TRIP B-1: LOWER PALEOZOIC METAMORPHIC STRATIGRAPHY AND STRUCTURE OF THE MAMARONECK AREA, NEW YORK

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INTRODUCTION

The rocks of southwestern Connecticut and southeastern New York can conveniently be divided into two northeast-southwest trending belts. The easterly strike belt is a metamorphosed eugeosynclinal assemblage of mixed clastic and volcanic rock (Hartland Formation and Harrison Gneiss). The Mamaroneck area is located within this belt on Long Island Sound (figure 1). The strike belt to the west is a Cambrian-Ordovician quartzite-carbonate sequence (predominantly Lowerre Quartzite and Inwood Marble) deposited on a Precambrian basement complex of the Fordham and Yonker's Gneisses. Overlying this miogeosynclinal sequence are the syntectonic and overthrust members of the Manhattan Formation (Hall, 1968a). From the Berkshire Highlands to the Manhattan Prong, these two belts meet along a sharp discontinuity known informally as Cameron's line. Cameron's line is interpreted by many (Clarke, 1958; Gates and Christensen, 1965) as a thrust fault. Locally in the Manhattan Prong, however, subsequent deformations may have obscured any local discontinuity.

METAMORPHIC STRATIGRAPHY

Hartland Formation

The Hartland Formation (Rodgers and others, 1959) represents the oldest rocks exposed in this area and is probably of Cambrian-Ordovician age. This formation is believed to be a metamorphosed assemblage of eugeosynclinal pelitic schists and graywackes. Numerous minor volcanic and intrusive rocks are also present. Recent mapping in this area indicates that three of Hall's (1968b) four subdivisions of the Hartland Formation are present. Although age relationships are uncertain here and elsewhere, the fourth and oldest member, the Amphibolite Member, may be present but not exposed. While the Carrington's Pond and White Gneiss Members can be found only in the extreme northwestern corner of the quadrangle, they are poorly exposed and will not be examined on this trip. The Schist and Granulite Member, the youngest member, comprises the bulk of the Hartland Formation in this area. Within this member numerous amphibolites have been observed. The largest of these discontinuous amphibolite units have been indicated on figure 1.

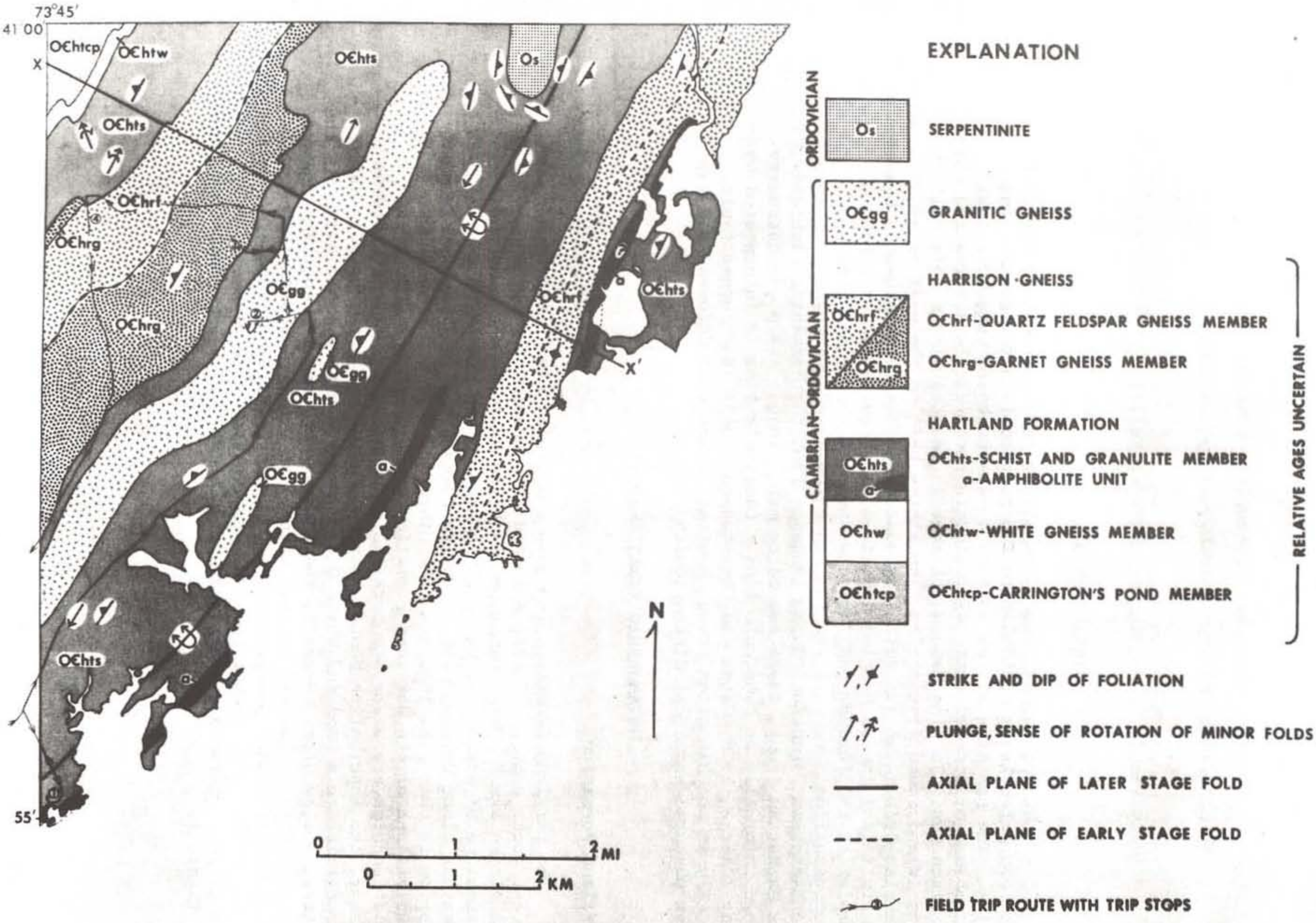

Figure 1. Geologic Map of the Mamaroneck area

These members are described briefly below in their probable order of decreasing age. In these and in all other rock descriptions, minerals are listed in order of increasing abundance.

Carrington's Pond Member: Interbedded white and gray biotite-muscovite-quartz-feldspar gneiss, rusty or brown weathering garnet-muscovite-biotite schist with local amphibolites.

White Gneiss Member: Light gray or white, medium-grained biotite-muscovite-quartz-feldspar gneiss with local garnet, light gray or white garnet-biotite-muscovite gneiss.

Schist and Granulite Member: Brown or rusty weathering, gray garnet-sillimanite-muscovite-biotite-quartz-feldspar schist and gray sillimanite-muscovite-biotite-quartz-feldspar schist with local garnet, interbedded with brownish tan weathering, gray, fine grained biotite-quartz-feldspar granulite with local garnet and coarser grained, white quartz-feldspar layers. Schist and granulite is commonly interbedded with gray, rusty weathering muscovite-biotite-quartz-feldspar gneiss or schistose gneiss. Lenses of kyanite and sillimanite are locally present. Calc-silicates interbedded with rusty weathering, sulphidic, fine grained muscovite-biotite schist are rarely present.

Amphibolite unit: Quartz-hornblende-plagioclase amphibolites with or without green calcite-diopside-epidote lenses are interbedded with the typical rocks described above.

Harrison Gneiss

Overlying the Schist and Granulite Member of the Hartland Formation is the Harrison Gneiss. In the Mamaroneck area, the Harrison Gneiss has been subdivided into the Quartz Feldspar Gneiss Member and the Garnet Gneiss Member. The Harrison Gneiss is interpreted here as metamorphosed andesitic to dacitic volcanic rock. The subdivided members of this formation are believed to have been formed contemporaneously. The Quartz Feldspar Gneiss Member is widespread throughout southeastern New York and southwestern Connecticut. Of more limited distribution is the Garnet Gneiss Member which appears only on the west limb of the major antiform (figures 1 and 2) and apparently pinches out elsewhere. Layers of the Quartz Feldspar Gneiss Member, two or three yards thick and up to a quarter of a mile in length, have been mapped within the Garnet Gneiss Member near the contact with the Hartland Formation.

The members of the Harrison Gneiss are described below.

Garnet Gneiss Member: Light gray weathering, locally rusty, medium-grained, medium gray garnet-biotite-and/or hornblende-quartz-feldspar gneiss. Poikiloblastic grains of garnet are noticeable but not abundant - often contains small prominent lenses of finer grained mafic minerals. Sphene is rare. Locally, porphyroblasts of microcline are present near the contact with the Hartland Formation in a more granitic zone.

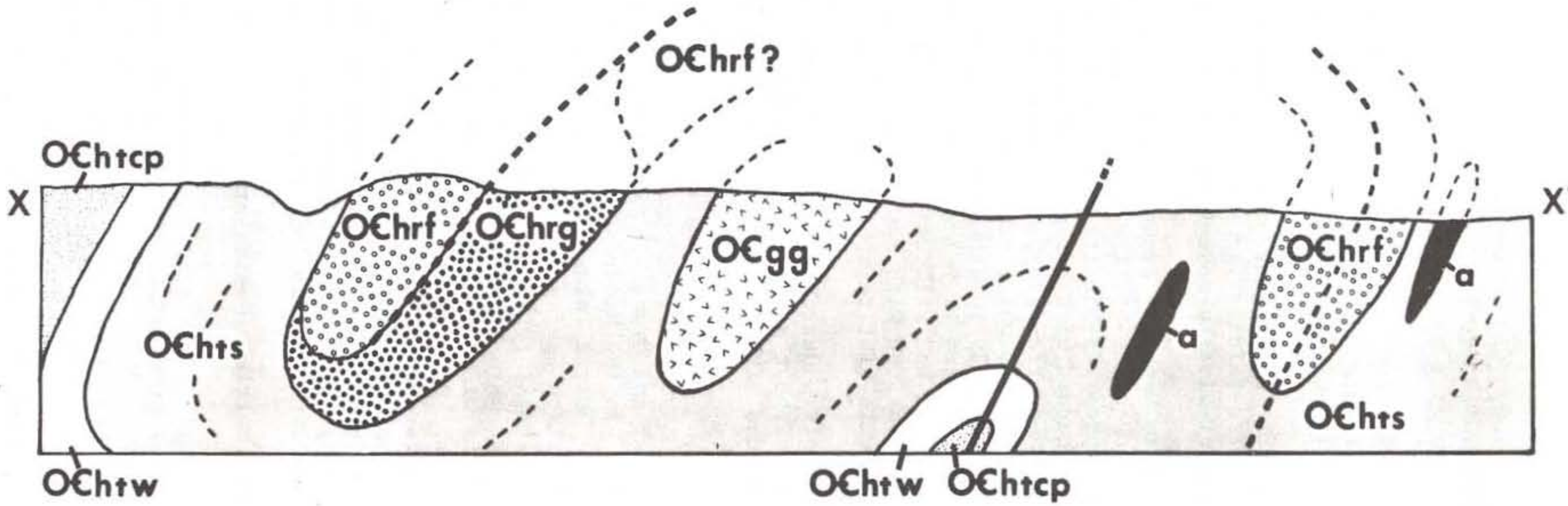

Figure 2. Generalized cross section. Refer to Figure 1 for location and symbol key. Topography exaggerated 4X.

Quartz-Feldspar Gneiss Member-Medium grained, dark gray biotite- and/or hornblende-quartz-feldspar gneiss or biotite-hornblende-feldspar gneiss with minor quartz. Sphene rare. Lenses of finer grained mafic minerals common. Easily distinguished by large irregularly shaped, coarse-grained quartz-feldspar segregations.

INTRUSIVE ROCKS

Granitic Gneiss

Numerous intrusive rocks can be found throughout the Mamaroneck area. Most of these intrusive bodies are small and not mappable at scales of 1:24,000. A large sill-like pluton and two smaller bodies of a unit informally called the Granitic Gneiss (Pellegrini, 1974, in press), however, have been indicated on figure 1. These intrusives were emplaced prior to or within the early phase of folding.

Serpentinites

Ultramafic rocks similar to those found in the Mamaroneck area have been found throughout the Appalachians in a long but narrow chain. In this area, Serpentinites have been emplaced within the Schist and Granulite Member. Since these rocks weather extremely rapidly, surface outcrops are rare and the actual contact cannot be observed. Detailed mapping in that area, however, indicated that the Serpentinite crosscuts and deforms the dominant foliation of the Schist and Granulite Member.

Although no stop is planned, there are excellent exposures of these serpentinites along the Cross Westchester Expressway. The rocks are light to medium-green weathering, fine-grained and massive often with no readily discernible lineation or foliation. When fresh, the rock is dark blackish green. Megascopic magnetite and carbonate-filled veins are common. In thin section, porphyroblasts of enstatite are commonly seen in a finer matrix of chrysotile and antigorite.

STRUCTURAL GEOLOGY

The stratigraphic units in the Mamaroneck area outline a structure resulting from at least two phases of deformation (figures 1 and 2). The dominant northeast trending bedding foliations (S_1) and related lineations (L_1) were developed during an early phase of isoclinal folding. All the units previously discussed with the exception of the Serpentinite and numerous small undeformed pegmatites were present for this early phase of folding. Metamorphism was probably in the amphibolite facies.

The early isoclinal fold is well displayed where the Schist and Granulite Member of the Hartland Formation appears continuously in contact with the Harrison Gneiss. (figures 1 and 2). On the west limb, the Garnet Gneiss Member of the Harrison Gneiss is in contact with the Schist and Granulite Member on both the east and west sides of the early-phase axial plane. This member is believed to be a continuous unit that wraps around the nose of the fold before pinching out.

In the north and northwest portions of this area, linear elements (L_1) indicate a northeasterly plunge for this early phase fold. Further to the south and southwest, the plunge reverses although locally there are horizontal, northeasterly and southwesterly plunges.

Evidence for a second major phase of folding is abundant. Minor folds,plunging in various directions and often showing opposite senses of rotation, folded lineations, and refolded isoclinal folds are relatively common. The westerly dipping limbs of the later stage antiformal fold are clearly shown by the Harrison Gneiss in the east and west portions of figures 1 and 2. The nose of this fold is clearly outlined by the Harrison-Hartland contact further north (Hall, 1968b). The axial plane of this isoclinal fold trends northeast and dips steeply to the west. Minor folds and boudin lines (L_2) generally plunge slightly west of north or north. Locally the plunge may be to the south, particularly in the central part of the area, and occasionally almost vertical. Further south near New Rochelle, the axial plane becomes vertical and still further south it dips to the east. Minor folds resulting from this deformation are usually easily recognizable since they refold the S_1 foliation about the L_2 axes.

Evidence for a third phase has also been observed. In large outcrops, large gentle warps are present in the foliation planes; the axes of which plunge steeply to the northwest. This possible third phase appears to have had no profound effect on the major structures previously described.

SPECULATIONS ON THE AGE OF DEFORMATION

Isotopic ages in southeastern New York and southwestern Connecticut suggest that at least three metamorphic events effected this region since the Precambrian (Long, 1961; Long and Kulp, 1962; Clark and Kulp, 1968). The dates obtained for these events are 480 to 460 m.y., 360 m.y. and 255 m.y. ago.. These ages correspond to the Taconic, Acadian and Alleghenian orogenies. The first event is believed to be the most intense while the 360 m.y. event was only a mild reheating. The youngest event becomes progressively more predominant eastward into Connecticut. In and near the Mamaroneck area, isotopic ages for these units range from 379 to 285 m.y. The emplacement of the Serpentinite may provide a basis for speculation on the age of the deformational phases and of the rocks themselves. Studies of orogenic zones (Hess, 1955; Coleman, 1971; Dewey and Bird, 1971) suggest that such emplacement occurred in the initial phases of orogeny shortly after the establishment of a subduction zone. The Serpentinite in the Mamaroneck area can be found exposed near the axial surface of the later-phase anticlinal fold. There they plunge northward in accord with that structure. These rocks were then emplaced prior to or within that phase of folding. Since they also appear to crosscut and deform the bedding foliation of the early phase fold, they must be younger than this phase.

The time of emplacement of similar ultramafic rocks throughout the northern Appalachians is generally accepted to have been during the Ordovician (Doll, 1961; Dewey and Bird, 1971; Zen, 1972). It is probable then that the rocks of the Mamaroneck area were intensely deformed during the Ordovician Taconic Orogeny. The Acadian thermal event (360 m.y.) may be recorded in the numerous small undeformed pegmatitic intrusions seen throughout this area (Clark and Kulp, 1968, p. 886). It is therefore apparent that the rocks of this area were not as severely deformed during the Devonian as they were in earlier periods, and that the earlier deformation consisted of at least two and probably more distinct pulses.

REGIONAL CORRELATIONS

Correlations of the various units in the Mamaroneck area are tentative. Regional considerations suggest that the Hartland Formation may correlate in whole or in part with the Lower Cambrian through Middle Ordovician Hoosac, Rowe and Moretown Formations of western Massachusetts (Hatch and others, 1966; Hatch, 1967). In the Glenville area, Hall (1968, p. 4) suggests that the youngest member of the Hartland Formation, the Schist and Granulite Member, does correlate with the lithologically similar Moretown Formation. If these correlations are valid, the Harrison Gneiss would be in the correct stratigraphic position to correlate with the volcanic Hawley Formation of western Massachusetts (Hatch, 1967). Although a detailed stratigraphic sequence has been established in areas of western Connecticut, the lack of outcrops permits only generalized correlation with this region. In southcentral Connecticut, Hall (1968b, p. 4) suggests that the Beardsley Gneiss Member of the Prospect Gneiss (Crowley, 1968) is a correlative of the Harrison Gneiss (in this paper, the Quartz Feldspar Gneiss Member) of the Glenville area. The Garnet Gneiss Member may also correlate with the Pumpkin Ground Member of that same formation and the Granitic Gneiss appears to be lithologically similar to the intrusive Ansonia Gneiss (Fritts, 1965). It is unclear, however, as to which units correlate with the Hartland Formation of this area.

The Harrison Gneiss has previously (Merrill and Magnus, 1904) been correlated with the Ravenswood Granodiorite at the westernmost end of Long Island. This interesting correlation may indicate that the proposed thrust fault (Cameron's line) between the eugeosynclinal and the miogeosynclinal sequences may extend through the East River. There the Hartland Formation which probably underlies Long Island, would be in contact with the miogeosynclinal Inwood Marble.

ACKNOWLEDGEMENTS

I would like to express my thanks to the following for allowing access to the exposures viewed on this trip: Larchmont Manor Park Society, Town of Harrison, and the Michael Harmony Corporation. I would also like to thank Leo M. Hall of the University of Massachusetts for first introducing me to the geology of this area and Leslie Sirkin of Adelphi University for his support.

ROAD LOG

Cumulative Miles	Miles from last point	Description
0.0	0.0	The road log begins at the toll booths at the north end of the Throgs Neck Bridge. After paying toll, bear to the right to take the New England Thruway (I-95) north.
8.6	8.6	Exit I-95 at North Avenue-Cedar Street (exit 8-last exit before toll). Turn right (south) off exit ramp.
8.9	.3	Turn left (east) onto North Avenue.
9.2	.3	Turn left (north) onto Main Street (US 1).
9.9	.7	The Granitic Gneiss outcrops on the west side of the road.
11.2	2.0	Turn right (east) onto Larchmont Avenue.
11.5	.3	After entering the Mamroneck Quadrangle, continue down Larchmont Avenue through the axial region of the later stage fold. After the road bends to the right, Larchmont Avenue becomes Park Avenue.
12.0	.5	Turn right onto Prospect Avenue and park for STOP 1 at the Larchmont Manor Park.
		STOP 1. Larchmont Manor Park. NO HAMMERING PLEASE! Enter the park along the paved path at the intersection of Prospect and Park Avenues. Proceed southeast (left) towards a small shelter on a promontory on Long Island Sound. The rocks here have been assigned to an amphibolite unit of the Schist and Granulite Member of the Hartland Formation. As the path continues before the clubhouse, it crosses a broad fold in interbedded schists and granulites which formed during the later stage of folding.

Generally, however, the minor folds related to this episode of folding are tight isoclinal folds. The parallel lithologic layering seen throughout this member is believed to be primary in origin. Although metasomatism may have accentuated this layering in the original S_o plane, these gross compositional differences are considered bedding, reflecting a sedimentary or volcanic origin. The early stage of isoclinal folding produced a foliation (S_1) generally parallel to the S_o. The later stage of folding refolded this early foliation. The S_2 foliation produced clearly crosscuts the S_1 here.

Continue down the path towards the shelter past a glacially grooved and striated amphibolite. The numerous interbedded amphibolites to the east of the shelter occupy a persistent stratigraphic position and are believed to be of volcanic origin. Similar rocks have been described at Pelham Bay to the south (Seyfert and Leveson, 1968). Greenish calc-silicate lenses composed primarily of epidote and diopside with calcite are common here and often prominent in the crestal regions of folds. The numerous northerly plunging folds are related to the later stage of deformation. The variation in the angle and direction of plunge of the L_2 axes may be due to an additional deformation, or it may be the reflection of the development of L_2 on a curvilinear surface. Crosscutting, undeformed pegmatites can be seen throughout the park. These pegmatites probably correspond to the Acadian thermal event.

Across the inlet northeast of the shelter, the interbedded schists and granulites are typical of the rocks of the Schist and Granulite Member although to the north schist may be more abundant. The rhythmic interlayering of these rocks may represent graded bedding.

Return along same path and board the bus. Proceed down Prospect Avenue and turn right (north) onto Magnolia Avenue.

12.2 .2 Turn left (west) onto Larchmont Avenue.

12.9 .7 Right turn (north) onto Boston Post Road (US 1).

14.0 1.1 The outcrops on the west side of the road near the playing fields behind the Administrative Offices of the Mamaroneck School District contain amphibolites very similar to those seen at STOP 1. Here, however, they are apparently a small isolated lens.

15.3 1.0 Bear to the left (west) at the fork for Harrison Avenue (Route 127) and proceed north towards Harrison.

16.7 1.4 After crossing the bridge over the railroad tracks, turn left (west) onto Calvert Street across the contact of the Granitic Gneiss and the Schist and Granulite Member. Continue down Calvert Street past Nelson Avenue.

17.1 .4 Park on Calvert Street in front of Pettijohn Park for STOP 2.

STOP 2. Pettijohn Park.
These outcrops of Granitic Gneiss lie near the center of this sill-like pluton. Typically this rock is a brown or brownish tan weathering, light bluish gray, fine to medium-grained, biotite-muscovite-quartz-feldspar gneiss. Microcline is the dominant feldspar; garnet is rare and occurs as small scattered grains. Biotite, although relatively sparse, gives the rock a distinct foliation which here trends northeast in accord with the major structures. The more typical fine-to-medium-grained gneiss at this exposure is commonly associated elsewhere with a white, foliated and lineated pegmatite. Although the contacts between the two types of rock tend to be sharp, the lineations and foliations pass without interruption into the more typical granitic gneiss. The pegmatites are therefore mapped as part of this unit.

Smaller bodies of this rock have been mapped throughout this area and the larger ones have been indicated on figure 1. Some crosscutting dikes have been observed within the Harrison Gneiss, however, the other bodies are all concordant. Although the smaller bodies tend to have sharp contacts, a zone of migmatite occurs along the contacts of this large body.

From the park continue west on Calvert Street. Go around the block by making a left (south) onto Adelphi Street, left (east) onto Rugby Street and left (north) again at Avondale Street. You should now be back at Pettijohn Park. Turn right onto Calvert Street.

17.6 .5 Turn left (north) onto Nelson Avenue.

18.1 .5 Cross the bridge over the New England Thruway and make a left (west) turn onto Crystal Street. Proceed down Crystal Street across the west contact of the Granitic Gneiss with the Schist and Granulite Member.

18.5 .3 At the end of Crystal Street, enter the Town of Harrison Veterans Memorial Park while crossing the contact of the Hartland Formation with the Garnet Gneiss Member of the Harrison Gneiss. Park in the unpaved parking area for STOP 3.

STOP 3. Veteran's Memorial Park.
Scattered throughout the park are excellent exposures of the Garnet Gneiss Member of the Harrison Gneiss. These exposures are on the west limb of the later-stage antiform. This member apparently pinches out further north and is not present on the east limb of the same fold (figure 1). The flat glaciated outcrops within and around the parking area expose a distinctly porphyroblastic zone within this member. The rock is more granitic than most of this member and the porphyroblasts are microcline commonly exhibiting Carlsbad twinning. This zone parallels the contact of this member with the Schist and Granulite Member of the Hartland Formation for at least two miles and appears as a distinct unit or units within the Garnet Gneiss Member. Intensely deformed metasedimentary layers are also present in these outcrops.

From the restrooms at the southern end of the parking area, proceed southwest (bearing 250°) across the recently filled valley to a dirt road and then up the east valley wall. PROCEED WITH CAUTION OVER THE CONSTRUCTION DEBRIS FILL! Total distance to the top of the ridge from the restrooms is about one thousand feet. These exposures contain some of the evidence for the volcanic origin of the Harrison Gneiss. The contact of both members of the Harrison Gneiss with the Schist and Granulite Member is always conformably interlayered with that member. As shown here, thin distinct metasedimentary layers, often only an inch or two thick, can be traced for tens of feet without interruption through the Harrison Gneiss. This interbedded contact can be up to 150 feet thick. The interlayering is suggestive of alternating sedimentary and possibly pyroclastic deposition rather than an intrusive or tectonic mechanism. The Prospect Gneiss, a possible western Connecticut correlative, has a similar contact. Crowley (1968, p. 39) believes that the Prospect Gneiss is a metamorphosed volcanic sequence. The Ravenswood Gneiss to the south also has an interbedded contact although Blank (1973, p. 656) considers it to be sedimentary.

Additional exposures of the contact, although quite deformed, can be seen west of the playing fields adjacent to the entrance to the park. The Schist and Granulite Member is exposed in the stream flowing by the nearby Louis M. Klein Middle School. As can be easily seen at this stop, topographic differences usually facilitate the location of the contact.

Return down Crystal Street to Nelson Avenue.

18.9	.4	Turn left (north) onto Nelson Avenue.
19.1	.2	Turn left (west) onto Union Avenue.
19.3	.2	Recross the contact of the Schist and Granulite Member with the Garnet Gneiss Member.
19.9	.6	Cross the axial plane of the early stage fold and the contact of the Garnet Gneiss Member of the Harrison Gneiss with the Quartz Feldspar Gneiss Member. Here the two members of the Harrison Gneiss have been folded against each other (figures 1 and 2).
20.3	.4	The outcrops in front of the Harrison High School are of the Quartz Feldspar Gneiss Member.
20.7	.4	After crossing the west contact of the Harrison Gneiss with the Schist and Granulite Member, turn left (south) onto Mamaroneck Avenue.
20.9	.2	Turn left (east) into the parking lot and park at the southern end of these continuous exposures for STOP 4.

STOP 4. Parking lot cuts off Mamaroneck Avenue. NO CLIMBING ON THE ROCKS PLEASE! These extensive cuts are in the Quartz Feldspar Gneiss Member of the Harrison Gneiss. Large irregularly shaped segregations of quartz and feldspar and the lack of megascopic garnet easily distinguish this member from the Garnet Gneiss Member. Although biotite commonly exceeds hornblende in both members, the great abundance of biotite here accounts for their somewhat slabby appearance. Present throughout both members and evident in these outcrops are small lenses or streaks of fine-grained hornblende, biotite and feldspar, usually measuring a few inches by a foot or more. Similar lenses have been interpreted as relict volcanic bombs in the Prospect Gneiss (Crowley, 1968, p. 39) and in the high grade metavolcanics of the Southern Appalachians (Tobisch and Glover, 1971, p. 2212).

At the north end of these cuts and along Union Avenue, the contact with the Schist and Granulite Member is exposed. Here the Hartland Formation, on the limb of a small fold (figure 1), contains rusty weathering, sulphidic looking schists. The contact of this member of the Harrison Gneiss with the continuous but folded contact of the Schist and Granulite Member is also interbedded.

Most of the exposures across the Mamaroneck River in the northern part of Saxon Woods Park are of the Quartz Feldspar Gneiss Member. To the southwest, near the Hutchinson River Parkway, the Garnet Gneiss Member is exposed. There it apparently wraps around the nose of the refolded early stage fold (figures 1 and 2) but pinches out before reaching this location.

Exit the parking lot by turning left (south) onto Mamaroneck Avenue.

21.4 .5 Recross the folded contact of the Quartz Feldspar Gneiss and Garnet Gneiss Members.

21.7 .3 Enter the southbound entrance ramp of the New England Thruway (I-95) passing exposures of the Garnet Gneiss Member and return to the Throgs Neck Bridge.

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