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### The Pre-Silurian Eugosynclinal Sequence Bonded by The Bloody Bluff and Clinton-Newbury Faults, Concord, Billerica, and Westford Quadrangles, Massachusetts

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Trips A-14 & B-14

THE PRE-SILURIAN EUGEOSYNCLINAL SEQUENCE BOUNDED BY  
THE BLOODY BLUFF AND CLINTON-NEWBURY FAULTS,  
CONCORD, BILLERICA, AND WESTFORD QUADRANGLES, MASSACHUSETTS

by

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Boston, Massachusetts

The purpose of this field trip is to show representative exposures of the stratified rocks mapped mostly by D.C. Alvord in the Concord, Billerica, and Westford quadrangles, Massachusetts. The trip was prepared and is led by M.H. Pease, Jr., and R.J. Fahey; Alvord is unable to be present because of work commitments in Utah.

These stratified rocks have general northeast strikes and steep northeast dips. The rocks are within a broad regional imbricate fault system which trends northeastward across eastern Massachusetts (fig. 1) and which is bounded on the north and northwest by the Clinton-Newbury fault zone, a major structural feature of the region. The sedimentary and volcanic protoliths of these rocks were deposited mainly in a marine environment, probably near the margin of an eugeosyncline. The stratigraphic units (fig. 2) include the Marlboro Formation; Shawsheen Gneiss; Fish Brook Gneiss; the Nashoba Formation, which is divided into 10 members; and the Tadmuck Brook Schist. A report by Bell and Alvord (in press) presents definitions or redefinitions of these formations, locations of type areas, and detailed descriptions of stratigraphy, structure, and of lithology of the rocks.

The sedimentary and volcanic deposits that formed the rocks described in this paper accumulated and were deeply buried within a broad geoclinal basin. These flysch deposits have been regionally metamorphosed to kyanite grade and intruded by silicic to intermediate plutonic rocks, regional faulting has profoundly affected the distribution of stratigraphic units.



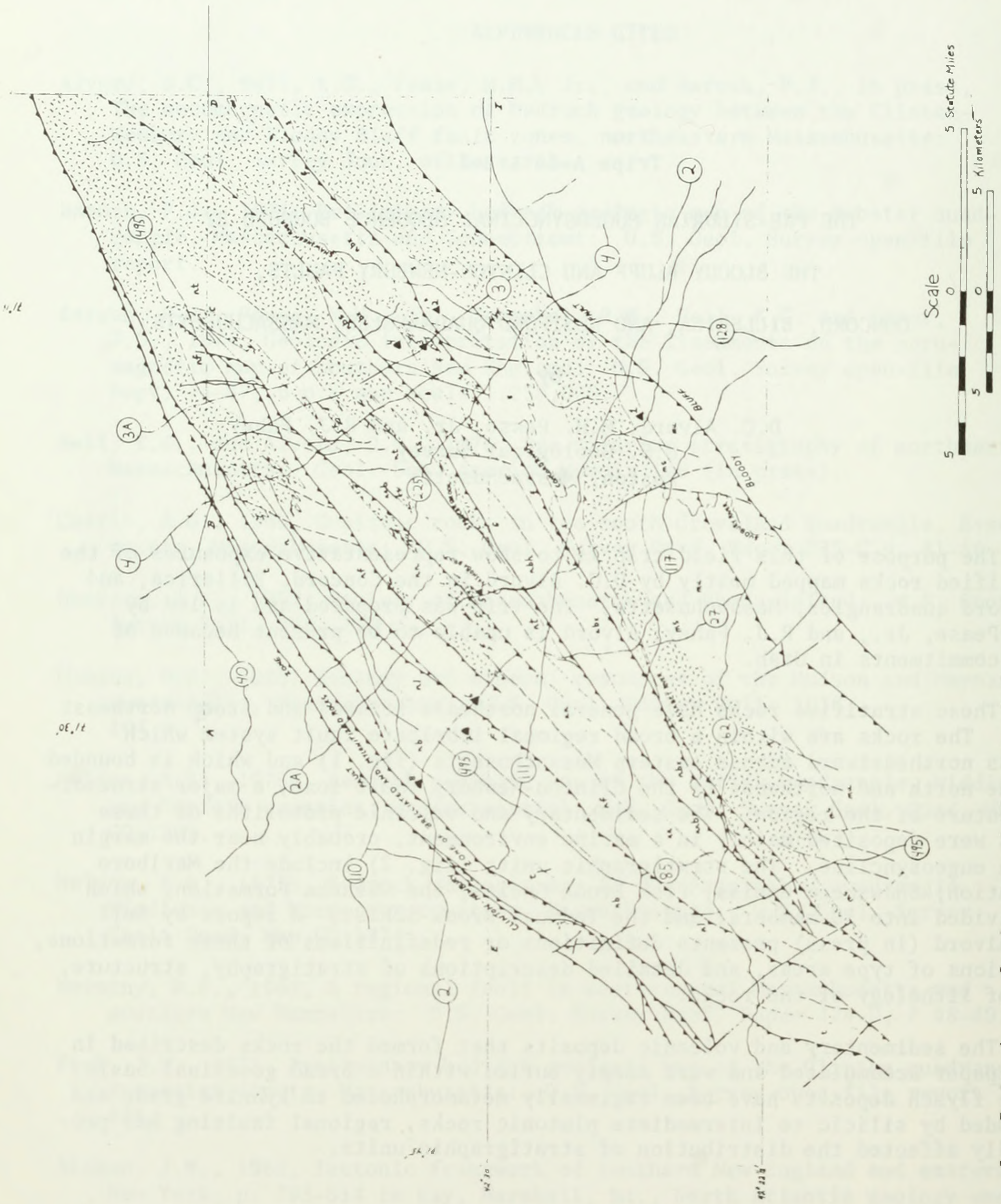
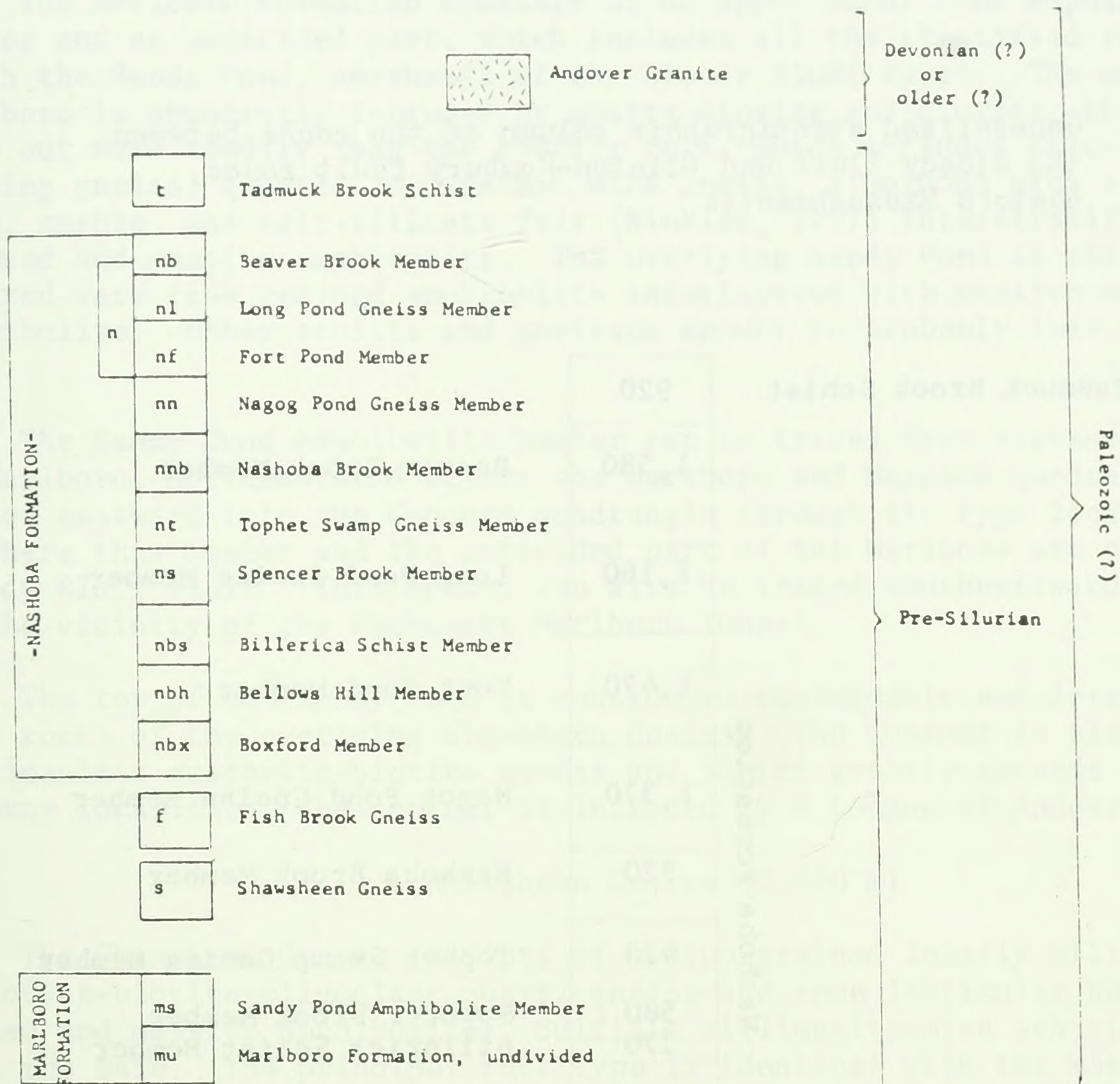


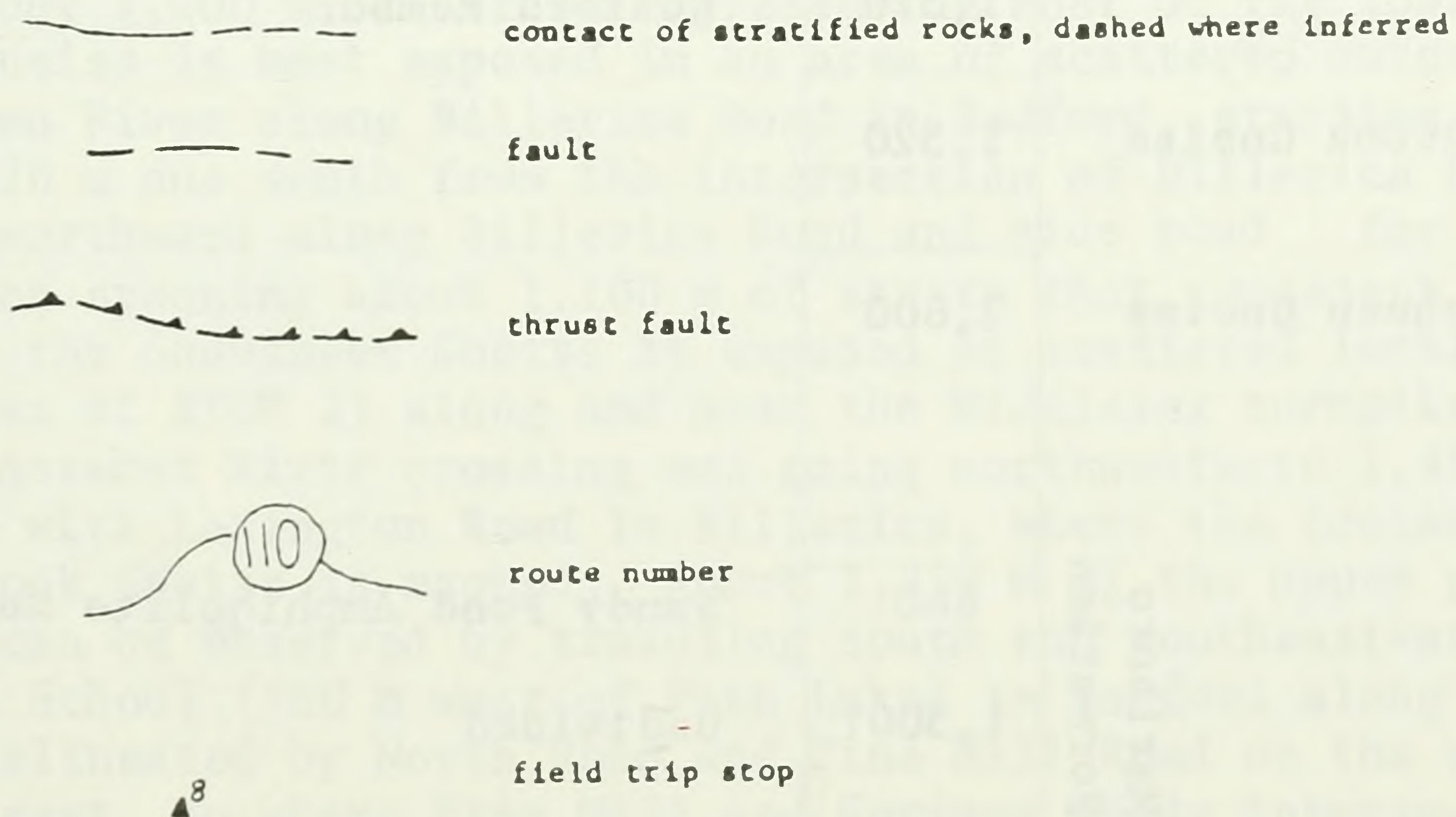
Fig. 1. Bedrock geologic map of the area between the Clinton-Newbury and Bloody Bluff fault zones, northeastern Massachusetts, showing locations of stops for field trip



EXPLANATION  
CORRELATION OF MAP UNITS



SYMBOLS



quadrangles (7½ minutes). keyed to letters in upper right corner.

- |              |           |              |
|--------------|-----------|--------------|
| A Ayer       | E Clinton | I Lexington  |
| B Westford   | F Maynard | J Shrewsbury |
| C Billerica  | G Hudson  | K Marlboro   |
| D Wilmington | H Concord | L Framingham |



Fig. 2. Generalized stratigraphic column of the rocks between the Bloody Bluff and Clinton-Newbury fault zones, eastern Massachusetts

Tadmuck Brook Schist	920	
	1,580	Beaver Brook Member
	1,160	Long Pond Gneiss Member
	1,470	Fort Pond Member
	1,370	Nagog Pond Gneiss Member
	920	Nashoba Brook Member
	920	Tophet Swamp Gneiss Member
	580	Spencer Brook Member
	270	Billerica Schist Member
	1,100	Bellows Hill Member
	1,520	Boxford Member
Fish Brook Gneiss	1,520	
Shawsheen Gneiss	2,600	
	640	Sandy Pond Amphibolite Member
	1,500?	undivided



### Marlboro Formation (2,140 m)

The Marlboro Formation consists of an upper Sandy Pond Amphibolite Member and an undivided part, which includes all the stratified rocks beneath the Sandy Pond, northwest of the Bloody Bluff fault. The undivided Marlboro is abundantly intruded by quartz diorite and diorite, which tends to crop out more readily than the country rock, which includes calc-silicate-bearing gneiss, quartzo-feldspathic mica gneiss, aluminous mica schist, quartzite, marble, and calc-silicate fels (Winkler, 1957) interstratified with both layered and massive amphibolite. The overlying Sandy Pond is chiefly thinly layered very fine grained amphibolite interlayered with massive medium-grained amphibolite. Other schists and gneisses amount to probably less than 20 percent.

The Sandy Pond Amphibolite Member can be traced from exposures in the town of Marlboro, northeastward across the Marlboro and Maynard quadrangles, and thence eastward into the Concord quadrangle through its type locality (STOP 1), to where this member and the undivided part of the Marlboro are cut out by the Bloody Bluff fault. This member can also be traced southwestward from Marlboro to the vicinity of the Wachusett-Marlboro Tunnel.

The top of the Sandy Pond is considered conformable and intergradational with rocks of the overlying Shawsheen Gneiss. The contact is placed where sillimanitic muscovite-biotite gneiss and schist greatly exceeds amphibolite. At many localities, the contact is intruded by a tongue of Andover Granite.

### Shawsheen Gneiss (2,600 m)

The Shawsheen Gneiss consists of medium-grained locally sillimanitic muscovite-biotite-oligoclase-quartz gneiss and some lenticular bodies of bedded and massive amphibolite. Sulfidic sillimanite-mica schist is present near the base. The principal rock type is identical with the most common rock type in the Nashoba Formation, but the formation is separated from the Nashoba by the Fish Brook Gneiss.

About 1,000 m of strata representing most of the lower half of the Shawsheen Gneiss is best exposed in an area of scattered outcrops close to the Shawsheen River along Billerica Road in Bedford, starting with excellent outcrops 120 m due south from the intersection of Billerica Road with Page Road, thence northward along Billerica Road and side road for a distance of 1530 m. A section spanning about 1,100 m of strata that represent most of the upper half of the Shawsheen Gneiss is exposed at scattered localities (including exposures at STOP 2) along and near the Middlesex turnpike from a point beginning at the Assebet River crossing and going northwestward 1,450 m to the intersection with Lexington Road in Billerica, where the contact with the overlying Fish Brook Gneiss is mapped. About 1,250 m of the upper part of the Shawsheen Gneiss can be observed by traveling south and southeastward from the vicinity of Lane School (460 m west of Fawn Lake) in Bedford along a network of suburban roads delineated by North Road and Pine Hill Road on the west and Springs Road on the east, to where Pine Hill and Springs Roads intersect, an across-strike



distance of about 1,835 m. At this locality, the nearest exposures of Fish Brook Gneiss can be seen by walking 60 m west from the north end of Lane School Building to an excellent exposure of Shawsheen Gneiss where the strata strike  $35^{\circ}$ , thence pace 170 m on a bearing of  $30^{\circ}$  to the first outcrop of Fish Brook Gneiss on the northeast side of an abandoned railroad bed. At this locality, the stream crossed enroute to the exposures of Fish Brook Gneiss closely follows the faulted contact of these formations.

The top of the Shawsheen Gneiss is placed where its medium-gray medium- to coarse-grained rocks are overlain by the generally very light gray, fine- to medium-grained rocks of the Fish Brook Gneiss (Castle, 1965), which is considered a formation by Bell and Alvord (in press). These formations are presumed conformable, but wherever they have been mapped, there is a concealed interval between the formations. Evidence for faulting is found at several localities near the contact. Some of the rocks of the Shawsheen Gneiss were included in the lower part of the Nashoba Formation of Hansen (1956), and some were included in the Gospel Hill Gneiss of Hansen (1956).

#### Fish Brook Gneiss (1,520 m)

The Fish Brook Gneiss forms a distinctive and mappable unit amidst a sea of drab metasedimentary units whose separation and mappability are fraught with difficulty. The name Fish Brook Gneiss (Castle, 1965) is therefore accepted with boundless waves of gratitude, and it has been assigned formational status (Bell and Alvord, in press). Rocks of this formation in the Hudson and Maynard quadrangle were included by Hansen (1956) in the lower part of the Nashoba Formation.

The upper boundary of the Fish Brook Gneiss is drawn at the base of the redefined Nashoba Formation. The contact is exposed at a small quarry 5,200 m north-northeast of Nutting Lake. This quarry, hardly more than a trench, is 122 m northeast of the Billerica-Wilmington town line along Hopkins Street, and about 9 m southwest of the street across a backyard at the edge of a woods. In the exposure, very thin beds of dark-greenish-gray, very fine grained amphibolite of the Boxford Member of the Nashoba can be seen interstratified with thin beds of very light gray Fish Brook Gneiss.

#### Nashoba Formation (10,890 m)

The Nashoba Formation includes all metasedimentary and metavolcanic rocks in the interval between the top of the Fish Brook Gneiss and the base of the Tadmuck Brook Schist. It is divided into 10 members.

Relatively homogeneous members composed chiefly of medium-grained biotite-oligoclase-quartz gneiss commonly containing muscovite and sillimanite alternate with members of more heterogeneous lithology including fine-grained amphibole-biotite gneiss and schist, amphibolite, locally sulfidic sillimanite-mica schist, diopsidic calc-silicate fels and gneiss, and a few lenses of marble.



The lower contact of the Nashoba is gradational. Dark-greenish-gray mafic-rich beds of amphibolite or biotite-amphibolite schist of the Boxford Member grade downward into the very light gray mafic-poor beds of the Fish Brook Gneiss. The upper contact also appears gradational, where beds of amphibolite or medium-grained biotite gneiss of the Beaver Brook Member grade upward into beds of sulfidic sillimanite-muscovite schist of the Tadmuck Brook Schist.

#### Boxford Member (1,520 m)

The Boxford is composed of thinly bedded amphibolite, massive amphibolite, and biotite-amphibole gneiss and schist interlayered with subordinate amounts of biotite gneiss, calc-silicate bearing fels and gneiss, and rare lenses of marble. Locally, particularly at its type locality and in the vicinity of Nutting Lake in the town of Billerica, the lower part of the Boxford is made up almost entirely of amphibolite and amphibole-bearing gneiss and schist. Regionally, however, the member has been found similar to many of the overlying complexly interstratified members of the Nashoba.

The Boxford Member is well exposed in the vicinity of Nutting Lake (STOP 4) in the town of Billerica. Exposures of mostly thin-bedded, very fine grained amphibolite are abundant across a 460-m-wide belt on the northwest side of this lake. On its southeast flank, the unit is separated from the underlying Fish Brook Gneiss by a tongue of Andover Granite, and some of the lower part of the Boxford is presumed missing. The upper part of the Boxford is not well represented in this area, but some good exposures of these rocks are found along suburban roads leading both northeast and southwest from junctions on Boston Road, about 1,225 m due north of the northeast end of Nutting Lake, or 1,225 m south of Billerica Center along Boston Road.

The Boxford also is well represented within a belt of exposures delimited on the northwest by the southeast shore of Batemans Pond, and on the southeast by a line between Farmers Cliff and Hubbard Hill. Rocks exposed in this area include every lithology attributable to the Boxford, including limestone, but varieties of amphibolite predominate slightly. From this reference locality, the belt can be easily followed northeastward some 3,100 m to Bedford Road in Carlisle, whence exposures are rare. It can also be easily traced southwestward some 4,300 m to Nashoba Brook at the southern end of the type locality of the Nashoba Formation. Here, rocks of the Boxford Member are fairly well exposed in a 600-m-wide belt immediately north of Warners Pond and east of Nashoba Brook in West Concord.

The upper boundary has not been seen in outcrop but attitudes of the strata are conformable, and intertonguing of rock types suggest that the contact is gradational. The amphibole-bearing gneiss and amphibolite of the Boxford apparently intertongue with and grade upwards into biotite gneiss that is predominant in the Bellows Hill Member.

#### Bellows Hill Member (1,100 m)

The Bellows Hill Member is almost entirely medium-grained sillimanitic muscovite-biotite gneiss that typifies the Nashoba. Subsidiary fine-grained amphibole-biotite gneiss and amphibolite and thin lenticular beds of marble



and related diopside-tremolite-calc-silicate fels occur discontinuously in the upper half.

The Bellows Hill Member is best exposed 2,600 m southwestward 220°, from Bellows Hill in the town of Carlisle and on the south and west of the Bemis estate, in the town of Concord. Excellent exposures of the middle part of this member are also present in a belt of exposures extending some 1,800 m northeastward from South Acton center.

The top of the member is not exposed. It is presumed conformable and intergradational, its biotite gneiss intertongued with and grading upwards into the sulfidic sillimanite-mica schist of the Billerica Schist Member. Wherever the member has been mapped, however, there is a concealed interval between the units, along which at many localities, evidence for faulting has been found.

#### Billerica Schist Member (270 m)

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

Best exposures of the Billerica Schist Member occur on the southeast side of Fox Hill and along the course of the Concord River between its crossing by U.S. Route 3 southwestward to the vicinity of Riverside, all in the town of Billerica. It has been traced with considerable difficulty northeastward just inside the Wilmington quadrangle and southwestward nearly to Nashoba Brook in Acton, a total distance of about 15.3 km.

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

#### Spencer Brook Member (580 m)

The Spencer Brook Member consists of complexly interstratified thin-bedded amphibole-biotite gneiss, thinly bedded amphibolite, and massive amphibolite, and notable amounts of amphibole-diopside calc-silicate fels and gneiss, biotite gneiss, and some thin lenses of marble.

The rocks of this member are generally well exposed, forming an outcrop belt ranging from 600 to 750 m in width over most of its mapped extent. The unit is readily traced from its type locality northeastward 6,100 m to the west side of Winning Pond in Billerica, where it is lost in or cut off by Andover Granite, and southwestward some 6,000 m across Nashoba Brook to where it is evidently cut out by the Spencer Brook fault about 750 m south of Acton Center. Along this belt, the rocks of the Spencer Brook Member are best represented in the area between Strawberry Hill and the Acton-Carlisle town line in Acton and the area between West Street and Hemlock Hill in Carlisle.

The generally amphibole-bearing and calc-silicate-bearing rocks of the Spencer Brook intertongue with and grade upwards into the rocks of the Tophet Swamp Gneiss Member, which are chiefly medium-grained biotite gneiss.



### Tophet Swamp Gneiss Member (920 m)

The Tophet Swamp Gneiss Member is chiefly the medium-grained sillimanitic muscovite-biotite-oligoclase-quartz gneiss characteristic of the Nashoba, containing a few lenticular bodies of thinly bedded amphibolite and massive amphibolite. This generally well exposed member is especially accessible in Carlisle along Cross Street from its junction with South Street northward about 1,200 m, from Carlisle Center northwestward for about 1,600 m along Westford Street and northward for about 1,650 m along Lowell Street. Its outcrop belt, mostly 900-1200 m wide where mapped, can readily be followed from Carlisle Center northeastward 15.3 km into the town of Tewksbury, where its most northeasterly exposures can be seen just west of Ames Hill. The unit has been cut off northeast of Ames Hill by intrusion of Andover Granite, and by faulting.

The medium-grained biotite gneiss of the Tophet Swamp intertongues with and grades upward into the complexly interstratified amphibole-bearing and calc-silicate bearing rocks characteristic of the lower part of the Nashoba Brook Member.

### Nashoba Brook Member (920 m)

The Nashoba Brook Member is a heterogeneous assortment of amphibole-biotite gneiss, diopsidic calc-silicate gneiss and fels containing amphibolite in the upper and lower parts. The middle part is chiefly sulfidic sillimanite-biotite-muscovite schist and gneiss and amphibolite and biotite gneiss.

The member is exposed at North Acton center, on the hill beginning about 325 m south-southeast of North Acton center and on the west side and close to Nashoba Brook; on the east side of Nashoba Brook at localities 760 m and 1,100 m due south of North Acton center; and on both sides of Nashoba Brook 610 m due east of North Acton center, all in the town of Acton. These exposures, in the aggregate, represent well the rocks of the member. Its rocks are also well displayed in the town of Carlisle, about 3,000 m northeast of North Acton center, especially at hills, respectively, 50° and 450 m and 115° and 450 m from the intersection of Acton Street and West Street. Where mapped, the rocks of this member form a northeast-trending belt of scattered outcrops 1,200 m wide. The member has been traced from its type locality in Acton southwestward about 4,600 m and northeastward 8,700 m to the southwest end of Russell Mill Pond in the town of Chelmsford. Here, the member evidently is cut off by two or more north-trending cross faults and is shifted north-northeast to where it is lost and concealed in a maze of complex structure and Andover Granite. Mapping indicates that the upper contact is conformable and gradational the amphibolite and calc-silicate rocks of the Nashoba Brook are intertongued with and grade upwards into the biotite gneiss that is predominant in the Nagog Pond Gneiss Member.

### Nagog Pond Gneiss Member (1,370 m)

The Nagog Pond Gneiss Member is chiefly the medium-grained muscovite-biotite-oligoclase-quartz gneiss that characterizes the Nashoba Formation. This dominant lithology is interstratified with some amphibole-biotite gneiss and lenticular bodies of thinly bedded amphibolite and massive amphibolite.



An area of good exposure of the Nagog Pond Gneiss Member is bounded on the northwest by Nagog Pond, on the southwest by Nagog Brook, on the southeast by the only southward-flowing tributary to Nagog Brook, and on the northeast by Great Road, all in the town of Acton. Within this area, rocks of the lower two thirds of the Nagog Pond Member are fairly well represented. Excellent exposures are also present in the town of Chelmsford south along Concord Road from its crossing of Farley Brook to the Chelmsford-Carlisle town line, and westward off Concord Road on a network of residential roads. The rocks exposed in this area represent the upper two-thirds of the Nagog Pond, the lower third is cut out on the southeast by an inferred fault. The rocks of the Nagog Pond form a belt that ranges in width from 1,400 to 2,000 m, the wider parts of which coincide with abundant sills of Acton Granite. This erratically exposed member has been traced from Nagog Brook southwestward about 3,000 m to Route 2, from which it evidently continues for some distance; it has been followed northeastward a little more than 10 m to Concord Road in Chelmsford. Farther northeast, rocks tentatively assigned to the Nagog Pond are sparsely and wildly distributed in an area dominated by the intrusion of granite and made complex by faults.

The upper contact with the Fort Pond Member has not been seen, the width of concealment between the units ranging from a minimum of 150 m to several times that width. Strata within the two units are mostly parallel, and the contact is parallel over a distance of at least 15 m. The medium-grained biotite gneiss of the Nagog Pond intertongues with and grades upward into the complexly interstratified biotite-amphibole gneiss, amphibolite, and calc-silicate-bearing (diopside-tremolite) rock of the Fort Pond Member. On these bases, the contact is considered conformable and gradational.

#### Fort Pond Member (1,470 m)

The Fort Pond is one of the members with varied lithology. The lower part is made up mostly of fine-grained amphibole-biotite gneiss, calc-silicate (diopside-tremolite)-bearing gneiss or fels, and amphibolite. The upper part consists chiefly of the same rock as the lower part but includes, in addition, some sulfidic sillimanite-mica schist and discontinuous beds of marble.

The lower third of the Fort Pond Member is particularly well exposed in the area from between the southeast shore of Fort Pond extending southeastward about 600 m to Fort Pond road, which nearly coincides with the lower, southeastern, boundary of the member. This same group of rocks is more conveniently observed in roadcuts along Route 2 by starting from a rock-cut on this route, 920 m due south from the southern tip of Fort Pond, and thence going northwestward over a total distance of 610 m. Fair exposure of the middle part of the unit is found in the area extending roughly from the north and northwest shores of Fort Pond northward and northwestward to Nashoba and Boxboro-Newtown Roads. Very excellent exposures of the upper third of the member begin 765 m due west of the southwest corner of Fort Pond, continue westward across Route 2 to the Boston and Maine tracks at Boxboro Station on the northeast side of the tracks, along both sides of Route 3, and are formed in the woods and fields between these two routes. Boxboro Station sits almost athwart the contact of the Fort Pond Member with the overlying Long Pond Gneiss Member, the nearest good exposure of Long Pond rock occurring in a string of outcrops that begin about 120 m southwest of the station on the southeast side of Depot Road.



The Fort Pond Member is also well exposed at Robbins Hill, about 12 km northeast of Fort Pond, in the town of Chelmsford. Within this area, an excellent representation of the Fort Pond Member can be observed by starting at the forks of Farley Brook and thence zigzagging from crop to crop on an average bearing of  $335^{\circ}$  across the top of Robbins Hill and on to Interstate 495, a straight-line distance of 2,450 m. The rocks of this member form a northeast-trending belt that ranges in width from 1,500 to 2,450 m; the wider parts are mostly where conformably emplaced sill-like bodies of granite or structural complexities have been seen. This belt of rocks has been mapped from its type locality at the southwestern corner of the Westford quadrangle, northeastward a little more than 16 km to the vicinity of North Road and Boston Road in Chelmsford Center. From here, northeastward, the rocks of the unit are lost under glacial deposits which cover its northwesterly course for a distance of more than 5 km to southeastern Lowell and northern Tewksbury. At this locality, rocks of the Tadmuck Brook Schist appear in scattered outcrops on the north; scattered outcrops of gneiss, schist, and amphibolite having wildly diverse attitudes and considered almost certainly to correlate with the underlying Nagog Pond Gneiss and Nashoba Brook Members, together with much Andover Granite, appear to the east and south of the projected course of the Fort Pond Member.

With the aid of Hansen's geologic maps of the Hudson and Maynard quadrangles (1956), the Fort Pond Member has been traced from its type locality southwestward 11 km to the town of Bolton. The outcrop belt narrows to less than 1,500 km near East Bolton.

The upper contact is believed to be conformable and gradational, the generally complexly interlayered amphibolite, calc-silicate-bearing gneiss, and sillimanite-mica schist of the Fort Pond intertonguing with and grading upward into the medium-grained biotite gneiss that is predominant in the Long Pond Gneiss Member. At many localities, the contact is faulted.

#### Long Pond Gneiss Member (1,160 m)

The Long Pond Gneiss Member consists mostly of the characteristic medium-grained sillimanitic muscovite-biotite-oligoclase-quartz gneiss of the Nashoba interstratified with a few lenticular bodies of thinly bedded amphibolite and massive amphibolite.

Scattered but good and representative exposures are found within a 1,530-m wide belt that extends from the southwest shores of Long Pond southwestward some 3,000 m to the southern and western borders of the Westford quadrangle and the vicinity of Boxboro station in the town of Boxboro. The southeast, lower boundary of the Long Pond Gneiss Member is almost coincident with a line connecting the eastern edge of Long Pond with the crossing of the Boston and Maine Railroad tracks by Depot Road at Boxboro Station in the town of Boxboro. The most complete section and the bulk of the outcrops in the area are along Route 2 and the adjacent Boston and Maine tracks (STOP 7).

Although not generally well exposed, the Long Pond Gneiss Member has been mapped from its type locality northeastward, on a consistent bearing of  $40^{\circ}$ , about 12.5 km to the junction of the forks of Tadmuck Brook in the town of Westford and close to the Westford-Chelmsford town line. The trace of these two forks, bearing  $60^{\circ}$ , is coincident with the lower contact of the Tadmuck Brook Schist. Northwest of these forks, the Tadmuck Brook Schist is exposed at



several places, showing rather consistently strikes of  $60^\circ$  and dips of  $80^\circ$  NW. At present, it is not certain whether this truncation, represented by a  $20^\circ$  divergence of strike between the units, is the result of faulting or of a disconformity. With the aid of Hansen's geologic maps of the Hudson and Maynard quadrangles, the Long Pond Gneiss Member has also been traced southwestward from its type locality about 9.8 km to Rattlesnake Hill in the town of Bolton. Here, its outcrop belt of mostly sillimanitic biotite gneisses has narrowed down to about 1,250 m.

The upper boundary is assumed to be conformable and gradational, its medium-grained sillimanitic biotite gneisses intertonguing with and grading upwards into the complexly interstratified amphibole-bearing and calc-silicate rocks characteristic of the lower part of the Beaver Brook Member.

#### Beaver Brook Member (1,580 m)

The Beaver Brook Member is the uppermost member of the Nashoba and is composed of a heterogeneous variety of rock types, chiefly amphibole-biotite gneiss, calc-silicate (tremolite-diopside)-bearing gneiss and fels, amphibolite, and rare discontinuous beds of limestone in the lowermost 400-500 m. The upper part includes medium-grained sillimanitic muscovite-oligoclase-quartz gneiss complexly interstratified with sulfidic sillimanite-muscovite-biotite-oligoclase-quartz schist, thin-bedded and massive amphibolite, and amphibole-biotite gneiss.

Representative exposures of the member occur in an area roughly bounded on the northeast by Mill Road in Littleton, on the southeast by Forster Street in Littleton and Hill Road in Boxborough, on the southwest by Littleton County Road in Harvard and Route 111 (Old Turnpike) in Boxborough, and on the northwest by the foot of Oak Hill in the towns of Harvard and Littleton. Oak Hill is underlain by rocks of the Tadmuck Brook Schist, and the foot of this hill coincides almost exactly with the upper boundary of the Beaver Brook Member. For the most part, the strata of both units strike about  $40^\circ$  and dip steeply to the northwest. Within this area, rocks of the approximate uppermost and lowermost thirds of the unit are generally well exposed; rocks of the middle third of the unit are represented by only a few exposures at the southwest end of the area and at Mill Pond on the northeast.

The Beaver Brook Member has been mapped from Mill Road in Littleton about 7.6 km northeastward on a bearing of  $40^\circ$  to the vicinity immediately south of Westford Center and Prospect Hill, all in the town of Westford. Here, as at the northeastward termination of the Long Pond Gneiss Member, the rocks of the Beaver Brook are truncated by the more east-trending rocks of the Tadmuck Brook Schist. Here the schists of the Tadmuck Brook (well exposed west and southwest of Westford center) mostly strike  $55^\circ$ - $65^\circ$  and dip  $80^\circ$ - $90^\circ$ , mostly northwest. With the aid of Hansen's geologic map of the Hudson quadrangle (1956) the Beaver Brook Member has also been traced from Mill Road southwestward 14.5 km to Bolton Center, where the unit is about 1,700 m wide at the surface.

The upper contact of the Beaver Brook Member with the Tadmuck Brook Schist is exposed on Littleton Road at the foot of Oak Hill, just northwest of the Oak Hill Road intersection. The contact appears to be conformable and gradational at this locality. Thin-bedded amphibolite intertongues with sillimanite-biotite-quartz-muscovite schist of the Tadmuck Brook. Northeastward along the



base of Oak Hill the strata of both formations strike about  $40^\circ$  and dip steeply northwest. The regional northeastward overlap of the Tadmuck Brook onto successively lower members of the Nashoba Formation, however, suggests the possibility of unconformity.

#### Tadmuck Brook Schist (920 m)

The Tadmuck Brook Schist is chiefly phyllite in the upper part, sericite-staurolite-andalusite phyllitic schist in the middle part, and sillimanite-quartz-mica schist in the lower part, all interstratified with lenticular bodies of thin-bedded to massive amphibolite.

The formation is exposed on both sides of Tadmuck Brook in the town of Westford. The area of exposure is well delineated on its southeast by the upper forks of Tadmuck Brook, which here coincide with the lower boundary of the schist unit, and on the northeast by Lowell Road, here coinciding closely with the upper boundary of the unit. The area is arbitrarily bounded on the northeast by Chamberlain Road and on the southwest by Providence Road. The best representation of the unit in this area is found among exposures on the hill immediately southwest of the main branch of Tadmuck Brook, between Lowell Road and Main Street. Excellent reference localities of the Tadmuck Brook Schist are 2,300m northeast ( $55^\circ$ ) of Tadmuck Brook along and near School and Westford Streets between Graniteville and Locke Roads, all in Chelmsford, and 4,100 m southwest ( $235^\circ$ ) of Tadmuck Brook along and near Hartford Road between Patten and Robinson Roads, all in Westford. The Tadmuck Brook Schist has been traced between the city of Lawrence on the northeast and the vicinity of Shrewsbury on the southwest, a distance of about 68 km. The Tadmuck Brook is also well exposed on Oak Hill in the Ayer quadrangle, STOP 8, where it consists almost entirely of rusty-weathering sulfidic, graphitic, micaceous, staurolite schist.

The pelitic schist of the Tadmuck Brook locally intertongues with and grades downward into the comparatively mafic-rich quartzo-feldspathic gneissose rock of the Nashoba Formation. Regionally along this boundary, however, commencing from about the Littleton-Westford town line and thence northeastward to the vicinity of Lawrence, where the Tadmuck Brook Schist is lost, the units of the Nashoba are truncated at low angle by the overlying pelitic schist of the Tadmuck Brook, and a reasonable case for a disconformity can be made, but, in places, this contact is known to be a fault.

The top of the Tadmuck Brook Schist is everywhere cut out by faults here considered to belong entirely to the Clinton-Newbury fault zone. This fault zone contains broken, slivered, and milled rock consisting of quartz and phyllite belonging to the Merrimack Group of gneiss; schist from the Tadmuck Brook Schist, and of granitic and mafic igneous rock broadly related to the Ayer Granodiorite and so-called "Chelmsford Granite". The fault zone is more than 1,500 m wide in the Hudson and Ayer quadrangles and progressively thins northeastward; it is difficult to recognize northeast of Lawrence. Many faults evidently related to the Clinton-Newbury faulting lace through the aluminous schists of the Tadmuck Brook, cutting it at high angles, and contribute to the discontinuity and irregular distribution of its rock types.



## Road Log for Trip A-14

Field trips starts at 8:00 A.M. sharp in the Boston University parking lot. Drive west on either Route 2 or Route 90 to 128. The zero starting point for this log is at the west side of the Route 128 overpass on Trapelo Road.

### Mileage

- 0.0 Entrance to L.F.E. building on Trapelo Road. Drive west on Trapelo.
- 0.7 Road crosses narrows of Cambridge Reservoir
- 2.5 Town of Lincoln intersection Trapelo Road and Bedford Road. Continue west on Sandy Pond Road.
- 2.9-3.1 Turn right at entrance to Cordova Museum; continue bearing right for 0.2 mi to parking lot. Leave bus and walk west back along road. Outcrops on lawn to the north are STOP 1.
- STOP 1. The Sandy Pond Amphibolite Member of the Marlboro Formation crops out well and is a conspicuous marker in this part of the section. Exposures consist mostly of thick even-layered greenish-gray to greenish-black fine-grained amphibolite. Thin felsic laminae accentuate the compositional layering. Partings range from paper thin to almost a metre thick.
- 3.1-3.7 Return to bus. Bus returns to Lincoln center crossroads again.
- 3.7-4.0 Travel east on Trapelo Road to Lexington Road. Turn left, leaving cemetery on right.
- 4.0-5.3 Lexington Road
- 5.3-5.4 Lexington Road is almost directly on a trace of the Bloody Bluff fault. Low light-gray outcrop on right side of bus is a mylonitized granite rock commonly found along the trace of the fault.
- 5.4 Turn right onto Route 2.
- 5.4-6.6 Travel east on Route 2; and turn right at entrance to Route 128 North.
- 6.7-11.4 Drive north and northeast on Route 128;
- 11.4 Take Route 3 exit. Keep to right after exit to avoid getting on Route 3-A



- 12.7 The trace of the Bloody Bluff fault is in the valley that the highway crosses here. Trace is more easterly than at Route 2.
- 13.7 Turn right at Exit 26.
- 14.1 Turn right from exit ramp onto Route 62.
- 14.1-14.5 Traveling east on Route 62.
- 14.6 Turn left on Middlesex Turnpike
- 16.5 STOP 2. Examine outcrops exposed for about 500 m on both sides of Middlesex Turnpike. This is a representative exposure of the Shawsheen Gneiss. Rock is a gray-weathering quartz-feldspar-biotite gneiss. Muscovite is conspicuously patchy in this formation, although it is not well shown here except in the northern outcrops or the west side. As explained in the introduction, this rock type cannot be distinguished from the most common rock type in the Nashoba Formation, but the Shawsheen is separated from the Nashoba by the distinctive Fish Brook Gneiss. Note contortion of the foliation and compositional banding. Also note chlorite, epidote, and slickensides on most fractures.
- 16.5 Buses continue north on Middlesex Turnpike.
- 16.9 Intersection with Lexington Road. This is the approximate trace of the contact with the Fish Brook Gneiss, not exposed.
- 17.1-17.4 Turn left on Manning Street and drive to end of pavement. Leave bus and walk along dirt road for about 0.3 mi.
- STOP 3: The outcrops for STOP 3 are roadcuts along Route 3. This is a heavily traveled road, so be careful. The best exposure extends for about 250 m on the east side; there is no need to cross the pavement. The Fish Brook is a light-gray felsic gneiss. Layering and compositional banding are weak and widely spaced. Biotite, generally amounting to less than 15 percent, defines the foliation, which is characteristically crinkled. Muscovite is rare to absent. Note presence of rusty schist layers. Note presence of diabase dike pair, not observed across the road. Slickensides on joints are nearly horizontal or plunge gently to the southwest. Return to bus. If time permits, examine the natural exposures of Fish Brook on the hillside north of the dirt road.
- 17.4-17.7 Return to Middlesex Turnpike



- 17.7-18.6 Turn right and travel north on Middlesex Turnpike to the top of the hill just north of Nutting Lake.
- STOP 4: Boxford Member of Nashoba Formation. The Boxford is one of the Nashoba members characterized by heterogeneity and a predominance of amphibolite. In this outcrop well-layered evenly layered light- to dark-greenish-gray color-banded calc-silicate-bearing amphibolite lies stratigraphically above rusty-weathering sulfide-rich calc-silicate-bearing schist.
- 18.6-19.3 Continue north on Middlesex Turnpike to its end. Turn left on Concord Road.
- 19.8 Cross Route 3, continue west on Concord Road.
- 20.5 Turn right on Dudley Road (unmarked)
- 21.0 Turn right on Nashua Road, cemetery on left-hand corner.
- 21.5 Cross Concord River
- 21.8-22.1 Outcrops of Andover Granite
- 22.5 Turn left on Treble Cove Road
- 23.5 Turn left on Maple Street - Exposure of Andover Granite on left.
- 23.6 Bear right on Brook Street.
- 24.8 End of Brook Street; turn right on Bedford Road, Route 225.
- 25.9 Center of Carlisle; continue west on Route 225. Tophet Swamp Gneiss Member exposed on right. Graded bedding indicates tops to west.
- 27.4 Turn left on Acton Street - right at east border of the Westford quadrangle.
- 28.3 Junction Acton Street with Route 27, Main Street. Drive south on Route 27.
- 29.8 Railroad crossing
- 30.7 Turn right at entrance to Wampus Heights Apartments. Turn right and proceed uphill into parking lot.
- STOP 5: lunch stop. Facilities should be available at several gas stations at the road intersection 100 m away.



Amphibolite-bearing gneiss of the Nashoba Brook Member are well exposed in the hills west and northwest of the parking lot. At parking lot level, the gneiss is more felsic and somewhat pelitic like the quartz-feldspar-biotite-muscovite gneiss characteristic of the more homogeneous members of the Nashoba Formation. These felsic rocks crop out in the woods to the northwest and apparently form the eastern scarp of outcrop. Back of the scarp, thickly bedded amphibolite predominates. This amphibolite gneiss is very different from the amphibolite in the Boxboro Member of STOP 4. It is more massive, less evenly layered, coarser grained, and calc-silicate minerals are not conspicuous. At the top of the ridge is somewhat finer grained more thinly layered amphibolite that extends to the southernmost exposures just north of the condominiums. Stringers of gneissic intrusive rock as much as several metres thick parallel the layering and locally are difficult to distinguish from the felsic country rock.

- 30.7 Leaving parking lot, turn right, west, on dirt road that joins Route 119.
- 30.8 Turn right and drive northwest on Route 119, Great Road.
- 32.1 Nagog Pond on left.
- 32.3 Turn left on Nashoba Road, north side of Nagog Pond.
- 33.5 Cross Nagog Hill Road.
- 34.1 Junction Nashoba Road on New town Road. Bear left on Newtown Road.
- 34.7 Fort Pond Member of Nashoba Formation exposed over crest of hills, right side of road.
- 35.0 Bear right where sign says "Not a through road." This is the old Boxboro Road and leads to exposures of the Fort Pond Member in roadcuts along Route 2.
- 35.5 STOP 6: Fort Pond Member of Nashoba Formation. Exposures are best on the northeast side of this well-traveled highway. Do not cross pavement. The country rock in this outcrop varies from limy sulfidic schist, through coarse calc-silicate bearing gneiss to dirty calc-silicate-bearing marble.
- Note that the alternation of lithology, particularly rusty and nonrusty, can be matched across the highway. If the strikes are not warped, there is a suggestion of a few metres of offset, the west side outcrops having moved south.



In the exposures south of the parking area, almost 50 percent of the exposures are intrusive, mostly sills of porphyritic and nonporphyritic Ayer Granodiorite. Also includes fine-grained 2-mica granite gneiss and coarser grained, gneissoid pegmatite. Note that these crosscut as well as parallel the layering.

- 35.5-35.9 Return to first right. This is a sharp turn for a bus, but better than turning into the more traveled road further along.
- 36.2 Turn right again
- 36.5 Pass under Route 2
- 37.1 Make sharp right onto Littlefield Road
- 38.4 Railroad crossing at Boxboro Station. Go straight uphill.
- 39.0 Long Pond Gneiss Member of Nashoba Formation exposed on west side of road.
- 39.3  
STOP 7 Park at edge of field and walk north beyond outcrop at edge of field to railroad tracks. Walk southeast about 200 m along tracks to railroad cuts. Exposures in woods on either side of track for about 400 m are representative of the Long Pond Gneiss Member. This is the most common lithology of the Nashoba Formation and is characteristic of the homogeneous gneiss members.
- 39.3-39.7 Continue west to end of Littlefield Road. Turn right on Foster Street.
- 40.1 End of Foster Street; turn right on Taylor Street.
- 40.1-41.7 Continue on Taylor Street, crossing by overpass of Interstate 495 and of Route 2, to the town of Littleton.
- 41.7 Turn left in front of Citgo Station on King Street
- 41.8 Bear right and continue uphill; road turns left to run subparallel to large outcrops of sulfidic schist of STOP 8.
- 43.0 Park beyond southwest end of outcrop. Walk back along road to observe excellent exposures of the sulfide-graphite-bearing facies of the Tadmuck Brook Schist. The lower 300 m of the Tadmuck Brook Schist from here on Oak Hill to where the formation crosses Route 2 is composed almost entirely of this highly sillimanitic biotite-quartz-feldspar schist.



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