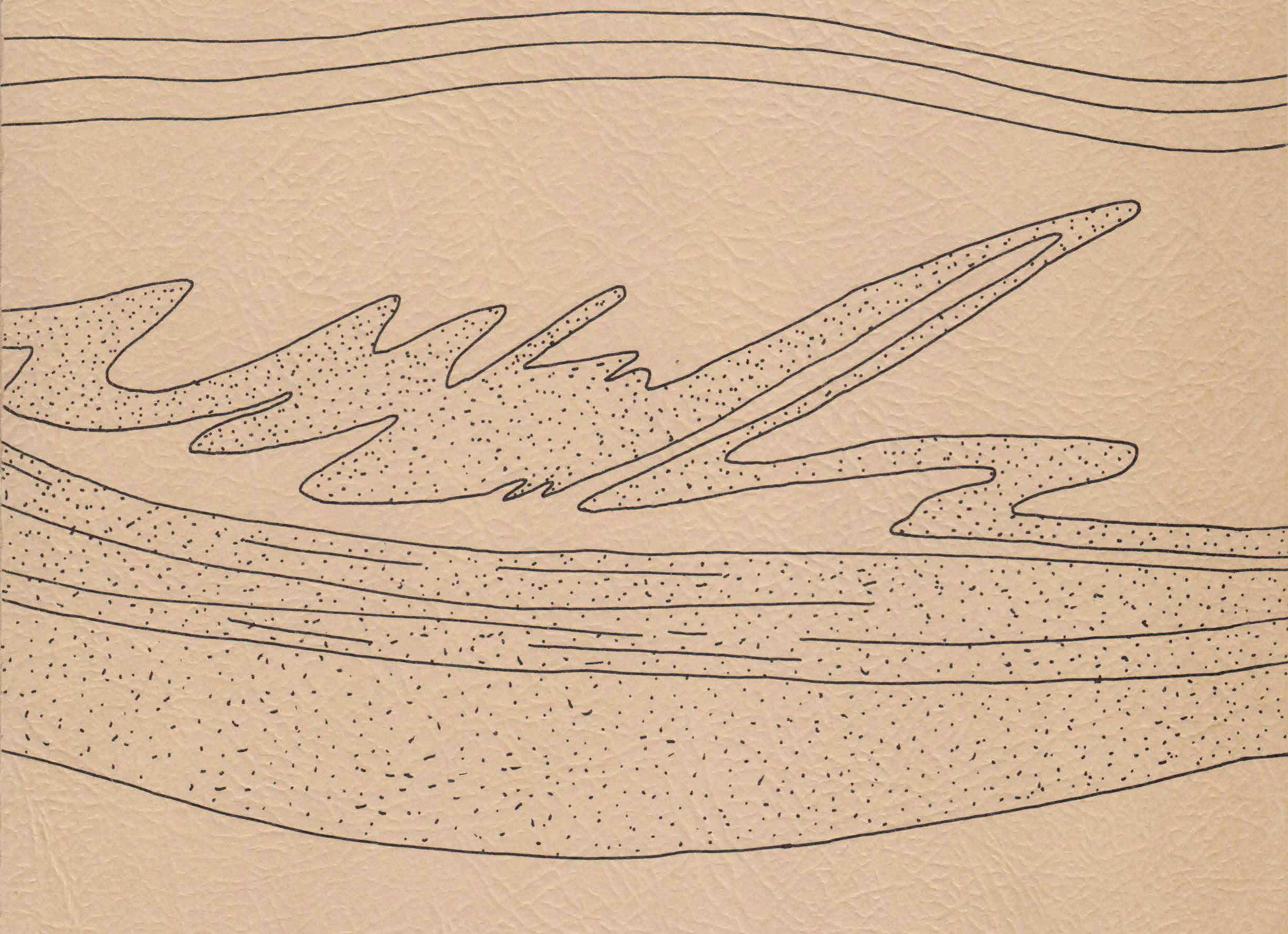
STRATIGRAPHY AND STRUCTURE NORTHERN PORTION OF THE PELHAM DOME NORTH-CENTRAL MASSACHUSETTS

BY DAVID D. ASHENDEN



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by

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Contribution No. 16
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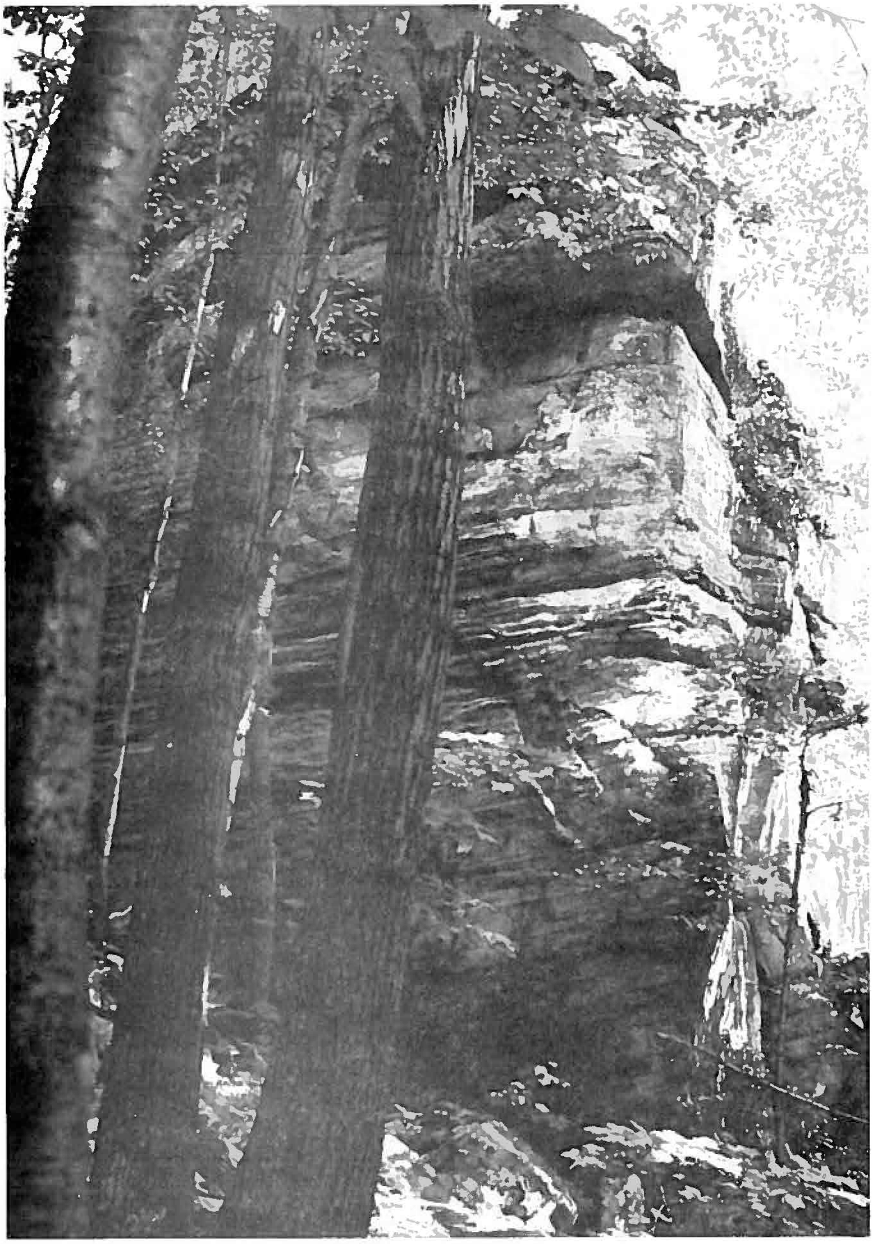


Frontispiece. Rose Ledge, on Northfield Mountain, Erving, Massachusetts; hornblende Member Dry Hill Gneiss.

ABSTRACT

The Pelham dome, in central Massachusetts, is one of about twenty mantled gneiss domes along the Bronson Hill anticlinorium, a major structural feature of the northern Appalachians. The present study of the northern portion of the dome was undertaken to supplement conventional field data with data obtained from bedrock tunnels and temporary outcrops made during the construction of the Northfield Mountain Pumped Storage Hydroelectric Project.

The rocks have been divided into a distinctive sequence of map units which, listed in believed order of age, includes the following:

1. Dry Hill Gneiss: layered pink quartz-feldspar-biotite-hornblende granite gneiss of probable volcanic derivation containing minor quartzite beds. Divisible into a hornblende member containing both biotite and hornblende and a biotite member containing no hornblende. The dark blue-green hornblende is unusual in that the 2V is close to zero degrees.
2. Poplar Mountain Gneiss: gray quartz-feldspar-biotite gneiss of probable sedimentary derivation with abundant white feldspar megacrysts up to ten centimeters across. A series of quartzite beds, some containing actinolite, form a basal unit within the Poplar Mountain Gneiss. The Poplar Mountain Gneiss occurs both in an inner exposure below the Dry Hill Gneiss and in an outer exposure lying above the Dry Hill.
3. Fourmile Gneiss: gray quartz-feldspar-biotite gneiss and plagioclase gneiss with minor amphibolite. The Fourmile Gneiss is of probable volcanic derivation.

4. Partridge Formation: rusty-weathering, sulfidic, muscovite-garnet-schist of sedimentary derivation.

Zircons from the Dry Hill Gneiss have been dated at 575 ± 30 my and the Poplar Mountain Gneiss is believed to be of comparable age but younger than the Dry Hill. Age of the Fourmile Gneiss is unknown but is inferred to be Ordovician. The Partridge Formation is Middle Ordovician. The area is in the staurolite-kyanite zone of regional metamorphism, but these minerals are not present because of insufficient alumina.

Foliation forms a broad anticlinal arch plunging very gently northward. The stratigraphic relations and map pattern of the rocks suggest a major west-over-east early recumbent fold such that the inner and outer exposures of the Poplar Mountain Gneiss are stratigraphically correlative. The recumbent fold was subsequently refolded about a north-south axis during the formation of the dome. A pervasive mineral lineation everywhere trends north and plunges gently north parallel to the axis of the dome. Numerous late folds with diverse orientation and north over south movement sense deform both the foliation and mineral lineation. These folds may account for some local repetitions of the stratigraphy along the crest of the dome and are believed to be related to the doming. The doming is attributed in part to movements caused by density differences between the gneiss and the mantling rocks within a regional stress field under conditions of kyanite-staurolite zone regional metamorphism. All the recognized folding was probably developed during the Acadian Orogeny. Numerous joints, small displacement normal faults and the major Triassic border fault formed since metamorphism and folding.

INTRODUCTION

Location

The area studied (Fig. 1) is located in north-central Massachusetts about 25 miles north-northeast of Amherst and is situated in parts of the Northfield, Millers Falls, and Greenfield 7 1/2 minute quadrangles. The outline of the area approximates a triangle with a base six miles long from east to west and a north-south height of five miles with the apex to the north. Total area is about 15 square miles. The area includes parts of the Townships of Erving, Montague, and Northfield. Specific boundaries were determined by geological considerations outlined in the section on geologic setting.

Topography and drainage

The region forms the northern portion of a prominent elongate topographic ridge extending northward from Belchertown for 25 miles to the vicinity of Northfield. The ridge slopes steep on the east and west sides. Its average elevation is about 800-900 feet with some rounded summits surpassing 1000 feet. Within the study area (Plate 1) Hermit Mountain is the highest point (elevation 1206 feet) and the confluence of the Connecticut and Millers Rivers (elevation approximately 175 feet) is the lowest point. Total relief is about 1030 feet.

Two major valleys bound the area. The Connecticut River on the west forms a flat-floored valley reaching at points a width in excess of one mile but south of Northfield Farms the valley is constricted. The valley floor is only 200 feet wide at its narrowest point in French King Gorge just north of the confluence with the Millers River. Numerous dairy farms utilize the good agricultural land of the Connecticut valley. The Millers River valley is nowhere more than one half mile wide and in most

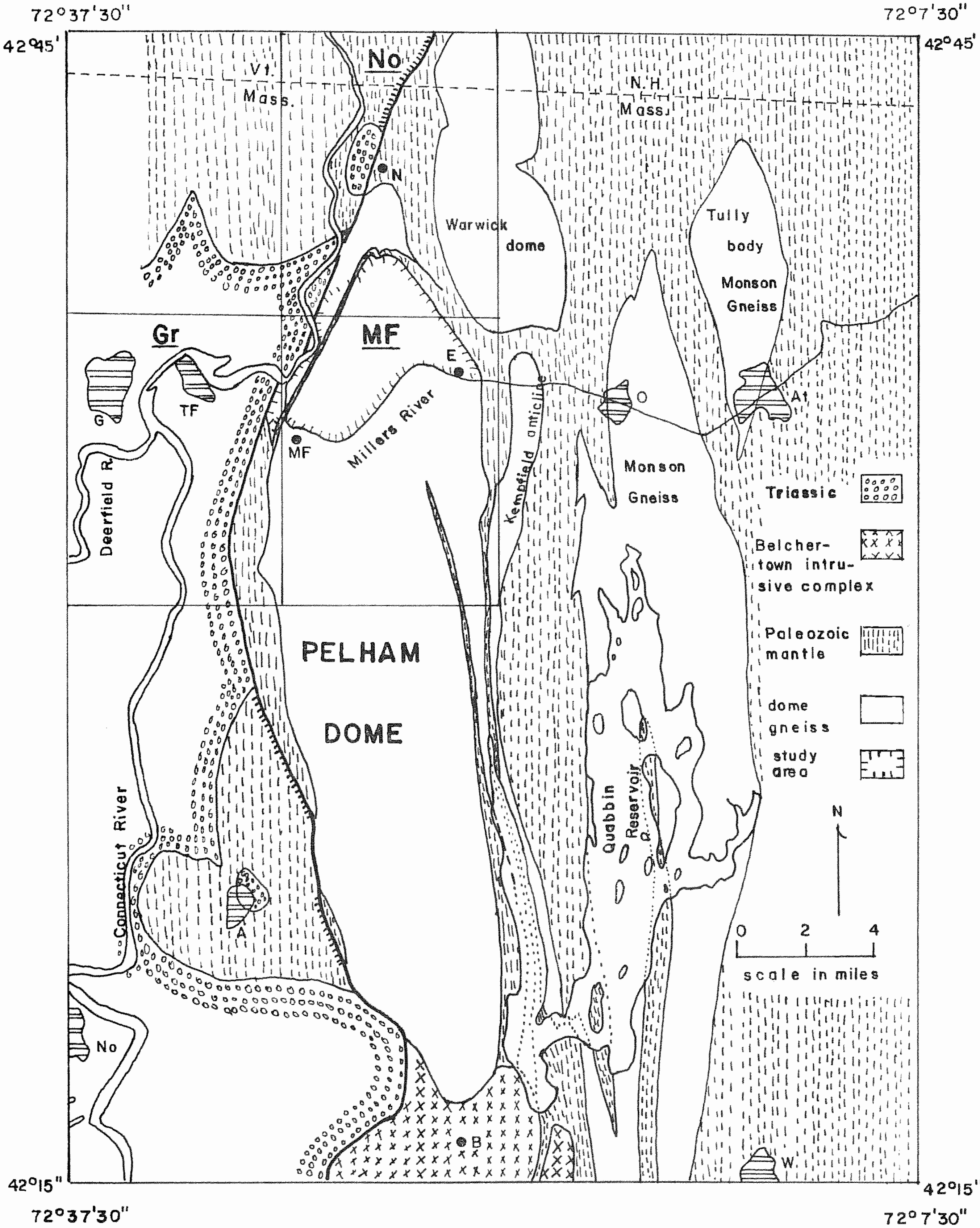


Figure 1. Generalized geologic map of north central Massachusetts. Study area (northern portion of Pelham dome) hachured.
Localities: A, Amherst; At, Athol; B, Belchertown; E, Erving; G, Greenfield; MF, Millers Falls; N, Northfield; No, Northampton.

places is more constricted. The Millers River is a superimposed stream forming a deep, narrow east-west valley across the ridge described above. On the north side of the valley the slopes are particularly steep cliffs below the summits of Poplar Mountain, Rattlesnake Mountain, and Hermit Mountain. The Millers River valley is the only major break in the ridge between its northern and southern ends and is utilized by two trunk east-west transportation routes, Massachusetts Route 2 and the Boston and Maine Railroad.

The area is drained by numerous small streams tributary to the Connecticut and Millers Rivers, both of which have their sources far beyond the limits of the area. The Millers River discharges into the Connecticut River west of Millers Falls. There are no prominent natural lakes or ponds in the area. There is one artificial lake, the Reservoir on Northfield Mountain connected with the Northfield Mountain Pumped Storage Hydroelectric Project.

Vegetation and Quaternary cover

The north slopes of the hills are predominantly covered by a hemlock-hardwood (maple, birch, beech) association whereas the tops of the hills and their south slopes are covered largely by red and chestnut oak. Nowhere else in central New England has the writer seen such a proliferation of chestnut oak as occurs on the upper slopes and summits of the hills. The very thin soil and consequent lack of moisture eliminates most species except chestnut oak which can tolerate dry locations. Some abandoned pasture and hay land is reverting to juniper, gray birch, and stands of white pine. Much of the valley bottoms are cleared, but, where they are not, a more varied and richer forest of hemlocks and hardwoods occurs.

The north, west, and east slopes of the hills have been smoothed by glaciation and left heavily covered by a thick veneer of till. Some north slopes today are completely devoid of outcrop. Glacial action has plucked the south slopes along well developed nearly vertical joints creating excellent bedrock exposures on the steep faces. The Connecticut Valley was occupied during deglaciation by Glacial Lake Hitchcock in which extensive bottom deposits of varved clays and marginal deltas formed. These, along with assorted shoreline features, cover much of the bedrock along the western margin of the area.

The present course of the Connecticut River (Plate 1) from a point about 3/4 of a mile south of Northfield Farms to French King Bridge and beyond is post-glacial. The former course of the river is now the site of a deep buried valley extending south from Northfield Farms along the route of the Central Vermont Railroad and Route 63 to Millers Falls. The buried valley extends southwest of Millers Falls beyond the map area. The site of this buried valley is occupied by a series of kettle holes and is completely devoid of outcrop. The buried valley appears to be filled with sand and gravel from the delta formed where the Millers River entered Glacial Lake Hitchcock.

The Millers River valley is flanked by gravel terraces, especially east of Farley. The river itself flows on a bed of cobbles and boulders. Outcrops along the river are rare and are restricted to three locations; near the bridge at Farley, along a stretch around the bend one mile east of Millers Falls, and at Millers Falls. The valley floor must have been filled with coarse alluvium during deglaciation when the presence of Lake Hitchcock effectively raised the base level of erosion. The valley floor has only been partially exhumed.

The Pleistocene geology of the Northfield quadrangle was mapped by Campbell during the 1968 and 1969 field seasons (Campbell, in preparation). Jahns (1966) has published a surficial geologic map of the Greenfield quadrangle. The surficial geology in the Millers River valley portion of the Millers Falls quadrangle has been published on a 1/125,000 scale map (Collings, Wiesnet, and Fleck, 1969) with short text but the surficial geology for the balance of the quadrangle has not been published.

Geologic setting

The area of this study forms the northern portion of the Pelham dome which is one of about 20 mantled gneiss domes situated along the Bronson Hill anticlinorium (Fig. 2). The anticlinorium is a major structural feature of the northern Appalachians and extends from Long Island Sound in Connecticut through central Massachusetts, and western New Hampshire to northwestern Maine near the Maine-New Hampshire state line. Another line of mantled gneiss domes occurs west of the Connecticut River and follows the Connecticut Valley-Gaspe synclinorium from Waterbury, Connecticut to northeastern Vermont.

The Pelham dome is an elongate structure containing extensive exposures of layered gneisses with interbedded quartzites and minor amounts of schist, amphibolite, and calc-silicate rocks. The dome extends from Northfield, Massachusetts southward 25 miles to Belchertown reaching a maximum width of 7 miles (Fig. 1). The dome gneisses form the backbone of the prominent north-south ridge described under topography and drainage.

The rocks mantling the dome have been shown to be metamorphosed Middle Ordovician to Early Devonian sedimentary and volcanic rocks (Robinson, 1963, 1967b; Thompson, Robinson, Clifford, and Trask, 1968). The gneisses in the cores of the domes, however, have been poorly understood and a source of controversy now going back nearly a century (Hitchcock, 1877, 1890; Emerson 1898, 1917; Billings, 1937, 1956; Chapman, 1939, 1942; Hadley, 1942, 1949; Rosenfeld and Eaton, 1956; Lundgren, 1962;

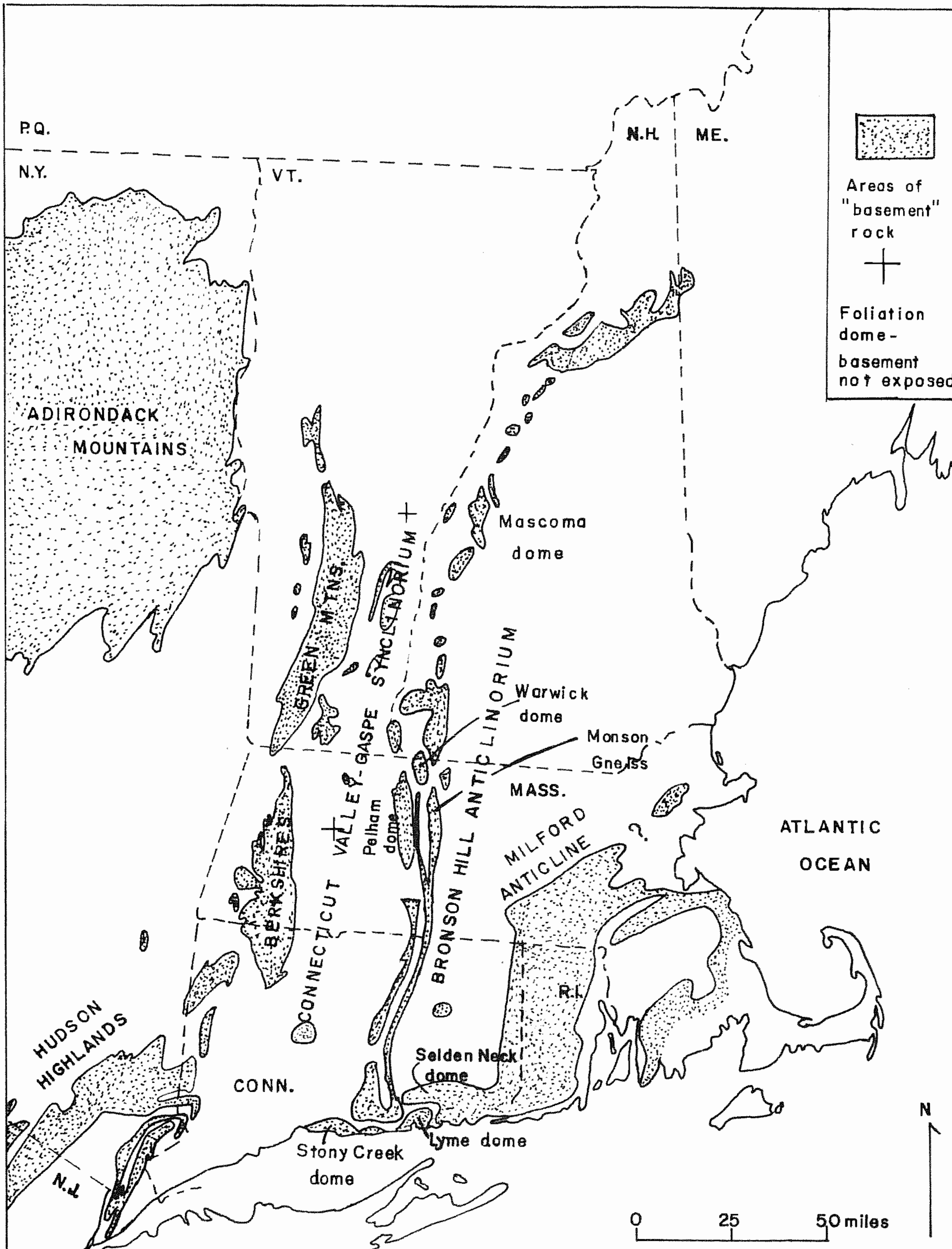


Figure 2. Map of "basement rock" in New England and eastern New York. "Basement" includes known Precambrian and also gneisses which may be younger but lie physically beneath Middle Ordovican rocks.

Robinson, 1963, 1967b; Naylor, 1969). Recent radiometric dating has shown one of the gneisses of the Pelham dome to be 575$\pm$ 30 million years old (Naylor, Boone, Bondette, Ashenden, and Robinson, 1973).

The Triassic border fault is immediately west of the Bronson Hill anticlinorium in Connecticut, Massachusetts, and southern New Hampshire. This fault cuts the west side of the northern portion of the Pelham dome.

The present study is restricted to an area of the northern portion of the Pelham dome bordered on the south by the Millers River, on the west by the Triassic border fault which follows approximately the course of the Connecticut River as far south as French King Bridge, on the north by an infolded layer of schist of the Partridge Formation from the mantle sequence, and on the east by the mantle sequence (Fig. 1). East Mineral Hill, west of Millers Falls and south of the Millers River, was included because it is isolated from pre-Triassic rocks to the south by Pleistocene cover and could not logically be included in a future study.

During revision of the original manuscript the author became employed by the Metropolitan District Commission as geologist in connection with a projected water tunnel from Northfield Mountain to Quabbin Reservoir. One of the first tasks was detailed mapping of the Bear Mountain area south of Millers River and the east side of the dome nearly all the way to the village of Wendell. This work has increased by nearly 50% the amount of the Pelham dome now mapped in detail. The main results of this mapping have been added to the original base map used in the study as far as the map extends. It is not intended to include further descriptions of the Bear Mountain area in this presentation, but the findings there have caused various revisions in interpretations, therefore requiring limited reference to the Bear Mountain area.

Purpose of study

The area was chosen to extend the work of Robinson (1963) immediately to the east. During his detailed study of the mantle rocks he made considerable reconaissance of the rocks of the northern portion of the Pelham dome and showed that the dome gneisses are apparently involved in the same recumbent fold system he had demonstrated in the mantle rock. A second and very important consideration for going into this area at this time was that the period during which the writer would be doing his field work would coincide with the excavation schedule for the Northfield Mountain Pumped Storage Hydroelectric Project (hereafter referred to more simply as the Northfield Mountain Project) located in the west central portion of the area. Hopefully, data obtained from outcrops in temporary surface exposures and a complex of tunnels totaling about two miles could be gathered simultaneously with the surface mapping of the area outlined above to add to the data from which interpretations might be drawn. It must be emphasized that much of the exposure in the Northfield Mountain Project was of a temporary nature to be seen only briefly during the construction period and that any information to be secured had to be gathered at this time.

The goals of the present study are summarized as follows:

1. to determine whether or not the layered gneisses form a distinct stratigraphic sequence,and if so,what that sequence is.
2. to gain a better understanding of the internal structure of the dome.
3. to describe the petrography of the rock units and consider their origin.

Previous work

The earliest serious work in the Pelham dome was that of Emerson

(1898, 1917). He gave very little detailed information for the northern portion but a general description of the dome and its rocks was offered with much specific detail from the Pelham and Shutesbury areas to the south. In the early 1940's Balk (1942, 1956a, 1956b) mapped the bedrock geology of the Millers Falls quadrangle and the Massachusetts portion of the Northfield quadrangle. Willard (1952) mapped the Greenfield quadrangle which includes the East Mineral Hill area of the Pelham dome west of Millers Falls. Robinson (1963, 1967b) has made a detailed study of the rocks mantling the Pelham dome immediately to the east and also included a brief consideration of the Pelham dome gneisses. Summations of the views of these geologists will be presented at appropriate points below.

Coverage and methods of study

Field methods consisted of detailed location of outcrops on topographic maps, field description of the rocks, measurement and recording of foliation and mineral lineation with a Brunton compass, measurement and recording of the trend, plunge, movement sense and style of minor folds, and carefully walking out and locating on topographic maps those contacts that could be followed in the field. A pocket altimeter was used to aid in location in the field.

Several deep drill cores (some over 700 feet) from the Northfield Mountain Project were examined very early in the study and proved to be of immense help in determining the stratigraphic sequence. Surface excavations of the Northfield Mountain Project were treated as additional outcrops except that in many cases much more detailed information could be gathered from the vast exposures of fresh rock than from typical weathered and lichen-covered woods outcrops. Much detailed information from the Portal and Reservoir areas of the Northfield Mountain Project was noted on large scale topographic maps supplied by Western Massachusetts

Electric Company. The tunnels, being at a substantial angle to the strike of the rocks, exposed a continuous series of layers for thousands of feet. Detailed description of each layer and its extent along the tunnel walls with reference to engineering survey marks was recorded thus building up a complete stratigraphic section for that portion of the rock through which the tunnel passed. Most of the collecting of specimens for thin sections was done in the tunnels because of the freshness of the rocks and also because by fortuitous chance the tunnel was so located as to run through nearly the entire stratigraphic section that was finally determined for the area.

One hundred twenty thin sections were examined with a petrographic microscope to identify all minerals present. Anorthite content of the plagioclase feldspars was determined by the Michel-Levy method of symmetrical extinction. Visual estimates of the modes were made for each section.

Structural data was plotted on equal area nets. Detailed discussion of techniques used will be presented below.

Acknowledgements

National Science Foundation Grant GA-390 to Professor Peter Robinson of the University of Massachusetts provided funds for thin sections, the base map, and travel expenses in the field. Officials of Stone and Webster Engineering Corporation and also those of Morrison-Knudsen Company and Associates were very cooperative in granting access to the Northfield Mountain Project and in providing services making work in the underground excavations feasible. Western Massachusetts Electric Company provided large scale topographic maps of the Northfield Mountain area. Appreciation is expressed to the many residents of Erving, Montague, and Northfield who granted access to their property and also to those whose lands were explored without their knowledge. A very great debt of gratitude is due Professor Robinson without whose help and guidance this project would have been impossible. He introduced the author to the area, spent many days in the field with him, and gave considerable time in discussion and guidance of the project. He is also largely responsible for the perseverance in the collecting of data in the tunnels,at times assisted by the writer but also continuing alone when the writer,due to the pressures of course work, could not afford the time and energy to go. It is through Professor Robinson's generous contribution of his unpublished data to my use that it has been partially utilized here to further an understanding of the geology of the area. Professor Leo M. Hall, also of the University of Massachusetts, took considerable interest in the progress of mapping and the structural aspects of the region and made many useful suggestions. Preparation and publication of this report was supported by National Science Foundation Grant GA-33857 to Professor Robinson.

STRATIGRAPHY

The present study has shown that the northern portion of the Pelham dome is divisible into several distinctive stratigraphic units. These units are composed largely of felsic gneisses,varying in composition from the igneous equivalents granite to quartz diorite. Lesser amounts of interbedded quartzite, quartzose gneiss, schist, and calc-silicate rock occur. Small pegmatite intrusions also occur. Fig. 3 is a diagram showing the arrangement of these units in a sequence from bottom to top as they occur from the core to the edge of the dome. The structure of the dome is like that of a north-plunging anticline such that these units successively overlie each other from the core of the dome outward to the east, north, or west. These units as shown are not necessarily in order

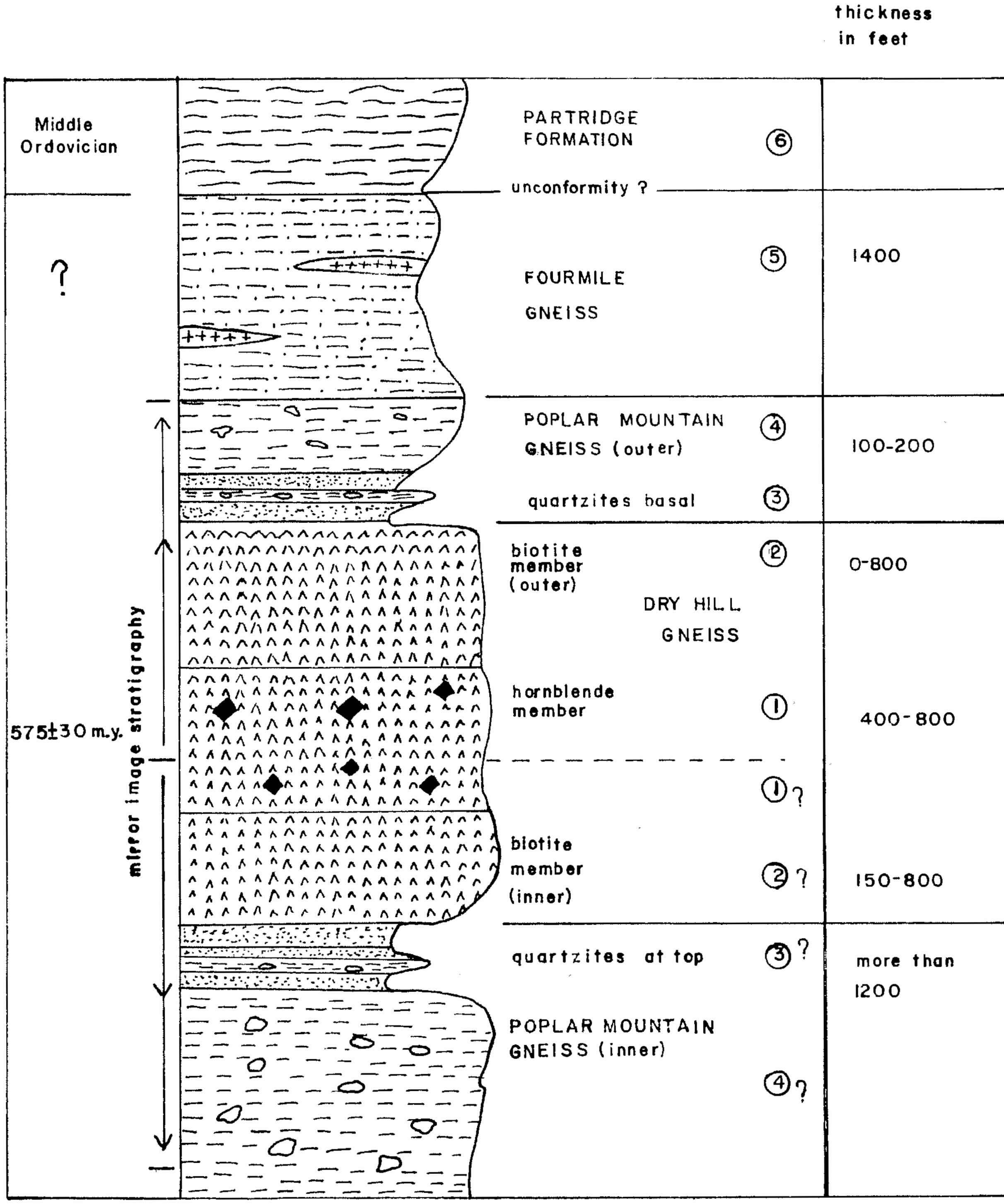


Figure 3. Stratigraphy of northern portion of the Pelham dome.

of age because part of the section may be inverted and the relative ages of the units have yet to be positively demonstrated. This cannot be done in the area now under study. Relative ages, on the basis of structural considerations, from oldest to youngest are believed to be: Dry Hill Gneiss, hornblende member; Dry Hill Gneiss, biotite member; Poplar Mountain Gneiss, quartzite member; Poplar Mountain Gneiss, gneiss member; Fourmile Gneiss; Partridge Formation. The mirror image stratigraphy bracketed in Fig. 3 emphasizes this conviction. The units will be described in the order of their considered relative age.

Dry Hill Gneiss

General statement. The Dry Hill Gneiss was originally named and described by Balk (1956a, 1956b), who separated the Pelham Granite of Emerson (1917) into the Dry Hill Gneiss and the Poplar Mountain Gneiss. The Dry Hill Gneiss is now further subdivided into a biotite member and a hornblende member on the basis of the predominance of these two minerals. Balk used the name Dry Hill Gneiss from the type locality of Dry Hill located about three miles southeast of Millers Falls and outside the area mapped in this study.

The Dry Hill Gneiss in the area under study is entirely contained between an inner (underlying) zone of Poplar Mountain Gneiss and an outer (overlying) zone of the same formation to be subsequently described. The hornblende member of the Dry Hill Gneiss is exposed over a broad area around the crest of the dome from Northfield Mountain and the Reservoir Area of the Northfield Mountain Project northward for three miles to South Mountain Road. Excellent exposures can be seen in the outcrops of Rose Ledge at the southwest end of Northfield Mountain.

The biotite member of the Dry Hill Gneiss is exposed in two main zones separated by the hornblende member. The inner zone directly overlies the Poplar Mountain Gneiss. Excellent outcrops occur on the face of Rattlesnake Mountain northwest of the village of Farley and are visible in the cliffs seen from Route 2. The unit extends southward to Millers Falls (Plate 1) to include a few outcrops directly east of the highway bridge across Millers River (Route 63) and also to connect with other known outcrops south of Millers River. This unit is very thin in the Millers Falls area but on the east side of the dome in the Hermit Mountain area the biotite member is 800-1200 feet thick.

The second, outer, zone is directly beneath the outer Poplar Mountain Gneiss but absent south of Fourmile Brook at the two locations where the Dry Hill Gneiss-Poplar Mountain Gneiss contact is reasonably exposed. These locations are the Portal area of the Northfield Mountain Project and a point outside the study area about one mile south of Millers Falls.

There also is an apparent lens of biotite member extending from an unnamed hill south of South Mountain southward to the northern part of Northfield Mountain. Lack of outcrop in the valley of Fourmile Brook makes the connection of the northern and southern parts of this body uncertain. The interpretation here is that it is a lens and not an infold of biotite member into the hornblende member because no connection on the ground can be shown with the outer zone of the biotite member.

Hornblende member. The hornblende member is a pink to gray, slabby to massive, granite gneiss composed mainly of quartz, microcline, oligoclase, biotite, and hornblende. The microcline is concentrated in pink laminae alternating with dark biotite-rich laminae giving the rock a pink streaked appearance. The hornblende occurs in abundant megacrysts giving the rock a very distinctive spotted appearance. These megacrysts of hornblende are usually restricted to the pink layers but where the rock is more homogeneous without the alternating pink feldspar and biotite laminations, the hornblende is scattered throughout the entire rock (Figs. 4 and 5). Within the member there are zones completely devoid of hornblende but these could not be separately mapped. Included throughout the entire rock are characteristic pink megacrysts of microcline. The rock splits along biotite layers which range in thickness from thin films to several inches.

Examination of 21 thin sections of typical hornblende member of the Dry Hill Gneiss revealed typical mineral contents as follows: quartz 25-30%; microcline 45-50%; oligoclase (An_{18-24}) 5-10%; biotite 5-15%; and hornblende usually about 5% but as high as 15% in a few specimens (see Table 1). The rock has the composition of granite. The composition of the plagioclase is such that it has nearly the same index of refraction as quartz and it is possible that some of the untwinned plagioclase may have been misidentified as quartz. One of the feldspar augen shows distinct albite twinning so at least some of the augen must be plagioclase but, based on the common microcline twinning, most are probably microcline. The biotite is pleochroic green to pale green in section and dark brown to black in hand specimen.

The hornblende is particularly deserving of comment. Common hornblende when observed in thin section is generally olive-green to olive-brown and has an interference figure that is biaxial negative with a large 2V. The hornblende seen in rocks in the Pelham dome other than the Dry Hill Gneiss fits this description. The hornblende in the Dry Hill Gneiss, however, is a vivid dark bluish green in thin section and centered optic axis interference figures show that it is essentially uniaxial negative. All the optically studied hornblende in this member of the Dry Hill Gneiss has the same unusual optical properties and hornblende of this nature is restricted to the two members of the Dry Hill Gneiss. No effort has been

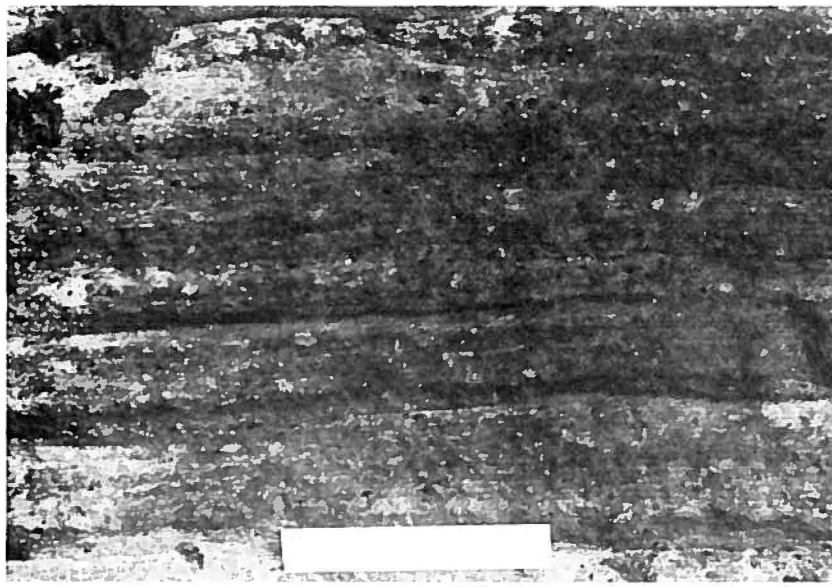


Figure 4. Hornblende member of Dry Hill Gneiss in outcrop on Rose Ledge. Megacrysts of hornblende are scattered over outcrop but with some concentration in given layers. Rule is 15 cm. long.

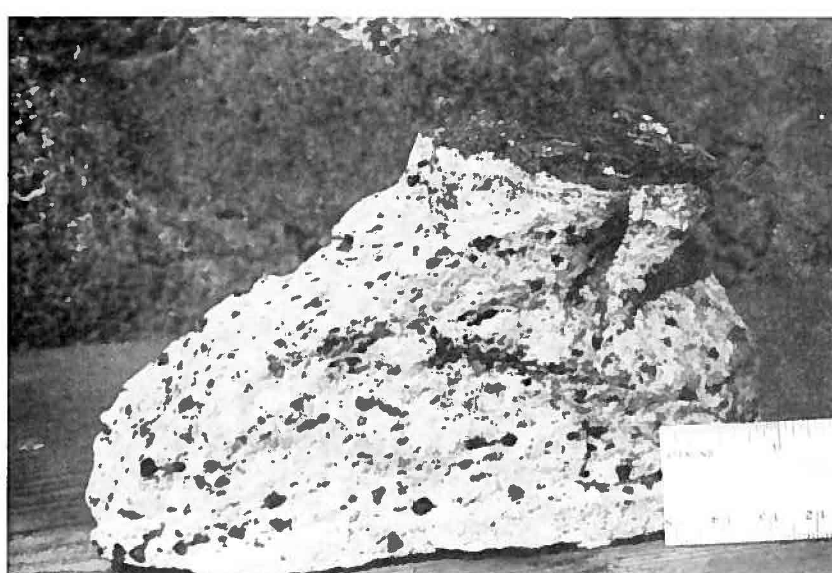


Figure 5. Handspecimen of hornblende member Dry Hill Gneiss particularly rich in hornblende. From Access Tunnel spoil pile. Rule marked in inches and centimeters.

Table 1. Estimated modes of specimens from the hornblende member of the Dry Hill Gneiss.

	typical													
	6+64	6+79	8+45	8+80	8+85	8+87	9+00	9+07	9+40A	9+40B	10+95	11+95A	13+90	14+25
Quartz	39	30	25	20	25	29	30	25	30	25	25	29	30	30
Plagioclase	10	5	5	15	2	10	5	5	5	10	5	2	2	3
		An_{23}	An_{18}	An_{23}	An_{18}	An_{17}	An_{23}	An_{18}	An_{18}		An_{23}	An_{18}	An_{18}	An_{18}
Microcline	43	47	55	45	55	45	53	60	50	54	46	49	48	55
Muscovite								tr	tr	tr				
Biotite	3	5	15	15	15	15	8	8	15	8	12	18	15	9
Garnet	tr	5	tr		tr			tr	tr		2	tr		tr
Hornblende*	5	8		5	3	1	4	2		3	10		4	3
Epidote		tr		tr	tr		tr	tr	tr	tr	tr		tr	tr
Allanite		tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr		tr
Calcite		tr		tr		tr	tr	tr			tr	tr		tr
Sphene	tr	tr	tr	tr	tr	tr	tr		tr	tr				
Apatite			tr	tr	tr	tr	tr		tr	tr	tr	tr	tr	tr
Pyrite														
Magnetite												2		
Zircon		tr	tr		tr		tr	tr			tr	tr		tr

* Hornblende is dark bluish green and uniaxial negative.

Table 1 continued next page.

Table 1 continued from previous page. Estimated modes hornblende member Dry Hill Gneiss.

	typical							quartzite		atypical
	14+82	15+84	15+96	16+13	16+15	16+67	#180A	6+40	#109	#180B
Quartz	30	25	25	28	28	23	30	75	76	30
Plagioclase	8 An_{18}	8 An_{23}	3 An_{18}	8 An_{18}	8 An_{23}	10 An_{24}	15 An_{18}	20	16 An_{23}	50 An_{23}
Microcline	50	50	60	55	45	52	38			
Muscovite				tr					tr	
Biotite	12	16	10	8	18	10	9	5	8	20
Garnet	tr	tr	tr	1		tr				tr
Hornblende*			1			5	8			
Epidote	tr	tr	tr			tr				
Allanite	tr		tr		tr	tr	tr			
Calcite	tr	tr	tr	tr	1	tr	tr			
Sphene	tr	tr	tr		tr	tr	tr	tr		
Apatite	tr	tr	tr		tr	tr	tr			
Pyrite		tr		tr	tr	tr				tr
Magnetite										
Zircon	tr	tr			tr	tr	tr		tr	tr

* Hornblende is dark bluish green and uniaxial negative.

Specimens in Table 1

6+64 - Medium-grained leucocratic pink feldspar-quartz gneiss with a few small megacrysts of hornblende up to 3 mm. in diameter. Northfield Mountain Project, Access Tunnel-664 feet from portal.

6+79 - Pink biotite-quartz gneiss with abundant megacrysts of hornblende up to 6 mm. in diameter and feldspar megacrysts up to 2 cm. in diameter. Northfield Mountain Project, Access Tunnel-679 feet from portal.

8+45 - Pink feldspar-quartz-biotite gneiss with some megacrysts of hornblende up to 4 mm. in diameter restricted to a 6 cm. layer of the rock (total thickness of specimen 20 cm.); a few megacrysts of feldspar up to 1.5 cm. Northfield Mountain Project, Access Tunnel-845 feet from portal.

8+80 - Pink feldspar-quartz-biotite gneiss with abundant megacrysts of hornblende up to 7 mm. in diameter. Northfield Mountain Project, Access Tunnel-880 feet from portal.

8+85 - Pink feldspar-quartz-biotite gneiss with abundant megacrysts of hornblende up to 1 cm. in diameter and white and pink feldspar megacrysts to 1.5 cm. in diameter; distinct layers of pink feldspar. Northfield Mountain Project, Access Tunnel-885 feet from portal.

8+87 - Pink quartz-feldspar-biotite gneiss with abundant megacrysts of hornblende up to 5 mm. in diameter; distinct pink feldspar zone 1 cm. wide running through center of specimen. Northfield Mountain Project, Access Tunnel-887 feet from portal.

9+00 - Pink feldspar-quartz-biotite gneiss with abundant megacrysts of hornblende up to 5 mm. in diameter; distinct alternating layers of pink feldspar and quartz-feldspar-biotite gneiss 2-3 cm. wide with the hornblende megacrysts largely restricted to the pink feldspar layers. Northfield Mountain Project, Access Tunnel-900 feet from portal.

9+07 - Pink feldspar-biotite-gneiss with scattered megacrysts of hornblende up to 5 mm. in diameter and rare feldspar augen up to 1 cm. in diameter; contains pink feldspar layers 5 mm. and less in thickness. Northfield Mountain Project, Access Tunnel-907 feet from portal.

9+40A - Large specimen 35 cm. high of pink feldspar-biotite gneiss
9+40B with hornblende megacrysts up to 5 mm. in diameter concentrated in two pink feldspar layers 3 and 6 cm. wide; remainder of rock is a fine-grained biotite gneiss with abundant pink and white feldspar megacrysts averaging 5 mm. in diameter with a few exceeding 1 cm. in size. Two sections from one large specimen. Northfield Mountain Project, Access Tunnel-940 feet from portal.

10+95 - Pink feldspar-biotite gneiss with small megacrysts of hornblende up to 7 mm. in diameter; contains thin layers of microcline (3 mm.) and compressed pink feldspar augen up to 1 cm. in length. Northfield Mountain Project, Access Tunnel-1095 feet from portal.

11+95A - Pink feldspar-biotite gneiss with prominent rounded feldspar augen 1.5 cm. in diameter; augen show trace of pink or are rimmed with pink; specimen spotted with yellow-brown alteration product. Northfield Mountain Project, Access Tunnel-1195 feet from portal.

13+90 - White feldspar biotite gneiss with megacrysts of hornblende up to 5 mm. and fine specks of garnet mostly 1 mm. and less in diameter but rarely up to 2 mm. Northfield Mountain Project, Access Tunnel-1390 feet from portal.

14+25 - White feldspar-biotite gneiss with scattered megacrysts of hornblende up to 5 mm. and compressed feldspar augen up to 1 cm. in length; contains a biotite rich layer 1 cm. in thickness. Northfield Mountain Project, Access Tunnel-1425 feet from portal.

14+82 - Pink feldspar biotite gneiss with megacrysts of hornblende smaller than 5 mm. in diameter; pink feldspar concentrated in narrow layers 5 mm. wide. Northfield Mountain Project, Access Tunnel-1482 feet from portal.

15+84 - Pink feldspar biotite gneiss; pink feldspar concentrated in narrow layers 5 mm. wide. Northfield Mountain Project, Access Tunnel-1584 feet from portal.

15+96 - Pink feldspar-biotite gneiss with abundant small megacrysts of hornblende some reaching 5 mm. in diameter; pink feldspar concentrated in layers. Northfield Mountain Project, Access Tunnel-1596 feet from portal.

16+13 - Pink feldspar-biotite gneiss specked with fine (less than 2 mm.) reddish brown spots (allanite radiation halos?); distinct alternating layers of feldspar and biotite gneiss up to 5 cm. Northfield Mountain Project, Access Tunnel-1613 feet from portal.

16+15 - Gray biotite-feldspar gneiss with minor pink layers; the top is a pink feldspar layer showing alteration to epidote; minor hornblende in specimen. Northfield Mountain Project, Access Tunnel-1615 feet from portal.

16+67 - Pink feldspar-biotite gneiss with abundant megacrysts of hornblende up to 1 cm. in diameter; megacrysts <u>not</u> restricted to the pink segregation layers. A few megacrysts of feldspar up to 1 cm. in diameter. Northfield Mountain Project, Access Tunnel-1667 feet from portal.

#108A - Light gray feldspar-quartz-biotite-hornblende-gneiss; pinkish feldspar megacrysts up to 2 cm. in diameter. Dark green megacrysts of hornblende up to 8 mm. in diameter. Northfield Mountain Project, Reservoir Area, from trench for Metropolitan District Commission discharge pipe on hill 965 southeast section of reservoir.

6+40 - Altered white granulite with grains up to 1 mm.; has distinctive odor of kaolinite when moistened. Rock was probably originally a feldspathic quartzite. Northfield Mountain Project, Access Tunnel at 640 feet.

#109 - Bluish gray fine to medium-grained quartzite with biotite and feldspar megacrysts up to 0.8 mm. in diameter and two layers of pink feldspar 2 mm. thick. Northfield Mountain Project, Reservoir Area, northwest dike.

#180B - Massive fine- to medium-grained feldspar-quartz-biotite gneiss; biotite concentrated in discontinuous lens-shaped clots up to 1 mm. in size. Northfield Mountain Project, southeast portion of Reservoir in trench for discharge pipe to the Metropolitan District Commission.

made by this writer to determine the composition of this mineral. The optical properties (Robinson, oral communication) suggest that it may be an iron-rich hastingsite,in contrast to normal hornblende containing a greater proportion of magnesium. Current research at the University of Massachusetts is being done to gain more information about the mineral.

Common accessory minerals include allanite, sphene, epidote, calcite, and garnet, in most of hhich calcium is an important constituent. Less common are apatite, zircon, and pyrite.

Biotite member. The biotite member of the Dry Hill Gneiss is a pink to light- or dark-gray layered granite gneiss composed of quartz, microcline, oligoclase, and biotite. The feldspar is usually concentrated in pink layers giving the rock a pink-streaked appearance. Rounded megacrysts of feldspar up to 2 cm. in diameter are common and some megacrysts are larger up to the maximum observed size of 25 cm. The rock ranges from well bedded and slabby to well foliated but compositionally massive with little or no suggestion of layering over a thickness of ten feet or more (Figs. 6 and 7). In places biotite layers reach thicknesses of several inches. Megacrysts of hornblende occur in a few beds and are widely scattered in some of the more massive layers, but most of the rock contains no hornblende.

Thin section examination of 9 specimens of typical biotite member of the Dry Hill Gneiss (Table 2) yielded estimated modes within the following ranges: quartz 25-35%; microcline 40-55% (microcline twinning common); oligoclase (An_{18-24}) 5-10%; and biotite (green in thin section) 8-20% except in two leucocratic specimens in which the biotite was 3% and 5%. The traces of muscovite present almost always occur as secondary growths within feldspar megacrysts. Common accessory minerals include allanite, epidote, sphene, and calcite in all of which calcium

Figure 6. Typical outcrop of biotite member Dry Hill Gneiss at elevation 770 feet, 1000 feet southeast of Rose Ledge.

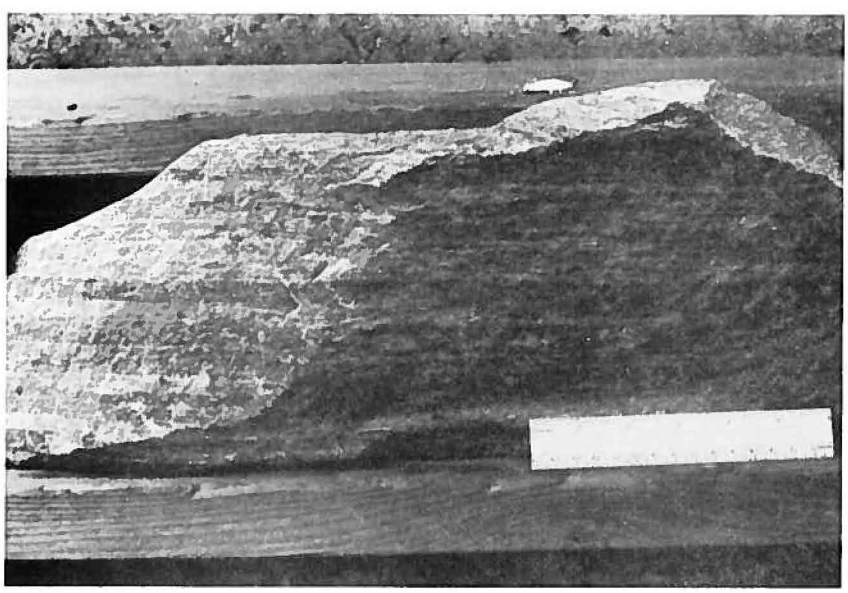


Figure 7. Close up view of fresh sample of biotite member Dry Hill Gneiss collected from spoil pile from Access Tunnel of Northfield Mountain Project. Rule is 15 centimeters.

Table 2. Estimated modes of specimens from the biotite member of the Dry Hill Gneiss

	16+99	17+07	17+21	17+60	17+82	18+43	19+00	S1 5+80	US 1+20
Quartz	30	32	30	25	32	30	27	27	30
Plagioclase	8 An_{18}	8 An_{23}	10 An_{23}	10 An_{19}	6 An_{24}	8	5 An_{18}	24	40 An_{24}
Microcline	54	55	57	53	50	52	45	40	6
Muscovite	tr		tr	tr	tr	tr	tr	1	
Biotite	8	5	3	12	8	10	23	8	24
Garnet		tr	tr		2			tr	
Chlorite	tr				tr				tr
Hornblende					tr				tr
Epidote					tr				tr
Allanite		tr			tr	tr	tr		tr
Calcite	tr			tr	tr	tr	tr	tr	
Sphene	tr			tr	tr				tr
Apatite				tr	tr	tr	tr	tr	tr
Pyrite	tr			tr				tr	
Zircon						tr	tr	tr	tr
Magnetite					2				

Specimens in Table 2

16+99 - Pink feldspar-biotite gneiss with white megacrysts of feldspar rimmed with pink 2 cm. across; definite segregation into pink and gray units with the biotite being concentrated in the gray feldspar bands. Northfield Mountain Project, Access Tunnel-1699 feet from portal.

17+07 - Pink fine-grained feldspar-biotite gneiss with distinct layers of fine grained pink microcline 5 mm. thick and larger (2 cm. diameter) megacrysts of white feldspar rimmed with pink; two prominent megacrysts of hornblende on cut end, one of them cutting across the foliation; layering wraps around the large feldspar megacryst. Northfield Mountain Project, Access Tunnel-1707 feet from portal.

17+21 - Very light pink feldspar-biotite gneiss with scattered megacrysts of white feldspar up to 1 cm. in diameter. Northfield Mountain Project, Access Tunnel-1721 feet from portal.

17+60 - Pink feldspar-biotite gneiss with prominent segregation into pink feldspar and gray felsic biotite rich layers. Northfield Mountain Project, Access Tunnel-1760 feet from portal.

17+82 - Very light pink feldspar-biotite gneiss with prominent segregation into pink feldspar and gray felsic biotite rich layers. Northfield Mountain Project, Access Tunnel-1782 feet from portal.

18+43 - Pink feldspar-biotite gneiss segregated into distinct pink feldspar layers up to 4 mm. thick and dark biotite laminations 1.5 mm. thick; contains a pink megacryst of feldspar 1.2 cm. in diameter. Northfield Mountain Project, Access Tunnel-1843 feet from portal.

19+00 - Dark fine-grained gneiss containing pink feldspar in compressed megacrysts up to 0.8 mm. in diameter; one white megacryst rimmed by pink feldspar, 1 cm. in diameter. Access Tunnel-1900 feet from portal.

S1 5+80 - Well laminated pink feldspar-quartz-biotite gneiss with common conspicious allanite with red radiation halos up to 3 mm. One half of specimen shows much more pink due to alteration along a joint plane; joint face covered with a fine grained green mineral. Northfield Mountain Project, Surge Gallery I-580 feet from junction with Access Tunnel.

US 1+20 - Gray biotite-quartz-feldspar gneiss with prominent pink and white feldspar megacrysts 2-10 cm.; smaller megacrysts are not present. Megacrysts contain intergrowths of quartz and traces of hornblende. Northfield Mountain Project, Surge Gallery II-120 feet from junction with the Access Tunnel.

is an important constituent. Much less abundant accessory minerals include apatite, zircon, garnet, pyrite, magnetite, and chlorite. The rock composition is typical of granite. The plagioclase has a composition such that it has nearly the same index of refraction as quartz, thus affecting the estimated percentages of these two minerals. Stained thin sections would be recommended for more detailed work. Microcline twinning was observed in the megacrysts of feldspar and they are believed to be largely microcline.

Quartzite and other rocks. Rare thin beds of quartzite ranging from one inch to a maximum of three feet thick are interlayered in the gneisses. Petrographic examination of one specimen indicates a large proportion of quartz with plagioclase (An_{18}), biotite, and trace amounts of muscovite (Table 1). In general the writer's field observations indicate that most of the quartzites in the Dry Hill Gneiss north of Millers River are fairly near the contact with the Poplar Mountain Gneiss. Field work on Bear Mountain south of Millers River has revealed two much more extensive zones of quartzite in the Dry Hill Gneiss and these are designated on the geologic map. The more southerly of the two is substantially removed from the Poplar Mountain contact and reaches a maximum thickness of 500 feet but thins and finally pinches out to the north. Its southern limit and a possible connection to the Poplar Mountain Gneiss remains undetermined at this time.

Also included in the Dry Hill Gneiss are minor beds, mostly gneissic, of obviously different composition. These are mostly biotite rich, but some contain minerals such as actinolite making the beds approach a calc-silicate composition.

Published analysis. A published analysis (Clarke, 1904) of a specimen collected by B. K. Emerson from "Frawley's Quarry", Erving, Massachusetts and subsequently described as the Pelham Granite from "Fraley's Quarry", Erving, Massachusetts (Emerson, 1917) follows (analyst, George Steiger, U.S.G.S.):

SiO_2	74.15%	K_2O	4.58%
Al_2O_3	13.35%	H_2O+	.13%
Fe_2O_3	1.26%	H_2O-	.50%
FeO	.53%	TiO_2	.12%
MgO	.23%	CO_2	--%
CaO	1.92%	P_2O_5	.06%
Na_2O	2.84%		

The norm as published by Washington (1917) is as follows:

Quartz	35.52%	Hypersthene	0.60%
Orthoclase	27.24%	Magnetite	1.16%
Albite	24.10%	Ilmenite	0.30%
Anorthite	9.45%	Hematite	0.48%
Corundum	0.20%		

Further computation yields normative plagioclase composition of An_{26}.

Unfortunately, the precise location of "Frawley's Quarry" is ambiguous and therefore the exact rock unit from which the specimen was derived cannot be stated with certainty. Frawley's main quarry was located south of Quarry Road in the southwestern corner of the Mount Grace quadrangle in the Township of Warwick, and in the Warwick dome which Emerson (1917) mapped as Monson Gneiss, and which is mapped as Pauchaug Gneiss by Robinson (1963). According to Mr. Ernest L. Derosiers, a long time resident of Erving, Frawley also operated a much smaller subsidiary quarry located in Erving at an elevation of 840 feet in the northwest point of the first hill northwest of the village. The writer visited this locality during field study and it is in the biotite member of the Dry Hill Gneiss. This quarry is the probable source area for the rock in question.

Although there are uncertainties about the analysis, the rock from which it was made, and its mineralogy, the analysis does show some possibly significant points: 1.) high normative orthoclase relative to other feldspar components, 2.) normative plagioclase composition of An_{26}, 3.) very high ratio of total iron to magnesium, 4.) high ferric iron consistent with the presence of magnetite and ferric green biotite and/or hornblende. The corundum in the norm seems anomalous in terms of the mineralogy of these rocks.

Inclusion. A clast measuring about 3 x 2 1/4 x 1 feet and unlike any rock known locally was found embedded in the hornblende member of the Dry Hill Gneiss in the Reservoir Area on top of Northfield Mountain. The till had been removed from the bedrock for construction purposes,providing a relatively fresh glacially smoothed surface from which the inclusion protruded slightly. The foliation in the gneiss wrapped around the boulder, which was removed from the gneiss with only moderate difficulty because the contact zone between the two had weathered. The boulder is very dense, and petrographic examination shows it consists of pyroxenoids, pyroxene, garnet, amphibole, quartz, magnetite, and sulfides. Its mineralogy and petrology has been studied in detail by Timothy Lincoln as a Senior Honors Thesis, spring semester 1972, at the University of Massachusetts. The only explanation that can be offered to explain the presence of the boulder in the gneiss is that it is a fragment from a previously existing terrain and was deposited by some means in the Dry Hill Gneiss.

Thickness. The biotite member ranges in thickness from zero to 1200 feet. The hornblende member ranges in thickness from 400 to 800 feet. In both instances the greater thickness is on the east limb of the dome.

Contact between the biotite and hornblende members of the Dry Hill Gneiss. The only criterion used in the field for separating these members was the presence of appreciable hornblende in outcrops. The question is: how much hornblende in outcrop is needed to place the gneiss in the hornblende member? On the west limb of the dome below Rose Ledge and eastward to Rattlesnake Mountain and Briggs Brook the contact is sharp and well exposed. Below the contact there is either no or very little hornblende in the outcrops; above the contact there is abundant hornblende. There may be a few hornblende zones in the biotite member or a hornblende free zone in the hornblende member, but mapping is no problem.

To the east, however, the contact is more confusing. Local zones of hornblende-bearing rock do occur but there is often a question about whether it is abundant enough to assign the rock to the hornblende member. It was the practice of this writer to map the rock as hornblende member only where there was an unquestioned abundance of this mineral and it could be followed from outcrop to outcrop for some distance. When working in the field with others, differences of opinion would arise as to what constituted bona fide hornblende member versus biotite member. Except for a thin but distinct zone of hornblende member contained within the biotite member extending parallel to and nearly at the eastern limit of the Dry Hill Gneiss, the contacts east of Packard Brook are vague and are drawn on the geologic map to enclose areas predominantly of one rock type or the other. A scarcity of outcrop between the base of Hermit Mountain and Millers River and also in the area between Mountain Road and Fourmile Brook makes the drawing of accurate contacts even more difficult. Outcrops present indicate that these two areas consist of extensive interbedding between the two members.

The main mass of hornblende member occurring on Northfield Mountain has been extended southward across the Millers River on the geologic map on the basis of exposure on Bear Mountain. The more eastern thin zone of hornblende member also is well exposed in Wendell on the east slopes of the Bear Mountain area. Although contacts between these two members have been delineated on the geologic map it must be emphasized that in many places the contact between the two members is poorly defined because of apparent extensive interbedding.

Derivation. The Dry Hill Gneiss has been considered to be an igneous intrusive (Emerson, 1917; Balk, 1942, 1956a, 1956b) because of its granitic mineralogy and texture. Here the suggestion is made that the rock is of sedimentary or pyroclastic derivation based on the strong layering and diverse composition and texture, including quartzite and other beds of probable sedimentary derivation. The original source material is unknown but may have been a felsic pyroclastic sequence that was locally weathered and reworked to produce distinctive included sedimentary beds. The Dry Hill Gneiss is worthy of a separate petrographic study beyond the scope of this paper.

Poplar Mountain Gneiss

General statement. The Poplar Mountain Gneiss was originally named and described by Balk (1956a, 1956b). It is exposed in two separate areas not connected on the ground within the boundaries of the geologic map.

One of these is a triangular area including Poplar Mountain and the Millers River valley from Farley westward to Millers Falls. This area comprises the deepest, innermost exposed portion of the dome. The south face of Poplar Mountain, the type locality of the Poplar Mountain Gneiss, has outcrops in prominent cliffs. A large road cut on Route 2 one mile east of Millers Falls affords an easily accessible fine exposure of fresh rock. Poplar Mountain Gneiss was also exposed in the furthest depths of the tunnels of the Northfield Mountain Project where it is a northward subsurface extension of the area outlined above. This area of exposure will be referred to as the inner Poplar Mountain Gneiss and is by far the larger and more prominent of the two.

The second area of outcrop of Poplar Mountain Gneiss is a narrow band from the switchyard of the Northfield Mountain Project (one half mile southeast of Northfield Farms) northward across the top of South Mountain, around the north end of the dome, and south into Erving where it outcrops in Jack's Brook and on a hillside northeast of the village. The outcrops in this band are mostly inconspicuous and widely separated, but when plotted on a map they definitely describe an outer layer of the Poplar Mountain Gneiss and act as a marker horizon between the Dry Hill Gneiss and the Fourmile Gneiss. The unit is extended southward on the geologic map (Plate 1) to the Millers River on both the east and west sides of the dome to connect with outcrops of Poplar Mountain Gneiss known to exist south of the river in similar stratigraphic position. This second area of exposure will be referred to as the outer Poplar Mountain Gneiss. In previous work (Balk, 1956), the outer Poplar Mountain Gneiss was overlooked with the exception of a few outcrops in the area that is now the switchyard and portal area of the Northfield Mountain Project.

In the present study the Poplar Mountain Gneiss has been divided into a gneiss member, consisting almost entirely of typical Poplar Mountain Gneiss, and a quartzite member consisting of interbedded quartzite, typical Poplar Mountain Gneiss, mica schist, and also granite gneiss resembling the Dry Hill Gneiss.

The quartzite member is present at the physical top of the inner Poplar Mountain Gneiss. Quartzite beds are more abundant to the west and thin to the east in favor of granite gneiss beds. Quartzite beds occur on the surface in the steep face of Rattlesnake Mountain near the village of Farley where they are interlayered with considerable granite gneiss. The same stratigraphic level was seen in the underground powerhouse of the Northfield Mountain Project where there is more quartzite and less granite gneiss. The quartzite member occurs in the saddle between Northfield and Poplar Mountains. A few outcrops of granite gneiss in this area suggest that there is an interbedding of the two rock types but that the granite gneiss is of minor occurrence only.

A similar quartzite zone is contained in the outer Poplar Mountain Gneiss but is not separately indicated on the geologic map because of its thinness. The quartzite outcrops are at the base of the outer Poplar Mountain Gneiss in contrast to their position at the top of the inner Poplar Mountain Gneiss.

The gneiss member makes up the balance of the formation and is by far the more abundant.

Quartzite member. The quartzite member of the inner Poplar Mountain Gneiss consists of a series of interbedded quartzites, typical Poplar Mountain Gneiss, granite gneisses, rare calc-silicate beds, and even more rare amphibolite.

The quartzites are gray to brown, thinly-bedded to massive (up to five feet) quartz-biotite-feldspar granulites with either muscovite or actinolite commonly visible in hand specimen (Fig. 8). Actinolite, where it occurs, is restricted to definite layers and in some cases is sufficiently abundant to impart a greenish tinge to the rock. It occurs as visible needles locally up to two centimeters long. Megacrysts of feldspar occur in some beds. Composition of the quartzites varies widely from bed to bed. Quartz ranges from 60-90+%; fine brown biotite plates

Figure 8. Quartzite member, Poplar Mountain Gneiss at elevation 690 feet west of saddle between Northfield and Poplar Mountains. Massive brown quartzite at base of outcrop is 3 feet thick; upper part of outcrop is composed of thin interbedded layers of quartzite and gneiss.

Figure 9. Close up of Poplar Mountain Gneiss exposed in large cut on Route 2 one mile east of Millers Falls. Note layering and the prominent scattered feldspar megacrysts.

range from 0-10%; plagioclase of variable composition ranges from 0-10%; muscovite or actinolite ranges from 0-15%. Accessory minerals include common pyrite and calcite, and minor garnet, zircon, apatite, epidote, and sphene. One specimen has minor scapolite.

The granite gneiss is a pink to dark-gray, layered, thinly bedded to massive gneiss consisting of quartz, microcline, oligoclase, and biotite. The massive layers may be in excess of ten feet thick and in places such as the southeast face of Rattlesnake Mountain make up as much as 50% of the total rock. The granite gneiss is very similar in appearance and mineralogy to the Dry Hill Gneiss previously described and therefore will not be further discussed here, with one exception. Both the Dry Hill Gneiss and the granite gneiss included in the quartzite member of the Poplar Mountain Gneiss contain hornblende megacrysts in various zones. On the basis of thin sections taken from this interbedded zone in the Access Tunnel of the Northfield Mountain Project the hornblende in many of the granite gneisses in the quartzite member is biaxial negative with a high 2V and is a dull green; the hornblende in the Dry Hill Gneiss is a bluish green and is nearly uniaxial with a negative sign. Estimated modes of the gneisses are included in Table 4.

Gneisses of the Poplar Mountain type are also interbedded with the quartzites and granite gneisses of the quartzite member. No further description will be given here because they are identical with those to be described in the section on the gneiss member of the Poplar Mountain Gneiss. Estimated modes are included in Table 5.

The calc-silicate rocks range from thin layers especially rich in actinolite included in the quartzites,to rare layers of nearly 50% hornblende or rocks particularly rich in diopside and/or tremolite. Interesting as these calc-silicate rocks are, they constitute only a very minor portion of the total Poplar Mountain Gneiss. Modes for the calc-silicate rocks are presented in Table 6.

Very rare thin beds and boudins of amphibolite also occur in the quartzite member. These amphibolites consist of oligoclase, biotite, and hornblende. Estimated modes are included in Table 6.

Gneiss member. The gneiss member of the Poplar Mountain Gneiss consists predominantly of light to dark gray strongly layered feldspar-quartz-biotite gneiss (estimated modes in Table 7) containing prominent and abundant white or rarely pink megacrysts of feldspar up to 10 centimeters in diameter (Fig. 9). Muscovite is a common constituent but some outcrops bear megacrysts of hornblende. The rock is uniform in appearance but does contain rare quartzite beds up to several inches thick. Locally the rock passes into thin layers of biotite schist, some beds of which contain euhedral tourmaline crystals. Leucocratic biotite-muscovite gneiss is another minor local rock type. Calc-silicate granulite occurs in rare layers 3 to 4 inches thick and also in very rare spheroidal masses up to 2 feet in diameter which may have been clasts. A few thin beds and pods of amphibole and diopside-bearing ultramafic rock of obscure origin occur in the gneiss.

Quartz comprises 25-35% of typical Poplar Mountain Gneiss. Some specimens run as high as 50% or higher bordering on feldspathic quartzites. Biotite is brown in thin section and comprises 15-25% of the rock imparting the distinctive gray appearance of the rock.

The feldspars make up 50-70% of the rock. Usually 50% or more of the entire mode is microcline with the remainder oligoclase (An_{24}) in most specimens. Two specimens of Poplar Mountain Gneiss (G78A and LS 6+20) have high plagioclase content with little to no microcline. Determination of feldspars was problematical because no staining was done.

Table 3. Estimated modes of quartzites from the quartzite member, Poplar Mountain Gneiss.

	19+16	19+45	19+83	20+60	20+90	21+65	21+75	22+30	22+65A	22+65B	22+71	23+04
Quartz	73	65	78	70	78	60	72	70	77	77	92	67
Plagioclase	10	5	tr	8	7	10	5	tr	2		tr	2
	An_{28}	An_{23}		An_{23}	An_{18}	An_{25}	An_{24}					
Microcline		17	18	3	10	14	10	20	10	8	5	10
Muscovite		3	tr	1		tr	tr	tr	tr	tr	tr	
Biotite	5	10	4	16	5	15	12	10	10	8	tr	4
Actinolite	5				tr		1		1	7	3	15
Chlorite									tr			
Epidote	2											
Clinozoisite												1
Scapolite												1
Calcite	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr
Sphene	5	tr			tr	tr	tr			tr		tr
Pyrite	tr	tr	tr	2	tr	1	tr	tr			tr	tr
Apatite	tr	tr	tr			tr	tr				tr	tr
Zircon	tr		tr	tr	tr	tr						tr

Table 3 continued on next page.

Table 3 con't. Estimated modes of quartzites from the quartzite member, Poplar Mountain Gneiss.

	LS 1+85B	LS 3+35	LS 4+40	LS 4+65	LSS 0+00	LSS 0+12	TR 64+33A	TR 64+33B
Quartz	74	79	72	71	77	78	72	78
Plagioclase	3	tr	1	2	8	6	1	1
	An_{38}				An_{24}	An_{30}		An_{24}
Microcline	10	10	15	10	4	8	10	10
Muscovite	2	8	6	8	1			
Biotite	11	3	5	8	10	8	10	8
Actinolite						tr	5	tr
Chlorite					tr			
Diopside								tr
Calcite					tr	tr	tr	1
Sphene						tr	tr	1
Pyrite	tr		1	1	tr	tr	2	1
Apatite		tr	tr	tr			tr	tr
Zircon	tr	tr						

Specimens in Table 3

19+16 - Gray biotite feldspathic quartzite with green calc-silicate layers. Northfield Mountain Project, Access Tunnel-1916 feet from portal.

19+45 - Gray quartzite with biotite and white feldspar megacrysts up to 2.5 cm. in diameter. Northfield Mountain Project, Access Tunnel-1945 feet from portal.

19+83 - Fine to medium-grained bluish gray clean quartzite. Northfield Mountain Project, Access Tunnel-1983 feet from portal.

20+60 - Gray feldspathic quartzite with scattered feldspar megacrysts up to 6 cm. in diameter. Northfield Mountain Project, Access Tunnel-2060 feet from portal.

20+90 - Light pink feldspar biotite gneiss with scattered hornblende megacrysts up to 2 cm. in diameter; a 2 cm. band of feldspathic quartzite included-section based on the quartzite. Northfield Mountain Project, Access Tunnel-2090 feet from portal.

21+65 - Quartzite with thin (1 mm.) feldspathic layers and actinolite; one white feldspar megacryst 1.5 cm. in diameter. Northfield Mountain Project, Access Tunnel-2165 feet from portal.

21+75 - Feldspathic quartzite with thin (2 mm.) layers of biotite; actinolite present on foliation surface. Small (4 mm.) white megacrysts of feldspar. Northfield Mountain Project, Access Tunnel-2175 feet from portal.

22+30 - Light gray fine-grained quartzite with weak layering and tinged with green on the surface. Northfield Mountain Project, Access Tunnel-2230 feet from portal.

22+65A - Grayish white clean glassy quartzite with a trace of layering. Northfield Mountain Project, Access Tunnel-2265 feet from the portal.

22+65B - Gray medium-grained quartzite with a trace of green (actinolite). Northfield Mountain Project, Access Tunnel-2265 feet from portal.

22+71 - Clean white quartzite with a tinge of green; suggestion of bedding. Northfield Mountain Project, Access Tunnel-2271 feet from portal.

23+04 - Purplish gray quartzite with green bands up to 1 cm. thick; muscovite exposed on the foliation surface. Northfield Mountain Project, Access Tunnel-2304 feet from portal.

LS 1+85B - Fine-grained purplish red clean quartzite with only a trace of layering; contains a cm. band of grayish white massive feldspar-quartz gneiss as a sill; section in Table 2 based on the quartzite alone. Northfield Mountain Project, adit to pressure shaft at 185 feet.

LS - Clean massive purplish fine-grained quartzite; trace of muscovite
3+35 and pyrite on surface. Northfield Mountain Project, adit to pressure shaft at 335 feet.

LS - Massive gray green quartzite with muscovite and pyrite on surface.
4+40 Northfield Mountain Project, adit to pressure shaft at 440 feet.

LS - Gray, tinged with green, poorly layered feldspathic quartzite with
4+65 muscovite and a few white feldspar megacrysts up to 0.5 cm. in diameter. Northfield Mountain Project, adit to pressure shaft at 465 feet.

LSS - Gray fine-grained laminated biotite-quartz-feldspar gneiss with
0+00 1 to 1.5 cm. bands of clean fine-grained quartzite. Northfield Mountain Project, southeast corner of Fourway Junction.

LSS - Fine-grained purplish massive quartzite with abundant actinolite
0+12 and muscovite on foliation surfaces; contains an actinolite rich layer 1 cm. thick. Northfield Mountain Project, adit to Surge Gallery III, 12 feet from Fourway Junction.

TR - A and B cut from same specimen. Fine-grained purplish red quartz-
64+33 ite with alternating green calc-silicate bands 1 cm. in thickness. Northfield Mountain Project, Tailrace Tunnel-6433 feet from western end.

Table 4. Estimated modes of granite gneisses and related types in the quartzite member of the Poplar Mountain Gneiss.

	19+75	19+79	20+12	20+24	20+48	21+15	21+25	21+60	PHW 6+70
Quartz	30	32	15	35	25	25	50	32	25
Plagioclase	10 An_{23}		15 An_{23}	tr	10 An_{25}	5 An_{24}		10	5 An_{25}
Microcline	45	62	30	53	52	35	40	53	39
Muscovite	tr	tr	2	tr					
Biotite	15	6	20	12	10	15	10	5	15
Garnet	tr				tr		tr	tr	
Chlorite							tr		
Hornblende			15		3*	20			15*
Epidote					tr			tr	
Allanite					tr			tr	
Pyrite	tr		tr						tr
Sphene	tr		3	tr	tr	tr			tr
Apatite	tr	tr	tr	tr		tr	tr		tr
Zircon			tr			tr	tr		
Calcite	tr		tr	tr	tr	tr	tr		1
Magnetite	tr				tr	tr			

* hornblende with low 2V; essentially uniaxial negative.

Specimens in Table 4

19+75 - Pink feldspar-biotite gneiss; pink feldspar concentrated in compressed megacrysts up to 1 cm. in diameter; one large pink feldspar megacryst 6 cm. in diameter with quartz intergrowths. Northfield Mountain Project, Access Tunnel-1975 feet from portal.

19+79 - Leucocratic feldspar-biotite gneiss. Northfield Mountain Project, Access Tunnel-1979 feet from portal.

20+12 - Dark medium grained-biotite-feldspar gneiss with thin laminations (4 mm.) of pink feldspar and megacrysts of white feldspar rimmed with pink; megacrysts of hornblende 5 mm. in diameter and mostly contained in pink feldspar bands. Northfield Mountain Project, Access Tunnel-2012 feet from portal.

20+24 - Pink feldspar-biotite gneiss with pink and white feldspar megacrysts; one white feldspar megacryst 3.5 cm. in diameter but most of the megacrysts are 1 cm. in diameter or less. Northfield Mountain Project, Access Tunnel-2024 feet from portal.

20+48 - Light grayish pink feldspar-biotite gneiss with scattered small hornblende megacrysts up to 5 mm. in diameter; pink feldspar in bands and in megacrysts up to 8 mm. Northfield Mountain Project, Access Tunnel-2048 feet from portal.

21+15 - Strongly layered pink feldspar-biotite gneiss; contains layers of feldspar up to 5 mm. thick, biotite layers up to 1 cm. thick. Hornblende megacrysts up to 5 mm. in diameter concentrated in some of the pink feldspar layers. White and pink feldspar megacrysts up to 1 cm. in diameter in the biotite layers. Northfield Mountain Project, Access Tunnel at 2115 feet from the portal.

21+25 - Very light feldspar-biotite gneiss with a trace of pink; layering not prominent. Northfield Mountain Project, Access Tunnel-2125 feet from portal.

21+60 - Leucocratic quartz-feldspar-biotite gneiss with trace of garnet; stretched pink feldspar megacrysts up to 1 cm. in diameter. Northfield Mountain Project, Access Tunnel-2160 feet from portal.

PHW 6+70 - Prominently laminated feldspar-quartz-biotite-hornblende gneiss with pink to white feldspar megacrysts up to 1.6 cm. in diameter and a larger one of 5 cm. in diameter; hornblende scattered throughout rock but shows a definite concentration in the pink feldspar laminations. Northfield Mountain Project, west wall of Powerhouse at 670 feet as measured through Surge Gallery II and Powerhouse Drift Adit from Access Tunnel.

Table 5. Estimated modes of gneisses of Poplar Mountain type in the quartzite member of the Poplar Mountain Gneiss.

	19+54	20+64	21+44	21+84	22+23	23+23	24+10	LS 4+70
Quartz	34	30	25	23	31	25	50	50
Plagioclase	23	10 An_{23}	20 An_{23}	39 An_{26}	15 An_{24}	35 An_{28}	3 An_{24}	15 An_{25}
Microcline		45	40		30		20	10
Muscovite					tr	tr	15	5
Biotite	34	15	15	18	22	40	12	20
Garnet					1	tr		
Chlorite					tr			
Hornblende		tr		15				
Epidote		tr						
Pyrite	9			tr	1	tr		
Sphene			tr	3	tr			
Apatite	tr	tr	tr	2	tr	tr	tr	
Zircon		tr	tr					tr
Calcite		tr	tr		tr			tr
Magnetite		tr						

Specimens in Table 5

19+54 - Gray fine-grained biotite feldspar gneiss containing abundant white feldspar megacrysts up to 1 cm. in diameter. Northfield Mountain Project, Access Tunnel-1954 feet from portal.

20+64 - Dark pink feldspar-biotite gneiss with scattered hornblende megacrysts up to 2 cm. in diameter; a 2 cm. band of feldspathic quartzite included. Northfield Mountain Project, Access Tunnel-2064 feet from portal.

21+44 - Gray quartz-feldspar-biotite gneiss with pink and white megacrysts of feldspar up to 1.5 cm. in diameter; pink feldspar concentrated in bands up to 5 cm. thick. Northfield Mountain Project, Access Tunnel-2144 feet from portal.

21+84 - Dark gray biotite-feldspar gneiss with megacrysts of hornblende up to 4 mm. in diameter concentrated in a white feldspathic layer 1.5 cm. thick. Northfield Mountain Project, Access Tunnel at 2184 feet from portal.

22+23 - Light gray feldspar-quartz-biotite gneiss with feldspar megacrysts up to 2.5 cm. in diameter and a biotite rich layer 1.5 cm. thick. Northfield Mountain Project, Access Tunnel-2223 feet from portal.

23+23 - Dark gray biotite-feldspar gneiss with white megacrysts up to 1 cm. in diameter; trace of muscovite on the foliation surfaces. Northfield Mountain Project, Access Tunnel-2323 feet from portal.

24+10 - Biotite-muscovite-feldspar-quartz-schistose gneiss with prominent large flakes of muscovite. Northfield Mountain Project, Access Tunnel-2410 feet from portal.

LS 4+70 - Gray to dark gray biotite-quartz-feldspar-muscovite gneiss with 1 to 1.5 cm. layers of clean fine-grained quartzite. Northfield Mountain Project, adit to pressure shaft at 470 feet from Access Tunnel.

Table 6. Estimated modes of calc-silicate rocks and amphibolites in the quartzite member of the Poplar Mountain Gneiss.

	calc-silicates						amphibolites				
	19+04	19+04B	20+34	TR 63+00A1	TR 63+00A2	TR 63+00B	19+05F	20+15A	20+15B	PHW 7+61	PHW 8+30
Quartz	34	20	20			50					
Plagioclase	12 An$_{23}$	14 An$_{25}$	35 An$_{35}$	tr An$_{23}$		5	35 An$_{30}$	21 An$_{23}$	33 An$_{23}$	27 An$_{27}$	30 An$_{24}$
Microcline				20	tr	20					
Muscovite	tr					tr	tr				
Biotite		20	5			5	15	50	43	22	31
Garnet					tr						
Hornblende	45	45	40				45	25	21	47	36
Actinolite	3			35	40	9					
Diopside				45	60	11					
Epidote	2										
Calcite	tr	tr	tr		tr	tr	2			tr	
Pyrite	tr	tr			(Fluorite tr)						3
Sphene	3	1	tr			tr	2	2	3	4	
Apatite	1	tr				tr	tr	2	tr	tr	tr
Zircon			tr	tr		tr		tr	tr		
Chlorite						tr	1				tr

Specimens in Table 6

19+04 - Coarse-grained calc-silicate rock bearing dark green hornblende up to 2 cm. in diameter with quartz and feldspar. Northfield Mountain Project, Access Tunnel-1904 feet from portal.

19+04B - Coarse-grained dark green calc-silicate rock containing crystals of dark green hornblende up to 2 cm. in diameter. Northfield Mountain Project, Access Tunnel-1904 feet from portal.

20+34 - Calc-silicate with dark green hornblende up to 1 cm. in diameter. Northfield Mountain Project, Access Tunnel-2034 feet from portal.

TR 63+00A 1 and 2 - Light grayish white and green calc-silicate rock with feldspar and abundant lineated needles of green actinolite averaging 5 mm. long with individual needles up to 10 mm. Two sections from the same specimen. Northfield Mountain Project, Tailrace Tunnel-6300 feet from west end.

TR 63+00B - Thinly bedded quartzite with prominent calc-silicate layers including green needles of actinolite 5 mm. long imbedded in white diopside. One coarse grained white feldspar layer 0.8 mm. thick. Northfield Mountain Project, Tailrace Tunnel-6300 feet from west end.

19+05F - Coarse-grained amphibolite with dark green hornblende, biotite, and a trace of pink feldspar. Northfield Mountain Project, Access Tunnel, 1905 feet from portal.

20+15A 20+15B - Very dark dense biotite-hornblende-schistose gneiss; occurs as a boudin. Two sections from the same specimen. Northfield Mountain Project, Access Tunnel-2015 feet from portal.

PHW 7+61 - Dark green hornblende-biotite-feldspar schist. Northfield Mountain Project, west wall of Powerhouse 761 feet from Access Tunnel measured through Surge Gallery II and Powerhouse Drift.

PHW 8+30 - Dark gray dense massive hornblende-biotite-feldspar schist. Northfield Mountain Project, west wall of Powerhouse 830 feet from Access Tunnel measured through Surge Gallery II and Powerhouse Drift.

Table 7. Estimated modes of specimens from the gneiss member, Poplar Mountain Gneiss.

	typical gneiss												Schist	ultramafic
	G78A	LS 4+70	LS 4+81	LS 5+25	LS 5+45	LS 5+73	LS 5+98	LS 6+20	LS 6+81	LS 7+20	LS 7+55	LS 7+80	4M5B	G78B
Quartz	28	50	56	50	30	35	30	25	25	25	30	30	42	1
Plagioclase	40	15	5	15	2	5	12	49	5	15	10	12	15	3
	An_{24}	An_{25}	An_{24}	An_{25}	An_{23}		An_{24}	An_{25}	An_{24}	An_{23}	An_{23}	An_{25}	An_{28}	
Microcline	10	10	15	10	60	55	53		55	45	40	38		
Muscovite	2	5	1	tr	tr		tr	tr	tr	tr	tr	tr	15	
Biotite	20	20	23	25	8	5	4	25	15	15	20	20	27	
Garnet							1						tr	
Chlorite	tr													
Hornblende														67
Diopside														23
Epidote	tr		tr									tr	tr	
Allanite			tr										tr	
Calcite	tr			tr			tr		tr	tr	tr	tr		tr
Sphene		tr						tr						4
Apatite	tr		tr	tr	tr	tr			tr	tr	tr	tr	tr	2
Pyrite				tr	tr	tr		1	tr	tr	tr	tr	tr	
Zircon	tr	tr	tr			tr						tr	tr	
Tourmaline													1	

Specimens in Table 7

G78A - Medium to coarse-grained gray feldspar-quartz-biotite gneiss with a trace of muscovite; white feldspar megacrysts up to 1 cm. in diameter. Very typical Poplar Mountain Gneiss. East end of new (1968) road cut on Route 2 one mile east of Millers Falls.

LS 4+70 - Gray to dark gray biotite-feldspar-quartz-muscovite gneiss with fair layering and white feldspar megacrysts up to 5 mm. in diameter. Northfield Mountain Project, adit to pressure shaft at 470 feet.

LS 4+81 - Poorly layered gray to dark gray biotite-quartz-feldspar gneiss with white feldspar megacrysts up to 2.5 cm. in diameter; the megacrysts have quartz inclusions up to 0.7 mm. in diameter. Northfield Mountain Project, adit to pressure shaft at 481 feet.

LS 5+25 - Dark gray fine-grained biotite-quartz-feldspar gneiss with a trace of muscovite and scattered white feldspar megacrysts up to 8 mm. in diameter. Northfield Mountain Project, adit to pressure shaft at 525 feet.

LS 5+45 - Light gray poorly layered feldspar-quartz-biotite gneiss with white feldspar megacrysts up to 2 cm. in diameter. Northfield Mountain Project, adit to pressure shaft at 545 feet.

LS 5+73 - Light and dark layered quartz-feldspar-biotite gneiss with megacrysts of feldspar up to 1 cm.; layers vary from 0.5 to 2 cm. in thickness. Northfield Mountain Project, adit to pressure shaft at 573 feet.

LS 5+98 - Light gray weakly laminated feldspar-quartz-biotite gneiss with abundant garnet up to 0.3 mm. in diameter. Northfield Mountain Project, adit to pressure shaft at 598 feet.

LS 6+20 - Dark gray well foliated biotite rich feldspar-quartz-biotite gneiss with abundant feldspar megacrysts up to 1 cm. in diameter. Northfield Mountain Project, adit to pressure shaft at 620 feet.

LS 6+81 - Pink poorly-laminated feldspar-quartz-biotite gneiss with pink feldspar megacrysts up to 1.5 cm. in diameter. Northfield Mountain Project, adit to pressure shaft at 681 feet.

LS 7+20 - Pink quartz-feldspar-biotite gneiss moderately well laminated with biotite rich zones and abundant pink feldspar megacrysts up to 1 cm. in diameter. Northfield Mountain Project, adit to pressure shaft at 720 feet.

LS 7+55 - Poorly laminated biotite-quartz-feldspar gneiss, feldspars tinged with pink; biotite rich zones and abundant white to light pink feldspar megacrysts up to 6 cm. in diameter. Northfield Mountain Project, adit to pressure shaft at 755 feet.

LS 7+80 - Dark gray biotite-quartz-feldspar gneiss with abundant white to pink feldspar megacrysts up to 1.5 cm. in diameter; one large (6 cm.) pink feldspar megacryst with quartz intergrowths. Northfield Mountain Project, adit to pressure shaft at 780 feet.

4M5B - Dark gray muscovite-biotite schist with a few feldspar megacrysts up to 8 mm. in diameter and also with dark euhedral needles of tourmaline. Located off map area on west side of Country Hill southeast of Millers Falls; typical of other rock seen at equivalent stratigraphic levels on Poplar and Rattlesnake Mountains.

G78B - Dark green dense medium-to coarse-grained ultramafic rock with needles of dark green hornblende up to 5 mm. in length and with interspersed diopside. East end of new (1968) road cut on Route 2 one mile east of Millers Falls.

In the Poplar Mountain Gneiss only limited microcline twinning was observed. The balance of the potassium feldspar is assumed to be microcline. The twinned plagioclase was determined to be oligoclase ranging in composition from An_{23} to An_{25} but mostly An_{24}. This composition of plagioclase has an index of refraction so close to that of quartz, however, that some of the untwinned plagioclase may have been mistaken for quartz and vice-versa in the visual estimates of the modes. The plagioclase content may be higher than that reported, at the expense of the quartz.

The composition of the feldspar megacrysts characteristic of this rock is also something of a problem. The megacrysts are not single crystals but the intergrowth of several crystals. Examined in thin section they reveal very little critical information concerning their optical properties. Only one megacryst of many examined showed typical microcline twinning; on the other hand only one megacryst had an apparent index of refraction greater than quartz,suggesting that it is plagioclase. X-ray diffraction studies conducted at the University of Massachusetts by R. J. Tracy have shown some of the megacrysts to be maximum microcline (P. Robinson-oral communication).

Thickness. The base of the inner Poplar Mountain Gneiss is not exposed in the study area. Total thickness, therefore, is not known except that it is in excess of 1200 feet at its greatest exposure at Poplar Mountain not accounting for repetition due to folding, tectonic thinning, or other deformation. The quartzite member ranges from 100-300 feet and is included in the total thickness of 1200 feet.

The outer Poplar Mountain Gneiss including both gneiss and quartzite not separately mapped is 100-200 feet thick.

Separation of the two occurrences of Poplar Mountain Gneiss. The two occurrences of Poplar Mountain Gneiss are separated by the Dry Hill

Gneiss lying above the inner Poplar Mountain Gneiss but below the outer Poplar Mountain Gneiss. Connection of the two bands of Poplar Mountain Gneiss outside the area currently under study has not been demonstrated. Further consideration of this possibility will be presented in the section on structural geology.

Derivation. The Poplar Mountain Gneiss is believed to be of sedimentary derivation. By careful selection of specimens one can show a continuous gradation in composition from a clean quartzite to a feldspathic quartzite to typical Poplar Mountain Gneiss all within the quartzite member. It is conceivable that these rocks formed in a depositional environment receiving mineralogically immature sediment from a volcanic source area. The generally low alumina and high alkali content of the section suggests that chemical weathering was of minor importance in the source area. The quartzites may be derived from an old shoreline along which the sediment was reworked. The actinolite and other calc-silicate minerals suggest that the depositional area either temporarily supported an environment in which dolomite formed or was sufficiently near one so that carbonate could be introduced.

Relationship of the Dry Hill Gneiss and the Poplar Mountain Gneiss. The two formations usually can be readily distinguished in the field. In each formation, however, there are a few beds suggestive of the other and commonly along the contact some rocks are intermediate and could be called one unit or the other. The similarity in the mineralogy is very striking. Both formations have modes that overlap for the major minerals; calcite is a distinctive accessory mineral in all these rocks. Both units contain minor quartzite beds that characteristically contain actinolite. The similarity of the composition and the gradational nature of the contact between the two is suggestive that the rocks are genetically related and were produced during the same depositional episode with some interbedding. The green biotite in the Dry Hill Gneiss presumably contains ferric iron (Deer, Howie, and Zussman, 1966, p. 213) suggestive of a slightly oxidized environment of deposition or of a primary igneous composition. The brown biotite in the Poplar Mountain Gneiss, however, presumably contains ferrous iron which is suggestive of deposition in an environment with reducing conditions.

Fourmile Gneiss

General statement. Balk (1956a, 1956b) included a border facies in the Dry Hill Gneiss. This facies is here separated from the Dry Hill Gneiss and considered a separate formation. The name Fourmile Gneiss is proposed for this formation after the type locality at the cascade on Fourmile Brook immediately west of Route 63 at Northfield Farms (Plate 1, and Fig. 10). The Fourmile Gneiss cannot be considered a part of the Dry Hill Gneiss because within the map area it has now been shown to be entirely separated from it by the Poplar Mountain Gneiss and in addition the Fourmile Gneiss differs compositionally from the Dry Hill Gneiss. The Fourmile Gneiss is more variable and generally has more plagioclase and less microcline. Also, in contrast to the Dry Hill Gneiss, the Fourmile Gneiss contains appreciable amphibolite and lacks the quartzites typically found in the Dry Hill. The two formations are different in general appearance mainly because the Fourmile Gneiss is darker. Mineralogically, the plagioclase in the Fourmile Gneiss has a slightly greater anorthite content. Biotite is reddish brown, and the hornblende (occurring mainly in the amphibolites) has typical optical properties compared to the unusual hornblende in the Dry Hill Gneiss.

The Fourmile Gneiss together with thin infolded zones of Partridge Formation forms a broad zone approximately one half to two miles wide

Figure 10. Outcrops of Fourmile Gneiss at its type locality in the cascade along Fourmile Brook at Northfield Farms.

around the outside of the dome, completely enclosing the Dry Hill Gneiss and the Poplar Mountain Gneiss. The Fourmile Gneiss is cut by the Triassic border fault on the west side of the dome. On the north and east sides of the dome the formation is overlain by Paleozoic mantle rock. Two thin layers of schist assigned to the Partridge Formation extend through the Fourmile Gneiss on the north and west sides of the dome with only one break in the inner layer between Northfield Farms and Beers Mountain (Plate 1). These layers of Partridge are interpreted as infolds of the mantle sequence into the gneiss and their presence will be discussed more fully under structure. The type locality of the Fourmile Gneiss in Fourmile Brook is situated between the two layers of Partridge Formation.

Quartz-feldspar-biotite gneiss. The bulk of the Fourmile Gneiss is made up of a light-to dark gray, fine-to medium-grained, slabby to massive gneiss composed of quartz, feldspar, and biotite, and bearing small megacrysts of feldspar. Some outcrops have small hornblende spots. Locally the rock is pink but the dominant color is gray.

Examination of eight thin sections of typical Fourmile Gneiss (Table 8) revealed quartz present from 20-30%; microcline 0-40%; plagioclase 10-60% (anorthite content ranges from 25-30%); biotite 10-20% (reddish brown in section); hornblende 0-20%; and epidote 0-10%. Accessory minerals include garnet, apatite, zircon, pyrite, calcite, sphene, allanite, and muscovite. The rock is highly variable in composition ranging from the igneous equivalents of granite to quartz diorite.

Amphibolite. Beds of dark gray coarse-grained amphibolite (Table 8) showed quartz 0-10%; andesine (An_{30-36}) 0-30%; biotite (brown in section) 10-20%; hornblende 20-75%; epidote 0-20%; and minor amounts of pyrite and sphene. Trace amounts of apatite and zircon were noted. The hornblende is olive-green in section, biaxial negative, and has a large 2V. One of

Table 8. Estimated modes of specimens from the Fourmile Gneiss and the Partridge Formation.

	Fourmile Gneiss														Partridge Formation
	gneiss									amphibolite				ultra-mafic	
	9J1	9J1C	9J1G	9J1H	9J1I	TR 16+97A	TR 17+00	TR 17+60A	#164	9J1F	OKO	TR 15+45	TR 16+08	9J1K	9J1A
Quartz	32	20	23	30	25	29	20	22	10	10		12		5	47
Plagioclase	10 An_{24}	30 An_{25}	58 An_{30}	22 An_{25}	44 An_{26}	20 An_{25}	28 An_{25}	25 An_{25}	42 An_{24}	25 An_{29}	35 An_{26}	30 An_{36}	30 An_{30}		5 (An_{25})
Microcline	35	24		40	5	39	28	25							
Muscovite								tr							25
Biotite	20	18	15	8	15	10	16	20	18	8		18	10	20	20
Garnet	2		1	tr	tr	2	tr	tr					1		2
Chlorite	tr														
Hornblende	tr	4			1				28	50	57	20	42	75	
Epidote	1	4	3		10		8	8	2	5		18	15		
Allanite	tr														
Calcite	tr	tr						tr							
Sphene	tr	tr					tr								
Apatite	tr	tr	tr	tr	tr	tr	tr	tr		tr	tr		tr		tr
Pyrite	tr	tr	tr	tr	tr					2	8	2	2	tr	1*
Zircon	tr	tr			tr		tr		tr			tr			
Graphite															tr

* pyrite or non-magnetic pyrrhotite

Specimens in Table 8

9J1 - Light gray fine-to medium-grained quartz-feldspar-biotite-gneiss with alternating feldspar laminations 2-3 mm. thick and biotite laminations less than 1 mm. Northfield Mountain Project, Tailrace Excavation.

9J1C - Light gray fine-grained feldspar-quartz-biotite-gneiss with scattered hornblende up to 1 mm. in diameter. Northfield Mountain Project, Tailrace Excavation.

9J1G - Gray fine-grained biotite-feldspar-quartz-gneiss with light laminations 2-5 mm. thick and darker laminations 1-2 mm. thick. Northfield Mountain Project, Tailrace Excavation.

9J1H - Leucocratic fine-grained weakly laminated feldspar-quartz-biotite gneiss. Northfield Mountain Project, Tailrace Excavation.

9J1I - Gray fine to medium-grained feldspar-quartz-biotite-gneiss with minor hornblende. Northfield Mountain Project, Tailrace Excavation.

TR 16+97A - Gray fine-grained quartz-feldspar-biotite-gneiss with light pink feldspar bands 1-5 mm. thick with garnet concentrations; these bands are probably associated with a large pegmatite only a few centimeters above. Gneiss is massive except for the feldspar bands. Northfield Mountain Project, Tailrace Tunnel-1697 feet from west end.

TR 17+00 - Gray homogeneous medium-grained feldspar-biotite gneiss. Northfield Mountain Project, Tailrace Tunnel-1700 feet from west end.

TR 17+60A - Massive gray-green biotite-feldspar-gneiss included in coarse grained pink and white feldspar quartz-garnet pegmatite. Section from the gneiss. Northfield Mountain Project, Tailrace Tunnel-1760 feet from west end.

#164 - Massive light gray feldspar-hornblende gneiss speckled with abundant dark green hornblende crystals 1-2 mm. in diameter. Northfield Mountain Project, outcrop exposed and subsequently buried near junction of roads about 600 feet north of portal area.

9J1F - Dense dark gray fine to medium-grained biotite-hornblende-feldspar-gneiss (amphibolite). Northfield Mountain Project, Tailrace Excavation.

OKO - Dense very dark medium-grained hornblende-feldspar gneiss (amphibolite). In pasture 200 feet east of Route 63 at Northfield Farms.

TR 15+45 - Dense massive dark green biotite-hornblende-feldspar gneiss poorly foliated. Northfield Mountain Project, Tailrace Tunnel-1545 feet from west end.

TR 16+08 - Massive dense dark poorly foliated greenish-gray biotite hornblende-feldspar gneiss. Northfield Mountain Project, Tailrace Tunnel-1608 feet from west end.

9J1K - Dense very dark fine to medium-grained hornblende-biotite schist (ultramafic). Northfield Mountain Project, Tailrace Excavation.

9J1A - Silvery gray fine to medium-grained muscovite-biotite-quartz schist with many crinkles developed in the foliation. From outer layer of Partridge Formation, Tailrace Excavation, Northfield Mountain Project.

Note concerning location of outcrops from which specimens were collected in relation to the two layers of Partridge Formation included in the Fourmile Gneiss:

specimens from localities east of both layers of Partridge Formation: #164, OKO.

specimens from localities between the two layers of Partridge Formation: 9J1F, TR16+97A, TR17+00, TR17+60, TR15+45, TR16+08.

specimens from localities west of both layers of Partridge Formation: 9J1, 9J1C, 9J1G, 9J1H, 9J1I, 9J1K.

the supposed amphibolite specimens proved to have no feldspar when examined in section and therefore is an ultramafic rock (specimen 9J1K in Table 8).

Thickness. On the east limb of the dome the Fourmile Gneiss is about 1400 feet thick. On the west limb at Northfield Farms the thickness from the top of the Poplar Mountain Gneiss to the inner layer of the Partridge Formation is 750 feet. The middle zone of Fourmile Gneiss between the two infolded layers of the Partridge Formation is 420 feet thick. The outer zone of the Fourmile Gneiss from Beers Mountain and Roman T Hill to the north end of the dome is approximately 2500 feet thick. On the west limb in the Northfield Farms area the original thickness of the outer zone cannot be determined because the Fourmile Gneiss has been cut by the Triassic border fault.

Contact between Fourmile Gneiss and Poplar Mountain Gneiss. Nowhere in the field was an interbedding observed between the Fourmile Gneiss and the Poplar Mountain Gneiss. Two drill cores from the Northfield Mountain Project (123 and 202) penetrated the Fourmile Gneiss-Poplar Mountain Gneiss contact. Neither of these cores showed any interbedding between the two formations. The Tailrace tunnel offered a complete exposure of this contact where a more detailed examination could be made. Professor Robinson reports a sharp contact between Fourmile massive hornblende-spotted gray biotite gneiss and sheared brown biotite schist of the Poplar Mountain Gneiss. Sheared layers 3 to 6 inches thick of gray hornblende-biotite gneiss of Fourmile type some 30 inches below this sharp contact appear to be the only evidence of interbedding between the two formations and could be due to structure.

Derivation. The strong layering and differing compositions suggest a sedimentary or pyroclastic origin rather than the intrusive origin proposed by Emerson (1917) and Balk (1942, 1956a, 1956b). Different parts of the gneiss have compositions equivalent to the igneous rocks rhyolite, quartz latite, and dacite and the amphibolites are equivalent to andesite.

Partridge Formation

The Partridge Formation is not a true part of the Pelham dome stratigraphy but is briefly included here because of the presence of thin layers of Partridge folded into the Fourmile Gneiss.

The Partridge Formation occurs in two narrow bands traceable from East Mineral Hill west of Millers Falls northward along the west side of the dome to Beers Mountain, and then passing out of the dome to connect with the Partridge Formation mantling the dome in the vicinity of Crag Mountain. The most extensive exposures are along the east band of the Connecticut River under French King Bridge and southward for about 1000 feet. No trace of the inner band of Partridge Formation has been found between Northfield Farms and Beers Mountain.

The rock as seen in the northern portion of the Pelham dome is a rusty-weathering sulfidic mica schist commonly with garnets up to one quarter of an inch in diameter. One specimen examined in thin section revealed about 50% quartz, 25% muscovite, and 25% biotite with minor oligoclase (An_{25}), an opaque believed to be non-magnetic pyrrhotite, and garnet (Table 8).

Throughout most of the distance the exposed Partridge Formation is thin, ranging in thickness from a few feet to less than one foot (Fig. 11). The portion exposed on the Connecticut River south of French King Bridge is more substantial, reaching a few tens of feet before being cut off by the Triassic border fault. The presence of the fault in this area complicates the structural interpretation

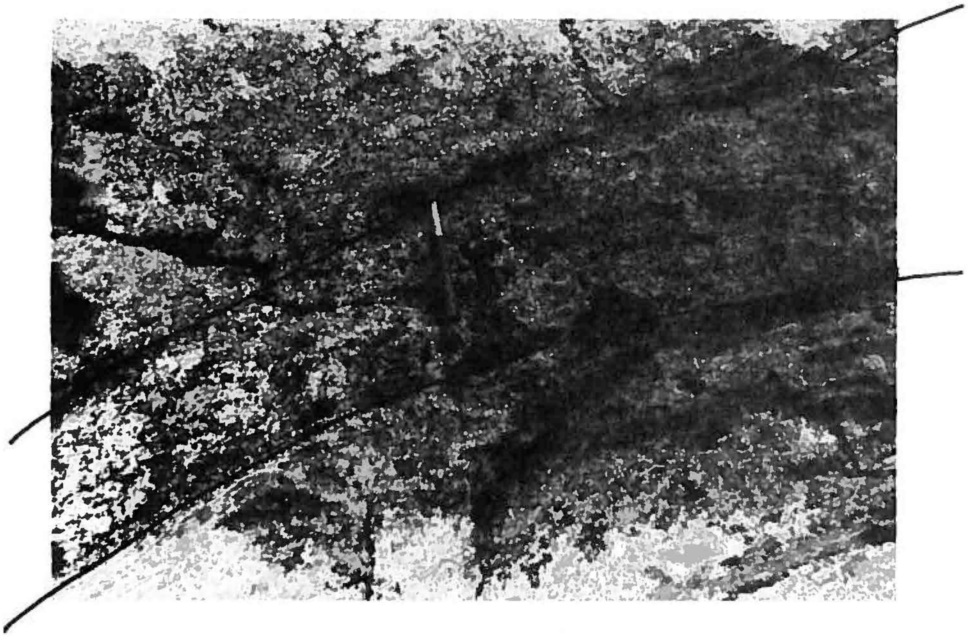


Figure 11. Narrow layer of Partridge Formation apparently infolded into the Fourmile Gneiss on East Mineral Hill. Contacts inked.

concerning the position of the Partridge here. It is not known whether the outer layer of Partridge Formation which is thickening southward has now become the base of the main mass of the Partridge mantling the dome (Partridge is 3000 feet thick 7 miles to the south) or is still only a thin infold overlain by gneiss to the west that has since been removed by the faulting. These problems will be considered in more detail under structure.

The Partridge Formation is believed to be metamorphosed marine black shale deposited in a reducing environment as demonstrated by its abundant iron sulfide and graphite (Robinson, 1963).

MANTLE SEQUENCE

In addition to the Partridge Formation described above, exposures of Clough Quartzite, Littleton Formation, Erving Formation, and Waits River Formation are indicated on the geologic map. No further description of the Clough Quartzite, Littleton Formation, or Erving Formation beyond that given in the explanation of the geologic map (Plate 1) will be given here because the rocks are outside the discussion in this paper and have been described elsewhere (Robinson, 1963, 1967b; Thompson, Robinson, Clifford, and Trask, 1968).

A very limited exposure of Waits River Formation occurs on the west bank of the Connecticut River about 3000 feet north of French King Bridge. Its presence here is interpreted as a sliver along the Triassic border fault. Although it is indicated above the Erving Formation in the explanation on the geologic map its exact stratigraphic position with respect to the Littleton and Erving Formations is not certain.

Intrusive and Other Rocks of Limited Occurrence

Pegmatite and granite sills. Pegmatite occurs throughout the area but is more common in the Fourmile Gneiss than in the Poplar Mountain Gneiss or the Dry Hill Gneiss. The hills north of Stoneville along the eastern contact between the Pelham dome and the mantle sequence are composed predominantly of pegmatite. Abundant pegmatite also occurs near the top of the Poplar Mountain Gneiss both in the tunnels of the Northfield Mountain Project and on the surface to the south. The pegmatites are generally foliated parallel to the regional foliation but their contacts in some cases form local departures from the regional foliation because of thinning or thickening over a short distance. A total of four pegmatites were examined in thin section (Table 9). Three of these have the composition of granite and the fourth one (specimen TR16+97B) has the composition of quartz diorite.

Four small igneous sills, only a few inches thick and located in the quartzite member of the Poplar Mountain Gneiss, were examined in thin section and have the composition of granite (Table 9). These sills are very minor. Two of them (BLA 2+12 and LS 5+59) have an aplitic texture.

Triassic diabase intrusions. Two small intrusions of fine-grained diabase were located during field investigation. One is a dike located in muscovite schist of the Partridge Formation on the east bank of the Connecticut River just south of the confluence with the Millers River and trends northwest. The other is a sill in Dry Hill Gneiss at the north end of the highway bridge carrying Route 63 across the Millers River at Millers Falls. The gneiss at this point trends N46E dipping 21°NW. The diabase follows approximately this attitude. The diabase is post-metamorphic and assumed to be Triassic. The sill is approximately 20 feet thick.

Hornblende diorite. Hornblende diorite of unknown age and relationship occurs in a 2000-foot zone of exposure on the east bank and in the bed of the Connecticut River between French King Bridge and French King Rock (located in the Connecticut River directly below the power line, see Plate 1). The rock is assumed to be a slice from a different tectonic level caught in the Triassic border fault.

Brecciated pegmatite and silicified zone. An 800 foot wide zone immediately east of the Triassic border fault at East Mineral Road contains brecciated pegmatite and a highly silicified zone (Plate 1). The pegmatite consists of fractured coarse-grained pink feldspar and quartz with conspicious specular hematite. The rock forms a distinct ridge east of East Mineral Road and appears to be in fault contact with the Fourmile Gneiss. Two ribs of highly silicified rock, resembling huge quartz veins, occur west of the pegmatite and can be seen from East Mineral Road. Like the pegmatite they contain abundant specular hematite. The pegmatite is of unknown relationship and uncertain age. The silicified zone is in contact with the Triassic border fault and may be a hydrothermal deposit located in the fault zone.

Table 9. Estimated modes of intrusive pegmatites and sills.

	pegmatite				sills			
	LS 5+79B	LS 6+03	TR 16+97B	Tr 17+60B	BLA 2+12	LS 5+59	LS 1+85	BL1 4+50
Quartz	35	22	28	30	35	34	25	28
Plagioclase	5 An_{23}		62 An_{24}		1 An_{23}	1 An_{23}	10	10 An_{24}
Microcline	55	75		70	42	55	59	52
Muscovite		tr	tr	tr	22	2	5	6
Biotite	5	3	8			8		4
Garnet		tr	2	tr				
Calcite		tr				tr	1	tr
Apatite			tr			tr	tr	tr
Chlorite						tr		
Pyrite						tr		
Zircon		tr						

Specimens in Table 9

LS 5+79B - Light pink weakly laminated pegmatite with white feldspar 7 cm. across containing intergrowths of quartz. Thin poorly marked biotite laminations run through specimen. Northfield Mountain Project, adit to Pressure Shaft at 579 feet.

LS 6+03 - Medium-to coarse-grained pegmatite showing only weak laminations. Contains white feldspar up to 2.5 cm. across and a trace of garnet. About 20% of specimen is granulated glassy vein quartz. Northfield Mountain Project, adit to Pressure Shaft at 603 feet.

TR 16+79B - Leucocratic coarse grained pink and white pegmatite with garnet and smears of included gray biotite-quartz-feldspar gneiss throughout. Northfield Mountain Project, Tailrace Tunnel at 1697 feet from west end.

TR 17+60B - Massive gray-green biotite-feldspar gneiss included in coarse-grained pink and white pegmatite with garnet. Northfield Mountain Project, Tailrace Tunnel at 1760 feet.

BLA 2+12 - Grayish white fine-grained massive quartz-feldspar-muscovite-gneiss included as an intrusive sill 10 cm. wide in gray biotite-muscovite-quartz-gneiss. Northfield Mountain Project, Branch Line A-212 feet.

LS 5+59 - Light gray medium-grained massive weakly foliated feldspar-quartz-biotite-gneiss with a trace of pyrite; could be called an aplite in an intrusive sill. Northfield Mountain Project, adit to Pressure Shaft at 559 feet.

LS 1+85 - Fine grained purplish red clean quartzite with only a trace of layering; contains a 2 cm. layer of grayish white massive feldspar-quartz gneiss. Northfield Mountain Project, adit to Four-way Junction at 185 feet.

BL1 4+50 - Fine-grained massive light gray quartz-feldspar-biotite gneiss; taken from a granitic gneiss (sill?) with pegmatite. Northfield Mountain Project, Branch Line 1 at 450 feet.

Age of the Rocks

The hornblende member of the Dry Hill Gneiss has been dated at 575± 30 my (Naylor, Boone, Boudette, Ashenden, and Robinson, 1973) based on a zircon Pb207/Pb206 age in a specimen collected from the northeast portion of the Reservoir Area on Northfield Mountain. The Poplar Mountain Gneiss is believed to be genetically related to the Dry Hill Gneiss as explained previously, and if so, probably has a comparable age. Age of the Fourmile Gneiss has not been established but it would appear to be younger than the Dry Hill Gneiss although older than the Partridge Formation which is Middle Ordovician. The Fourmile Gneiss could be Ordovician volcanics. The Clough Quartzite is late lower Silurian. The Littleton, Erving, and Waits River Formations are Lower Devonian (Thompson, Robinson, Clifford, and Trask, 1968).

Metamorphic Grade

Detailed consideration of the petrogenesis and metamorphism of these rocks is beyond the scope of this paper. Such considerations will be limited to comment on the metamorphic grade. Garnet occurs as an accessory mineral in many of the rocks but is not commonly seen in hand specimen due to its small size and low abundance. No staurolite, kyanite, or sillimanite was noted in any thin section or outcrop in the area mapped. However, staurolite is abundant in mica schists of the Littleton, Partridge, and Erving Formations in the portion of Plate 1 done by Robinson (1963), and kyanite occurs in the belt of Erving Formation extending from Round Mountain at the north edge of the map to the southeast corner. Thus, based on evidence in the mantle rocks not directly investigated in this study, the area can be considered to be in the staurolite-kyanite zone of regional metamorphism.

STRUCTURAL GEOLOGY

Gross Structure

The Pelham dome, north of the Millers River, is like a broad anticline plunging north at about 10°. To the south of the river the plunge levels off and may even be southward (Balk, 1956b). Foliation, bedding, and contacts between rock units are essentially parallel and form a map pattern typical of a north-plunging anticline. Eastward dips on the east limb average 35°, those on the west average 20-25° westward. The crest of the dome can be only vaguely defined because the rocks contain many local warps in foliation. The approximate line of the crest is plotted on the tectonic map (Plate 2). In general the crest runs north-south except near Millers River where it trends northeast. Detailed mapping by graduate students from the University of Massachusetts in areas south of Millers River during the preparation of this manuscript has confirmed that the inner Poplar Mountain Gneiss forms a local structural high within the dome as a whole.

The arrangement of the stratigraphic units is suggestive of a large early recumbent fold with the Dry Hill Gneiss in the core of the fold and the Poplar Mountain Gneiss in the upper and lower limbs. The quartzites of both the inner and outer Poplar Mountain Gneiss are in contact with the Dry Hill Gneiss. Movement sense is believed to have been northwest to southeast with the inner Poplar Mountain Gneiss being on the inverted limb. Evidence and argument for the existence of the recumbent fold will be presented in the section on structural interpretation. The recumbent fold was subsequently deformed into the present anticlinal structure of the Pelham dome.

One major normal fault, the Triassic border fault, cuts the western margin of the northern portion of the Pelham dome. The Triassic border fault extends from the vicinity of New Haven, Connecticut northward, at least 150 miles to southwestern New Hampshire, parallel to the west limb of the Bronson Hill anticlinorium. North of Middletown, Connecticut the border fault is parallel to the eastern margin of the Connecticut valley. Vertical displacement on the Triassic border fault has been estimated to be 18,000 to 28,000 feet or 5.5 to 8.5 kilometers (Robinson, 1967a). The fault marks the eastern edge of the basin of Triassic sedimentation in central New England. In the area of immediate concern the trace of the fault follows the course of the Connecticut River very closely and passes through the gorge directly under French King Bridge at the confluence of the Connecticut and Millers Rivers (Fig. 1). About 1000 feet south of French King Bridge the Connecticut River turns abruptly westward away from the fault and flows across Triassic rocks. The trace of the fault continues southward,passing between East and West Mineral Hills.

Minor Structural Features

Bedding. The contacts between distinct rock types such as quartzites, calc-silicate rocks, gneisses, and particularly the intricate layering in some of the quartzites and gneisses are suggestive of primary bedding. It is significant that practically everywhere these bedding surfaces are essentially parallel to the foliation except around the hinges of a few questionable early folds. Lack of primary graded
the hinges of a few questionable early folds. Lack of primary graded
bedding or crossbedding renders an unequivocal indication of the original direction of tops impossible.

structural aspect of the rocks in the Pelham dome. Foliation is here used to refer to the surfaces in the rocks along which minerals are arranged in parallel orientation. Foliation in some of the gneisses is only moderately developed except for biotite layers, calc-silicate rocks, and amphibolites which are more prominently foliated. Layering and foliation appear to be parallel and were not distinguished separately in the field except in the quartzite units where layering is almost certainly determined by original sedimentary bedding.

Over 1100 readings of attitudes in foliation and bedding were taken on surface outcrops of the northern portion of the Pelham dome. The area was arbitrarily divided into 14 sectors in such a way that each sector would embody a related region of similar strikes and dips. The number of stations recorded in each sector differed from a low of 19 to a high of 206 depending on the size of the sector and the abundance of outcrop. The average number of stations is 76 per sector.

The poles to foliation determined at all the stations in each sector were plotted on a separate equal area diagram (Appendix). Since the majority of attitudes in any given sector showed only a slight variation, the poles would rarely describe a meaningful girdle. Therefore, a careful visual estimate of the mean position of the poles was made and that mean position was regarded as the pole to the average attitude in that sector. The sectors and their average attitudes are presented on a map in Fig. 12. The broad anticlinal structure of the Pelham dome described by the foliation is very clearly shown. Figure 13 is a summary diagram in which the pole to the average foliation for each sector has been plotted. These poles form a distinct girdle such that beta is located at N 2 W plunging 12° N.

Mineral lineation. The northern portion of the Pelham dome has a pervasive north-trending mineral lineation plunging gently north. Mineral lineation as used here refers to the approximately parallel orientation of elongate minerals and mineral aggregates and is recorded in terms of

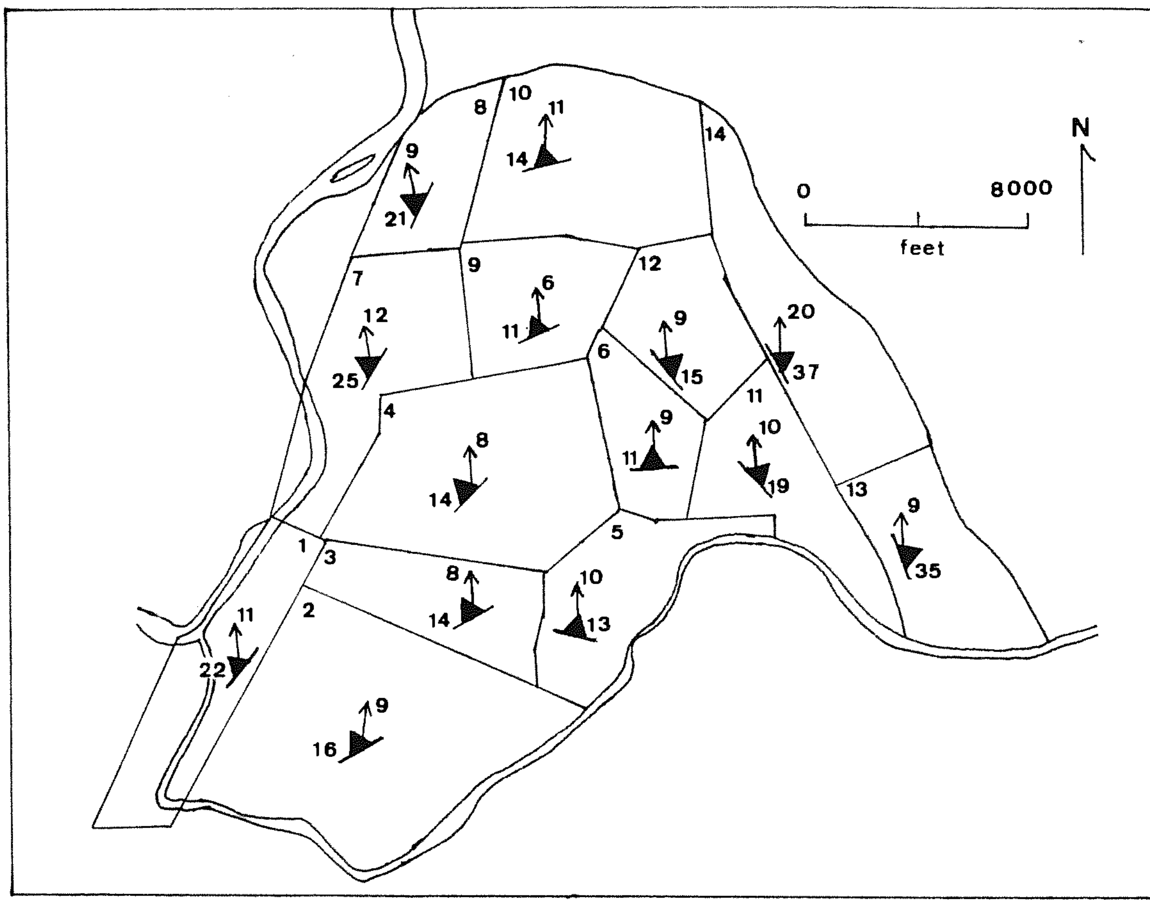


Figure 12. Sector map of the northern portion of the Pelham dome. Structural symbols give visually estimated mean strike and dip of foliation and trend and plunge of mineral lineation. Each sector is numbered separately. Individual equal area diagrams for each sector are included in the appendix.

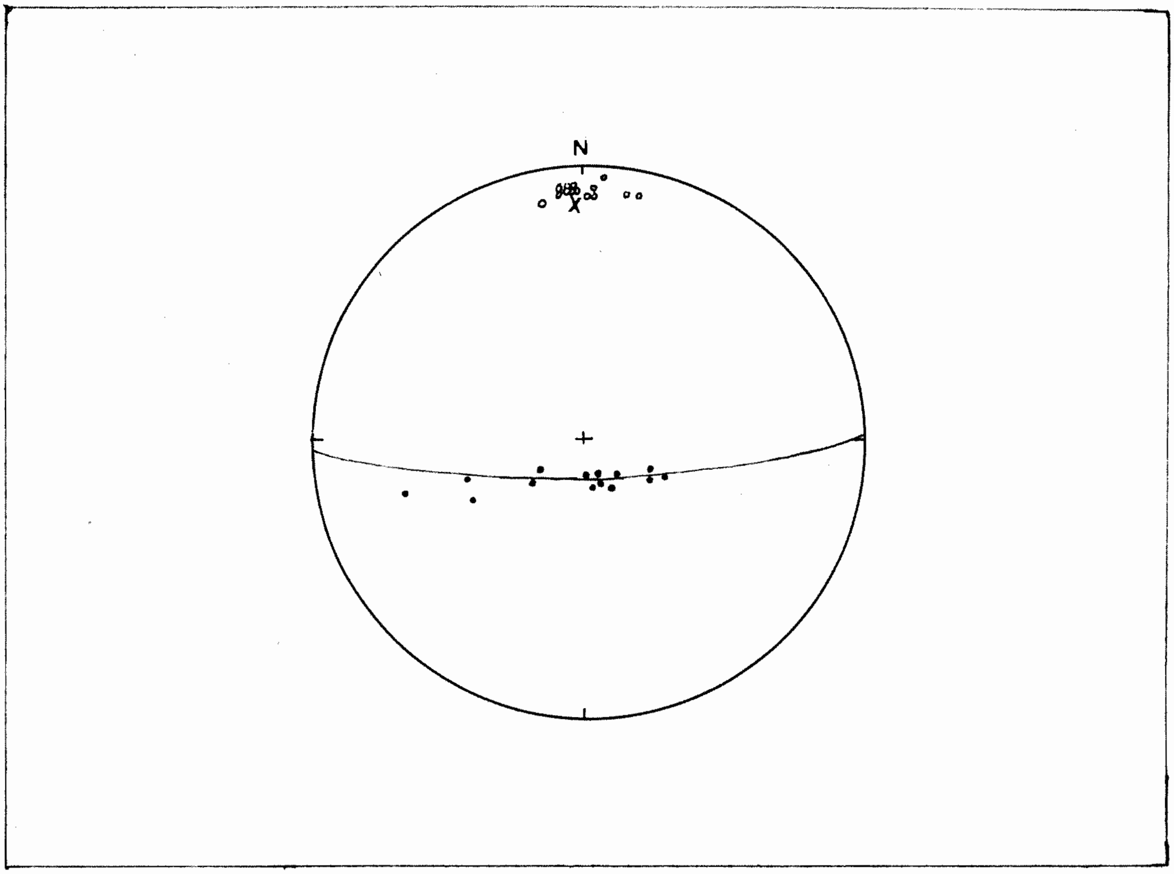


Figure 13. Summary equal area diagram for 14 sectors in the northern portion of the Pelham dome. The 14 poles define a girdle such that beta is N2°W plunging 12°N.

• pole to average foliation for each of 14 sectors

X beta to girdle

o average mineral lineation for each of 14 sectors trend and plunge. The mineral lineation in the Pelham dome is almost universally that of fine elongate flakes of biotite, but quartz and actinolite lineation was noted in some of the quartzites. Some hornblende lineation occurs in the Fourmile Gneiss but the hornblende in the Dry Hill Gneiss occurs in knots and does not define a lineation.

In the field the trend of lineation was measured with a Brunton compass and at times the plunge was also directly measured. In most cases the plunge was determined on an equal area net using the trend of the lineation and the attitude of the foliation that contains the lineation. For the low dipping surfaces common in the Pelham dome, this technique gives more accurate plunges of lineation than direct readings. 731 mineral lineations were recorded.

Lineations generally trend within a few degrees of north and plunge gently north. Lineations trending more than 20 degrees from north are rare and none were observed to trend more than 30° from north. Locally the plunge is to the south by a few degrees. This general observation holds excepting those lineations occurring on the hinges and short limbs of minor folds which have much more variable attitudes.

In an effort to determine if there is any systematic variation in lineation over the northern part of the dome, the lineations for each of the 14 sectors described above were plotted on equal area nets (presented in the appendix). A visual mean for the lineation for each sector was picked and treated as the average lineation for that sector. These mean attitudes of lineation are summarized in the sector map in Fig. 12. There is no apparent significant variation in mineral lineation throughout the dome. The lineation in sector 14 is anomalous because it plunges at 20° rather than 10-12° as in the other sectors. This sector, however, is an area of scarce outcrop and only 10 readings of lineation were obtained so that the mean may not be truly representative.

Minor folds. Observed minor folds fall into two general categories. These are (1) early recumbent folds and (2) late asymmetrical folds overturned to the south, southwest, or southeast. Confusion still exists, however, as to the criteria for definitive separation of these two fold sets. Early in the study it was believed that the early recumbent folds trend NE and the late asymmetric folds trend NW. As the study progressed, however, it became apparent that the late asymmetric folds were extremely variable in orientation and included many with a northeast trend. There were also many, which at first were assumed to be early recumbent folds, but proved not to be. Had it not been for the excellent exposures in the underground workings of the Northfield Mountain Project the true nature and variability of the late folds might not have been detected. This was not accomplished until near the completion of the field work. Many of the folds previously assigned to the early generation are now thought to belong to the late generation. One of the frustrations of mapping in the tunnels of the Northfield Mountain Project is that the exposures there could not be reexamined at a later time after more of the character of these folds was known. Any false impressions recorded with the original data must now be sifted out with caution.

Those folds now considered to definitely be early recumbent folds are rarely seen and so poorly exposed as to preclude collection of any significant geometrical data. For these two reasons no general analysis of them was attempted. These recumbent folds are presumably of an early generation because most of them have since been refolded. Detailed discussion of the best known exposure of one of these early recumbent folds will be postponed until after description of the late folds, because of refolding by the late fold which dominates the structure. An understanding of the late folds is essential to appreciate the structural interpretation that will be presented.

The late folds are very common throughout the studied portion of the dome where they are characteristically asymmetric and overturned to the south, southeast, or southwest. The late folds have axes of diverse orientation, deform both foliation and mineral lineation, and have observed amplitudes from a few inches to twenty feet. They probably occur with even larger amplitudes which are not seen in single outcrops. Areas of anomalous foliation attitudes could be in the hinge areas of some of these postulated larger late folds. Vein quartz is commonly associated with these folds as a prominent mass approximately parallel to the axial plane. The folds are disharmonic, dying out completely within a short distance along the axial surface. Many of these features are shown in the photographs in Fig. 14.

In granite gneiss the folds are commonly obscure, being indicated only by the folding of scattered thin biotite layers or by the subtle deformation of foliation in a homogeneous rock. In the quartzites, however, the folds are prominent both because of the bedding which forms distinct marker horizons and also because the folds are much tighter due perhaps to a greater competency of the quartzite compared to the gneiss during deformation. Fig. 15 is a photograph and line sketch of a typical fold of this type in quartzite seen in a surface exposure. Fig. 16 is a sketch made from color slides of folded quartzites in the Access Tunnel showing the intense folding typical of the quartzites. Both of these figures show marked contrast in general appearance of the folds to those in granite gneiss in Fig. 14.

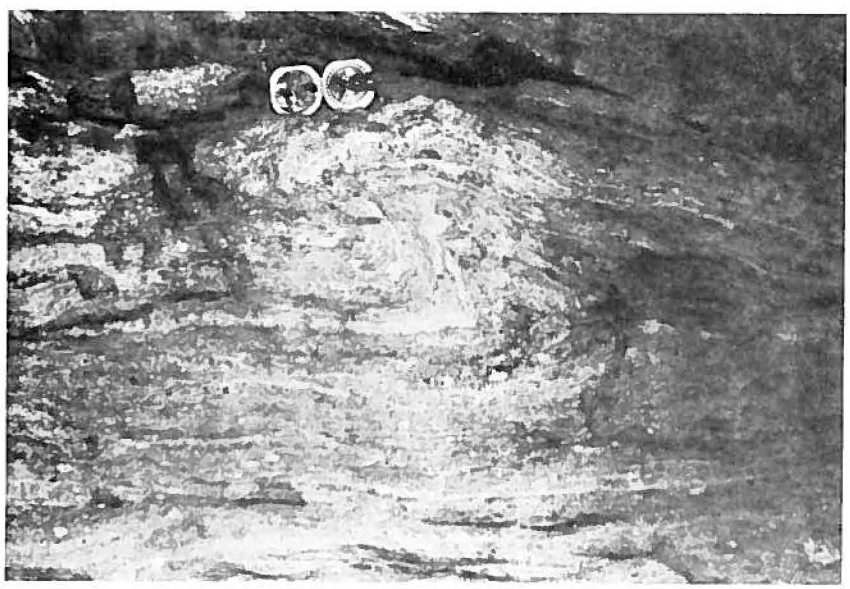
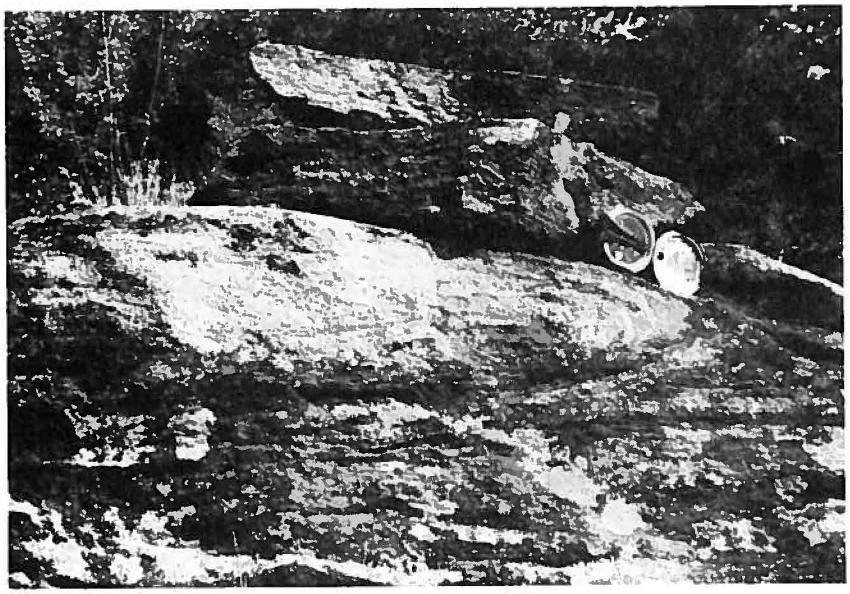


Figure 14. a (above) and b (below). Two typical late generation folds in granite gneiss within the quartzite member of the Poplar Mountain Gneiss exposed at the base of Rattlesnake Mountain near Farley. Disharmonic nature of the folds is very noticeable. White rule in Fig. 14a is 6 inches. Approximate orientation of vertical face in both photos is: SW to left, NE to right. Fold axes trend and plunge northwest.



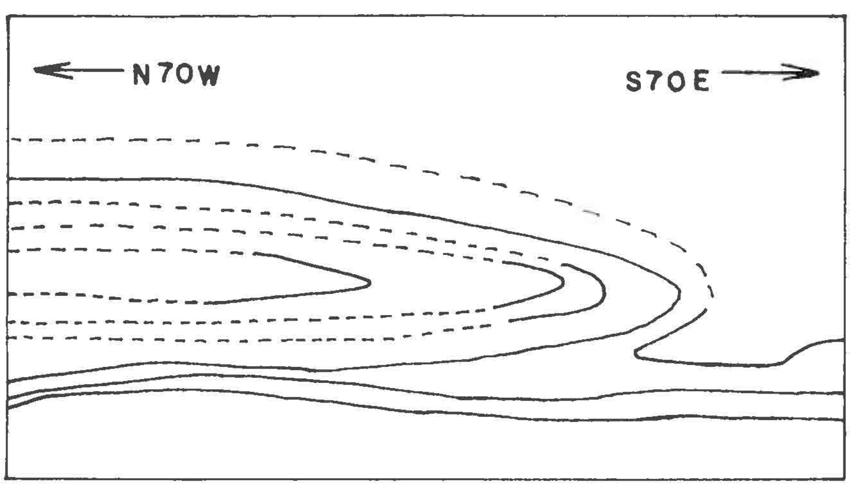


Figure 15. Typical late generation fold in quartzite of the quartzite member of the Poplar Mountain Gneiss exposed at the base of Rattlesnake Mountain near Farley. Line sketch helps to show the geometry of fold. Attitude of fold axis is N44°E plunging 19°NE.

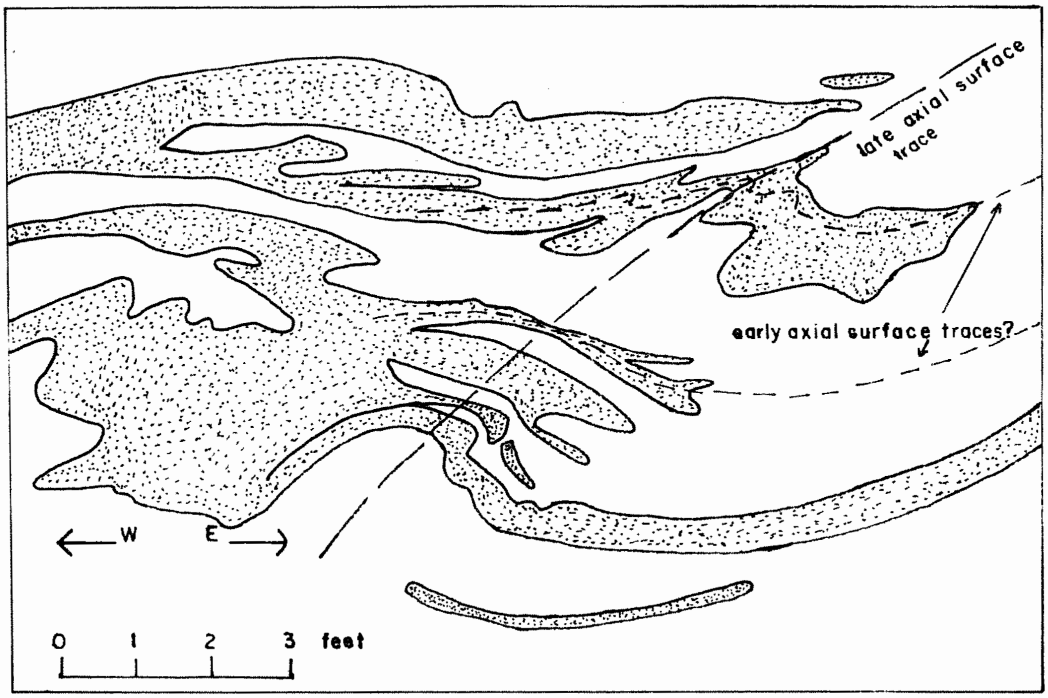


Figure 16. Sketch of late generation folds in quartzite of the quartzite member of the Poplar Mountain Gneiss exposed on north wall of the Access Tunnell of the Northfield Mountain Project at about 22+40 feet. Folds show a marked contrast in style to those in granite gneiss as shown in Fig. 14. Quartzite stippled, white area is layered gray biotite-feldspar-quartz-gneiss.

Figure 16 is of further interest because its pattern is strongly suggestive of both early recumbent folds and the late folds. Unfortunately the exposure was observed directly only with the aid of small low powered electric lanterns at a time when the tunnel was in total darkness. The full extent of the folds was not appreciated until much later after development of a color slide taken with flash. By that time it was impossible to observe the outcrop again.

Fig. 17 is a carefully drawn scale diagram of a large fold in granite gneiss in one of the tunnels near the Powerhouse of the Northfield Mountain Project. The fold was studied about one year prior to the full realization of the truly diverse nature of the late folds. The fold axis at "A" in Fig. 17 trending nearly east-west was seriously believed to be the hinge of an early recumbent fold related to the "northeast" folds seen in the quartzites. The structure as a whole was cited as evidence of early recumbent folding subsequently refolded around the axis at "B", a typical late fold trending northwest and including the large mass of vein quartz sub-parallel to the axial plane. From what was later learned concerning the "late folds" and detailed in the following paragraphs, this interpretation is now open to question and it is possible that both A and B are of the same generation. This exposure, like most in the Northfield Mountain Project, cannot be reexamined and the true nature of the hinge at "A" will forever remain a mystery. This is but another example of the confusion still existing concerning lack of absolute criteria to distinguish these two fold sets believed to exist in the Pelham dome.

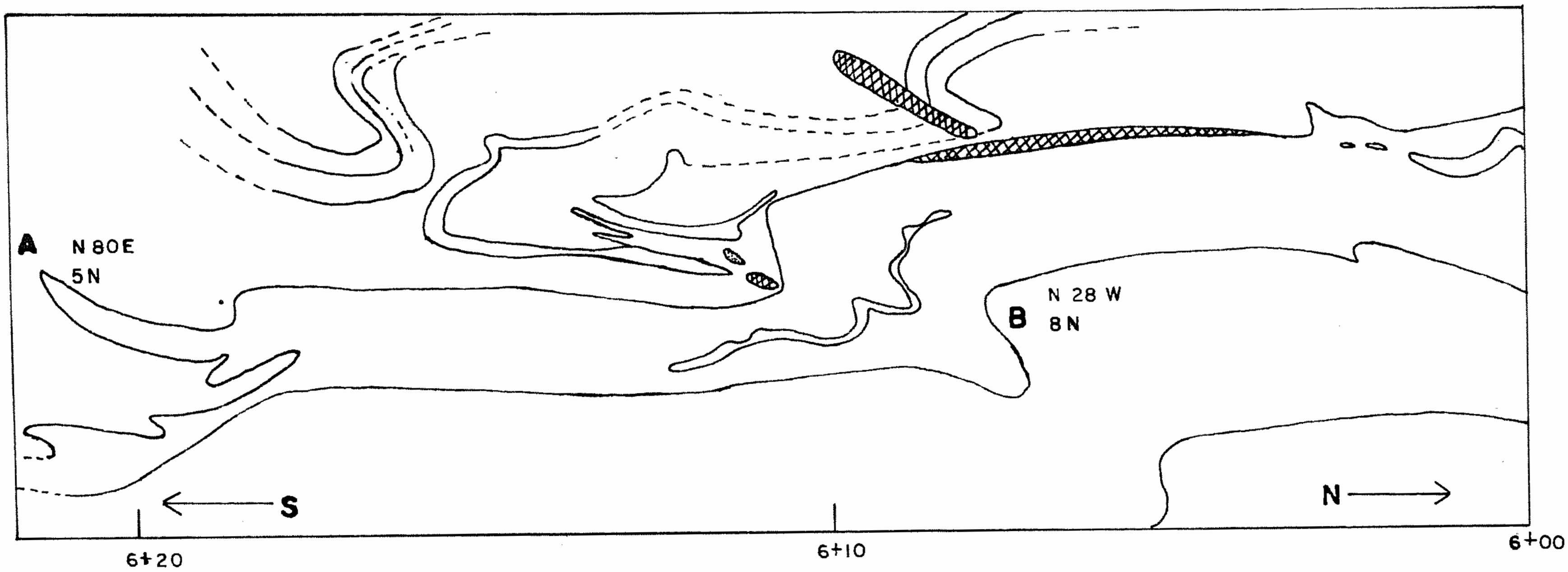


Figure 17. Diagram of a complex fold structure seen on west wall of adit to powerhouse drift, Northfield Mountain Project. Numerical values in feet, vertical scale the same. Folds are delineated by darker and lighter layers of granite gneiss (biotite member of the Dry Hill Gneiss). "A" may be an early isoclinal fold hinge or a late fold hinge (see text for discussion); "B" is a fold hinge of the late generation type. If "A" is an early recumbent fold hinge the layers shown here may be involved in a larger recumbent fold structure which cannot be seen within the confines of the tunnel exposure. Such a larger fold, if it exists, has been refolded about the axis at "B".

vein quartz — calcite pod — N80E trend of fold axis; 5N plunge of fold axis

inferred contacts-poor lighting rendered visibility above eye level uncertain.

A particularly large fold of the "late" or second type was found exposed in cross section in the Reservoir Area of the Northfield Project on top of Northfield Mountain. Fig. 18 is a sketch of this fold with structural data plotted on an equal area projection. The biotite lineations, all measured on the short limbs, do not describe a complete great circle but form a substantial part of one. The intersection between the axial plane of the fold and the great circle suggested by the biotite lineation trends N6E with a plunge of 13° to the north and is the orientation of the slip line (Ramsay, 1960). This is within a few degrees of the regional mineral lineation and is for all practical purposes the same.

A collection of folds of the late type which could be measured were found in close proximity in the underground powerhouse of the Northfield Mountain Project. Fig. 19 is an equal area plot of these folds after the method of Hansen (1966). All of the northwest plunging folds are of a counterclockwise rotation sense. The northeast plunging folds are of a clockwise rotation sense. Collectively they define a separation angle of 18°. The mineral lineation measured on nearby surfaces unaffected by these folds exactly fits the separation angle. These lineations and the separation angle are, like the other mineral lineations measured in the northern portion of the Pelham dome, a few degrees from north and plunging gently northward. Applying the method of Hansen the slip line is oriented approximately north-south plunging at about 10° to the north with movement such that the upper layers have moved south over the lower layers

Discovery of this very important aspect of the late folds suggested that the northwest and northeast fold sets described above are indeed the same. Some of the minor folds of pseudo recumbent style may also be of this generation. When viewed parallel to the fold axis on a north-south

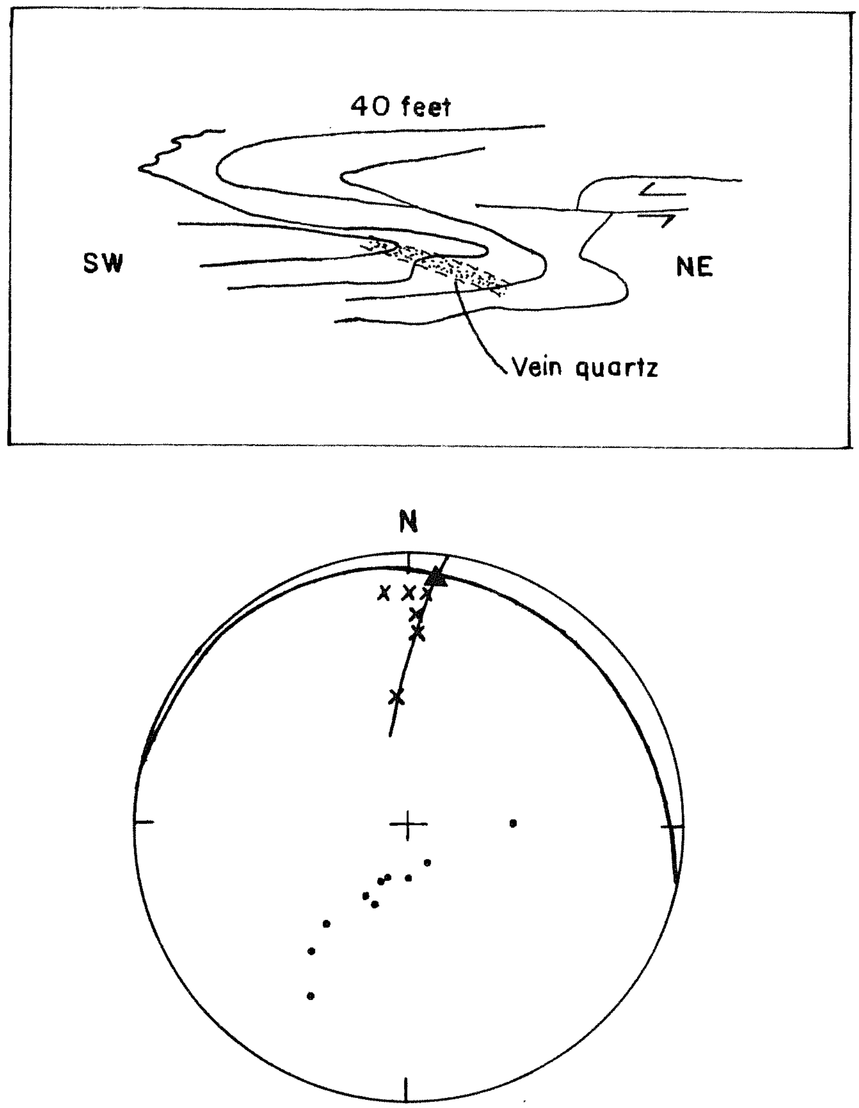
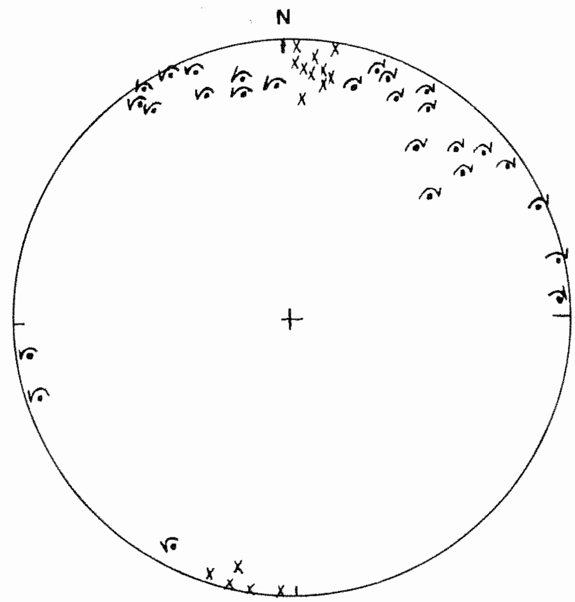


Figure 18. Diagram of a fold of late type and plot of structural data from station #185 in Reservoir Area of Northfield Mountain Project.

- • poles to layering in gneiss
- X biotite lineation
- ▲ intersection of axial plane of fold and biotite lineation at N6°E plunging 13°N



minor fold axis with movement sense

X mineral lineation

Figure 19. Equal area projection of selected structural data from Powerhouse of Northfield Mountain Project. Minor folds of opposite movement sense define a separation angle of 18°. Biotite lineation on nearby undeformed surfaces fits the separation angle. See text for further description. From unpublished data of P. Robinson.

face (Figs. 14, 17) the overturned nature of the fold is evident. When viewed on an east-west face, however, (Figs. 15, 16) perpendicular to the fold axis, their overturned nature is not evident but their gently curving hinge lines going into the face of the outcrop make them appear more like recumbent folds. This is particularly true of the more tightly folded quartzites. The fold in quartzite in Fig. 15 was at first believed to be an early recumbent fold but later inspection showed it to be an atypical late fold.

As noted above the slip line has the same orientation as the mineral lineation. These late folds are believed to be later than the mineral lineation because the mineral lineation is deformed about the hinges and short limbs of the folds. The question is, therefore, why are they parallel? The matter is not resolved but will be further considered under interpretation of structural features.

Another example of these late features is a "bullseye" structure in well bedded quartzite found in Branch Line A at 0+20 feet near the general vicinity of the Powerhouse of the Northfield Mountain Project. Fig. 20 is a scale drawing made from a poor color slide of the fold. The exposure is on an essentially east-west wall looking north. Here folds of both clockwise and counterclockwise rotation sense are seen together and those axes measured are indicated in the diagram. A cross sectional-diagram of the fold is also provided to aid the reader in a three dimensional visualization of the folds. If the vertical view on the wall seen in the diagram is taken as a map, then the marked beds outline an axial depression in a doubly plunging syncline and the structure immediately above would be an anticline showing both a depression and a culmination. Here is a very simple and straightforward example of the true nature of

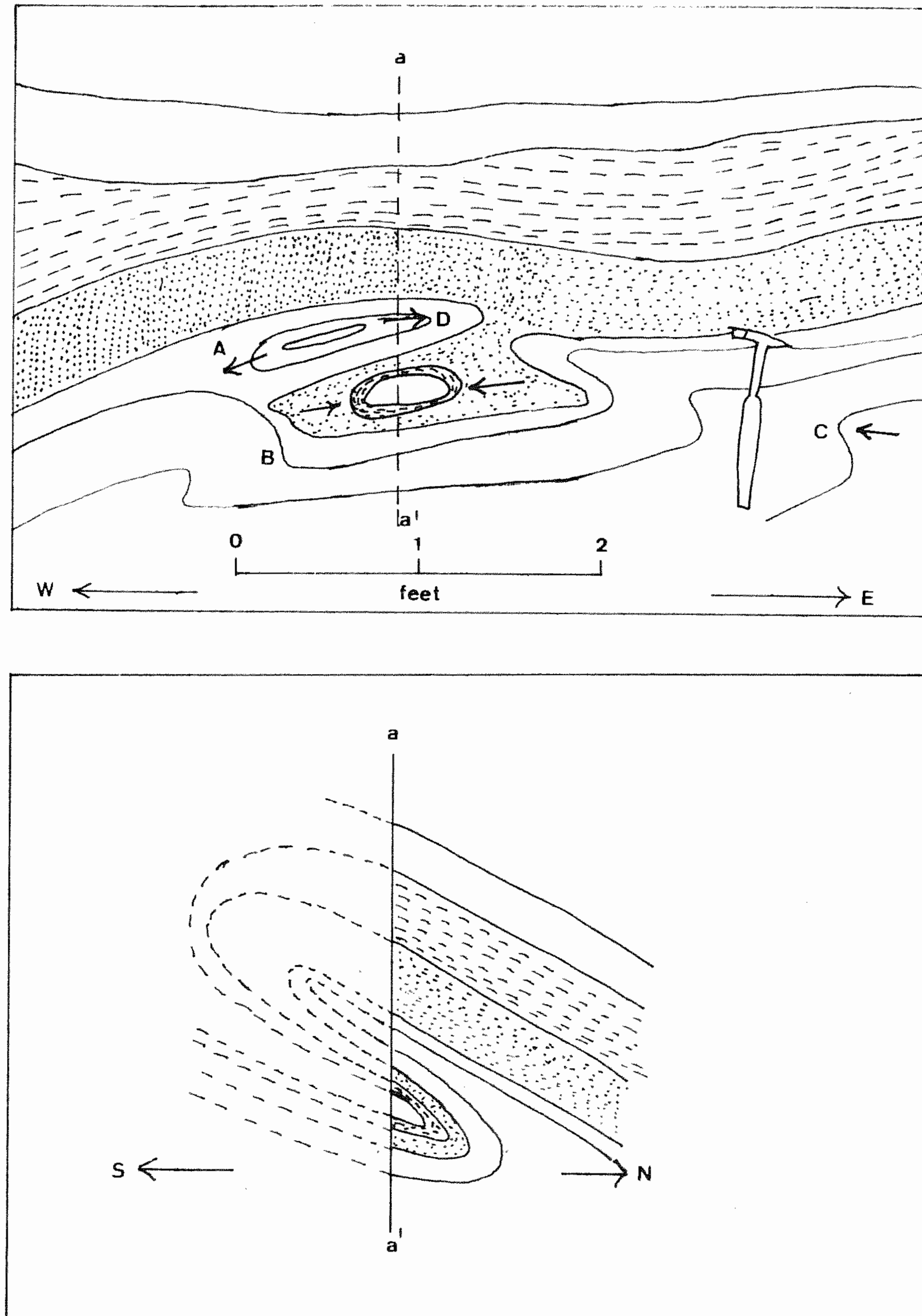


Figure 20. "Bullseye" structure in well bedded quartzite, Branch Line A at 0+20 feet, Northfield Mountain Project. Upper sketch as seen on tunnel wall; standard size pick for scale. Lower sketch is interpretation of fold geometry along a-a' to same scale. Arrows show direction of plunge into vertical wall.

Fold axes:	A N74°W at 21°NW	B N26°E at 5NE
	C N24°W at 14°NW	D N36°E at 9NE

these folds, with hinges bending as much as 52° within one foot. Folds seen in most outcrops are large enough so that their "doubly plunging" nature and curved hinge lines are not apparent and as a result they caused great confusion for a considerable time during the study of the area.

The possible effect these late fold type structures may have upon the early recumbent folds is offered in the sketch (Fig. 21) of a complex series of folds in Poplar Mountain Gneiss on Route 2 west of Farley. Detail of a part of the outcrop is shown in a close-up photograph but the differences in lithology are too subtle to show in a more general picture of the whole. In fact they are sufficiently subtle to make the outcrop difficult to understand even when viewing it directly and the fold geometry is not fully understood. The present interpretation is that the folds on the northeast end of the outcrop are early recumbent folds and those on the southwest are the late generation folds. The layering in the lithic unit designated typical Poplar Mountain Gneiss is very vague but in good light can be seen wrapping around the hinges of the folds. Development of the late style fold has apparently deformed the two westward extending early recumbent folds of the "light gray felsic gneiss" complete with development of vein quartz parallel to the axial plane of the second generation folds. All fold axes appear to plunge northeast. The supposed early recumbent folds are sympathetic to the postulated major west-over-east recumbent fold structure described under gross structure because this outcrop is on its inverted limb. They are not, however, to be taken as proof of its existence.

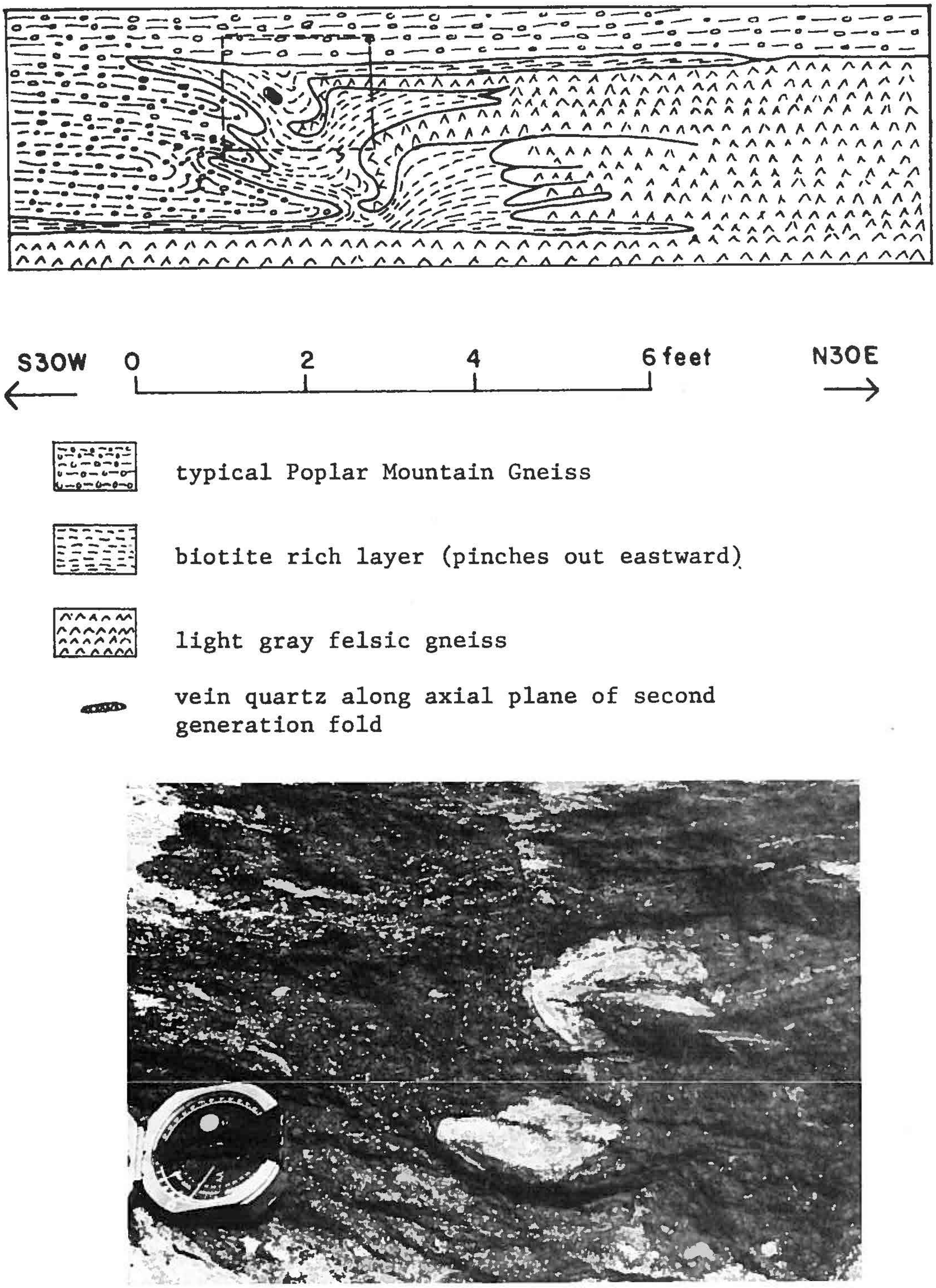
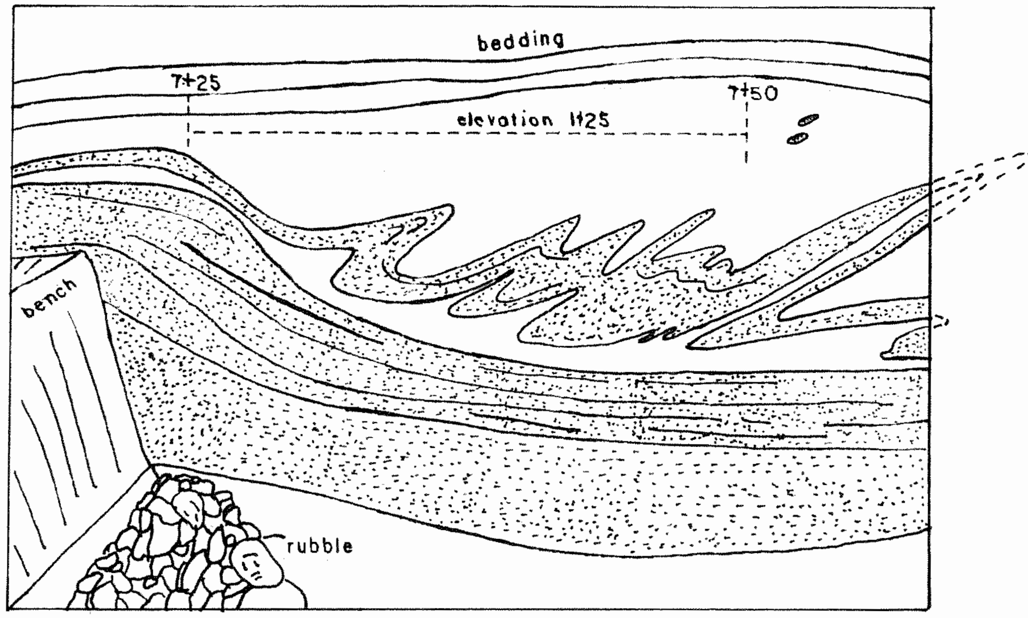


Figure 21. Sketch and photograph of a possible early recumbent fold deformed by late folds. Outcrop west of Farley on Route 2. Area outlined by dashed line in sketch above is shown in photograph below. See text for discussion.

"Decollement structure". During excavation of the underground powerhouse cavern, a striking decollement-like structure was exposed on the east wall (Fig. 22). Conditions were such that the structure could be observed only from the opposite side of the powerhouse at a distance of 70 feet. In addition, part of it was covered by dust from blasting. Fig. 22 is a composite sketch made from a poor photograph in which only a part of the structure could be documented and is supplemented from data in a sketch made at the same time. The figure is intended primarily to convey an impression of the style of deformation and is not necessarily accurate in detail.

An upper quartzite layer has been thrown into a series of folds overturned to the south but more massive quartzites below are relatively unaffected. The upper quartzite would appear to have been detached from some point north of the bench face and slid forward to the south crumpling as it went. The structure as a whole is significant in that the folds are all asymmetric and overturned to the south. They are clearly related to the late style of folding. The thin quartzite beds were sufficiently competent in contrast to the gneiss that a series of folds resulted; the more massive beds of quartzite, however, were relatively unaffected. Had the powerhouse wall not afforded such a large expanse of rock at a substantial angle to the axes of these folds the nature of the deformation might have escaped detection.

Joints and faults. The rocks are well jointed. The massive layers of granite gneiss on south-facing slopes present nearly vertical faces unquestionably due to glacial plucking and separation along steep joints. The quartzites are more thinly bedded and possess much more closely spaced jointing, joints in some instances being seen every few inches breaking the outcrops up into a mass like cobblestones in a street. The quartzite



North South

Figure 22. Decollement-like structure on the east wall of Powerhouse, Northfield Mountain Project. Stippled area quartzite; where lined, thin beds of gneiss included; where unlined, massive quartzite. White areas represent gray biotite-feldspar-quartz-gneiss. Distances on wall are in feet and give scale. Distances are measured from the Access Tunnel through Surge Gallery II and the Adit to Powerhouse Drift.

member of the Poplar Mountain Gneiss passes through the low point in the saddle between Poplar and Northfield Mountains. The existence of this saddle in the ridge between these two mountains is almost certainly due to the more closely spaced jointing and thinner bedding in the quartzites enabling the glacial ice to remove a greater amount of material.

Brittle fracture was not a point of interest in this study. Subsequent work along the line of the proposed tunnel from Northfield Mountain to Quabbin Reservoir has shown that most joints fall into one of two sets. One of these sets trends northeast and dips steeply to the northwest; the other trends northwest and dips steeply to the southwest. Joints having other orientations are of minor occurrence. The jointing appears to be widespread because the generalizations made above apply the entire length of the tunnel line extending 10 miles to the southeast. The northeast set is the better developed of the two and is parallel to a number of small faults and at least one diabase dike known to occur to the southeast. For these reasons the described joints may be related to the forces which produced the Triassic border fault.

Numerous faults of small displacement (a few inches to 1 or 2 feet) were observed, mostly in large exposures of fresh rock in the Northfield Mountain Project. These faults are of two types, high angle normal faults and bedding plane gravity faults. As was the case with the joints, the faults were outside the main area of interest of the research and no analysis of them has been made. The faults, like the joints, are believed to be related to the forces causing the major Triassic border fault on the west side of the dome.

Early Recumbent Folds

General statement. The early folding proposed here may be a nappe structure with an amplitude of at least five miles and with northwest-over-southeast movement direction. It is impossible to demonstrate this fold in the field with present knowledge and its existence is based on five lines of evidence presented below, which, taken collectively, present an argument in its favor.

Mirror image stratigraphy. Starting from the middle of the hornblende member of the Dry Hill Gneiss and going out either way, higher or lower in the stratigraphic section, the following sequence of beds is present: Dry Hill Gneiss, hornblende member; Dry Hill Gneiss, biotite member; Poplar Mountain Gneiss, quartzite member; Poplar Mountain Gneiss, gneiss member. The base of the lower Poplar Mountain Gneiss is not exposed and therefore, there is no Fourmile Gneiss below the inner Poplar Mountain Gneiss to mirror the Fourmile Gneiss above the outer Poplar Mountain Gneiss. The upper biotite member of the Dry Hill Gneiss is absent southwest of Northfield Farms but is present north of Fourmile Brook, around the north end of the dome, and on the east side of the dome.

Possible presence of recumbent fold hinges. Ideally a complete wrap around by the Poplar Mountain Gneiss about a nose of Dry Hill Gneiss would clearly demonstrate a connection between the outer and inner Poplar Mountain Gneiss and that they are the same stratigraphic unit. An unquestioned hinge of the early fold has not been located north of Millers River. Mapping south of the river has now been extended to the vicinity of the village of Wendell but no clear hinge has yet been located. Hopefully, detailed mapping even further to the south in the future may reveal such a hinge. However, even if such a hinge does exist, it may not rise above the present erosion level the entire length of the Pelham dome.

The contact of the hornblende and biotite members of the Dry Hill Gneiss may describe hinges in the vicinity of Hermit Mountain (Plate 1). Such structures, if present, are elusive partly because of the difficulties in mapping this contact, particularly in the area between Packard Brook and Hermit Mountain. West of Briggs Brook the contact between the two members is sharp, can easily be followed in the field, and above the contact hornblende-poor Dry Hill Gneiss (equivalent to biotite member) is sufficiently rare to be of little consequence. East of Briggs Brook, however, the contact is harder to follow because the hornblende and biotite members are interbedded in thin units and in passing through areas of sparse outcrop it is impossible to connect the various interbedded horizons together with confidence. There is a gradual transition from predominance of hornblende member on the west to the predominance of biotite member on the east. Northfield Mountain and the Reservoir Area of the Northfield Mountain Project in the west are predominantly hornblende member; the Packard Brook area (central) is an interbedded zone; Hermit Mountain to the east is largely biotite member with only rare thin beds of hornlende member.

The explanation of the gradual west to east change, with an intermediate interbedded zone, is not known with certainty. The area around Hermit Mountain could be a series of digitations on a nappe structure involving the two members of the Dry Hill Gneiss. These digitations are compatible with a northwest-to-southeast movement direction and also with structures in the mantling rock to be subsequently described. Due to the similarity of the two rock types and the discontinuity of outcrop it is impossible to map the separate digitations any appreciable distance and connect them together confidently. On Plate 1 the interfingering has been somewhat generalized. Fig. 23 (see also Plate 3) is an attempt to portray the style of folding that may be involved and what the hinge region might look like.

An alternative to the hinge interpretation is that of a facies change from west to east with hornblende less abundant to the east and

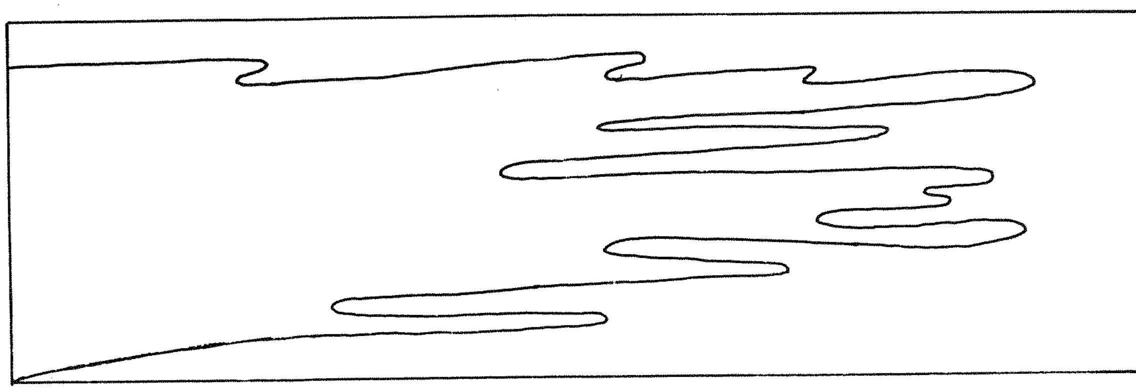


Figure 23. Diagram showing hypothetical style of early folds. Digitations in the hinge extend for thousands of feet.

restricted to fewer beds accounting for the observed inter-digitation. Detailed mapping south of Millers River, currently in progress, has not resolved the matter but is more suggestive of a facies change relationship. It may be risky to define structure within the Dry Hill Gneiss on the basis of the hornblende and biotite members of the Dry Hill Gneiss alone. Thus the interbedding may be an expression of a facies change, a fold pattern, or both.

Should a series of small hinges exist around Hermit Mountain it would be evidence that the Dry Hill Gneiss forms the core of a nappe rooted to the west or northwest, and that the Dry Hill Gneiss is the oldest rock unit followed in order of age successively by the quartzite member of the Poplar Mountain Gneiss, the gneiss member of the Poplar Mountain Gneiss, the Fourmile Gneiss, and the Partridge Formation. Those units structurally underlying the Dry Hill Gneiss would be an inverted section lying on the lower limb of a nappe structure. The predominance of hornblende member of the Dry Hill Gneiss at the center of the core suggests that it might be the older of the two members but an extensive interfingering with the biotite member suggests that the two are more likely of the same age.

Recumbent folds north and northeast of the Northfield Mountain Area. Robinson (1963, 1967b) has demonstrated recumbent folds in the mantle sequence and also between the mantle sequence and the gneiss of the Pelham dome. Fig. 24 is a map of the general geology as it is presently known in the northern half of the Pelham dome and the immediately adjacent area. East of Erving there is a hinge of a recumbent fold defined by the granulite and amphibolite of the Erving Formation. Further northwest on the same axial surface is a hinge formed by the Littleton, Clough, and Partridge Formations. Still further northwest at Crag Mountain there is another hinge formed by Fourmile Gneiss enclosed by Partridge Formation. Collectively these hinges define a structure that has been named the Jack's Brook recumbent anticline by Robinson (1967b). The Jack's Brook recumbent anticline has the same style and orientation as the major fold now being postulated involving the Dry Hill and Poplar Mountain Gneisses. This fold is separated from the Jack's Brook anticline by a narrow band of Partridge Formation in a structure named the Beers Mountain recumbent syncline by Robinson (1967b).

Recumbent folds southeast of the Northfield Mountain area. Several miles to the south is another infold of Paleozoic rock originally shown on Emerson's 1917 map. Robinson (1967b) has reexamined this structure and has now shown it to extend from Quabbin Reservoir to the southern part of Wendell (Fig. 1). Its relationship to the postulated large nappe structure involving the Dry Hill and Poplar Mountain Gneisses is uncertain at present. The quartzite mass in the Dry Hill Gneiss on Bear Mountain currently being mapped and shown on Plate 1 may be a synclinal hinge of Poplar Mountain quartzite member as an extension of this recumbent syncline into a digitation on the major nappe. This is the hypothetical relationship shown on the regional map in Fig. 24. Lack of sufficient detailed

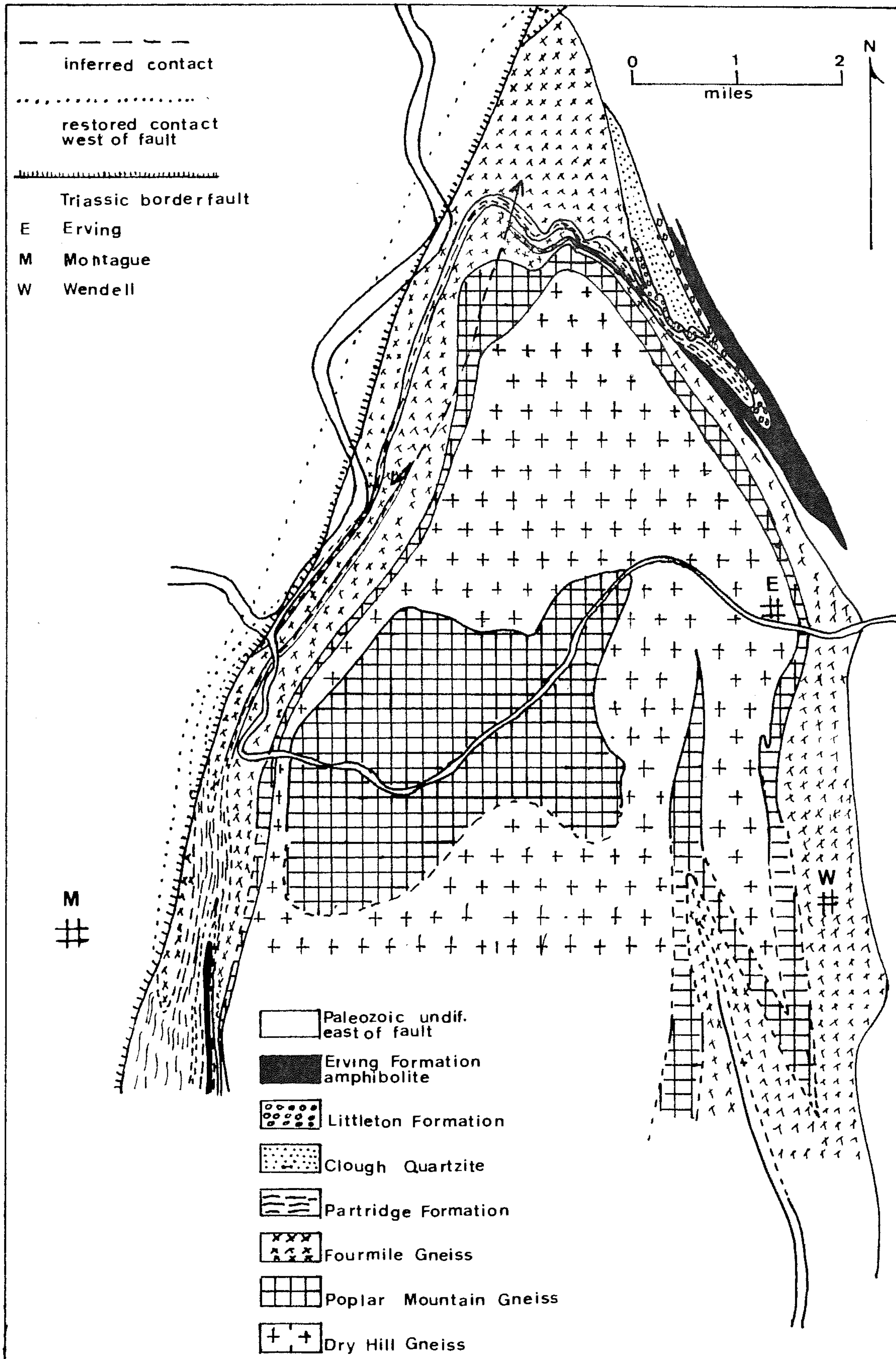


Figure 24. Regional geologic map of the northern half of the Pelham dome and immediately adjacent area.

mapping south of Wendell renders the map pattern and connection of the units uncertain at this time.

Foliation. The foliation observed today could have an axial plane orientation with respect to the early recumbent fold system. The foliation, as well as the early recumbent folds themselves, have been subsequently deformed and the structure that the foliation now defines, the Pelham dome, is a late structure.

Trend. The trend of the early recumbent fold system is not known. A tentative northeast trend is suggested by the connecting of the hinge in the Fourmile Gneiss in the vicinity of Crag Mountain with that of a suspected hinge somewhere between Millers Falls and the village of Montague, or at least in that general area. Fig. 24 shows the location of these two hinges. The area around Montague and to the south along the western side of the Pelham dome as far as Leverett has been mapped in terms of the present understanding of the stratigraphy only by reconnaisance by various students from the University of Massachusetts. The Fourmile Gneiss west of the narrow band of Partridge in the Beers Mountain recumbent syncline must pinch out somewhere around Montague because no trace of this outer Fourmile Gneiss exists further to the south in Leverett where the dome is mantled by a thick mass of Partridge Formation.

Northeast trending folds have also been reported on the south end of the Keene dome only about 10 miles to the northeast (Robinson, 1963, 1967b). The relationship between these folds and the Pelham dome folds has not been confirmed but is suggestive of a regional set of early northeast trending recumbent folds with northwest-over-southeast movement sense.

The northwest-over-southeast movement sense is in conflict with the east-over-west movement sense of the Cornish, Skitchewaug, and Fall Mountain nappes described by Thompson, Robinson, Clifford, and Trask (1968) affecting the mantling Paleozoic rock in the immediate area. However the west-over-east movement sense is the same as that found by Lundgren (1963, 1964, 1966) and by Dixon and Lundgren (1968) for similar rocks to the south in Connecticut. The full significance of these regional relationships is not presently understood.

Late Folding and Formation of the Dome

The second discernable stage of deformation in the area is the formation of the Pelham dome. During doming the axial planes of the early folds as well as the foliation were deformed into the broad anticlinal arch structure described earlier as the Pelham dome.

The Pelham dome, like the other domes along the Bronson Hill anticlinorium, is generally considered to have been emplaced due to the density differences between the gneiss and the mantle rock. Many of the gneisses in the core of the dome have compositions typical of granite and therefore probable specific gravities of about 2.7. The mantle rocks contain greater proportions of amphibolites and schists with somewhat higher densities. During metamorphism the rocks were sufficiently hot and plastic so that the less dense gneisses could rise up into the more dense overlying mantle rock, forming a series of bubble-like domes separated by infolds or synclines of sinking mantle rock. Upwelling of an underlying gneiss would deform a previously existing foliation and recumbent fold set into a broad arch as described. This model of emplacement follows that of Eskola (1949) at least in part.

Minor folds of the second type, those that are asymmetrical, overturned to the south, and have diverse orientation, are considered to be related to the emplacement of the dome but such a relationship cannot be conclusively proved. These folds deform a previously existing foliation and a pre-existing mineral lineation and therefore are late features. These folds probably represent the latest stage of plastic deformation. The "second type" folds occur throughout the entire area under study, south of the Millers River in the Bear Mountain area, on the west limb of the dome south of the river, and also very rarely in the area immediately to the north and east (Robinson, pers. comm. 1970). Insufficient detailed work to the south, plus Triassic cover to the west, renders their full geographic extent unknown at the present time. Work currently in progress has shown that these folds occur as far south as Pelham.

Fig. 25 is a plot of all minor folds of this nature measured in surface outcrops. Most of the northwest plunging folds were measured in gneiss on the crest or the west limb of the dome and have a counterclockwise movement sense; most of the northeast plunging folds were measured in quartzite near the crest of the dome and have a clockwise movement sense. Folds are less abundant on the east limb. A separation angle is described between the folds of the opposite movement sense as was described specifically for the Powerhouse folds (Fig. 19), in the section under minor folds. Unlike those in the Powerhouse, however, it is not safe to assign a slip line direction because the folds are too scattered in their geographic distribution. One could theorize that the folds on the west limb of the dome should plunge northwest and those on the east limb should plunge northeast. Field observation bears this out to a limited extent especially in the Bear Mountain area south of Millers River and on the east limb of the dome where the vast majority of the folds plunge northeast. Folds of opposite plunge and shear sense, however, are found on both sides of the dome. In general the rock as noted above appears to be more of the controlling factor. Locations and structural data concerning the minor folds are given on Plate 2.

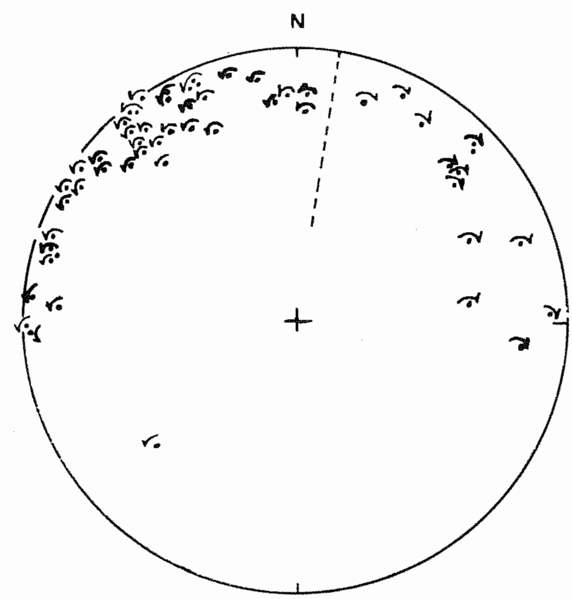


Figure 25. Equal area plot of 57 fold axes of late fold type from the entire northern section of the Pelham dome. All folds west of dashed line have a counterclockwise movement sense; those to the east have a clockwise movement sense. Orientation of dashed line is N9°E but it is not necessarily the slip line as discussed in text.

These late folds are difficult to understand. Early in the study when first encountered on the west side of the dome they were though possibly to be reverse drag folds for they had that general appearance. Subsequent work showed that there are no reverse drag folds as such discernable in the northern portion of the Pelham dome. These late folds are now presumed to be folds formed in response to a north over south shear during the formation of the dome. Lithology of the various units has definitely been a factor in their geometric configurations. At the two points where the slip line could be determined it was N6E and N5E with a north over south movement sense (Figs. 18 and 19). Whether this is a local phenomenon due to the squeezing of the rocks between rising and mushrooming gneiss domes or of more regional significance is not known. The adjacent Warwick dome is overturned both to the south and the west (Robinson, 1963, 1967b). This overturning, probably due to the mushrooming out of the rising dome, could also be responsible for the squeezing of the Pelham dome as it rose, thereby forming the late folds and the observed decollement-like structure.

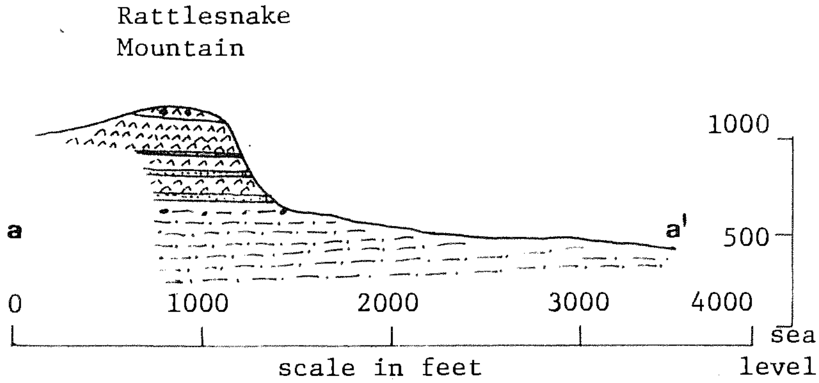
The relationship between the late folds and the mineral lineation is also far from understood. As shown in Fig. 19 the separation angle between the folds of opposite movement sense is coincident with the mineral lineation as seen on nearby surfaces undeformed by the late folds. It can be argued that the lineation is an a lineation with respect to these folds. In that event, the pervasive north-south mineral lineation seen throughout the dome could be considered a late feature related to these folds and the doming. One possible explanation of this seeming paradox is that north-over-south movement did cause the lineation and then after the mineral lineation was established additional movement of the same sense and orientation formed the folds and deformed the mineral lineation by great circle rotation. Further complicating an already complex picture is the fact that the same north-south mineral lineation in the mantling strata north and east of the dome is clearly a b lineation parallel to the axes of minor folds and statistically parallel to the fold axis that marks the north end of the Pelham dome itself (see Fig. 13). The fact that the dome axis, the mineral lineation, and the slip line of the late folds all have the same north-south trend seems too fortuitous to be a matter of chance. These relationships are obviously worthy of special structural study.

In summary, the late folds have been shown to be folds with a slip line oriented north-south, to have curving hinge lines, to be overturned in a southerly direction, and to deform both foliation and mineral lineation. Their genesis is not understood and the problem of the parallelism of the slip line of these folds, the axis of the Pelham dome, and the pervasive mineral lineation within the dome remains unresolved.

Possible Fold Patterns on the Southeast Face of Rattlesnake Mountain

The quartzite member of the Poplar Mountain Gneiss has already been described as an interlayered series of quartzites and granite gneisses. The exposure on Rattlesnake Mountain northwest of the village of Farley may offer some insight into structural relationships caused by folding, and the reasons for the interlayering of the rock units. Rattlesnake Mountain is a hill with an exceptionally steep southeastern face. This face displays almost continuous outcrop over a vertical distance of 400 feet passing from typical Poplar Mountain Gneiss at the base through the Poplar Mountain quartzite member and into the Dry Hill Gneiss (Fig. 26). On the face of Rattlesnake the individual quartzite layers are better exposed than elsewhere and can be followed for a distance approaching 1 mile (Fig. 27). In addition to the expected quartzite occurring at the top of the Poplar Mountain Gneiss, there are two thin upper quartzite beds only a few feet thick contained in more massive layers of granite gneiss (Figs. 28, 29).

The uppermost of the quartzites pinches out a few hundred feet northeast of Briggs Brook. The middle quartzite unit pinches out about a thousand feet west of Briggs Brook. The lowest of the quartzite beds crosses Briggs Brook but is lost in a region of no outcrop to the northeast. To the west these three horizons can be traced around the southwest rib of Rattlesnake Mountain beyond which outcrop is too poor to allow the tracing of the individual quartzite layers. Nowhere can these three quartzites be shown to be connected. There are three alternative



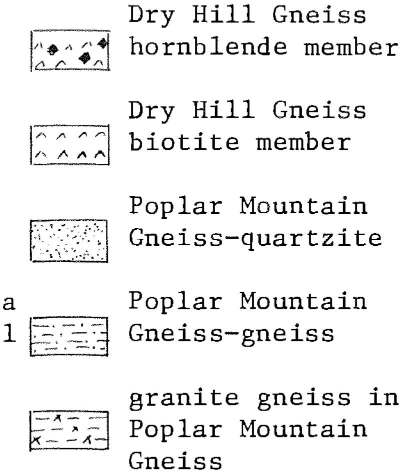


Figure 26. Profile of Rattlesnake Mountain near Farley. Thickness of upper two quartzites is exaggerated.

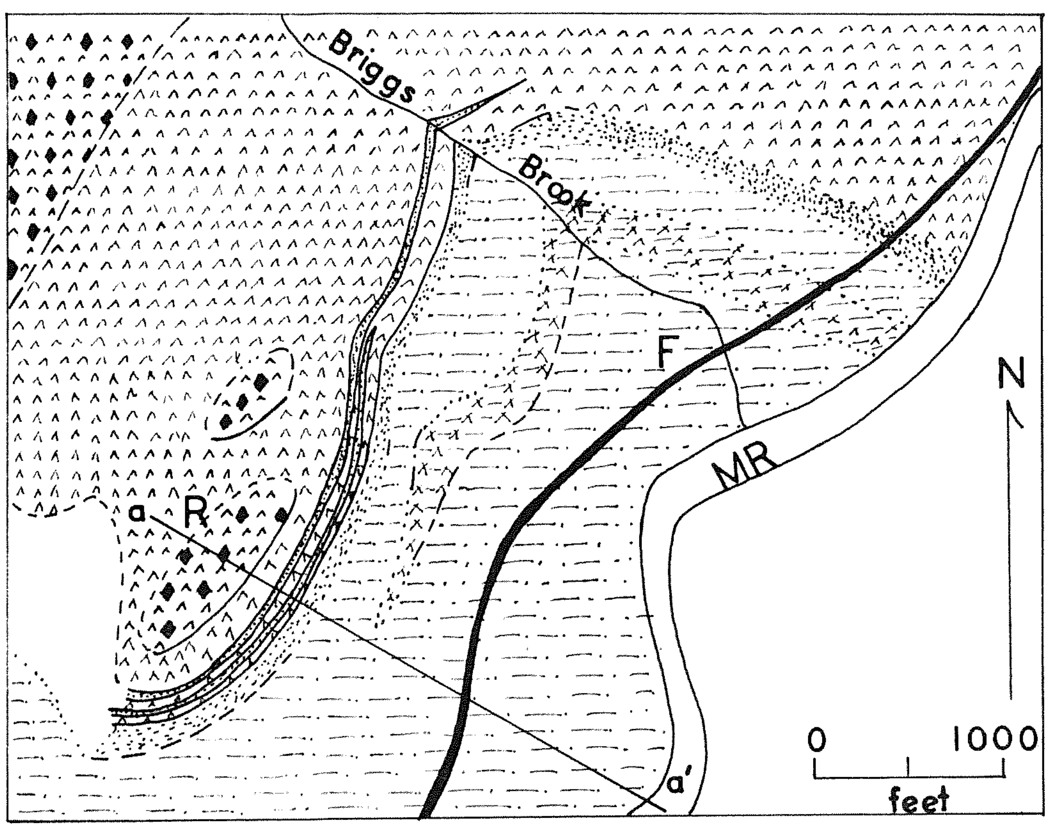


Figure 27. Detailed geologic map of Farley and Rattlesnake Mountain area. Rock units as keyed in Fig. 26. This map shows some details of divisions within the Poplar Mountain Gneiss-quartzite member. For topography see Plate 1.

F village of Farley; MR Millers River; R Rattlesnake Mountain

a-a' approximate line of cross section shown in Fig. 26.

Figure 28. View of a portion of the southeast face of Rattlesnake Mountain near Farley. Middle quartzite layer can be seen running through center of photograph-contacts inked. Cliffs of massive rock are granite gneiss.

Figure 29. Telephoto view of a portion of the photograph in Fig. 28 above, showing quartzite in detail.

hypotheses concerning their relationship.

The first and simplest hypothesis is that this is a zone of interbedded Poplar Mountain Gneiss, quartzite, Dry Hill Gneiss, and minor amounts of other rocks including calc-silicate rocks. Such an interlayering could be due to fluctuating conditions during deposition.

As a second hypothesis there is the possibility that the quartzites are folds of second order size related in time to the major west over east recumbent fold previously described. In that event they would be arranged as shown in a of Fig. 30. In such a hypothetical case two quartzite zones could be interfolded with granite gneiss, but the quartzites would close to the west instead of to the east as observed in the field. The problem could be resolved by picturing the recumbent fold closing to the west instead of to the east or assuming the recumbent fold to be a syncline rather than an anticline (b in Fig. 30). In either of the two cases illustrated in Fig. 31 the interbedded quartzites and granite gneisses as observed in the field would fit second order folds on the inverted limb of a major recumbent fold. But other evidence already cited favors a major recumbent fold closing to the east and not to the west, hence neither situation in Fig. 31 seems to be consistent with regional relations. For these reasons the case for the quartzite layers being second order recumbent folds subsidiary to a larger recumbent fold is weak or these folds argue against the major recumbent fold interpretation.

A third hypothesis is that these repetitions of quartzite are extremely tight recumbent folds related to the common north over south late folds and the decollement-like structure seen on the east wall of the Powerhouse of the Northfield Mountain Project. Fig. 31 is a diagram showing the possible geometric relations between quartzites and the granite

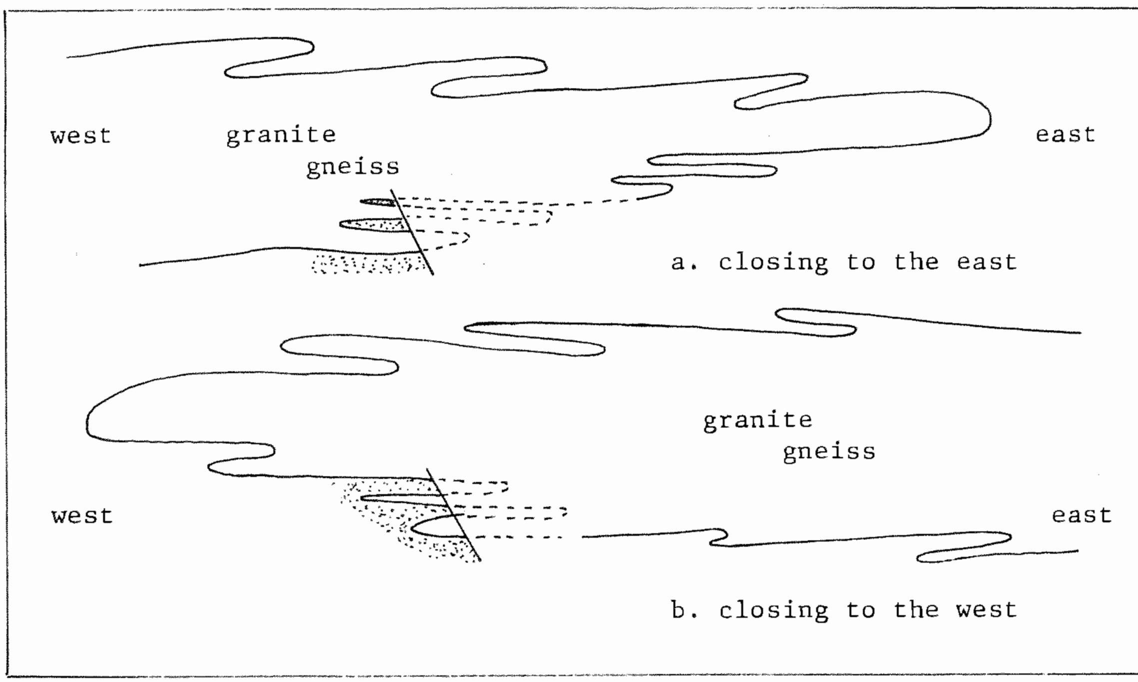


Figure 30. Generalized diagrams showing possible geometric relationships of second order early recumbent folds in the vicinity of Rattlesnake Mountain near Farley. Face of Rattlesnake Mountain indicated by line slanted to the southeast.

a. recumbent fold rooted to west and closing to the east; second order quartzites pinch out to the west.
b. recumbent folds rooted to the east and closing to the west; second order quartzites pinch out to the east.

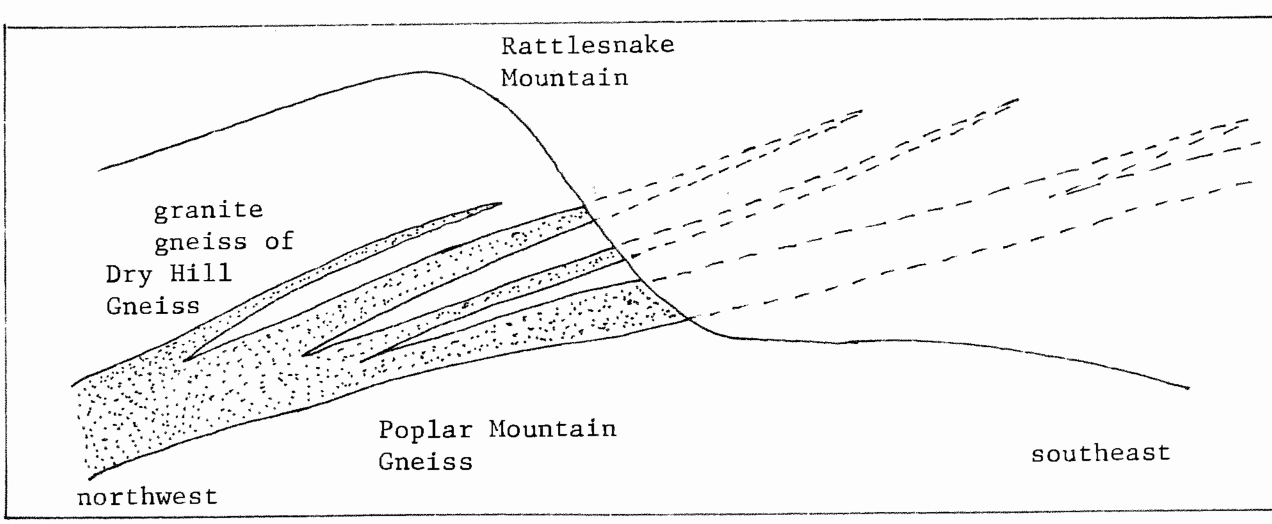


Figure 31. Generalized cross section of a possible structural relationship on the face of Rattlesnake Mountain, Farley. Quartzite stippled. See text for discussion.

gneiss in a similar but larger decollement-type structure as it might appear in Rattlesnake Mountain. Unlike the previous hypotheses, no known objection to this type of structure can be made. Although entirely hypothetical, it fits the outcrop pattern and to some extent matches the style and orientation of the decollement-like structure seen in the Powerhouse.

In the event that the quartzite layers on Rattlesnake are related to a decollement-type structure, the pinch outs of the middle and upper quartzites could be simply explained as the points where the curving fold hinges of the late folds intersect the surface. Fig. 32 illustrates this point. Should this hypothesis be a model of the true structure, the bottom quartzite would not pinch out to the east but continue because it is the main basal unit. As noted previously, the main basal unit is lost to the east in an area of no outcrop, but subsequent to the original mapping, thick massive quartzites were located 300 feet below the surface in a diamond drill bore hole on the proposed Northfield-Quabbin tunnel line where it crosses the Millers River valley one half mile northeast of Farley. This quartzite is almost certainly the subsurface connection between the quartzites exposed at the top of the Poplar Mountain Gneiss on Rattlesnake Mountain in Farley and those exposed at the base of the west slope of Bear Mountain south of Millers River.

A small body of quartzite surrounded entirely by granite gneiss has been located in subsequent work south of Millers River. It is located on the northwest slope of Bear Mountain just above Farley Road (see Plate 1). This quartzite may be the southern extension of one of these suggested long quartzite layers in a decollement-type structure, or a similar extension rooted somewhere south of Rattlesnake in the Millers River Valley so that erosion has removed its connection to the basal quartzite.

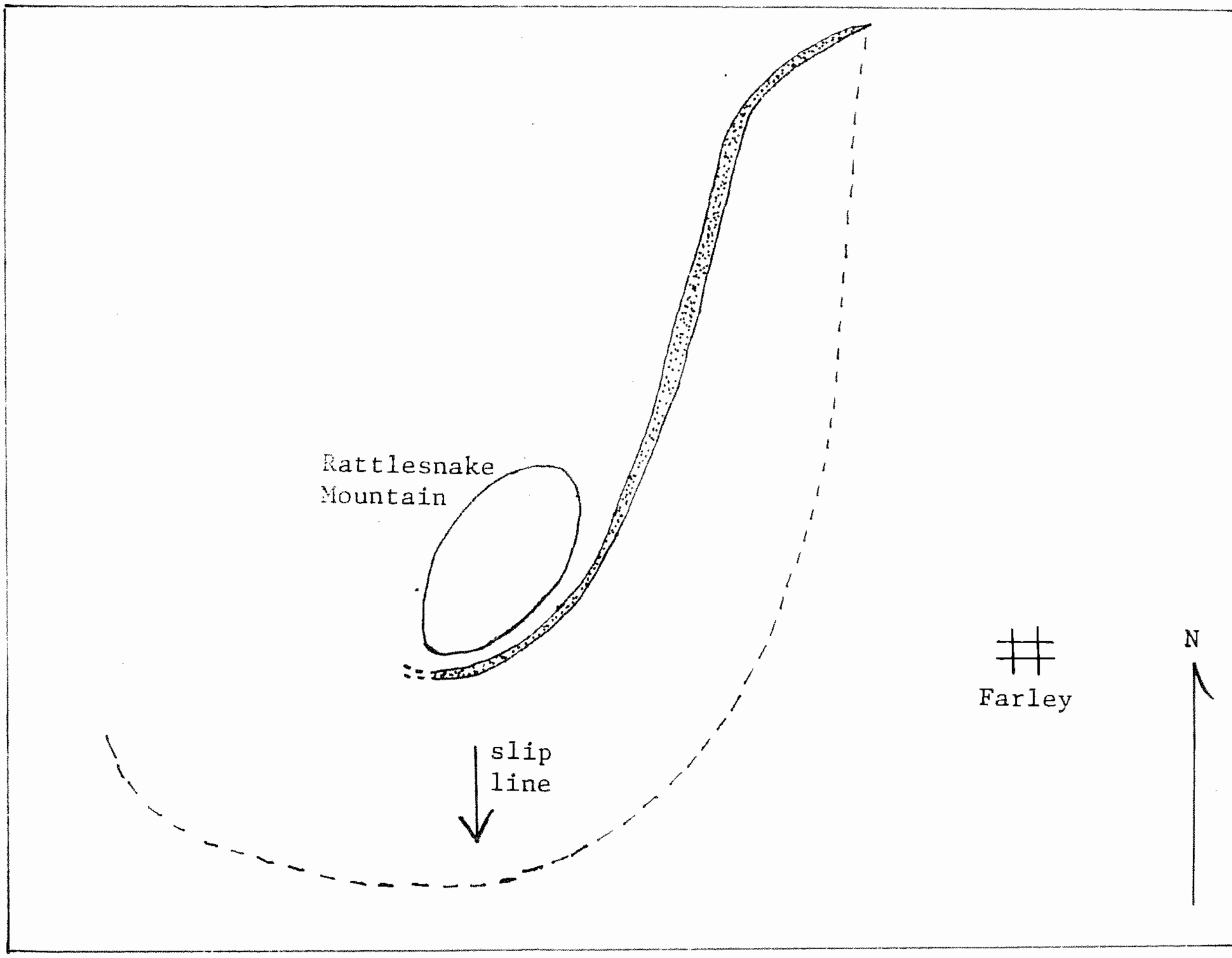


Figure 32. Hypothetical diagram showing pinch out of quartzite on Rattlesnake Mountain. Dashed line represents generalized hinge line defining outer limit of fold now eroded away. Slip line based on known regional considerations.

The decollement-type structure as described above may be a possible explanation for the repetition of the quartzites seen on Rattlesnake Mountain and also for similar repetitions seen in the Access Tunnel of the Northfield Mountain Project. Such a structure, however, may be complicated by having formed in a series of beds already interfingering by primary interbedding as described in hypothesis 1. The zone of granite gneiss contained in the Poplar Mountain Gneiss and crossing Briggs Brook just north of Farley pinches out about 2000 feet to the west. This granite gneiss zone is distinctly below the quartzite member of the Poplar Mountain Gneiss and its presence there is probably explained by primary interbedding.

Triassic Border Fault

For a brief period in October 1969 the level of the Connecticut River was greatly lowered in connection with the reconstruction of the dam at Turners Falls. This offered an opportunity for examination of outcrops normally covered by water or not readily accessible because of water levels both along the banks of the river and in its bed near French King Bridge. Several structural and stratigraphic features associated with the Triassic border fault were observed. Although these features lie outside the main area of interest of this study, they are significant and since the opportunity to observe them again may not occur for many years brief mention of them is warranted.

Structural features include a total of five fault surfaces, three sets of slickensides on some of those surfaces, one mylonite foliation, and one quartz lineation in the mylonite. These features are plotted on the equal area net in Fig. 33. The faults strike from N5E to N80E and the trend of the Triassic border fault from the map is N24E, within this range. The five faults dip to the northwest: one at 22°, three at 39°, and one at 59°. The slickensides trend from N37W to N85W and plunge from 22° to 39° northwest. Collectively this data is compatible with a major fault trending northeast in agreement with the map and dipping about 40° to the northwest. The 40° dip suggested by the data is lower than would be expected for a normal fault or had been suspected for the Triassic border fault which is usually thought of as a typical normal fault.

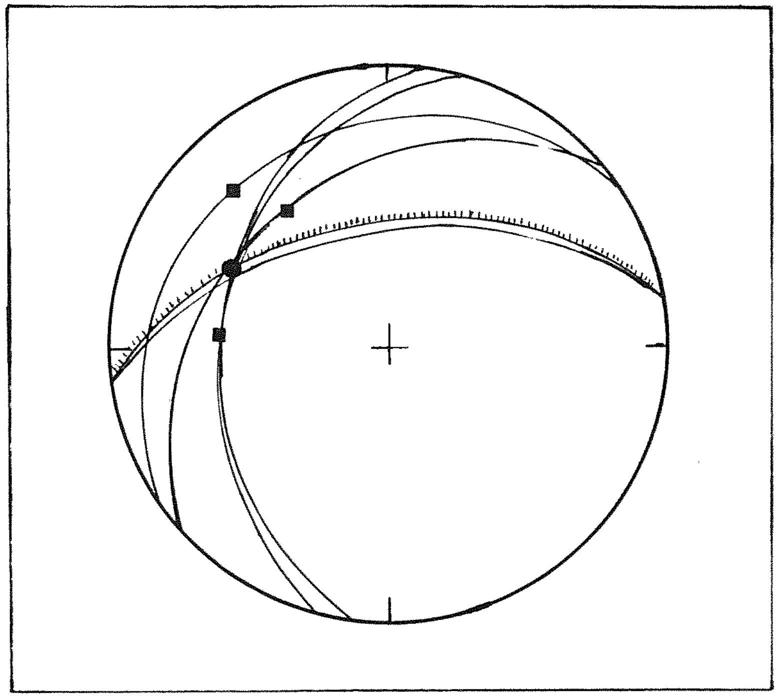


Figure 33. Equal area diagram of structural features associated with the Triassic border fault near French King Bridge. Great circles are fault surfaces; squares are slickensides measured on the faults. Hachured great circle is mylonite foliation and circle on that plane is quartz lineation in the mylonite.

Along the immediate course of the river, several thin lithologic units of uncertain relationships or foreign to the area were found located between Partridge Formation and dome gneisses to the east, and the Triassic rocks to the west. These include a small area of Waits River Formation not known elsewhere in the immediate vicinity, hornblende diorite of unknown relationship to the regional geology, and a hematitic phyllite exposed on the south band of the Connecticut River immediately in contact with the Triassic and not separately marked on the map. This phyllite is also of unknown relationship. These thin rock units are probably thin slices of stratigraphically higher rocks caught in the Triassic border fault. Their presence is suggestive that there is no such thing as a single simple fault plane but instead that the Triassic border fault is a zone consisting of a series of faults. In this area such a fault zone is probably from 100 to 600 feet wide.

Structure Cross Section

The east-west structure section (Plate 3) was drawn in a position about halfway between the northern and southern extremities of the mapped area, and where it would pass through the underground Powerhouse of the Northfield Mountain Project and also close to various diamond drill holes, tunnels, etc. from which subsurface data are available. The known elevations of the subsurface contacts in the vicinity of the Powerhouse cast doubt upon the validity of a cross section drawn by simple axial projection.

Examination of average dips and mineral lineations from near the crest of the dome suggests a plunge of 10-12° to the north. The reader is referred to Plate 2, Fig. 12, and also the equal area diagrams in the Appendix for substantiating data. Projection of exposed surface contacts from north and south of the section along the dome axis at an average plunge of 11° to the north yields contact elevations on the crest of the dome as given below in Table 10. These are directly compared with elevations deduced in the construction of the cross section by a method to be described. The elevations determined by the latter method are considered more probable.

In the Powerhouse the base of the biotite member of the Dry Hill gneiss is at an elevation of about 200 feet above sea level. The Powerhouse is nearly one mile west of the crest of the dome and therefore the elevation of this contact on the crest along the line of section would have to be at a higher elevation than 200 feet which is in disagreement with the projected value of -275 feet. The same reasoning is also true of contact e (Table 10) which has a projected elevation below sea level along the crest but is exposed in the underground workings of the Northfield

Table 10. Elevations of contacts on the crest of dome along the line of section

Contact:	Elevation by axial projection:	Elevation by construction as described in text:
a through d are from north of the line of section:		
a.) Fourmile Gneiss and Devonian Littleton	4800 feet	4000 feet
b.) Beers Mountain syncline (Partridge layer in the Fourmile Gneiss)	3840 feet	2600 feet
c.) Poplar Mountain Gneiss and Fourmile Gneiss	1950 feet	2050 feet
d.) Dry Hill Gneiss and Poplar Mountain Gneiss	1760 feet	1800 feet
e through f are from south of the line of section:		
e.) Dry Hill Gneiss-horn-Blende member and biotite member	-75 feet	700 feet
f.) Dry Hill Gneiss-biotite member and the Poplar Mountain Gneiss	-275 feet	450 feet

Mountain Project. Projected elevations of other contacts are in the air and there is no evidence to indicate how far these may be removed from their actual levels prior to their removal by erosion.

Since the validity of axial projection in this area is questionable, the cross section as presented in Plate 3 was drawn by first connecting surface contacts along the line of section on the west limb with their known subsurface elevations from diamond drill hole data made in connection with preliminary engineering studies of the Northfield Mountain Project and their observed positions in the underground excavations. The subsurface contacts on the west limb in the general vicinity of the Northfield

Mountain Project, therefore, are known to be essentially correct and when compensation is made for the strike of the rock, apparent dips are at 10° and comparable to the apparent dips observed in the Access and Tailrace Tunnels. These contacts have then been extended across the dome in a smooth curve to connect with their equivalents exposed on the surface in the east limb. Thus the general basis for the cross section was established. It was modified to conform to the outcrop pattern. The subsurface crest of the dome has been shifted slightly westward because the crest of the dome does migrate to the west south of the line of section. The strike and dip data between Poplar Mountain and Rattlesnake Mountain on the tectonic map (Plate 2) shows this westward shift of the crest. Trend and plunge of the recumbent folds involving the Partridge Formation and the Fourmile Gneiss are not known but are shown in the section assuming a northeast trend. Bore hole #21 on the Northfield-Quabbin Tunnel line at the southeast corner of the Reservoir area passed directly from Dry Hill Gneiss into Poplar Mountain Gneiss at 306 feet above sea level. Lack of quartzite here implies a pinch out to the east of the quartzites occurring at the top of the Poplar Mountain Gneiss in the Powerhouse and this pinch out is indicated in the section but its exact position is not known.

In the southern part of the map area, where there is knowledge of the subsurface position of the contacts, the plunge of the dome works out to be about 3° in contrast to the 11° calculated from surface dips and lineations. Had there been no knowledge of the subsurface a cross section drawn by axial projection using a plunge of 11° would have been accepted without question. Some explanation is in order for the failure of simple axial projection technique. There are probably many unknown variables affecting the structure but the nature of the late folds alone could render a typical axial projection along the crest of the dome meaningless.

The quartzite member of the Poplar Mountain Gneiss has been substantially deformed by the readily observed north-over-south late folds and decollement-like structure previously described. Similar folds, but apparently of more limited occurrence, exist in the gneiss member of the Poplar Mountain Gneiss and also in the Dry Hill Gneiss. Some of these folds are fairly large (Fig. 18). It is possible that these folds are also as abundant as in the quartzite member but less noticeable because of fewer marker horizons. Collectively these folds may have a great effect on the plunge. Fig. 34 is a diagramatic sketch showing that in a direction parallel to that of the slip line of the late folds there is a great buckling and piling up of rock to the south such that the mean dip (B-B') is much less than the dip (A-A') that can be measured on individual bedding surfaces. The coincidence of the direction of the slip line of the late folds and the crest of the Pelham dome renders a valid simple axial projection along the crest impossible.

Other variables also probably affect the overall geometry of these rock bodies. One of these is the variability in the overall plunge of the dome. To the south on Dry Hill, the plunge levels out and south of there reverses, at least locally, to the south (Balk, 1956b; Peter Robinson, oral communication). Also the change in the trend of the crest of the dome from north-south to northeast-southwest in the southern part of the mapped area may also have an effect on projection.

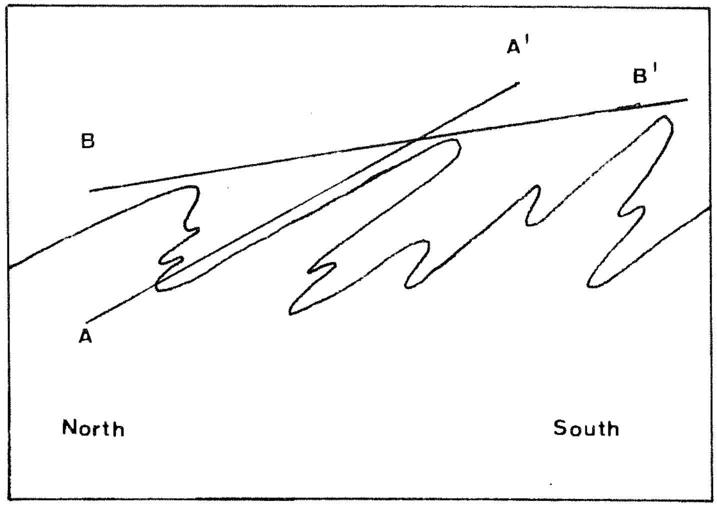


Figure 34. Effect of late folds on plunge of the northern portion of the Pelham dome. A-A' is plunge estimated from outcrop dips; B-B' is the mean dip of bedding and plunge of the crest.

CORRELATION WITH ROCKS ELSEWHERE IN NEW ENGLAND

The Silurian and Devonian portions of the mantle sequence consisting of the Clough Quartzite, Littleton Formation, Erving Formation, and Waits River Formation have been discussed elsewhere (Robinson, 1963, 1967b; Thompson, Robinson, Clifford, and Trask, 1968) and are beyond the primary concern of this study. Discussion of possible correlations, therefore, will be restricted to the pre-Silurian rocks.

The only known case for a good stratigraphic correlation of the Poplar Mountain and Dry Hill Gneisses forming the core of the Pelham dome is with rocks exposed in the Selden Neck and Lyme domes of southeastern Connecticut approximately 90 miles to the south-southeast (Fig. 3) and described by Lundgren, (1963, 1964, 1966). The Plainfield Formation, consisting of a series of lens-like zones of both muscovitic and calc-silicate quartzites and gneisses, forms a discontinuous ring around both the Selden Neck and Lyme domes. Where the Plainfield Formation is absent, the overlying

Mamacoke Formation butts directly against the cores of the domes. The Mamacoke Formation consists primarily of biotitic gneiss but also contains calc-silicate rocks and biotite schists. The Plainfield and Mamacoke Formations may correlate with the quartzite and gneiss members respectively of the Poplar Mountain Gneiss as described here. In both localities the quartzites are discontinuous and interfinger with gneiss but where present the quartzite is basal. (This assumes the interpretation presented here, that the inner Poplar Mountain is in an inverted section, and that the quartzites occurring at its top were basal when deposited.)

The innermost cores of these two Connecticut domes are composed of the Sterling Granite Gneiss, a pink biotite gneiss or a pink hornblende gneiss. Where personally seen in the Seldon Neck dome by this writer, the hornblende granite gneiss had exactly the same spotted aspect as does the Dry Hill Gneiss. In appearance the two are identical. Lundgren is of the opinion that the Sterling is intrusive forming a series of sills in the Plainfield Formation. The structural position of the Sterling in the cores of the domes, however, is consistent with the interpretation given here that the Dry Hill Gneiss, its possible correlative, is the oldest rock in the Pelham dome. Since the Sterling Gneiss of the Selden Neck and Lyme domes does not show a cross-cutting relationship it may be possible that it too is a sedimentary gneiss of volcanic derivation as is believed to be the origin of the Dry Hill Gneiss.

The Sterling Granite Gneiss, the Plainfield Formation, and the Mamacoke Formation forming the cores of the Selden Neck and Lyme domes are overlain by the Ivoryton Group (Lundgren, 1966) composed of a series of gray plagioclase gneisses. These have been divided from bottom to top into the New London Gneiss, the Monson Gneiss, and the Middletown Gneiss.

Location / Age	Western Massachusetts Hatch and Hartshorn, 1968 Norton, 1969 western facies miogeosynclinal	eastern facies eugeosynclinal	Pelham dome north-central Massachusetts this report	North-central Massachusetts Robinson, 1963, 1967b	Southeastern Connecticut Lundgren, 1966
Middle Ordovician	Berkshire Schist ~unconformity~	Hawley Formation (includes gneiss in the Shelburne Falls dome)	Partridge Formation ~unconformity~ Fourmile Gneiss (time range uncertain)	Partridge Formation Ammonoosuc Volcanics Monson Gneiss	Brimfield Schist Ivoryton Group: Middletown Gneiss; Monson Gneiss; New London Gneiss
Lower Ordovician	carbonate facies: marbles and dolomites	Moretown Formation	break in record-time boundaries uncertain	(time of the Monson Gneiss uncertain by Robinson)	major break in record, time boundaries uncertain
Upper Cambrian Middle Cambrian		Rowe Schist	~unconformity?~		
Lower Cambrian	Cheshire Quartzite Dalton Formation basal conglomerate	Hoosac Formation	Poplar Mountain Gneiss quartzite		Mamacoke Formation Plainfield Formation*
Late Precambrian ("Avalonian"?)	Hoosac Formation	includes basal granitic gneiss	Dry Hill Gneiss		Sterling Plutonic Group-* intrusive in Mamacoke and Plainfield Formations
Precambrian "Grenville"	gneisses in the core of the Berkshire anticlinorium		not exposed	not exposed	not exposed

*also Plainfield Quartzite and Stony Creek Granite of Hills and Dasch, 1972

Figure 35. Proposed correlations of the rocks in the Pelham dome with rocks elsewhere in New England.

The Middletown Gneiss of the Ivoryton Group is correlated with the Ammonoosuc Volcanics of central Massachusetts and western New Hampshire on the basis of lithology, stratigraphic position, continuous exposure, and radiometric dates (Brookins and Hurley, 1965; Lundgren, 1966). The correlation is well established and accepted. Lundgren (1966) includes the Middletown Gneiss in the dome complex of southeastern Connecticut on the basis of its discontinuous exposure and interfingering with the underlying Monson Gneiss. Lundgren (1966) also makes the Monson the unifying element of the Ivoryton Group because the New London Gneiss, like the Middletown Gneiss, is discontinuous and interbedded with the Monson. In north-central Massachusetts, on the other hand, Robinson has included the Ammonoosuc in the mantle sequence because it is found beneath the Partridge Formation and overlying different "basement gneisses" in five of the six gneiss domes and anticlines in the Orange area excepting only the Pelham dome (Robinson, 1963), because it occurs in contact with the Monson Gneiss only in two of the domes, and because he has found a sharp contact between the Monson and the Ammonoosuc including at one point a quartz pebble conglomerate at the base of the Ammonoosuc (P. Robinson, oral communication, 1971). The Monson Gneiss of Connecticut is continuous with the large mass of Monson in Massachusetts a few miles east of the Pelham dome (Fig. 1). The New London Gneiss in Connecticut has no presently established direct connection into Massachusetts.

The Fourmile Gneiss of the Pelham dome almost certainly correlates with some part of the Ivoryton Group. The Fourmile Gneiss bears striking similarity to the gneiss in the Kempfield anticline about one mile east of the Pelham dome in Wendell, and superficial resemblance to the Monson Gneiss further east. No known mappable connection exists between the

Fourmile Gneiss and these other units but Robinson (1967c) has discussed a probable connection between the Monson and the gneiss of the Kempfield anticline near Quabbin Reservoir (Fig. 1). The Ammonoosuc Volcanics occur stratigraphically above the Monson Gneiss in north-central Massachusetts and also above the gneiss of the Kempfield anticline but are nowhere known to be present on the Pelham dome. Anthophyllite, which is sometimes used as a criterion for distinguishing Ammonoosuc from the similar underlying gneisses and amphibolites, has recently been found locally at the base of the Fourmile Gneiss in Wendell very near the contact with the Poplar Mountain Gneiss. This occurrence of anthophyllite, although not conclusive, suggests a relationship between the Fourmile and the Ammonoosuc. Whether the Fourmile is a facies equivalent of the Ammonoosuc or one of the older underlying gneisses, and whether the Fourmile should be elevated to be a part of the mantle sequence or left grouped with the dome gneisses, are subtle distinctions that remain in doubt. In any event the rocks of the Pelham dome reveal a distinct break in the stratigraphic record between the outer Poplar Mountain Gneiss and the Fourmile Gneiss. A similar break is also recognized by Lundgren (1966) in southeastern Connecticut as one in which clastic sedimentation gave way to volcanism between the Mamacoke Formation and the gneisses of the Ivoryton Group.

Correlation on the basis of radiometric ages is difficult because dating of the rocks is very fragmentary. The only determined age in the Pelham dome is a Pb^{207}/Pb^{206} age of 575± 30 m.y. determined from zircons in the Dry Hill Gneiss (Naylor, Boone, Boudette, Ashenden, Robinson, 1973) previously noted in the section "Age of Rocks." There are no age dates on the rocks of the Selden Neck and Lyme domes of southeastern Connecticut on which the stratigraphic correlations have been based. The date determined on Dry Hill Gneiss is on the borderline between Cambrian and late

Precambriam and could be considered either. Assuming that the age of the Poplar Mountain Gneiss is about the same as the Dry Hill Gneiss, then the age of the Poplar Mountain Gneiss and its associated quartzites compares favorably with the Cambrian age suggested by Lundgren (1966) for the Plainfield and Mamacoke Formations. Other age dates of interest and in the same general range as that on the Dry Hill Gneiss of the Pelham dome include a U-Th-Pb zircon isotopic age of 600-650 m.y. on the Northbridge Granite Gneiss of the Milford anticline in southeastern Massachusetts (Zartman and Naylor, 1972) and a Rb/Sr whole rock date of 616 ± 78 m.y. on the Stony Creek Granite in the Stony Creek dome of Connecticut (Hills and Dasch, 1972) located 25 miles west of the Selden Neck and Lyme domes. Both of these granite gneisses are said to be intrusive and to cross-cut a quartzite, the Plainfield Formation in the Stony Creek dome and the Westboro Quartzite in the Milford anticline. The Westboro Quartzite has been correlated with the Plainfield Formation (Lundgren, 1966). The implication is that the quartzites are older than the granite gneisses. To be noted, however, is that the granite gneisses of the Stony Creek dome, like those of the Selden Neck, Lyme, and Pelham domes are generally concordant with the overlying quartzites. The cross-cutting aspect of the gneiss is inferred from the discontinuity of the quartzites and the interpretation that they may be large xenoliths. Such a relationship, however, may be more apparent than real. The possibility of the sedimentary derivation of the Sterling Granite Gneiss in the Selden Neck and Lyme domes has already been discussed. Hills and Dasch have also allowed that such a possibility may be the case in the Stony Creek dome, in that the Stony Creek Granite inferred to be younger and apparently cross cutting the Plainfield as noted above, could actually be older and derived from rhyolites. The apparent cross-cutting relationship, in their opinion, might be due to subsequent mobilization during one or more stages of dome formation. No structural information about the Milford anticline is available to this writer. Evidence presented is strongly suggestive that many of these older granite gneisses date at about 600 m.y. and may be volcanics or intrusives associated with the Avalonian episode as best described in Newfoundland (Rodgers, 1972). In the Pelham dome, the gneiss is believed to be derived from rhyolite volcanics originally overlain by the quartzite of the Poplar Mountain Gneiss. Available information on the Connecticut domes suggests they also contain a similar granite gneiss overlain by quartzite. Thus a consistent stratigraphy between the Pelham dome and the domes of southeastern Connecticut seems to exist.

Also of interest, although somewhat more removed, is the Yonkers Gneiss in southeastern New York. The Yonkers is very similar to the Dry Hill Gneiss both in appearance and mineralogy. A Rb/Sr whole rock age determination by Long (1969) yielded a result of 570 ± 30 m.y. and is suggestive that the Yonkers Gneiss may be genetically related to similar granitic gneisses exposed in the cores of some of the domes along the Bronson Hill anticlinorium.

Two published age dates are suggestive that the Fourmile Gneiss may be Ordovician. Brookins and Hurley (1965) have reported a Rb/Sr whole rock date of 472 ± 15 m.y. from the Monson Gneiss in central Connecticut. The possible relationship between the Monson and Fourmile Gneiss has been discussed above. Naylor (1969) reports a similar date of 450 ± 25 m.y. derived from Pb^{207}/Pb^{206} ratios in zircon separates from a stratified gneiss in the Mascoma dome of west-central New Hampshire. This gneiss occurs directly below the Ammonoosuc Volcanics and is a gray layered gneiss ranging in composition from the igneous equivalent of a quartz diorite to a grandodiorite. Because of its stratigraphic position and

and lithic composition it could and probably does correlate with the gray plagioclase gneisses including the Monson Gneiss of Massachusetts and Connecticut, and possibly the Fourmile Gneiss of the Pelham dome.

Correlation with rocks in the Berkshire anticlinorium to the west is more difficult because of lack of similar rocks. This could be due in part to lower grade metamorphism and facies changes toward the Cambro-Lower Ordovician miogeosynclinal carbonate deposits of the Middlebury synclinorium (Doll, Cady, Thompson, and Billings, 1961). An exception to this is in the Middle Ordovician, when eugeosynclinal sedimentation persisted further westward, providing in fact the only reliable correlation. The Partridge Formation of the Bronson Hill anticlinorium correlates with the upper part of the Hawley Formation on the east limb of the Berkshire anticlinorium (Hatch and Hartshorn, 1968), consisting of typical rusty weathering schists with interbedded amphibolites. The lower part of the Hawley Formation consists primarily of amphibolite with interbedded felsic gneiss and corresponds to the Ammonoosuc Volcanics. On the west limb of the Berkshire anticlinorium the Berkshire Schist (Norton, 1969) corresponds to the Hawley and Partridge Formations to the east.

There are at present no established correlations between Fourmile Gneiss, Poplar Mountain Gneiss, and Dry Hill Gneiss of the Pelham dome with any rocks west of the Connecticut River. Hatch (in Hatch and Hartshorn, 1968) has considered the gneiss of the Shelburne Falls dome (originally called Monson by Emerson, 1917) as a part of the Hawley Formation and as such implies a Middle Ordovician age. There remains a possibility that this gneiss, therefore, may correlate with the Fourmile Gneiss for which an Ordovician age has been suggested above.

The Dry Hill Gneiss and the Poplar Mountain Gneiss have no recognizable counterparts to the west. The Hoosac Formation of western Massachusetts has been considered to be lower Cambrian or older (Norton, 1969). If such an age assignment for the Hoosac is correct, then it is of approximately comparable age to the Dry Hill Gneiss and the Poplar Mountain Gneiss as described above. The Hoosac on the east side of the Berkshire anticlinorium grades downward into a granitic gneiss considered by Norton (1969) to be a part of the Hoosac and implying that there are felsic facies in the formation. On the west side of the Berkshire anticlinorium the Hoosac grades upward into the Dalton Formation and the Cheshire Quartzite both of which are also considered Lower Cambrian (Norton, 1969). Some of the brown quartzites in the Poplar Mountain Gneiss have remarkable similarity in appearance to the Cheshire Quartzite. Thus it is interesting to speculate on a possible correlation of Dry Hill Gneiss and Poplar Mountain Gneiss and their associated quartzites in the Pelham dome with the Lower Cambrian Hoosac Formation, Dalton Formation, and Cheshire Quartzite of the Berkshire anticlinorium. Such a correlation would require east to west facies changes, possibly related to distance from volcanic sources. The Cambrian Rowe Schist and Lower Ordovician Moretown Formation on the east limb of the Berkshire anticlinorium cannot be equated with any rocks in the Pelham dome.

TIME OF THE DEFORMATIONS

All described folding of the rocks is thought to be attributed to the Acadian Orogeny of the Devonian Period but some of the deformation may have occurred later. The postulated early recumbent fold structures as described include all crystalline rocks in the immediate area from the oldest, the Dry Hill Gneiss, to the youngest, the Erving Formation of

Early Devonian age (Thompson, Robinson, Clifford, and Trask, 1968). Structures related to earlier deformations have not been detected. The time of the second deformation, the doming, is somewhat more obscure. Based on regional considerations (Thompson, Robinson, Clifford, and Trask, 1968), the doming was also probably an Acadian event.

GEOLOGIC HISTORY

This is a short summary of the depositional and tectonic events deciphered from the rocks of the Pelham dome. The earliest recorded event in the area was the deposition of layers of volcanic debris now the Dry Hill Gneiss interbedded with quartzites and other rocks of probable sedimentary derivation. This material, deposited nearly 600 million years ago at the end of the Precambrian or the earliest Cambrian, may have been a product associated with the Avalonian event. Sedimentary material, probably largely derived from these same volcanics, provided the material for what is now the Poplar Mountain Gneiss. Interbedding of the Dry Hill and Poplar Mountain Gneiss suggests that they are of approximately the same age, but according to the interpretations presented in this paper, the great bulk of the Poplar Mountain is younger, if only by a little, and was deposited on the Dry Hill.

The next recorded geological event was the deposition of the volcanic material that now forms the Fourmile Gneiss. The hypothesis that these volcanics are Ordovician has been presented. They may have been part of an offshore volcanic island arc formed during some phase of the Taconic Orogeny. Deposition of the volcanics that formed the Fourmile Gneiss was followed by the accumulation of a black marine shale under anaerobic conditions. This shale is now the Middle Ordovician Partridge Formation. The Taconic Orogeny, occurring late in the Ordovician and possibly extending into the early Silurian, is generally regarded as a period of metamorphism and deformation in this area, but no Taconic structures as such have been identified in the rocks of the Pelham dome.

A brief period of erosion followed in the aftermath of the Taconic Orogeny until deposition of the Clough Quartzite in the Lower Silurian. This was followed by clastics and volcanics in the Lower Devonian which now form the Littleton and Erving Formations respectively. Intense metamorphism to staurolite-kyanite grade and deformation during the Acadian Orogeny in the Lower Devonian formed the major fold structures of the area that exist today. At least two major fold sets were formed during this tectonic event. The first of these is a series of recumbent folds. These were deformed later in the same orogeny by the rising of the Pelham dome, one of several in the area. The mineral lineation and late folds may have formed during this phase.

Major normal faulting during the Triassic formed the Triassic border fault, one of the major geologic features of Massachusetts, on the western margin of the mapped area. Many of the joints, small faults, and the diabase intrusions probably also formed at this time. Accumulation of thick masses of conglomerate and arkose occurred immediately west of the fault.

From the Triassic to the Pleistocene there are no records of additional deposition or tectonic activity. During the Pleistocene one or more continental ice sheets invaded the area, leaving glacially plucked outcrops on south slopes, a thick mantle of till on the north slopes, and an accumulation of outwash and lake deposits in the valleys.

REFERENCES CITED

Ashenden, D. D., 1971, Stratigraphy and structure of the northern portion of the Pelham dome, north central Massachusetts (abs): Geol. Soc. Amer., abstracts with programs, v. 3 no. 1, p. 15.

Balk, Robert, 1942, The Pelham gneiss dome, Massachusetts (abs): Amer. Geophys, Union Trans., v. 23, p. 343-344.

_____, 1956a, Bedrock geology of the Massachusetts portion of the Northfield quadrangle, Massachusetts, New Hampshire, and Vermont: U. S. Geol. Survey, Geol. Quad. map G. Q. 92.

_____, 1956b, Bedrock geology of the Millers Falls quadrangle, Massachusetts: U. S. Geol. Survey, Quad. map G. Q. 93.

Billings, M. P., 1937, Regional metamorphism of the Littleton-Moosilaukee area, N. H.: Geol. Soc. Amer. Bull., v. 48, p. 463-566.

_____, 1945, Mechanics of igneous intrusion in New Hampshire: Amer. Jour. Sci., v. 243-A (Daly volume), p. 40-68.

_____, 1956, The geology of New Hampshire, part II-bedrock geology: N. H. Plan. and Devel. Comm., 203p.

Brookins, D. G., and Hurley, P. M., 1965, Rb-Sr geochronological investigations in the Middle Haddam and Glastonbury quadrangles, eastern Connecticut: Am. Jour. Sci., v. 263, p. 1-16.

Campbell, Kerry (in preparation) Surficial geology of the Northfield Massachusetts, New Hampshire, and Vermont quadrangle: to be published by U. S. Geol. Survey.

Chapman, C. A., 1939, Geology of the Mascoma quadrangle, New Hampshire: Geol. Soc. Amer. Bull., v. 50, p. 127-180.

_____, 1942, Intrusive domes of the Claremont-Newport area, New Hampshire: Geol. Soc. Amer. Bull., v. 63, p. 381-425.

Clarke, F. W., 1904, Analyses of rocks from the laboratory of the United States Geological Survey, 1880-1903: U. S. Geol. Survey Bull. 228.

Collings, M. R., Wiesnet, D. R., and Fleck, W. B., 1969, Water resources of the Millers River basin in north-central Massachusetts and southwestern New Hampshire: U. S. Geol. Survey, Hydrologic Investigations Atlas HA-293.

Deer, W. A., Howie, R. A., and Zussman, J., 1966, An introduction to the rock-forming minerals; John Wiley and Sons, Inc., New York, 528p.

Dixon, H. R., and Lundgren, L. W., Jr., 1968, Structure of eastern Connecticut: Chapter 16 in Zen, E., White, W. S., Hadley, J. B., and Thompson, J. B., Jr., editors, Studies of Appalachian geology: northern and maritime: New York, Interscience, 475p.

Doll, C. G., Cady, W. M., Thompson, J. B., Jr., and Billings, M. P., compilers and editors, 1961, Centennial Geologic Map of Vermont: Montpelier, Vermont. Vermont Geol. Survey, scale 1:250,000.

Eaton, G. P., and Rosenfeld, J. L., 1960, Gravimetric and structural investigations in central Connecticut: Internat. Geol. Cong., 21st, Copenhagen, 1960, Rpt., pt 2, p. 168-178.

Emerson, B. K., 1898, Geology of old Hampshire county, Massachusetts: U. S. Geol. Survey Monograph 29, 720 p.

_____, 1917, Geology of Massachusetts and Rhode Island: U. S. Geol. Survey Bull. 597, 289p.

Eskola, P. E., 1949, The problems of mantled gneiss domes: Geol. Soc. London, Quart. Jour., v. 104, p. 461-476.

Hadley, J. B., 1942, Stratigraphy, structure, and petrology of the Mt. Cube area, New Hampshire: Geol. Soc. Amer. Bull., v. 53, p. 113-176.

_____, 1949, Bedrock geology of the Mt. Grace quadrangle, Massachusetts: U. S. Geol. Survey Geol. Quad. Map GQ-3.

Hansen, Edward, 1966, Methods of deducing slip line orientations from the geometry of folds: Annual report of the director, Geophysical Laboratory, 1965-66, p. 387-405.

Hatch, Norman L., Jr. and Hartshorn, Joseph P., 1968, Geologic map of the Heath quadrangle Massachusetts and Vermont: U. S. Geol. Survey, Quad. map G. Q. 735.

Hills, F. Allan, and Dasch, E. Julius, 1972, Rb/Sr study of the Stony Creek Granite, southern Connecticut: a case for limited remobilization: Geol. Soc. Am. Bull., v. 83, p. 3457-3464.

Hitchcock, C. H., 1877, The geology of New Hampshire, Part II-stratigraphical geology: Concord, N. H., 684p.

_____, 1890, Significance of oval granitoid areas in the lower Laurentian (abs. with discussion by G.H. Williams): Geol. Soc. Amer. Bull., v. 1, p. 557-558.

Jahns, R. H., 1966, Surficial geologic map of the Greenfield quadrangle Franklin county, Massachusetts: U. S. Geol. Survey, Geol. Quad. Map GQ-474.

Long, Leon, E., 1969, Whole rock Rb-Sr age of the Yonkers Gneiss, Manhattan Prong, Geol. Soc. Am. Bull., v. 80, pp. 2087-2096.

Lundgren, Lawrence, Jr., 1962, Deep River area, Connecticut-stratigraphy and structure: Am. Jour. Sci., v. 260, p. 1-23.

_____, 1963, The bedrock geology of the Deep River quadrangle: State Geological and Natural History Survey of Connecticut: Quadrangle Report #13.

______, 1966, The bedrock geology of the Hamburg quadrangle, Connecticut: Connecticut Geol. Nat. History Survey Quad. Rept. 21, 30p.

Naylor, R. S., 1969, Age and origin of the Oliverian domes, central-western New Hampshire: Geol. Soc. Am. Bull., v. 80, p.405-428.

Naylor, R. S., Boone, G. M., Boudette, E. L., Ashenden, D. D., and Robinson, P., 1973, Pre-Ordovician rocks in the Bronson Hill and Boundary Mountain anticlinoria, New England, U.S.A.:Trans. Amer. Geophys. Union, v. 45, no. 4, p. 495.

Norton, Stephen A., 1969, Unconformities at the northern end of the Berkshire Highlands: in Bird, John M. ed., Guidebook for field trips in New York, Massachusetts, and Vermont, New England Intercollegiate Geological Conference, 61st annual meeting, sec. 21, p. 1-20.

Ramsay, J. G., 1960, The deformation of early linear structures in areas of repeated folding: Jour. of Geol., v. 68, p. 75-93.

Robinson, Peter, 1963, Gneiss domes of the Orange area, Massachusetts and New Hampshire: Ph. D. thesis, Harvard Univ., 253p.

______, 1967a, Introduction to the geology of the Connecticut valley of Massachusetts: in Robinson, Peter, ed., Guidebook for field trips in the Connecticut valley, Massachusetts, New England Intercollegiate Geological Conference, 59th annual meeting, p. 1-4.

______, 1967b, Gneiss domes and recumbent folds of the Orange area, west-central Massachusetts: in Robinson, Peter, ed., Guidebook for field trips for the Connecticut valley, Massachusetts, New England Intercollegiate Geological Conference, 59th annual meeting, p. 17-47.

______, 1967c, Geology of the Quabbin Reservoir area, central Massachusetts: in Robinson, Peter, ed., Guidebook for field trips in the Connecticut valley of Massachusetts, New England Intercollegiate Geological Conference, 59th annual meeting, p. 114-127.

Rodgers, John, 1972, Latest Precambrian (Post-Grenville) rocks of the Appalachian region: Am. Jour. Sci., v. 272, pp. 507-520.

Rosenfeld, J. L. and Eaton, G. P., 1956, Metamorphic geology of the Middle Haddam area, Connecticut-a progress report (abs.): Geol. Soc. Amer. Bull., v. 67, p. 1823.

Thompson, J. B., Jr., Robinson, Peter, Clifford, T. M., and Trask, N. J. Jr., 1968, Nappes and gneiss domes in west-central New England: Chapter 15 in Zen, E., White, W. S., Hadley, J. B., and Thompson, J. B., Jr., editors, Studies of Appalachian geology: northern and maritime, New York, Interscience, 475p.

Trask, N. J., Jr., 1964, Geology of the Vernon-Chesterfield area, Massachusetts, New Hampshire, Vermont: Ph. D. thesis, Harvard University.

______, and Thompson, J. B., Jr., 1967, Stratigraphy and structure of the Skitchewaug nappe in the Bernardston area, Massachusetts and adjacent New Hampshire and Vermont, in Field Trips in the Connecticut valley, Peter Robinson, editor, guidebook, New England Intercollegiate Geological Conference, 59th annual meeting.

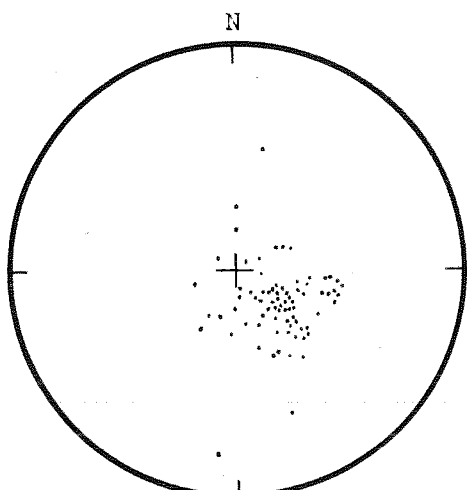
Washington, H. S., 1917, Chemical analyses of igneous rocks published from 1884 to 1913 inclusive: U. S. Geol. Survey, Prof. Paper 99.

Willard, M. E., 1952, Bedrock geology of the Greenfield Quadrangle, Massachusetts: U. S. Geol. Survey, Quad. map GQ 20.

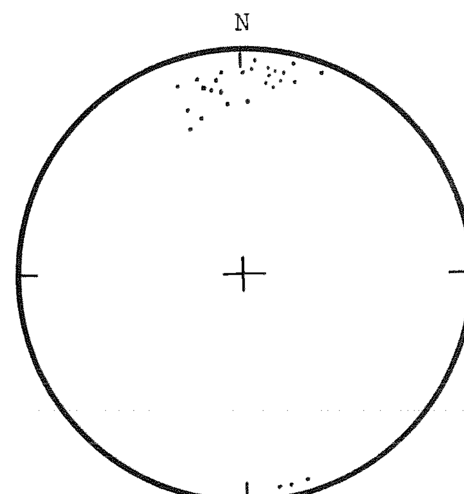
Zartman, R. E., and Naylor, R. S., 1972, Structural implications of some U-Th-Pb zircon isotopic ages of igneous rocks in eastern Massachusetts: Geol. Soc. Amer., Abstracts with programs (Northeastern section) v. 4 no. 1, p. 54-55.

APPENDIX

The appendix presents a total of 28 equal area diagrams. There are 2 separate diagrams for each of the 14 sectors: one for poles to bedding and foliation, the other for mineral lineation. The sectors are indicated on the map in Fig. 12.

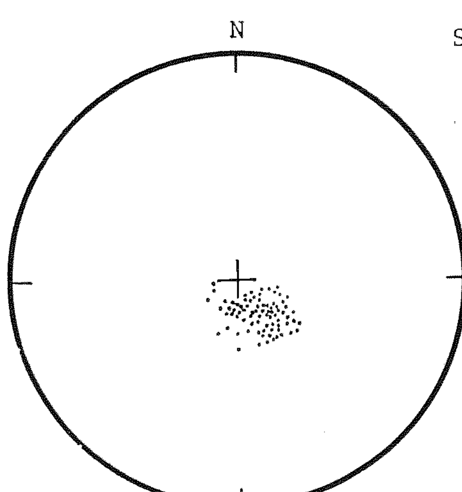


85 poles to bedding and foliation

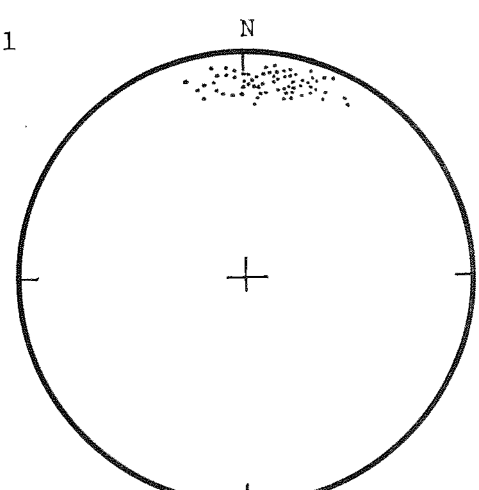


25 mineral lineations

Sector 1

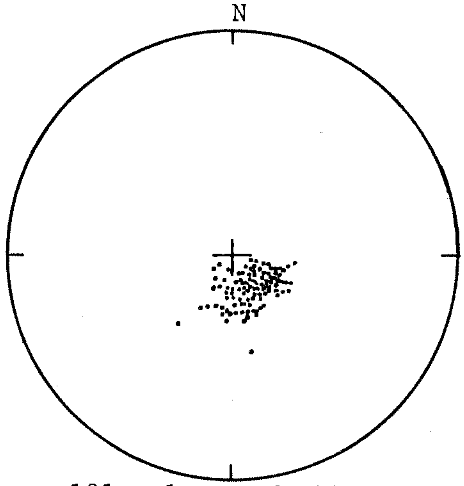


113 poles to bedding and foliation

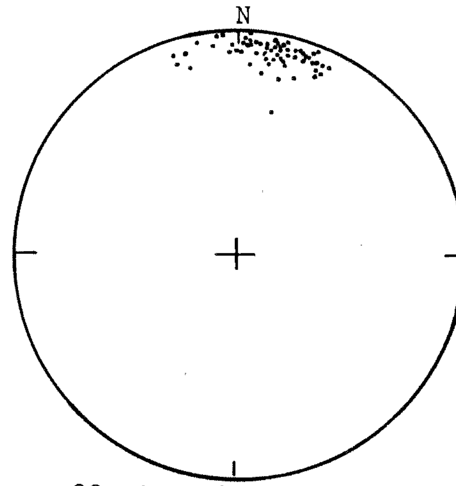


63 mineral lineations

Sector 2

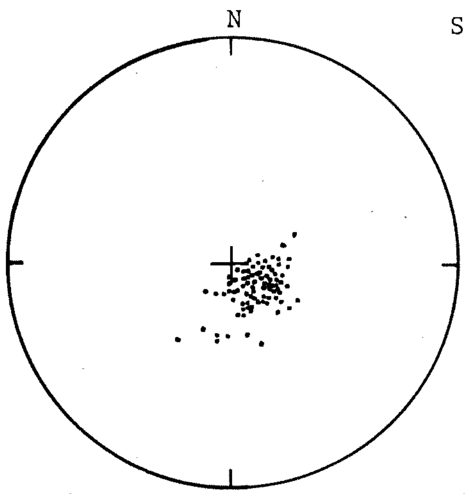


121 poles to bedding
and foliation

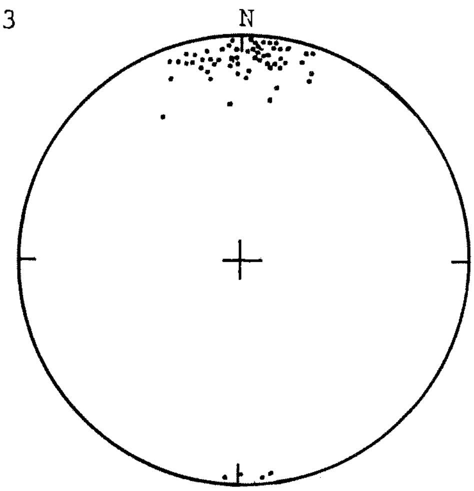


80 mineral lineations

Sector 3

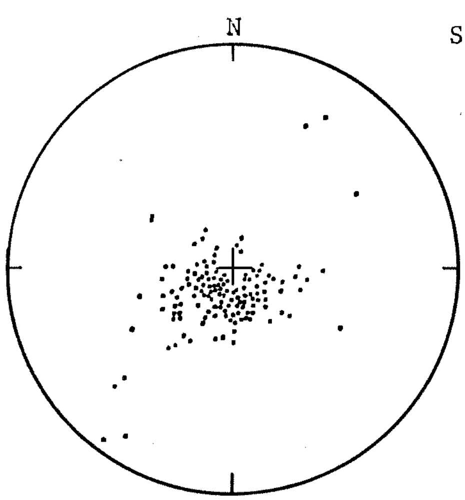


106 poles to bedding
and foliation

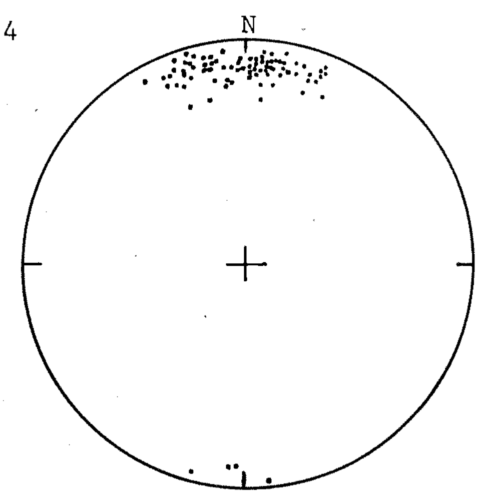


76 mineral lineations

Sector 4

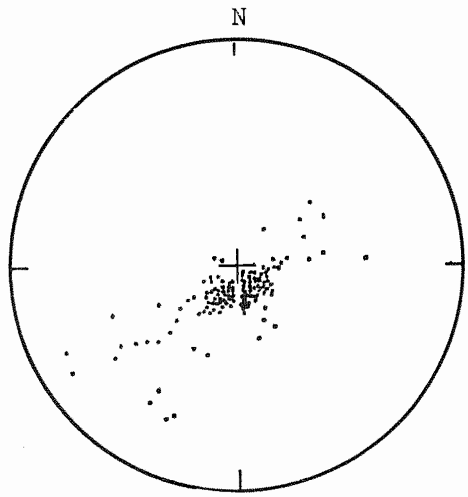


181 poles to bedding
and foliation

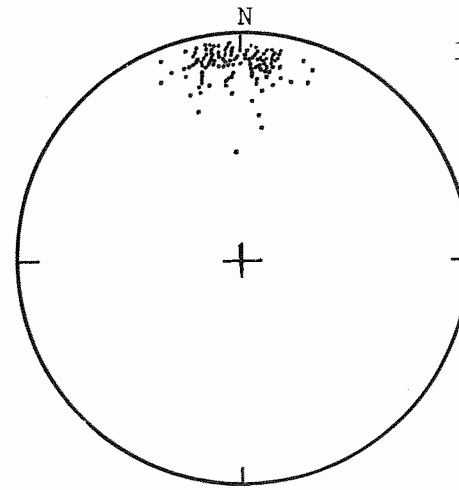


104 mineral lineations

Sector 5

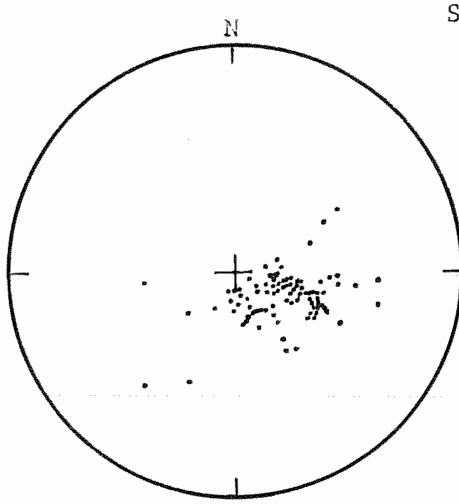


206 poles to bedding
and foliation

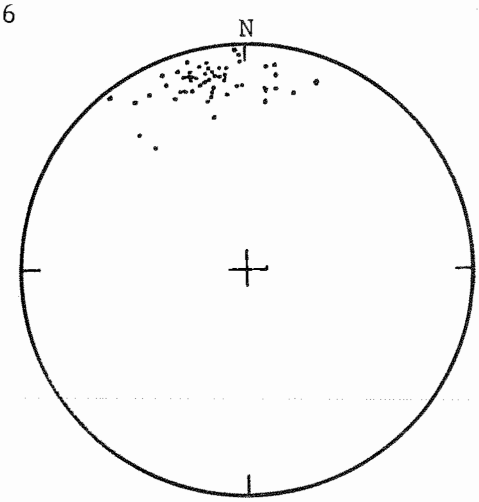


111 mineral lineations

Sector 6

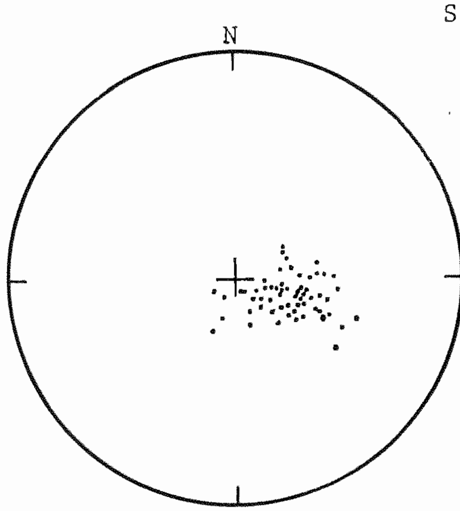


93 poles to bedding
and foliation

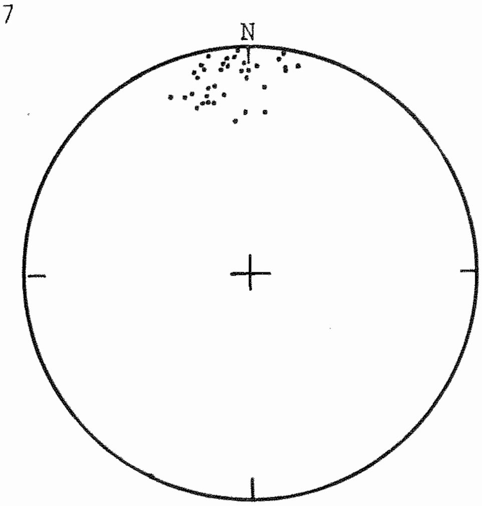


63 mineral lineations

Sector 7

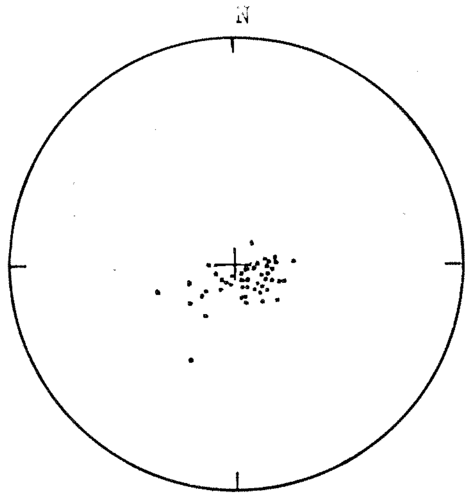


60 poles to bedding
and foliation

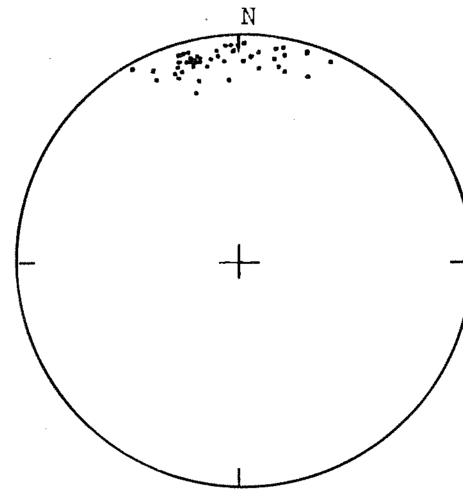


44 mineral lineations

Sector 8

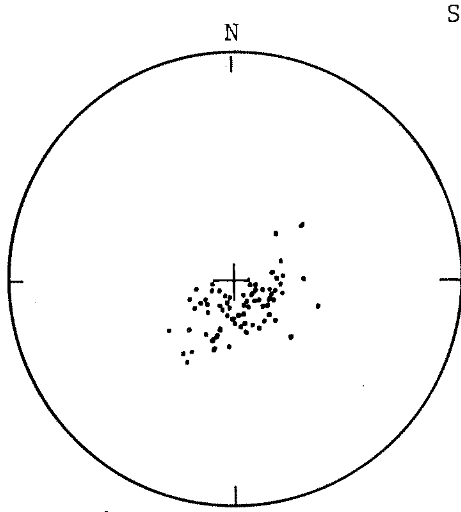


59 poles to bedding and foliation

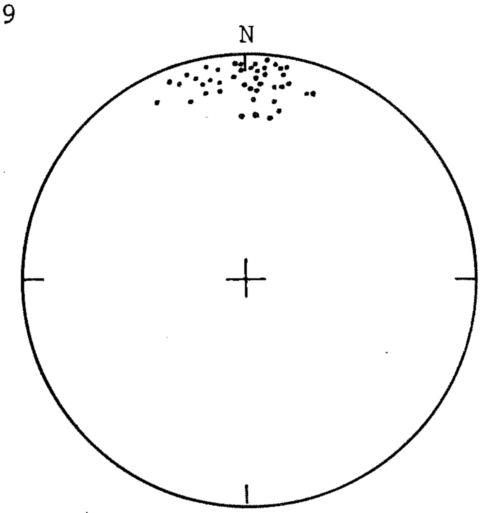


52 mineral lineations

Sector 9

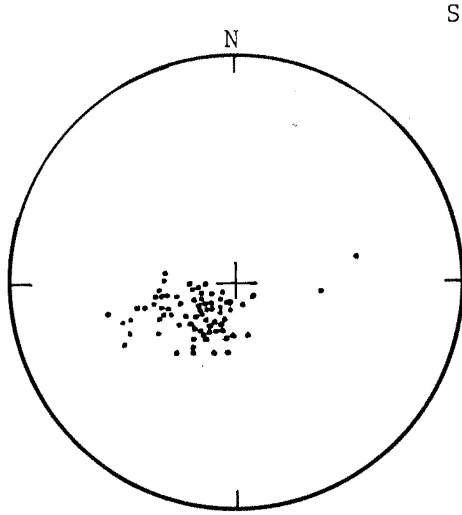


76 poles to bedding and foliation

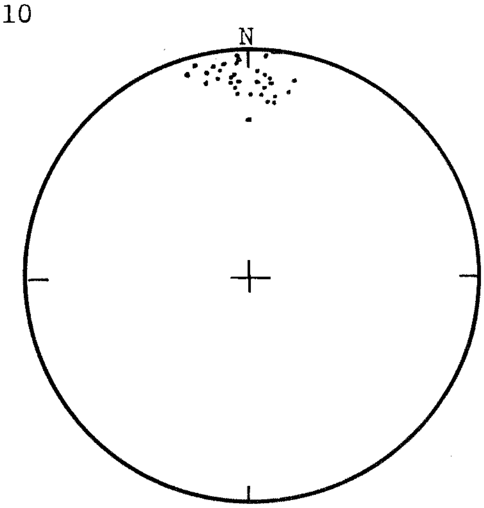


47 mineral lineations

Sector 10

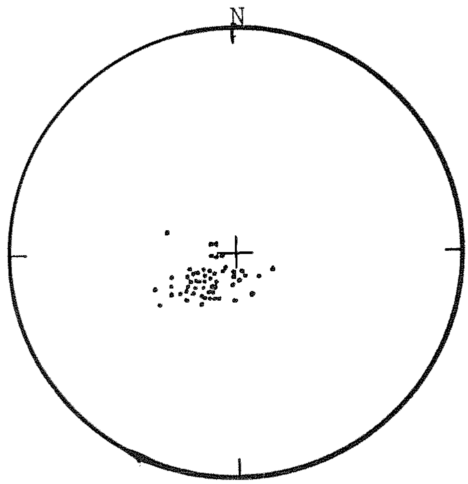


45 poles to bedding and foliation

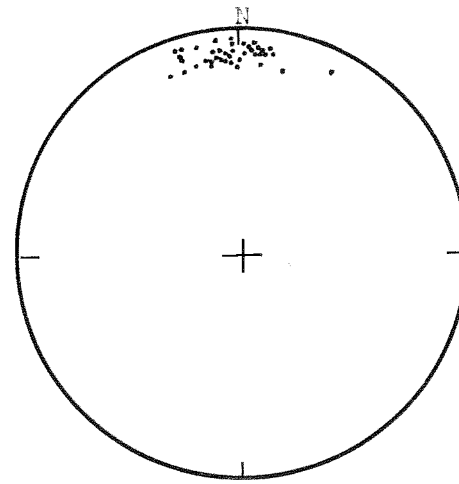


35 mineral lineations

Sector 11

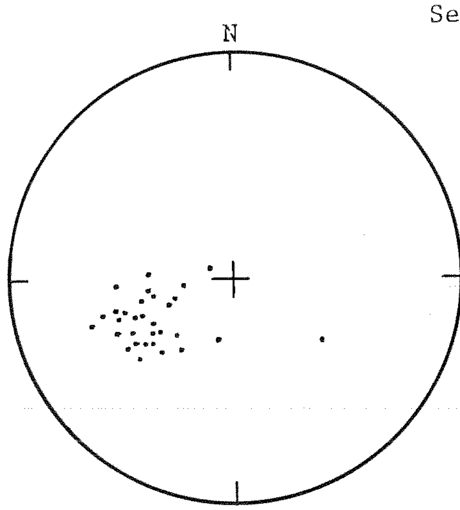


68 poles to bedding
and foliation

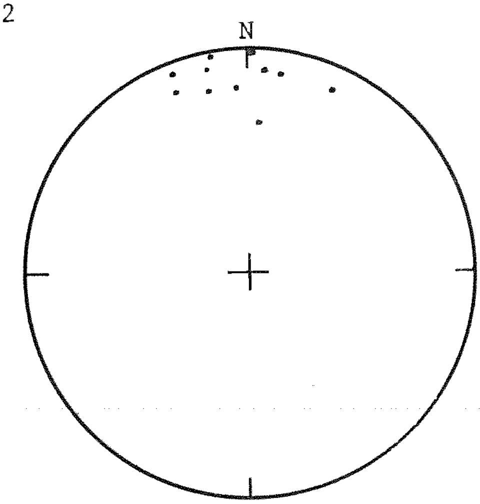


45 mineral lineations

Sector 12

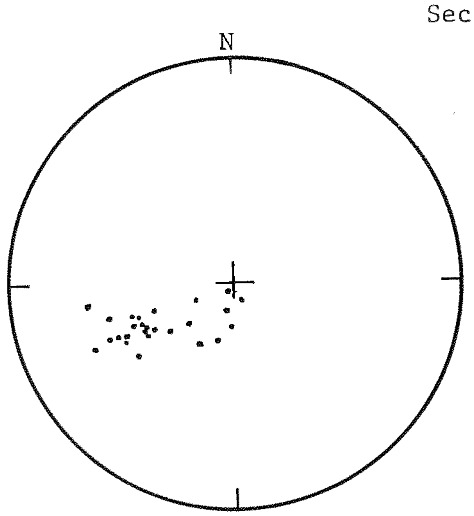


28 poles to bedding
and foliation

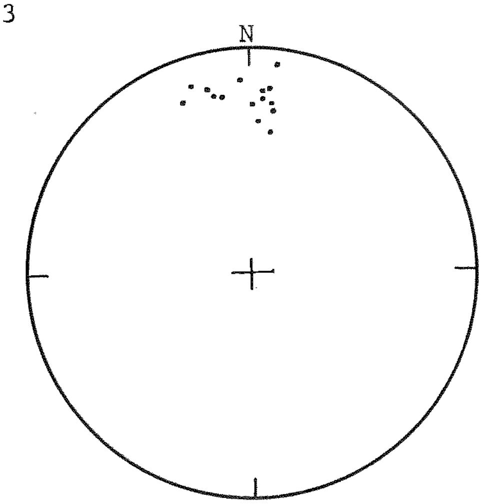


11 mineral lineations

Sector 13



26 poles to bedding
and foliation



15 mineral lineations

Sector 14

PLATE I. GEOLOGIC MAP: NORTHERN PORTION OF THE PELHAM DOME

EXPLANATION

Rock Units:

Triassic

- **Tr** — Sedimentary rocks, undivided; conglomerate, sandstone, siltstone.
- **Trd** — Diabase dikes and sills.

UNCONFORMITY

Lower Devonian

- **Dw** — Waits River Formation: chlorite-phyllite and calcareous granulite.
- **Dea / Deg** — Erving Formation: Dea, hornblende-epidote amphibolite; Deg, bedded fine-grained granulite with schist and calc-silicate.
- **Dl** — Littleton Formation: gray mica-garnet-staurolite schist.

Silurian

- **Sc** — Clough Quartzite: quartzite, quartz pebble conglomerate, and schist.

UNCONFORMITY

Middle Ordovician

- **Op** — Partridge Formation: rusty weathering mica schist with garnet.

UNCONFORMITY (?)

Ordovician?

- **fg** — Fourmile Gneiss: gray biotite gneiss containing beds of hornblende-epidote amphibolite.

UNCONFORMITY (?)

Late Precambrian to Lower Cambrian

- **pm / pmq** — Poplar Mountain Gneiss: pm, gneiss member: gray quartz-biotite-microcline-oligoclase gneiss with minor muscovite and conspicuous white feldspar megacrysts; pmq, quartzite member: white to brown quartzite with biotite and muscovite, or actinolite; minor calc-silicate beds; interbedded granite gneiss and gray biotite gneiss.
- **db / dh / dq** — Dry Hill Gneiss: db, biotite member: gray to pink granite gneiss with biotite; dh, hornblende member: granite gneiss with knots of hornblende up to 1/4 inch; dq, quartzite of uncertain relationship contained in Dry Hill Gneiss.

Age Uncertain

- **d** — Hornblende diorite.
- **p** — Brecciated pegmatite with specular hematite.

EXPLANATION

Symbols:

- strike and dip of bedding.
- strike and dip of foliation.
- trend and plunge of mineral lineation.
- silicified fault zone.
- diamond drill hole location and number.

Lithologic contacts:

- location accurate
- location approximate
- location inferred

Normal faults: hachured on downthrown side

- location accurate
- location approximate
- location inferred

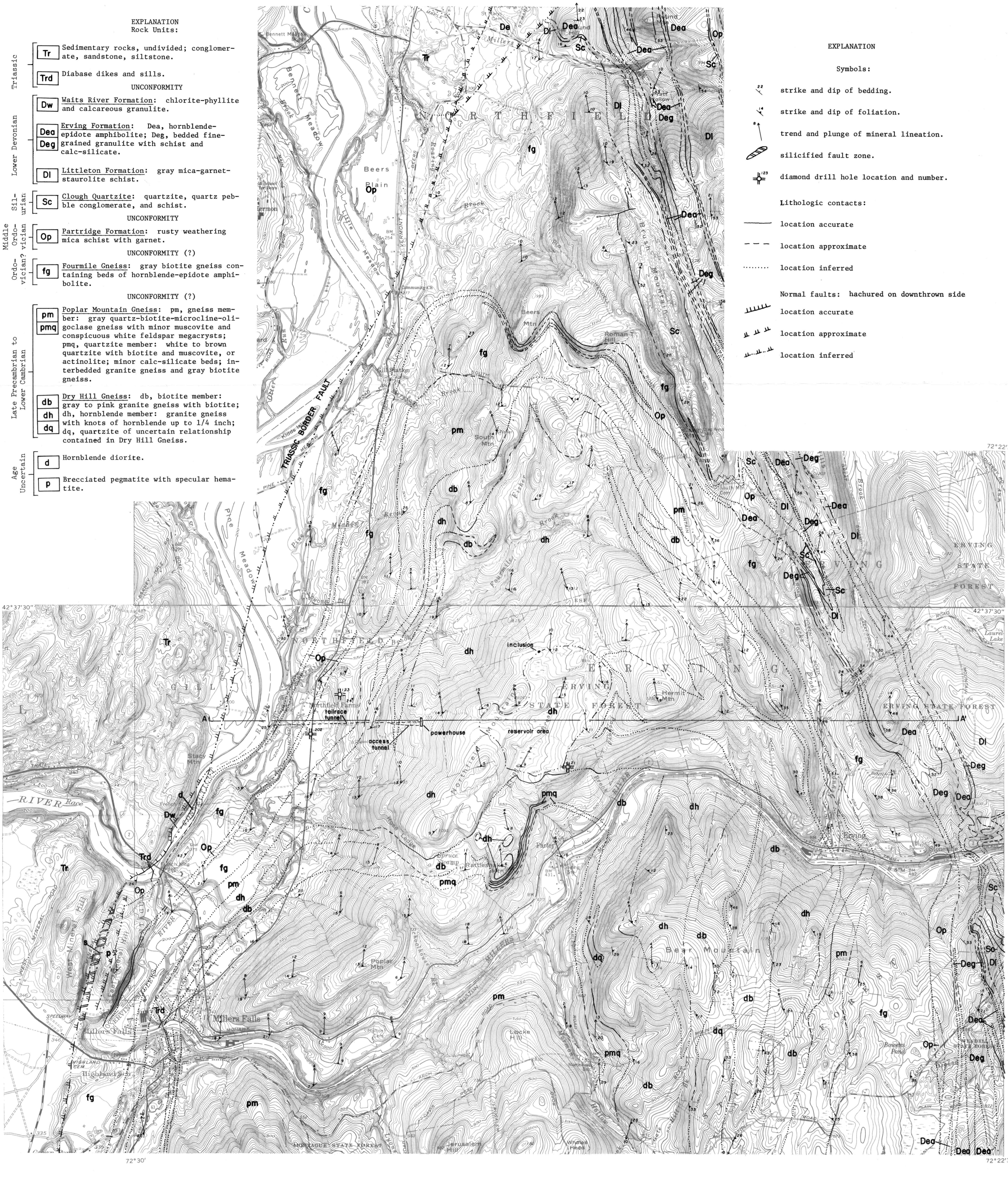


PLATE 2. TECTONIC MAP: NORTHERN PORTION OF THE PELHAM DOME

EXPLANATION

Rock units:

p	Brecciated pegmatite and silicified fault zone.
fg	Fourmile Gneiss with included thin layers of Partridge Formation undif. The outer limits of this unit represent the Ordovician-Silurian (Taconic) unconformity. See Plate 1 for details of included Partridge Formation.
pm	Poplar Mountain Gneiss including gneiss and quartzite members undifferentiated.
dg	Dry Hill Gneiss including biotite and hornblende members undifferentiated.

Note: Siluro-Devonian rocks not indicated; rocks west of the Triassic border fault not indicated. See Plate 1, Geologic Map for these details.

EXPLANATION Cont.

Symbols

Lithologic contacts:

Location accurate	Location approximate	Location inferred

Normal faults, hachured on downthrown side:

Location accurate	Location approximate	Location inferred

Strike and dip of bedding.

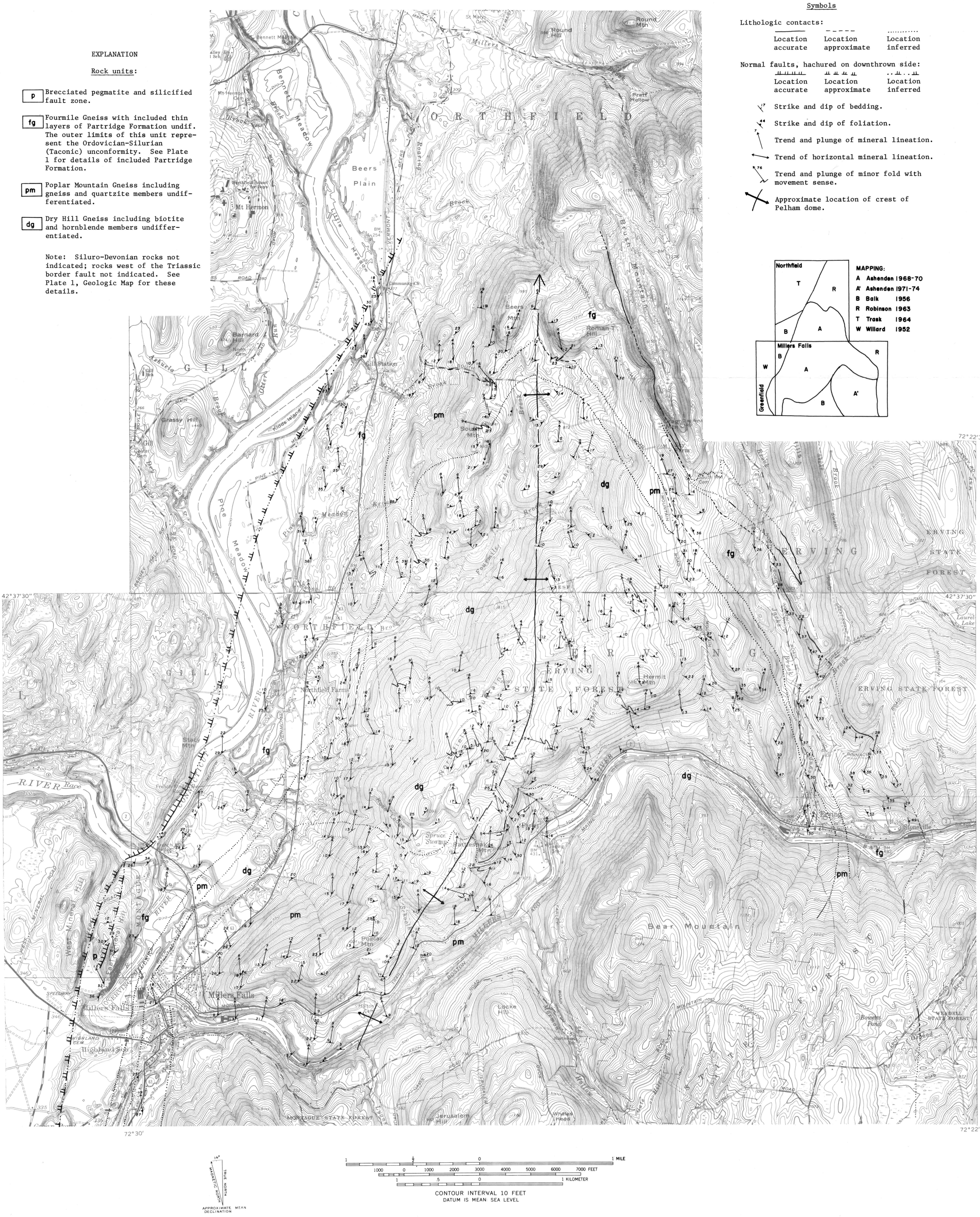
Strike and dip of foliation.

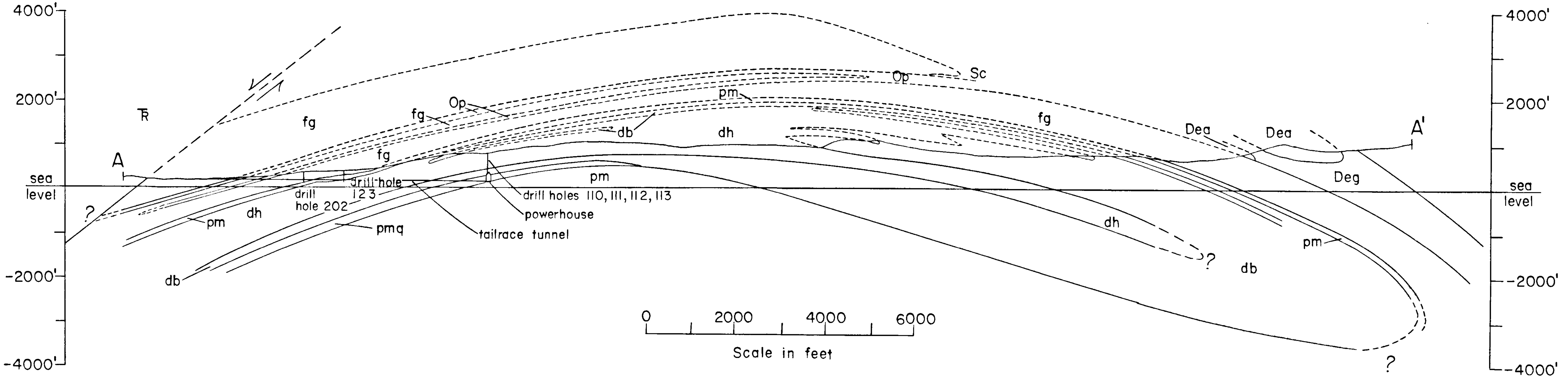
Trend and plunge of mineral lineation.

Trend of horizontal mineral lineation.

Trend and plunge of minor fold with movement sense.

Approximate location of crest of Pelham dome.





STRUCTURE SECTION ALONG A – A'

symbols same as geologic map — plate 1

PLATE 3