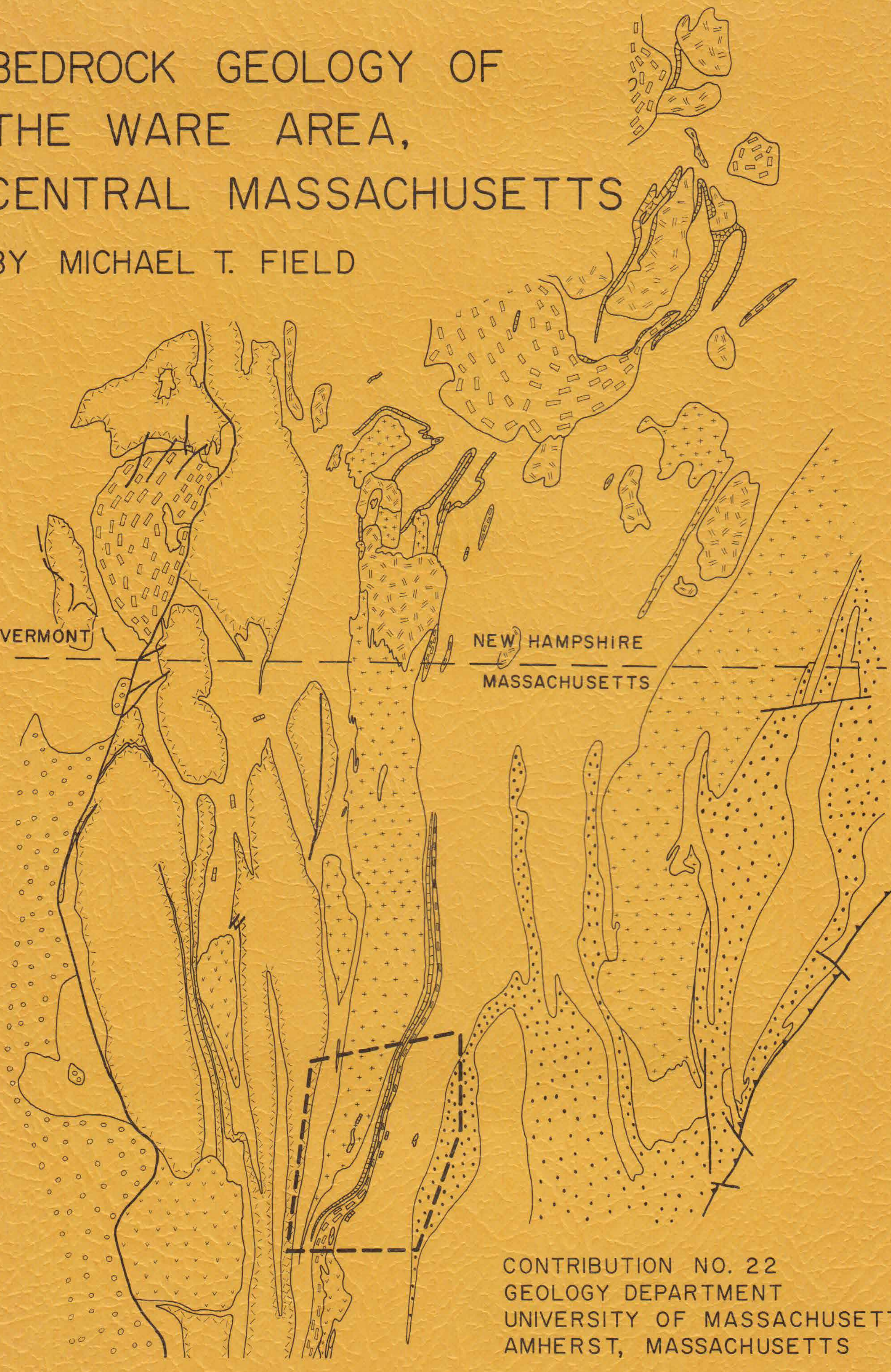
BEDROCK GEOLOGY OF THE WARE AREA, CENTRAL MASSACHUSETTS

BY MICHAEL T. FIELD



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by

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Contribution No. 22

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ABSTRACT

The Ware area, consisting of the Ware quadrangle and portions of adjacent quadrangles, is an area of highly deformed Paleozoic rocks in central Massachusetts at the western edge of the Merrimack synclinorium, that were metamorphosed to sillimanite-orthoclase-garnet-cordierite grade. The stratigraphy in most of the area is similar to that in the nearby Bronson Hill anticlinorium.

The pre-Middle Ordovician Monson Gneiss, quartz-feldspar gneisses and amphibolites of probable volcanic origin, forms the base of the section. Above that is the Middle Ordovician Partridge Formation, consisting of biotite-garnet-sillimanite-orthoclase(-cordierite) schist with varied amounts of sulfide. The Partridge includes a few small lenses of amphibolite and hornblende-orthopyroxene gneiss, believed to represent metamorphosed mafic volcanics. An olivine-phlogopite hornblendite body is found in the Partridge in the eastern part of the area.

The Silurian rocks are thin and discontinuous, except in the southeast part of the area. The Fitch Formation, in the central part of the area, is sulfidic graphitic calc-silicate rock identical to rocks mapped as Fitch Formation, or rusty quartzite member or Francestown Member of the Littleton Formation in southwest New Hampshire. The thick Paxton Schist, found in the southeast part of the area, is a gray granular quartz-labradorite-biotite schist with calc-silicates. The Paxton and its equivalents are widespread in east-central New England, and the presence of the Paxton indicates a zone of eastward

thickening of sediments during the Silurian. In the Ware area, the Paxton includes a basal very sulfidic sillimanite-Mg cordierite-Mg biotite-orthoclase schist that is lithically similar to the Silurian Smalls Falls Formation of Maine.

The youngest stratigraphic unit in the area is the Lower Devonian Littleton Formation, consisting of gray, bedded, biotite-garnet-sillimanite-orthoclase (-cordierite) schist. Quartz-feldspar gneiss and orthopyroxene-cummingtonite gneiss, believed to represent metamorphosed volcanic rocks, are locally found at the top of the Littleton.

There are three major syntectonic plutonic bodies in the area, the Hardwick Quartz Diorite, a biotite and biotite-hornblende quartz diorite equivalent to the Spaulding Quartz Diorite of New Hampshire, the garnet-bearing porphyritic Coys Hill Granite equivalent to the Kinsman Quartz Monzonite in New Hampshire, and the leucocratic biotite-garnet gneiss of Ragged Hill. The Hardwick and Coys Hill are confined to the Littleton Formation and the same appears to be true of their extensions and equivalents in southwest New Hampshire. The gneiss of Ragged Hill can be seen to cross-cut the Partridge and Fitch Formations, but it is confined to a single early anticline. Other igneous bodies are the New Braintree Gabbro (hornblende-orthopyroxene $\pm$ olivine), the two bodies of Goat Hill Diorite (hornblende-clinopyroxene $\pm$ orthopyroxene) and a post-metamorphic diabase dike. The intrusive rocks are believed to be of Devonian age, except the New Braintree Gabbro, which may be Ordovician, and the diabase, which is Triassic-Jurassic.

The structure of the area consists of early westward-transported isoclinal folds of extreme elongation, correlated in time with the regional nappes of the Bronson Hill anticlinorium, followed by two phases of later tight folds whose axial planes dip gently west. The second phase of folding was followed by localized intense mylonitization of various rock types and the mylonitic rocks were then deformed and recrystallized during the third phase of folding. Mineral lineations and minor fold axes, mostly related to the third phase of folding, lie within the plane of the dominant foliation, the majority plunging gently to the southwest. Metamorphism, starting with the early phases of folding, continued to very high grade at the end of the third phase. No definitive evidence of post-metamorphic faulting was found.

Electron probe analyses and theoretical studies done by others on garnet-cordierite-sillimanite schists collected in this study, suggest final prograde equilibration at about 675°C and 6.3 kb. Occurrences of sillimanite pseudomorphs after andalusite in the same rocks indicate an early high temperature low pressure metamorphism and a different P-T path than the kyanite-sillimanite facies series of the nearby Bronson Hill anticlinorium. Adjacent plagioclase-bearing mafic rocks contain the assemblages cummingtonite-hornblende-orthopyroxene and hornblende-orthopyroxene-diopside, but the assemblage orthopyroxene-K feldspar, characteristic of the highest temperature granulite facies, is unknown in the area.

INTRODUCTION

Location

The Ware area is located in central Massachusetts, just east of the southern part of Quabbin Reservoir, 100 km (60 mi) west of Boston (Figure 1). The area covered by this report includes the Ware 7 1/2-minute quadrangle and adjacent parts of the Petersham quadrangle to the north, the Winsor Dam quadrangle to the west, the Palmer quadrangle to the southwest, the Warren quadrangle to the south, the North Brookfield quadrangle to the east and the Barre quadrangle to the northeast (Plate 1). It includes large portions of the townships of Hardwick, New Braintree, West Brookfield and Ware, and small portions of the townships of Warren and North Brookfield.

The area is one of rolling hills rising one or two hundred meters (a few hundred feet) above their bases. The highest elevation is 368 m (1206 ft) on Ragged Hill in the central part of the area, and the lowest is a little below 122 m (400 ft) at the Ware River in the southwest. All streams in the area, with the exception of those in the southeast, drain into the Ware River, which flows out of the area to the southwest. The streams in the southeast flow south into the Quaboag River, which flows westward, joining the Ware River at Three Rivers to form the Chicopee River, which continues westward to the Connecticut River at Springfield. Most of the streams in the area are small and have eroded to bedrock in very few places.

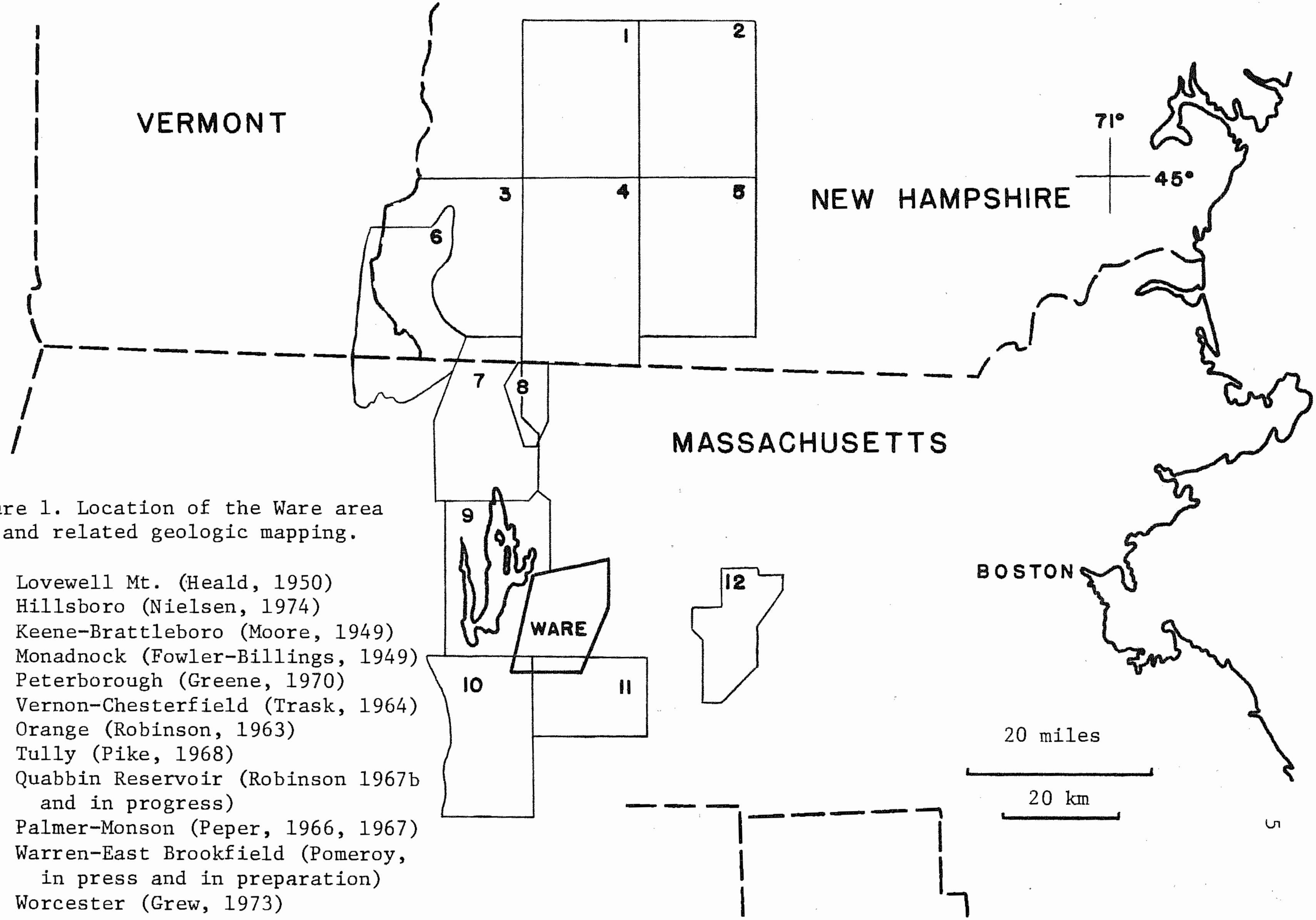


Figure 1. Location of the Ware area and related geologic mapping.

1 Lovewell Mt. (Heald, 1950)
2 Hillsboro (Nielsen, 1974)
3 Keene-Brattleboro (Moore, 1949)
4 Monadnock (Fowler-Billings, 1949)
5 Peterborough (Greene, 1970)
6 Vernon-Chesterfield (Trask, 1964)
7 Orange (Robinson, 1963)
8 Tully (Pike, 1968)
9 Quabbin Reservoir (Robinson 1967b and in progress)
10 Palmer-Monson (Peper, 1966, 1967)
11 Warren-East Brookfield (Pomeroy, in press and in preparation)
12 Worcester (Grew, 1973)

Culture and History

Aside from the factories in Ware and Gilbertville, the dominant industry at present is dairy farming. Several decades ago the area was largely open farmland, but now roughly 80% of it is covered by forest.

One of the earliest colonial settlements between Massachusetts Bay and the Connecticut Valley was Quaboag Plantation (now West Brookfield) founded in 1660 in the southeast part of the Ware quadrangle and adjacent areas. This settlement was the scene of early action in King Philip's War, a major Indian uprising of southern New England. One of the first Indian attacks of the war was on August 2, 1675, near Padre Road in the central part of the Ware area, when Philip's men ambushed a group of colonial soldiers from Boston.

The town of Ware itself was settled about 1725 and incorporated in 1761, being named after the Ware River, which in turn was named for the fishing weirs used by Indians at the falls in the present town of Ware. Factories were built near these falls starting in the early 1800's. In the present century, Ware suffered the fate of many New England towns when the textile mills closed during the depression of the 1930's, but through a strong citizen effort new industries were attracted, earning the town its slogan "The town that can't be licked" and the informal appellation, "The factory outlet capital of New England."

The birthplace of Lucy Stone, pioneer abolitionist and advocate of women's rights, is on the northeast slope of Coys Hill in the southern part of the area.

Surficial Deposits and Distribution of Bedrock Outcrops

Density of bedrock outcrops in the Ware area varies considerably. Thick glaciofluvial deposits fill the valley of Muddy Brook in the west, the Ware River valley from the southwest to the northeast, the abandoned Ware River valley west of Ragged Hill and the Mill Brook--Sucker Brook--Winimusset Brook valleys in the east. Many of the hilly areas have a thin to thick cover of till, particularly on north slopes. In areas underlain by the Hardwick Quartz Diorite, outcrops are generally limited to hilltops. Areas underlain by the Wickaboag Pond belt of the Partridge Formation, such as Whortleberry Hill and the terrain south of New Braintree, have very poor outcrop. The best outcrop (Plate 3) is in the belt of diversified rock types extending diagonally northeastward from Coys Hill to the Ware River valley. Outcrop is also good on the Paxton Formation in the extreme southeast part of the area.

Glacial features, other than the glaciofluvial deposits mentioned above, include a moraine, portions of which can be found from just southeast of Hardwick westward to the Ware-Greenwich road near the 802 foot elevation (Mulholland, 1974). There was a peat bog behind the moraine in the flat area just east of Hardwick.

In addition to surface exposures, the Quabbin Aqueduct tunnel passes through the northern part of the map area and is a source of geologic data. The geology was recorded by Fahlquist (1935) during construction of the tunnel, and hand specimens were collected. These specimens are stored at the intake works on the Ware River in the town of Barre, northeast of the Ware area, and were examined during this study.

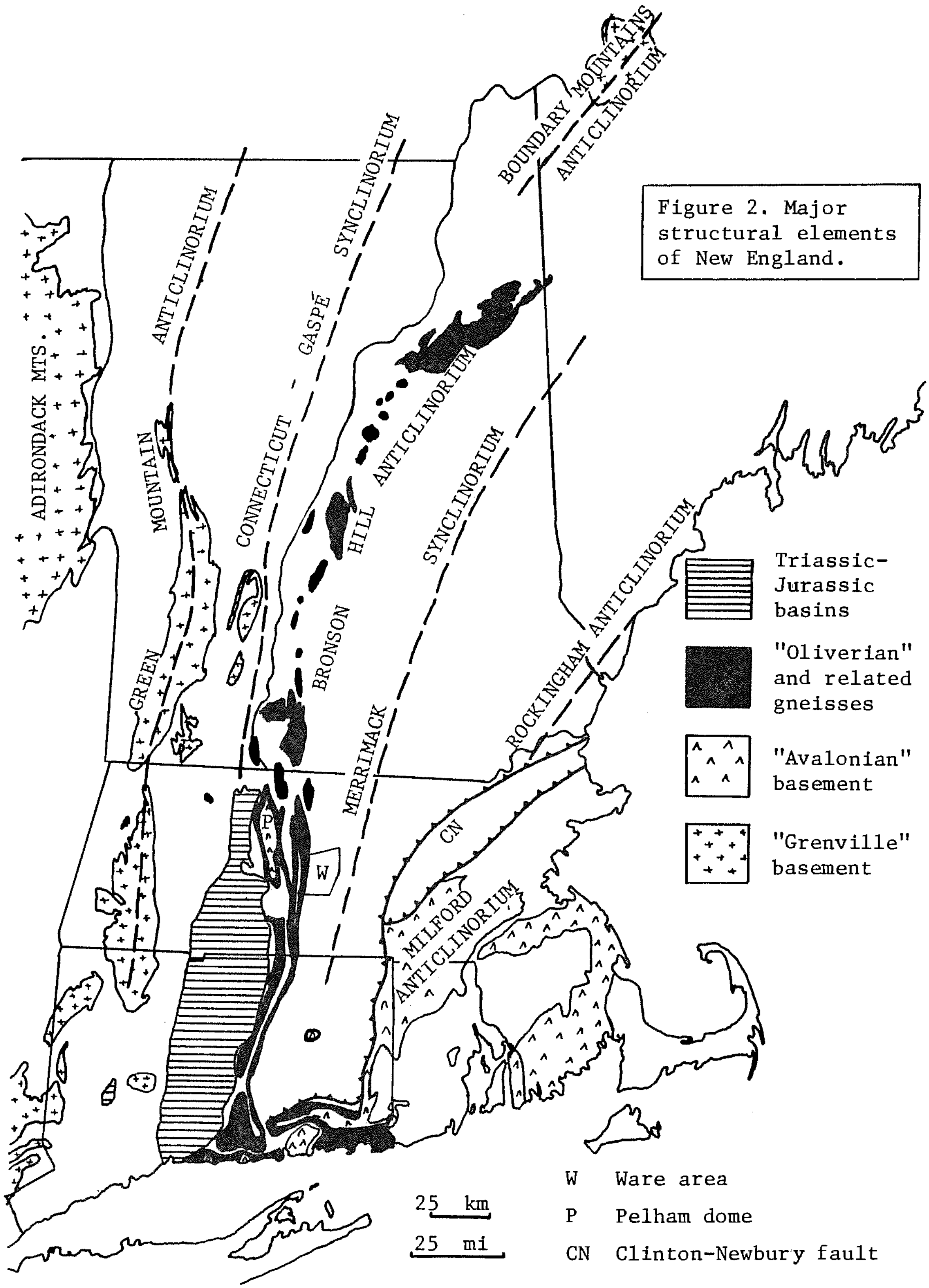
Regional Setting

Much of New England is underlain by deformed, metamorphosed and intruded sedimentary and volcanic rocks of Early Cambrian through Early Devonian age. The Precambrian basement beneath these stratified rocks appears to belong to two age groups. Rocks metamorphosed 900 to 1100 m.y. ago, in an event commonly referred to as "Grenville," are found in and near the Green Mountain anticlinorium (Figure 2) as well as in the Adirondack Mountains of New York and in nearby parts of the Canadian shield. Volcanic, sedimentary and plutonic rocks of "Avalonian" age (550-650 m.y.) are found in southeast Massachusetts, coastal New Brunswick, Cape Breton Island and southeastern Newfoundland (Rodgers, 1968, p. 147; Lyons and Faul, 1968, p. 307; Brückner, 1974, p. 1-15; Naylor, 1975).

Most of the Grenville age rocks in New England are in the west and most of the Avalonian age rocks in the east, but there are several exceptions, as summarized by Naylor (1975). One exception is that the rocks of the core gneisses of the Pelham Dome in the Bronson Hill anticlinorium in central Massachusetts (Figure 2) were formed in Avalonian time (575 m.y.; Naylor and others, 1973). With this exception, Massachusetts, between the Grenville age Precambrian in the west and the Avalonian age Precambrian in the east, is underlain by the complexly folded and metamorphosed Lower and Middle Paleozoic sedimentary, volcanic and plutonic rocks typical of central New England.

New England is divided into several structural zones (Zen, 1968, p. 1-3; Figure 2, this report). Eastward from the Green Mountain anticlinorium, a generally east-dipping sequence of Cambrian to Lower

Figure 2. Major structural elements of New England.



W Ware area

P Pelham dome

CN Clinton-Newbury fault

Devonian rocks extends to the axis of the Connecticut-Gaspé synclinorium (Zen, 1968, p. 2; Hatch and others, 1968, p. 178). The west limb of the synclinorium is strongly modified by isoclinal folds and domes (Doll and others, 1961; Rosenfeld, 1968, p. 186).

The Bronson Hill anticlinorium, east of the Connecticut-Gaspé synclinorium, consists of metamorphosed Middle Ordovician, Silurian and Lower Devonian rocks overlying a basement that is Ordovician or older. Some of these basement rocks have been referred to as rocks of the Oliverian plutonic series (Figure 2; Billings, 1956). All these rocks have been metamorphosed and folded into a series of nappes with east over west overfolding, and subsequently deformed into domes (Thompson and others, 1968). Avalonian rocks in the core of the Pelham dome of Massachusetts (Figure 2; Naylor and others, 1973) appear to have been intensely metamorphosed before the Middle Ordovician (Robinson and others, 1975).

East of the Bronson Hill anticlinorium is the Merrimack synclinorium, an area of tightly folded high-grade metamorphic rocks. The Ware area (Figure 2) lies on the west limb on the Merrimack synclinorium and on the east limb of the Bronson Hill anticlinorium. The Merrimack synclinorium was defined by Billings (1956, p. 114) in New Hampshire as a north-northeast trending area underlain by rocks of the Lower Devonian Littleton Formation, but subsequent study has shown that it is not a simple synclinorium, except perhaps in western Maine (Osberg and others, 1968, p. 241-243). In Massachusetts, and probably in southern New Hampshire (Nielsen, 1974; Nelson, 1975), it consists of a complex sequence of overturned isoclinal folds. In eastern

Connecticut the area of the Merrimack synclinorium is occupied by broad foliation arches and basins, which are interpreted by Dixon and Lundgren (1968b) to be late structures superimposed on a large east-facing recumbent syncline.

Many of the rock units in the Merrimack synclinorium are the same as those in the well studied Bronson Hill anticlinorium to the west. Others, particularly in the eastern part, are unlike those in the Bronson Hill anticlinorium. There appears to be a great increase in Silurian sediment thickness to the east across the synclinorium (Boone and others, 1970, p. 8; Boone, 1973, p. 32), and it has been suggested that the pre-Silurian (Taconic) unconformity may not be present in the eastern part of the synclinorium (Moench, 1969, p. 14; Boone and others, 1970, p. 5-6).

East of the Merrimack synclinorium is a poorly known area of plutonic and probable pre-Devonian metamorphic rocks. In southeast New Hampshire, Billings (1956, p. 112) has used the name Rockingham anticlinorium for the area east of the Merrimack synclinorium (Figure 2). In eastern Massachusetts, the Milford anticlinorium contains metamorphosed rocks of Avalonian and younger ages. Gneisses in the core of the Milford anticlinorium can be crudely correlated with those in the Pelham dome via the belt of gneiss domes along the Connecticut coast as well as on lithologic and isotopic grounds.

East of the Milford anticlinorium, and in uncertain relationship to it, lies the "Avalon platform" proper, with its unmetamorphosed late Precambrian plutonic rocks locally overlain by fossiliferous Cambrian sandstones and shales. These Cambrian rocks contain faunas of "European" affinity characteristic of other localities along the eastern margin of the Appalachians (Theokritoff, 1968).

Purpose of This Study

The Ware area lies within the region generally designated as the Merrimack synclinorium and has at its western boundary one of the basement gneisses of the Bronson Hill anticlinorium. The primary purpose of this study was to examine the stratigraphic and structural changes between these two major tectonic divisions. The major effort in achieving this goal was to develop a stratigraphy and compare it with that of the Bronson Hill anticlinorium. There is a considerable difference between the stratigraphic interpretation of workers to the northwest of the Ware area and those to the south, so one task of this study was to see which model seemed appropriate for the Ware area.

Also of interest was to make a contribution to an understanding of the complex structural and metamorphic history of the region. It has been suggested that some of the roots of the Bronson Hill anticlinorium nappes may lie in the western part of the Ware area (Thompson and others, 1968, p. 213-214) and it was hoped that this study would produce information relevant to that theory.

Previous Work

The bedrock of the Ware area was mapped in reconnaissance by Emerson (1898, 1917) as part of the geologic map of Massachusetts and by Shea (1953) as a University of Massachusetts Master's thesis. The Quabbin Reservoir area west of Ware is being mapped by Robinson (1967b;

in progress)(Figure 1). To the south and southeast are the Warren and East Brookfield quadrangles, being mapped by Pomeroy (in press and in preparation, respectively). Peper (1966; 1967) mapped the Palmer-Monson area southwest of Ware, and Fahlquist (1935) studied the geology of the Quabbin Aqueduct tunnel, which passes through the northern part of the area. Mulholland (1974) has mapped the surficial deposits of the Ware quadrangle.

Field Work

Field work for this report was done in the summer of 1972 and the summer and fall of 1973, with follow-up visits in the spring and fall of 1974. Outcrops were plotted directly on the 1:24000 base map except for some detailed portions in the central part of the area, where photo enlargements at 1:8000 were used. Topography and culture were commonly sufficient to locate the outcrops, but an aneroid altimeter was used on hillsides, and pace and compass traverses were necessary in areas of monotonous relief. Some data were taken from unpublished work of Robinson in the Winsor Dam quadrangle and from Pomeroy (in press) in the northwestern part of the Warren quadrangle.

Acknowledgments

This paper was submitted in partial fulfillment of the requirements for the Ph.D. degree at the University of Massachusetts, Amherst, in August 1975. Peter Robinson suggested the project and served as my advisor during the preparation of this dissertation. He has been of great help in unravelling field problems, educating me as to regional relationships, interpreting the metamorphic assemblages, and aiding in the subtle distinctions of the New England rock units. Frank Smith served ably and cheerfully as a field assistant during the wet summer of 1972. Jack Pomeroy of the U. S. Geological Survey, mapping in the Warren and East Brookfield quadrangles to the south and southeast of Ware, permitted me to use his manuscript map of Warren and showed me the rock types of his areas. James Mulholland, mapping the surficial deposits of the Ware quadrangle, enlightened me as to the glacial geology of the quadrangle and informed me of outcrops in unlikely places. Peter D'Onfro showed me some of his findings in the Templeton, Massachusetts, area on strike to the north of the Ware area. Norman Hatch, Leo M. Hall, Michael Pease, John D. Peper and James B. Thompson, Jr., made useful suggestions in the field and in the office. Leo M. Hall, Peter Robinson and Donald U. Wise reviewed the manuscript and made numerous helpful suggestions. Claude Deane and Dennis Nielsen, mapping in the Lovewell Mountain and Hillsboro quadrangles of New Hampshire, respectively, showed me the geology of their areas. Carl Nelson informed me of his progress in mapping a portion of the Monadnock, New Hampshire, quadrangle. Robert J. Tracy performed electron microprobe analyses of minerals in several specimens. The farmers and other landowners of Ware, Hardwick, New Braintree and West Brookfield townships were helpful and friendly in providing me access to their land.

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STRATIGRAPHY

The oldest unit in the area is the pre-Middle Ordovician Monson Gneiss, exposed along the western boundary of the map area, which forms one of the "domes" of the Bronson Hill anticlinorium. Above it to the east is an isoclinally folded sequence of rocks interpreted to be Middle Ordovician, Silurian, and Lower Devonian, based on lithologic correlation with rocks in the Bronson Hill anticlinorium (Figure 3).

The stratigraphy of the Bronson Hill anticlinorium was established in northwest New Hampshire by Billings (1937), who started with fossiliferous rocks of known age and traced them into areas of higher grade metamorphism. This stratigraphy has been followed southward along the anticlinorium nearly to Long Island Sound (Moore, 1949; Billings, 1956; Rodgers and others, 1959; Robinson, 1963, 1967 a,b; Thompson and others, 1968; Dixon and Lundgren, 1968b). A generally similar stratigraphy is found in the Connecticut-Gaspé synclinorium to the west (Doll and others, 1961), and some units very similar to those of the Bronson Hill anticlinorium are found to the east in the Merrimack synclinorium (Dixon, 1968; Dixon and Lundgren, 1968 a,b; Grew, 1973).

Two major units of Billings' (1937; 1956) stratigraphy are the Middle Ordovician Partridge Formation and the Lower Devonian Littleton Formation. The Partridge is typically a rusty-weathering pelitic schist containing mafic and felsic volcanics in its lower part. The Littleton is typically a well bedded, gray-weathering pelitic schist. The Littleton does not invariably weather gray, nor the Partridge invariably rusty, but in the Bronson Hill anticlinorium separation of

	CENTRAL WARE AREA	SOUTHEAST WARE AREA
LOWER DEVONIAN	Littleton Formation	Littleton Formation?
	Unconformity?	
SILURIAN	Fitch Formation	Paxton Schist
	Unconformity?	
MIDDLE ORDOVICIAN	Partridge Formation	Partridge Formation
	Unconformity?	
PRE-MIDDLE ORDOVICIAN	Monson Gneiss	Monson Gneiss?

Figure 3. Stratigraphic units in the Ware area.

these units is made easier by the presence of two distinctive Silurian units between them. These are the Clough Quartzite, consisting largely of quartzite and quartz pebble conglomerate, and the Fitch Formation, consisting of calc-silicate granulite, biotite-plagioclase granulite and sulfidic biotite schist. Unfortunately, the Clough and Fitch of the Bronson Hill anticlinorium have not been definitely identified by earlier workers in the Merrimack synclinorium. A unit probably correlative with the Fitch Formation is found in the Ware area, but its areal extent is small, and it is of limited help in making positive identification of the Littleton and Partridge Formations. The result is that in the Ware area weathering color and the sulfide content which it reflects is a major criterion to separate Partridge from Littleton.

This criterion for separation of rock units was little used by some workers in southern New Hampshire and adjacent Massachusetts, who included rusty-weathering units in the Littleton (for instance, Fowler-Billings, 1949; Hadley, 1949; and Greene, 1970) and was strongly emphasized by others (Robinson, 1963, 1967; Trask, 1964; Peper, 1966). The Merrimack synclinorium in New Hampshire is shown as largely Littleton by Billings (1956) on the basis of reconnaissance mapping, but it can be inferred from the information just stated, and is known from personal observation, that this area contains both gray- and rusty-weathering rocks. An indication of the problem of identifying Partridge and Littleton in the Merrimack synclinorium is shown by the fact that Billings' first map of the Mount Washington area (1941) divided it into Partridge, Fitch and Littleton Formations which were later (1946) all included as members of the Littleton Formation.

A basic question in the Merrimack synclinorium of central New England, therefore, is whether the Littleton and Partridge Formations can be differentiated by their weathering color, along with various supplemental criteria, as is usually true in the Bronson Hill anticlinorium, or whether some rusty units belong in the Littleton, as workers in New Hampshire east of the Bronson Hill anticlinorium have placed them (Fowler-Billings, 1949; Greene, 1970). In this report, schists with greatly varying degrees of rustiness have been placed in the Partridge Formation, and all units included in the Littleton Formation are gray-weathering. A thin unit of sulfidic calc-silicate granulite, tentatively assigned to the Silurian Fitch Formation, lies between the Partridge and Littleton Formations in the central part of the area.

The stratigraphy in the southeast part of the Ware area is different from the above. Here is found the Paxton Schist, consisting of a gray biotite granulite and calc-silicate granulite with related schists. This unit is not seen in nearby parts of the Bronson Hill anticlinorium, although it can be argued that it is a thick equivalent of the Fitch Formation. The Paxton Schist is widespread to the east, where it is a major Silurian unit in the stratigraphy of the Merrimack synclinorium. The Ware area is its present western limit at this latitude. The appearance of the Paxton may correspond to a zone of eastward thickening of the Silurian found in the Merrimack synclinorium in Maine, as discussed below under CORRELATION.

The conclusion reached in this study, based on the criteria discussed above and the resulting consistency of stratigraphic sequence, is that stratigraphy in the Ware area is not greatly different from that in the Bronson Hill anticlinorium, that the stratigraphic units of the area consist largely of the Partridge and Littleton Formations repeated several times by isoclinal folding, and that there are some facies changes between different belts of the same formation. Alternative interpretations are discussed at the end of the CORRELATION section of this report.

MONSON GNEISS

The Monson Gneiss is the oldest rock in the Ware area, and except within the Ware quadrangle its eastern edge is taken as the western boundary of the area covered by this report. It forms the easternmost "dome" of the Bronson Hill anticlinorium at this latitude. Two bodies of Monson Gneiss are present in the area, the main body, which extends westward into the Winsor Dam quadrangle, and a very thin anticlinal band, the North Orange band of Robinson (1963, p. 16a), which lies east of the main body and is separated from it by a narrow syncline of the Partridge Formation.

The name Monson Gneiss was first assigned by Emerson (1898, p. 56-65) to rocks exposed in the Flynt quarry at Monson, Massachusetts, 19 km (12 mi) south of Ware.

Lithology

The Monson Gneiss consists primarily of two rock types, quartz-feldspar gneiss (mf) and hornblende amphibolite (ma), which are present in varying proportions. Much of the main body seen in the Ware area

Table 1. Estimated modes of the Monson Gneiss.

	M46E-Felsic gneiss	M48-Amphibolite
Quartz	32	
Plagioclase	66 (ol)*	45 (la)
Hornblende	2 (green)	50 (blue-green)
Clinopyroxene	tr	2
Sphene	tr	1/2
Magnetite	tr	2 1/2
Apatite	tr	

*Plagioclase composition estimated by maximum extinction angles of albite twins. ol--oligoclase la--labradorite

List of specimens.

M46E Light-colored fine-grained quartz-feldspar-hornblende gneiss.
NW# Cliff 0.29 mi west of Ware-Greenwich Road 0.15 mi south of Gaudet Road.

M48 Medium-grained amphibolite.
NW 0.2 mi west of Ware-Greenwich Road 0.22 mi south of Gaudet Road.

#This symbol denotes the general location within the map area by 2 1/2 minute quadrants: south-central, northeast, central, etc. If the outcrop is outside the Ware quadrangle, the quadrangle is named.

is quartz-feldspar gneiss with a small amount of amphibolite, but there is a belt of nearly pure amphibolite within the main body in the northwest part of the area about 800 m (1/2 mile) from the eastern contact (Table 1). The North Orange band (mn) consists of alternating 1-3 cm stripes of quartz-feldspar gneiss and amphibolite, which give the rock a very distinctive appearance.

Thickness

At least 900 meters (3000 ft) of Monson Gneiss are present in the Ware area, but the formation extends for some distance west of the map area and may be much thicker.

PARTRIDGE FORMATION

The Partridge Formation in the Ware area is exposed in seven belts that trend north-northeast across the area. Because the lithology, particularly the sulfide content, varies, each belt is discussed separately. The different varieties are : gray- to red-weathering schist (Opl), red- to rusty-weathering schist (Opr), red- to rusty-weathering schist with amphibolite (Opra), and sulfidic schist (Ops). Small bodies of mafic gneiss (Opa) are also found. The locations of the structures in which the Partridge occurs are given in Plate 6.

Lithology

The Partridge Formation consists of rusty-weathering sillimanite-biotite schists and biotite granulites with minor calc-silicate granulite and amphibolite. The large amounts of amphibolite and feldspathic gneiss, found in the lower part of the Partridge elsewhere, are present only in the extreme western part of the Ware area where the Partridge rests on Monson Gneiss. Despite the great variation in sulfide content, the Partridge Formation is always less gray than the Littleton Formation. Compared to the Littleton, the Partridge generally contains more plagioclase, and less orthoclase, garnet and biotite.

Near contact with the Monson Gneiss. This thin zone includes Partridge Formation between the main body and the North Orange band of the Monson Gneiss and local lenses along the east side of the North Orange band. These rocks have been traced along the east edge of the main body of Monson Gneiss from known Partridge in the Orange area to the north (Thompson and others, 1968, pl. 15-1a). The unit is composed of roughly equal portions of sulfidic sillimanite schist and amphibolite with minor feldspathic gneiss (Opra). It is the only belt in the Ware area in which the Partridge contains more than a trivial amount of amphibolite, although mafic and felsic volcanics are common in the formation in the Bronson Hill anticlinorium (Robinson, 1963, p. 34-35; Thompson and others, 1968, p. 206).

Muddy Brook area. The Partridge Formation near the western edge of the Ware quadrangle is very poorly exposed. It is inferred to have weathered to form Muddy Brook valley (Figure 4), which is straight and nearly parallel to strike. This inference is supported by the presence in the Quabbin Aqueduct tunnel of Partridge in the appropriate place. Some of the Partridge on the east side of the valley is a red-weathering schist with low sulfide content.

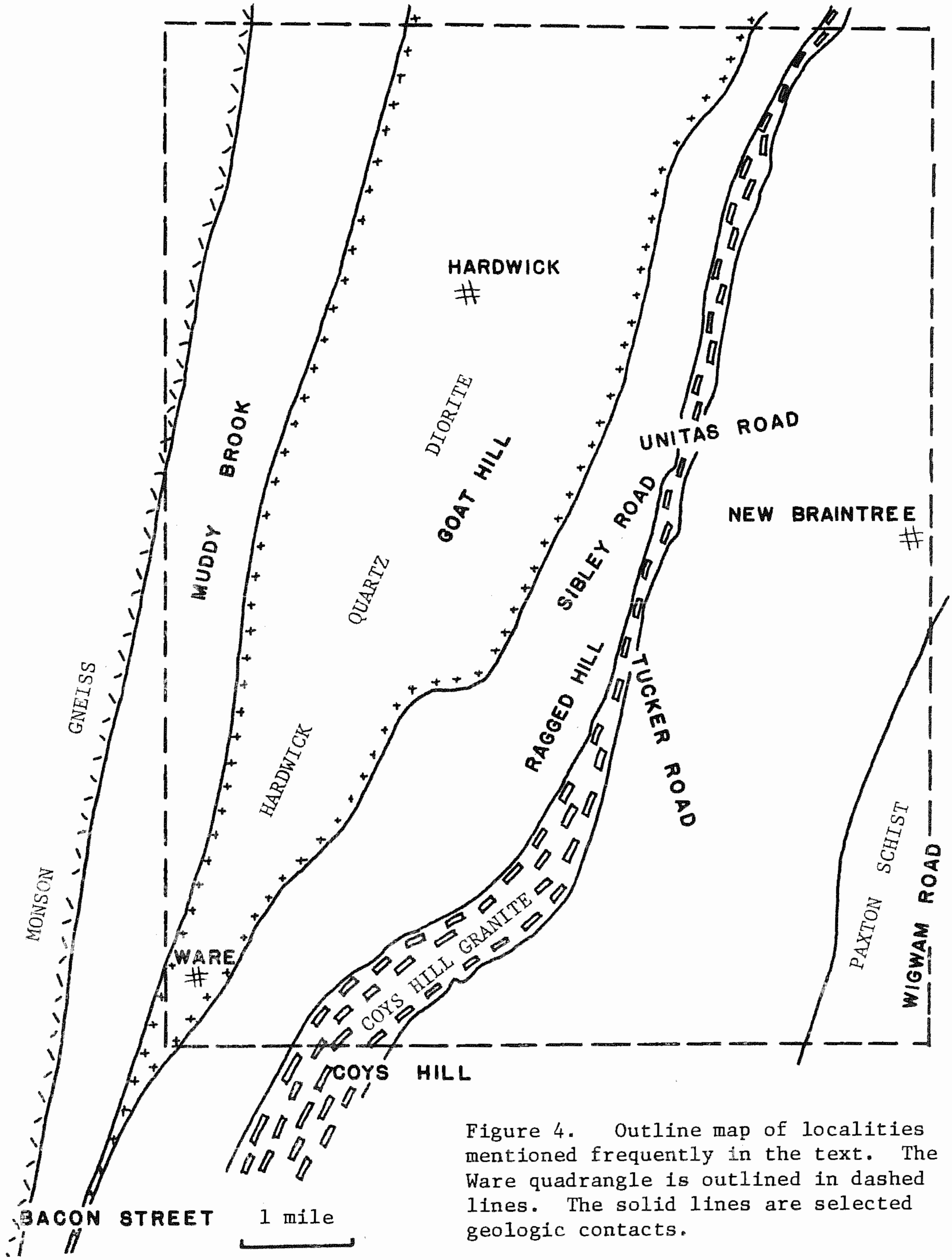


Figure 4. Outline map of localities mentioned frequently in the text. The Ware quadrangle is outlined in dashed lines. The solid lines are selected geologic contacts.

Location of the southern extension of the Muddy Brook anticline is difficult. In the southwest part of the map area, three belts of Partridge and three of Littleton are exposed in an area only 0.5 km (0.3 mile) across strike. Presumably one of these narrow anticlines of Partridge expands to the north to become the Muddy Brook anticline, but it is difficult to tell which one. The Partridge in this area is brown-weathering, with some rusty patches (Opr) similar to the Partridge of the Unitas Road and Lamberton Brook anticlines.

The only other Partridge outcrops east of the Monson in this area are in the Ware High School anticline in the southeast part of the Winsor Dam quadrangle. This is a sulfidic sillimanite schist, like the schists in the Wickaboag Pond anticline (Table 2, D23).

Lyon Road, Ragged Hill and West Coys Hill anticlines. These belts lie between the Coys Hill Granite and the Hardwick Quartz Diorite. They are partly separated by synclines of the Littleton Formation and intruded by the gneiss of Ragged Hill, so the map pattern is confusing. The differences between this variety of Partridge (Opl) and the Littleton Formation are not so great as is the case with the rocks in the other belts of Partridge. It is composed primarily of schist, in contrast to the granulites and granular schists in the Partridge anticlines to the east. It generally contains more sillimanite and garnet and slightly less plagioclase than the Partridge in the eastern anticlines (Table 2). It weathers gray to red, the red-weathering color being characteristic. A yellow stain may be present in fractures and under overhanging ledges.

Table 2 Estimated modes of sulfidic schists of the Partridge Formation.

	Ware H.S.	Lyon Road						Unitas Road	Lamberton Brook		Wickaboag Pond		
	D23	FW-2A	213A	217	219A	283	390	304A	21A	664	407	748	879
Quartz	70	45	50	30	75	25	62	57	57	62	30	15	45
Plagioclase	6 ad*	15 An39	15 ol	25 ol	15 ad			10 ol	28 An29	25 An37	13 An34	42 An52	45 An38
Orthoclase	4	3	3	10		30	6	10			12		
Biotite	12	15	10	12	5	15	8	9	10	10.5	15	35	7
Garnet	3	7	15	12	4	12	10	3	3	2	8		1
Sillimanite	3	12	6	10		15	12	9	1.5		12		
Cordierite		2				1					2		
Pyrrhotite	2	1	0.5	0.5	0.5		1.5	1	tr	0.5	8	7	2
Graphite		tr	0.5	0.5	0.5	tr	0.5	1	0.5				
Ilmenite						2							
Zircon	tr							tr	tr	tr	tr	tr	tr
Sphene												tr	
Chlorite												tr	
Apatite												1	tr

*Plagioclase compositions determined by maximum extinction angles of albite twins. In some cases, compositions were estimated by this method and are indicated as follows: ol-oligoclase, ad-andesine, la-labradorite, by-bytownite.

List of specimens in Table 2.

D23 Rusty-weathering sillimanite schist.
Winsor Dam SE Northeast corner of Ware High School.

FW-2A Red- to gray-weathering garnet-sillimanite schist with 1 cm garnet.
SC Just south of Ragged Hill Road 0.2 mi east of intersection with Pierce Road.

213A Red- to gray-weathering garnet-sillimanite schist.
SC On east-west powerline north of Route 9, 0.5 mi east of Gilbertville Road.

217 Red- to gray-weathering garnet-sillimanite schist.
SC 0.5 mi north of east-west powerline north of Route 9, 0.36 mi east of Gilbertville Road.

219A Gray-to red-weathering quartzose biotite garnet schist.
SW 0.6 mi north of east-west powerline north of Route 9, 0.22 mi east of Gilbertville Road.

283 Gray- to red-weathering sillimanite schist, with sillimanite pseudomorphs after andalusite.
SW On county line 0.46 mi south of corner at edge of Ware River about 1 mi upstream from Ware.

390 Gray- to red-weathering garnet-sillimanite schist.
C 0.2 mi north and 0.08 mi west of intersection of Gilbertville and Tucker Roads.

304A Red-weathering sillimanite schist.
C 0.06 mi east of Tucker Road and just south of the east-west portion of the West Brookfield-New Braintree boundary about 0.4 mi south of Gilbertville Road.

21A Gray- to rusty-weathering garnet-sillimanite schist.
SE 0.26 mi east of Tucker Road 0.5 mi north of Woods Road.

664 Red- to rusty-weathering feldspathic granulite.
EC Top of hill east of Padre Road.

407 Pyrrhotite-rich sillimanite schist.
Warren NC Road cut on south side of Routes 19 & 67, 0.75 mi west of the Warren-West Brookfield town line.

748 Rusty-weathering schistose granulite
EC Road cut on West Brookfield Road 0.1 mi south of intersection with Gilbertville Road. Near the ultramafic body.

FW-879 Slabby gray- to rusty-weathering granulite.
EC Small stream gully 0.2 mi south of Wine Road on the west-facing slope of Winimusset Brook valley about 0.85 mi west of New Braintree.

The schist in these anticlines commonly contains numerous small pegmatite veinlets and masses, 1 or 2 centimeters wide and several centimeters to a few tens of centimeters long, folded with the schist. These are somewhat similar in appearance to, although not the same as, the porphyroblasts noted in the porphyroblastic orthoclase gneiss unit of the Dakin Hill Member of the "Littleton Formation" of Heald (1950, p. 54) in the Lovewell Mountain, New Hampshire, quadrangle (Figure 1).

Calc-silicate "footballs" -- lenticular pods one half to two meters long and several centimeters thick -- are found in places (Figure 5). These make up much less than one per cent of the unit. They are hard and brittle granulites, composed of approximately equal portions of quartz, calcic labradorite and diopside (Table 3, FW-219B). The presence of such "footballs" was one of the reasons cited by Billings and others (1946, p. 266) for changing the classification of some rocks from Partridge to Littleton in the Mount Washington area of New Hampshire. They have also been noted in the Dakin Hill and May Pond Members of the "Littleton" by Heald (1950, p. 51).

Unitas Road anticline. This anticline lies immediately east of the Coys Hill Granite. The rocks in this anticline are moderately sulfidic, distinctly less so than those of the wide Wickaboag Pond anticline but more so than those of the Lyon Road, Ragged Hill and West Coys Hill anticlines. Typically the rock (Opr) weathers reddish gray in outcrop, and the rusty to yellow color is visible only on weathered fracture planes. It is, however, distinctly less gray and less pelitic than the Littleton Formation. Granulite and granular schist are more common than schist, as in the Wickaboag Pond anticline. The rocks

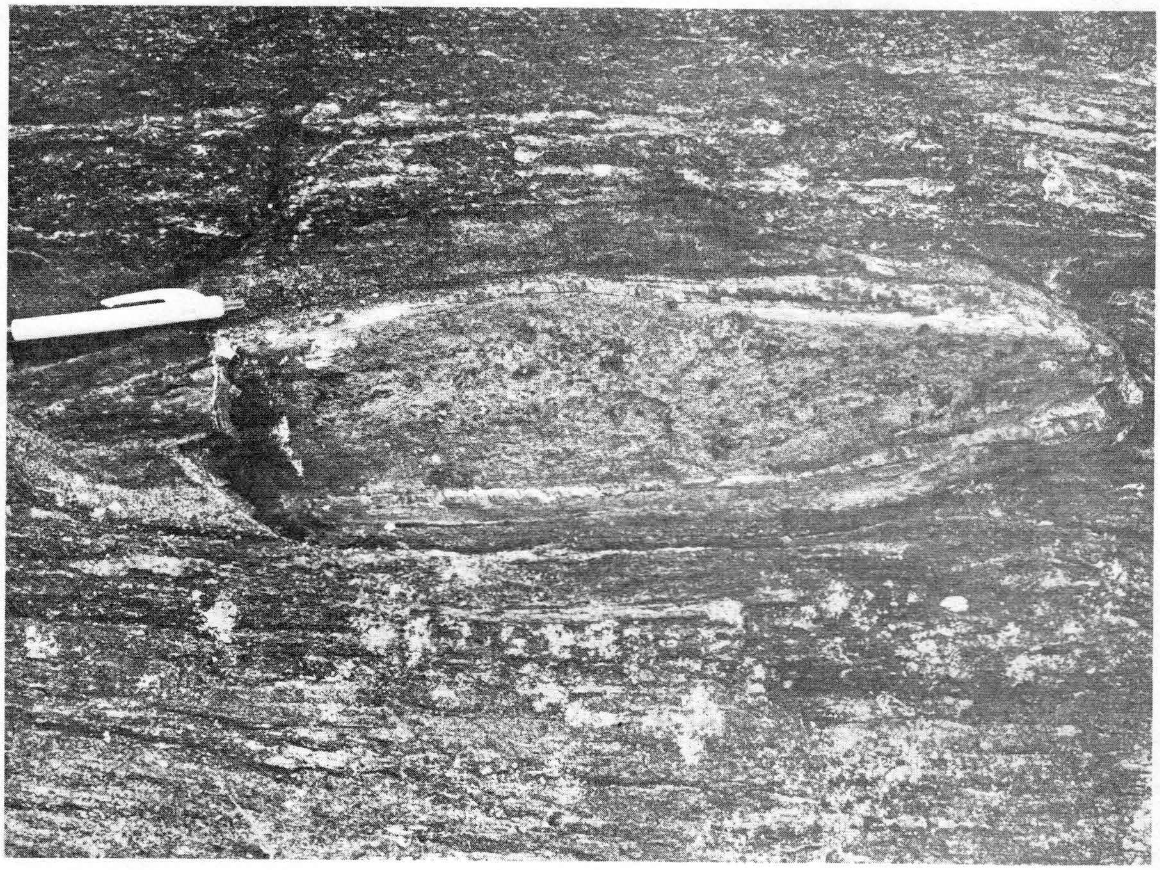


Figure 5. Calc-silicate granulite nodule in the Partridge Formation northwest of Coys Hill.

Table 3. Estimated modes of mafic gneisses and calc-silicate granulites in the Partridge Formation.

	Calc-silicate granulites			Mafic gneisses				
	Lyon Road	Wickaboag Pond	Lyon Road	Unitas Road				Lamberton Brook
	FW-219B	629	233	559	899	979B	982	854B
Quartz	29	45	5	20	tr	3		
Plagioclase	35 An68*	37 An72	24 An54	50 An45	72 An51	40 An75	68 An51	15 An68
Biotite			20		2	10	4	7
Diopside	34	12						
Cummingtonite			20	20		40	6	
Hornblende		2	30				10	58
Orthopyroxene					25		8	20
Garnet	1	3		8				
Magnetite		0.5	1	2	1			tr
Pyrrhotite		tr		tr				
Graphite						5		
Ilmenite						2	4	
Apatite	tr		tr					
Zircon			tr					
Sphene	tr	0.5						
Scapolite	1							
Chlorite				tr				

*Plagioclase composition determined by maximum extinction angles of albite twins.

List of specimens in Table 3.

219B Gray-weathering, fine-grained calc-silicate granulite "football". Same location as 219A.

629 Hard brittle red-weathering calc-silicate granulite.
NE Stream just south of Hardwick Road, southeast of Wheelwright, about 0.3 mi west of the intersection where the road turns south to New Braintree.

233 Medium-grained amphibolite with biotite, gray- to red-weathering, at contact between the gneiss of Ragged Hill and the Fitch Formation.
SC 20 feet north of road cut on north side of Route 9, 0.14 mi west of west junction with former road, about 1/4 mi west of the high point where Route 9 goes over Coys Hill.

559 Hard brittle slabby red-weathering mafic gneiss.
EC 0.14 mi north of Unitas Road, 0.14 mi west of the sharp bend about 1/4 mi by road west of West Road.

899 Coarse unfoliated plagioclase-orthopyroxene gneiss.
SC Coys Hill area. 0.2 mi west and 0.08 mi north of BM 863 west of Coys Hill Road about 0.4 mi south of Route 9.

979B Coarse brown-weathering amphibole gneiss with biotite.
NE 0.45 mi west of Barre Road (Route 32) 0.39 mi north of railroad crossing west of Wheelwright.

982 Coarse brown-weathering mafic gneiss.
NE 0.41 mi east of Prouty Road at the 740 foot elevation.

854B Dark colored weakly foliated coarse grained hornblende-orthopyroxene plagioclase-biotite gneiss; in Lamberton Brook anticline of Partridge.
SC 0.36 mi north and .05 mi east of intersection of Route 9 and the south edge of the Ware quadrangle.

(Table 2) are composed mostly of quartz, oligoclase, orthoclase and biotite, with lesser amounts of garnet and sillimanite.

While most of the Partridge Formation in this anticline is similar to that in nearby anticlines, it has two special features. One is the presence of a variety of rock types immediately east of the Coys Hill Granite. These are best displayed in the northeast part of the area, but are found all along the contact (Figure 6; Table 3). Among these rocks are small exposures of the Fitch Formation and the gneiss of Ragged Hill, which are mapped separately. There are also thin layers of gray sillimanite schist, rusty schist, calc-silicate granulite, mafic gneiss and amphibolite, all of which are included in the Partridge Formation. Some of the mafic gneisses are very similar in outcrop to the orthopyroxene gneiss found in the Prouty Road syncline of the Littleton Formation. A few occurrences of mafic gneiss and amphibolite are large enough to map separately.

The other special feature of this anticline is that in the south, on Coys Hill, it widens drastically, and the rock type is generally more quartzose than other Partridge schists and granulites of the Ware area. It is slabby and brittle, breaking into small angular blocks. The weathering color is gray to red, and a few 1 to 2 cm thick calc-silicate beds are present.

Lamberton Brook anticline. This anticline lies between the Unitas Road anticline to the west and the wide Wickaboag Pond anticline to the east. The rocks are lithologically similar to those of the Unitas Road anticline (Opr) but contain less orthoclase (Table 2). A small body of mafic gneiss, resembling those in the Unitas Road anticline, is found

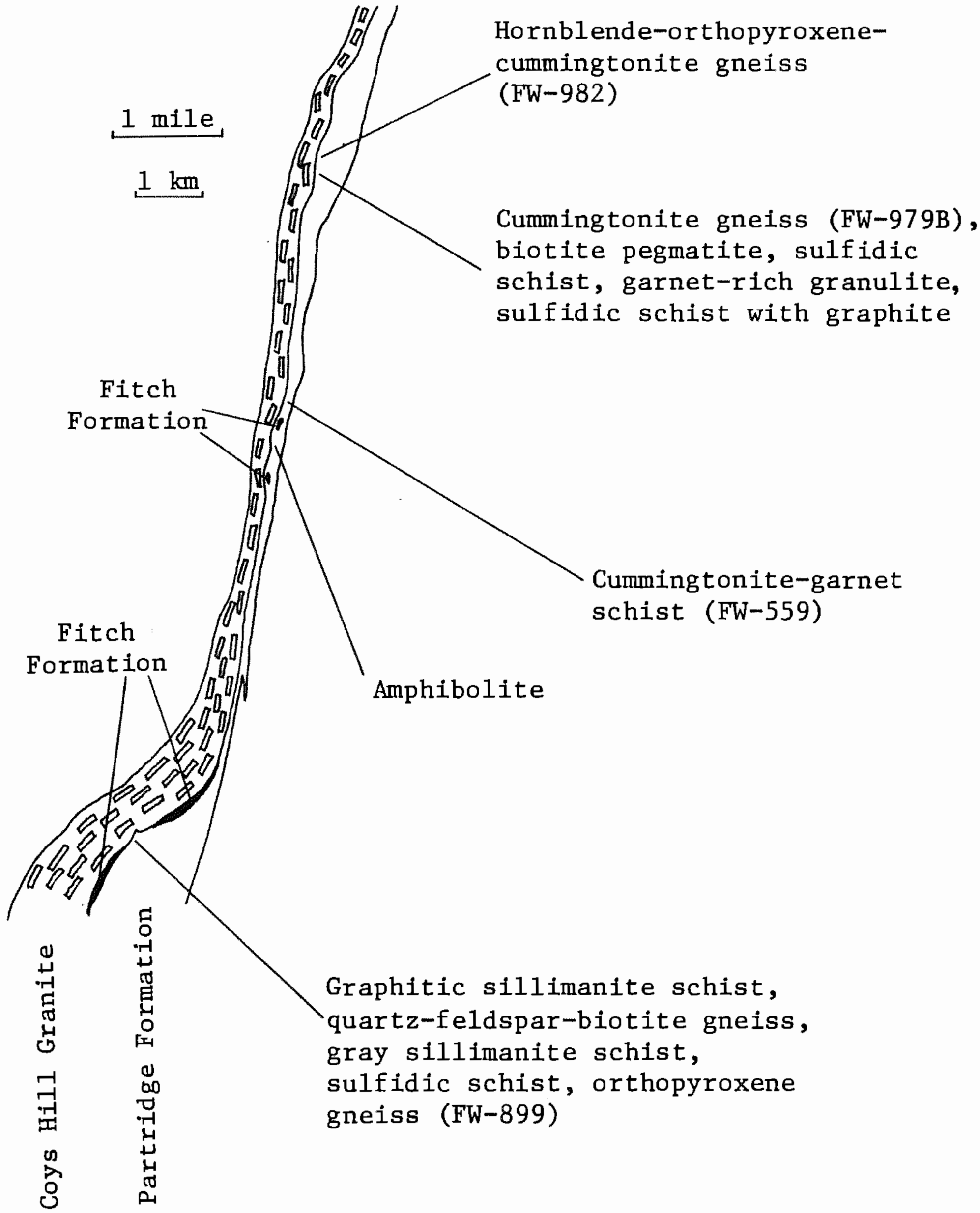


Figure 6. Some rock types found near the western contact of the Partridge Formation in the Unitas Road anticline. The specimens noted by number are in Table 3.

west of Wickaboag Pond (Table 3).

Wickaboag Pond anticline. This anticline contains the major belt of Partridge Formation in the area, and it is generally more sulfidic than that of the other belts (Ops). The high sulfide content causes the rock to weather rapidly, with the result that outcrop is very poor. The rapid weathering of this unit is illustrated by samples from the Quabbin Aqueduct tunnel. Although fresh when collected and stored indoors for forty years, many samples from this belt have crumbled into yellow powder in their cabinet drawers as the sulfides oxidized to sulfates. Exposure of this rock to many thousands of years of New England weather would have resulted in considerable erosion, and is probably the reason for the broad valley in the eastern part of the Ware quadrangle, from Wickaboag Pond in the south to the Ware River in the north, with almost no evidence of Partridge bedrock except for the rust-stained sands and gravels. The few outcrops within this belt are weathered schist and comparatively fresh granulite. This poses a problem in lithologic description because those rocks which crop out are the most resistant and may not be typical of the unit. Perhaps the only fresh representatives of the easily eroded schist are in a road cut 1 km (3/4 mile) northeast of Warren in the Warren quadrangle, and in a small stream valley 1 1/2 km (1 mile) south-southeast of Wheelwright in the northeast part of the Ware quadrangle where there is 0.4 km (1/4 mile) of fairly continuous exposure.

The dominant rock type of the belt is probably this rarely exposed schist, which is a massive biotite-sillimanite-garnet-cordierite schist with a brown- and yellow-weathering crust (Table 2, FW-407). It contains several per cent of pyrrhotite and is magnetic in hand specimen. Segregation laminations, 2 to 5 mm thick, rich in quartz and feldspar, are interspersed with layers rich in biotite, sillimanite, garnet and cordierite.

The other major rock type is a slabby granulite composed largely of quartz and plagioclase, with biotite, garnet, rare sillimanite, and sulfides (Table 2, FW-879). Beds are commonly 3-5 cm thick, fresh on the interior but separated by rusty-weathering fracture planes. The fresh color is a purplish medium gray. Another specimen (FW-748), from close to the New Braintree ultramafic body, is a calcic granulite with calcic plagioclase and sphene. This specimen contains considerably more biotite and less quartz than FW-879.

In a few areas in the eastern part of this anticline are outcrops of resistant red-weathering schist similar to those in the Lyon Road, Ragged Hill, and West Coys Hill anticlines and that part of the Unitas Road anticline which is on Coys Hill in the southern part of the area. These outcrops, which are not mapped separately, are north of Ravine Road in the northwestern part of the North Brookfield quadrangle, just west of Wigwam Hill, and 0.7 km (0.4 mile) west of the New Braintree ultramafic body. The last resembles the sandy Partridge of the Unitas Road anticline on Coys Hill, even to the thin calc-silicate beds. The thin layer of schist within the New Braintree Gabbro is well-bedded and rather gray-weathering (Opl).

Slabby calc-silicate beds are interbedded with the schists and granulites in a few places (Table 3, FW-629). A small body of amphibolite is mapped east of Whortleberry Hill in the southeast part of the area, and Pomeroy (in press) notes a body of amphibolite on strike to the south in the east-central part of the Warren quadrangle.

Lower Contact

The contact with the Monson Gneiss is seen or closely approached in a few places in the northwest part of the map area, and is approached within a few meters (10-20 feet) south of Bacon Street in the southwest part of the area. In all cases the contact appears to be sharp. Robinson (1967a) has discussed the possibility that this contact is an unconformity.

Derivation

The Partridge Formation was originally deposited as shales whose sulfide content indicates deposition in a reducing environment. Where the Partridge is in contact with Silurian rocks, it appears that the less sulfidic varieties of Partridge are near the contact, suggesting that the less sulfidic Partridge is younger than the other varieties. A possible model for the depositional environment of the Partridge Formation, therefore, is a basin whose lower part was closed so that sediments were initially deposited in a stagnant reducing environment. As the basin filled, the sediments were deposited in less stagnant water, giving a gradual decrease in sulfide content toward the top of the section.

Thickness

The greatest width of the Partridge Formation in the map area is in the Wickaboag Pond anticline, which is 1200 meters (4000 ft) thick as measured in cross-section. If this is a simple anticline, the thickness of the unit is 600 meters (2000 ft). If there is a syncline in the middle of the belt, as discussed under Wickaboag Pond anticline in the structure section of this report, the thickness of the unit may be only 300 meters (1000 ft).

FITCH FORMATION

The Fitch Formation as mapped in the Ware area is a thin unit, found a short distance west of the Coys Hill Granite and in discontinuous lenses just east of it. There are two belts west of the Coys Hill Granite in most of the northern half of the area, separated by the big garnet unit of the Littleton Formation. That unit pinches out on the east side of Ragged Hill in the central part of the area, and from there south there is a single, comparatively wide, belt of Fitch. The east-west extent of the Fitch Formation in the Ware area is limited (Figure 22).

The name is from Fitch Farm in northwest New Hampshire (Billings and Cleaves, 1934, p. 415). This name is used here because there is good evidence that the unit in the Ware area is equivalent to the Fitch Formation elsewhere (see <u>CORRELATION</u>), and because the introduction of a new name does not seem useful at this point. It is designated Sf on the map.

Lithology

The Fitch Formation as mapped in the Ware area is a very sulfidic graphite-rich granular calc-silicate rock. It is medium to dark gray when fresh, and light gray with a brown crust when weathered. In the field, it tends to form narrow ridges. It is composed largely of 0.2-0.3 mm crystals of quartz and labradorite-bytownite in varied proportions, with 3-35 per cent diopside, 1-7 per cent pyrrhotite plus graphite and 1-2 per cent pink pleochroic sphene (Table 4). Two specimens contain a few per cent of biotite and one contains a little actinolite. Many beds have conspicuous amounts of graphite that help distinguish the rock in the field. Other beds have enough pyrrhotite to be magnetic in hand specimen.

A thin unit resembling the Coys Hill Granite, with feldspar megacrysts in a fine quartz-feldspar-biotite matrix, is associated with the Fitch Formation in scattered places the length of the Ware quadrangle. It is a meter or less thick in most places. Its position within the Fitch is usually confused by the intrusive gneiss of Ragged Hill, but it can be seen at the west contact of the Fitch Formation in a few places on Ragged Hill and within the Fitch in the northeast part of the area. The nature of this unit is uncertain. It somewhat resembles a pegmatitic intrusion, possibly associated with the gneiss of Ragged Hill, but its persistence in approximately the same stratigraphic position for at least 14 km (10 mi) implies that it is a stratigraphic unit, possibly a metamorphosed tuff.

A small body of Fitch Formation is found within the Hardwick Quartz Diorite pluton (Table 4, FW-509B), a couple of meters west of an

Table 4. Estimated modes of the Fitch Formation.

	FW-2B	175	200	239H	243	260C	509B	928
Quartz	30	30	40	50	40	40	60	20
Plagioclase	50 An75*	57 la	40 An75	30 An64	35 by	35 An70	35 ad	37 An80
Microcline		2						
Diopside	7	8	14	10	20	15	3	35
Biotite	3					5		
Scapolite				3				
Sphene	2	2	2	1	1	1	1	1
Pyrrhotite	4	0.5	3	6	3	3	tr	5
Graphite	2	0.5	1		1	1	1	2
Apatite				tr				tr
Zircon						tr		tr
Calcite	tr					tr		
Actinolite	2							

*Plagioclase compositions determined as described in Table 2.

List of specimens in Table 4.

2B Rusty-weathering slabby calc-silicate granulite.
SC Just north of Ragged Hill Road 0.2 mi east of intersection with Pierce Road.

175 Graphitic sulfidic feldspathic medium-grained gneiss.
SC 0.17 mi west of Pierce Road, 0.36 mi south of intersection with Ragged Hill Road.

200 Sulfidic graphitic feldspathic schist.
SW Just east of north-south powerline 0.44 mi south of Route 9.

239H Massive gray rusty-weathering calc-silicate granulite, very fresh specimen from stream outcrop.
SW 680 foot elevation in stream north of Prendiville Road.

243 Sulfidic feldspathic graphitic fine-grained gneiss.
SW North end of ridge 0.12 mi south of Prendiville Road 0.23 mi west by road of first crossing of West Brookfield town line east of Ware.

260C Rusty-weathering graphitic schist.
NE East-facing slope about 100 feet east of Prouty Road in the northern part of the closed 920 foot contour.

509B Rusty-weathering feldspathic graphite-rich gneiss. Occurs within Hardwick pluton, with Hardwick outcrop several feet to the east.
NC 0.21 mi east of Church Street at 980 foot contour about 0.6 mi south of Barre Road.

928 Sulfidic feldspathic fine grained calc-silicate granulite. East of the Coys Hill Granite.
SC Road cut on south side of Route 9, 0.51 mi by road west of Coys Hill Road.

outcrop of the quartz diorite. It and the outcrops of Partridge Formation exposed immediately to the west and south are interpreted to be a synclinal infold on top of the Hardwick pluton.

Lower Contact

The contact with the Partridge Formation is not exposed, but is approached within 2-3 m (10 ft) east of Sibley Road (Figure 4) and appears to be sharp. The Fitch Formation is seen in contact only with the big garnet unit of the Littleton Formation or with the red-weathering Partridge Formation (Opl) of the Ragged Hill and West Coys Hill anticlines. The only exception is a few small bodies of Fitch east of the Coys Hill Granite, which are in contact with the Partridge of the Unitas Road anticline.

Derivation

The Fitch Formation of the Ware area was derived from calcareous sediments whose sulfide and graphite content indicates they were deposited in a stagnant environment and supplied with organic material. The Fitch Formation further north in New Hampshire (see CORRELATION) was deposited in shallow water, as indicated by the marbles and quartzites, but in that area the water was apparently not generally so stagnant.

Thickness

The Fitch Formation has a maximum thickness of about 15 meters (50 ft). The belt of Fitch in the southern part of the area is rather wide, but this is believed to be tripled in thickness by a pair of folds (Figure 22).

PAXTON SCHIST

The Paxton Schist is found in the Ware area only in the extreme southeastern part, but is widespread east of there. The belt of Paxton seen in the Ware area pinches out to the south, according to Emerson (1917), possibly in a fold hinge. Pomeroy (in press) gives a different interpretation, but reconnaissance mapping in conjunction with this report tends partially to confirm Emerson's interpretation while revealing other complications.

This unit was called the Paxton Quartz Schist by Emerson (1898, p. 18; 1917, p. 62) after the town of Paxton, 18 km (11 mi) east of the Ware quadrangle. Two units, the sulfidic biotite schist and the sulfidic white schist, are recognized in the Paxton in addition to the dominant gray granular schist. These are not proposed as members because they are not yet well enough studied.

Lithology

Gray granular schist. This dominant rock type of the Paxton schist is a monotonous slabby gray granular rock (Sp), easily distinguished from other rock types in the area. A thin-bedded variety is shown in Figure 7. The beds are commonly 2 to 10 cm thick and are uniformly medium to dark gray. The rock consists primarily of quartz, labradorite and biotite, with a few per cent of garnet (Table 5). The crystals are 1/2 mm or less in diameter. Areas of coarser rock are found on the west side of Wigwam Hill in the Ware quadrangle, and near Wigwam Road in the southwest part of the North Brookfield quadrangle.

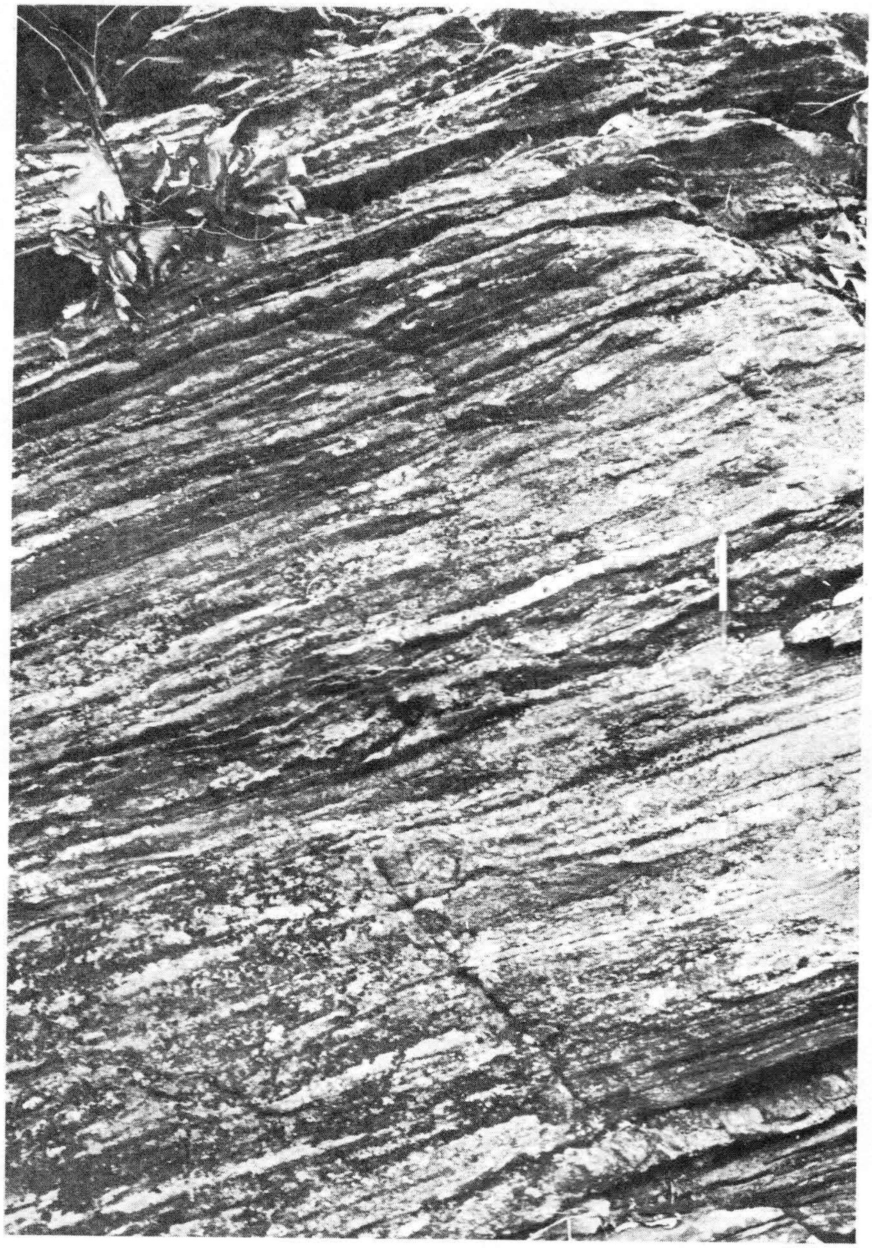


Figure 7. Thin-bedded Paxton Schist east of Wigwam Road. Pen in right center of picture gives scale.

Table 5. Estimated modes of the Paxton Schist.

	Gray granular schist				Calc-silicate granulite		Amphibolite	
	Normal		Coarse					
	FW-679A	923	683B	699	679B*	922	686	694
Quartz	50	45	10	56	45	45		
Plagioclase	17 An59#	35 An72	70 An45	25 ad	30 An68	36 An70	40 An60	27 An69
Orthoclase				2				
Biotite	30	17	19	15		4.5		1
Garnet	3		1	2				
Hornblende		2			18	8	59	25
Cummingtonite					2			
Diopside		0.5			3	5		
Orthopyroxene								45
Magnetite			tr	tr			1	2
Pyrite		0.5			2	1		
Sphene		tr				0.5		
Apatite	tr		tr	tr		tr		
Zircon			tr	tr				
Fibrolite				tr				
Calcite						tr		

*Hornblende-cummingtonite and hornblende-diopside assemblages are in different layers.

#Plagioclase compositions determined as described in Table 2.

List of specimens in Table 5.

FW-679A Gray quartz-feldspar-biotite granulite with 15 mm garnets.
SE Wigwam Hill. Powerline 0.25 mi west of Wigwam Road.

923 Massive fine-grained gray biotite granulite with 1 cm hornblende crystals.
North Brookfield SW 0.07 mi east of Downey Road 0.85 mi north of intersection with Summer Street.

683B Coarse dark-colored granular biotite gneiss.
SE Wigwam Hill. 0.05 mi east of New Braintree Road 0.2 mi north of powerline.

699 Coarse light-colored granular biotite gneiss with 1-3 mm garnet.
North Brookfield SW Just south of Wigwam Road intersection 0.1 mi west of West Brookfield-North Brookfield town line.

679B Fine- to medium-grained hard, brittle, slabby amphibolite.
Same location as 679A.

922 Fine-grained slabby quartz-feldspar-biotite-hornblende-diopside granulite.
Warren NE West side of Wigwam Road just north of North Brookfield Road.

686 Medium-grained slabby foliated hornblende amphibolite.
SE Wigwam Hill. Just south of old road 0.08 mi west of Wigwam Road 0.32 mi north of powerline.

694 Medium to coarse weakly foliated hornblende-orthopyroxene gneiss associated with the sulfidic biotite schist unit. The orthopyroxene crystals are 2-3 mm long and poikilitic, with a composition of about FS 35.
SE Wigwam Hill. 0.14 mi west of Wigwam Road 0.57 mi north of powerline.

This is a light gray rock of the same general composition as typical Paxton, but the plagioclase is about An 45, there is somewhat less biotite and the crystals are about 1mm across (Table 5). It has some resemblance to the gneiss of Ragged Hill, and it is possible that this rock is intrusive.

Calc-silicate beds are rare in the Paxton of the Ware area, but to the east, Emerson (1917, p. 62) describes green calcareous layers containing actinolite, diopside and minor calcite. Future mapping may show that there are more and less calcareous members of the Paxton. In the Ware area, the rare calc-silicate beds are several centimeters thick and composed of quartz, plagioclase (An 70), and hornblende, with small amounts of diopside and opaques (Table 5).

Some hornblende-plagioclase amphibolite is found west of the sulfidic white schist unit on Wigwam Hill (Table 5, FW-686).

In contrast to all but the westernmost part of the rest of the map area, pegmatites are common in areas underlain by the Paxton schist, where at least a third of the outcrops are pegmatites. A short distance to the east, in the North Brookfield quadrangle, pegmatites are even more numerous, commonly comprising most of the outcrop. Such areas dominated by pegmatite were referred to by Emerson (1917, p. 233-236) as the Hubbardston Granite, which he felt was a border facies of the "Central Batholith" (the Fitchburg Pluton) much contaminated by country rock.

Sulfidic biotite schist unit. This is a single thin poorly exposed unit found on the east side of Wigwam Hill. The lithology varies, but is ordinarily dominated by a sulfidic biotite schist (Sps) resembling the Partridge Formation rather than the sulfidic white schist unit. An outcrop of hornblende-orthopyroxene gneiss (Table 5, FW-694) is found in it. It is possible that this unit represents a narrow anticline of Partridge Formation, but it is assumed to be a part of the Paxton Schist until more mapping is done in the Paxton.

Sulfidic white schist unit. This unit is made up of an unusual rock type (Spw) that occurs in three narrow belts in and at the western contact of the Paxton Schist. The sulfidic white schist unit contains no iron minerals except sulfides. It weathers white with an extreme rusty stain. Some portions have 2-5 mm laminations, and the weathered rock breaks into 3-10 cm slabs. The composition is fairly similar to that of the pelitic schists in the area, except for the absence of iron-bearing silicates. The dominant minerals are quartz and potassium feldspar, and other important minerals are cordierite, sillimanite, and plagioclase, with a few per cent of iron sulfides, phlogopite or biotite, graphite and rutile (Table 6). Electron microprobe analyses (Table 18) have shown that the cordierite and phlogopite in one specimen are pure magnesian end-members, indicating that all the iron in the rock is in the sulfides.

Lower Contact

The contact of the Paxton Schist with the Wickaboag Pond belt of the Partridge Formation is not exposed in the Ware area. The closest approach of the two units is near the powerline on New Braintree Road, where they are 200 m (600 ft) apart across strike. On the map, a thin belt of the sulfidic white schist unit is extrapolated through the

Table 6. Estimated modes of the sulfidic white schist unit of the Paxton Schist.

	FW-316	318B	319	882
Quartz	75	71	50	40
Plagioclase		3 An33*	2 An46	10 An37
Microcline	17	20	40	
Orthoclase				30
Sillimanite	2	2	3	11
Cordierite	3		2	2.5
Biotite/phlogopite	2 lyb#	1 pb	2 lyb	1 colorless
Pyrite**		3		1
Graphite	0.5	tr	0.5	4
Zircon		tr		
Rutile	0.5	tr	0.5	0.5

*Plagioclase composition determined by maximum extinction angles of albite twins, except FW-882, where composition was determined by electron microprobe analysis (Table 18).

#Biotite/phlogopite color: pb-pale brown, lyb-light yellow-brown.

**The pyrrhotite originally present has altered to other sulfides or been leached from many specimens.

List of specimens in Table 6.

316 Coarse-grained foliated sulfidic quartzose graphitic schist.
SE 0.18 mi east of West Brookfield Road 0.16 mi north of corner of three townships.

318B Sulfidic graphitic slabby medium-grained quartz-feldspar gneiss.
SE 0.1 mi south and 0.02 mi east of intersection of Prouty Road and New Braintree-North Brookfield town line.

319 Sulfidic graphitic medium coarse quartz-feldspar gneiss.
EC East side of small 740 foot hill just north of intersection of Prouty Road and New-Braintree-North Brookfield town line.

882 Sulfidic slabby medium-grained quartz-feldspar gneiss.
Warren NE Ridge 0.3 to 0.45 mi south and about 0.1 mi west of the northeast corner of the Warren quadrangle.

contact. Robinson (personal communication, 1975) has recently discovered a Partridge-Paxton contact on Harding Hill, during reconnaissance in the southeast part of the Barre quadrangle northeast of Ware. Here exposures of Paxton and the underlying Partridge are within one meter of each other.

Contacts of the gray granular schist and the various belts of the sulfidic white schist unit are very poorly exposed. On Wigwam Road in the southeast corner of the Ware quadrangle, the eastern contact with the gray granular schist is approached within 30 meters (100 ft) and the western contact, also with gray granular schist, within about 100 meters (300 ft). East of Hales Hill in the west-central part of the North Brookfield quadrangle, the western contact with the gray granular schist is approached within 30 meters (100 ft). In all cases, including the only area where both contacts are approached, on Wigwam Road, the sulfidic white schist unit and the gray granular schist form ridges and are separated by distinct valleys, implying the presence of sulfidic schist or other easily eroded rock between them.

Derivation

The Paxton Schist differs from the Partridge and Littleton Formations by its low aluminum and high calcium content. Garnet is very minor, sillimanite is almost unknown, and the plagioclase is usually labradorite or bytownite. As mentioned above, calc-silicate rocks are found in the Paxton Schist east of the map area. The Paxton was apparently deposited as a sediment with a lower clay content than the other schists in the area and a small to moderate carbonate content. The original rock could probably have been described by the general terms calcareous graywacke or calcareous litharenite.

The fact that the shale content was apparently low suggests a closer source or more rapid sedimentation than in the case of the Partridge and Littleton Formations. Emerson (1917, p. 62) believed that the Paxton grades eastward into the Oakdale Quartzite. If this is so, it suggests a nearby eastern source for the sediment.

Thickness

As interpreted in the cross-sections (Plate 6), the Paxton is folded into a series of synclines and anticlines, with the sulfidic white schist unit exposed in the core of the anticlines. In this interpretation, the synclines of Paxton are 340 meters across, giving a thickness for the Paxton of 170 meters (550 ft). If in fact the Paxton is a simple syncline, the unit is at least 750 meters (2500 ft) thick. The Paxton Schist in the Ware area is part of a comparatively small body of the unit (Emerson, 1917), and the main body may be considerably thicker.

LITTLETON FORMATION

Seven isoclinal synclines of the Littleton Formation are found in the Ware area, two of which are dominated by syntectonic igneous rocks (Hardwick Quartz Diorite and Coys Hill Granite), and one of which includes a large proportion of metamorphosed volcanic rocks. The Littleton Formation consists primarily of gray pelitic schist (Dl), but

Feldspar Gneiss (Dlf) and Orthopyroxene Gneiss Members (Dlo) are recognized in the eastern synclines. Because the lithology of the gray schists varies somewhat, each belt is discussed separately. The synclines in which the belts are found are shown on Plate 6.

The name is from the town of Littleton in northwest New Hampshire (Billings, 1937, p. 487-494).

Gray Pelitic Schist Member

Western part of the area. Scattered exposures of Littleton Formation are found in the hills west of Muddy Brook valley. These are interpreted to be a pair of synclines of Littleton Formation, separated from the Littleton and Hardwick that forms the eastern side of the valley by an anticline of Partridge Formation in the valley. This belt of Littleton has been traced continuously southward from areas of Littleton Formation in northern Massachusetts and southern New Hampshire (Thompson and others, 1968).

Most rocks in this part of the map area are more deformed than elsewhere in the area, and the Littleton Formation is composed largely of gneissic partially mylonitized rock or coarse granulite consisting of quartz, feldspar, and biotite (Table 7, FW-547, 1026). The sheared rock is dark purplish gray from fine biotite, and has augen of feldspar. Layers of mylonite a few centimeters wide are seen in many places. Matrix crystals in the mylonitic layers are typically only 0.01 mm across, whereas those in the mylonite gneiss range from 0.05 to 0.5 mm. Pegmatites from several centimeters to several meters thick are common in this area. Near the Monson Gneiss contact, the Littleton Formation is somewhat less mylonitic and outcrops of gray schist are found as well as gneissic mylonitized rock.

Small bodies of Hardwick Quartz Diorite are found in the Littleton Formation or at the contact between the Littleton and the Monson Gneiss. Some of the larger bodies of Hardwick are shown separately, but where sheared, the Littleton and Hardwick appear rather similar, and small bodies of Hardwick are present in the area mapped as Littleton Formation. It is felt that these bodies of Hardwick are structurally connected with the main body of Hardwick, and are found as scattered small bodies because of tectonic attenuation (Figure 21). A large body of Hardwick, 15 kilometers (9 miles) long, is found along strike to the north in the Petersham and Athol quadrangles (Figure 15) and is probably in the same syncline of Littleton.

Next to the Hardwick Quartz Diorite. West and southeast of the Hardwick pluton are a few outcrops of Littleton Formation whose extent and relationship to other units are poorly known. These have been interpreted on the map as a syncline of Littleton Formation dominated by the Hardwick Quartz Diorite pluton. This interpretation is supported by specimens from the Quabbin Aqueduct tunnel, which show identical gray schists at the east and west contacts of the Hardwick pluton, and by observations in the Templeton area to the north, where the Littleton has been seen near the eastern contact of the Littleton Hardwick (D'Onfro, personal communication, 1973).

For the most part the schists are typical bedded pelitic schists of the Littleton Formation (Table 7, FW-161). A nodule containing small amounts of mafic minerals was found in a large outcrop near the dam in

Table 7. Estimated modes of the gray-weathering schists of the Littleton Formation.

	Western part of area		Hardwick syncline	Ragged Hill syncline		Big garnet unit			Prouty Road syncline		Gilbert Road syncline		Mafic Nodule
	FW-547	1026	161	116	154	95	122	579	139	751	7	810B	238C*
Quartz	23	58	14	30	15	55	11	45	32	20	40	50	60
Plagioclase	15	5 ol#	1	4		26 An46	1 An27			40 An30	10 An34		26 An68
Orthoclase	10	20	18	20	5		20	20	30	1	20	20	
Biotite	35	10	15	15	15	15	35	8	7	9	10	15	
Garnet	4	3	35	20	20	3.5	10	15	15	25	14	5	7
Sillimanite	12	2	15	10	23		20	10	13	4	5	10	
Cordierite					20		2		1				
Magnetite	1						0.5						1
Ilmenite		1	1.5	1	2	0.5		1.5	2		1	tr	
Graphite			0.5	tr			0.5	0.5		1	tr		
Zircon				tr	tr	tr				tr	tr	tr	tr
Apatite						tr							
Secondary Chlorite	tr	1											

*238C also contains 4 orthopyroxene, 1 cummingtonite, 1 hornblende.

#Plagioclase compositions determined as described in Table 2.

List of specimens in Table 7.

FW-547 Gray fine-grained biotite-garnet-sillimanite schist.
NW 0.35 mi south and 0.26 mi east of the bend at 805 ft elevation in Ware-Greenwich Road.

1026 Mylonitized gray schist with 6 mm feldspar augen.
Winsor Dam SE Very small 660 ft bump 0.67 mi east of Ware Center.

161 Gray sillimanite schist with 2 mm garnet.
C West side of Lower Road 0.15 mi north of main intersection with Goddard Road.

116 Dark gray slabby biotite-garnet schist with 1 cm feldspar pods.
C 200 ft east of Sibley Road 0.08 mi north of Gilbertville Road.

154 Gray schist rich in sillimanite and 1/2 cm garnet.
SC South end of Ragged Hill 0.18 mi north of intersection of Ragged Hill and Pierce Roads.

95 Gray fine-grained slabby biotite-garnet schist.
C 0.45 mi north of Gilbertville Road 0.2 mi east of Tucker Road.

122 Gray schist, rather massive, rich in sillimanite and 1-2 cm garnet.
C Knob in field 0.1 mi southwest of intersection of Tucker and Gilbertville Roads.

579 Massive gray- to red-weathering garnet-sillimanite-biotite schist.
C 0.25 mi south of Unitas Road 0.23 mi east of intersection with Sibley Road.

139 Rather massive gray schist rich in sillimanite and 1/2 cm garnet.
SC North side of Ragged Hill Road 0.07 mi east of the easternmost of three forks of Lamberton Brook which cross the road.

751 Gray garnet-biotite-sillimanite schist with 2 mm garnets.
Warren NC East of Cutler Road, 0.3 mi south of north edge of quadrangle.

7 Well bedded gray garnet-sillimanite schist.
SC Gilbert Road 0.08 mi south of powerline.

810B Well bedded gray biotite-sillimanite-garnet schist.
Barre SW (Outside map area) Elevation 740 ft on Galloway Brook north of Joyce Cemetery.

238C Hard medium-grained nodule of mafic gneiss in gray sillimanite schist.
SW Near east abutment of dam in town of Ware.

Ware (Table 7, FW-238C).

Ragged Hill syncline. Well bedded gray schists are found north of Coys Hill, on the southwest slopes of Ragged Hill and in the western part of the Sibley Road-Unitas Road area. These are interpreted to be a belt of Littleton Formation which pinches out to the south, although the syncline continues, as indicated by small bodies of Littleton found southward in the same structural position. The Littleton Formation in this syncline is rich in garnet and sillimanite (Table 7), and resembles the Littleton in the Prouty Road and Gilbert Road synclines. One specimen (FW-154, Table 7) is the most cordierite-rich rock known in the area.

Big garnet belts. A variety of Littleton Formation informally called the big garnet unit lies west of the Coys Hill Granite. There are two narrow belts of this rock. One, less than 20 m (65 ft) wide, is at the western contact of the Coys Hill Granite throughout most of the map area. This is assumed to be part of a syncline containing Littleton Formation and Coys Hill Granite which is dominated by the Coys Hill. The main syncline of the big garnet unit is just west of the first, and separated from it by a narrow anticline of Fitch Formation and, locally, Partridge Formation. This big garnet syncline terminates southward in a fold hinge on the east side of Ragged Hill in the central part of the area. It continues from there northward across Unitas Road and becomes very narrow in the northeast part of the area. In the Templeton quadrangle, however, about 25 km (15 mi) north-northeast of the Ware area, reconnaissance mapping of the same horizon by Robinson (personal communication, 1971) shows the two belts of big garnet unit separated by the Fitch Formation at the western contact of the Coys Hill Granite, the same relationship and width of units as in much of the Ware area.

The big garnet unit is a very aluminous schist, with a high content of garnet and sillimanite (Table 7). Its distinctive characteristic is the presence of areas of rock with garnets 1 cm and more in diameter, surrounded by a light colored rim consisting largely of potassium feldspar (Figure 8). This feature is best seen in a large outcrop in a field 150 m (500 ft) southwest of the intersection of Gilbertville and Tucker Roads in the central part of the area (Table 7, FW-122).

The big garnet unit is rather similar in composition to the Littleton Formation in the Prouty Road syncline, but sillimanite is more conspicuous in the latter and the feldspathic rims around the garnets are much more common in the big garnet Littleton.

Prouty Road syncline. This is the first syncline of Littleton Formation east of the Coys Hill Granite and the second easternmost syncline of Littleton in the area. Narrow belts of Partridge Formation separate it from the Gilbert Road syncline on the east and the Coys Hill Granite on the west. It is characteristically rich in sillimanite. In the southern half of the area, the syncline is divided down the middle by the Feldspar Gneiss and Orthopyroxene Gneiss Members, but the rocks on either side of this division are virtually identical. In the northern part of the area, the rocks are too poorly exposed to know what the relationship with the gneisses is, but the syncline appears to contain only the Feldspar Gneiss Member. The gneisses appear to pinch out to

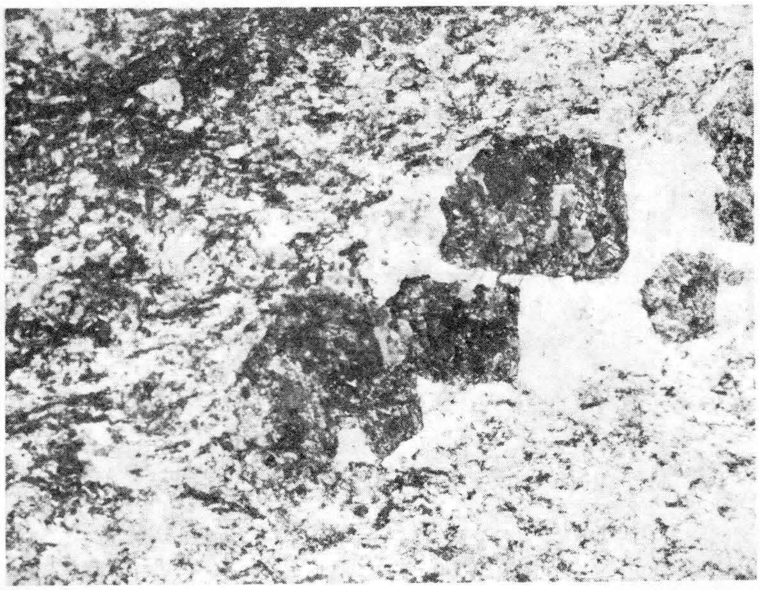


Figure 8. Big garnet unit of the Littleton Formation, showing the feldspar-rich partial rims on the garnets. About twice actual size.

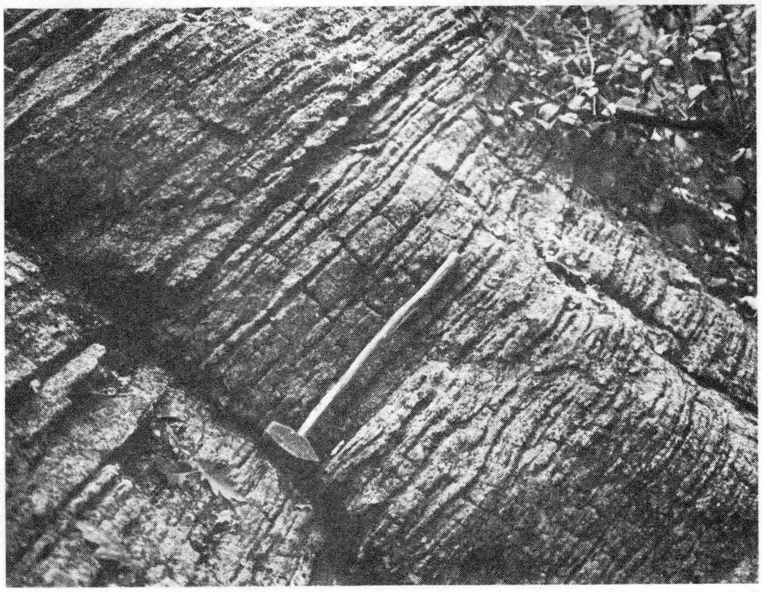


Figure 9. Well bedded Littleton Formation schist in the Gilbert Road syncline, exposed on the hill northwest of Wickaboag Pond in the southern part of the map area.

the south, because they are not found in the Warren quadrangle (Pomeroy, in press).

The Prouty Road syncline contains gray-weathering, massive garnet-sillimanite schist (Table 7). It is not much different from schist in the Gilbert Road syncline, but bedding is not commonly identifiable, and in many places the garnet and sillimanite are conspicuous in hand specimen. The garnets are from a few to several millimeters across, and the bundles of sillimanite crystals give a silky sheen to the rock.

This syncline is on strike with, and identical to, the eastern part of the Mt. Pisgah Formation, as shown to the south in the Warren quadrangle by Pomeroy (in press).

<u>Gilbert Road syncline</u>. This is the easternmost syncline of Littleton in the Ware area. The rock is a well bedded, gray-weathering garnet-sillimanite schist. Bedding, with thicknesses averaging 6-8 cm, is commonly present, though it is rarely possible to determine tops (Figure 9). Typically, 5 to 15 per cent each of garnet and sillimanite are present, and somewhat more than that of biotite. The rock contains about 20 per cent orthoclase, and less than 10 per cent plagioclase (Table 7). Exposures of the Feldspar Gneiss Member have been found at the eastern contact in the northeast part of the area.

This syncline is on strike with, and identical to, a belt of rock in the Warren quadrangle to the south, designated <u>husg</u> of the Hamilton Reservoir Formation by Pomeroy (in press). Pomeroy's map can be interpreted to show this syncline extending the length of the Warren quadrangle. The syncline has also been identified as far north as 4 km (2 3/4 mi) north-northeast of the northeast corner of the Ware quadrangle, giving a minimum length for the syncline of 32 km (20 mi). It has been tentatively identified in the southern part of the Templeton quadrangle (Robinson, personal communication, 1974).

Feldspar Gneiss and Orthopyroxene Gneiss Members

These are two rock types which occur together in the center of the Prouty Road syncline. They are not interbedded within an outcrop, but instead large masses of one type or the other occur alternately along strike, or side by side in a few places. Some interbedding is found just north of Ragged Hill Road, and small lenses of Orthopyroxene Gneiss are found in the Feldspar Gneiss Member just north of Unitas Road. The gneisses appear to die out to the south, because they are not reported in the Warren quadrangle by Pomeroy (in press). However, rocks resembling the Feldspar Gneiss Member have been seen in the central part of the Warren quadrangle on Bemis Road 0.6 km (0.4 mi) north of the turnpike. Just north of the map area the Feldspar Gneiss Member is seen in Cooks Canyon south of the town of Barre, so the belt continues at least that far. The Prouty Road syncline appears to be dominated by the Feldspar Gneiss Member in the northern part of the map area. Feldspar gneiss is also found discontinuously at the eastern contact of the Prouty Road and Gilbert Road belts.

The gneisses are believed to be metamorphosed mafic and felsic volcanics because of the restriction of the main belt to a specific stratigraphic position, the interbedding of Feldspar Gneiss with gray schist at the eastern contact of the main belt, and the discontinuous pattern, which suggests alternate deposition of the two rock types.

<u>Orthopyroxene Gneiss</u>. This rock is coarse (1/2 - 1 cm crystals), weakly foliated and brown-weathering. The brown crumbly rounded appearance of weathered outcrops is characteristic. The rock consists primarily of labradorite, orthopyroxene, and cummingtonite in very variable proportions. Biotite and magnetite are common, and hornblende and garnet are found in some specimens (Table 8).

A wet chemical analysis of this rock and electron microprobe analyses of the minerals are given in Table 17. Emerson (1917, p. 213-214) included the Orthopyroxene Gneiss Member east of Tucker Road (Figure 4) in the central part of the area with the ultramafic rock south of New Braintree in his discussion, and the analysis he gives (p. 213) is of the Orthopyroxene Gneiss. The text of Emerson's report incorrectly locates the outcrop as south of the town of New Braintree, but the footnote to the analysis given by Emerson on page 213 correctly locates the outcrop as 2 1/2 miles southwest of New Braintree, which agrees with Emerson's (1917) map and corresponds to the Orthopyroxene Gneiss Member east of Tucker Road in the vicinity of FW-307.

Small bodies of a rock lithically similar to the Orthopyroxene Gneiss Member are found in the Unitas Road and Lamberton Brook anticlines of the Partridge Formation (Table 3). Some of these are shown on the map.

<u>Feldspar Gneiss</u>. This is a light colored rock, with a small percentage of dark minerals and a strong foliation. It is composed of quartz and orthoclase, with very variable amounts of microcline and plagioclase, a biotite content varying from 1 to 15 per cent, and, in places, garnet and oxides (Table 8). A distinctive variety, found at

Table 8. Estimated modes of the Feldspar Gneiss and Orthopyroxene Gneiss Members of the Littleton Formation.

Feldspar Gneiss Member

	FW-399B	616A	728
Quartz	29	45	25
Plagioclase	60 ol*	2 ol	2 ol
Orthoclase	4	11	45
Microcline		40	10
Biotite	6.5	1	13
Garnet		1	
Magnetite	tr		
Ilmenite	0.5		1
Muscovite		tr	4
Sillimanite		tr	
Zircon			tr
Chlorite			tr

*Plagioclase compositions determined as described in Table 2, except FW-307, where composition was determined by electron microprobe analysis (Table 19).

Orthopyroxene Gneiss Member

	FW-307	612	665	722
Quartz		1	tr	4
Plagioclase	15 An48*	28 An55	60 An55	55 An52
Orthopyroxene	62#	60		3
Cummingtonite	15	8	36	7
Hornblende	3		1	
Biotite	5	2	1	13
Garnet				15
Magnetite		1	2	2
Apatite			tr	1
Zircon	tr	tr		tr
Chlorite	tr			
Sphene			tr	

#Composition estimated from 2V as En70 in all specimens.

List of specimens in Table 8.

FW-399B Medium to coarse grained quartz-biotite-feldspar gneiss, light colored.
EC 860 foot knob 0.8 mi south along ridge from sharpest bend in Unitas Road about 0.2 mi west of West Road. This is the first ridge west of West Road, east of the large cliff.

616A White quartz-feldspar gneiss with scattered garnet up to 2 cm across.
EC East slope of ridge 0.75 mi south along ridge from sharpest bend in Unitas Road. Vicinity of Fw-399.

728 Medium grained foliated quartz-feldspar-biotite gneiss.
SE 0.02 mi south of New Braintree-West Brookfield town line 0.27 mi east of Tucker Road from a point about 0.9 mi south of Gilbertville Road.

307 Massive unfoliated coarse brown-weathering orthopyroxene gneiss.
C Knob 0.06 mi south of BM 855 east of Tucker Road.

612 Coarse unfoliated brown-weathering orthopyroxene gneiss with poikilitic orthopyroxene crystals to 15 mm.
EC Isolated 800 foot knob 0.15 mi west of Padre Road 0.27 mi southwest of intersection with West Road.

665 Medium grained weakly foliated cummingtonite amphibolite.
NE Ridge just northeast of sharpest bend in Unitas Road.

722 Coarse unfoliated plagioclase-garnet-biotite-cummingtonite-orthopyroxene gneiss.
SC 0.2 mi west of high point on Prouty Road.

the eastern contact of the main belt with the gray schists of the Littleton Formation, has almost no dark minerals except for widely scattered garnet up to 2 centimeters in diameter (Table 8, FW-616A).

Within the Feldspar Gneiss Member, particularly in the area south of Unitas Road in the central part of the area (Figure 4), are coarse quartz-feldspar-biotite granulites (Table 8, FW-399B) and pegmatites containing biotite. Biotite is ubiquitous, and distinguishes the pegmatites from the simple quartz-feldspar pegmatites found elsewhere in the map area. The granulites and pegmatites are presumed to be the result of melting of the Feldspar Gneiss Member.

Feldspar gneisses resembling those within the Prouty Road syncline are found in other structural positions. One body is at the eastern contact of the Prouty Road belt with the Partridge Formation in the central part of the area (Table 8, FW-728). This rock contains a few per cent of muscovite, suggesting that it may be of later, intrusive origin, although it is very similar to the Feldspar Gneiss Member in the center of the syncline. Another body of feldspar gneiss is found at the eastern contact of the Gilbert Road belt in the northeast part of the area, and others, too small to show on the map, are found in the Partridge Formation just west of the Littleton Formation on the hill west of the north end of Wickaboag Pond in the southern part of the area. These gneisses are all very similar, and it is difficult to explain their varied stratigraphic positions. It may well be that they are of different origins. Orthopyroxene gneisses are not associated with these feldspar gneisses outside the main belt.

Lower Contact

Contacts of the Littleton Formation in the western half of the map area are very poorly exposed, with some exceptions. Contacts are approached within a few meters (10-20 ft) south of Bacon Street, southwest of the town of Ware (Figure 4), and in some places on and near the Monson Gneiss contact. The contacts of the narrow belt of Littleton Formation in the Ragged Hill syncline are approached very closely north of Route 9, but the Littleton and Partridge Formations are so similar to each other near the contact that the contact cannot be placed with certainty. At a distance of several meters (a few tens of feet) from the contact, the units are easily distinguished, and at a greater distance from the contact the differences are even more marked.

The contact of the Littleton Formation in the big garnet syncline with the Fitch Formation is approached to within 1-2 m (5 ft) on the east side of Ragged Hill. Here there is a puzzling transition through an intermediate unit which is sulfidic but is otherwise identical to the big garnet Littleton. Possibly some sulfide from the Fitch Formation has been introduced into the gray schists here. The big garnet unit is seen in contact only with the Fitch Formation or the Coys Hill Granite, except in the northeast part of the map area, where it appears to be in contact with the Partridge Formation.

Contacts of the two eastern belts of Littleton Formation with the Partridge Formation are not exposed, but are approached within several meters (a few tens of feet) in a few places. In the central part of the Warren quadrangle, south of the map area, the west contact of the

Gilbert Road belt is approached within one meter on a telephone line east of Bemis Road. In all cases, the contacts appear to be sharp. No additional rock types were seen at the contact, with the exception of discontinuous bodies of the Feldspar Gneiss Member along the eastern contacts of the Littleton Formation in the Prouty Road and Gilbert Road synclines.

The main belt of the Feldspar Gneiss and Orthopyroxene Gneiss Members lies entirely within the Prouty Road syncline of the Littleton Formation and the contact is approached within several meters (a few tens of feet) in a few places. The eastern contact of the Feldspar Gneiss with gray schists of the Littleton is exposed south of Unitas Road in the central part of the area. The contact consists of an interval of about a meter containing interlayered gray schist and feldspar gneiss.

Derivation

The Littleton Formation consists of metamorphosed shale and quartz-rich sand, the two rock types usually alternating in layers a few centimeters thick (Figure 9). Graded bedding is found in a few outcrops, suggesting deposition in rather deep water (Blatt and others, 1972, p. 15, 210). The broad area over which the Littleton is found (Billings, 1956; Thompson and others, 1968) indicates deposition during a time of widespread consistent conditions in the region.

Thickness

The greatest thickness of Littleton in the area, taken as half of the width measured in cross-section D-D' across the Prouty Road syncline, is 200 m (700 ft). The Feldspar Gneiss and Orthopyroxene Gneiss Members vary from 0 to 120 m (0-400 ft).

INTRUSIVE IGNEOUS ROCKS

The ages of the intrusive igneous rocks of the Ware area are interpreted to be as follows:

Phlogopite-olivine hornblendite and New Braintree Gabbro -- Ordovician, pre-tectonic.

Coys Hill Granite -- Early Devonian, pre-tectonic or early syntectonic.

Hardwick Quartz Diorite and gneiss of Ragged Hill -- Devonian, early syntectonic.

Goat Hill Diorite -- Devonian, late in the tectonic sequence.

Diabase -- Triassic or Jurassic, post-tectonic.

A striking feature of some of the large igneous bodies of the Ware area is the way in which they are confined to stratigraphic and structural horizons. This is not simply a matter of contacts becoming parallel because of extreme folding, as the gneiss of Ragged Hill can be seen to cross-cut units, although it is generally parallel to structures. In contrast, the Coys Hill Granite is never seen to be cross-cutting, and very thin units next to the Coys Hill can be followed for long distances. The Coys Hill Granite and Hardwick Quartz Diorite are interpreted to lie within, and comprise most of, synclines of the Devonian Littleton Formation. However, small Partridge Formation inclusions in the Hardwick are not easily explained.

PHLOGOPITE-OLIVINE HORNBLENDITE

A small ultramafic body (um) is found in the Partridge Formation east of the intersection of Gilbertville and West Brookfield Roads 2 km (1.2 mi) south of the village of New Braintree in the east-central part of the area. It is 60m (200 ft) thick and at least 400m (1300 ft) long.

Lithology

The ultramafic rock is a phlogopite-olivine hornblendite, composed primarily of pale brown hornblende, with pale brown phlogopite, olivine, pyrite and orthopyroxene. The rock is massive, unfoliated and coarse grained. The largest hornblende and phlogopite crystals are 20 mm across and poikilitic

Table 9. Estimated modes of the phlogopite-olivine hornblendite.

Hornblende	78	
Biotite	12	
Olivine	7	approximately Fo 70*
Orthopyroxene	1	approximately En 75*
Pyrite	2	
Iddingsite (?)	tr	alteration of olivine

*Estimated optically from the 2V.

Derivation

Ultramafic rock is believed to have originated as either an intrusion or as an obducted piece of oceanic crust (for instance, Stevens and others, 1974). The field evidence in the Ware area is too poor to permit comment on the probable origin of the New Braintree body. The only evidence for the origin is negative, that the ophiolite suite characteristic of oceanic crust is not found, but it is surrounded by a schist which was originally black shale like many deep ocean sediments.

Contacts

The hornblendite has a tabular shape, and its eastern contact is with a pegmatite sill which forms the top of the hill. The western contact is with the sulfidic schists of the Partridge Formation. It is 60 m (200 ft) thick and at least 400 m (1300 ft) long. North and south contacts of the hornblendite are not seen nor is it known what is east of the pegmatite, so the extent of the body is not known. It appears that the hornblendite is exposed here only because the pegmatite locally protected it from being eroded as much as the surrounding rock. It should be emphasized that outcrop is very poor in this area, and in particular that no outcrop is found between the hornblendite and the New Braintree Gabbro and amphibolite. It is possible that all these mafic rocks are associated.

NEW BRAINTREE GABBRO

In the low hills northwest of the town of New Braintree in the east-central part of the area is a body of gabbro with some amphibolite. The body is irregularly shaped and is approximately 400 by 1500 meters (1500 by 5000 ft).

Lithology

The gabbro (nbg) consists of 30-50 per cent plagioclase (An 50-57) and 30-57 per cent hornblende, with several per cent of biotite, cummingtonite or clinopyroxene, and one per cent oxides (Table 10). The hornblende is light-brown in thin section, and the biotite is medium brown. One specimen contains 5 per cent each of orthopyroxene and olivine (Table 10, FW-974). The olivine crystals are partially surrounded by orthopyroxene which is enclosed by hornblende. The gabbro is unfoliated and rather coarse, the plagioclase laths being up to 1/2 x 3 mm. Amphibolite (a) is found in the western part of the gabbro body. It consists almost entirely of hornblende (brown-green in thin section) and plagioclase, and has a metamorphic texture altogether different from that of the gabbro (Table 10, FW-632A). This amphibolite is interpreted to be a sheared metamorphosed border phase of the gabbro. The gabbro in general has been subject to metamorphic hydration, but only the outer part has had a major textural change.

Contacts

The relationship of the gabbro to the surrounding Partridge

Table 10. Estimated modes of the New Braintree Gabbro.

	Gabbro			Amphibolite
	FW-633	636	974	632A
Plagioclase	50 An57*	47 An50	30 An51	50 An38
Hornblende	30 tn#	40 lyb	57 tn	47 mbg
Cummingtonite	10			
Orthopyroxene		10	5.5	
Olivine			5	
Biotite	9	2	1	1
Magnetite	0.5		1	
Ilmenite	0.5	1		2
Apatite				tr
Zircon				tr
Spinel			0.5	

*Plagioclase composition determined by maximum extinction angles of albite twins.

#Hornblende color: tn-tan, lyb-light yellow-brown, mbg-medium brown-green.

List of specimens.

FW-633 Coarse unfoliated hornblende-cummingtonite-biotite gabbro.
EC 0.15 mi west of Hardwick Road 0.75 mi north of New Braintree.

636 Coarse unfoliated gabbro with ophitic hornblende to 1 cm long.
EC 0.16 mi west of Hardwick Road 0.55 mi north of New Braintree.

974 Coarse brown-weathering unfoliated hornblende-pyroxene-olivine gabbro.
EC 0.35 mi west of Hardwick Road 0.42 mi north of New Braintree.

632A Strongly foliated hornblende-plagioclase amphibolite.
EC 0.14 mi west of Hardwick Road 0.83 mi north of New Braintree.

Formation is poorly known. Contacts with the schist are approached within about 60 m (200 ft) at the south and northeast sides of the body, but contacts in other directions are not even crudely approached. On the map, contacts are drawn rather arbitrarily outside the area of gabbro outcrop.

Exposures are few outside the New Braintree hills, particularly to the south. It should be noted that there is no outcrop between the New Braintree hills and the hornblendite 2 kilometers (1 1/2 mi) to the south, and that it is possible that these units are connected in some kind of mafic complex.

Contacts with the thin layer of Partridge schist (Opl) are sharp. This schist is well bedded and red- to gray-weathering, very different from the sulfidic schists found at the south contact of the gabbro. Graded bedding in this schist indicates tops to the east.

COYS HILL GRANITE

The Coys Hill Granite underlies a narrow diagonal zone across the Ware area from southwest to northeast. It is normally 0.35 km (0.2 mi) across but widens to 1.1 km (0.7 mi) in the south. It continues northward, parallel to other structures, at least as far as Baldwinville, Massachusetts (Emerson, 1917; Robinson, personal communication, 1973) and may be continuous with bodies of the Kinsman Quartz Monzonite in New Hampshire (Figure 15). It extends south to within 6 km (4 mi) of Connecticut (Emerson, 1917). South of the Ware quadrangle, large bodies of diorite are present within and adjacent to the Coys Hill Granite, reducing its width (Pomeroy, in press). Emerson (1917) mapped this diorite as Hardwick Quartz Diorite although he showed no connection on the map. Southwest of the Ware quadrangle, the gneiss of Ragged Hill widens and the rocks between it and the Coys Hill thin to almost nothing, with the result that the gneiss has been mapped as a fine grained phase of the Coys Hill in this area (Emerson, 1917; Peper, 1966; Pomeroy, in press).

The name is derived from numerous exposures on the north and west sides of Coys Hill in the southern part of the area (Emerson, 1898, p. 319).

Lithology

The Coys Hill Granite (ch) is a distinctive unit, strongly foliated, with very large (1-15 cm) microcline phenocrysts and 3-10 mm garnets in a dark matrix of biotite, quartz and feldspars (Figure 10). The feldspar phenocrysts have rounded corners and tapered ends, and are aligned parallel to foliation. In many places the crystals are crushed and strung out. Despite the strong foliation, the Coys Hill forms large, massive outcrops.

Most of the Coys Hill is a granite with microcline phenocrysts, but in areas where the phenocrysts are sparse or absent, it may be a quartz monzonite or quartz diorite (Table 11). It contains an average of 40 per cent potassium feldspar, commonly microcline, less commonly microcline microperthite or orthoclase, 15 per cent plagioclase (An 30), 30 per cent quartz, 10 per cent biotite, 4 per cent garnet, 1 per cent oxides and trace amounts of apatite and zircon. The biotite is

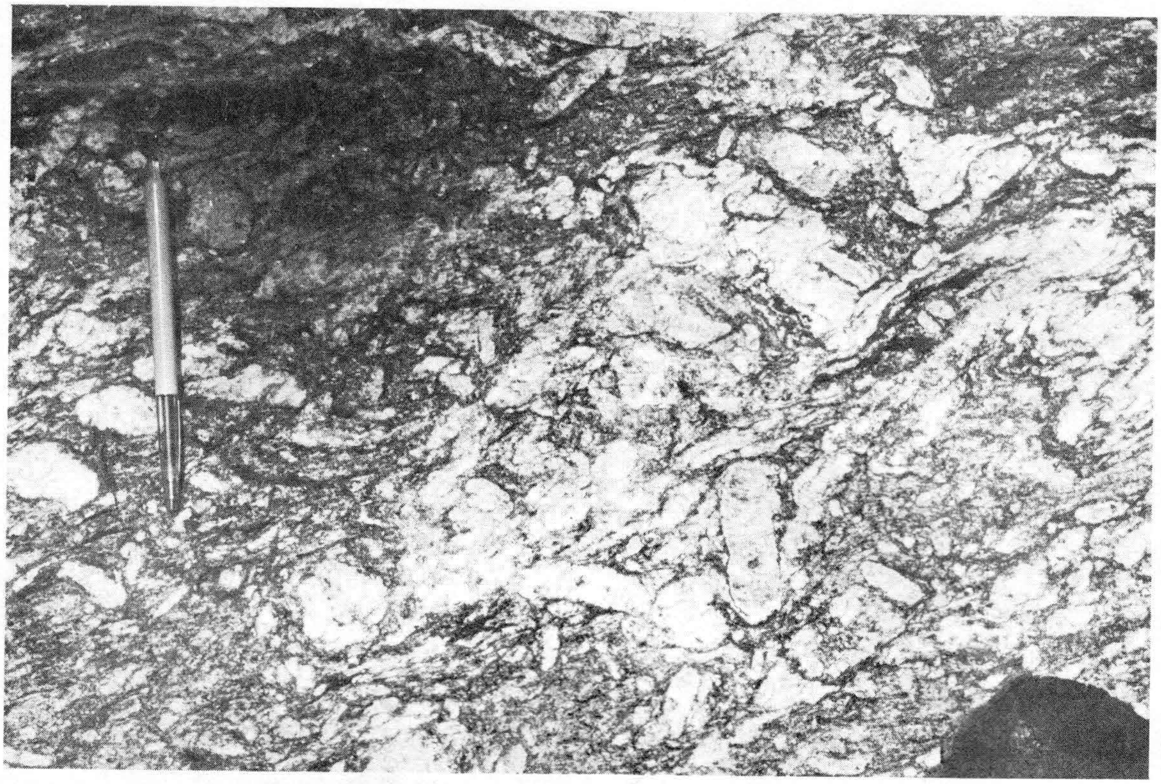


Figure 10. Coys Hill Granite with typical folding, Unitas Road area.

Figure 11. Hardwick Quartz Diorite. Sawed surface of a hand specimen from the cliff west of Mara Road in the central part of the map area.

Table 11. Estimated modes of the Coys Hill Granite.

	FW-14	192	196	244A	250	672
Quartz	40	7	35	35	30	30
Plagioclase	25 An28*	4 An34	25 An35	40 An39	10 ad	10 An28
Orthoclase		80	30	tr		
Microcline	20		5		43	50
Biotite	10	3	3	15	10	5
Garnet	4	5	2	9	4	5
Magnetite				1		
Ilmenite	1	1	tr		tr	tr
Apatite	tr	tr	tr	tr	1	tr
Zircon	tr	tr	tr	tr	tr	tr
Secondary Muscovite					2	

Mafic Gneisses

	FW-657	674	913
Plagioclase	65 An45*	54 An41	55 An41
Biotite	2	5	0.5
Hornblende	15	40	25
Diopside	1	0.5	
Orthopyroxene	15		14
Magnetite		tr	0.5
Ilmenite	1.5		3.5
Apatite	0.5	0.5	1.5
Zircon			tr

*Plagioclase compositions determined as described in Table 2.

List of Specimens in Table 11.

FW-14 Strongly foliated porphyritic quartz monzonite with 2-6 cm feldspar crystals.
SC South of Woods Road 0.28 mi east of base of Ragged Hill.

192 Granite porphyry, 2-3 cm orthoclase crystals form 80% of rock.
SW 950 foot knob just south of northeast-pointing corner of Ware-West Brookfield town line. On Coys Hill.

196 Strongly foliated fine grained granite porphyry.
SW On Coys Hill. Knob 0.07 mi south of intersection of Prendiville Road and powerline.

244A Moderately foliated porphyritic quartz diorite.
SW On Coys Hill. North end of ridge 0.11 mi west of intersection of Prendiville Road and powerline.

250 Strongly foliated porphyritic granite.
NE 0.28 mi east of Prouty Road at 870 foot elevation about 0.65 mi south of north border of Ware quadrangle.

672 Foliated porphyritic granite.
SC On Coys Hill. 0.7 mi north of south boundary of Ware quadrangle 0.34 mi east of 72°12'30".

657 Weakly foliated, brown-weathering, coarse-grained hornblende-orthopyroxene gneiss.
SW 0.22 mi east of Prendiville Road 0.12 mi south of powerline.

674 Massive unfoliated medium-grained amphibolite.
SC On Coys Hill. 0.79 mi north of south boundary of Ware quadrangle 0.22 mi east of 72°12'30".

913 Massive fine- to medium-grained hornblende-orthopyroxene gneiss.
SW On Coys Hill. 0.07 mi east of Prendiville Road 0.38 mi south of intersection with Coys Hill Road.

brown to red-brown in thin section, generally not so red as in the schists and gneisses of the area, but distinct from the green-brown biotite of the Hardwick Quartz Diorite. The garnet is conspicuous because of its size (several millimeters in diameter), despite its small amount. The size and percentage of feldspar phenocrysts is highly varied. They range from 1 to 15 centimeters long, usually 2-6 centimeters, and make up 15 to 80 per cent of the rock. They may be absent where the rock is strongly sheared. The small potassium feldspar crystals found in all specimens are partly the result of crushing of the larger ones.

Belts of hornblende-pyroxene gneiss (chm) are found in the center of the Coys Hill Granite in the southern part of the area. A small body of mafic gneiss is also found in the northeast, and there is a specimen of mafic gneiss in the collection of Coys Hill specimens from the Quabbin Aqueduct tunnel. The gneiss in the south is composed primarily of andesine, hornblende, and orthopyroxene (Table 11, FW-657, 674, 913). Minor amounts of biotite and diopside are present. The contact with the Coys Hill Granite is sharp, with a little interfingering, and no other rock types are present at or near the contact.

A variety of origins have been suggested for the Kinsman Quartz Monzonite of New Hampshire, to which the Coys Hill Granite is related. These possible origins are referred to by Thompson and others (1968, p. 208), who suggest that the Kinsman may be mobilized metamorphosed ignimbrite masses in the Littleton Formation similar to those found in the Devonian in central Maine. The thin elongate form and strata-bound occurrence offer support to this theory. The mafic gneisses could be a mafic volcanic layer deposited above the typical Coys Hill Granite and now found in the core of the Coys Hill syncline.

If the Coys Hill Granite is a metamorphosed volcanic rock, it is in a stratigraphic position similar to the Feldspar Gneiss and Orthopyroxene Gneiss Members of the Littleton Formation, and it is possible that they are all part of the same volcanic series. However, the rocks are very different in composition and texture, and such an inference is not warranted on the basis of present data.

Contacts

Contacts of the Coys Hill Granite with units to the east and west are exposed in a few places, and approached within several meters (a few tens of feet) in several places. Where exposed, the contacts are sharp. The Partridge Formation is found within 15 meters (50 ft) of the western exposure of the Coys Hill Granite in the northern part of the area. Except in the north, the big garnet unit of the Littleton Formation is the unit next to the Coys Hill at the western contact, and the next unit west of that is the Fitch Formation. The same relationship is found at the western contact in the Templeton quadrangle, 25 km (15 mi) north-northeast of the Ware area by Robinson (personal communication, 1973). The same units may have been present at the eastern contact before folding, but now the Fitch Formation is seen only at scattered intervals along this contact. Normally the unit present at the eastern contact is the Partridge Formation of the Unitas Road anticline. Scattered occurrences of the gneiss of Ragged Hill are also found along the eastern contact, commonly associated with the Fitch Formation.

The Coys Hill Granite appears to be confined to a particular stratigraphic horizon, lying above the big garnet unit of the Littleton Formation and forming an overturned isoclinal syncline in the Ware area. The near-absence of the big garnet unit and the Fitch Formation at the eastern contact is interpreted as structural, rather than stratigraphic thinning because the gneiss of Ragged Hill, an intrusive unit, is also present discontinuously.

The Coys Hill Granite is in a body 120 to 600 meters thick (400 - 2000 ft) as measured in cross-section. Assuming that it forms a syncline and the mafic gneiss in the southern part of the area marks the center of the syncline, the unit is 500 meters (1600 ft) thick.

HARDWICK QUARTZ DIORITE

This unit forms an elongate wedge which occupies almost a third of the Ware quadrangle. It narrows considerably in the southwest and is roughly 20 m (60 ft) wide in the Palmer quadrangle. It continues northward to just beyond the New Hampshire border (Emerson, 1917; Mook, 1967a; 1967b, p. 279; Thompson and others, 1968). North and northeast of the Hardwick, several smaller bodies of a similar unit, the Spaulding Quartz Diorite, are found in southern New Hampshire (Fowler-Billings, 1949), as is discussed under CORRELATION.

The name is derived from Hardwick township, in the northern part of the Ware area. It was called the Hardwick Granite by Emerson (1898, p.239).

Lithology

The Hardwick Quartz Diorite (h) is typically a strongly foliated, medium- to dark-gray biotite-rich gneiss which forms massive to slabby outcrops. White to pink phenocrysts 3 to 5 mm long are characteristic and are almost invariably deformed, with irregular outlines. In thin section many of the "phenocrysts" prove to be clusters of quartz and feldspar rather than single crystals. The presence of these phenocrysts and clusters in the biotite-rich matrix gives the rock a mottled look (Figure 11). It is typically a quartz diorite (Table 12), although in several areas the potassium feldspar content is sufficient to call it a granodiorite, or, rarely, a quartz monzonite (Table 13). In the extreme northern part of the Ware quadrangle, microcline phenocrysts are present, increasing the potassium feldspar content to that of a granite.

Plagioclase, the dominant mineral (30 to 50 per cent) is andesine, An 35-40. The feldspar phenocrysts are commonly plagioclase, but the largest ones (over 5 mm), where present, are microcline. Quartz is commonly 15 to 25 per cent. Biotite is normally the only mafic mineral, typically 20 to 35 per cent of the rock. It is greenish brown in thin section, in contrast to the reddish brown biotite of the other igneous and metamorphic rocks of the area. The green color indicates a high content of ferric iron relative to titanium (Deer and others, 1966, p. 213). The biotite may be reddish in the general vicinity of contacts

Table 12. Estimated modes of quartz diorites of the Hardwick Quartz Diorite.

	FW-35B	39	238A	273	386A	476	479	496	507	509A	527	538A	540	541
Quartz	39	40	45	15	15	14	30	53	13	17	26	20	10	15
Plagioclase	45 An30*	30 An33	25 An36	40 An47	50 An39	50 An37	40 An37	35 An36	40 An36	45 An30	50 An34	29 An29	45 An36	45 An36
Orthoclase				5		8		1	tr	5				2
Microcline	5	3									5			
Biotite	9	25	15	36	30	22	29	9	40	30	15	50	27	35
Hornblende						1							15	0.5
Garnet	1		14.5				0.5							
Apatite		0.5		1	2.5	1	tr		3	1	0.5	tr	1	1
Sphene				1	tr	2			2	1		0.5	0.5	1
Magnetite	0.5	1	0.5	1	1	1	0.5	1	1	0.5	1	0.5	1.5	tr
Zircon	tr	tr	tr	tr	0.5	tr	tr	tr	tr		tr		tr	
Allanite				1	1	1			1	0.5			tr	0.5
Secondary Muscovite	0.5	0.5	tr					1			2			
Secondary Chlorite	tr										0.5			

*Plagioclase compositions in this table and Table 13 determined by maximum extinction angles of albite twins.

Table 13. Estimated modes of granites, quartz monzonites, granodiorites and diorites of the Hardwick Quartz Diorite.

	Granite		Quartz Monz.		Granodiorite					Diorite	
	FW-313	314	38	62B	62C	64	265A	265B	275	60	532
Quartz	15	20	19	20	15	25	20	16	20	1	2
Plagioclase	20 An28	15 An33	25 An37	26 An31	30 An30	40 An35	45 An38	30 An38	40 An32	55 An40	43 An50
Orthoclase			21	30	15	10	10	15	5	1	
Microcline	45	50							6		
Biotite	18	12	30	20	30	20	22	27	25	35	40
Hornblende					6			7		5	12.5
Apatite	tr	1	2	2	1.5	1	1	1	1	2	0.5
Sphene			1		1		0.5	3	1		2
Magnetite	0.5	1	2	1	1	1	1	1	1	1	tr
Zircon	0.5	tr		tr	0.5	tr	tr		tr	tr	tr
Allanite		tr	tr	1			0.5		1		
Secondary Muscovite	1	1				2	tr		tr		
Secondary Chlorite		tr				1			tr		

List of specimens in Table 12.

FW-35B Medium-grained foliated porphyritic quartz diorite.
C Cliff just west of Mara Road about 0.2 mi south of Gilbertville Rd.

39 Massive medium-grained foliated porphyritic quartz diorite.
NW Czeski Road 0.05 mi north of intersection with Lucas Road.

238A Small body of red-weathering medium-grained foliated porphyritic quartz diorite contaminated with Littleton Formation, not shown on map.
SW In Ware River gorge just north of Route 9 bridge in town of Ware.

273 Medium-grained foliated porphyritic quartz diorite.
NC Just east of Old Petersham Road 0.37 mi south of intersection with Charity Road. About 1/4 mi north-northwest of Poverty Hill.

386A Dark colored fine-grained strongly foliated quartz diorite; isolated body of Hardwick west of Muddy Brook valley.
Winsor Dam SE 0.28 mi north of east-west powerline at east edge of Winsor Dam quadrangle. 0.28 mi west of north junction of Sorel Road in Ware quadrangle.

476 Medium-grained foliated porphyritic quartz diorite.
WC Hill with BM 884 just east of Old Gilbertville Road about 2 1/2 mi north of Ware.

479 Massive medium-grained foliated porphyritic quartz diorite.
C Cliff just west of Mara Road.

496 Light colored medium-grained foliated porphyritic quartz diorite.
NC Ruggles Hill. 1080 ft hill east of Ridge Road 3/4 mi north of intersection with Barre Road.

507 Rather dark-colored, medium-grained foliated quartz diorite.
NC Mandell Hill. Small 940 foot knob about 1/2 mi north of intersection of Goddard Road with fork to Lower Road.

509A Medium-grained foliated porphyritic quartz diorite.
NC 0.21 mi east of Church Street at 980 foot contour about 0.6 mi south of Barre Road.

527 Light colored coarse-grained foliated quartz diorite with feldspar phenocrysts to 1-2 cm and a small amount of garnet.
NW West side of top of 1010 foot hill north of Lucas Road.

FW-538A Dark colored, fine-grained, strongly foliated quartz diorite with some 6 mm feldspar augen.
NC Top of 970 foot hill east of Simpson Road.

List of specimens in Table 12, continued.

520 Rather fine-grained foliated quartz diorite.
NC Top of 1010 foot hill about 1/4 mi southwest of Hardwick village.

541 Medium-grained foliated porphyritic quartz diorite.
NC Just west of Hardwick-Petersham Road (Route 32A) at 960 feet, 0.4 mi south of quadrangle boundary.

List of specimens in Table 13

313 Feldspar-rich, medium- to coarse-grained foliated porphyritic granite.
NE Southeast side of top of 970 foot hill east of Moose Brook and west of Prouty Road.

314 Foliated granite porphyry with 3-4 cm feldspar crystals.
NC Top of hill east of Jackson Road.

38 Medium- to coarse-grained strongly foliated porphyritic quartz monzonite.
WC Road cut on north side of Turkey Street, 0.1 mi east of intersection with Czeski Street.

62B Medium-grained strongly foliated porphyritic quartz monzonite.
SW 0.4 mi north on old road which goes north from Church Street about 0.2 mi west of crossing of Ware River.

62C Medium-grained foliated porphyritic granodiorite.
Location same as 62B.

64 Medium-grained foliated porphyritic granodiorite.
NW North end of small hill about 0.3 mi west of intersection of Patrill Hollow and Czeski Road.

265A Fine- to medium-grained foliated porphyritic granodiorite with 1/2 - 1 cm feldspar crystals.
WC Dougal Mt. Small hill 0.64 mi west of Gilbertville Road 0.09 mi north of intersection with Church Street in the center of Gilbertville.

265B Fine-grained dark colored foliated granodiorite.
Location same as 265A.

275 Medium- to coarse-grained foliated granodiorite with 1-2 cm feldspar phenocrysts.
NC Small hill west of Ridge Road 0.35 mi north of intersection with Clapp Road.

List of specimens in Table 13, continued.

60 Fine-grained strongly foliated diorite.
SW 0.14 mi west of Church Street, 0.11 mi south of BM 550 about 1.8 mi north of Ware.

532 Fine- to medium-grained foliated diorite.
NC Just north of Lucas Road 0.15 mi west of Gilbertville Road.

and inclusions. This is particularly noticeable in the north-central part of the pluton where there are several small inclusions of schist. A few per cent of hornblende, green in thin section, is found in the granodiorite, quartz diorite and diorite in several locations, generally near the central axis of the pluton. Some secondary muscovite has formed by the alteration of feldspar in a few specimens.

In most localities, the rock contains 1-2 per cent sphene, a distinctive characteristic also noted in the Spaulding Quartz Diorite in New Hampshire (Chapman, 1952, p. 398; Greene, 1970, p. 18). Apatite is also commonly 1-2 per cent of the rock. Magnetite averages 1 per cent, accounting for the strong peaks shown on aeromagnetic maps over the Hardwick pluton. Up to 1 per cent allanite, many crystals of which are brown and pleochroic with an orange metamict core, is present in many specimens.

There is a moderate amount of compositional variation from one outcrop to the next within the Hardwick, but only a few systematic variations. As mentioned above, in the extreme north-central part of the quadrangle, the Hardwick contains 1 to 2 cm long microcline phenocrysts, resulting in a potassium feldspar content of up to 50 per cent. The porphyritic Hardwick does not resemble the Coys Hill Granite. In the extreme eastern part of the pluton, on Mandell Hill and near Mara Road, 1 per cent or less garnet is present, perhaps due to contamination by country rock.

A small body of amphibolite (a) is found west of the Goat Hill diorite. The extent and associations of this body are not known. It may be part of another synclinal body like the Goat Hill diorite and associated schists, the other rocks of the syncline being hidden under the cover of the long valley just west of this amphibolite.

Contacts

The contacts of the Hardwick with other rocks are seen only in the Quabbin Aqueduct tunnel, and are approached in only a few places on the ground surface. In the tunnel, the Hardwick is bordered on both sides by a sheared biotite-garnet schist which is probably the Littleton Formation. On the ground, the Hardwick is separated from other rocks by broad alluvial valleys in most of the area. Except near Goat Hill, the outcrops of schist closest to the Hardwick are Littleton. The closest approach to the contact on the ground is in a stream valley northeast of Hardwick Pond, where slices of Hardwick and Littleton are interleaved with each other and with bands of mylonite. Specimens from the Quabbin Aqueduct tunnel also show interleaving of the Hardwick with the Littleton on both the east and west at intervals of 30-60 m (100-200 ft).

Some inclusions of Partridge Formation (Opl) are found in the Hardwick in the central part of the area. The contacts with these, when exposed, are sharp.

Of particular interest in a discussion of the contacts is the indirect evidence provided by the relationship between the Hardwick Quartz Diorite and the Fitch Formation (Figure 15). The Fitch lies east of and subparallel to the eastern border of the Hardwick. This relationship continues northward to the Monadnock quadrangle, where the Fitch equivalent, the rusty quartzite member of the Littleton Formation (Fowler-Billings, 1949) is present at a roughly constant distance from the north and east borders of the several bodies of Spaulding Quartz Diorite. This close relationship suggests that the Hardwick-Spaulding may be confined largely or entirely to one stratigraphic horizon, apparently in the Littleton Formation.

The Hardwick Quartz Diorite in the Ware area is in a sill-shaped body about 1500 meters (5000 ft) thick. It is not known how much of this thickness may be due to repetition by folding.

GNEISS OF RAGGED HILL

This unit forms a narrow belt about 0.2 km (0.1 mi) wide in the schists west of the Coys Hill Granite. Its stratigraphic position is not consistent, but varies within the Partridge and Fitch Formations in the Ragged Hill anticline. It is the only syntectonic plutonic rock in the area which demonstrably cuts across other units.

South of the Ware quadrangle, the gneiss is wider and the belt of schists between it and the Coys Hill Granite is very thin, with the result that it appears to be a fine variety of the Coys Hill, and has been mapped as such (Emerson, 1917; Peper, 1966; Pomeroy, in press). Its extent north of the Ware area is unknown. A few small bodies of the same lithology are found in the Partridge Formation just east of the Coys Hill Granite.

The informal name is taken from the large exposures on the east side of Ragged Hill in the central part of the quadrangle.

Lithology

The gneiss of Ragged Hill (rh) is a quartz-feldspar gneiss, with a few per cent of biotite and garnet. It has a lower percentage of ferromagnesian minerals than most of the other rocks in the area , and the light color is a distinguishing characteristic. Another characteristic is the massive outcrops it forms, because it does not normally weather along foliation planes. The biotite is in elongate patches, typically 1 x 30 mm, which give the rock a discontinuous striped appearance (Figures 12, 13).

The gneiss averages 45 per cent quartz, varying several per cent, and there are 20 to 30 per cent plagioclase (Table 14). The amount of potassium feldspar is very varied, 1 to 30 per cent, and is orthoclase in the central part of the area, microcline in the northeast, and both in the south in the Warren and Palmer quadrangles. There are a few per cent of garnet and biotite, rare small amounts of sillimanite and trace amounts of oxides and zircon. Quartz and feldspar crystals are commonly 1-2 mm across, except where the rock has been crushed, in which case 1/2 mm crystals are common. The garnets are 1 to 3 mm across. The small garnets are round and slightly crushed, and the large ones are deeply embayed. The sillimanite is commonly associated with biotite.

Contacts

The contacts of the gneiss with the adjacent schists are exposed in a few places and approached within several feet in numerous places.

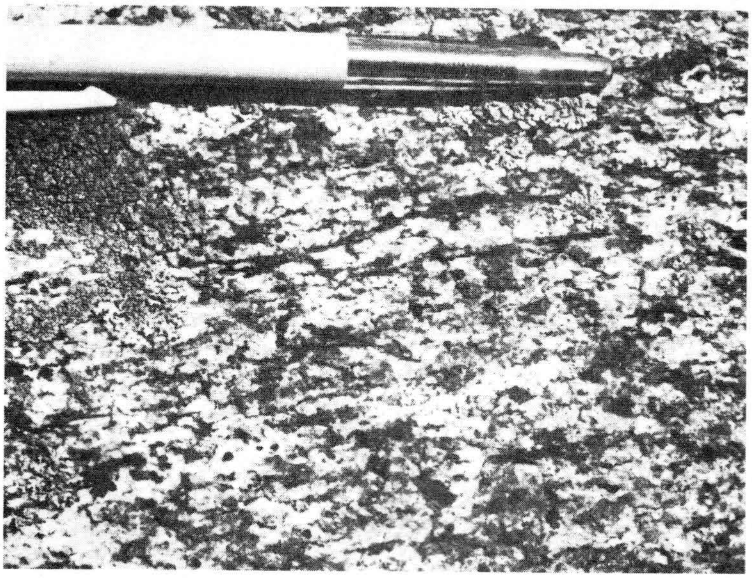


Figure 12. Gneiss of Ragged Hill, on the powerline north of route 9 in the southwest part of the map area. The massive appearance, light color, small garnets and very thin elongate patches of biotite are characteristic.

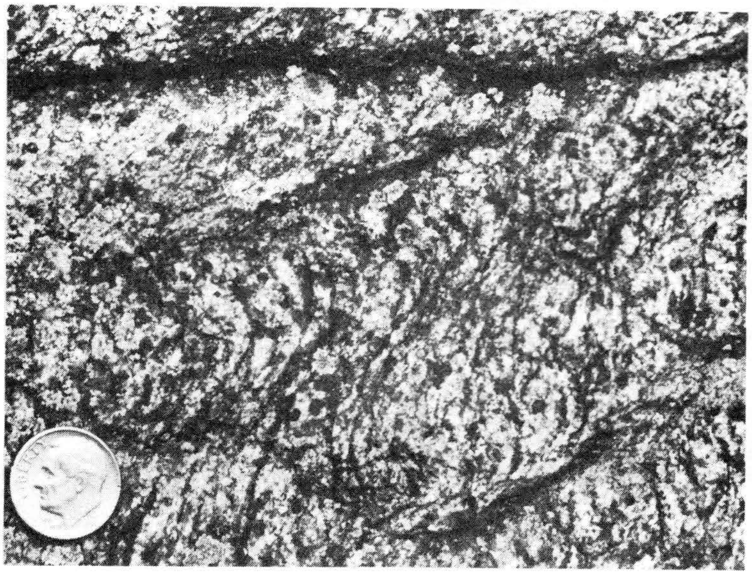


Figure 13. The second foliation as seen in the gneiss of Ragged Hill on the central part of Ragged Hill. The first foliation, dipping steeply to the left (west) is deformed by the second foliation, dipping less steeply in the same direction. The photograph was taken looking north.

Table 14. Estimated modes of the gneiss of Ragged Hill.

							Outside Main Body	Relationship to Main Body Uncertain	
	FW-11	146	241	247	375	389	301A	366A	366C*
Quartz	60	53	45	47	24	42	42	50	40
Plagioclase	15 An20#	30 An30	30 An28	20 ol	54 ad	40 ol	30 ol	24 ol	41 An31
Orthoclase	10	1	17		2	10	20		2
Microcline				30				20	
Biotite	2	10	6	3	15	7	3	3	10
Garnet	10	2	2		5	1	3	2	5
Sillimanite	2	3.5					1		
Ilmenite			tr	tr		tr	1	1	1
Graphite		0.5							
Secondary Chlorite	1					tr			
Zircon		tr	tr	tr	tr		tr		tr
Apatite									tr

*366C also contains 1% orthopyroxene altering to cummingtonite that is in turn altering to hornblende.

*Plagioclase compositions determined as described in Table 2.

List of specimens in Table 14.

FW-11 Massive strongly foliated quartz-feldspar biotite gneiss with 1 mm garnet.
SC On east-west powerline north of Route 9, 0.83 mi east of Gilbertville Road.

146 Foliated red-weathering quartz-feldspar-biotite gneiss with garnet.
C Ragged Hill 0.7 mi south of Gilbertville Road 0.06 mi west of Sibley Road.

241 Massive strongly foliated quartz-feldspar-biotite gneiss with 1/2 mm garnet.
SW 0.23 mi east of the intersection of Prendiville Road with Route 9.

247 Strongly foliated light colored quartz-feldspar-biotite gneiss.
NE Just east of Prouty Road at the 915 foot elevation south of the high point.

375 Massive medium- to coarse-grained light-colored quartz-feldspar-biotite gneiss with 1-2 mm garnet.
Palmer NE 950 foot knob 0.16 mi east of West Warren Road 0.08 mi south of the Ware-Palmer town line.

389 Light-colored coarse-grained quartz-feldspar-biotite gneiss with 1-2 mm garnet.
C 0.2 mi north and 0.07 mi west of the intersection of Tucker and Gilbertville Roads.

301A Thin body of light-colored quartz-feldspar-biotite gneiss with 1 mm garnet, east of the Coys Hill Granite.
C Just east and north of the northern crossing of Tucker Road by the town line.

366A Massive light-colored medium- to coarse-grained quartz-feldspar-biotite gneiss east of the Fitch Formation.
366C Massive light-colored medium- to coarse-grained quartz-feldspar-biotite gneiss with 1 mm garnet, west of the Fitch Formation.
Warren NW These specimens were taken less than a hundred feet apart on either side of a small body of Fitch Formation. 0.34 mi east and 0.06 mi south of the northwest corner of the Ware-Palmer town line at elevation 708 feet.

In all cases the contacts are sharp, without transition or interfingering. In the northern and southern parts of the area, the gneiss is at the western contact of the Fitch Formation, but on Ragged Hill it is further west, in the Partridge Formation, and a small sill is within the Fitch Formation. North of Ragged Hill in the area of Unitas Road (Figure 4), the position of the gneiss is irregular, but is always within the Ragged Hill anticline.

GOAT HILL DIORITE

A body of diorite is found on and near Goat Hill in the central part of the area, and another in the extreme northwest part of the Ware quadrangle and in the adjacent Petersham quadrangle. The two bodies are very similar and are discussed here together.

A striking thing about the diorite is its fresh, undeformed igneous texture. It appears to have been emplaced after much of the deformation and metamorphism in the area had ceased.

Lithology

The composition averages 50 per cent plagioclase (An 40), 25 per cent biotite, yellowish-brown in thin section, 7 per cent light green hornblende, 5 per cent augite partly altered to hornblende, and 6 per cent quartz (Table 15). Accessories are apatite and magnetite, each 1 to 3 per cent, and a trace of zircon. The texture is hypidiomorphic-granular, and the crystals are normally 2-5 mm long. In some specimens, the apatite and zircon are near euhedral and unusually large (zircon to

Table 15. Estimated modes of the Goat Hill Diorite.

	Normal			Coarse		Northwest
	FW-513	515	516	56	522	437
Quartz	5	9	7		5	1
Plagioclase	53 An38*	40 An35	58 An41	45 An53	55 An40	65 An40
Orthoclase			tr			
Hornblende	13 mg#	15 mg	2 mg	15 lg	5 mg	8 lg
Clinopyroxene	2	5	8		3	
Orthopyroxene			2	8	1	3
Biotite	25	25	20	30	28	20
Apatite	1	3	1	1	2	2
Magnetite	1	3	2	0.5	1	1
Zircon		tr	tr	0.5	tr	
Sphene	tr				tr	

* Plagioclase composition determined from maximum extinction angles of albite twins.

#Hornblende color: mg-medium green, lg-light green

List of specimens in Table 15

FW-513 Weakly foliated medium- to coarse-grained hornblende-pyroxene-biotite diorite.
C Northern knob (900 ft) of Goat Hill.

515 Unfoliated medium- to coarse-grained hornblende-pyroxene-biotite diorite.
C 900 foot knob 0.33 mi west of Church Street 0.3 mi south of intersection with Goddard Road.

516 Weakly foliated medium-grained hornblende-pyroxene-biotite diorite.
C Ridge 0.28 mi west of Church Street 0.3 mi south of intersection with Goddard Road.

56 Coarse unfoliated hornblende-pyroxene-biotite diorite with 1-2 cm biotite crystals.
C Low knob 0.07 mi west of intersection of Church Street and Goddard Road.

522 Coarse biotite-hornblende-pyroxene diorite with 1 cm biotite crystals.
C Steep slope east of high point of Goat Hill, 0.17 mi west of Church Street 0.04 mi north of intersection with Goddard Road.

437 Unfoliated medium-grained hornblende-pyroxene-biotite diorite.
Petersham SW Knob 0.23 mi east of Mellon Road 0.71 mi north of intersection with unnamed road at elevation 728 ft.

1/2 mm, apatite to 2 mm).

A coarse variety on the northern part of Goat Hill has randomly oriented biotite 1/2 to 4 cm across. The composition is similar to that of the rest of the diorite, except that orthopyroxene is more common than clinopyroxene. Both pyroxenes are altered to hornblende at their edges.

Contacts

The contacts of the diorite body in the northwest are not seen. Samples from the Quabbin Aqueduct tunnel indicate that it lies at the contact between the Partridge and Littleton Formations. On Goat Hill, the contact is gradational over 20 m (60 ft) or more where the diorite is in contact with the Hardwick Quartz Diorite. The Hardwick in this area also has inclusions of schist, but no inclusions of Hardwick or diorite have been seen in each other.

DIABASE

A diabase dike is present in the southwest part of the Ware area. It cuts across the other units, but is broadly parallel to the regional strike. The dip is vertical, as seen in an old quarry east of Ware. It is about 30 m (100 ft) wide in the northern part of the Warren quadrangle, and narrows gradually to the north until it disappears 0.25 km (0.15 mi) south of Route 9 along the powerline east of the town of Ware. North of this point 3 1/2 km (2 mi) in the same direction, by Mara Road in the central part of the area, is a cluster of boulders of diabase, probably very close to outcrop. This is probably the same dike, which has continued northward below or above the present ground surface.

From Mara Road northward, the probable location of the dike lies along the Ware River valley where it is covered, if present, at the ground surface. Near South Barre in the southwest part of the Barre quadrangle, diabase 40 m (130 ft) wide is noted in the Quabbin Aqueduct tunnel (Fahlquist, 1935, Section 78). This is interpreted to be part of the same dike or *en echelon* set of dikes.

Lithology

The diabase is hard, massive and fine-grained. It consists of a mesh of plagioclase laths and augite, the crystals being up to 1/2 - 1 mm long in thick parts of the dike, with some plagioclase crystals a few millimeters long. The composition is 58 per cent plagioclase, 40 per cent augite, and 2 per cent magnetite.

Contacts

The contacts are seen in a few places, and are always sharp, with chilled margins.

CORRELATION AND AGE OF ROCKS IN THE WARE AREA

No fossils have been found in the Ware area, but most of the stratigraphic units resemble units in the Bronson Hill anticlinorium in Massachusetts and New Hampshire, and the stratigraphic sequence is similar to that in the Bronson Hill anticlinorium. The Coys Hill Granite and Hardwick Quartz Diorite can also be correlated with rocks in New Hampshire which are associated with the Bronson Hill stratigraphic sequence.

STRATIFIED ROCKS

Monson Gneiss

The Monson Gneiss exposed in the Ware area is continuous with the main body of Monson Gneiss and the type location (Emerson, 1898, p. 56-65). The age is Ordovician or older, possibly early Ordovician (Thompson and others, 1968, p. 208).

Partridge Formation

Correlation. The Partridge Formation west of the Hardwick Quartz Diorite pluton is exposed in the North Orange syncline, the west Crescent Street syncline and the Muddy Brook anticline, and has been traced southward from areas of Partridge Formation in the Orange area, Massachusetts (Robinson, 1963; Thompson and others, 1968). The Partridge in the Orange area has been traced southward from the type area in northwest New Hampshire (Billings, 1937, 1956; Thompson and others, 1968).

The sulfidic schists in the Ware area east of the Hardwick pluton resemble the Partridge west of the Hardwick, in the Orange area, and elsewhere in Massachusetts and New Hampshire (Billings, 1937, p. 480-481; 1956, p. 18-21; Robinson, 1963, p. 30; 1967a, p. 19; Peper, 1966; 1967, p. 106; Thompson and others, 1968, p. 206).

The easternmost belt of Partridge Formation in the Ware area, in the Wickaboag Pond anticline, was mapped as Brimfield Schist by Emerson (1917, p. 69 and map), and it extends southward through the type area near the town of Brimfield, Massachusetts. The town was named from the rusty-weathering rocks, because secondary sulfates on the outcrops resemble "brimstone" (sulfur). The name Partridge Formation is used here because of its widespread use in western New Hampshire and central Massachusetts.

Personnel of the U. S. Geological Survey, mapping south of Ware, have assigned the name Hamilton Reservoir Formation to a variety of rock types which include some of the Partridge Formation (Seiders, 1974; Peper and Pease, 1975; Pomeroy, in press). The names Brimfield Schist and Tatnic Hill Formation are used in eastern Connecticut for equivalents of the Partridge Formation (Dixon and Lundgren, 1968a, p. 223).

Identification of the Partridge below the Fitch Formation is not always certain (Figure 14). At Gee Mill, the Fitch Formation is in the normal Bronson Hill anticlinorium stratigraphic position, above the Clough and Partridge Formations and below the Littleton. To the east and south from there, the rocks below the Fitch Formation are not always obvious Partridge Formation.

Figure 14. Rocks adjacent to the Fitch Formation and correlative rocks in Massachusetts and southern New Hampshire. Age interpretations are those of this author.

	Gee Mill, N.H. (Thompson and others, 1968; reconnaissance by this author)	Hillsboro quadrangle, N. H. (Nielsen, 1974)	Ware area, Mass. (This report)
LOWER DEVONIAN	Kinsman Quartz Monzonite? Littleton Formation Bedded gray schist	Kinsman Quartz Monzonite Littleton Formation, Mt. Kearsage Member Bedded gray schist	Coys Hill Granite Littleton Formation, big garnet unit Massive gray schist
SILURIAN	Fitch Formation Sulfidic calc-silicate granulite Clough Quartzite Conglomerate Bedded gray schist Conglomerate	Littleton Formation, Warner Member Gray calc-silicate granulite Littleton Formation, Francestown Member Sulfidic graphitic calc-silicate granulite	Fitch Formation Sulfidic graphitic calc-silicate granulite
MIDDLE ORDOVICIAN	Partridge Formation Sulfidic schist and amphibolite	Littleton Formation, Crotched Mountain Member sulfidic schist gray schist schist	Partridge Formation of the Lyon Road, Ragged Hill, and West Coys Hill anticlines (Opl) Gray- to red-weathering schist

In the Ware area, the problematic unit below the Fitch is the gray- to red-weathering Partridge of the Lyon Road, Ragged Hill, and West Coys Hill anticlines, which is the least sulfidic variety of Partridge in the area (Opl). In the Hillsboro quadrangle, the unit below the Francestown is the Crotched Mountain Member of the Littleton Formation (Nielsen, 1974), which in places is a rusty schist like the Partridge and in others is a gray schist full of andalusite pseudomorphs and containing some rusty spots and "footballs" (calc-silicate nodules 1/2 to 2 meters long and several centimeters thick). This gray Crotched Mountain Member appears to be a problematic unit possibly related to the gray- to red-weathering Partridge in the Ware area.

In the Ware area, the Fitch Formation is in contact with this variety of Partridge Formation and no others. The Paxton Schist, the other Silurian unit in the area, may also be in contact with the same variety of Partridge, although the outcrop was not sufficient to permit differentiating this variety on the map. A possible explanation is that the Partridge Formation decreases in sulfide content upward and that the Silurian units were deposited on this low-sulfide Partridge. Erosion followed, so that where the low-sulfide Partridge is not present, the Silurian rocks are also not present. This explanation seems in conflict with the generalized geologic history of the Bronson Hill anticlinorium and other parts of the region, where the major erosion is found between the Ordovician and Silurian strata, rather than between Silurian and Devonian. However, in the nearby portion of the Bronson Hill anticlinorium, Robinson (1963) tentatively identified an unconformity at this position also.

Age. The Partridge Formation in New Hampshire is correlated on the basis of lithology and position in sequence with graptolitic Middle Ordovician slates in western Maine (Harwood and Berry, 1967; Thompson and others, 1968, p. 206).

Fitch Formation

Correlation. The Fitch Formation in the Ware area has a limited east-west extent (Figure 22), but where it is found it is between the Partridge and Littleton Formations. It is virtually identical to, and generally on strike with, the rusty quartzite member of the Littleton Formation in the Monadnock quadrangle (Fowler-Billings, 1949, p. 1258-1261; Nelson, 1975) and the Francestown Member of the Littleton Formation in the Peterborough (Greene, 1970, p. 14) and Hillsboro (Nielsen, 1974) quadrangles, all in New Hampshire (Figure 15). Despite their assignment to the Littleton Formation, these are all similar to the Fitch Formation at Gee Mill in the Lovewell Mountain, New Hampshire, quadrangle (Dll of Heald, 1950; Thompson and others, 1968; Deane, in preparation). Because the unit is widespread, and because it appears that it correlates with the Fitch Formation and is not a member of the Littleton Formation, it is so referred to in this report. This is the first use of the term in this area.

Most of the Fitch Formation in New Hampshire is not sulfidic, but consists of gray calc-silicate granulite and schist with some mica schist, marble and quartzite (Billings, 1956, p. 25-26). A little sulfide is found in the Fitch Formation in north-central Massachusetts, both in pelitic schist and in calc-silicate beds (Robinson, 1963, p.62;

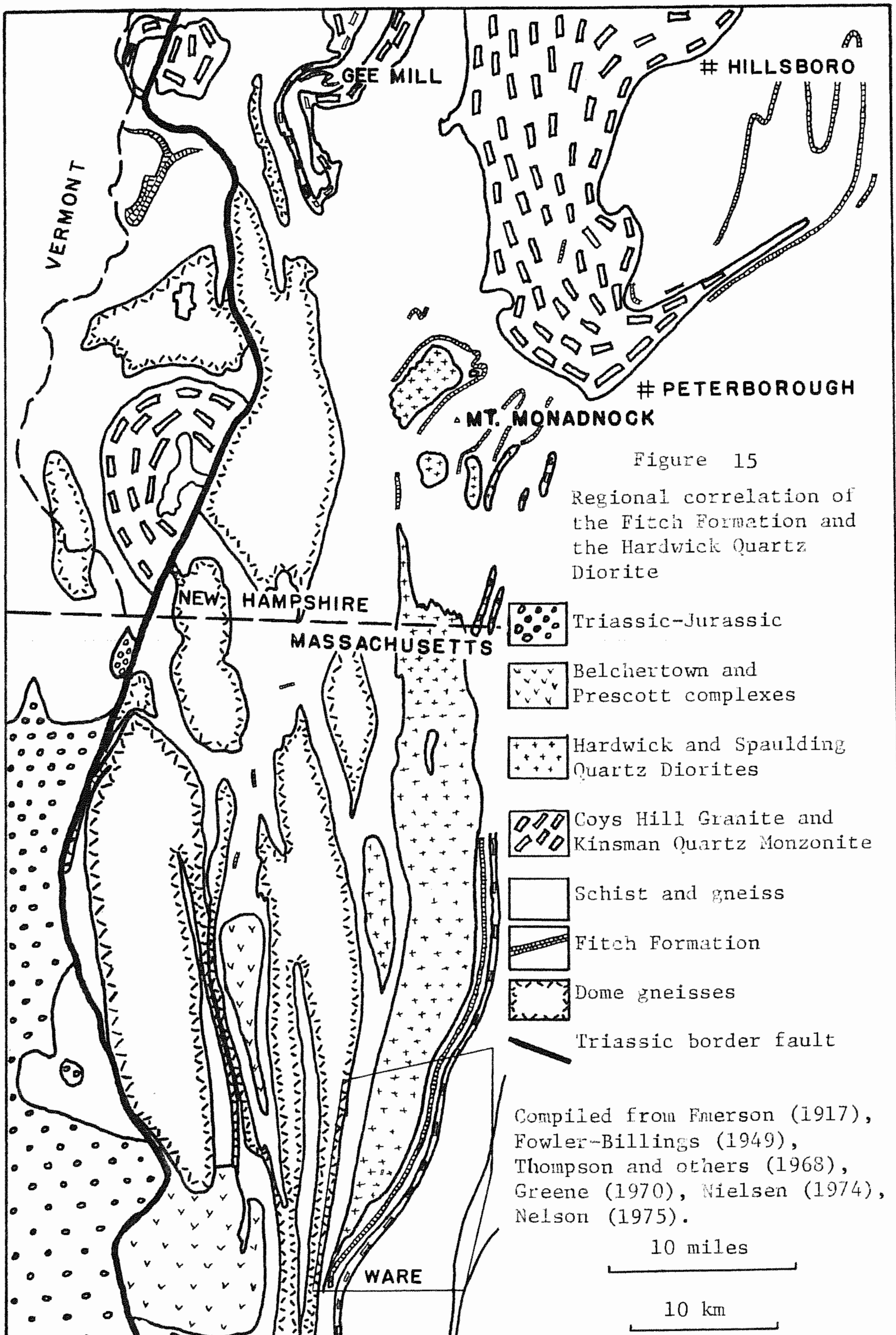


Figure 15

Regional correlation of the Fitch Formation and the Hardwick Quartz Diorite

Compiled from Emerson (1917), Fowler-Billings (1949), Thompson and others (1968), Greene (1970), Nielsen (1974), Nelson (1975).

1967a, p. 19). In the Hillsboro quadrangle (Nielsen, 1974) and Mt. Monadnock area (Nelson, 1975), both in New Hampshire, the Warner Member of the Littleton Formation is found stratigraphically above the Francestown Member and below the Littleton Formation proper (Figure 14). The Warner Member is a gray calc-silicate granulite resembling the typical Fitch Formation of northwest New Hampshire. Thus there appear to be two facies of the Fitch Formation, a lower sulfidic one and an upper non-sulfidic one, the non-sulfidic variety being found in western New Hampshire, the sulfidic variety in the Ware area and at Gee Mill, and both varieties in the Hillsboro and Mt. Monadnock areas.

Possible correlation of the Fitch Formation with the sulfidic white schist unit of the Paxton Schist is discussed under that unit.

Age. The Fitch Formation in the Bronson Hill anticlinorium is considered to be of Ludlow age (Late Silurian; Thompson and others, 1968, p. 206-207).

Paxton Schist

Correlation. Emerson (1917, p. 62 and map) considered the Paxton Schist to be an equivalent of the Oakdale Quartzite in the Worcester area to the east, and found these units to be rather extensive in east-central Massachusetts (Figure 16). Along strike to the northeast are the similar Kittery, Eliot and Berwick Formations of southeast New Hampshire and southern Maine (Billings, 1956, p. 44, 100; Hussey, 1968, p. 294-295; Pease and Peper, 1968, p. 5; Grew, 1973, p. 120, 123). These units have collectively been called the Merrimack Group. South of the Ware area, the Paxton Schist has been correlated with the Hebron

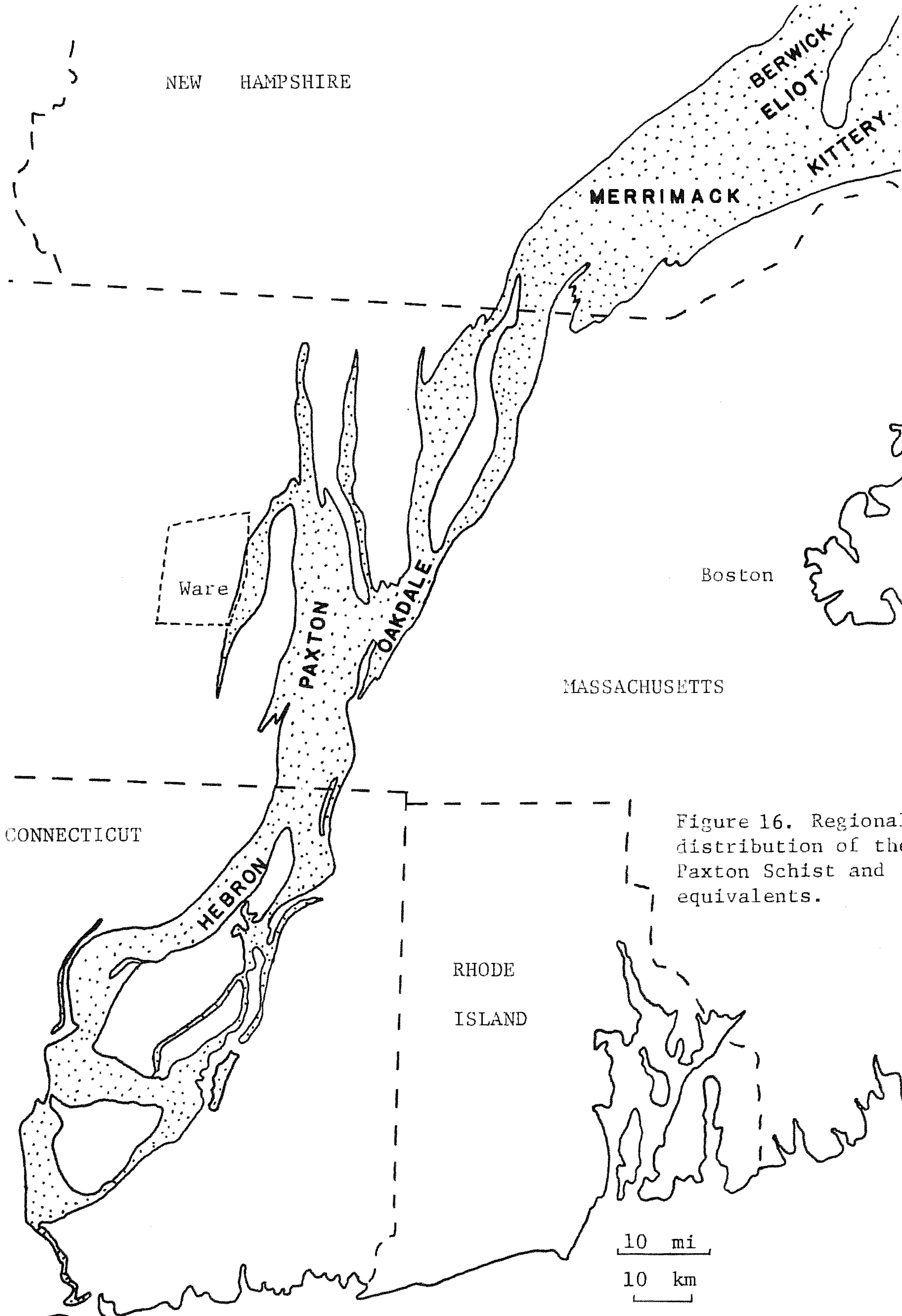


Figure 16. Regional distribution of the Paxton Schist and equivalents.

Formation in eastern Connecticut (Dixon, 1968; Pease and Peper, 1968, p. 5).

No unit similar to the sulfidic white schist unit is known in the immediate region. The only unit which has any similarity to it is the Fitch Formation, which is more calcareous and less pelitic, but is also a thin graphitic and very sulfidic rock with fine laminations and a slabby weathering form. These two units may be of similar age, and both contain minor amounts of rock types which resemble those of the other unit.

A section in western Maine which may be analogous to the section including the Paxton is shown by Boone (1973, p. 32). Here a graphitic sulfidic unit (Smalls Falls Formation) is overlain by a granular calc-silicate unit (Madrid Formation) and a thick pelitic sequence (Carrabassett Formation). The sequence is Silurian to Lower Devonian. The Smalls Falls is similar to the sulfidic white schist unit in being sulfidic to the extent that the ferromagnesian minerals contain very little iron (Guidotti and others, 1975), and the Madrid Formation can be compared to the Paxton Schist.

The section in Maine described by Boone represents an eastward thickening of the Silurian, and the Paxton schist and equivalents appear to represent the same eastward thickening. Boucot (1968, p.87) notes that the area of greatest Silurian sediment thickness in the region lies along a southwest-northeast axis across central New England and New Brunswick. Ware and western Maine appear to be near the western boundary of these thick Silurian sediments. Thus the western boundary boundary of the Paxton Schist could be considered the western boundary of the Merrimack synclinorium in a stratigraphic sense.

Doyle and Warner (1965, p. 32) note that rusty quartzite is common at the base of the Vassalboro Formation in Maine. The Upper Silurian or Lower Devonian Vassalboro is correlated with the Madrid Formation (Osberg and others, 1968, p. 248) and with the Berwick Formation (Hussey, 1968, p. 296), which is probably partly equivalent to the Paxton Schist.

Age. The Paxton, Hebron, Oakdale, Kittery, Eliot and Berwick Formations are considered Silurian to Lower Devonian for two reasons. The formations in southern Maine are correlated with the Mayflower Hill, Waterville and Vassalboro Formations in central Maine (Hussey, 1968, p. 299; Osberg and others, 1968, p. 248). Graptolites of late Llandovery age are found in the Mayflower Hill Formation, and possible Wenlock to Ludlow age graptolites are found in the Waterville Formation, giving a Middle Silurian to Late Silurian or Early Devonian age for these units and the overlying Vassalboro. Grew (1973, p. 123) suggests a similar correlation for the Paxton Schist in the Worcester area.

In Connecticut, the Hebron Formation lies between the Brimfield and Scotland Formations, which are similar to the Ordovician Partridge Formation and Lower Devonian Littleton Formation, respectively (Dixon and Lundgren, 1968a, p. 3-4; 1968b, p.223). In addition to these reasons for correlation, the sequence sulfidic white schist below gray granular schist with calc-silicates is correlated with Silurian rocks in Maine, as described above. It is concluded that the Paxton Schist is probably Middle or Upper Silurian to Lower Devonian.

Littleton Formation

Correlation. The Littleton Formation in the Crescent Street synclines in the western part of the area has been traced southward from the Orange area, Massachusetts (Robinson, 1963; Thompson and others, 1968). The Littleton Formation in all of the Ware area is lithically similar to the Littleton in the Orange area and in other parts of Massachusetts and New Hampshire. Diagonally across strike to the southeast, in Connecticut, the Scotland Schist has also been correlated with the Littleton (Zartman and others, 1965, p.8; Dixon, 1968; Dixon and Lundgren, 1968b, p. 220-221).

No rocks identical to the Feldspar Gneiss and Orthopyroxene Gneiss Members are known in the Littleton Formation elsewhere in the region, and lithically they most closely resemble the Ordovician Ammonoosuc Volcanics. Their stratigraphic position in the Littleton is similar to that of the Coys Hill Granite and the Feldspar Gneiss Member contains garnet in places. It has been suggested (Thompson and others, 1968, p. 208) that the Kinsman Quartz Monzonite of New Hampshire, to which the Coys Hill is closely related, is the metamorphosed mobilized equivalent of Lower Devonian felsic volcanics in central Maine. Possibly the Feldspar Gneiss Member is an unmobilized equivalent.

Possible equivalents of the Orthopyroxene Gneiss Member are more difficult to find. Mafic volcanic rocks are rare in Devonian schists of New England although some have been found in the Littleton Formation of the Littleton area (Billings, 1956, p. 28-30). Some New Scotland age (Early Devonian) andesites are known near Presque Isle in northeastern Maine (Boucot and others, 1964, p. 41, 47). The Erving

Formation, lying unconformably above the Littleton Formation in the Orange, Massachusetts, area north of Ware, contains amphibolite of probable volcanic origin (Robinson, 1963, p. 78-79; 1967a, p. 19,32).

Age. Lower Devonian fossils have been found in the Littleton Formation in the Littleton and Whitefield areas in New Hampshire (Billings and Cleaves, 1934, p. 412-438; Boucot and Arndt, 1960, p. 41-53) and in equivalent rocks in western Maine (Boucot, 1961).

INTRUSIVE IGNEOUS ROCKS

Phlogopite-Olivine Hornblendite

No other ultramafic rocks have been reported in this portion of the Merrimack synclinorium. In the Bronson Hill anticlinorium, however, numerous small bodies of ultramafic rocks have been found in the Pelham Gneiss (Emerson, 1898), in the Monson Gneiss, the Ammonoosuc Volcanics, and the Partridge Formation (Robinson, 1963, p. 46-47; Wolff, 1975). The hornblendite is in the Partridge Formation, and therefore was emplaced in Ordovician or later time. The fact that ultramafics are not found in any unit younger than the Partridge in the region implies that they were emplaced in Ordovician time.

New Braintree Gabbro

No rock similar to the New Braintree Gabbro is known in the area. In general composition and in the fresh, undeformed texture of the central body, the gabbro has some resemblance to the Goat Hill Diorite, but there are several mineralogical differences. The associated amphibolite and olivine gabbro of the New Braintree body have no counterpart on Goat Hill, and the coarse biotite variety of Goat Hill is not found in New Braintree. The hornblende in New Braintree is brown, while that on Goat Hill is green in thin section. The New Braintree rocks lack the ubiquitous apatite of the Goat Hill diorite, the Hardwick Quartz Diorite and the Warren diorite of Pomeroy (1974).

The Belchertown Complex, 13 km (8 mi) west of Ware, contains a variety of felsic to mafic plutonic rocks (Guthrie, 1972; Hall, 1973; Ashwal, 1974). The inner portion of the Belchertown contains fresh two pyroxene monzodiorite whereas the outer portion has been hydrated and metamorphosed to hornblende granodiorite gneiss (Ashwal, 1974). It is suggested that the outer portions of the New Braintree Gabbro may have been hydrated in a similar way while the core retained more or less the primary lithology.

The gabbro intrudes the Partridge Formation and is therefore Middle Ordovician or younger. It is much more deformed than the Goat Hill Diorite, as indicated by the strong metamorphic texture of the bordering amphibolite. The gabbro is assumed to be Ordovician because of this strong metamorphism of its margins and because of possible association with the hornblendite body south of New Braintree. It is possible that the gabbro is Devonian.

Coys Hill Granite

The Coys Hill Granite is virtually identical to the widespread Kinsman Quartz Monzonite of New Hampshire and may be continuous with it.

The Kinsman has the same porphyritic texture and the same general composition, although it generally contains less potassium feldspar than the Coys Hill (Billings, 1956, p. 58-61; Chapman, 1952, p. 394-397; Fowler-Billings, 1949, p. 1264-1266; Greene, 1971, p. 18-19; Heald, 1950, p. 58-87).

The Coys Hill is on strike with small units of the Kinsman in the Monadnock quadrangle of southern New Hampshire and with the large Cardigan pluton (Fowler-Billings, 1949; Billings, 1956; Figure 15, this report) and may be continuous with these bodies. Although the Kinsman Quartz Monzonite comprises several extensive bodies in New Hampshire, very few lithologies other than the narrow Coys Hill Granite can be compared with this rock type in southern New England. The Kinsman is always found within the Littleton Formation in New Hampshire (Thompson and others, 1968, p. 208) and its presence in the Ware area strengthens the argument that the Ware area contains rocks of the Littleton Formation.

The Kinsman Quartz Monzonite, equivalent to the Coys Hill Granite, occurs as concordant sheetlike masses in the lower part of the Lower Devonian Littleton Formation (Thompson and others, 1968, p. 208) and hence is Early Devonian or younger. If the Kinsman is derived from metamorphosed volcanics, it is Lower Devonian.

Hardwick Quartz Diorite

Correlation. The northern end of the Hardwick pluton is nearly continuous with the Spaulding Quartz Diorite of the Monadnock area of southern New Hampshire and is similar to it (Fowler-Billings, 1949, p. 1266-1268; Figure 15, this report). The name Spaulding has also been applied to quartz diorites in the Sunapee (Chapman, 1952, p. 397) and Peterborough (Greene, 1970, p. 17) quadrangles of New Hampshire. These quartz diorites are very similar to each other and to the Hardwick, and are probably closely related. They have the following features in common:

1. General composition and compositional variation.
2. Dark color.
3. Spotted appearance due to irregular feldspar phenocrysts and biotite clusters.
4. Great variation in potassium feldspar content (0-50%) due to the variable presence of phenocrysts of this mineral.
5. Greenish color of the biotite in thin section.
6. Sporadic presence of small amounts of garnet.
7. The abundance of sphene and, to a lesser extent, of apatite and allanite.

It is concluded that the Hardwick Quartz Diorite and the various bodies of Spaulding Quartz Diorite are of very similar origin, perhaps a single source, or possibly all parts of a single body, now very much attenuated.

Other quartz diorites are found in New Hampshire, the Winnipesaukee Quartz Diorite and Remick Tonalite (Billings, 1956, p. 54-55), but it is not clear from the descriptions of the units (Billings, 1937, p. 507; Quinn, 1944, p. 478) if they are as similar to the Hardwick as is the Spaulding. The Belchertown Intrusive Complex, 13 km (8 mi) west of Ware, does not generally resemble the Hardwick, but does contain green biotite, allanite and sphene in its hydrous portion (Guthrie, 1972, p. 43-46; Hall, 1973; Ashwal, 1974). The Cooleyville Gneiss of the Prescott Complex, 17 km (10 mi) northwest of the Ware area, is composed of quartz monzonite, quartz diorite and granodiorite containing sodic andesine, sphene and some allanite (Makower, 1964, p. 38-39). Small bodies of quartz diorite of similar description to the Hardwick, and with abundant sphene, are present in extreme southern Maine, 110 km (70 mi) and more across strike from any body of Hardwick or Spaulding (Hussey, 1962, p. 38).

Age. The Hardwick Quartz Diorite appears to be largely contained within the Littleton Formation of Devonian age and thus is Lower Devonian or younger. Its strong schistosity parallel to that of the country rock indicates it was intruded prior to or during deformation. Other syntectonic intrusives in the area are Lower Devonian. The Prescott Complex, which is gneissic but does cut across early nappe structures, has been dated at 385 m.y. (Thompson and others, 1968, p. 209) and the Belchertown Complex at 380-390 m.y. (R. E. Zartman, personal communication, 1975).

Gneiss of Ragged Hill

No other unit comparable to the Gneiss of Ragged Hill is known in the region, although it is compositionally somewhat similar to the Coys Hill Granite. The gneiss is younger than the Partridge and Fitch Formations, because it intrudes them. It has not been seen to intrude Devonian rocks. It was intruded early in the tectonic cycle, because it has been folded along with the metamorphosed sedimentary rocks. Its discordance suggests it was intruded a little later than the very concordant Hardwick Quartz Diorite and Coys Hill Granite, but it has not been seen to cut across the early nappe structures.

Goat Hill Diorite

No similar diorites are presently known, but there are plutonic rocks in the region which may be related. Thirteen kilometers (8 mi) to the west is the Belchertown complex which contains some diorite and is unfoliated in its interior (Thompson and others, 1968, p. 209; Guthrie, 1972; Hall, 1973; Ashwal, 1975). Seventeen kilometers (10 mi) northwest of the Ware area is the Prescott Complex of granodiorite and gabbro, which cross-cuts Devonian and older rocks but which is strongly foliated (Makower, 1964; Thompson and others, 1968, p. 209). In the Warren quadrangle south of Ware, Pomeroy (1974) has found large bodies of light and dark diorite with 1-2 per cent apatite. These bodies do not closely resemble the Goat Hill Diorite because they have less biotite and more amphibole and pyroxene, but they are apparently of similar age and future studies may show them to be related.

The Goat Hill Diorite does not appear to be comagmatic with the Hardwick Quartz Diorite. Apatite is common, as in the Hardwick, but the diorite lacks the sphene and allanite which are typical of the Hardwick, and the biotite color is brown to reddish brown, rather than green-brown in thin section.

The fresh unfoliated texture of the Goat Hill Diorite implies that it was intruded late in the tectonic sequence, when deformation had nearly ceased. The diorite was subject to some metamorphism, as the hydration of the margins of the pyroxenes indicates, but it was not subject to enough metamorphism to change the textures, even though the body is generally parallel to the structures of the surrounding rocks.

Diabase

The diabase dike is presumably Triassic or Jurassic, associated with other Triassic-Jurassic diabase dikes in Massachusetts and the basalt flows in the Connecticut valley.

ALTERNATE INTERPRETATIONS OF THE STRATIGRAPHY OF THE WARE AREA

Members of the U. S. Geological Survey, mapping in south-central Massachusetts and north-central Connecticut, have used an entirely different stratigraphic concept and nomenclature (Peper, 1974; Seiders, 1974; Peper and Pease, 1975; Pomeroy, in press). They believe there is a major fault east of the Monson Gneiss and that the stratigraphy east of the fault is entirely different from that of the Bronson Hill anticlinorium. In their concept, this is a varied stratigraphy, formed in a major basin, where lithic variations are due to fluctuations in the type of sediment being supplied. Accordingly, the bedrock of Ware and adjacent areas represents a homoclinal sequence without repetitions.

The Ware area lacks evidence which would conclusively prove a particular stratigraphic sequence, such as fossils, abundant graded bedding, or a sequence of several identifiable units, and the conclusions reached in this report are necessarily interpretive. The extreme attenuation of lithic units and their numerous repetitions requires structures which can only be demonstrated on a regional scale, if at all, and the interpretation that the Ware area is underlain by a homoclinal sequence is less difficult to comprehend. However, the conclusions of this report are supported by several lines of argument.

In the stratigraphic interpretation of an area, the first assumption against which the data should be considered is that the stratigraphy is similar to that in nearby areas. If the comparison cannot be made, then other models should be considered. The Ware area stratigraphy is similar to that in nearby areas. There is a good match, in rock type and in sequence, to the well studied stratigraphy in the Bronson Hill anticlinorium to the northwest. The presence of the Coys Hill Granite strengthens the argument that the Ware area is underlain by western New Hampshire stratigraphy, as its equivalent, the Kinsman Quartz Monzonite, is associated with the Littleton Formation in New Hampshire (Thompson and others, 1968, p. 208).

The absence of the Clough Quartzite and the discontinuous nature of the Fitch Formation are typical of the thin discontinuous Silurian sediments in the region, and should not be taken as evidence that the Ware area stratigraphy differs from that of the Bronson Hill anticlinorium. Robinson (1963) finds that the Ammonoosuc Volcanics, Clough Quartzite and Fitch Formation are very thin or absent in the eastern part of the Bronson Hill anticlinorium, so it might be expected that they would be thin or absent in the Ware area. The absence of the complete Bronson Hill sequence is a handicap in positive identification of the stratigraphic units and determination of tops, but where the Fitch is present it is found in the appropriate place, between the

Partridge and Littleton Formations.

Graded bedding is also rare, but where it is found, it supports the interpretation of this report. Graded bedding indicating an isoclinal overturned syncline in the western part of the Warren quadrangle has been reported by Pomeroy (in press). Most graded bedding observed in the Ware area indicates that the beds are overturned, which complicates any interpretation of a homoclinal sequence.

If there is a major fault east of the Monson Gneiss, this does not categorically mean that the sequences on either side are different. For one thing, the age of the fault is not known and it was not necessarily there at the time of deposition. If it was there, any differences between the deposition on different sides of the fault would depend on the amount and direction of movement, and cannot be postulated simply on the presence of a fault.

STRUCTURAL GEOLOGY

Introduction

The Ware area lies on the eastern overturned limb of a late major anticline, and is dominated by a north-northeast strike and moderate west dip of foliation. This simple appearance masks the fact that the rocks have undergone several earlier periods of intense deformation. The elongate belts of Ordovician, Silurian and Devonian schists and igneous rocks which characterize the map pattern of the Ware area are interpreted to be extremely elongate and compressed isoclinal anticlines and synclines believed to represent the roots of a series of nappes originally overfolded from east to west. The axial surfaces of these isoclines were subsequently backfolded toward the east to give the present pattern of west dipping foliation. Later deformations gave rise to various other foliations and mineral lineations.

No faults are shown on the map or sections, because no definitive evidence for any was found. On the contrary, the evidence is that of great plasticity, as shown by the extreme elongation of rock units and folds in the area. Members of the U. S. Geological Survey mapping to the south (Peper, 1974; Peper and Pease, 1975; Pomeroy, in press; Seiders, 1974) have shown several thrust faults parallel to schistosity. Such faults could be placed on the Ware map in elongate drift-covered areas parallel to schistosity, such as Muddy Brook valley, but there is little direct evidence for such faults, to say nothing of the amount and direction of displacement.

The sequence of structural events is interpreted to be as follows:

(1) Formation of large amplitude nappes folded from east toward west under moderate to high grade metamorphic conditions resulting in the pattern of extremely attenuated isoclinal anticlines and synclines that dominates the area, as well as the dominant metamorphic foliation. Intrusion of the Hardwick Quartz Diorite, Coys Hill Granite and gneiss of Ragged Hill took place prior to or in the early stages of this folding.

(2A) Tight isoclinal folding with west dipping axial planes, probably contemporaneous with northeastward flowage of the Monson Gneiss in the adjacent Bronson Hill anticlinorium and the eastward emplacement of the Colchester Nappe in Connecticut. Evidence for this folding is largely to be found in the Orange and Quabbin Reservoir areas (Robinson, 1963; 1967b) and is scarce in the Ware area. Subsequent to this folding and probably separate from it was locally intense mylonitization and cataclastic thinning of units, still under metamorphic conditions.

(2B) Main formation of gneiss domes to the west and tight folding along roughly north-south axes in the Ware area, with development of gentle west-dipping axial plane foliation and southwest plunging mineral lineation. Intrusion of the Goat Hill diorite took place near the end of this folding.

(3) Broad open folding along west-southwest axes.

(4) Brittle fracture and emplacement of diabase dikes.

Stages 1 to 3 are presumably Devonian (Acadian) in age, 4 is Triassic-Jurassic. These stages of deformation generally correspond to those observed in the Bronson Hill anticlinorium to the west (Robinson, 1967a, p. 21). The sequence of nappe formation followed by tight folding has been found in other orogenic areas (Turner, 1968, p. 372-374).

Minor Structural Features

Bedding. In virtually every outcrop of schist where bedding is evident, the dominant foliation is parallel to it. The symbol for bedding is used on the maps in schist where it is reasonably certain that bedding is represented, and a foliation symbol is used for planar features in igneous rocks, and in schists where bedding is uncertain. Bedding is particularly well developed in the eastern synclines of the Littleton Formation.

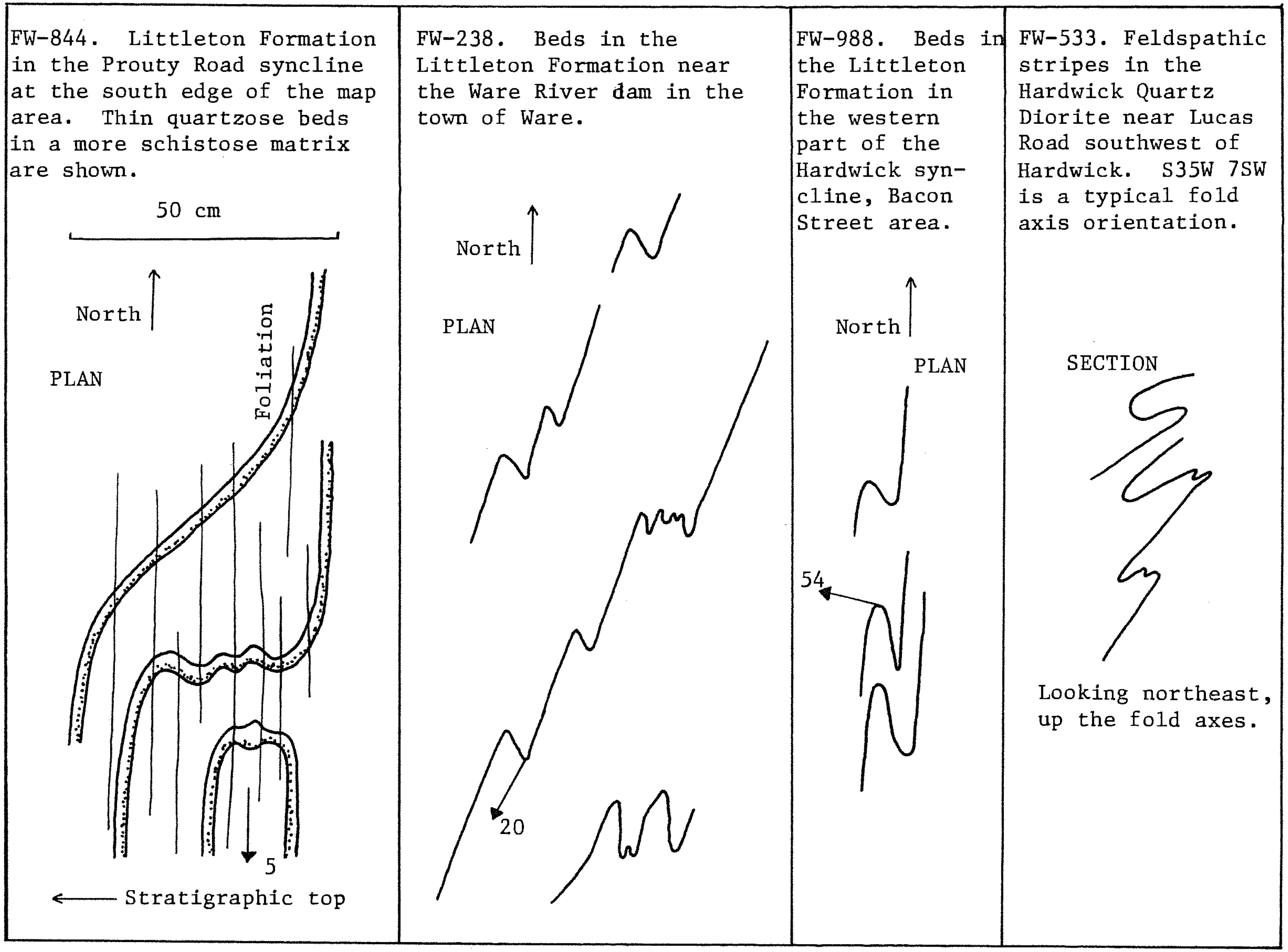
Graded bedding was found in a few widely scattered outcrops and is consistent with the interpretation that the rocks believed to be Devonian lie above those believed to be Ordovician. These localities are shown on the geologic map (Plate 1) and on the map of planar structural features (Plate 4). They are, from north to south: (1) Just east of Goat Hill in a schist infold in the Hardwick Quartz Diorite, where tops are east. (2) In a small layer of schist in the New Braintree Gabbro, where tops are east. (3) On the northeast slope of Ragged Hill, in the Big Garnet syncline of the Littleton just east of the Fitch Formation, where tops are again east. (4) Near the southern edge of the map area in the Prouty Road syncline, where tops are west just west of the contact with the Partridge.

Foliation. The major foliation is shown primarily by parallel arrangement of biotite crystals, and to a lesser extent by flattened quartz and feldspar crystals. This foliation is the dominant planar feature of every outcrop, with rare exceptions. It typically strikes N10E and dips 30 degrees west (Plate 4; Figures 18, 19, 20). The dip is generally steeper in the western part of the map area, 50 to 60 degrees, and is quite shallow east-northeast of the map area (Fahlquist, 1935; Figure 24 of this paper).

The second foliation is generally more subtle than the major foliation, although in some outcrops it is more conspicuous. It is seen mainly in the more massive rocks, particularly the Hardwick Quartz Diorite and the gneiss of Ragged Hill. When both foliations are seen in an outcrop, the first is typically seen most strongly in the mineral alignment, whereas the second is seen in distortion of the first and in surfaces revealed by weathering (Figure 13). The attitude of the second foliation averages N18E 15W and has a shallower dip than the major foliation it occurs with, although the dips of both are locally variable (Figure 19). The second foliation can be identified with certainty only when it and the major foliation occur together, and there are probably outcrops where foliations have been misidentified. In an area such as Coys Hill, where there are many foliation attitudes at a high angle to contacts, some of the attitudes may be second foliations misidentified as major foliations.

Minor folds. Asymmetric minor folds are moderately common and are from several centimeters to half a meter across. Where movement sense can be determined, most of the folds have an east-side up

Figure 17. Style and sense of minor folds in the Ware area. Scale same in all boxes.



movement sense (dextral in plan view if the fold plunges south; Plate 5; Figure 17). These folds are believed to be folds in the bedding and early foliation with the second foliation developed parallel to the axial planes.

Mineral lineations. Mineral lineations consist primarily of the long axes of sillimanite crystals, clusters of biotite crystals, and elongate feldspar crystals in the foliation plane. There appear to be two sets of lineations, one plunging down-dip, the other plunging gently southwest, but the two groups are not separable on the equal area net plots (Figures 19, 20).

Boudins. Some boudins of pegmatite are found in the area, the short axes rarely more than a meter across. The long axes generally trend west, but a few in the southeast part of the area trend northwest (Figure 20, Domain 21). Boudins were not seen in any rock except pegmatite.

Orientation of Minor Structural Features

Structural domains. Figure 18 is a small-scale map of the Ware area divided into twenty-one domains within which the minor structural elements are more or less homogeneous. Within each domain the dominant foliation and lineation attitude is shown, except in domain 2, where the distribution is particularly random. The most notable thing about the map is the general homogeneity of the Ware area. The only variations are a steeper dip of foliation in the western part of the area and more westerly strike of foliation and trend of lineation in some domains.

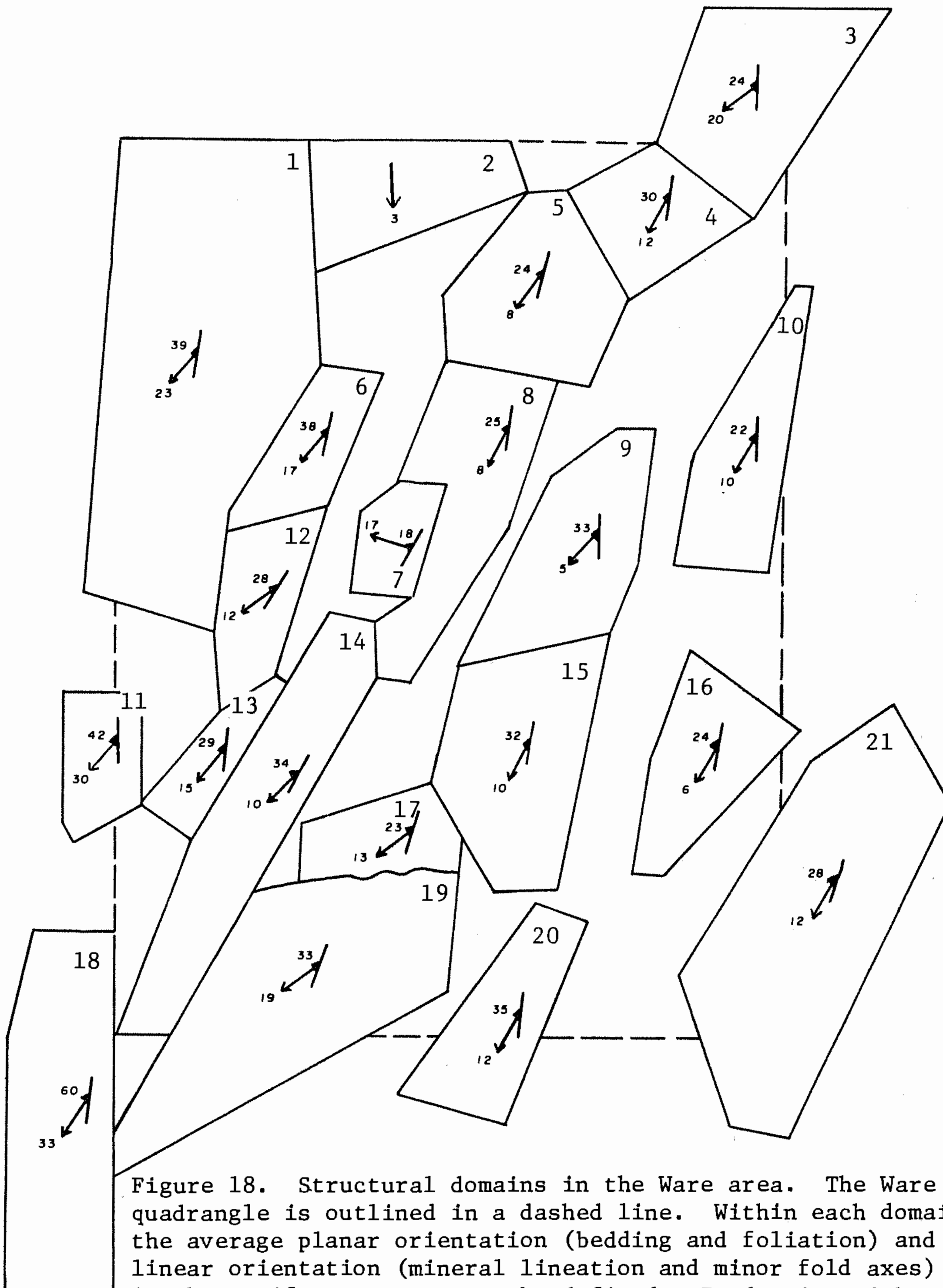


Figure 18. Structural domains in the Ware area. The Ware quadrangle is outlined in a dashed line. Within each domain, the average planar orientation (bedding and foliation) and linear orientation (mineral lineation and minor fold axes) is shown, if an average can be defined. In domains with a small number of linear features (2, 6, 7, 11, 16), β-plots were used to define an average direction of linear features. The equal area plots and numbers of measurements for each domain are given in Figure 20.

Figure 19. Equal area diagrams summarizing structural features in the Ware area.

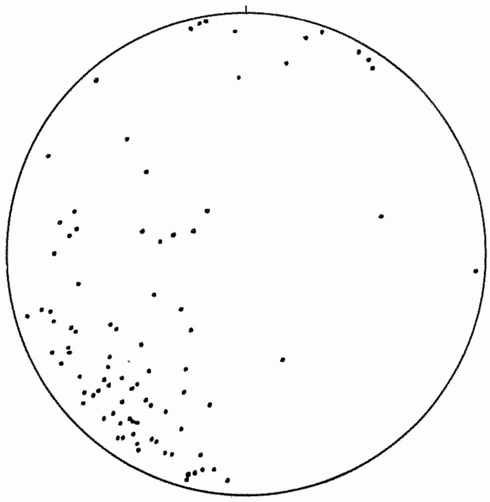
Minor fold axes: All minor fold axes measured in the map area.

Mineral lineations: All mineral lineations measured in the map area.

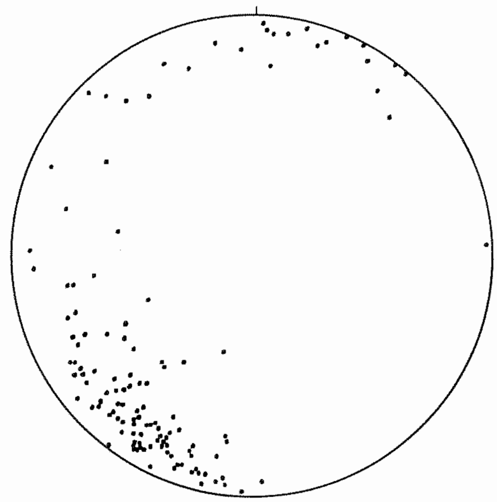
Intersections of first and second foliation: Trend and plunge of the line that marks the intersection of the two foliations, where both are found in the same outcrop.

Second foliation: Poles to second foliation.

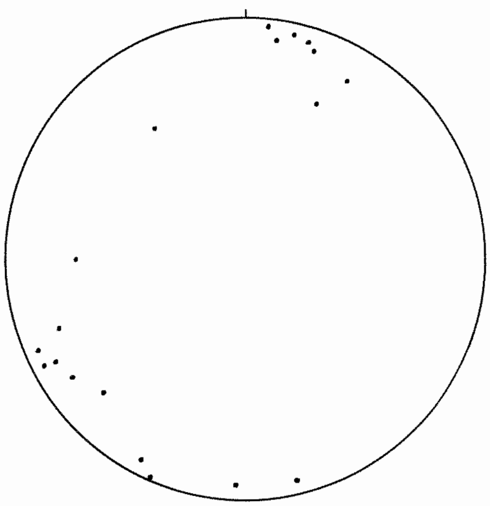
Late open folds: Each arc connects poles of representative foliation planes from some of the late open folds. Poles to the planes defined by these arcs, representing the late open fold axes, are shown as large circles in the southwest quadrant of the net.



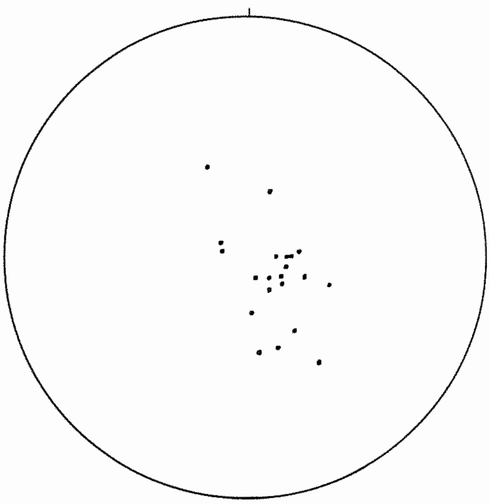
MINOR FOLD AXES



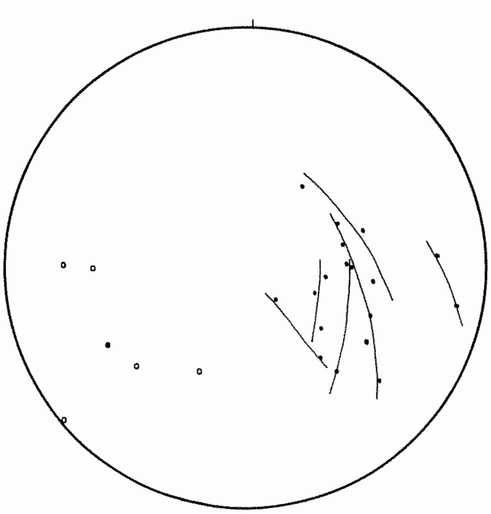
MINERAL LINEATIONS



INTERSECTIONS OF FIRST AND SECOND FOLIATIONS



SECOND FOLIATION



LATE OPEN FOLDS

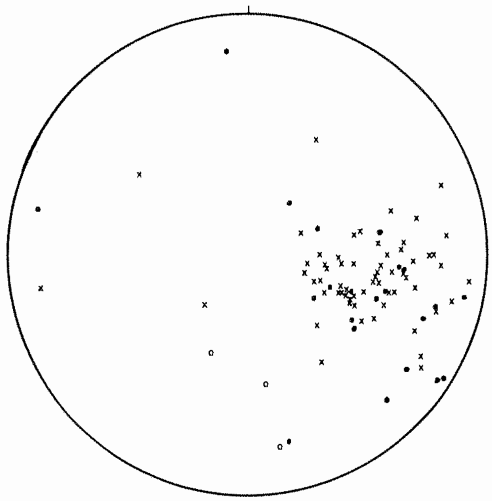
Figure 20. Equal area net plots of planar and linear features for the domains shown in Figure 18.

For each domain, the planar features are shown on the left side of the page and the linear features on the right. The symbols are:

Planar		Linear	
.	Bedding	.	Mineral lineation
x	Foliation	x	Fold axis
0	Second foliation	0	Boudin axis
		Δ	Beta intersection

Numbers of measurements:

Domain	Bedding	Foliation 1	Foliation 2	Beta intersection	Minor fold axis	Mineral lineation	Boudin long axis
1	22	62	3		5	9	1
2		10	2	6	1	1	
3	20	66	1		2	6	
4	17	21			3	1	
5	4	22	1		2	1	1
6	1	26		10	1	2	
7	8	18	1	22		3	
8	1	33	2		3	3	1
9	101	42			13	9	4
10	40	6				13	
11	8	17	1	11	3	4	1
12		28	4		9	9	
13	1	29			2	9	
14	8	22			20	8	1
15	82	32	1		8	5	1
16	12	1		8		1	1
17	37	3			2	8	
18	40	8	2		2	3	
19	102	97	5		26	12	
20	3	22				8	1
21	2	47	1		1	5	5



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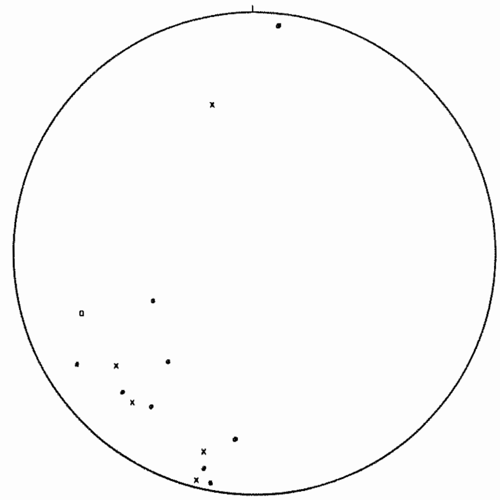

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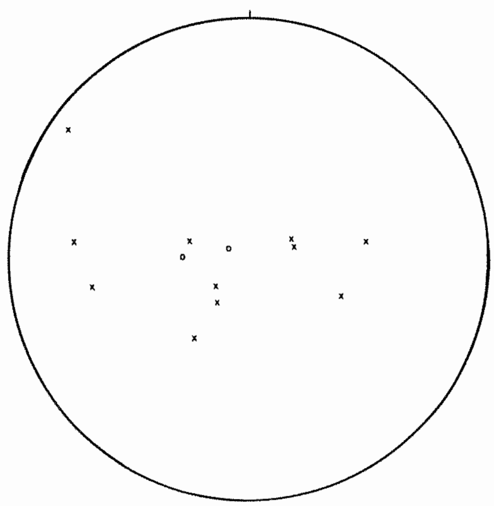

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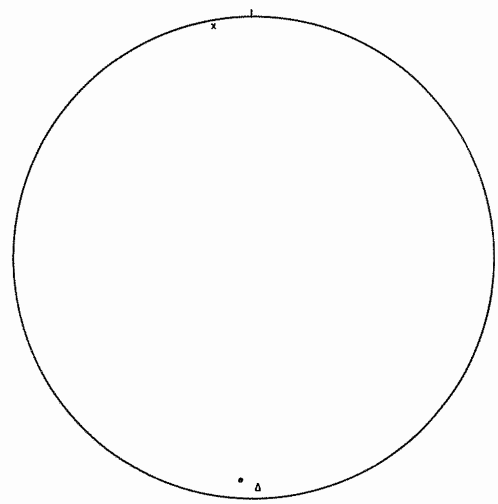

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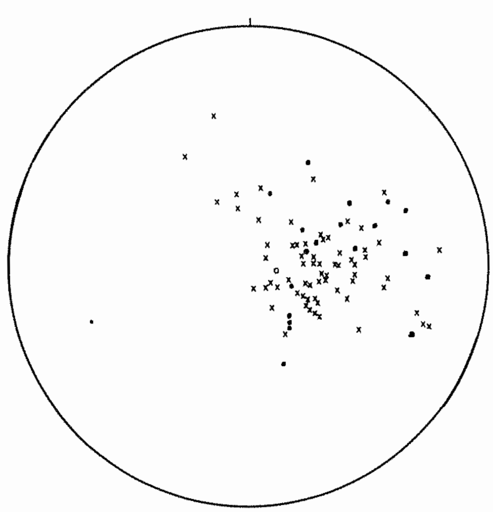

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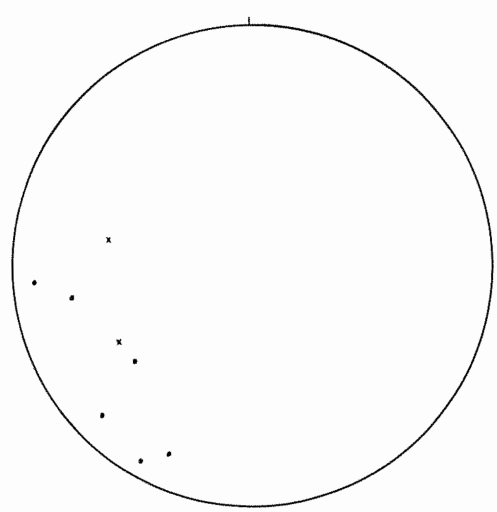

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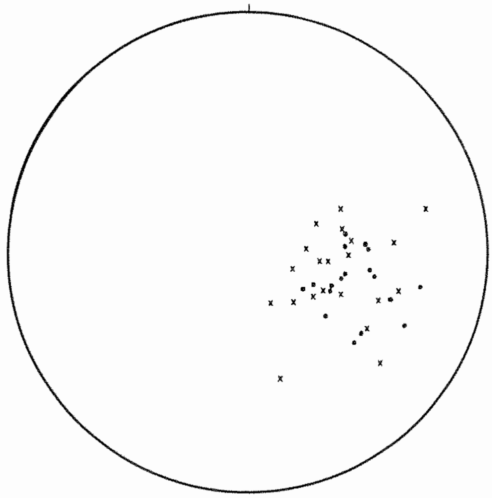

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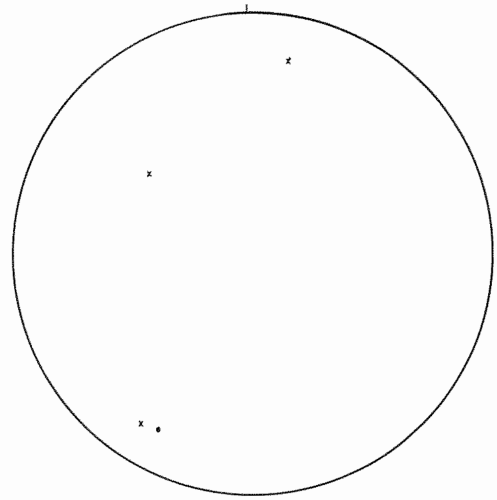

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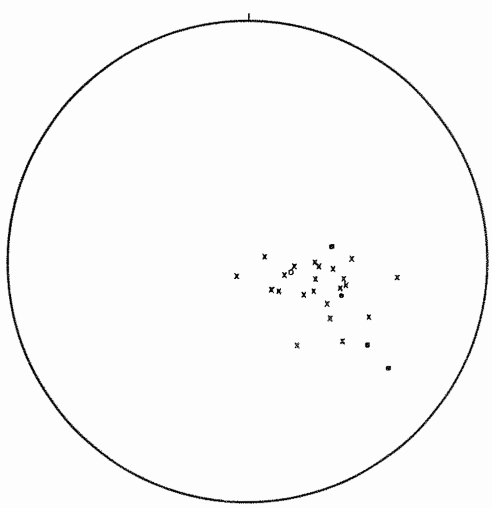

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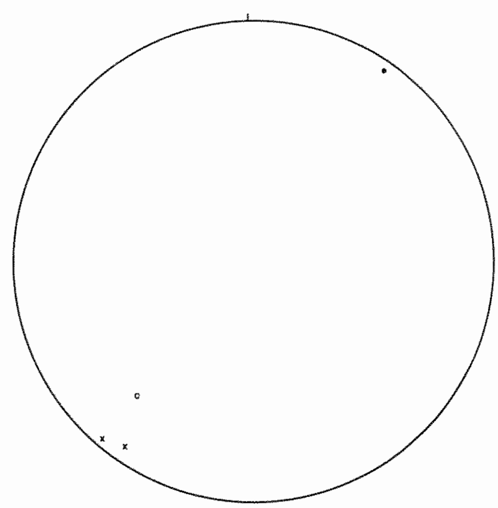

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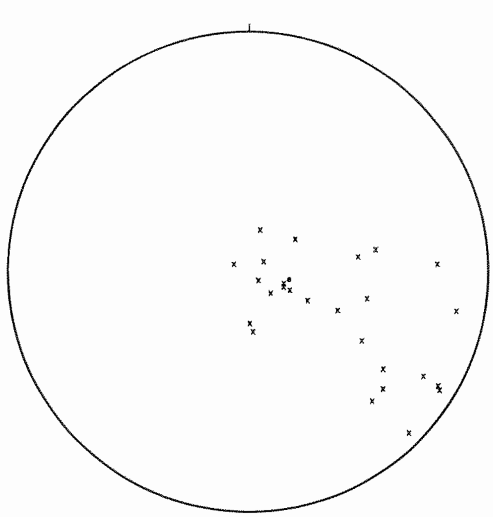

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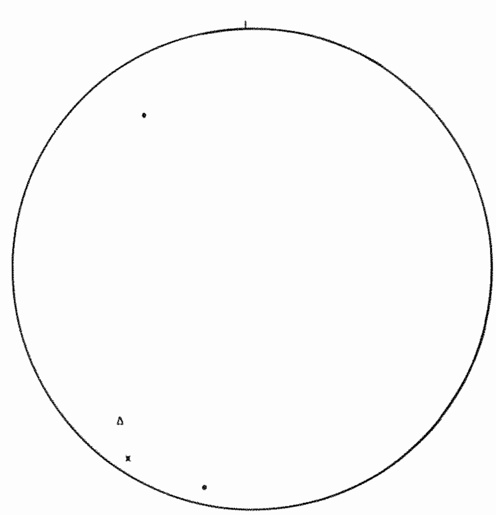

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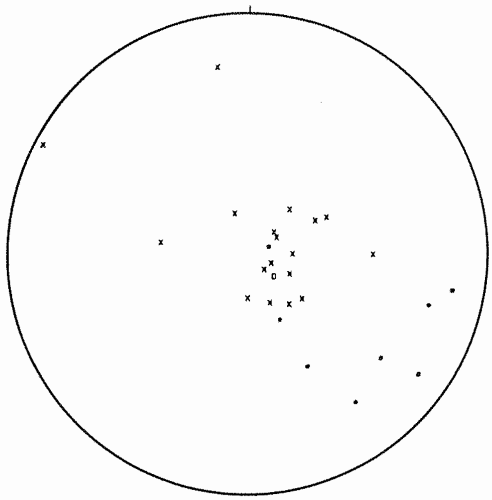

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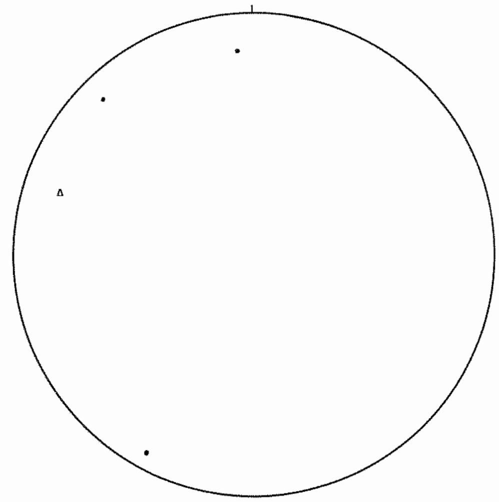

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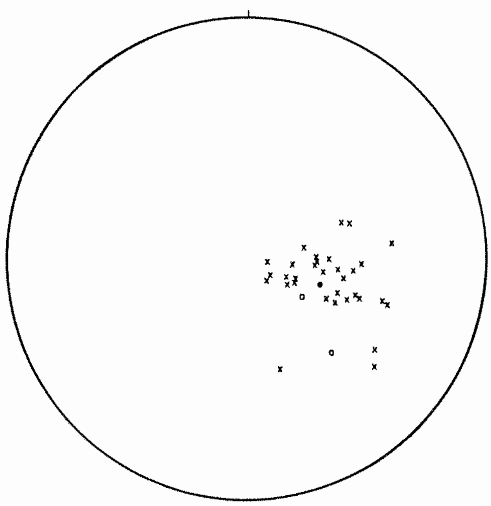

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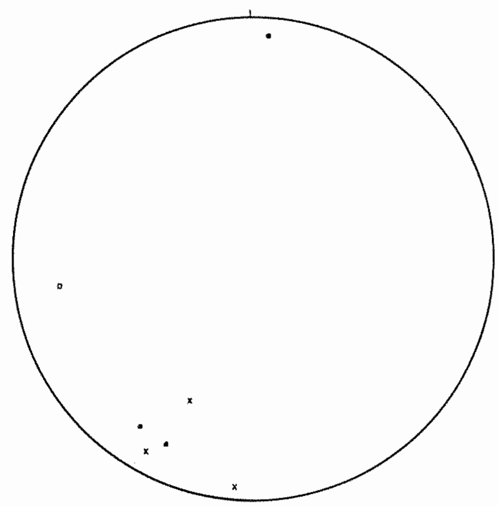

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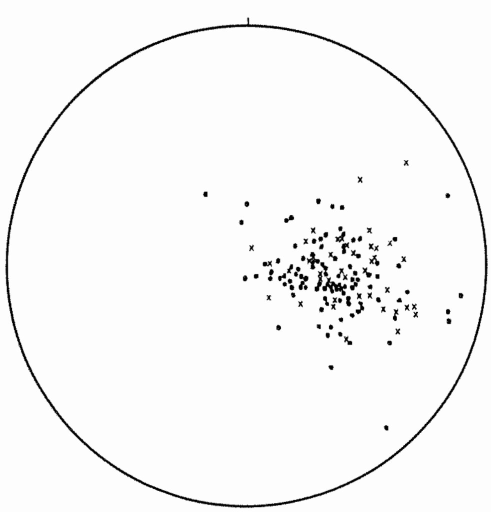

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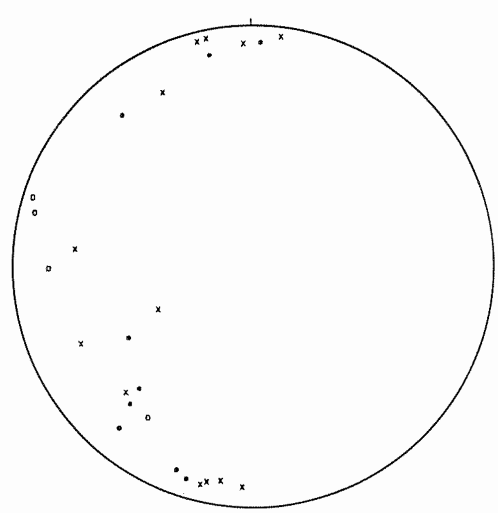

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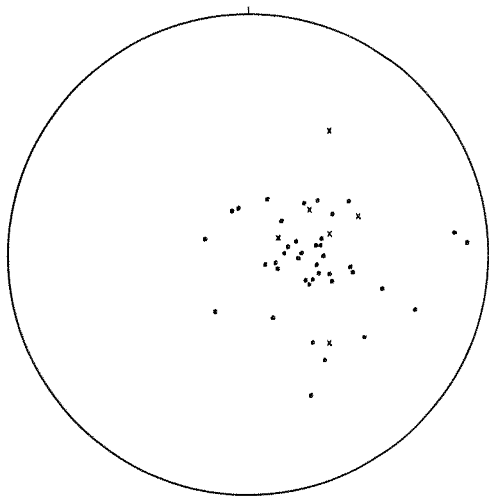

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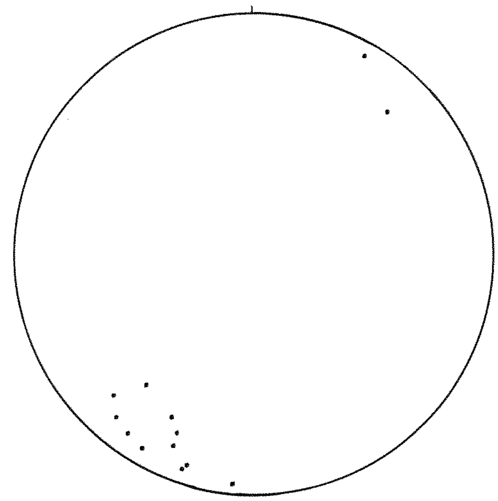

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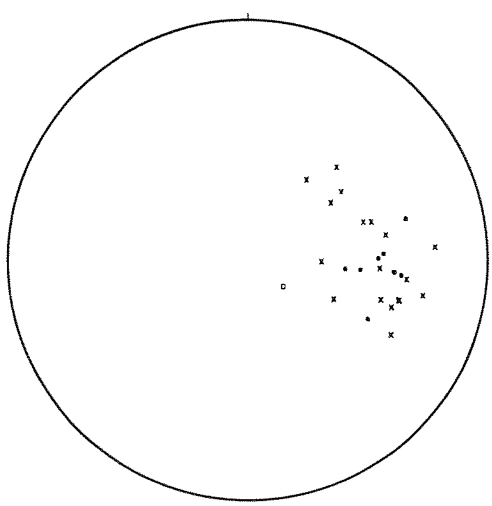

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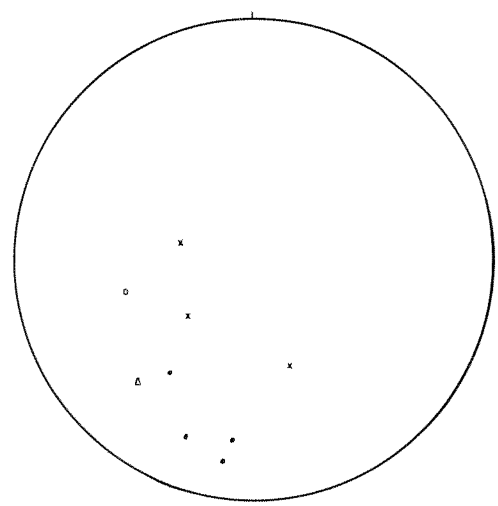

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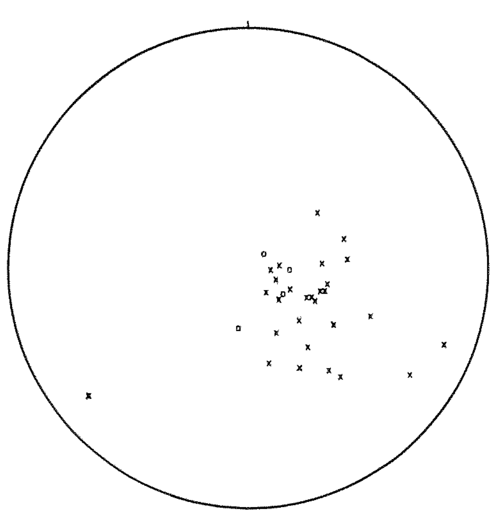

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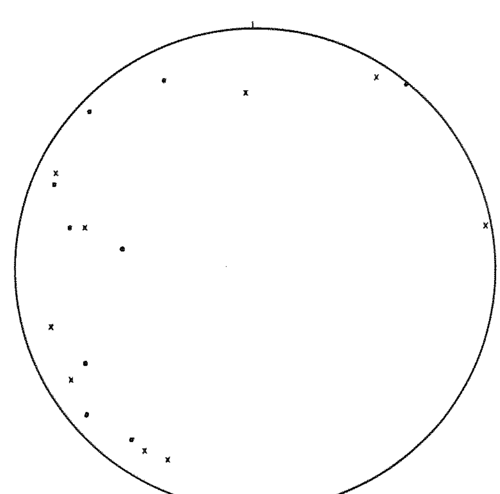

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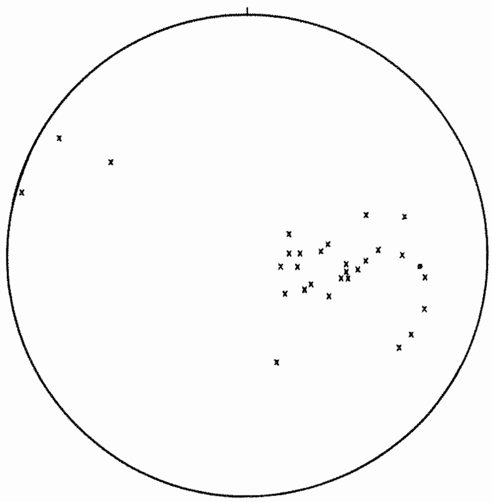

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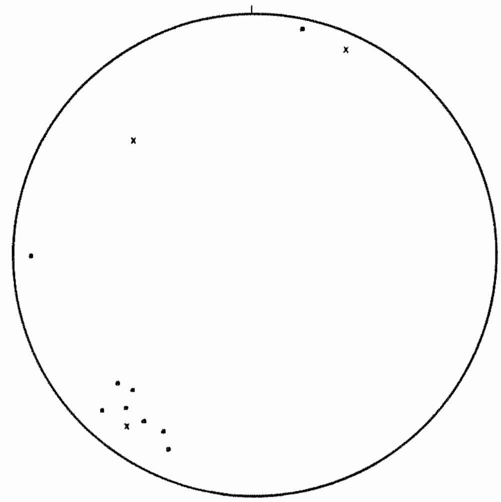

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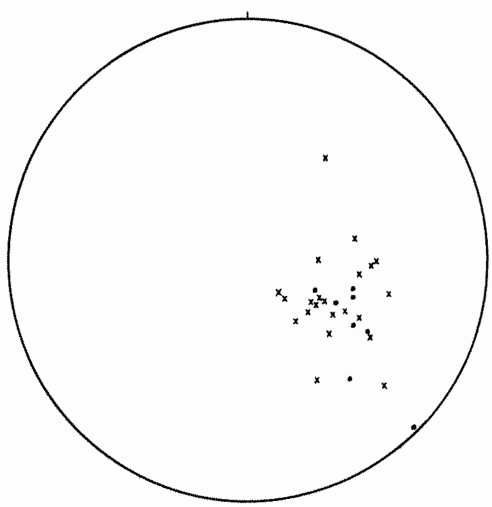

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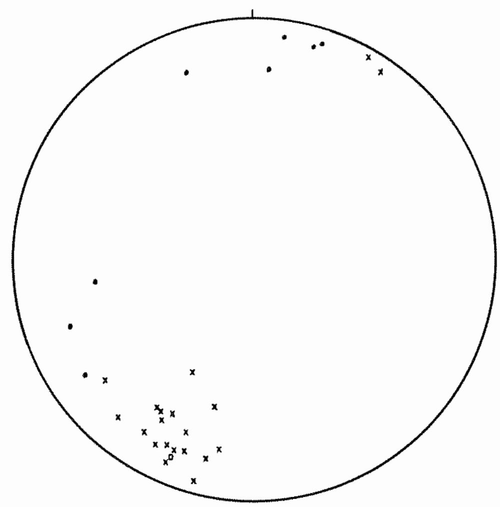

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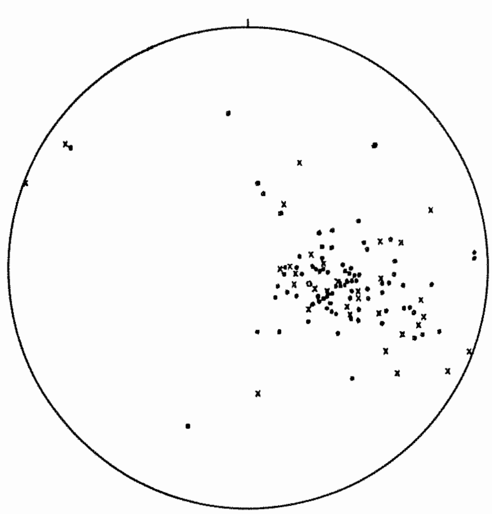

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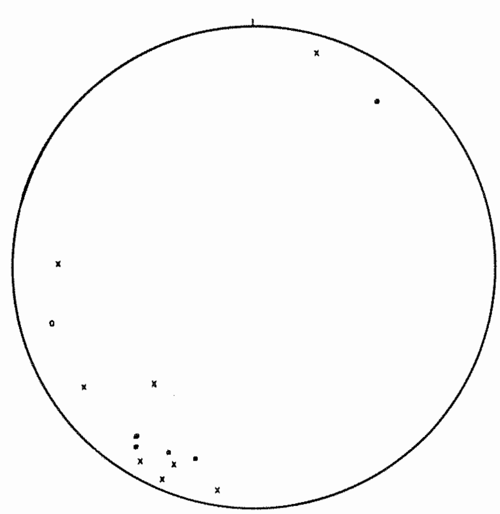

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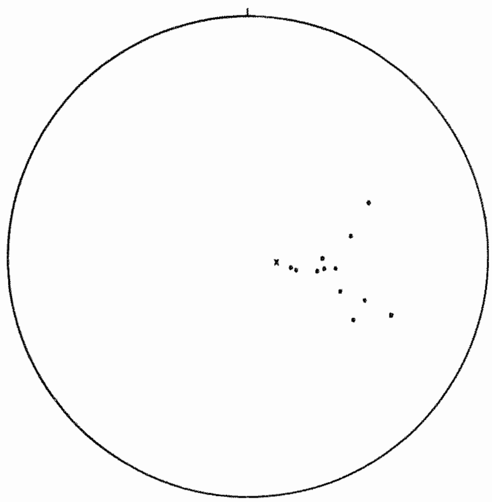

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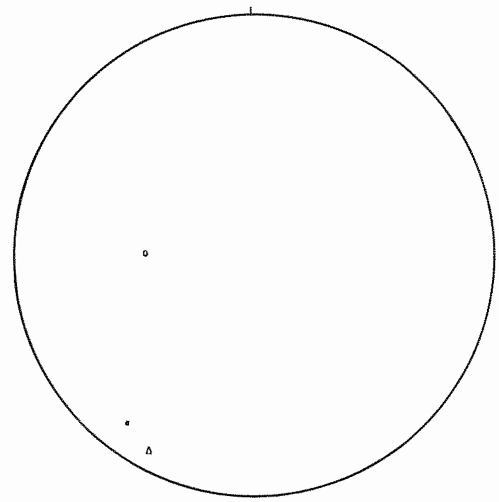

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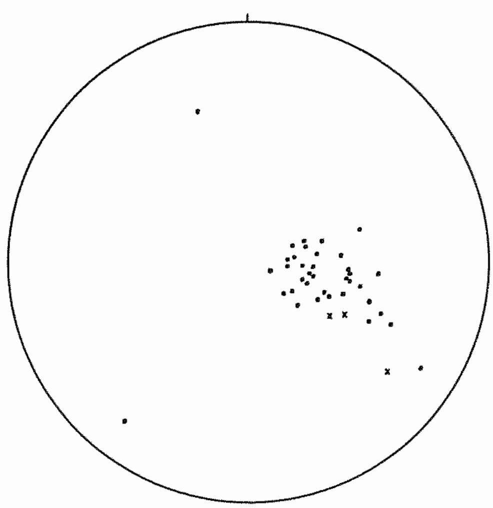

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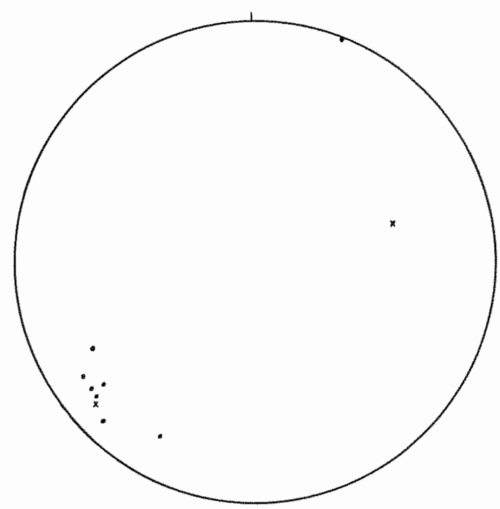

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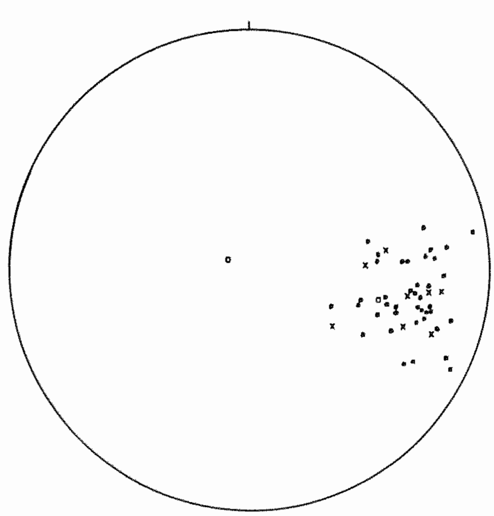

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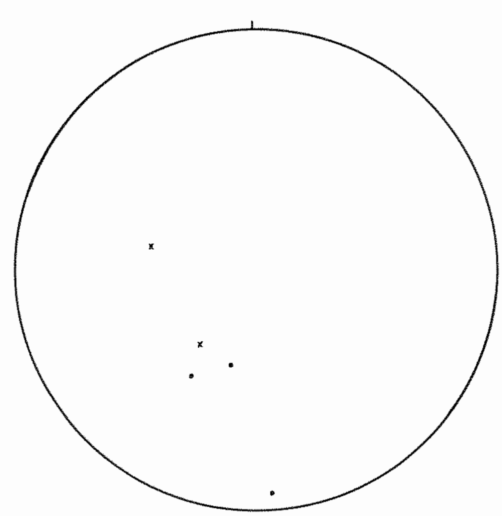

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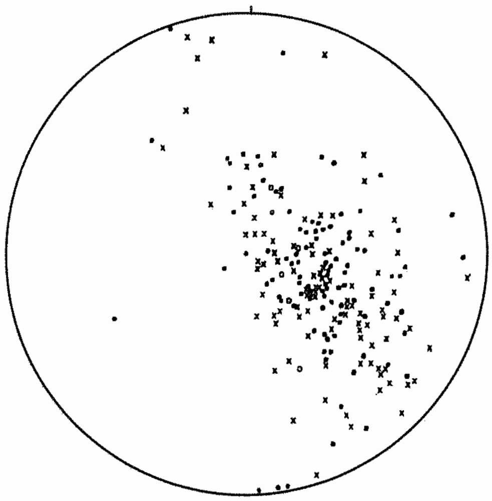

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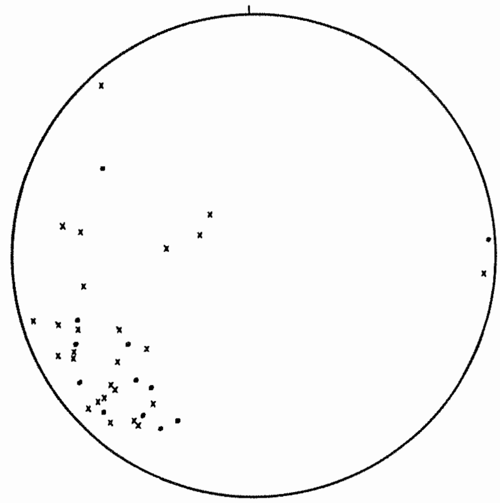

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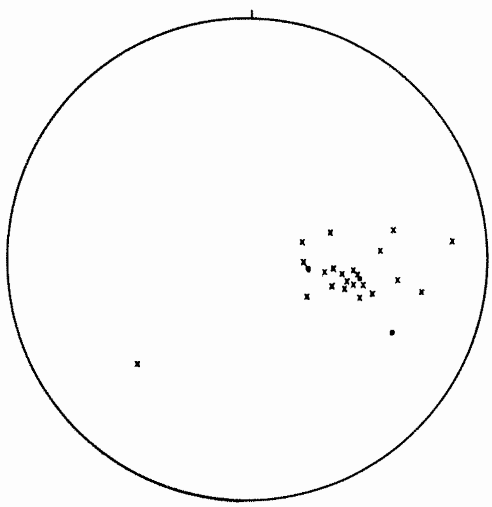

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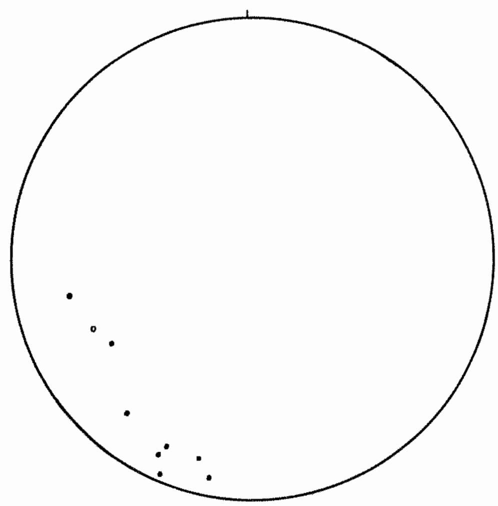

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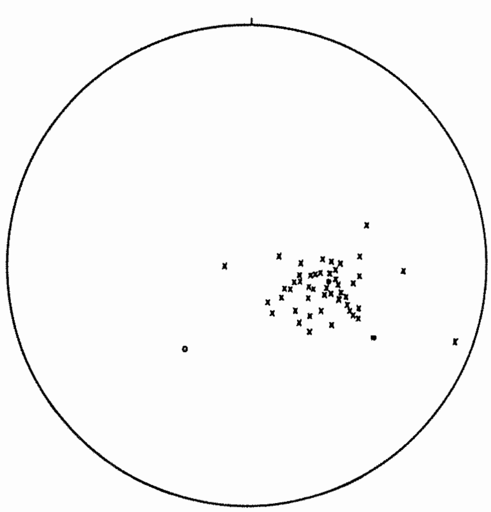

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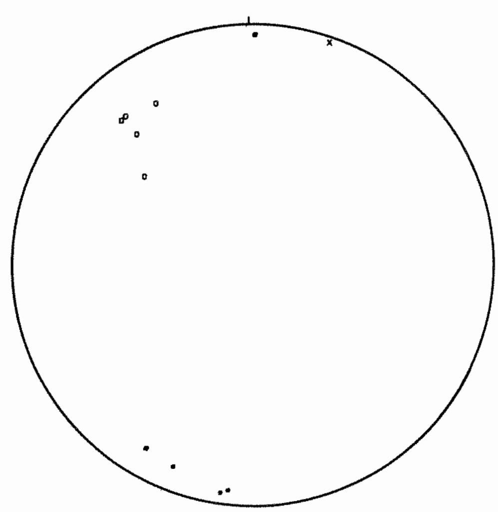

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Patterns of linear features. Equal area diagrams of the mineral lineations and minor fold axes (Figures 19, 20) show that many of them plunge to the south-southwest at about 15 degrees. The other lineations and fold axes form a broad girdle that conforms roughly with the mean attitude of foliation. This is particularly evident in Domain 9 of Figure 20. This girdle is believed to be due to a combination of linear features, as follows: (1) Some of the west and northwest plunging fold axes and mineral lineations may predate the shallow southwest trending ones. This can be demonstrated in the East Brookfield and Barre quadrangles, southeast and northeast of Ware, respectively, where two such sillimanite lineations occur together with clear-cut age relations. (2) Most of the southwest-northeast trending linear features plunge southwest, but some plunge northeast. This can be seen in Domains 9, 14, and 15 of Figure 20. (3) In parts of the area, linear and planar features have been re-oriented up to 30 or 40 degrees by the late open folding. Whatever distinctive groups of linear features there were in the equal area net patterns before this folding are now combined, forming the girdles that are seen in Figures 19 and 20.

Other areas in the region have comparable patterns of linear features. Greene (1970, p. 24; note that his figure captions are transposed) shows the distribution in orientation of minor fold axes and mineral lineations in the Peterborough area of southwest New Hampshire. The majority of minor fold axes lie in the plane of the dominant foliation and plunge gently south-southwest or north-northeast, whereas the average trend of lineations is west or northwest, down-dip. Seiders

(1974, Figure 1), mapping in the Wales quadrangle south of the Warren quadrangle, finds that mineral lineations form a girdle in the plane of foliation, but the lineations plunging northeast are almost as numerous as those plunging southwest.

Major Early Isoclinal Folds

The complex anticlinal body of the Monson Gneiss, considered to be more or less autochthonous basement by Thompson and others (1968, plate 15-1), forms the western boundary of the map area. Major early isoclinal folds form the various belts of schist and igneous rock which characterize the map pattern of the rest of the Ware area (Figure 23; Plate 6). The trend and plunge of axes of these early folds is unknown and must be inferred from the map pattern, not by projection of the southwest-plunging folds which have been superimposed on them. It has been postulated that one of the nappes of the Bronson Hill anticlinorium, the Fall Mountain nappe, is rooted in the western part of the Ware area (Thompson and others, 1968, p. 212-214), and the other early isoclinal anticlines in the Ware area may be the roots of similar high amplitude folds. Because of the great distances along which the anticlines and synclines of the Ware area can be traced, over 30 km (20 mi) in the case of the big garnet and Gilbert Road synclines, it must be concluded that either their axes average nearly horizontal or their amplitudes are extreme compared to their wavelengths.

North Orange syncline. Just east of the main body of the Monson Gneiss is a very narrow syncline of the Partridge Formation. This syncline has been followed southward from a broader belt of Partridge

Formation to the north in the Orange, Massachusetts, area by Thompson and others, (1968, plate 15-1) and in their interpretation may trace into the synclinal axis below the Skitchewaug nappe.

North Orange anticline. East of the narrow North Orange syncline is an equally narrow band of Monson Gneiss, the North Orange band of Robinson (1963, p. 16a), which has been followed south from the Orange area. In the Orange area, Robinson (1963; 1967a) has demonstrated that this feature is a stratigraphic anticline by tracing two members of the Partridge Formation around the north end of the gneiss band and for some miles down the east side. Thompson and others (1968, p. 214) speculated that this anticline might represent involvement of the Partridge-Monson contact in the anticlinal axial zone of the Skitchewaug nappe. If correct, this is the only known case in which pre-Partridge basement rocks are involved in the early regional nappe structures.

West Crescent Street syncline. This syncline and the east Crescent Street syncline of the Littleton Formation lie along the west side of Muddy Brook valley. They are separated by the Ware High School anticline. In the southern part of the map area, the Partridge Formation is found in the core of the Ware High School anticline, but in the north it is not present and the Littleton Formation in the two synclines merges to form a single belt.

Partridge Formation is present in places along the western contact with the North Orange band of the Monson Gneiss. There are several small bodies of Hardwick Quartz Diorite in this syncline and the east Crescent Street syncline, some of which are large enough to show on the map. These are interpreted to be structurally connected with the main body of Hardwick (Figure 21). A large body of Hardwick is found along strike to the north (Figure 15).

Ware High School anticline. This anticline separates the Crescent Street synclines. In the southern part of the area, the core of the anticline is occupied by the Partridge Formation, but it does not appear to be present in the north. Evidence for the location and extent of the anticline is poor. Outcrops of Partridge schist in the Bacon Street area (Figure 4), at and near Ware High School, and north-northwest of Ware, generally on strike with each other, are interpreted to be in the core of this anticline. The position and nature of the northern termination of the Partridge Formation in the anticline is very speculative.

East Crescent Street syncline. This is discussed above with the west Crescent Street syncline.

Muddy Brook anticline. The valley of Muddy Brook is interpreted to be an anticline of Partridge Formation less resistant to erosion than the Littleton Formation which forms the sides of the valley. As in the case of the Ware High School anticline, this is matched with the most likely Partridge belt in the Bacon Street area. North of Bacon Street, there are no outcrops of this belt in the southern half of the map area. There are some outcrops of the red-weathering Lyon Road type of Partridge on the east side of the valley in the northern part of the area, and the Partridge Formation is found in the Quabbin Aqueduct tunnel under the valley. The Muddy Brook anticline has been postulated to be the root zone of the Fall Mountain nappe (Thompson and others, 1968,

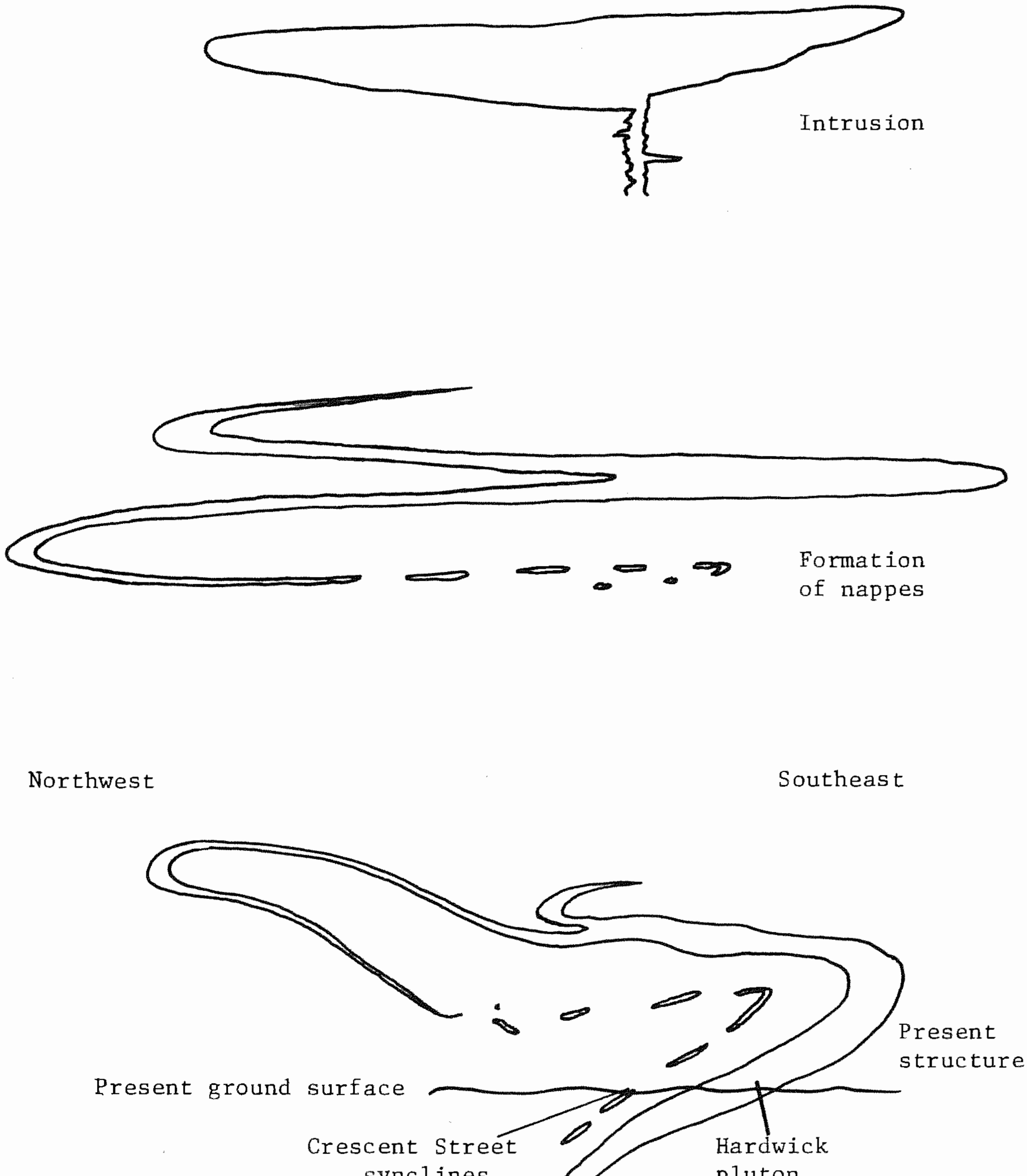


Figure 21. Diagram of possible sequence of folding of the Hardwick Quartz Diorite, to explain its presence in the Crescent Street synclines. All drawings are cross-sections.

p. 212-214).

Hardwick syncline. This conspicuous structure of the area is interpreted to be a syncline of Littleton Formation, the core of which is occupied by a large igneous body, the Hardwick Quartz Diorite. This syncline is much wider than the other early folds in the area, suggesting that either the Hardwick Quartz Diorite formed a large resistant unit during folding or that there are several undetected folds within the Hardwick. As discussed in the description of the Hardwick, control on the contacts is very poor, but it does appear to be bordered by Littleton Formation on the west side and on the southern part of the east side. In samples from the Quabbin Aqueduct tunnel, identical gray schists are seen on both sides of the Hardwick.

Some schist inclusions are found within the Hardwick Quartz Diorite. The large apparent inclusions on Goat Hill are interpreted to be part of a late stage syncline that deforms the eastern contact (see below). The other small inclusions of schist are not easily explained.

The Hardwick pluton becomes extremely narrow to the south in the Bacon Street area, where it is only 20 m (60 ft) wide and mylonitized, but very distinctive in thin section. Here it is bordered by the Littleton Formation.

Lyon Road anticline. The Partridge Formation in this anticline appears to be continuous with that in the Ragged Hill anticline in the southern part of the area, but farther north the two anticlines are separated by the Ragged Hill syncline. The Lyon Road anticline has an irregular map pattern, being 1.3 km (0.8 mi) wide in the south-central part of the area, but becoming very narrow northward. Because of poor outcrop this anticline could not be distinguished from the Ragged Hill anticline in the north.

Ragged Hill syncline. This syncline of Littleton Formation is exposed on the south slopes of Ragged Hill, the hills south of there and a few places near Sibley Road (Figure 4) in the central part of the area. It and the Ragged Hill anticline are extrapolated to the northern limit of the map area, although with one exception they are not seen north of the Ware River. The main body of Littleton Formation appears to pinch out before the syncline gets as far south as Route 9, but the syncline axial surface apparently continues southward from there, because small lenses of Littleton occur just west of the gneiss of Ragged Hill as far as the southern boundary of the map area.

Ragged Hill anticline. The axial surface of this anticline lies in Partridge Formation just west of the thin belt of Fitch Formation. The intrusive gneiss of Ragged Hill is confined to this anticline, at various stratigraphic positions. In the south, this anticline becomes very narrow and the Partridge Formation in it merges with the Partridge in the Lyon Road anticline, but the two structures are separated by the Ragged Hill syncline.

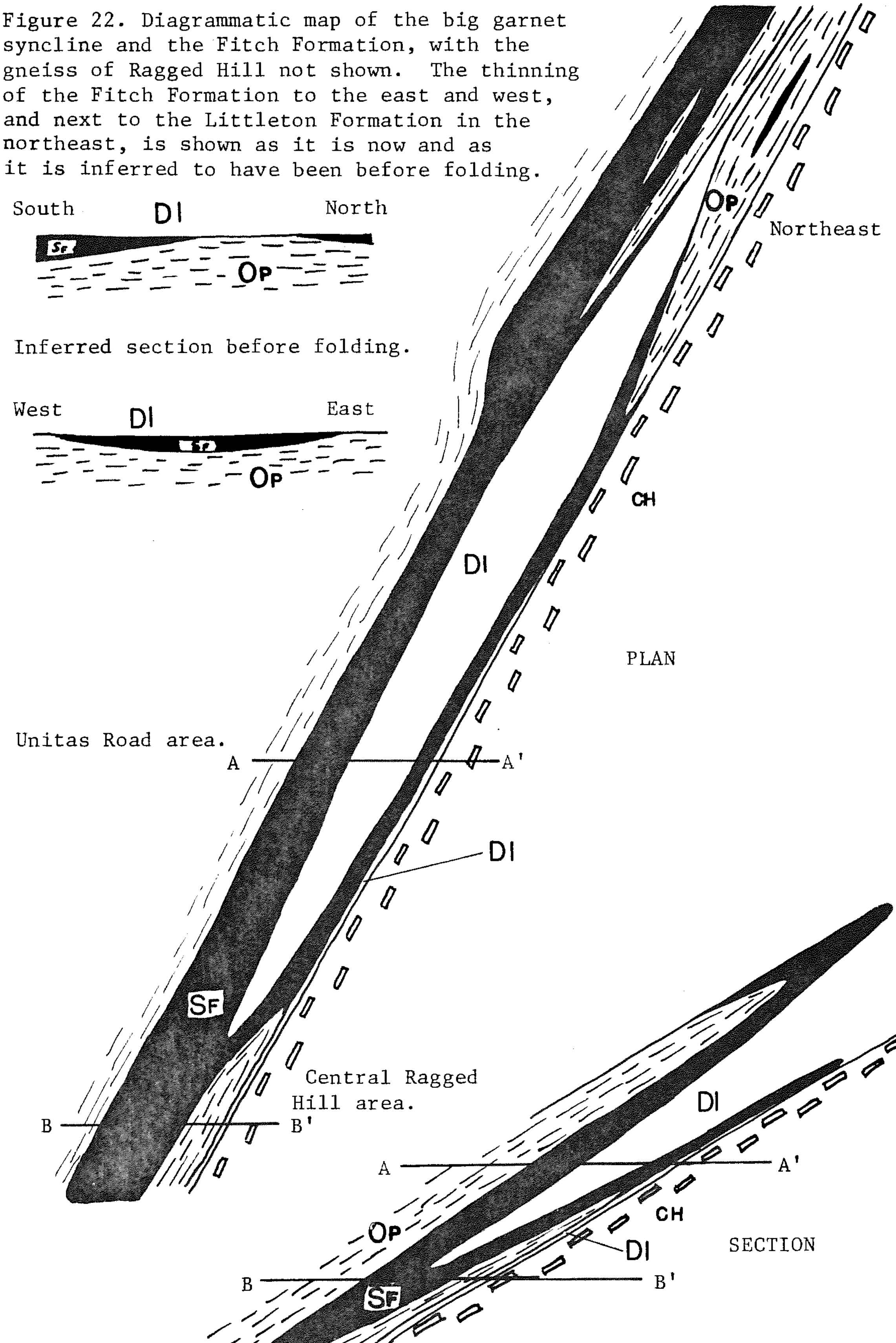
Big garnet syncline. The main body of the big garnet unit of the Littleton Formation occupies this syncline in the central and northern part of the area. South of Ragged Hill, the Littleton pinches out and the syncline is occupied by a comparatively wide belt of Fitch Formation. In the north, the Littleton Formation becomes very narrow but apparently does not pinch out altogether. The same syncline has been recognized in the western part of the Templeton quadrangle (Robinson, personal communication, 1973). Graded bedding on the west limb of this syncline on Ragged Hill in the central part of the Ware area indicates that the Littleton is stratigraphically above the Fitch. Figure 22 is a simplified map of the big garnet syncline and the Fitch Formation without the gneiss of Ragged Hill, so the form of the syncline can be seen, as well as the thinning of the Fitch next to the big garnet unit in the north.

West Coys Hill anticline. This is a very narrow feature, usually shown by the presence of a thin (10 m [30 ft] wide) belt of Fitch Formation east of the main body of big garnet Littleton and west of the thin big garnet belt next to the Coys Hill Granite. The Partridge Formation is also seen in this anticline, east of Ragged Hill and in the northeast part of the map area.

Coys Hill syncline. This is interpreted to be a syncline of Devonian rock consisting largely of the Coys Hill Granite with a very narrow belt of big garnet Littleton Formation along the west side. The Littleton is not found at the east contact of the Coys Hill, but a few patches of Fitch Formation and the gneiss of Ragged Hill are. This is similar to the relationship of the Hardwick Quartz Diorite with surrounding schists, the western boundary being consistently with Devonian rocks, the eastern boundary with older rocks in part.

Unitas Road anticline. This is the anticline of Partridge Formation just east of the Coys Hill Granite. The map pattern of this belt has a rather irregular shape which is partly explained by the effects of later folding, which widen the belt in the south.

Figure 22. Diagrammatic map of the big garnet syncline and the Fitch Formation, with the gneiss of Ragged Hill not shown. The thinning of the Fitch Formation to the east and west, and next to the Littleton Formation in the northeast, is shown as it is now and as it is inferred to have been before folding.



Prouty Road syncline. This is a syncline of Littleton schist, with the core occupied by the Feldspar Gneiss and Orthopyroxene Gneiss Members of the Littleton Formation. The Feldspar Gneiss Member is also present at the eastern contact of this belt of Littleton. To the south, in the Warren quadrangle, this belt strikes into and is identical to part of the belt of Mt. Pisgah Formation as shown by Pomeroy (in press). In the southern part of the Warren quadrangle, Pomeroy shows the Mt. Pisgah belt as a syncline on the basis of graded bedding. Graded bedding on the east limb in the southern part of the Ware area indicates that the Littleton is stratigraphically above the Partridge Formation. In the northern part of the Ware area, this syncline appears to be occupied almost entirely by the Feldspar Gneiss Member.

Lamberton Brook anticline. This is an anticline of the Partridge Formation. This and the belts of Littleton Formation on either side of it are very poorly exposed in the north-central part of the map area, and they are traced into the belts in the north on the basis of lithologic matching.

Gilbert Road syncline. The belt of well bedded Littleton occupying this syncline is at least 32 km (20 mi) long, despite the fact that it is only 200-300 m (800-1000 ft) wide.

Wickaboag Pond anticline. This anticline is cored by the largest belt of Partridge Formation in the Ware area, but despite its width, no rocks below the Partridge are exposed. It appears that it is an anticline of great amplitude, because the post-Ordovician rocks on either side are completely different, implying that a gradual facies change has been telescoped by folding.

The syncline shown in the center of this belt in the cross-sections (Plate 2) is an interpretation of the map of Pomeroy (in press). Pomeroy shows a narrow belt of Littleton lithology, designated hush by him, in the southern three-quarters of the Warren quadrangle. This is interpreted here as a syncline whose axis plunges south in the northern part of the Warren quadrangle so that the belt of Littleton is not found in the syncline in the Ware quadrangle.

Wigwam Hill synclines. The Paxton schist is interpreted to occupy a synclinal complex in the southeast part of the map area. Emerson (1917) showed this belt of Paxton in a map pattern possibly suggesting a syncline plunging gently to the north. It is uncertain what phase of folding formed these synclines, and Robinson (1966) has suggested that it may be the intermediate stage.

The several belts of the sulfidic white schist unit within the Paxton Schist are interpreted to occur along the axial traces of isoclinal anticlines. This interpretation may change as further mapping is done in the Paxton, and it is possible that there is more than one unit of sulfidic white schist.

Folds of Intermediate Stage

Unlike the Orange and Quabbin Reservoir areas (Robinson, 1967a, 1967b) no direct evidence for this stage of folding was found in the Ware area. It is based on evidence from other areas and on the argument that in the region in general, east over west folded nappes have been demonstrated in the Bronson Hill anticlinorium (Thompson and others, 1968) but the west-dipping foliations in the Ware area require the existence of a later period of folding. Robinson (1966) has suggested that the hinge for a major syncline of this period may lie within the Wigwam Hill synclines of Paxton Schist (Figures 23 and 24, this report). Some major folds described as early isoclinal folds may actually be folds of this stage, and the general map pattern of the area is primarily the resultant of these two stages of folding.

Much of the map pattern of the Ware area could be explained by a series of imbricate thrust faults. There is limited evidence to disprove this, but there are reasons for preferring the interpretation of this report. Some of the nappes in the Bronson Hill anticlinorium are believed to come from the Ware area (Thompson and others, 1968, p. 213-214), and the presence of these extremely elongate plastic structures suggests that other structures in the area are also plastic. The limited occurrences of graded bedding support the fold hypothesis, as does the fairly regular nature of repetition of the belts of the Partridge and Littleton Formations. Thrust faults, now obscured by later events, may well be present and may explain such features as the repetition of the sulfidic white schist unit of the Paxton Schist, but isoclinal folds are believed to be the best explanation for most of the map pattern in the Ware area.

Zones of Cataclasis

Many of the rocks west of Muddy Brook, particularly in the Littleton Formation and in the Bacon Street area (Figure 4), have undergone various degrees of mylonitization. Some mylonitization is also found in the western part of the Hardwick QUartz Diorite about 2 km (1 1/2 mi) north of Ware and in the Monson Gneiss in the northwest part of the area. The mylonitization is believed to have taken place at an intermediate stage because in every case observed in thin section, the mylonitized matrix of these rocks shows evidence of thorough metamorphic recrystallization. The relative age of the mylonite probably corresponds with that found by Robinson (1967b, p. 125, 127) in the Quabbin Reservoir area west of Ware, where the mylonitic rocks postdate the first two phases of folding but are deformed by the last one.

The location of these areas in a zone generally parallel to the Monson Gneiss contact raises the question of whether the mylonitization is caused by movement along this transitional zone between the Bronson Hill anticlinorium basement and the overlying schists. In fact, a Monson border fault is postulated by personnel of the U. S. Geological Survey mapping to the south. However, no major stratigraphic change is seen across this mylonitized zone, or between the Bronson Hill anticlinorium in general and the Ware area. There may be movement along the zone, but its direction and amount are unknown.

A possible reinterpretation of the southwest part of the map area is to connect the small body of Hardwick Quartz Diorite in the southwest corner with the small bodies of Hardwick west of Muddy Brook in the Crescent Street synclines, and to interpret it as a mylonitized zone of schist with small bodies of Hardwick caught up in it. However, the interpretation of this report is a better fit to all of the data.

Folds of Late Stage with Associated Second Foliation

Most of the minor folds in the area (Figure 17), the large fold on Coys Hill and the small folds in the southwest part of the area are dextral folds with shallow west-dipping axial planes. The second foliation is believed to be the axial plane foliation of this stage of folding. The large fold on Coys Hill is interpreted to trend northward with an undulating axis and to be the cause of the infold of schist within the Hardwick pluton just east of Goat Hill (Plates 2, 6).

Some folds of this generation are believed to be present south of the town of Ware and are shown in the map pattern. Another group of folds of this stage is shown in the northeast part of the area. These folds in the northeast are rather abrupt, and the outcrop pattern could be explained by faulting, but the map pattern and variation in attitudes are similar to those of other folds of this stage.

Late Open Folding

Late open folds with west-southwest trending axes locally deform all earlier foliations and lineations and affect the map pattern (Plates 1 and 6; Figure 23). These folds deform the earlier structures in a broad, smooth manner, whereas those associated with the second foliation deform earlier structures to a much greater degree. Folds of this generation are found mainly in the central part of the map area. Some representative fold axes are shown in Figure 19. In this figure, each arc connects poles of representative foliation planes from some of the late open folds seen in the map pattern. Poles to the planes defined by these arcs, representing the late open folds, are shown as large circles in the southwest quadrant of the net.

Post-Metamorphic Brittle Fractures

The diabase dike is assumed to be of similar age to the Triassic-Jurassic dikes elsewhere in southern New England, and the fracture along which it intrudes is presumably of this age. No faults were found in the area, and minor fractures were not studied.

Construction of Cross-Sections

The attitudes of bedding and foliation used to contruct the cross-sections are a combination of individual attitudes on or near the line of section and the average attitude in the domains crossed by the section. The map pattern is largely the result of the earlier stages of folding, with few hinges exposed in the area. Mineral lineations and late stage minor folds are superimposed on these. Axial projections of early folds were not possible because axial orientations are not known and exposed axes are scarce, so the cross-sections rely primarily on the map pattern. The late stage folds associated with the second foliation were projected.

There is a problem in the Quabbin Aqueduct section (Plate 2, section A-A') east of the Hardwick pluton. The location of contacts of the Hardwick Quartz Diorite and Coys Hill Granite are considerably westward from those contacts on the ground. All of the aqueduct data in Fahlquist's (1935) report and on the labels of specimens stored at the Ware River intake works are internally consistent, implying that the offset of contacts is a geologic fact, not an error in recording data, but it requires considerable thinning of units in the cross-section. An alternative explanation would be that there are faults in this area.

A regional cross-section and a schematic diagram illustrating the major phases of folding are shown in Figures 24 and 23. The cross-section shows the major nappes found in the region, which have too great an amplitude to show in the cross-sections on Plate 2. The shallow foliation attitudes found east of the Ware area (Fahlquist, 1935) are also shown on Figure 24.

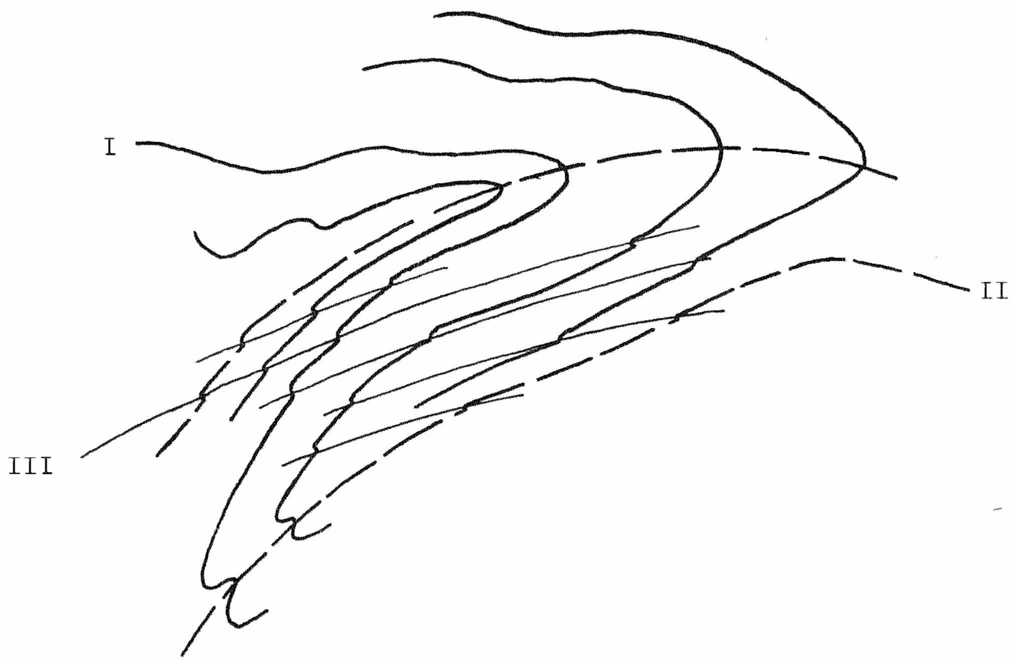


Figure 23. Schematic diagram of the axial surfaces of the major phases of folding. The scale is the same as in Figure 19.

I--Major early isoclinal folds
II--Folds of intermediate stage
III--Folds of late stage with associated second foliation

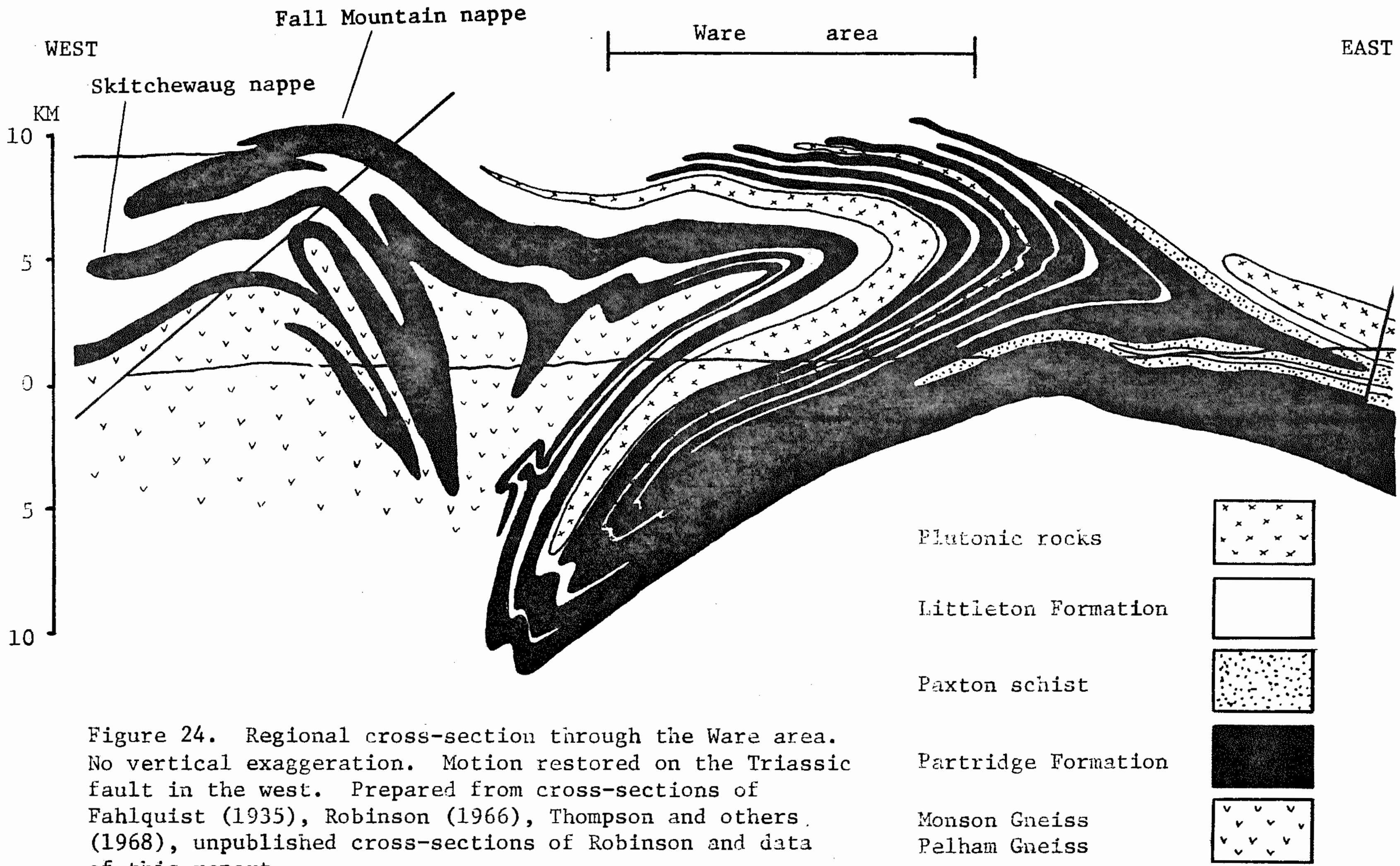


Figure 24. Regional cross-section through the Ware area. No vertical exaggeration. Motion restored on the Triassic fault in the west. Prepared from cross-sections of Fahlquist (1935), Robinson (1966), Thompson and others (1968), unpublished cross-sections of Robinson and data of this report.

METAMORPHISM

The Ware area appears to lie entirely within the sillimanite-potassic feldspar zone of metamorphism of pelitic schists in central New England, as shown by Thompson and Norton (1968), and the portion east of the Hardwick Quartz Diorite is characterized by the assemblage quartz-potassic feldspar-sillimanite-garnet-cordierite similar to rocks in the Sturbridge area to the southeast studied earlier by Barker (1962) and Hess (1969, 1971). The absence of cordierite in pelitic schists west of the Hardwick Quartz Diorite seems to indicate a transition toward lower grade conditions and eventually toward the sillimanite-potassic feldspar to sillimanite-muscovite transition zone in the central part of the Winsor Dam quadrangle studied in detail by Tracy (1975). Presence of a kyanite-staurolite to sillimanite-staurolite transition in the western part of the Winsor Dam quadrangle places the area in context and suggests metamorphism under pressure conditions above the Al_2SiO_5 triple point. Reconnaissance and specimens from the Quabbin Aqueduct tunnel indicate that muscovite may be stable east of the Ware quadrangle as well. The Ware area thus lies astride the belt of highest grade regional metamorphism known in New England.

Pelitic Rocks

The garnet-cordierite assemblage referred to above is found in many outcrops east of the Hardwick Quartz Diorite pluton and west of the Paxton Schist (Figure 25; Tables 2, 7, 16, 17) and is more

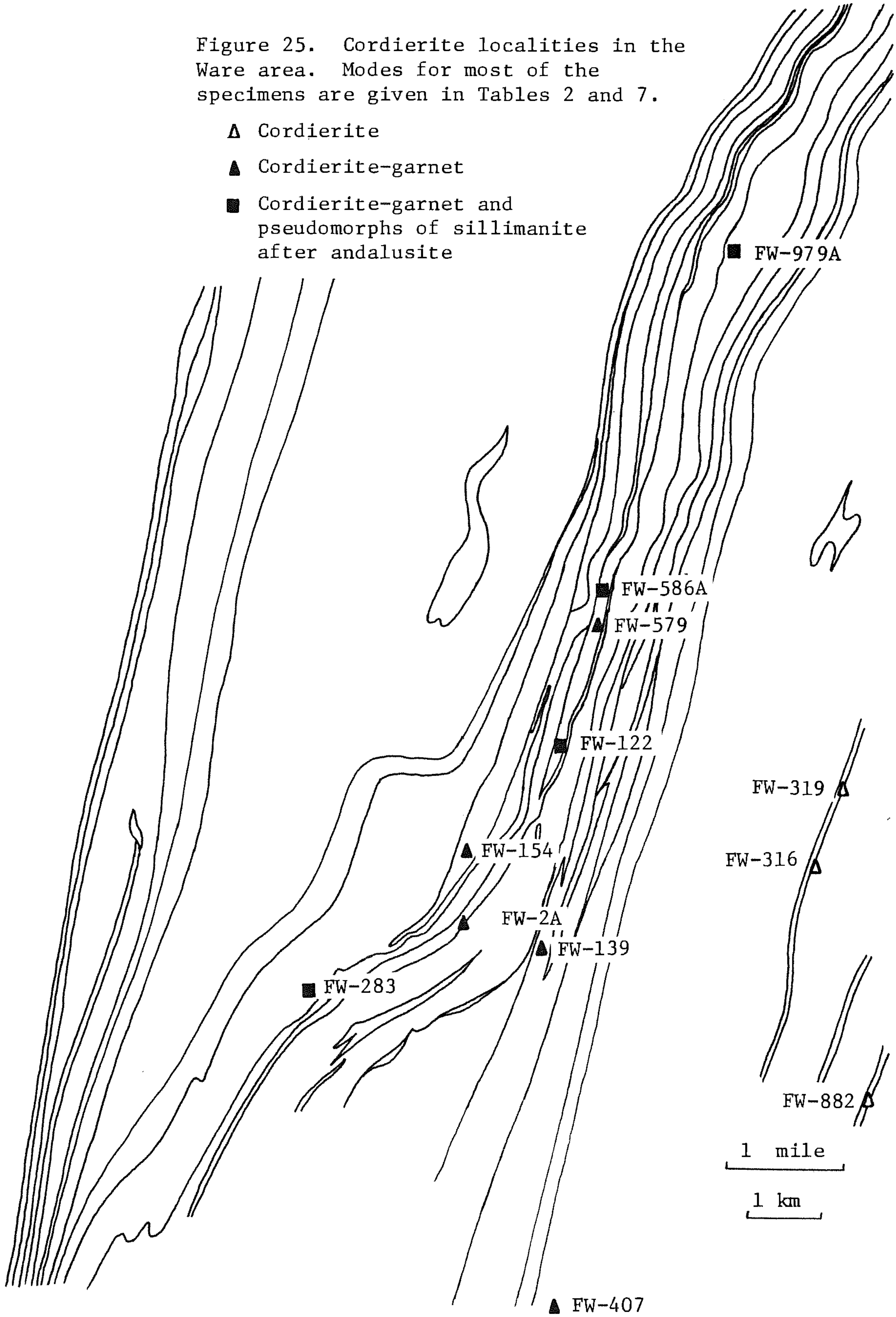


Figure 25. Cordierite localities in the Ware area. Modes for most of the specimens are given in Tables 2 and 7.

Δ Cordierite

▲ Cordierite-garnet

■ Cordierite-garnet and pseudomorphs of sillimanite after andalusite completely described as:

Quartz-orthoclase-(oligoclase/andesine)-biotite-sillimanite-garnet-cordierite-ilmenite.

Pseudomorphs of sillimanite after andalusite are found in several places (Figures 25, 26) in these rocks. The same assemblage without cordierite is common in the pelitic rocks of the area both east and west of the Hardwick pluton. Sillimanite and cordierite are not found in the gray Paxton Schist because of its low aluminum and high calcium content. Sillimanite and cordierite are found in the sulfidic white schist member of the Paxton Schist (Tables 6, 18), but this is a rock of extremely magnesian composition and should not be compared with the typical pelitic schists of the area.

Wynne-Edwards and Hay (1963, p. 472), studying the assemblage quartz-orthoclase-biotite-sillimanite-garnet-cordierite in southeastern Ontario, find that cordierite occurs in rocks low in calcium and hence low in plagioclase. The evidence in the Ware area is compatible with these findings, as those rocks with cordierites have little or no plagioclase (Tables 2, 7). Winkler (1965) has found that in metamorphic rocks with high calcium content, the alumina goes into the formation of plagioclase, leaving an insufficient amount to form cordierite. In the Ware area, cordierite is found in rocks that are both low in plagioclase and high in sillimanite content. It is possible that cordierite might be found west of the Hardwick pluton in rocks of appropriate composition, but since none has been found, the pluton is taken as the western boundary of the garnet-cordierite assemblage.

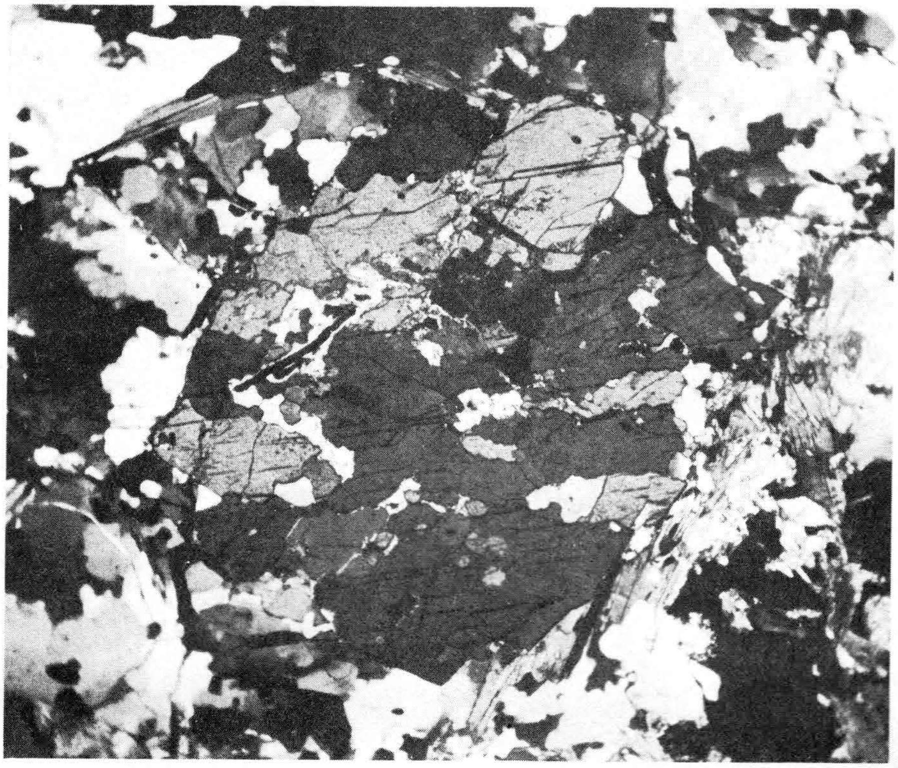


Figure 26. Microphotograph of a pseudomorph of sillimanite after an andalusite crystal. The pseudomorph is about 2 mm wide. Crossed polars.

Compositions of minerals from four rocks, based on electron probe analyses in Tables 16, 17, and 18, are plotted in the K feldspar projection (Barker, 1962) in Figure 27. As in the case of the rocks studied by Hess (1971), the outer edges of the garnets show retrograde effects and only the core compositions are listed and plotted. Detailed examination of phase relations in these rocks (Tracy, Robinson, and A. B. Thompson, in preparation) suggests the cordierite composition

Table 16. Electron microprobe analyses of minerals in FW-407, Partridge Formation in the Wickaboag Pond anticline.

Oxides	Garnet	Cordierite	Biotite
SiO_2	37.45	48.35	35.79
TiO_2	.06	.00	4.34
Al_2O_3	21.51	32.78	17.12
Cr_2O_3	.08	.02	.08
FeO	33.62	6.77	16.43
MnO	1.20	.00	.06
MgO	6.33	9.54	12.33
CaO	1.11	.01	.01
Na_2O	.02	.06	.09
K_2O	.01	.00	8.50
Total	101.33	97.31	94.69

Formula	Cations per		
	12ox	18ox	11ox
Si	2.938	4.982	2.937
Ti	.003		.267
Al	1.99	3.983	1.656
Cr	.005		.005
Fe	2.207	.584	1.128
Mn	.079		.003
Mg	.74	1.466	1.509
Ca	.092		.001
Na	.002	.012	.014
K	.000		.89
Total	8.061	11.027	8.415

Table 17. Electron microprobe analyses of minerals in the Littleton Formation.

Oxides

	Kfs	Plag	Gar	Cord	Biot	Ilm	Kfs	Gar	Cord	Biot
SiO_2	64.31	58.68	37.67	47.89	35.36	0.17	64.14	38.54	49.16	36.13
TiO_2	.09	.05	.07	.00	4.28	50.63	.00	.05	.00	4.07
Al_2O_3	18.94	24.91	20.70	34.38	18.62	.20	18.94	21.94	33.62	18.00
Cr_2O_3	.00	.00	.15	.00	.07	.20	.00	.03	.00	.09
FeO	.00	.07	32.11	6.66	16.43	45.57	.00	31.67	5.40	14.82
MnO	.00	.01	1.29	.00	.06	.62	.02	.89	.00	.03
MgO	.00	.00	6.26	9.25	12.03	.50	.02	6.13	10.03	12.91
CaO	.04	6.54	1.25	.00	.00	.00	.03	.95	.00	.02
BaO	.41	.00	.10	.00	.40	---				
Na_2O	2.13	9.98	.00	.28	.02	.00	1.81	.00	.10	.24
K_2O	13.50	.09	.01	.00	9.58	.05	13.96	.00	.00	9.21
Total	99.42	100.31	99.61	98.45	96.86	97.92	98.92	100.20	98.32	95.51

Formula Cations per

	8ox	8ox	12ox	18ox	11ox	3ox	8ox	12ox	18ox	11ox
Si	2.972	2.633	2.991	4.892	2.622	.004	2.975	3.013	4.987	2.683
Al	.028		.009	1.108	1.378	.006				
	3.000		3.000	6.000	4.000					
Al	1.004	1.316	1.929	3.032	.247		1.034	2.021	4.020	1.576
Ti	.003	.001	.002	.000	.236	.981	.000	.002		.227
Cr	.000	.000	.009	.000	.004	.004	.000	.000		.004
Fe	.000	.002	2.133	.569	1.019	.981	.000	2.070	.455	.919
Mn	.000	.000	.086	.000	.001	.014	.000	.057		.000
Mg	.000	.000	.740	1.408	1.330	.019	.000	.713	1.516	1.427
					2.837					
Ca	.002	.313	.105	.000	.000	.000	.001	.078		.000
Ba	.007	.000	.002	.000	.011					
Na	.191	.867	.000	.055	.001	.000	.162	.000	.021	.032
K	.796	.004	.000	.000	.876	.002	.826	.000	.018	.872
Total	2.003	5.137	5.006	5.064	.917	2.011	4.998	7.955	11.007	7.739

Table 18. Electron microprobe analyses of minerals in the sulfidic white schist unit of the Paxton Schist. (FW-882)

Oxides	Biot	Cord	Kfs	Plag	Sill
SiO_2	40.68	50.09	65.23	56.94	37.03
TiO_2	1.48	.00	.00	.00	.00
Al_2O_3	19.64	34.43	18.98	28.44	62.78
Cr_2O_3	.00	.00	.00	.00	.00
FeO	.04	.00	.02	.00	.00
MnO	.07	.08	.06	.00	.05
MgO	24.02	14.18	.02	.02	.07
CaO	.03	.04	.05	6.79	.00
Na_2O	.16	.14	.95	6.62	.03
K_2O	10.39	.01	15.59	.15	.02
Total	96.51	98.57	100.90	98.90	99.98

Formula	Cations per			
	11ox	18ox	8ox	8ox
Si	2.778	4.939	2.981	2.560
Al	1.222	1.061	.079	1.440
	4.000	6.000	4.000	4.000
Al	.357	2.94	.003	.067
Ti	.074	.000	.000	.00
Fe	.002	.000	.000	.00
Mn	.004	.005	.001	.00
Mg	2.446	2.083	.00	.00
Ca	.002	.002	.001	.327
Na	.020	.036	.083	.576
K	.904	.000	.909	.008
Total	3.809	5.056	.997	.978

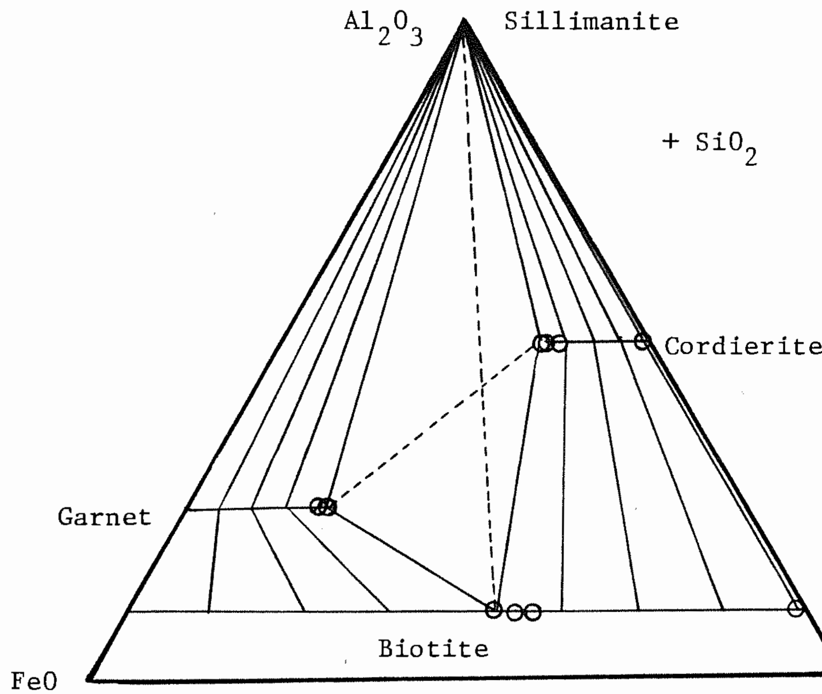


Figure 27. Tetrahedron K_2O-FeO-MgO-Al_2O_3 projected from $KAlO_2$ to the opposite face, showing the assemblage garnet-biotite-cordierite-sillimanite in FW-122. Other analyses from other minerals in tables 16, 17 and 18. Magnesian phases of FW-882 (Table 18) are shown at extreme right.

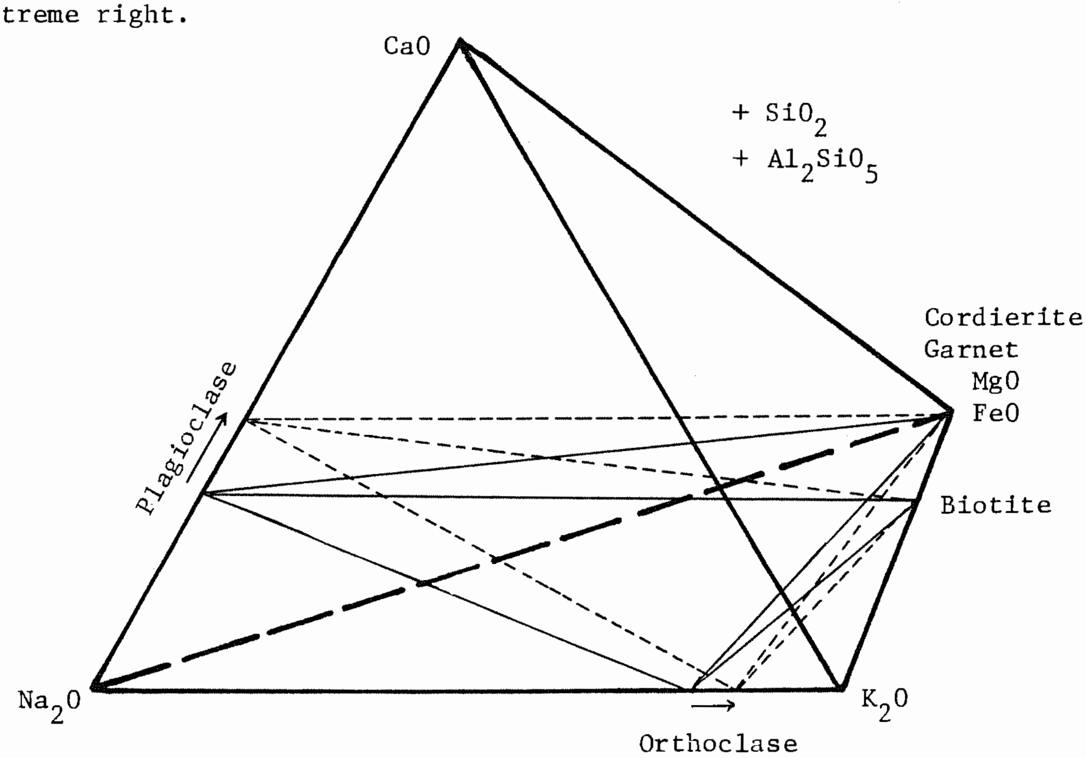


Figure 28. Tetrahedron showing the assemblage orthoclase-plagioclase-biotite-garnet-sillimanite-cordierite in FW-122 (Table 17). The same assemblage, more dehydrated, is shown in dashed lines.

in specimen FW-154 has also suffered retrograde changes.

It would appear from Figure 27 that the reaction

biotite + sillimanite + quartz =

cordierite + garnet + orthoclase + H_2O

has taken place. However, all of these rocks are still characterized by the association of sillimanite + biotite, strongly suggesting that the number of components used to construct Figure 27 is insufficient to describe the actual assemblage. The mineral which deviates most dramatically from Figure 27 is orthoclase itself, which contains up to 20% albite component. Any reasonable treatment of albite component must also consider anorthite as well. This has been accomplished in a tetrahedron in Figure 28 by the expedient of projection from Al_2SiO_5 and lumping the components FeO and MgO. The importance of this viewpoint is that it shows that any reaction in a plagioclase-bearing rock in which biotite + sillimanite begins to dehydrate to form garnet and/or cordierite + potassic feldspar component would drive the existing potassic feldspar toward a more Or-rich composition <u>and at the same time</u> would drive the plagioclase toward higher anorthite content. There is thus the possibility of a region of continuous reaction in which bulk compositions within the four phase volume biotite-cordierite and/or garnet-orthoclase-plagioclase(-quartz-sillimanite) retain exactly this assemblage, but the orthoclase becomes continuously more sodic and the plagioclase more calcic. This continuous reaction is very similar in character to the one demonstrated for the breakdown of muscovite at lower grade by Tracy (1975).

In Figure 27 specimen FW-882 would appear to represent a special problem in that the cordierite is exactly colinear with sillimanite + phlogopite and suggests the rock might actually be undergoing the experimentally studied reaction (Schreyer and Seifert, 1969),

sillimanite + phlogopite = Mg cordierite + orthoclase + H_2O.

The titanium in the phlogopite might be considered an exception to this, but since the rock is already saturated with TiO_2 in the form of rutile, this cannot explain the assemblage. However, examination of the orthoclase, with 10% albite component, shows that considerations illustrated in Figure 28 provide the definitive answer to this problem as well.

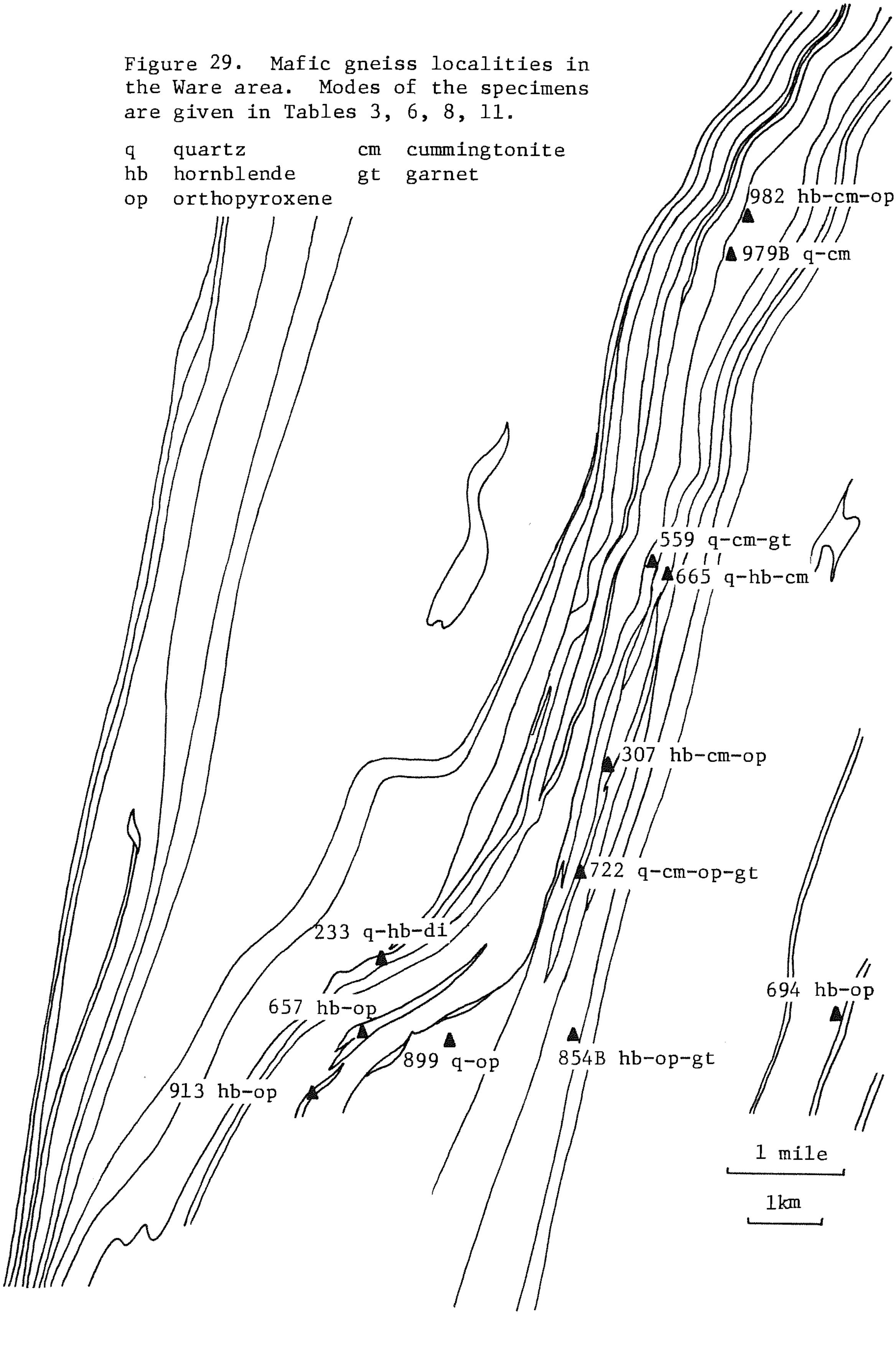
In closing this discussion, it should be pointed out that Figure 28 also gives a clear graphical demonstration of the fact, discussed above, that the cordierite-sillimanite-K feldspar assemblage tends to occur in rocks with low normative anorthite content.

Ferromagnesian Rocks

These include the Orthopyroxene Gneiss Member of the LIttleton Formation, and scattered small bodies of mafic gneiss and amphibolite in the Partridge Formation, Paxton Schist, Littleton Formation, and Coys Hill Granite (Tables 3, 5, 7, 8, 9, 10, 11). Other ferromagnesian rocks that occur as lenses in the Partridge Formation in the North Orange syncline along the west border of the area are currently under study by Robinson. The following assemblages are found, with plagioclase and biotite (Figure 29):

Figure 29. Mafic gneiss localities in the Ware area. Modes of the specimens are given in Tables 3, 6, 8, 11.

q	quartz	cm	cummingtonite
hb	hornblende	gt	garnet
op	orthopyroxene		



With quartz:

Hornblende-diopside

Hornblende-cummingtonite

Cummingtonite-orthopyroxene-garnet

Without quartz:

Hornblende-orthopyroxene-diopside

Hornblende-orthopyroxene-cummingtonite

Hornblende-orthopyroxene-garnet.

The assemblages without quartz are shown in Figure 30, with the compositions of hornblende, cummingtonite and orthopyroxene as found by electron microprobe analyses of FW-307 (Table 19). Coexisting cummingtonite and orthopyroxene are considerably more magnesian than in mafic gneisses in the Quabbin Reservoir area west of Ware (Robinson, personal communication, 1975) showing that the continuous dehydration reaction involving the breakdown of Fe-richer cummingtonite to orthopyroxene + Mg-richer cummingtonite has progressed significantly farther. This is another indication of the increased metamorphic grade of the Ware area compared to the area immediately to the west.

The hornblende color is pale brown in the hornblende-orthopyroxene-cummingtonite assemblage, yellow-brown to green in the others. Brown-green hornblende was found by Binns (1964, p. 287) in amphibolites transitional to a facies in which hornblende coexists with two pyroxenes. The pelitic rocks in both of Binns' facies contain sillimanite and orthoclase, with sporadic cordierite.

Table 19. Analyses of the Orthopyroxene Gneiss Member of the Littleton Formation.

Oxides	Rock#	Plag*	Opx*	Hb*	Cumm*	Biot*
SiO_2	50.64	55.93	51.34	47.17	55.68	36.45
TiO_2	.82	.00	.15	1.16	.16	3.59
Al_2O_3	7.93	28.09	1.46	10.42	1.36	16.11
Cr_2O_3	.05	.02	.25	.82	.15	.73
Fe_2O_3	1.41					
FeO	14.82	.04	21.31	10.07	17.55	11.46
MnO	.16	.04	.56	.22	.41	.08
MgO	18.58	.03	24.33	16.49	22.20	17.07
CaO	3.41	10.61	.32	10.77	.66	.00
BaO	--		.08	.16	.05	.52
Na_2O	.96	5.33	.09	1.49	.07	.54
K_2O	.21	.06	.00	.30	.00	9.11
H_2O	.87					
P_2O_5	.27					
Total	100.13	100.16	99.90	99.06	98.29	95.66

Clarke and Hillebrand (1897, p.77) wet chemical analysis by L. G. Eakins of a sample believed to be from the vicinity of FW-307 (see text). Washington (1903, p.355) calculates the norm of this rock to be orthoclase 1.1%, albite 6.8, anorthite 17.2 (An 72), hypersthene 66.5, olivine 3.4, magnetite 2.1 and ilmenite 1.5.

* Electron microprobe analyses of minerals.

Formula

Cations per	8ox	6ox	23*ox	23ox	11ox
Si	2.510	1.916	6.666	7.853	2.686
Al	1.486	.064	1.334	.147	1.314
	3.996	1.980	8.000	8.000	4.000
Al			.402	.080	.085
Ti		.004	.123	.017	.199
Cr	.001	.007	.092	.017	.043
Fe^{3+}			.255		
Mg	.002	1.353	3.473	4.667	1.875
Fe^{2+}	.002	.665	.654	.220	.706
Mn	.002	.018			.005
Ca		.013			
			4.999	5.001	2.913
Fe^{2+}			.281	1.850	
Mn			.026	.049	
Ca	.510		1.631	.100	.000
Na		.007	.062	.001	
		2.067	2.000	2.000	
Na	.464		.346	.018	.077
K	.003		.054		.856
	.984		.400	.018	
Ba					.015
					.948

*Formula recast with Fe^{3+} correction according to the concept of "Ideal hornblende" (Robinson and others, 1971; Ashwal, 1974).

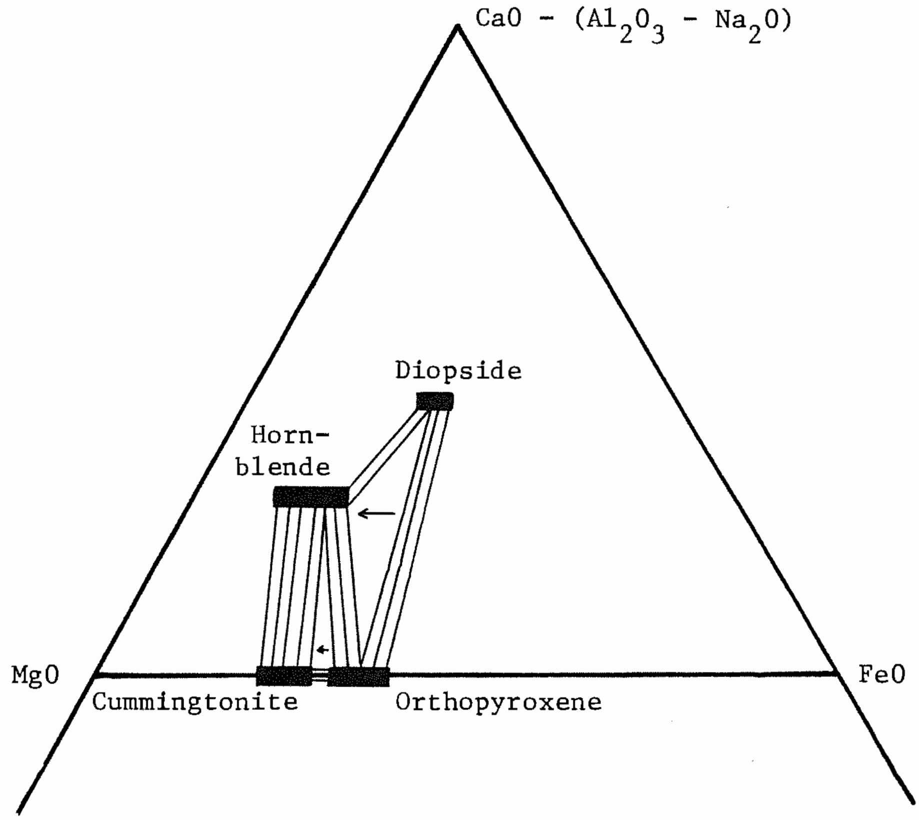


Figure 30. Plagioclase projection on the face $CaO - (Al_2O_3 - Na_2O)$, MgO, FeO, of the phases in FW-307. Position of the three-phase field hornblende, cummingtonite and orthopyroxene according to analyses in Table 19. Other fields and compositional ranges of minerals are schematic. Arrows indicate movement of the three-phase fields with increasing metamorphism.

Calc-Silicate Rocks

The Fitch Formation is composed almost exclusively of calc-silicate granulite, and other calc-silicate beds and nodules are found in the Partridge Formation and in the Paxton Schist (Tables 3, 4, 6). The assemblage quartz-plagioclase-diopside-sphene is ubiquitous in these granulites. All plagioclase is An 70 ± 5. Three specimens contain, in addition to the above, biotite and traces of calcite. One specimen south of Ragged Hill contains actinolite, and scapolite is found in a specimen of Fitch Formation and in a calc-silicate nodule in the Partridge Formation, both on the western slopes of Coys Hill. As compared to rocks of similar composition reported from lower grade regions to the west (Robinson, 1963), there seems to be a scarcity of amphibole consistent with the higher metamorphic grade, but no detailed studies of phase relations were undertaken.

Conditions of Metamorphism

Rocks in the Ware area have been metamorphosed to a very high grade, with metamorphic facies that are typical of many Precambrian shield areas. The assemblages

quartz-orthoclase-biotite-sillimanite-garnet-cordierite and

plagioclase-hornblende-orthopyroxene-diopside-biotite

indicate metamorphism to the upper part of the amphibolite facies, a grade which has been called the hornblende-granulite subfacies (Fyfe, Turner and others, 1958, p. 235; Winkler, 1965, p. 115-116), characterized by the presence of the assemblage hornblende-orthopyroxene-diopside and brownish-green rather than green or blue-green hornblende. Surprisingly, magnesian cummingtonite still persists in appropriate bulk compositions at this grade though it never occurs with diopside. The only higher grade of metamorphism that has been defined is that of the breakdown of the hydrous minerals, biotite and hornblende, to pyroxenes, giving the granulite facies. DeWaard (1966, p. 483) considers that the reaction of biotite and sillimanite to give cordierite, garnet, and orthoclase takes place at the transition from the almandine-amphibolite to the pyroxene-granulite facies. However, neither in the Ware area nor anywhere else in New England regional metamorphism is there evidence of the higher-grade reaction in which biotite breaks down to orthopyroxene plus potassic feldspar.

The activity of water in the Ware area must have been low at the time of metamorphism, as partial melting would probably occur under these metamorphic conditions in a water-saturated system (Winkler, 1965, p. 179, 191). Not only that, but the central part of the Ware area, between Muddy Brook and the Paxton Schist contact, is conspicuously lacking in the migmatites and pegmatites which are typical of many high-grade terrains. Tracy (1975), studying the transition from muscovite-bearing rocks to those in which muscovite is no longer stable, has suggested that pegmatitic melts may have absorbed the water formed by the breakdown of muscovite and removed the water from the system by migrating out of the area fairly early in the metamorphism.

Compositions of garnet cores, cordierites, and biotites from specimens FW-122 and FW-407 (Figure 27; Tables 16, 17) have been used by Tracy, Robinson, and A. B. Thompson (in preparation) to estimate conditions of metamorphism in the Ware area. Using the diagrams of

$$K_{D_{Mg-Fe}}^{Gar-Bi} \quad \text{and} \quad K_{D_{Mg-Fe}}^{Gar-Cord}$$

of A. B. Thompson (in press), specimens FW-122 and FW-407 yield self-consistent temperature estimates of 685°C and 665°C, respectively, consistent with similar estimates made using the data of Hess (1971). Application of the garnet compositions, with appropirate spessartine corrections, to the garnet isopleths on the P-T diagram of A. B. Thompson, using an average temperature of 675°C, yields a pressure estimate of 6.3 kb. This temperature and pressure are well within the stability field of sillimanite and well above the pressure of any experimentally determined Al_2SiO_5 triple point. On this basis the occurrence of andalusite pseudomorphs (Figures 25, 26) in these rocks must be interpreted as evidence of earlier lower pressure-high temperature metamorphism followed by some form of tectonic burial to yield the present assemblage. This is in distinct contrast with the adjacent Bronson Hill anticlinorium where there was a direct prograde transition from the kyanite to the sillimanite zone. The tectonic significance of these contrasting metamorphic paths in relation to the regional geologic cross-section (Figure 24) is worthy of future speculation.

GEOLOGIC HISTORY OF THE WARE AREA

The earliest event in the Ware area of which there is any record is deposition of the layered volcanic rocks of the Monson Gneiss in Middle Ordovician time or earlier. This was followed by deposition of thick sulfidic shales of the Partridge Formation over a wide area of central New England. Some folding of the Monson may have preceded Partridge deposition.

The Taconic orogeny (reviewed by Pavlides and others, 1968) affected much of the northeast United States and maritime Canada in the middle and later part of the Ordovician. Later events have obliterated evidence of an unconformity in the Ware area, if it existed, but the late Ordovician through Silurian was a time of erosion or limited deposition in most of the Ware area and in the Bronson Hill anticlinorium. In much of the area, Silurian rocks were not deposited or were eroded after deposition. In a narrow central belt the thin calcareous Fitch Formation was deposited under reducing conditions, as indicated by the sulfides and graphite found in the unit. In the southeast part of the area, the thick calcareous Paxton Schist was deposited in a comparatively deep basin which extended some distance eastward. The late Lower Silurian Clough Quartzite of the Bronson Hill anticlinorium has not been seen in the Ware area, implying that either the area was too far from the source to receive sediment, or was a positive area at the time.

The Silurian period of limited deposition was followed by deposition of the thicker and more widespread early Devonian Littleton

Formation in the Ware area and in the Bronson Hill anticlinorium. The comparatively thick, rhythmically bedded pelitic sediments of the Littleton Formation indicate deposition in moderately deep water. Felsic and mafic volcanics were locally deposited on top of Littleton sediments.

The early Devonian Littleton Formation is the youngest sediment known in the Ware area. Figure 30 shows a diagrammatic cross-section of the Ware area before the Acadian folding. Following deposition of the Littleton, the rocks were strongly deformed, intruded and metamorphosed in the Acadian orogeny of Early to Middle Devonian time. The formation of nappes with westward transport was the earliest recorded structural event of the Acadian orogeny and Thompson and others (1968, p. 216) have given evidence that the rocks were already undergoing intense metamorphism at this stage. This was followed by continued east-west compression and continued metamorphism, enough to develop sillimanite-potassium feldspar-garnet-cordierite assemblages. The continued compression resulted in eastward-overturned isoclinal folds, then more open eastward-overturned folds with shallow axial surfaces. The domes in the Bronson Hill anticlinorium are believed to have formed contemporaneously with these overturned folds. The last folding in the Ware area was much weaker, and resulting in broad open warping.

The last pre-Pleistocene event for which there is any record in the Ware area is the intrusion of the Triassic or Jurassic diabase dike, but the area was probably subject to the Permian metamorphism which affected the potassium-argon ages of rocks in a large part of New England (Zartman and others, 1970).

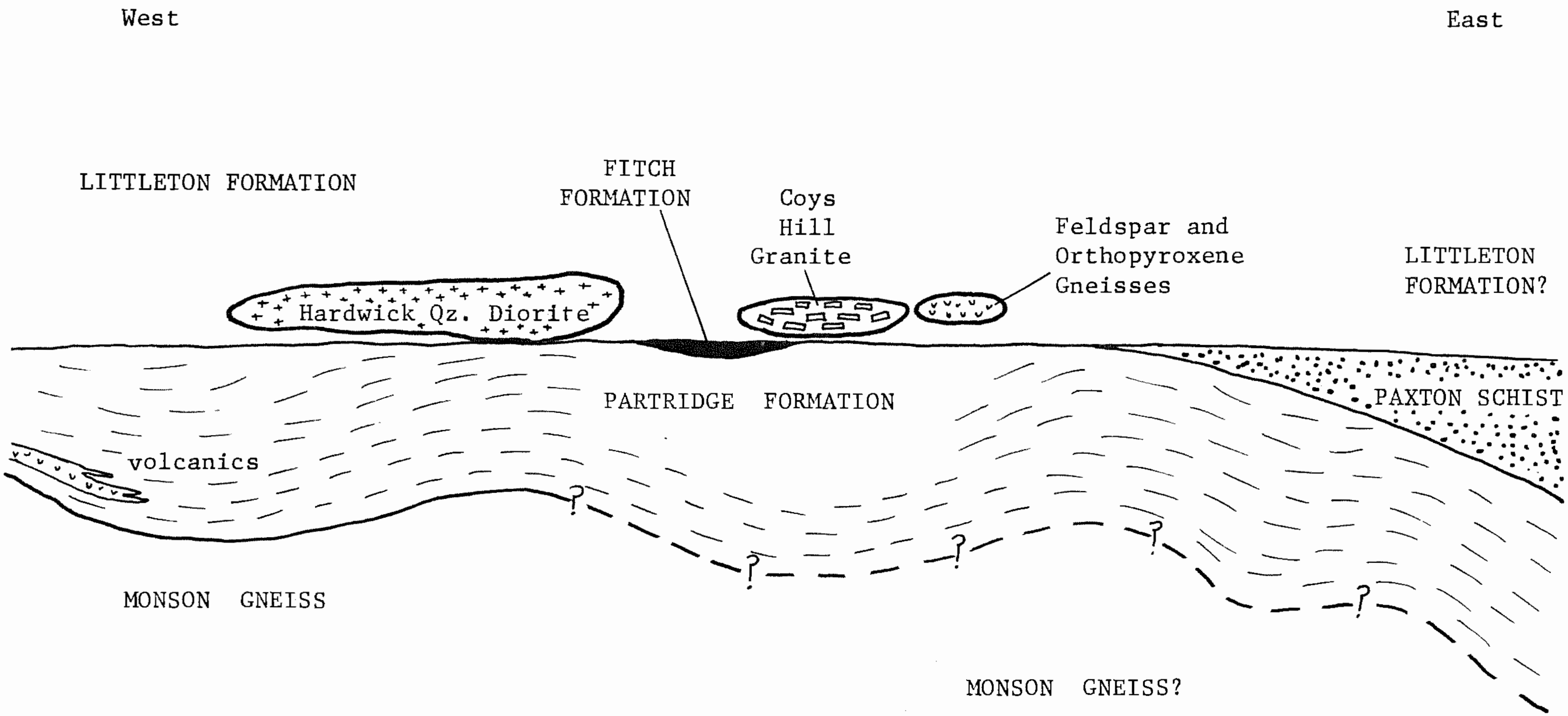


Figure 31. Diagrammatic cross-section of the Ware area before Acadian folding. The nature of all unconformities is very speculative.

Pleistocene ice covered much of the area with till and left extensive fluvioglacial deposits in the major valleys as the ice retreated gradually, with several temporary standstills (Mulholland, 1974). Modification of the landscape since the glacial retreat is minor, except along the major river valleys.

CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

Conclusions

(1) The stratigraphic sequence in most of the Ware area is essentially the same as that in the Bronson Hill anticlinorium.

The stratigraphy of the Ware area west of the Paxton Schist differs from the Bronson Hill anticlinorium stratigraphy mainly in the absence of the Clough Quartzite and Ammonoosuc Volcanics, and the limited extent of the Fitch Formation, but as discussed under Alternate Interpretations of Ware Area Stratigraphy, these are absent or very thin in the eastern part of the Bronson Hill anticlinorium and it is reasonable that they would be thin or absent in the Ware area. The scarcity of volcanic rocks in the Partridge Formation indicates either that only the upper part of the Partridge is found in the Ware area, or that the Ware area was too far from the source of volcanics in the Bronson Hill anticlinorium.

(2) The Paxton Schist in the southeastern part of the area and eastward is a Silurian unit much thicker than the Silurian formations of the Bronson Hill anticlinorium and most of the Ware area, and its presence indicates a zone of eastward thickening similar to that observed in the Merrimack synclinorium in western Maine by Osberg and others (1968) and Boone (1973).

The reasons for this statement are discussed under Paxton Schist in the section on correlation.

(3) The structures in the Ware area are compatible with the theory that some of the Bronson Hill anticlinorium nappes originated in this area, but there is not enough evidence to prove the theory.

The folds in the Ware area are of the same units and appear to be of similar amplitude to the Bronson Hill nappes, and the positions of the axial surfaces of the Skitchewaug and Fall Mountain nappes can be tentatively located west of the Hardwick pluton. If the isoclinal folds east of the Hardwick pluton are nappes, then they are nappes structurally higher than the Fall Mountain nappe that have not been found in the Bronson Hill anticlinorium. If the Hardwick Quartz Diorite is involved in a nappe (Figure 21), small bodies of it may be found in the Bronson Hill anticlinorium.

(4) The later deformational history of the Ware area also appears to be compatible with that in the Bronson Hill anticlinorium. The major difference in deformational history between the two is the formation of domes in the latter.

The different phases of deformation, with the exception of doming, seem to be the same in the two areas, but the evidence in Ware has not yet been developed in as much detail as in the Bronson Hill anticlinorium. The intermediate stage of folding is believed to be contemporaneous with early stages of dome formation in the Bronson Hill, while folding with more shallow axes took place at the same time as the major doming.

Suggestions for Future Work

Detailed mapping in the Mt. Monadnock, New Hampshire, area should help clarify many relationships in the western part of the Merrimack synclinorium. Reconnaissance and the regional maps suggest that the map pattern observed in the Ware area continues northward with little change to about the New Hampshire border. There, in the Mt. Monadnock area, the map pattern is very different, indicating that different structures are present and suggesting that some relationships which which are obscure in the Ware area might be decipherable. The Mt. Monadnock area also provides a link with the western New Hampshire stratigraphy. The entire stratigraphy, much thinned, is found in the western part of the quadrangle. Mt. Monadnock is composed of Littleton Formation. A major body of Kinsman Quartz Monzonite, the Cardigan pluton, is found in the northeast part of the quadrangle, and two varieties of Fitch Formation are present (see Fitch Formation in the section on correlation). Mapping in the Mt. Monadnock area and tracing key units from Ware to Mt. Monadnock should clarify the relationship of the Ware area stratigraphy to the western New Hampshire stratigraphy and at the same time provide valuable evidence about the early nappe structures.

Mapping has recently started east and northeast of Ware, which should help in understanding the widespread but little studied Paxton Schist. When the internal stratigraphy of the Paxton is better known, it may be possible to compare it in some detail with its fossiliferous equivalents in central Maine. A presumed equivalent of the Littleton Formation is found above the Paxton equivalent in eastern Connecticut (Dixon and Lundgren, 1968b, p. 220-221), and if this can be verified, it is an important fact in the stratigraphic interpretation of the region.

The New Braintree Gabbro should be studied in more detail. This is an irregularly shaped body of variable composition and texture, and detailed mapping should reveal more about its metamorphic history and relationship to the country rock than was possible to delineate in this study.

More detailed structural studies could be done in the Ware area and might reveal more about the relative ages of the deformational phases. Perhaps the two lineations of different ages that have recently been found in reconnaissance in the East Brookfield and Barre quadrangles might be found in the Ware area.

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PLATE I BEDROCK GEOLOGIC MAP OF THE WARE AREA, CENTRAL MASSACHUSETTS

EXPLANATION

STRATIFIED ROCKS

LOWER DEVONIAN

Dlo | Dlf | Dl

Littleton Formation

Dl: Gray-weathering biotite-garnet-orthoclase-sillimanite (-cordierite) schist, generally in beds 2-10 cm thick. Locally rich in garnet and sillimanite. Conspicuous garnet up to 2 cm in diameter is found in the central part of the area.

Dlf: Feldspar Gneiss Member: Light-colored quartz-feldspar gneiss with a few per cent of biotite and garnet. Biotite pegmatite is commonly associated.

Dlo: Orthopyroxene Gneiss Member: Dark brown, coarse-grained, weakly foliated orthopyroxene-cummingtonite-labradorite gneiss.

SILURIAN

Sp | Sps | Spw

Paxton Schist

Sp: Medium- to dark-gray, slabby granular quartz-biotite-labradorite schist with minor garnet and rare beds of calc-silicate granulite and amphibolite.

Sps: Quartzose sulfidic biotite-sillimanite schist.

Spw: Sulfidic white schist composed of quartz-potassium feldspar-Mg cordierite-Mg biotite-sillimanite.

Sf

Fitch Formation

Sf: Sulfidic graphitic quartz-calcic plagioclase-diopside granulite with sphene.

MIDDLE ORDOVICIAN

Opl | Ops | Opa | Opr | Opra

Partridge Formation

Opl: Gray- to red-weathering biotite-garnet-orthoclase-sillimanite (-cordierite) schist of the Lyon Road type.

Ops: Sulfidic biotite-garnet-orthoclase-sillimanite (-cordierite) schist and slabby quartz-plagioclase-biotite-garnet granulite.

Opr: Red- to rusty-weathering biotite-garnet-orthoclase-sillimanite schist.

Opra: Rusty-weathering biotite-garnet-orthoclase-sillimanite schist with amphibolite.

Opa: Labradorite-cummingtonite-hornblende amphibolite, labradorite-hornblende-orthopyroxene, and labradorite-cummingtonite-hornblende-orthopyroxene gneisses, generally coarse-grained and poorly foliated.

MIDDLE ORDOVICIAN OR OLDER

ma | mf | mn

Monson Gneiss

mf: Layered and unlayered quartz-feldspar gneiss with some interbedded amphibolite.

ma: Hornblende amphibolite with some quartz-feldspar gneiss.

mn: North Orange band: quartz-feldspar gneiss and hornblende amphibolite regularly interbedded at 2-5 cm intervals.

PLUTONIC ROCKS

TRIASSIC-JURASSIC

d

Diabase dike

d: Fine-grained augite-plagioclase diabase.

DEVONIAN

gdi

Goat Hill Diorite

gdi: Medium- and coarse-grained unfoliated biotite-hornblende-clinopyroxene diorite and biotite-orthopyroxene-clinopyroxene norite. A coarse variety of norite has 2 cm biotite crystals.

rh

Gneiss of Ragged Hill

rh: Light-colored, massive, strongly foliated quartz-plagioclase-potassium feldspar-biotite-garnet gneiss.

h | a

Hardwick Quartz Diorite

h: Strongly foliated porphyritic biotite quartz diorite with minor biotite granite, quartz monzonite or granodiorite and biotite-hornblende quartz diorite and diorite. Microcline crystals 1/2 to 1 cm across are found in the northern part of the map area. Sphene and allanite are distinctive minor constituents.

a: Fine-grained, foliated amphibolite of uncertain origin.

chm | ch

Coys Hill Granite

ch: Massive, strongly foliated porphyritic granite, quartz monzonite and quartz diorite. Microcline and orthoclase phenocrysts are commonly 2-4 cm long, range up to 20 cm, in a matrix of quartz, oligoclase and biotite. Garnet 1/2 to 1 cm across is conspicuous.

chm: Massive, weakly foliated hornblende-andesine and hornblende-andesine-orthopyroxene gneiss with minor biotite and diopside.

ORDOVICIAN?

a | nbg

New Braintree Gabbro

nbg: Medium- to coarse-grained unfoliated labradorite-hornblende-cummingtonite-biotite, labradorite-hornblende-orthopyroxene-biotite, and labradorite-hornblende-orthopyroxene-olivine gabbros.

a: Fine-grained strongly foliated andesine-hornblende amphibolite.

ORDOVICIAN

um

Ultramafic rock

um: Massive coarse-grained unfoliated phlogopite-olivine hornblendite.

Quadrangles included in map area.

Contact, well located.

Contact, approximately located or speculative.

Contact, covered by water or extensive surficial deposits.

Strike and dip of:

36 bedding, dot shows stratigraphic top.

51 foliation.

Trend and plunge of:

8 minor fold axis, showing movement sense where known.

15 mineral lineation.

B—B'

Line of cross-section.

Geology by Michael T. Field 1972-1974

Assisted by Frank Smith 1972

MN GN 14° 249 MILS 1°54' 34 MILS

UTM GRID AND 1969 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

1 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET

DATUM IS MEAN SEA LEVEL

MASS.

QUADRANGLE LOCATION

ROAD CLASSIFICATION

Primary highway, all weather, hard surface

Light-duty road, all weather, improved surface

Secondary highway, all weather, hard surface

Unimproved road, fair or dry weather

PLATE 2 GEOLOGIC CROSS-SECTIONS OF THE WARE AREA

NO VERTICAL EXAGGERATION

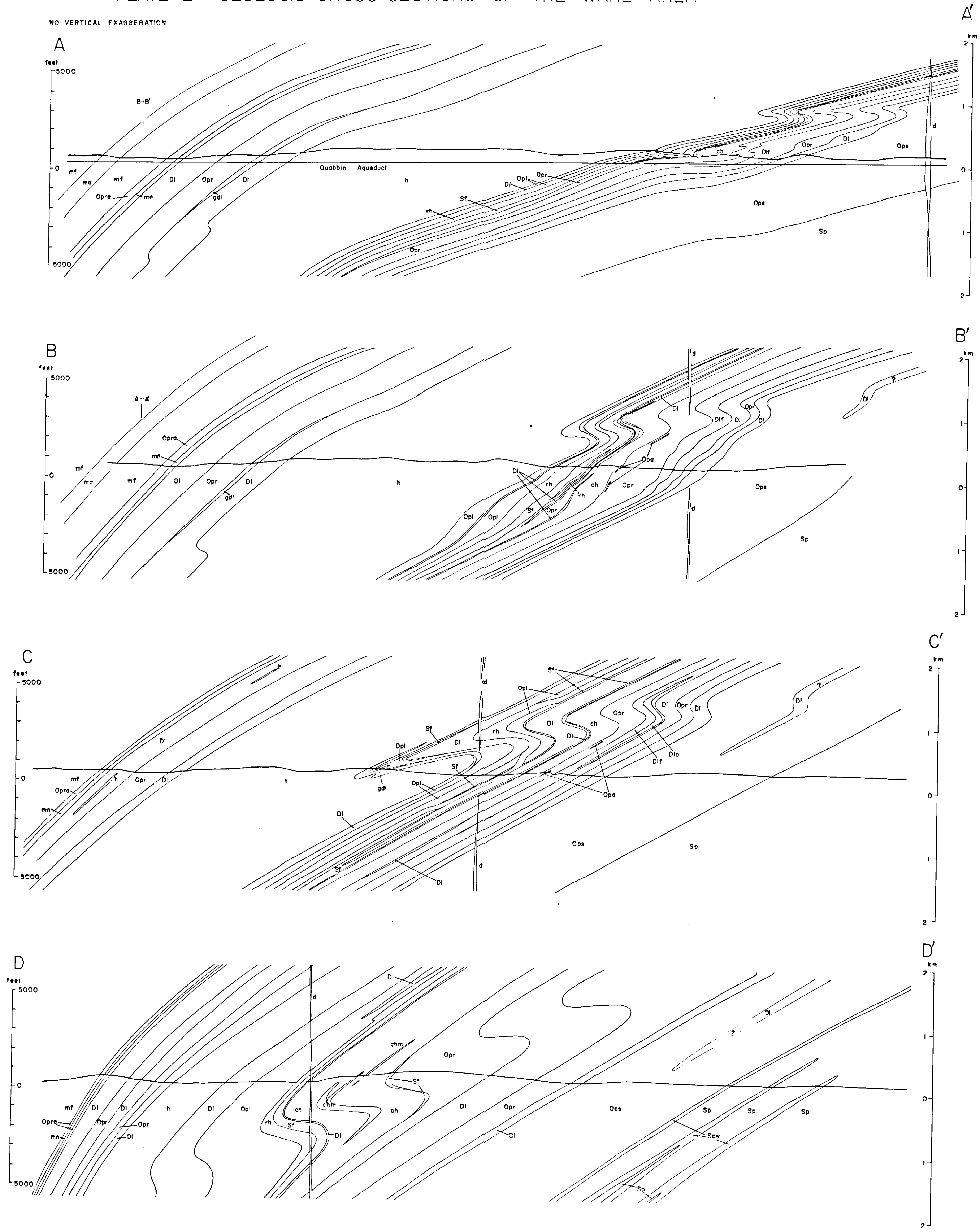

PLATE 3 OUTCROP MAP OF THE WARE AREA

CROSS-HATCHING DENOTES AREAS OF NUMEROUS OUTCROPS

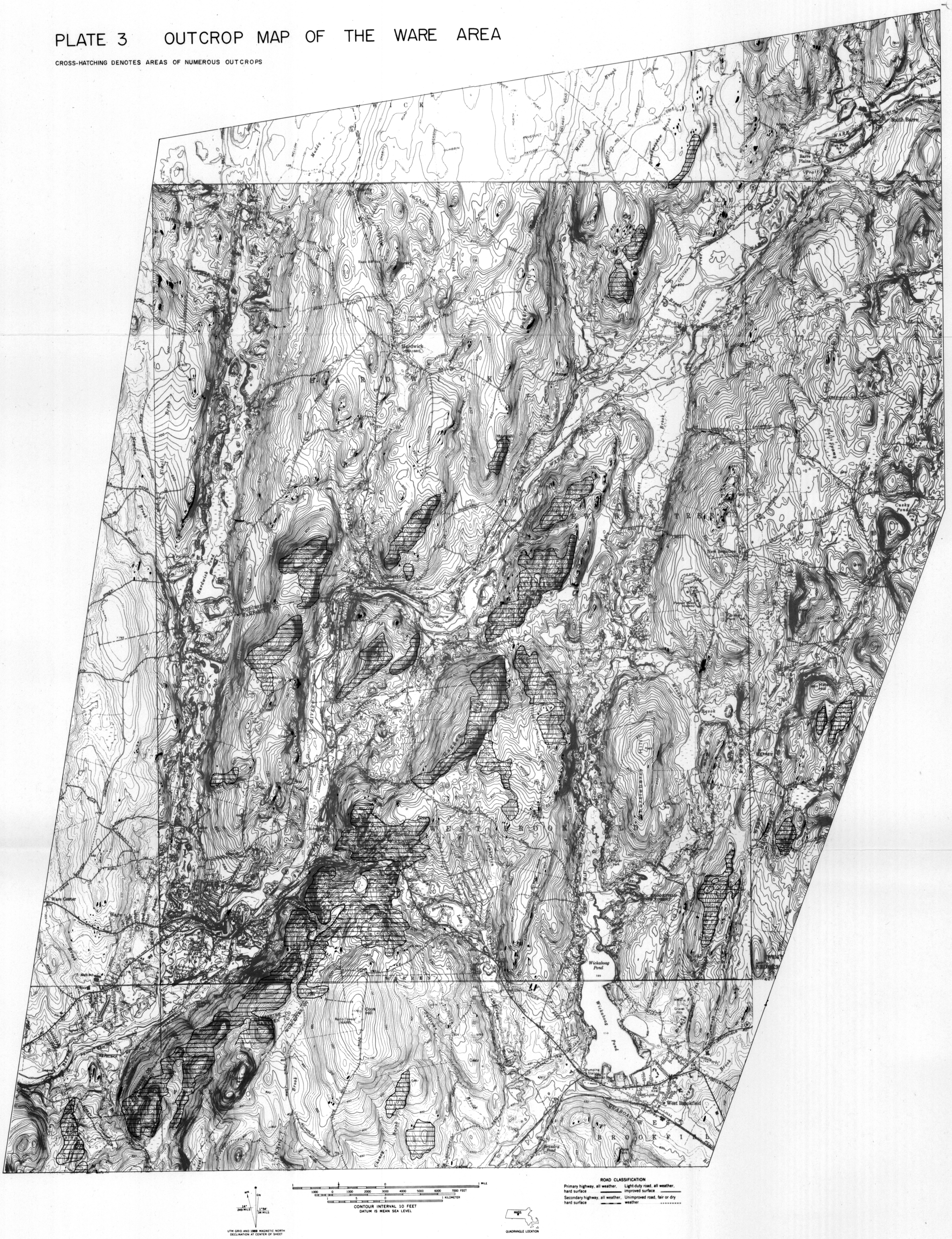

Plate 4 PLANAR STRUCTURAL FEATURES, WARE AREA

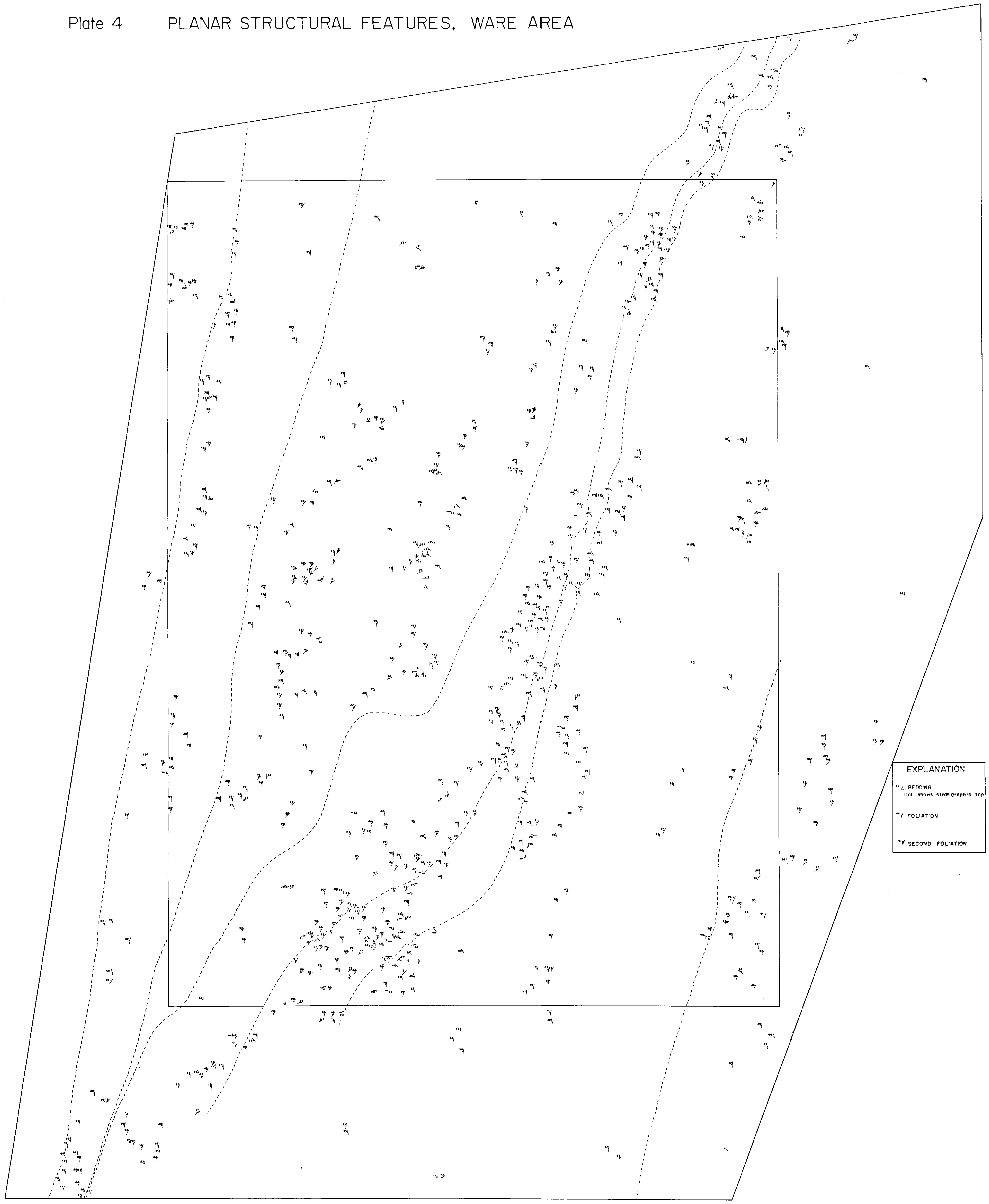

PLATE 5 LINEAR STRUCTURAL FEATURES, WARE AREA

PLATE 6 AXIAL SURFACES, WARE AREA