfide that are exposed on the north side of the Massabesic Gneiss are also correlated with the Bigelow Brook Formation into which they can be traced westward. These too have been mapped previously as Littleton (Billings, 1956, Srirtadas, 1955).

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bms

muscovite schist in the Bigelow Brook Formation

Roof pendants of muscovite schist within plutonic rock, in the Fitchburg quadrangle and on strike with strata of the Bigelow Brook Formation.

gss

garnet sillimanite schist in the Bigelow Brook Formation

Roof pendants within plutonic rock in the Fitchburg quadrangle. On strike with and correlated with the Bigelow Brook Formation.

hr

Hamilton Reservoir Formation

The Hamilton Reservoir Formation (Peper, Pease, and Seiders, 1975) was named for a thick sequence of rocks that comprise most of the Brimfield Group rocks in north-central eastern Connecticut. The Hamilton Reservoir Formation is separated from the Bigelow Brook Formation by the Kinney Pond fault. The similarity of strata on either side of the fault, however, suggest that stratigraphic displacement may not be large and that the Hamilton Reservoir overlies the Bigelow Brook (Peper, Pease, Seiders, 1975). In the type area the Formation is divided into lower, middle, and upper schist members of predominantly rusty weathering fissile sulfidic sillimanite garnet schist separated by two gneiss members that contain laterally extensive lenses of intermediate to mafic quartz-poor and quartz-rich gneisses.

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The formation has not been divided into members for the purpose of this map; it is on strike with and contains lithologically similar strata to the Peterborough, Francistown and Crotchet Mountain Members of ;the Littleton Formation (Greene, 1970) in the Peterborough quadrangle, New Hampshire.

p & g

Phyllite and Metagraywacke

A dark gray, very carbonaceous phyllite, that weathers to brownish gray, with thin beds of black to dark gray very impure meta-antracite crops out north of Millstone Hill in Worcester. It contains a few garnet porphyroblasts less than 1 mm in diameter. The maximum exposed thickness of the unit is about 50 m (J. C. Hepburn, personal commun.). It contains few plant fossils at probable Middle, but possibly Early Pennsylvanian age (Paul Lyons, personal commun.).

A unit of dark gray to brownish gray mudstone to phyllite carbonaceous phyllite and thin beds of feldspathic granule conglomerate occurs south of Millstone Hill in Worcester. The conglomerate contains feldspar and quartz in a shale or phyllite matrix. It also contains some shale fragments, some blue quartz and some possible granitic granules. Also some stretched pebble conglomerate of granitic clasts in a shale or phyllite matrix. The exposed thickness is about 130 to 200 m (J. C. Hepburn, personal commun.). No fossils have been found in this unit, but it has been grouped with the fossiliferous phyllite due to some similarities in lithology (Grew, 1970).

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867-100

References cited

Alvord, D.C., 1975, Preliminary bedrock geologic maps of the Westford and Billerica quadrangles, Middlesex County, Massachusetts: U.S. Geol. Survey open-file report 75-387, 12p., scale 1:24,000.

Alvord, D.C., Bell, K.G., Pease, M.H., Jr., and Barosh, P.J., 1976, The aeromagnetic expression of bedrock geology between the Clinton-Newbury and Bloody Bluff fault zones, northeastern Massachusetts: U.S. Geol. Survey Jour. Research, v. 4, no. 5, p. 601-604, scale 1:125,000.

Barosh, P.J., 1974, Preliminary bedrock geologic map of the Webster quadrangle, Massachusetts-Connecticut: U.S. Geol. Survey open-file report 74-192, 2p., scale 1:24,000.

_____, 1976, Preliminary bedrock geologic map of the Oxford quadrangle, Massachusetts-Connecticut-Rhode Island: U.S. Geol. Survey open-file report 76-622, 5p., scale 1:24,000.

_____, 1977, Preliminary map showing bedrock geology superposed on an aeromagnetic base map of the Worcester region, Massachusetts, Connecticut, Rhode Island: U.S. Geol. Survey open-file report 77-131, 51 p., scale 1:125,000.

Barosh, P.J., and Johnson, C.K., 1976, Reconnaissance bedrock geologic map of the Leicester quadrangle, Massachusetts: U.S. Geol. Survey open-file report 76-814, 9 p., scale 1:24,000.

Bell, K.G., 1948, Geology of the Boston basin, Massachusetts: Cambridge, Mass., Mass. Inst. Technology, unpub. Ph.D. thesis, 421 p.

Bell, K.G., 1977, Preliminary bedrock geologic map of the Lynn and Marblehead South quadrangles, Massachusetts: U.S. Geol. Survey open-file report 77-180, 82p., scale 1:24,000.

Bell, K.G., and Alvord, D.C., 1974, Geologic sketch map of northeastern Massachusetts: U.S. Geol. Survey open-file report 74-356, 1pl., scale 1:250,000.

Bell, K.G., and Alvord, D.C., 1976, Pre-Silurian stratigraphy of northeastern Massachusetts, in Page, L.R., ed., Contributions to the stratigraphy of New England: Geol. Soc. America Mem. 148, p. 149-216.

Bell, K.G., and Dennen, W.H., 1972, Plutonic series in the Cape Ann area [abs.]: Geol. Soc. America Abs. with Programs, v. 4, no. 1, p. 2.

Bell, K.G., Shride, A.F., and Cuppels, N.P., 1977, Preliminary bedrock geologic map of the Georgetown quadrangle, Essex County, Massachusetts: U.S. Geol. Survey open-file report 77-179, 30 p., scale 1:24,000.

Besancon, J.R., Gaudette, H.E., and Naylor, R.S., 1977, Age of the Massabesic Gneiss, southeastern New Hampshire: Geol. Soc. America Abs. with Programs, v. 9, no. 2, in press.

Billings, M.P., 1929, Structural geology of the eastern part of the Boston basin: Am. Jour. Sci., 5th ser., v. 18, p. 97-137.

_____, 1937, Regional metamorphism of the Littleton-Moosilauke area, New Hampshire: Geol. Soc. America Bull., v. 48, no. 4, p. 463-566. (includes geol. maps of the Moosiluake quad. and the N.H. part of the Littleton quad.) scale 1:62,500.

9.1267 Billings, M.P., Rodgers, John, and Thompson, J.B., Jr., 1952, Geology of the Appalachian Highlands of east-central New York, southern Vermont, and southern New Hampshire, in Geol. Soc. America, Guidebook for field trips in New England, November 10-12, 1952: p. 1-71.

Billings, M.P., 1956, Bedrock geology, Part 2 of The geology of New Hampshire: Concord, N.H., New Hampshire State Plan. Devel. Comm., 203 p.

_____, 1976, Bedrock geology of the Boston basin, in New England Intercollegiate Geol. Conf., 68th Ann. Mtg., Boston, Mass., Oct. 8-10, 1976, Geology of southeastern New England; a guidebook for field trips to the Boston area and vicinity: Princeton, N.J., Science Press, p. 28-45.

Billings, M.P., and Wolfe, C.W., 1944, Spodumene deposits in the Leominster-Sterling area, Massachusetts: U.S. Geol. Survey-Mass. Dept. Public Works Coop.Geol. Project Inf. Circ. III, 10 p.

Callaghan, Eugene, 1931, A contribution to the structural geology of central Massachusetts: New York Acad. Sci. Annals, v. 33, p. 27-75.

Castle, R.O., 1964, Geology of the Andover Granite and surrounding rocks, Massachusetts: U.S. Geol. Survey open-file report, 550 p.

_____, 1965a, A proposed revision of the subalkaline intrusive series of northeastern Massachusetts: U.S. Geol. Survey Prof. Paper 525-C, p. C74-C80.

_____, 1965b, Gneissic rocks in the South Groveland quadrangle, Essex County, Massachusetts: U.S. Geol. Survey Prof. Paper 525-C, p. C81-C86.

Chute, N.E., 1965, Geologic map of the Duxbury quadrangle, Plymouth County, Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ-466, scale 1:24,000.

_____, 1965, Geologic map of the Scituate quadrangle, Plymouth County, Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ-467, scale 1:24,000.

U. S. GOVERNMENT PRINTING OFFICE : 1959 O - 511171
867-100

Chute, N.E., 1966, Geology of the Norwood quadrangle, Norfolk and Suffolk Counties, Massachusetts: U.S. Geol. Survey Bull. 1163-B, 78 p.

_____, 1969 Bedrock geologic map of the Blue Hills quadrangle, Norfolk, Suffolk, and Plymouth Counties, Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ-796, scale 1:24,000.

_____, 1975, Coal resources of southeastern Massachusetts, in U.S. Federal Energy Administration Region I, Potential coal deposits, Massachusetts and Rhode Island: Boston [30 p.] [report originally prepared in the early 1940's].

Clapp, C.H., 1910, Igneous rocks of Essex County, Massachusetts [abs. of thesis]: Cambridge, Mass., Mass. Inst. Technology, 12 p.

_____, 1921, Geology of the igneous rocks of Essex County, Massachusetts: U.S. Geol. Survey Bull. 704, 132 p.

Crosby, W.O., 1876, Report on the geologic map of Massachusetts [Mass. Commission to the Centennial Exposition]: Boston, 42 p. (reviewed in Am. Jour. Sci., 3rd ser., v. 12, p. 459-460)

_____, 1880, Contributions to the geology of eastern Massachusetts: Boston Soc. Nat. Hist. Occas. Paper no. 3, 286 p.

Currier, L.W., 1937, The problem of the Chelmsford, Massachusetts granite: Am. Geophys. Union, 18th Ann. Mtg., Trans., pt. 1, p. 260-261.

_____, 1952, Geology of the "Chelmsford granite" area, in Geol. Soc. America, Guidebook for field trips in New England, November 10-12, 1952: p. 103-108.

Dennen, W.H., 1975, Preliminary bedrock geologic map of the Rockport quadrangle, Massachusetts: U.S. Geol. Survey open-file report 75-545, 6 p., scale 1:24,000.

_____, 1975 , Preliminary bedrock geologic map of the Gloucester quadrangle, Massachusetts, U.S. Geol. Survey open-file report 75-546, 7 p., scale 1:24,000.

Dennen, W.H., 1975 , Preliminary bedrock geologic map of the Ipswich quadrangle, Massachusetts: U.S. Geol. Survey open-file report 75-544, 26 p., scale 1:24,000.

______, 1975 ,Preliminary bedrock geologic map of the Marblehead North quadrangle, Massachusetts: U.S. Geol. Survey, open-file report 75-543, 9 p., scale 1:24,000.

______, 1976, Plutonic series in the Cape Ann area, *in* New England Intercollegiate Geol. Conf. 68th Ann. Mtg., Boston, Mass., Oct. 8-10, 1976, Geology of southeastern New England; a guidebook for field trips to the Boston area and vicinity: Princeton, N.J., Science Press, p. 265-278.

Dixon, H.R., 1964, The Putnam Group of eastern Connecticut: U.S. Geol. Survey Bull. 1194-C, 12 p.

______, 1974, Bedrock geologic map of the Thompson quadrangle, Windham County, Connecticut, and Providence County, Rhode Island: U.S. Geol. Survey Geol. Quad. Map GQ-1165, scale 1:24,000.

______, 1976, Preliminary bedrock geologic map of the Putnam quadrangle, Connecticut: U.S. Geol. Survey open-file report 76-271, 42 p., scale 1:24,000.

Dixon, H.R., and Lundgren. L.W., Jr., 1968, Structure of eastern Connecticut, *in* Zen, E-an, and others, *eds.*, Studies in Appalachian geology--northern and maritime: New York, Interscience Publishers, p. 219-230.

Dott, R.H., Jr., 1961, Squantum "tillite" Massachusetts--Evidence of glaciation or subaqueous mass movements?: Geol. Soc. America Bull., v. 72, no. 9, p. 1289-1305.

Dowse, A.M., 1950, New evidence on the Cambrian contact at Hoppin Hill, North Attleboro, Massachusetts: Am. Jour. Sci., v. 248, no. 2, p. 95-99.

Emerson, B.K., 1917, Geology of Massachusetts and Rhode Island: U.S. Geol. Survey Bull. 597, 289 p., scale 1:250,000.

Emerson, B.K., and Perry, J.H., 1907, The green schists and associated granites and porphyries of Rhode Island: U.S. Geol. Survey Bull. 311, 74 p.

Fairbairn, H.W., Moorbath, Stephen, Ramo, A.O., Pinson, W.H., Jr., Hurley, P.M., 1967, Rb-Sr age of granitic rocks of southeastern Massachusetts and the age of the Lower Cambrian at Hoppin Hill: Earth and Planetary Sci. Letters, v. 2, no. 4, p. 321-328

Fessenden, F.W., 1971, The geology and hydrology of the Pepperell Springs area, Pepperell, Massachusetts: Boston Univ., unpub. Ph.D. thesis, 180 p.

Fowler-Billings, Katherine, 1949, Geology of the Monadnock region of New Hampshire: Geol. Soc. America Bull., v. 60, no. 8, p. 1249-1280.

_____, 1959, Geology of the Isles of Shoals [N.H.-Maine]: Concord, N.H., New Hampshire State Plan. Devel. Comm., 51 p.

Freedman, Jacob, 1950, Stratigraphy and structure of the Mt. Pawtuckaway quadrangle, southeastern New Hampshire: Geol. Soc, America Bull., v. 61, no. 5, p. 449-492.

Gielisse, P.J., 1959, The bedrock geology of the Newton quadrangle, Massachusetts: Boston College, unpub. MS thesis.

Goldsmith, Richard, 1966, Stratigraphic names in the New London area, Connecticut: U.S. Geol. Survey Bull. 1224-J, 9 p.

Gore, R.Z., 1973, Geology of the porphyritic Ayer Quartz Monzonite and associated rocks in portions of the Clinton and Ayer quadrangles, Massachusetts: Boston Univ., unpub. Ph.D. thesis, 299 p.

_____, 1976, Ayer crystalline complex of Ayer, Harvard, and Clinton, Massachusetts, in Lyons, P.C., and Brownlow, A.H., eds., Studies in New England geology: Geol. Soc. America Mem. 146, p. 103-125.

Greene, R.C., 1970, The geology of the Peterborough quadrangle, New Hampshire: Concord, N.H., New Hampshire Dept. Resources and Econ. Devel., Bull. IV, 88 p.

Gregory, H.E., and Robinson, H.H., 1907, Preliminary geological map of Connecticut: Conn. Geol. Nat. Hist. Survey Bull. 7, 39 p., map [map is dated 1906].

Grew, E.S., 1970, Geology of the Pennsylvanian and pre-Pennsylvanian rocks of the Worcester area, Massachusetts: Cambridge, Mass., Harvard Univ., unpub. Ph.D. thesis, 263 p.

_____, 1973, Stratigraphy of the Pennsylvanian and pre-Pennsylvanian rocks of the Worcester area, Massachusetts: Am. Jour. Sci., v. 273, no. 2, p. 113-129; includes geologic sketch maps.

Hansen, W.R., 1956, Geology and mineral resources of the Hudson and Maynard quadrangle, Massachusetts: U.S. Geol. Survey Bull. 1038, 104 p.

Hitchcock, C.H., 1870, Second annual report upon the geology and mineralogy of the State of New Hampshire: Manchester, N.H., 37 p.

Hitchcock, Edward, 1861, On the conversion of certain conglomerates into talcose and micaceous schists and gneiss, by the elongation, flattening, and metamorphosis of the pebbles and the cement: Am. Jour. Sci., 2d. ser., v. 31, p. 372-392.

Hussey, A.M., 2d, 1962, The geology of southern York County, Maine: Maine Geol. Survey Spec. Studies Ser. no. 4, 67 p.

Jahns, R.H., 1952, Stratigraphy and sequence of igneous rocks in the Lowell-Ayer region, Massachusetts, in Geol. Soc. America, Guidebook for field trips in New England, November 10-12, 1952: p. 108-112.

Jahns, R.H., Willard, M.E., and White, W.S., 1959, Preliminary bedrock geologic map of the Lowell-Westford area, Massachusetts: U.S. Geol. Survey open-file report, 1 pl., scale 1:31,680.

Katz, F.J., 1917, Stratigraphy in southwestern Maine and southeastern New Hampshire [abs.]: Washington Acad. Sci. Jour., v. 7, p. 198.

_____, 1918, Stratigraphy in southwestern Maine and southeastern New Hampshire: U.S. Geol. Survey Prof. Paper 108-I, p. 165-177.

Kaye, C.A., 1965, Folding of the Nahant Gabbro, Massachusetts: U.S. Geol. Survey Prof. Paper 525-C, p. C12-C19.

Koteff, Carl, Oldale, R.N., and Hartshorn, J.H., 1967, Geologic map of the North Truro quadrangle, Barnstable County, Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ-599, scale 1:24,000.

Lacroix, A.V., 1968, Structure and contact relationships of the Marlboro Formation, Marlboro, Massachusetts: Boston College, unpub. MS thesis, 83 p.

LaForge, Laurence, 1909, Correlation of the rocks of the Boston region [abs.]: Science, n.s., v. 29, p. 945-946.

_____, 1932, Geology of the Boston area, Massachusetts: U.S. Geol. Survey Bull. 839, 105 p., scale 1:62,500.

U. S. GOVERNMENT PRINTING OFFICE : 1959 O - 511171
867-100

9.1267

Legarde, C.N., III, 1967, The petrography, structural geology and tectonic history of a portion of the Wachusetts-Marlborough Tunnel, Massachusetts: Boston College, unpub. MA thesis, 100 p.

Lyons, P.C., 1969, Bedrock geology of the Mansfield quadrangle, Massachusetts: Boston Univ., unpub. Ph.D. thesis, 282 p., 18 pl., map, scale 1:28,000.

Lyons, P.C., and Krueger, H.W., 1976, Petrology, chemistry and age of the Rattlesnake Pluton and implications for other alkalic granite plutons of southern New England, in Lyons, P.C., and Brownlow, A.H., eds., Studies in New England geology: Geol. Soc. America Mem. 146, p. 71-102.

Lundgren, Lawrence, Jr., 1962, Deep River area, Connecticut--Stratigraphy and structure: Am. Jour. Sci., v. 260, no. 1., p. 1-23.

Mansfield, G.R., 1906, The origin and structure of the Roxbury conglomerate: Harvard Coll. Mus. Comp. Zoology Bull., v. 49, geol. ser. v. 8, no. 4, p. 91-271.

Naylor, R.S., and Sayer, Suzanne, 1976, The Blue Hills Igneous Complex, Boston area, Massachusetts, in New England Intercollegiate Geol. Conf. 68th Ann. Mtg., Boston, Mass., Oct. 8-10, 1976, Geology of southeastern New England; a guidebook for field trips to the Boston area and vicinity: Princeton, N.J., Science Press, p.135-146.

Nelson, A.E., 1974, Changes in nomenclature of upper Precambrian to lower Paleozoic(?) formations in the Natick quadrangle, eastern Massachusetts, and their tentative correlations with rocks in Rhode Island and Connecticut: U. S. Geol. Survey Bull. 1395-E, 14p.

_____, 1975a, Bedrock geologic map of the Framingham quadrangle, Middlesex and Worcester Counties, Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ-1274, scale 1:24,000.

_____, 1975b, Bedrock geologic map of the Natick quadrangle, Middlesex and Norfolk Counties, Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ-1208, scale 1:24,000.

Norton, H.A., 1974, Trace element geochemistry of the Cape Ann Pluton, eastern Massachusetts: Univ. of Kentucky, unpub. MS thesis.

Novotny, R.F., 1968, Geology of the Sea Coast Region, New Hampshire: Concord, N.H., New Hampshire Div. of Econ. Devel. Quad. Report, 46p.

Page, L.R., 1968, Devonian plutonic rocks of New England, in Zen, E-an, and others, eds., Studies in Appalachian geology--northern and maritime: New York, Interscience Publishers, p. 371-383.

Page, L.R., 1976, Introduction and summary, in Page, L.R., ed., Contributions to the stratigraphy of New England: Geol. Soc. America Mem. 148, p. 1-24.

Pease, M.H., Jr., 1972, Geologic map of the Eastford quadrangle, Windham and Tolland Counties, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-1023, scale 1:24,000.

Peck, J.H., 1975, Preliminary bedrock geologic map of the Clinton quadrangle, Worcester County, Massachusetts: U.S. Geol. Survey open-file report 75-658, 31 p., scale 1:24,000.

_____, 1976, Silurian and Devonian stratigraphy in the Clinton quadrangle, central Massachusetts, in Page, L.R., ed., Contributions to the stratigraphy of New England: Geol. Soc. America Mem. 148, p. 241-253.

Peper, J.D., Pease, M.H., Jr., and Seiders, V.M., 1975, Stratigraphic and structural relationships of the Brimfield Group in northeast-central Connecticut and adjacent Massachusetts: U.S. Geol. Survey Bull. 1389, 31 p., scale 1:125,000.

Perry, J.H., and Emerson, B.K., 1903, Geology of Worcester, Massachusetts: Worcester Nat. Hist. Soc., 166 p.

Pomeroy, J.S., 1975, Preliminary bedrock geologic map of the East Brookfield quadrangle, Worcester County, Massachusetts: U.S. Geol. Survey open-file report 75-530, 12 p., scale 1:24,000.

Quinn, A.W., 1971, Bedrock geology of Rhode Island: U.S. Geol. Survey Bull. 1295, 68p., scale 1:125,000.

Quinn, A.W., Ray, R.G., and Seymour, W.L., 1949, Bedrock geology of the Pawtucket quadrangle, Rhode Island-Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ-1, scale 1:31,680.

Rehmer, J.A., and Roy, D.C., 1976, The Boston Bay Group--the boulder bed problem, in New England Intercollegiate Geol. Conf., 68th Ann. Mtg., Boston, Mass., Oct. 8-10, 1976, Geology of southeastern New England; a guidebook for field trips to the Boston area and vicinity: Princeton, N.J., Science Press, p. 71-91.

Richmond, G.M., 1952, Bedrock geology of the Georgiaville quadrangle, Rhode Island: U.S. Geol. Survey Geol. Quad. Map GQ-16, scale 1:31,680.

Rice, W.N., and Gregory, H.E., 1906, Manual of the geology of Connecticut: Conn. Geol. Nat. Hist. Survey Bull. 6, 273 p., map.

Robinson, G.R., Jr., 1976, Interim geologic map of the Pepperell quadrangle, Massachusetts-New Hampshire: U.S. Geol. Survey open-file report 76-266, scale 1:24,000.

Russell, S.J., and Allmendinger, R.W., 1976, Interim geologic map of the Shirley quadrangle, Massachusetts: U.S. Geol. Survey open-file report 76-267, scale 1:24,000.

Sears, J.H., 1905, The physical geography, geology, mineralogy, and paleontology of Essex County [Mass.]: Salem, Mass. Essex Institute, 418 p

Shaler, N.S., 1871, On the relations of the rocks in the vicinity of Boston [with discussion by C.T. Jackson] : Boston Soc. Nat. Hist. Proc., v. 13, 172-177.

Shaler, N.S., Woodworth, J.B., and Foerste, A.F., 1899, Geology of the Narragansett basin: U.S. Geol. Survey Mon. 33, 402 p.

Shaw, C.E., 1967, Geology of the Milford Granite: Providence, R.I., Brown Univ., unpub. Ph.D. thesis, 141 p.

Shride, A.F., 1976a, Preliminary maps of bedrock geology of the Newburyport East and Newburyport West quadrangles, Massachusetts-New Hampshire: U.S. Geol. Survey open-file report 76-488, 3 p., scale 1:24,000.

_____, 1976b, Stratigraphy and correlation of the Newbury Volcanic Complex, northeastern Massachusetts, in Page, L.R., ed., Contributions to the stratigraphy of New England: Geol. Soc. America Mem. 148, p. 147-178.

Skehan, J.W., 1964, Folio of maps and cross sections of the Wachusett-Marlborough tunnel, Clinton to Marlborough, Massachusetts: Boston, unpub. rept. for Metropolitan District Commission, 42 maps and sections, scale 1:24,000.

_____, 1968, Fracture tectonics of southeastern New England as illustrated by the Wachusett-Marlborough Tunnel, east-central Massachusetts, in Zen, E-an, and others, eds., Studies of Appalachian geology--northern and maritime: New York, Interscience Publishers, p. 281-290.

Skehan, J.W., and Barton, C.W., 1973, The geology of Newton: Newton, Mass., Newton Conservators, Inc., 28 p.

Sriramadas, Aluru, 1966, Geology of the Manchester quadrangle, New Hampshire: Concord, N.H., New Hampshire Dept. Resources and Econ. Devel. Bull. II, 92 p.

The bedrock

Sundeen, D.A., 1971, Geology of the Haverhill 15' quadrangle, New Hampshire-Massachusetts: Concord, N.H., New Hampshire Dept. Resources and Econ. Devel. Bull. 5, 125 p., scale 1:62,500.

Tilton, J.L., 1896, The area of slate near Nashua, New Hampshire: Iowa Acad. Sci., Proc., v. 3, p. 66-71.

Toulmin, Priestley, 3d, 1964, Bedrock geology of the Salem quadrangle and vicinity, Massachusetts: U.S. Geol. Survey Bull. 1163-A, 79 p.

U.S. Geological Survey, [1976], Geologic history of Cape Cod, Massachusetts [by R.N. Oldale]: Washington, D.C., U.S. Govt. Print. Off., 23 p.

Volckmann, R.P., 1973a, Preliminary bedrock geologic map of the Holliston quadrangle, Massachusetts: U.S. Geol. Survey open-file report, scale 1:24,000

______, 1973b, Preliminary bedrock geologic map of the Medfield quadrangle, Massachusetts: U.S. Geol. Survey open-file report, scale 1:24,000.

Wandke, Alfred, 1922, Intrusive rocks of the Portsmouth basin, Maine and New Hampshire: Am. Jour. Sci., 5th ser., v. 4, p. 139-158.

Warren, C.H., and McKinstrey, H.E., 1924, The granites and pegmatites of Cape Ann, Massachusetts: Am. Acad. Arts and Sci., Proc., v. 59, no. 14, p. 315-357.

Whitehead, W.L., 1913, The geology of the Rattlesnake Hill granite of Sharon, Massachusetts: Cambridge, Mass., Mass. Inst. Tech. Mining Dept. thesis (mining thesis case) 35 p.

Williams, C.R., 1934, Geology in the Franconia region: Appalachia, v. 20, no. 4, p. 69-78.

Williams, J.R., and Willey, R.E., 1974, Bedrock topography and texture of unconsolidated deposits, Taunton River basin, southeastern Massachusetts: U.S. Geol. Survey Misc. Inv. Map I-742, scale 1:48,000.

Woodard, H.H., 1957, Diffusion of chemical elements in some naturally occurring silicate inclusions [Maine]: Jour. Geology, v. 65, no. 1, p. 61-84.

Zartman, R.E., and Marvin, R.F., 1971, Radiometric age (late Ordovician of the Quincy, Cape Ann, and Peabody granites from eastern Massachusetts: Geol. Soc. America Bull., v. 82, no. 4, p. 937-958.

Zartman, R.E., and Naylor, R.S., 1972, Structural implications of some U-Th-Pb zircon isotopic ages of igneous rocks in eastern Massachusetts [abs.]: Geol. Soc. America Abs. with Programs, v. 4, no. 1, p. 54-55.

Zartman, Robert, Snyder, George, Stern, T.W., Marvin, R.F., and Bucknam, R.C., 1965, Implications of new radiometric ages in eastern Connecticut and Massachusetts: U.S. Geol. Survey Prof. Paper 525-D, p. D1-D10.

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