PRECAMBRIAN ROCKS OF THE NEW JERSEY HIGHLANDS

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INTRODUCTION

Rocks exposed along Route 15 offer an excellent opportunity to observe most of the major metamorphic and igneous units that make up the New Jersey Highlands (Fig. 1). Rock is exposed along almost the entire twenty kilometers of Route 15 that traverse the strike of the rock units. The purpose of this field guide is to describe the rock units exposed along Route 15 and to report on the current status of recent efforts aimed at understanding the metamorphic and igneous environments that formed the rocks.

Most early descriptions of the New Jersey Highlands subdivide the Precambrian into four major units: These four units appear on the legend of Lewis and Kummel's (1910-1912) Geologic Map of New Jersey as:

1. Byram Gneiss "Gray granitoid gneiss composed of microcline, micro-perthite, quartz, hornblende or pyroxene, and sometimes mica".

2. Losee Gneiss "White granitoid gneiss composed of oligoclase, quartz, and occasionally orthoclase, pyroxene, hornblende, and biotite".

3. Pochuck Gneiss "Dark granular gneiss composed of pyroxene, hornblende, oligoclase, and magnetite".

4. Franklin Limestone "Coarse white marble...."

More recent works by Hotz (1952), Sims (1958), Drake (1969), Smith (1969), and Baker and Buddington (1970) have subdivided the Byram Gneiss into a "Hornblende Granite" and a "Pyroxene Granite" and a few minor units; have substituted rock names such as "Quartz-Oligoclase Gneiss" and "Hypersthene-Quartz-Oligoclase Gneiss" for portions of the Losee Gneiss; have subdivided the Pochuck Gneiss into "Amphibolite" and "Pyroxene Gneiss"; and have recognized several additional rock units such as "Quartz-Potassium Feldspar Gneiss and "Syenite Gneiss". Widmer (1964) has recognized twenty-four mappable Precambrian rock units in the New Jersey Highlands including marble, quartzite, skarn, pegmatite, quartz diorite, four kinds of granite, and fifteen kinds of gneiss. Because of the general reconnaissance nature of this field trip only the major units among the complex assortment of Highlands rock types will be described in this report.

STRUCTURAL SETTING

The igneous and metamorphic rocks of the New Jersey Highlands are divided into northern and southern structural blocks by the Paleozoic rocks of the Green Pond Mountain "Syncline" (Fig. 1). Drake (1969) has shown that the southwestern portion of the Highlands consists of a series of allochthonous slices that overly Paleozoic rocks. In the southwestern portion of the Highlands Drake (1969) reports cataclastic, mylonitic fabric, and retrograde metamorphism. These features, however, are absent from the northeastern portion of the Highlands. Dallmeyer (1974) accepts Drake's structural interpretation but uses a combination of geophysical (gravimetric) and more conventional structural data to show that the northeastern portion of the Highlands has not undergone similar large-scale lateral transport and is instead autochothonous basement.

PETROLOGY OF IGNEOUS AND METAMORPHIC ROCKS OF NEW JERSEY HIGHLANDS

The major rock units that make up the New Jersey Highlands include: 1. Granite; 2. Hypersthene-Quartz-Oligoclase Gneiss (or Quartz Diorite?); 3. Quartz-Oligoclase Gneiss (or Tonalite?); 4. Syenite Gneiss; 5. Amphibolite; 6. Pyroxene Gneiss; and 7. Marble. Each of these rock units, except for the Hypersthene-Quartz-Oligoclase Gneiss are exposed along Route 15.

1. Granites

Granites are the most abundant rock type in the New Jersey Highlands. Buddington (1959) uses the granites of the Highlands as an example of his "catazonal" level of granite emplacement. He also describes the granites as phacoliths, the most striking feature being the lack of large scale discordant features between the granites and

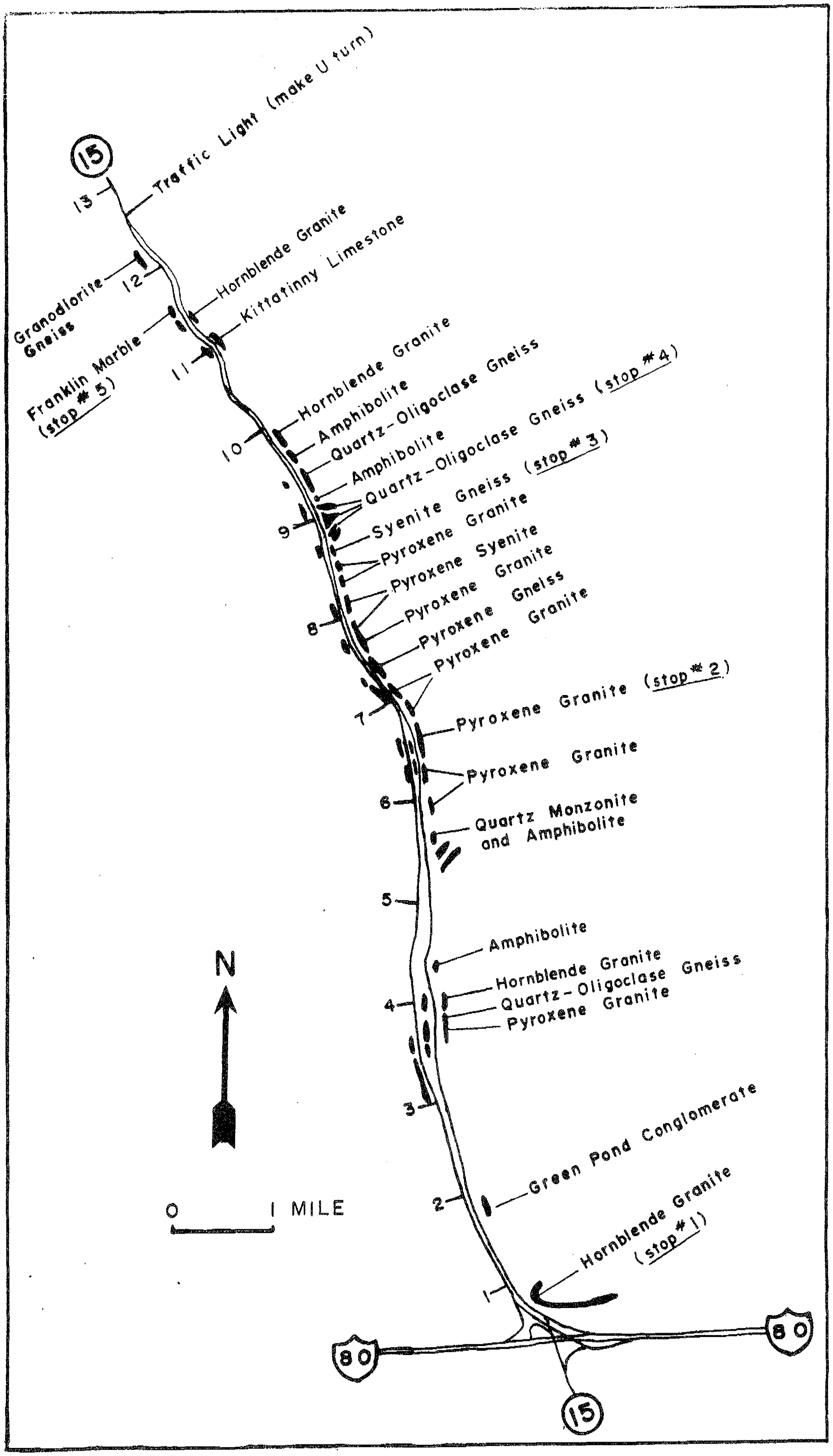

Fig. 1 Map showing road-cut locations with rock type identification, and field trip stop locations along New Jersey State Route 15.

the metamorphic rocks that contain them. Other catazonal characteristics displayed by the Highlands granites include: (1) the presence of gneissic foliation developed throughout the granite; (2) an association with high grade metamorphic rock (at least as high as amphibolite facies) and (3) a lack of chill zones. The two major granite types exposed in the Highlands are Hornblende Granite and Pyroxene Granite.

Hornblende Granite and Alaskite.

Hornblende Granite is found in both the northern and southern blocks of the New Jersey Highlands but is more common in the southern block. Drake (1969) has correlated the Hornblende Granite with the Storm King Granite of New York (Lowe, 1955) based on petrologic similarities. The granite is pinkish buff to greenish buff with a distinct gneissoid structure. It contains numerous xenoliths and large amphibolite schlieren and numerous pegmatites. The average composition of the granite is 46.5 percent microperthite and microcline, 26.9 percent quartz, 8.9 percent hornblende, 16.3 percent plagioclase with accessory and trace magnetite, ilmenite, apatite, zircon, sphene, biotite, and fluorite. (Table 1). The hornblende, biotite, and magnetite contents are highly variable (Table 1). The granite is mapped as an alaskite by Baker and Buddington (1970) and Sims (1958) where the mafic mineral content is less than five volume percent. The alaskite facies is closely associated with most of the magnetite ore deposits found in the New Jersey Highlands. The amphibole from hornblende granite sampled near Splitrock Pond is a hastingsitic variety (Collins, 1964) but the Fe^3 /Fe^2 ratio was not determined. Rhett (1977) has found traces of "relic" pyroxene commonly associated with the hornblende component of Hornblende Granite.

The microcline perthite component of the Hornblende Granite is a micro to mesoperthite variety. Baker and Buddington (1970) have suggested that it was originally an orthoclase before exsolution took place. Exsolution of plagioclase to grain boundaries creating an outer rim of plagioclase is commonly observed in thin sections but less extensive exsolution is more typical. The compositional range of the plagioclase is An_{22} to An_{35}, $Or_{2.4}$ to $Or_{6.8}$with no antiperthitic exsolution (Vogel and others, 1968). The opaque oxides consist of subhedral grains of magnetite containing exsolution lamellae of ilmenite and independent grains of homogeneous ilmenite.

Pyroxene Granite and Pyroxene Syenite.

Pyroxene bearing granite is less common than hornblende granite and is restricted to the central portion of the northern structural block of the New Jersey Highlands, with minor exceptions. The Pyroxene Granite is light to dark green and displays a gneissoid structure that Baker and Buddington (1970) interpret as resulting from magmatic flowage. The granite contains numerous amphibolite schlierien and magnetite bearing pegmatites. The average composition of the granite (Table 1) is 61.6 percent perthite, 21.1 percent quartz,

Table 1.

Modes of New Jersey Highlands Rock Types

	Hb. Granite and alaskite		Pyrox. Granite and syenite		Quartz-Olig. Gneiss		Hyper.-Qtz. Olig. Gneiss		Amphibolite		Pyroxene Gneiss		Syenite Gneiss	
No. of samples	25	Range	15	Range	44	Range	48	Range	43	Range	34	Range	8	Range
Plagioclase and antiperthite	16.3	7.0-32.4	8.4	2.6-22.7	62.7	44.0-77.0	63.8	37.4-78.2	49.0	25.0-78.0	50.3	0-83.5	39.0	7.2-48.7
K-feldspar and perthite	46.5	34.0-57.1	61.6	41.0-70.4	0.1	0- 3.0	1.2	0-16.8	tr	0-tr	9.2	0-67.5	47.8	35.8-74.5
Quartz	26.9	12.8-34.2	21.1	7.8-34.9	29.7	17.5-37.5	17.8	0-30.8	0.3	0- 8.5	17.0	0-50.0	2.5	tr- 4.8
Hornblende	8.9	0-15.8	0.6	0- 2.0	1.5	0 - 6.5	1.7	0- 8.0	27.9	2-64.9	2.1	0-13.0	4.3	0-13.7
Pyroxene	tr	-	5.6	2.0-11.0	1.1	0 - 5.0	9.7	2.5-23.3	16.6	0-51.5	15.2	0.4-42.6	3.8	0-12.1
Biotite	0.1	0-1.7	0	-	2.1	0 -12.5	1.9	0-19.0	1.6	0-19.0	0.1	0- 1.5	0	-
Opaque oxides	0.9	0.2-2.2	1.9	0.2- 5.8	0.4	0 - 9.5	1.2	0- 5.0	1.3	0- 9.5	1.0	0-11.0	1.5	0.1- 3.7
Sphene	tr	0-0.1	0.2	0- 0.9	0	-	tr	-	tr	0- 1.0	0.7	0- 4.9	0.3	0- 1.5
Apatite	0.1	0-0.5	0.2	tr- 0.9	0.3	0 - 1.5	0.2	0- 0.6	0.2	0- 1.5	0.3	0- 1.0	0.3	0- 0.6
Zircon	tr	0-0.2	0.1	tr- 0.6	tr	0 - tr	tr	0- tr	-	-	-	-	0.1	0- 0.4
Other	0.3	-	0.3	-	2.1	-	2.5	-	3.2	-	4.1	-	0.4	-

8.4 percent plagioclase and antiperthite, 5.6 percent pyroxene, 0.6 percent hornblende with accessory opaque oxides, apatite, zircon, and sphene (Table 1).

The pyroxene is typically intergrown with opaque oxides and hornblende. Chlorite is a common alteration product of some of the pyroxene. Both clino- and ortho-pyroxenes occur in the granite but clino-pyroxene predominates. The ortho-pyroxene component has been identified as ferrohedenbergite by Baker and Buddington (1970) and as hypersthene by Rhett (1977). The clino-pyroxene component is probably calcic augite (Rhett, 1977). Rhett has observed that the clino-pyroxene typically displays varying degrees of replacement by hornblende. Rhett (1977) concludes that syn- and post-kinematic metamorphism reactions occurred in both the northern and southern blocks that produced hastingsitic amphibole and quartz from clino-pyroxene plus oxides plus feldspar plus water; but these reactions failed to convert all the pyroxene in the northern block because of a relatively low P_{O_2} and P_{H_2O} environment.

The perthite component is typically a microperthite to microantiperthite with the plagioclase portion of the intergrowths approximately equivalent to the K-spar portion. Mesoperthite with rims or "halos" of exsolved plagioclase on grain boundaries is also common. Some independent plagioclase also exists but is difficult to clearly distinguish in thin section from exsolved plagioclase. The opaque-oxide component includes magnetite with exsolved ilmenite lamellae and co-existing grains of ilmenite.

Where the mafic mineral content is less than five volume percent the rock is mapped by Baker and Buddington (1970), Sims (1958), and Smith (1969) as Pyroxene Alaskite; and where the quartz content of the granite is less than 10 volume percent, it is mapped as Pyroxene Syenite. Both Pyroxene Alaskite and Pyroxene Syenite are common varieties of the granite. Young (1979) has suggested that the syenite was generated at very deep crustal levels from partial melting of quartz-feldspathic and anorthositic rocks at higher temperatures and lower P_{H_2O} than the granites of the southern block.

Because of the catazonal setting it might be suspected that much of the Highlands granite formed in place and was not intruded from a still deeper source. Evidence that disagrees with this suspicion is the lack of a continuous envelope of rock surrounding the granite bodies that could be interpreted as refractory residual source rock. If the metasedimentary rocks of the Highlands underwent partial melting to yield granite magma then a partitioning of several elements probably occurred at the liquid-solid interface. The K_20 and $Si0_2$ content of the granite exceeds that of most of the metasedimentary host rocks (Table 2) and probably involved diffusion out of the metamorphic rocks into the granite magma. The FeO, CaO, MgO, and Al_2O_3 contents of the granite, however, are lower than in most of the common Highlands metamorphic rocks. These elements should be found concentrated in a refractory residue around the granites assuming that the granites formed in place. The Pyroxene Gneisses and perhaps some of the amphilbolite associated with the granites may have formed as just such a residue. But since the granites are found in contact with a variety of rock types in the Highlands area and display no consistent relationship with any mafic of migmatitic rock type it appears that at least some granite magma escaped from its residual envelope and intruded into overlying rocks.

2. HYPERSTHENE-QUARTZ-OLIGOCLASE GNEISS (OR QUARTZ DIORITE?)

About one-half of what is referred to as the Losee Gneiss on the Geologic Map of New Jersey (Lewis and Kummel, 1912) is mapped by Smith (1969) as a Hypersthene-Quartz-Andesine Gneiss; by Baker and Buddington (1970) and Dodd (1962) as a Hypersthene-Quartz-Oligoclase Gneiss; and by Sims (1958) and Drake (1969) as a Quartz Diorite. Minor portions of the "Byram Gneiss" are also remapped as Hypersthene-Quartz-Andesine Gneiss (Smith, 1969). The rock is foliated and is characterized by alternating light buff or light green and dark greenish gray or brownish gray bands. It contains numerous amphibolite schlieren and pegmatites. The average mineral composition is 63.8 percent plagioclase, 17.8 percent quartz, 8.2 percent orthopyroxene, 1.5 percent clinopyroxene, 1.9 percent biotite, 1.7 percent hornblende, 1.2 percent potassium feldspar, with accessory opaque oxides, zircon apatite, and graphite (Table 1). The dark layers contain more mafic minerals than the light layers. The clinopyroxene is a diopside (Smith, 1969) that is intergrown with hypersthene, and hornblende as mafic clusters. The plagioclase component is typically an antiperthitic andesine that ranges from An_{33} to An_{50}, $Or_{2.4}$ to $Or_{6.9}$ (Vogel and others, 1968).

There is very little agreement among petrologists concerning the origin of the Hypersthene-Quartz-Oligoclase Gneiss. Baker and Buddington (1969) and Collins (1969) suggest a metasedimentary origin in contrast to Sims (1958) and Drake (1969) who favor an igneous origin. Dodd (1962) suggests a metavolcanic origin. Vogel and other (1968) point out that the Gneiss is intimately interlayered with Hornblende Granite and suggest that both rocks formed under similar temperature and pressure conditions. Most authors recognize the charnokitic characteristics of the Gneiss and refer to long standing controversies pertaining to the origin of such rock.

Table 2.

Chemical Composition of Some Rock Types

	H.Q.O.[1] Gneiss	Q.O.[2] Gneiss	Hb[3] Granite	Pyrox.[4] Granite	Tonalite[5]	Quartz[6] Diorite	Dacite[7]	Graywacke[8]
SiO_2	67.69	71.69	74.89	72.43	66.15	61.54	63.58	66.7
TiO_2	0.48	0.43	0.21	0.24	0.62	0.66	0.64	0.6
Al_2O_3	15.99	14.88	12.33	12.94	15.56	16.21	16.67	13.5
Fe_2O_3	0.64	0.50	0.69	1.44	1.36	2.54	2.24	1.6
FeO	2.42	1.32	1.50	1.38	3.42	3.77	3.00	3.5
MnO	0.05	0.04	0.03	0.34	0.08	0.10	0.11	0.1
MgO	1.16	0.89	0.16	0.34	1.94	2.80	2.12	2.1
CaO	2.88	2.39	0.91	1.70	4.65	5.38	5.53	2.5
Na_2O	4.64	5.85	2.95	3.83	3.90	3.37	3.98	2.9
K_2O	2.86	1.39	5.38	4.74	1.42	2.10	1.40	2.0
H_2O+	0.35	0.51	0.35	0.37	0.69	1.22	0.56	2.4

[1] Hypersthene-Quartz-Oligoclase Gneiss collected from just north of the old road 0.5 mile northwest of where Pacock Brook enters Canistear Reservoir, Newfoundland quadrangle (Baker and Buddington, 1970).

[2] Average of four Quartz-Oligoclase Gneiss samples from the New Jersey Highlands after Drake, (1969), Sims (1968), and Baley (1941).

[3] Hornblende Granite collected from 0.75 miles east of upper end of Splitrock Pond, Boonton quadrangle, Dover District, (Sims, 1968).

[4] Pyroxene Granite collected 6200 ft. east of outlet of Sickel Pond, Stanhope quadrangle (Baker and Buddington, 1970).

[5] Average Tonalite (Nockolds, 1954).

[6] Average Quartz Diorite (Daly, 1942).

[7] Average Dacite (Nockolds, 1954).

[8] Average Graywacke (Pettijohn, 1963).

From a geochemical standpoint the chemical composition of the Hypersthene-Quartz Oligoclase Gneiss resembles an average graywacke more closely than an average quartz diorite (Table 1). If the chemical composition of the Hypersthene-Quartz-Oligoclase Gneiss appearing in Table 1 is typical (it has been described as typical by Buddington and Baker, (1970) there are no major elements with the exception of Na_20 and H_20 that deviate by more than a single percent from an average graywacke although $Si0_2$, total iron, Mg0, Ca0, and Na_20 all deviate by more than a percent from an average quartz diorite (Table 2).. Mineralogically the average Hypersthene-Quartz Oligoclase Gneiss (Table 1) qualifies as a quartz diorite but contains what would be an unusually low pyroxene plus amphibole content.

The chemical composition of the Hypersthene-Quartz-Oligoclase Gneiss also resembles some volcanic rock types such as dacite (Table 2). A metavolcanic origin as suggested by Dodd (1962) can not be ruled out but the very wide ranging mineral composition (Table 1) and banding is probably more typical of sedimentary and metasedimentary rock than relatively homogeneous igneous or metaigneous rock. In addition the accessory graphite content of the Hypersthene-Quartz-Oligoclase Gneiss is much more typical of metasedimentary rock than igneous or metaigneous rock.

3. QUARTZ OLIGOCLASE GNEISS (OR TONALITE?).

Quartz-Oligoclase Gneiss is widely distributed throughout both the northern and southern blocks of the New Jersey Highlands. On Smith's (1969) map of the Highlands, Quartz-Oligoclase Gneiss constitutes roughly one half of what is referred to as the Losee Gneiss on the Geologic Map of New Jersey (Lewis and Kummel, 1912). It is exposed along Route 15 (Stop # 4) near the type locality of the Losee Gneiss (Losee Pond renamed Beaver Lake,). It has been correlated with the Canada Hill Gneiss of New York State by Drake (1969). The Quartz-Oligoclase Gneiss appears white to light green, is medium grained and foliated. It contains numerous pegmatites some of which are conformable to the foliation of the gneiss and some of which are discordant. The mineral component of the Quartz-Oligoclase Gneiss averages 62.7 percent plagioclase, 29.7 percent quartz and 2.1 percent biotite with accessory garnet, hornblende, pyroxene, chlorite, epidote, orthoclase, apatite, zircon sillimanite and opaque oxides. (Table 1). The principal mafic mineral is biotite which is typically intergrown with chlorite, epidote, and opaque oxide. The plagioclase component is commonly clouded with epidote and chlorite.

The origin of the Quartz-Oligoclase Gneiss is at least as controversial as the origin of the Hypersthene-Quartz-Oligoclase Gneiss. Baker and Buddington (1970) include it in their petrographic description of "rocks of uncertain origin". They point out that Baker's (1955) and Hague and other's (1956) igneous interpretation is supported by discordant relations between the Gneiss and layers of metaquartzite and amphibolite. They also report a small amount of feldspathic pyroxene skarn at the contact between the amphibolite and the Quartz-Oligoclase Gneiss. But, in general, there is conformity between the Quartz-Oligoclase Gneiss and the amphibolite layers.

If the Quartz-Oligoclase Gneiss correlates with the Canada Hill Gneiss, additional support for an igneous origin is found. Mose (1978) has suggested that the Canada Hill Gneiss is younger than and discordant to the Storm King Granite and proposes that the Canada Hill Gneiss was derived by partial anatexis of paragneiss during late stage Grenville metamorphism.

The metasedimentary origin suggested by Sims (1958) is supported by the banded or layered nature of the rock, its garnet and sillimanite content, and its intimate concordant interlayering with obviously metasedimentary (or) metavolcanic rocks.

The chemical composition of the Quartz-Oligoclase Gneiss resembles an average graywacke (Table 2) except for the low potassium and iron content of the Quartz-Oligoclase-Gneiss. If the Quartz-Oligoclase Gneiss was an igneous intrusive rock it would be classified as a tonalite on the basis of its minerology. The chemical composition of an average tonolite, however, is approximately equivalent to an average graywacke (Table 2). Despite the ambigous chemical composition of the Quartz-Oligoclase Gneiss I tend to favor a metasedimentary origin largely on the basis of the same evidence as suggested by Sims (1958).

There is probably no way of determining exactly how much, if any, FeO and K_2O was removed from any sedimentary precursor of the Quartz-Oligoclase Gneiss. (Table 2) But since granite magma probably melted in close proximity to the Quartz-Oligoclase Gneiss it is logical to suspect that large quantites of K_2O diffused into the granite magma from the surrounding host rocks. According to Eskola (1932) the residuum from anatexis can be expected to be depleted in one or more of the three major minerals found in granite. This might explain the low K-spar content of the Gneiss.

Some iron may have also been mobilized during anatexis in a catazonal-granulite facies environment. Since the FeO/MgO ratios of the ferromagnesian components of the Gneiss were presumably decreasing in response to increasing temperatures and pressures during anatexis and since water is generally released during

DISTRIBUTION OF IGNEOUS AND METAMORPHIC ENVIRONMENTS

Radiometric data (Long and Kulp, 1962; Tilton and others, 1960; Mose and Helenk, 1976) suggest that the New Jersey Highlands underwent metamorphic recrystallization during the Grenville about 1100 Ma and was then invaded by Granites about 840 Ma. The metamorphic setting invaded by the granites was very deep seated and was within the hornblende granulite facies (Drake, 1969; Smith, 1969; and Young, 1971) or at least within the sillimanite-almandine-orthoclase subfacies of the amphibolite facies (Baker and Buddington, 1970) of Turner and Verhoogen (1960). Of particular interest are the charnockitic characteristics of much of the rock, as recognized by Sims (1958), Offield, (1967), and Drake (1969) particularly the Hypersthene-Quartz-Oligoclase Gneiss.

The natural division of the Highlands into two blocks has made it tempting to compare the igneous petrology of the two blocks. One such attempt was made by Rhett (1977) who applied the magneteite-ilmenite geothermometer and oxygen barometer to 13 granite samples from the southern block and 18 granite samples from the northern block. His data indicate considerable overlap of T-fO_2 conditions among the granites of the two blocks. The granites of the northern structural block equilibrated at temperatures ranging from 570° to 680 C°. Rhett suggested that probably all of the granitic magma initially contained pyroxene but that amphiboles plus quartz formed at the expense of clinopyroxene plus feldspar plus iron-titanium oxides during and after granite emplacement. Similar reactions occurred in the non-granites as a response to T, P_{H_2O}, Po_2 changes that accompained granite emplacement and deformation. The reactions did not go to completion in the case of the pyroxene granites of the northern block because of locally "dry" environments. Rhett's (1977) calculations agree with Young's (1978) suggestion that the pyroxene granites and syenites of the northern block probably equilibrated in a relatively low P_{H_2O} environment but do not agree with Young's suggestion that the pyroxene granites, and particularly the associated syenites of the northern block, equilibrated at higher temperatures than the granites of the southern block. Young (1978) has proposed that the syenites of the northern block formed through very deep-seated partial melting of quartz-feldspathic and anorthositic rocks.

There is also some evidence that eastern portions of the Highlands may have been more directly effected by Paleozoic igneous and metamorphic events than western portions. Long and Kulp (1962) described a "transition zone" that was effected by the "profound metamorphism of the Manhattan Prong in Paleozoic time". When the metamorphic grade of the Cambro-Ordovician rocks of the Manhattan Prong is compared to the virtually unmetamorphosed Cambro-Ordovician rocks associated with the western portion of the Highlands their suggestion seems valid. But the distribution of Paleozoic metamorphic effects on the Precambrian rock depends on the initial location of the allochthonous slices of Precambrian rock and the timing and extent of any overthrusting.

PETROGENESIS - DISCUSSION

There is general agreement among petrologists that have studied the New Jersey Highlands that it consists largely of metasedimentary rock that has been invaded by igneous magmas. But details concerning the sequence of geologic events that generated the Highlands are obscured by the high degree of tectonic activity and metamorphism that occurred there. The exact nature of the sedimentary precursors of the paragneisses, for example, may never be determined. Metaquartzites are, however, scarce in the Highlands and metabasalts (amphibolites) are common. In addition, much of the metasedimentary rock of the Highlands chemically resembles graywacke. The original sedimentary rocks, therefore, were probably more like a "flysch" sequence than a "molasse" or "orthoquartzitic" sequence. As an admittedly speculative working model a typical flysch sequence containing considerable graywacke may not be too far out of line as a starting point. Progressive regional metamorphism of graywackes presumably would have included intermediate grade metamorphic rocks containing hydrous ferromagnesian silicates (chlorite, mica, etc.). When the stability field of some of the hydrous potassium and iron bearing silicate assemblages was exceeded by prograde metamorphism approaching the granulite facies some iron, potassium, and aqueous fluid may have been mobilized and forced to diffuse along thermal and pressure gradients. Some of the iron may have precipitated in shear zones parallel to the foliation of the metasedimentary rocks to form magnetite concentrations common throughout the Highlands. Some potassium, silica, and other elements probably diffused into increasing quantities of granite magma that was forming during anatexis. The Quartz-Oligoclase Gneiss associated with the granites of the Highlands may have supplied a considerable portion of the potassium required to form granite. The most refractory, depleted, residual portions of the metasedimentary rock adjacent to newly formed granite magma were enriched in magnesium, calcium, aluminum, and other elements not required by the granite. These residual portions may be represented by the Pyroxene Gneiss of the Highlands and perhaps some of the other less common mafic rocks.

The fact that these mafic metasedimentary rocks no longer form a continuous envelope around the granite bodies probably indicates that some of the granite magma broke out of the site of origin and moved some distance through the metamorphic complex. Portions of the metagraywacke that were further removed from the zones of melting have become less involved in the chemical exchange that was going on. These less effected portions of the metasedimentary-igneous complex are probably represented by the Hypersthene-Quartz-Oligoclase Gneiss that chemically resemble graywacke more closely than the other rock types of the Highlands. The Hypersthene-Quartz-Oligoclase Gneiss may represent portions of the metasedimentary country rock that were simply too anhydrous to get involved in the melting process. Perhaps much of the water supply of this rock escaped before anatexis began, and at temperatures and pressures too low to dissolve much iron or potassium.

ROAD LOG

MILES	
0.0	Exit north onto New Jersey Route 15 from westbound on Interstate Routh 80.
0.9	**STOP 1.** Hornblende Granite (sample 0.9, Table 3). Exit at the Picatinny Arsenal. The rock exposed along the hill to the right is Hornblende Granite. Exercise extreme caution when crossing the road to examine the granite. The granite here is quite homogeneous but on the other side of the hill contains less hornblende and becomes an alaskite. Note the well developed foliation. Busses will turn around and proceed north on Route 15.
1.0	Green Pond Fault.
1.8	Green Pond Conglomerate; silurian correlative of Shawangunk Conglomerate. Most of the pebbles are rounded milky quartz.
3.5	Very complex mixture of Pyroxene Granite near the south end of the roadcut (sample 3.6, Table 3). Quartz-Oligoclase Gneiss near the center, and Hornblende Granite near the north end (4.0 mile on log). Several disconnected xenoliths of amphibolite may be observed in the granite as well as numerous granite pegmatites implaced parallel to the foliation of the granite.
4.3	Amphibolite (sample 4.3, Table 3).
5.7	Fine grained quartz monzonite alaskite along end of roadcut; Amphibolite along the north end.
5.9	Pyroxene Granite (sample 5.9, Table 3).
6.5	**STOP 2.** Pyroxene Granite. Note the wide ranging quartz content, dark color, and well developed foliation. The pyroxene component of the rock here is deeply altered; the feldspar component ranges from a plagioclase rich perthite (as in sample 5.9, Table 3) to a K-spar rich antiperthite (as in sample 6.6, Table 3). Busses will part on breakdown lane. Watch out for loose rock on vertical face of road cut.
6.5	Pyroxene granite
7.3	Pyroxene Gneiss composed of approximately 50 percent antiperthite, 10 percent plagioclase, 15 percent quartz, 20 percent pyroxene-amphibole intergrowths, and 5 percent opaque oxides.
7.6	Pyroxene Granite
7.9	Pyroxene Syenite (sample 8.2, Table 3).
8.2	Pyroxene Granite including bands of syenite and various gneisses that have a similar general appearance but dissimilar mineralogies making up a virtually unmappable complex for 0.3 mile. Amphibolite bands are also found here.
8.7	**STOP 3.** Syenite Gneiss (sample 8.7, Table 3).
9.1	**STOP 4.** Quartz-Oligoclase Gneiss, (samples 9.1a and b, Table 3). Both white and pink varieties of Quartz-Oligoclase Gneiss occur here. Most of the rock here contains less biotite and is less foliated and banded than more typical Quartz-Oligoclase Gneiss. Amphibolite schliern are common. Busses park on abandoned entrance road to Route 15.
9.2	Amphibolite.
9.4	Quartz-Oligoclase Gneiss
9.6	Amphibolite
9.8	Hornblende Granite. Alternating plagioclase rich and K-spar rich bands make this rock less homogeneous than the granite at STOP 1.
11.0	Kittatinny Limestone. Cambro-Ordovician dolomitic limestone.
11.4	Hornblende Granite
12.7	Traffic light (make U-turn).
13.2	Granodiorite Gneiss. Highly foliated rock composed of 40 percent plagioclase, 30 percent quartz, 20 percent K-Spar, and 10 percent biotite.
13.8	**STOP 5.** Franklin Marble. The marble is intruded by granite pegmatites. If traffic is heavy it may be necessary to skip this stop. The road shoulder is quite narrow.
13.8	Continue south on Route 15.
25.4	Turn east on Interstate Route 80 and return to the Rutgers-Newark Campus.

Table 3.

Modes of Precambrian Rock Samples Collected Along New Jersey Route 15

Mileage*	0.9	3.6	4.0	4.3	5.9	6.3	6.6	7.8	8.2	8.7	9.1a	9.1b
Plagioclase and antiperthite	11	2	2	55	1	5	45	25	24	47	69	65
K-feldspar and perthite	44	60	66.5	tr	70.5	59.5	tr	27	64	38.5	0.5	2.5
Quartz	28	30	28	tr	24	30	49	23	4	5	28	30
Hornblende	15	tr	2	31.5	tr	tr	tr	10	tr	4	0.5	tr
Pyroxene	0	7	tr	8	2	1.5	1	6	4	3	0	tr
Biotite	0	tr	0	3	0	0	0	6	0	0	1.5	2.5
Opaque oxides	2	1	1.5	2	1.5	4	5	1	2	2	0.5	tr
Sphene	tr	tr	tr	tr	0	tr	0	0.5	1	0.5	0	0
Apatite	tr	tr	tr	0.5	tr	tr	tr	0.5	tr	tr	tr	tr
Zircon	tr	tr	tr	0	tr	tr	tr	0	tr	tr	tr	tr
Other	tr	tr	tr	tr	1	tr	tr	1	1	tr	tr	tr
Rock Type	H.G.	P.G.	H.G.	Amph.	P.G.	P.G.	P.G.	P.Gn.	P.Sy.	Sy.Gn.	Q.O.G.	Q.O.G.

*Mileage from New Jersey State Route 15 exit off Interstate Route 80 proceeding north (Fig. 1).

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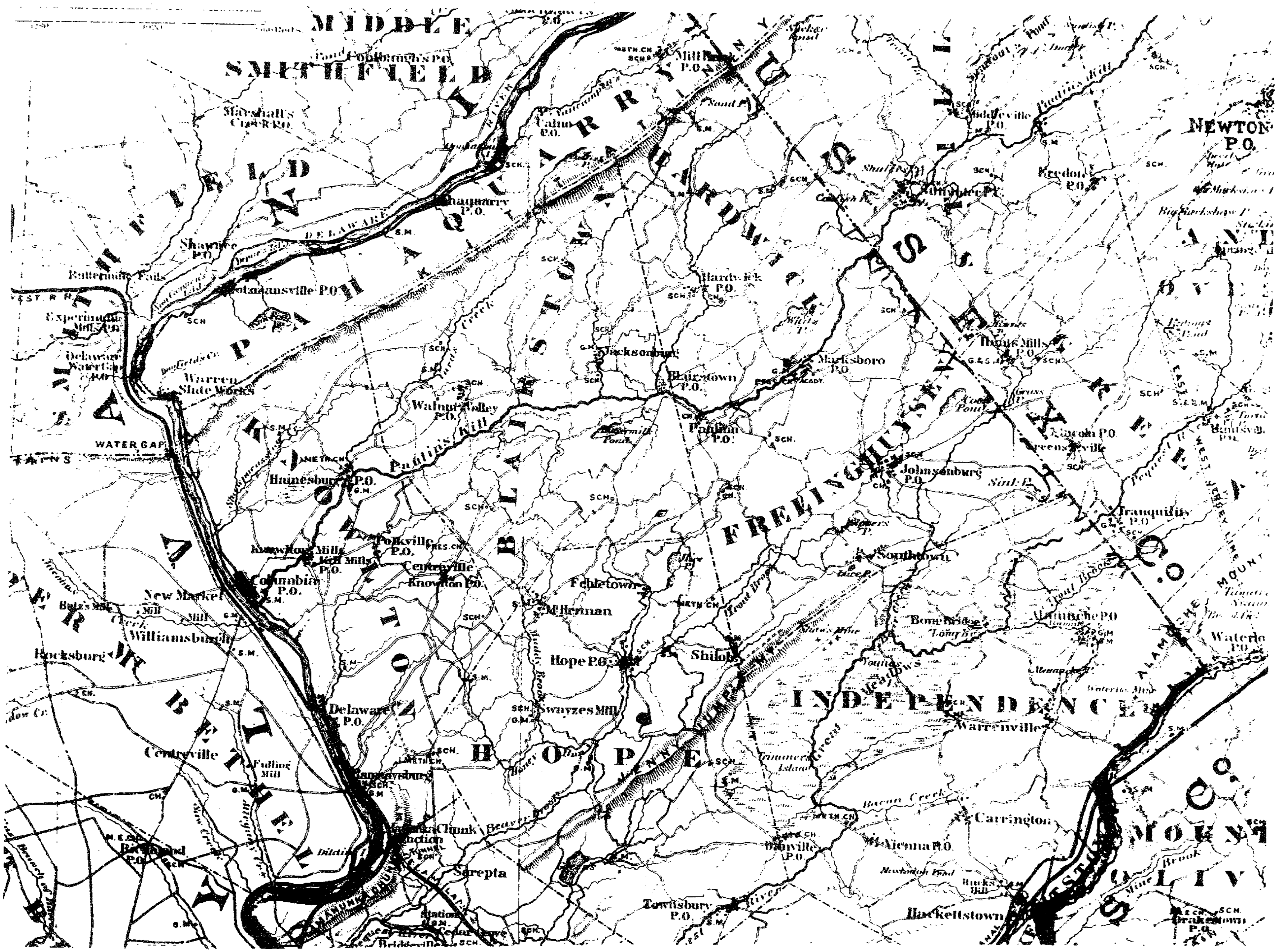
Fig. 2 Photograph of contorted amphibolite inclusion in Quartz-Oligoclase Gneiss located at field trip stop 4 (see Fig. 1)



Relief Map, Warren County, State Atlas, 1872