STATE GEOLOGICAL AND

NATURAL HISTORY SURVEY

OF CONNECTICUT

THE BEDROCK GEOLOGY OF THE DANBURY QUADRANGLE

With Map

Open Map

By

JAMES W. CLARKE, PH.D.

Quadrangle Report No. 7

1958

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INTRODUCTION

The Western Highlands of Connecticut have attracted geologists since the beginning days of the science in this country. The superior work of James G. Percival culminated in the publication in 1842 of the *Report of the Geology of the State of Connecticut;* in this treatise the Western Highlands are described with remarkable accuracy. The close proximity of the region to Yale and Columbia universities has made it readily accessible to a large number of outstanding geologists. It has also supplied many of the definitive mineral specimens that have been studied in the mineralogical laboratories of Yale and other universities. Yet, the Western Highlands have long remained one of the least known regions geologically in the country. The high degree of metamorphism, the complex structure, and the absence of fossils render these rocks almost indecipherable except by very detailed work on large-scale maps. Recent publication of a great number of 7½ minute quadrangles has now made detailed mapping possible.

The purpose of this study was to map the bedrock of the Danbury 7½ minute quadrangle, to determine the geologic history of the area, and to search out and evaluate any mineral resources. Some of the more significant problems were:

(1) The age and correlation of the marble and associated sillimanite biotite gneiss; these are the Inwood marble and the Manhattan formation.

(2) The relation between the Inwood marble and the Hartland formation.

(3) The extent of the Brookfield plutonic series and the Danbury augen granite; these have been known previously as the Brookfield diorite and the Danbury granodiorite respectively.

(4) The extent of the Precambrian Highlands and the practicality of the differentiation of this area into more specific units.

The many plutons of the quadrangle presented ample opportunity to study mode of emplacement. This subject occasioned many canny discussions in the field with other geologists working in the region.

ACKNOWLEDGEMENTS

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long hours to critical reading of the manuscript. He also arranged numerous field parties, which enabled the geologists of the region to work more closely and profitably.

DESCRIPTION OF THE FORMATIONS

The units of the Precambrian Highlands are described first; they are:

Gneissic granite and trondhjemite
Hornblende gneiss and amphibolite
Danbury augen granite

Next, the metasediments to the east and south of the Precambrian Highlands are described. These are:

New York City group	Manhattan formation Inwood marble Fordham gneiss
Hartland formation	

Finally, the igneous rocks that cut the New York City group and the Hartland formation are described. These are:

Brookfield plutonic series
Younger granite

Structual features characteristic of each unit are described under the unit. The broader aspects of structure, however, are discussed in the section that follows the description of the formations.

GNEISSIC GRANITE AND TRONDHJEMITE

INTRODUCTION

The older granitic rocks of the Precambrian Highlands are here designated the *gneissic granite and trondhjemite.* These rocks are interlayered on a large scale with the *hornblende gneiss and amphibolite.* The relation between the granite and the trondhjemite was not determined; no systematic distribution was observed. Some of the granite is strongly banded, but most is characterized by biotite-rich septa; the suggestion is made that the latter type originated by flooding of metasediments with granitic material.

HISTORIC REVIEW

The gneissic granite and trondhjemite terrane has not previously been differentiated. Percival (1842, p. 92) treated the terrane as a part of formation H2beta; it is designated as part of the Becket gneiss on the State Geological Map of 1906. The unit as set up in this report is not a genetic one; rather, it is a granitic terrane that is mappable by virtue of its petrographic contrast with the surrounding hornblende gneisses, amphibolites, and augen granite.

AREAL DISTRIBUTION

The gneissic granite and trondhjemite terrane is the most extensive unit of the Precambrian Highlands. The largest area underlain by this material is northwest of the city of Danbury; it underlies 7.4 square miles within the quadrangle and extends into the Brewster quadrangle. A lens-shaped pluton in the northwestern part of the quadrangle underlies 1.1 square miles; it extends northward from the village of New Fairfield. An area along the northern quadrangle boundary and one in the northwestern corner are not sharply defined, for there is a gradation through a migmatite zone into hornblende gneiss. The contacts were drawn to separate areas that contain over 50 percent of the different rock types. The area along the northern border underlies 0.2 square miles, and that in the northwest corner underlies 0.1 square miles,

APPEARANCE IN OUTCROP

The gneissic granite and trondhjemite unit is well exposed throughout most of the area that it underlies. It is more resistant to weathering than the surrounding hornblende gneisses and consequently forms hills. Individual outcrops are generally flat pavements 30 to 50 feet wide. In some places low cliffs up to 10 feet high have formed; they are controlled by joints.

Exposures of typical granite may be seen on the hill north of the junction of State Route 37 and Padanarum Road. Trondhjemite crops out in the hills west of South King Road in the vicinity of Dickens Pond.

PETROGRAPHY

The petrographic types that constitute the gneissic granite and trondhjemite terrane are granite, quartz monzonite, granodiorite, and trondhjemite. The granite and trondhjemite are the most common and are present in about equal proportions. There is also a small amount of metasediment, which is not mappable as a separate rock.

The rock is everywhere gneissic, and two kinds of gneissosity are common. In one kind, closely spaced layers of biotite-rich material alternate with sialic material; these layers are 1 to 2 mm. thick. The other kind of gneiss is characterized by widely spaced, discontinuous biotite-rich septa, which are typically 2 mm. thick, 30 mm. long, and spaced 10 to 50 mm. from one another. This second type is by far the more widespread.

Quartz occurs as equant grains that range from 0.1 to 1 mm. in diameter. The intergrain contacts are straight; there is no interlocking. Patches of fine-grained material appear to have developed by crushing of single larger grains.

Microcline ranges in grain size from 0.5 to 2 mm., and grid-twinning is moderately to well developed in most grains. Exsolution lamellae are commonly present; they are about 0.01 by 0.002 mm. The interior of some grains is composed of over 50 percent lamellae whereas the margins are free of them.

Plagioclase ranges from An_{10} to An_{30}; the more sodic material is not common and is confined to granite. Trondhjemite generally carries oligoclase, An_{25}. The grain size ranges from 0.5 to 2 mm.

Biotite is pleochroic from light brown to rich brown or opaque. The flakes are about 0.5 by 0.1 mm.

Sillimanite is widespread but is nowhere abundant. It occurs as stringy patches of randomly oriented to subparallel needles, which are about 0.02 mm. by 0.001 mm. The patches are generally confined to the biotite-rich septa.

Zircon, apatite, and black iron ores are ubiquitous, and a small amount of sphene and garnet is present in some places.

Rosiwal analyses (in percent) of typical specimens of granite and trondhjemite are given in Table I.

Table I

	1	2	3	4
Quartz	14	34	25	34
Microcline	71	66	tr	
Plagioclase	5		56	59
Biotite	10	tr	19	7

1. Biotite granite.
2. Leucogranite.
3. Biotite trondhjemite.
4. Biotite trondhjemite.

STRUCTURE

The rock of this terrane is everywhere gneissic. The strongly banded varieties are commonly interlayed with gneisses that appear to be metasediments, but they also occur alone over large areas. Xenoliths were nowhere found in this type. Gneisses characterized by the discontinuous septa of biotite-rich material occur as more discrete plutons. They commonly carry isolated, blocky xenoliths where amphibolite is the invaded rock; these xenoliths are a similar amphibolite and show no alteration. Gneisses that are banded and those that carry biotite-rich septa grade into one another, and separation into mappable units was considered impractical.

The relation of the granite to the trondhjemite was not determined; they have a similar appearance in hand specimen, and the thin-section study failed to reveal any systematic distribution.

The gneissic granite and trondhjemite terrane is interlayed on a large scale with the contiguous hornblende gneiss and amphibolite; it also contains a small amount of non-feldspathized metasediment. In some places the gneiss cuts across the amphibolite; in others it is lit-par-lit. The relation of the gneiss to the metasediment is lit-par-lit in some places and gradational in others.

GENESIS

The gneissic granite and trondhjemite do not form a petrogenic unit except in the broad sense that all parts may have developed simultaneously.

The well banded types appear to have developed by feldspathization of metasediments. No evidence was found, however, to indicate the manner in which this change was effected.

Those gneisses that contain the discontinuous biotite-rich septa have the character of igneous rocks; they occur in part as lens-shaped plutons, and they carry xenoliths. Close to the contact with metasediments the septa are closely spaced, and farther out they are more widely spaced. The septa are similar in composition to the bordering metasediments; they carry stringy patches of sillimanite needles. The hypothesis is suggested that these gneisses developed by gradual flooding of sillimanite-biotite schist with granitic igneous material. As the new material was added, the layers of biotite schist were broken up into septa and then spread farther apart. Such an idea calls for the added material to have been supplied from depth; a source across foliation in the hornblende gneisses is not mechanically likely. The magma could, of course, be of palingenic development from similar hornblende gneisses or metasediments at depth. Further, the process that gave rise to the development of those gneisses that carry the septa may also have been responsible for the feldspathization that produced the well-banded gneisses.

HORNBLENDE GNEISS AND AMPHIBOLITE

INTRODUCTION

The hornblende gneiss and amphibolite terrane is a composite field unit that is made up of several rock types. The feature that most of these rocks have in common is the prominence of hornblende; the only exceptions are the calc-silicate granulites, which are included here because of their association with the hornblende gneisses. A small amount of gabbro (troctolite) and diorite is also included in this terrane. The unit, in fact, contains all the non-granitic rocks of the Precambrian Highlands. These hornblendic rocks may be genetically related in part.

HISTORICAL REVIEW

The hornblendic rocks of the Precambrian Highlands were noted early by Percival (1882, p. 92), who grouped them with his formation H2 beta. On the State Geological Map of 1906 part of this terrane is mapped as amphibolite within the Becket gneiss. In the present report several rock types are grouped to form the unit. The final word in the subdivision of the Precambrian Highlands, however, may be far off, and this unit may be further differentiated into several mappable units.

AREAL DISTRIBUTION

Hornblende gneiss and amphibolite crop out in five separate mappable areas within the quadrangle. Many single exposures occur within the contiguous gneissic granite and trondhjemite terrane and in the Danbury augen granite, but none of these were large enough to map.

Just north of Mill Plain Swamp in the southwestern part of the quadrangle is an area of 0.6 square miles, in which the rock is principally hornblende gneiss.

Amphibolite and hornblende troctolite compose the hill southeast of Lower Kohanza Reservoir. The body is lens-shaped and underlies 0.1 square miles.

Hornblende gneiss and amphibolite crop out over an area of 0.3 square miles north of Upper Kohanza Reservoir.

Amphibolite and diorite underlie 0.1 square miles north of East Lake Reservoir.

The largest area of hornblende gneiss and amphibolite extends from just north of Danbury northward for several miles into the Brewster and New Milford quadrangles. It underlies 3.6 square miles within the Danbury quadrangle, and is host to several plutons of gneissic granite, trondhjemite, and Danbury augen granite.

Where the hornblendic rocks have been injected by small bodies of granite, it is difficult to draw contacts. This is particularly true for the mass that extends into the Brewster and New Milford quadrangles. The contacts north of Upper Kohanza Reservoir are also ill-defined.

APPEARANCE IN OUTCROP

Outcrops of the hornblende gneiss terrane are unevenly distributed. In the western portion of the quadrangle north of U. S. Route 6, exposures are closely spaced, but farther north outcrops are generally fewer.

Outcrops are rarely as much as 50 feet long, and the relief of the individual exposure ranges from a smooth pavement to low, craggy knolls up to 10 feet high.

The topography developed on this terrane is generally of low relief. Outcrops on valley sides indicate that the hornblende rocks underlie many of the lakes and swamps, and that in general they form valleys.

Layered hornblende gneiss may be seen on the small hill just north of U.S. Route 6 about 0.2 miles from the western margin of the quadrangle. Calc-silicate granulite crops out east of B.M. 464 on U.S. Route 6 west of Danbury. Hornblende troctolite is exposed on the hill southwest of Lower Kohanza Reservoir. Quartz diorite may be seen on East Lake Brook 2000 feet south of Gillette Road. Amphibolite crops out at several places along State Route 37 northwest of the village of New Fairfield.

PETROGRAPHY

Several types are included in this terrane; the unit indeed includes all the non-granitic rocks of the Precambrian Highlands. The genetic relation of these rocks is obscure. The layered hornblende gneisses are certainly metasediments, and some of these layers are amphibolite; there are also large areas of amphibolite. The amphibolites in turn grade petrographically into troctolite, which appears to be igneous.

The unifying characteristic of these rocks is their hornblende content; they stand in petrographic contrast to the gneissic granite and trondhjemite terrane and the Danbury augen granite.

Hornblende gneiss. The hornblende gneiss exhibits pronounced layering in many places. Layers in which hornblende predominates alternate with sialic layers that contain little or no hornblende.

Quartz occurs as irregular, elongate grains that are up to 2 mm. in diameter. It is abundant in the sialic layers and absent in the mafic-rich layers.

The plagioclase is andesine, An_{45}. Pericline and albite twinning produce a grid like that of microline. The grains are anhedral and about 1 mm. in diameter.

Hornblende occurs as equant to elongate grains that range from 0.5 to 1 mm. in diameter. A typical pleochroic formula is: X=light yellowish green, Y=dark green, Z=dark green.

Minor amounts of biotite and apatite are also present.

Rosiwal analyses of a hornblende-rich layer and of a hornblende-free layer are given in Table II.

Calc-silicate granulites. These rocks have a restricted distribution and appear to occur near the margins of the hornblende gneiss masses. Three typical varieties are:

(1) Quartz-andesine-diopside granulite. In hand specimen this rock has a spotted appearance. Dark-green rounded grains of diopside lie in a continuum of quartz and feldspar.

The diopside occurs as irregular, anhedral grains from 0.5 to 1 mm. in diameter. Z:c=33°, and birefringence=0.029.

The quartz grains are equant and not interlocking; they range from 0.1 to 0.3 mm. in diameter.

Plagioclase is andesine, An_{30}. The combination of albite and pericline twinning looks like a poor development of the grid twinning of microcline.

Small amounts of sphene, apatite, biotite, and pyrite are present.

A Rosiwal analysis of this rock is given in Table II.

(2) Microcline-augite granulite. This rock is composed of about 90 percent augite and 10 percent microcline. Small amounts of sphene and quartz are present.

(3) Augite-quartz-albite granulite. The augite and quartz are similar to that in the other calc-silicate granulites; the plagioclase is albite,

however. The average grain size is 0.5 to 1 mm. This particular rock carries so much iron sulphide in one place that a prospect pit had been put down on the outcrop. Allanite is also an abundant accessory mineral. A Rosiwal analysis is given in Table II.

Amphibolite. Much of the rock of this terrane is non-layered, granulitic, and composed of hornblende and plagioclase; this rock type is called amphibolite.

Hornblende occurs as irregular, anhedral grains, which range from 0.1 to 1 mm. in diameter. A typical pleochroic formula is: X=light greenish brown, Y=greenish brown, Z=dark greenish brown.

Plagioclase commonly does not exhibit well-defined polysynthetic twinning; rather, twinning is ill-defined and resembles poorly developed grid twinning of microcline. The composition ranges from An_{35} to An_{55} in the several specimens examined.

Biotite is abundant in some rocks of this type. It is pleochroic from brown or light brown to nearly opaque.

Garnet and augite are present in some places but are nowhere abundant.

Magnetite and apatite are common accessory minerals.

The Rosiwal analysis of a typical specimen is given in Table II.

Hornblende troctolite. The principal minerals of this rock are hornblende, olivine, and plagioclase, An_{50}; the rock might just as well be called an olivine diorite.

Olivine occurs as clear, colorless, subhedral grains that range from 0.5 to 1mm. in diameter. It has altered in places to a fine-grained material that has the appearance of talc and magnetite.

The hornblende grains are subhedral and 0.5 to 1 mm. in diameter. The pleochroic formula is: X=light greenish yellow, Y=dark greenish brown, Z=dark greenish brown.

Plagioclase occurs as equant, anhedral grains about 1 mm. in diameter. It is An_{50}.

Small amounts of biotite and apatite are present.

A Rosiwal analysis of hornblende troctolite is given in Table II.

Augite-biotite quartz diorite. A small amount of this rock occurs in the western part of the quadrangle. It is allotriomorphic and has an average grain size of 0.5 to 1 mm. The plagioclase is An_{30}. A Rosiwal analysis is given in Table II.

STRUCTURE

The hornblende gneisses commonly exhibit a marked layering; hornblende-rich layers alternate with layers containing little or no hornblende.

Table II (values in percent)

	1a	1b	2	3	4	5	6
Hornblende	73				43	33	
Plagioclase	27	55	43	68	53	41	46
Quartz		45	12	22			7
Augite				10			21
Olivine						23	
Biotite					4	3	26
Diopside			45				

1a Hornblende-rich layer of hornblende gneiss.
1b Hornblende-free layer of hornblende gneiss.
2 Quartz-andesine-diopside granulite.
3 Augite-quartz-albite granulite.
4 Amphibolite.
5 Hornblende troctolite.
6 Augite-biotite quartz diorite.

The hornblende-rich layers are relatively more competent and show boudinage in many places. Where the space between boudins is only a few centimeters, a pegmatitic aggregate of quartz and feldspar has developed.

The amphibolite is granulitic. Although the hornblende grains are somewhat elongate and subparallel, they do not impart to the rock a platy structure like that of the amphibolites in the Manhattan formation.

The troctolite and diorite are but weakly foliated; the mafic minerals are slightly elongate and evenly distributed so that the rock has a planar structure but no layering.

The rock of this terrane occurs in large lenses within the gneissic granite and trondhjemite terrane. Lenses of gneissic granite and trondhjemite occur in turn within the hornblendic rocks. The margins of these lenses are commonly ill-defined because of lit-par-lit relationships.

GENESIS

The marked layering of much of the hornblende gneiss is indicative of a water-laid deposit. Persistent layers carrying 75 percent hornblende alternating with layers carrying no hornblende can certainly not be attributed to metamorphic differentiation. This material was probably deposited originally as calcareous muds. The calc-silicate rocks are apparently derived from calcareous grits or sandstones.

The amphibolites have the general composition of basalt, and this composition is uniform over large areas. These features suggest an origin as basaltic flows or intrusions.

The association in space of gabbro (troctolite) and diorite with the hornblendic rocks may be genetic; they could be a preorogenic co-magmatic series. The association could also be due to structure; one type may have shown a predilection for invading another. Finally, the association may be purely fortuitous.

DANBURY AUGEN GRANITE

INTRODUCTION

The Danbury augen granite is a porphyritic gneissic granite that crops out along the western shore of Lake Candlewood in the towns of Danbury and New Fairfield. It is a distinctive rock characterized by large microcline megacrysts[1].

The host rock is nearly everywhere amphibolite of the Precambrian Highlands. Sharp contacts and unoriented xenoliths suggest an igneous origin. This unit has not been observed outside the Precambrian Highlands.

HISTORICAL REVIEW

The Danbury granodiorite was established as a unit by Rice and Gregory (1906, p. 108); the western shore of Lake Candlewood as well as the Shelter Rock area were apparently considered typical localities. On the State Geological Map that accompanies their report the unit includes extensive areas in southwestern Connecticut.

Percival (1842, p. 90) denoted part of this unit H2 alpha. Agar (1933, p. 1-19) gives a complete description of the unit and recognizes that several rock types are present.

In this report much of the area that was mapped as Danbury granodiorite on the State Geological Map of 1906, including the Shelter Rock area, is assigned to the Brookfield plutonic series. The name Danbury augen granite is retained for the granites that crop out along the western shore of Lake Candlewood in the towns of Danbury and New Fairfield; this granite is quite different from the rock in those other areas.

AREAL DISTRIBUTION

Four plutons of the Danbury augen granite crop out in the quadrangle. The largest of these is a long, narrow mass just west of Lake Candlewood; it underlies 3.1 square miles within the quadrangle and extends into the New Milford quadrangle. Two small plutons lie west of the village of New Fairfield; the southwesterly one underlies 0.03 square miles, and the other 0.04 square miles. The fourth pluton is located along the northern border of the quadrangle; it underlies 0.015 square miles within the quadrangle and extends into the New Milford quadrangle.

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[1]A megacryst is here defined as any crystal or grain in an igneous or metamorphic rock that is significantly larger than the surrounding ground-mass or matrix. It is a nongenetic term and includes phenocrysts, porphyroblasts, and porphyclasts.

APPEARANCE IN OUTCROP

The area underlain by the Danbury augen granite is marked throughout by excellent outcrops. This rock type forms hills and accounts for the high relief just west of Lake Candlewood. Outcrops make smooth pavements on the tops and on the dip slopes (west slopes) of the drumlins; many of these pavements are over 100 feet wide. The scarp slopes (east slopes) are marked by cliffs, and vertical faces 50 feet high are common. At many places along the base of the scarp slopes, piles of huge joint blocks have collected; these render the terrane almost impassable.

The rock itself is easily recognizable in the field. The large, closely spaced augen of microcline in a thin, anastomosing matrix of mafic-rich material are distinctive. This rock is similar to part of the Brookfield plutonic series, and the two might easily be confused in some outcrops. The Brookfield series, however, is not so silicic; it carries more plagioclase and generally more mafic minerals.

Exposures of typical material may be seen on the hill northwest of Wildmans Landing and along Candlewood Lake Drive West just west of Candlewood Knolls.

PETROGRAPHY

The Danbury augen granite has a distinctive appearance; megacrysts (augen) of microcline are embedded in a finer-grained mafic-rich material. Either the megacrysts or the mafic-rich septa may form the continuum. Foliation is strongly developed; it is due to parallelism not only of the mafic-rich septa but also of the longer dimensions of the individual mineral grains. Lineation within the foliation is produced by a columnar habit of the microcline megacrysts. The rock is a true granite; plagioclase is everywhere subordinate to microcline. The most common variety is hornblende-biotite granite.

Quartz occurs as rounded to angular anhedral grains, which range from 0.1 to 1 mm. in diameter.

Microcline occurs abundantly as flattened columnar megacrysts, which are typically 1 cm. by 2 cm. in cross-section and 5 to 10 cm. long. These are commonly compound; they are aggregates of many grains of microcline and some of quartz. The plunge of the lineation is generally almost vertical; therefore the cross-section presented by most outcrops is transverse to the lineation and reveals only the lens-shaped cross-section of the megacysts. Grid twinning is well developed for the most part, but in many rocks it is barely visible.

The plagioclase is albite, An_{10}; it is not abundant. The average grain size is 0.5 mm.

The flakes of biotite are about 0.5 by 0.05 mm. Pleochroism is from pale yellowish brown to opaque.

Hornblende occurs as irregular grains about 0.5 mm. in diameter. The pleochroic formula is: X=light brownish green, Y=deep green, Z= deep green.

Apatite and zircon occur as euhedral to subhedral grains, which are about 0.05 mm. in diameter. Sphene is common in some specimens; the grain size is 0.1 to 0.2 mm. Epidote and allanite are sparingly present; the allanite forms rims around the epidote. Black iron ore is ubiquitous and ranges from 0.1 to 0.2 mm. in diameter.

The Rosiwal analysis (in percent) of a typical specimen is given in Table III.

Table III

	1
Microcline	**45**
Quartz	**35**
Biotite	**16**
Hornblende	**4**

1 Hornblende-biotite granite.

STRUCTURE

The Danbury augen granite is strongly gneissic; there is also a lineation produced by elongation of megacrysts (augen). The foliation is nearly everywhere vertical or steep to the west, and the lineation, where determinable, is vertical or plunges steeply to the north or northwest. The foliation has a general north-south trend parallel to the regional structure and to the long dimension of the largest pluton. In many places, however, there are swirls in the foliation, which have a radius of curvature of a few feet. In other places the foliation is transverse to the regional structure and has an east-west trend. The southern contact of the larger pluton northwest of New Fairfield is exposed. Within a few inches of the contact the north-south foliation of the augen granite gives way to an east-west foliation that parallels the contact.

The steep plunge of the elongate microcline megacysts suggests that their lineation is parallel to the direction of movement during emplacement of the pluton; this is particularly impressive in the small plutons. At the exposure northwest of New Fairfield described above, this lineation is parallel to:

(1) the axes of undulation of the contact,

(2) the fold axes of the marginal foliation,

(3) the axes of drag folds within the invaded amphibolite.

The augen granite shows a predilection for amphibolite. Not only does amphibolite constitute the invaded rock nearly everywhere, but also it is the principal type found as screens and xenoliths. The foliation of the amphibolite is cut by that of the augen granite; also, xenoliths of amphibolite lie with random orientation in the augen granite.

GENESIS

The segregation of the mafic minerals in well defined septa in this rock is suggestive of a metasomatic origin; these septa are schistose. No gradational contacts were found, however, nor were nebulites or skialiths anywhere observed. Rather, the contacts are sharp, and unoriented xenoliths are common. Further, the foliation of the augen granite cuts across the foliation of the invaded rock at many places. A magmatic or rheomorphic origin is therefore favored.

The augen granite shows a predilection for amphibolite of the Precambrian Highlands. The hornblende gneiss and amphibolite terrane has also been invaded by gneissic granite and trondhjemite of the Precambrian Highlands. The question therefore arises whether the gneissic granite and trondhjemite or the augen granite is older. A xenolith of amphibolite within the augen granite contains a small dike of granitic material that is similar to the gneissic granite. On this basis the augen granite is believed to be younger than the gneissic granite and trondhjemite. The augen granite invaded amphibolite probably because it was the most receptive host at the time. The schistose rock of the Precambrian Highlands apparently had already been flooded by the gneissic granite and trondhjemite, which destroyed the schistose structure so favorable to magmatic intrusion.

The general appearance of the Danbury augen granite is not that of typical granites. This difference probably lies in the mode of origin. That no pegmatites are associated with this rock indicates that on emplacement the material was low in volatiles. If low in volatiles, the megacrysts probably developed before consolidation; there is no indication of later activity that could have caused the growth of porphyroblasts. The steep plunge of the megacrysts is thus apparently primary and related to the movement of emplacement. A vertical elongation of this type is characteristic of salt domes; this is particularly true in the case of elongate anhydrite crystals (Balk, 1949, p. 1806). Escher and Kuenen (according to Balk, 1949, pp. 1814-1815) have demonstrated that vertically plunging folds develop in a plug-like intrusion if there is a range in the mobility of adjacent layers. The suggestion is therefore made that the augen granite was emplaced in a manner similar to that of a salt plug, that it is rheomorphic. A metasediment, mobilized and forced upward, would be characterized by a range in mobility of adjacent layers. This would produce a differential slip between layers, which would develop elongation like that in the augen granite. The distance traveled from the place of origin at depth may have been great, and the amount of remelting could have been small. In fact, the principal change in the rock during the whole process may have been merely the growth of the megacrysts.

FORDHAM GNEISS

INTRODUCTION

The Fordham gneiss underlies the Inwood marble stratigraphically and is the oldest exposed unit of the New York City group. It is generally recognizable in outcrop because of its persistent layering. The principal rock type is hornblende-biotite-andesine gneiss, which is probably derived from siltstone.

HISTORICAL REVIEW

The Fordham gneiss was named by Merrill (1890, p. 389) for exposures in Fordham Heights, New York City. The part of this unit that lies within the Danbury quadrangle was denoted H1 by Percival (1842, p. 86); he recognized the difference between it and the gneisses to the north in the Precambrian Highlands. On the State Geological Map of 1906 the area is lumped with the Precambrian Highlands and mapped as Becket gneiss. The correlation in this report is based on a reasonable projection along strike from material that is recognizably Fordham gneiss.

AREAL DISTRIBUTION

Only five definite outcrops of Fordham gneiss were found within the quadrangle. These are widely spaced and were recognized only by following known Fordham material from the Peach Lake and Bethel quadrangles into the Danbury quadrangle. The five outcrops, however, indicate that an area of about 0.5 square miles within the quadrangle is underlain by this unit.

Material that is petrographically and structurally similar to Fordham gneiss also crops out on Pine Island and Vaughn's Neck and occurs as screens in the younger granite to the east of Lake Candlewood. This Fordham type rock extends on northward into the New Milford quadrangle.

APPEARANCE IN OUTCROP

The Fordham gneiss is generally well exposed in southwestern Connecticut and southeastern New York. Just south of the Danbury quadrangle in the Bethel quadrangle it makes large outcrops of low relief and stands as hills above valleys that have developed on Inwood marble, the formation stratigraphically above. Original bedding is commonly visible; persistent layers rich in hornblende and/or biotite alternate with more sialic layers, and the outcrops have a banded appearance.

An exposure of Fordham gneiss may be seen on the southern margin of the quadrangle on top of the hill just west of Parks Pond.

PETROGRAPHY

The Fordham gneiss within the Danbury quadrangle is a hornblende-biotite-andesine gneiss. It is strongly foliated and weakly layered; individual layers are very persistent. The layering is produced by a range in the ratio of mafic to sialic minerals present. There is also a range in the ratio of hornblende to biotite.

Quartz occurs as equant to slightly elongate grains that are 0.1 to 0.3 mm. in diameter.

The plagioclase is andesine, An_{30-35}. It is part antiperthitic; exsolution lamellae of microcline make up 5 to 10 percent of some grains. The grain size is 0.5 mm.

Biotite is pleochroic from light brown to dark greenish brown, and the grains average 0.5 mm. in diameter.

Hornblende occurs as irregular grains that are 0.5 mm. in diameter. The pleochroic formula is: X=light greenish yellow, Y=greenish brown, Z=brownish green.

Chlorite is pleochroic from yellowish green to rich green, and the flakes are 0.1 mm. or less in diameter.

Magnetite and apatite are abundant accessories.

A Rosiwal analysis (in percent) is given in Table IV.

Table IV

	1
Plagioclase	46
Quartz	19
Biotite	27
Hornblende	8

1 Hornblende-biotite-oligoclase gneiss.

STRUCTURE

Since there are but five definite outcrops of the Fordham gneiss within the Danbury quadrangle, the regional structural setting must be determined elsewhere. These rocks extend to the south and southwest into the Bethel and Peach Lake quadrangles where they are involved in sweeping isoclinal folds; the Fordham gneiss within the Danbury quadrangle appears to be the core of one of these folds.

The Fordham gneiss is stratigraphically below the Inwood marble (Prucha, 1955, p. 1606). In the Bethel quadrangle to the south the marble is absent in some places, and the Fordham gneiss lies against the Manhattan formation. Fordham type gneiss also occurs within Manhattan type gneiss. These two rocks may alternate stratigraphically or they may be infolded into one another. Prucha (1955, p. 1606) believes that they alternate stratigraphically.

The interpretation that the Fordham formation lies stratigraphically below the Inwood marble is based on the work of Prucha mentioned above and also on structural relations observed by the writer to the south in the Bethel quadrangle. Within the Danbury quadrangle, however, no contribution to this problem can be made. There is indeed a possibility that the Fordham formation is part of the Precambrian of the Hudson Highlands and that it lies uncomfortably under the Inwood marble.

GENESIS

The persistent layering of the Fordham gneiss is indicative of a sedimentary origin. The biotitic varieties were probably derived from argillaceous siltstones, and those rich in hornblende from somewhat calcareous siltstones.

The mineral assemblages in these gneisses belong to the amphibolite facies. The subfacies is not determinable.

INWOOD MARBLE

INTRODUCTION

The Inwood marble lies stratigraphically above the Fordham gneiss and below the Manhattan formation; the three units comprise the New York City group. The composition ranges from pure calcite in some areas to pure dolomite in others. In many places the two types are interbedded or mixed within the same bed.

The Inwood marble is an excellent stratigraphic marker; the Manhattan and Hartland formations would perhaps otherwise be indistinguishable.

This is the only unit within the quadrangle that is of commercial value.

HISTORICAL REVIEW

The Inwood formation was named by Merrill (1890, p. 390) from the Inwood district of New York City; the original name was *Inwood limestone.* Percival (1842, p. 85) denoted this formation as H1, and on the State Geological Map of 1906 it is called the Stockbridge limestone. In subsequent work dealing with this unit within the quadrangle, Moore (1935, p. 15) used the term Stockbridge series, and Balk (1936, pl. 1) Wappinger marble. In this report the name Inwood marble is used because the formation is very nearly physically continuous with the Inwood of the type locality.

AREAL DISTRIBUTION

The main belt of the Inwood marble within the Danbury quadrangle underlies an area if 10.0 square miles. The northern extension of this belt passes through the New Milford quadrangle and finally pinches out in the New Preston quadrangle (Gates, 1952, p. 15). To the south the belt swings westward; in making the turn the outcrop area assumes a highly irregular form. The westward extension of this belt passes into New York State where it ramifies into several belts, some of which extend to New York City.

A second area of 0.06 square miles lies along the southern quadrangle boundary and extends into the Bethel quadrangle.

A third area is mapped as Inwood marble, though no outcrops were found within its bounds; it is a projection from outcrops in the Bethel quadrangle to the south and the Brewster quadrangle to the west. This belt is obscured by Mill Plain Swamp.

APPEARANCE IN OUTCROP

The marble crops out in closely spaced exposures within a particular outcrop area; these areas, however, are widely separated. Outcrops are elongate parallel to foliation and are typically about five feet wide and twenty feet long. Although the marble commonly makes low hills, the outcrops themselves show little or no relief.

Layering is generally present; it is caused by a range in grain size and/or a range in mineral composition and has the appearance of original bedding. Foliation is parallel to the layering except at the crest or trough of some of the isoclinal folds where it passes without deflection across the layering.

In many places the marble shows post-glacial weathering; it has disintegrated into a loose sand.

There is a large exposure of typical dolomite marble just west of the junction of U.S. Route 7 and Laurel Hill Road north of Brookfield. Excellent exposures of calcite marble occur in a quarry just east of Still River southeast of Beaver Brook Mountain.

PETROGRAPHY

In some areas the marble is made up almost entirely of calcite, in others of dolomite. Extensive areas are also made up of a mixture of both these minerals. The accessory minerals present are phlogopite, tremolite, diopside, forsterite, quartz, microcline, zircon, tourmaline, and antigorite.

Both the calcite and the dolomite marble are gray to white. The only coloration observed is the brown stain of supergene limonite.

The grain size ranges from 0.1 mm. to 2 mm.; the average is 1 mm. In detail the calcite grains interpenetrate along their boundaries; this fabric is referred to as denticulate by Dale (1912, p. 18) and as zig-zag by Vogt (1898, p. 12). The grain boundaries of dolomite are generally straight. The individual grains of both calcite and dolomite are equant in general but have a slight elongation parallel to the layering and foliation. All grains are highly twinned; none of the twin lamellae show any deformation.

Phlogopite occurs as isolated flakes and in discontinuous zones parallel to foliation. It is colorless in thin section, $2V=0°$. The average grain size is 0.1 by 0.3 mm., and the flakes commonly are slightly bent. There is no indication of any alteration to another mineral.

Tremolite occurs as isolated, bladed crystals up to 2 cm. in length. $Z{:}c=22°$. It has altered in part to an ill-defined fibrous aggregate, which has the general appearance of talc.

Diopside occurs as equant, subhedral grains that average 0.5 mm. in diameter. $Z{:}c=33°$. It is not abundant.

Forsterite is abundant in many places in the marble. It occurs as equant, subhedral grains that range from 0.1 to 0.5 mm. in diameter. $2V = 95°$ and the sign is positive; this indicates pure forsterite. Near contacts with granite intrusives it has been altered partly or completely to antigorite.

Quartz and microcline occur as scattered grains, which are equant, rounded, and on the average 0.1 mm. in diameter. Zircon occurs as elongate, rounded grains, which are 0.02 to 0.1 mm. in diameter. Some of the zircon is pleochroic: slow=colorless, fast=brownish yellow. That the grain size of these minerals is about the same indicates that they may be detrital.

Tourmaline is apparently hydrothermal; it encloses rounded grains of microcline and quartz. The pleochroism is: fast=pale greenish brown, slow=greenish brown. Cross fractures are common.

Antigorite has developed by alteration of forsterite. The alteration is complete in marble that lies directly in contact with granitic intrusives, but there is none in specimens taken 50 feet from intrusive contacts.

Rosiwal analyses (in percent) of typical specimens are given in Table V.

Table V

	1	2	3	4
Calcite	94	91	75	73
Phlogopite	6		16	8
Tremolite			1	tr
Olivine			8	1
Microcline		6		
Quartz		3		
Serpentine				18

1 Phlogopite marble.
2 Quartz-microcline marble.
3 Olivine-phlogopite marble.
4 Serpentinized olivine-phlogopite marble.

STRUCTURE

Foliation within the Inwood marble is produced not only by a preferred orientation of phlogopite and tremolite but also by a preferred orientation of slightly flattened grains of calcite and dolomite. The silicates are characteristically concentrated in layers, and the layers are generally parallel to foliation; this layering has all the appearances of original bedding. Foliation parallels the layering around the crests of larger folds, but it passes across the layering where the folds are small enough to be seen in hand specimen.

Small-scale isoclinal folding can be observed in many outcrops, and a great degree of transposition is indicated. There is no way of determining, however, how much this unit has been thickened by isoclinal folding.

The most common types of lineation within the unit are streaking and fluting. The streaking is generally produced by phlogopite; more rarely it is due to tremolite. Fluting commonly takes the form of deep grooves imposed on the foliation. In all places where their relations are determinable, the streaking and fluting are parellel to the fold axes of the larger folds.

Small granitic bodies are intrusive into the marble; these are in general conformable to the foliation but locally cross-cutting.

A mechanical deformation has affected both marble and granite. Large lenses (20 feet wide) as well as small isolated fragments of granite occur in high-angle shear zones within the marble.

GENESIS

The Inwood marble developed by regional metamorphism of limestones and dolomites, which were generally pure but in places somewhat argillaceous. Progressive metamorphism reached a stage corresponding apparently to the sillimanite-almandite sub-facies of the amphibolite facies (Turner, 1948, p. 85). Subsequently a low-temperature hydrothermal action associated with granitic intrusion effected local diaphthoresis; forsterite altered to antigorite. This second mineral assemblage corresponds to the muscovite-chlorite sub facies of the greenschist facies (Turner, 1948, pp. 96-98).

Little mineralogical change is connected with the mechanical deformation that post-dates the granitic intrusives, though a small amount of talc occurs in some of the fault planes.

MANHATTAN FORMATION

INTRODUCTION

The principal rock type of the Manhattan formation is sillimanite-garnet-biotite gneiss. In places the gneiss grades into mica schist and into quartzite; these are quantitatively unimportant, however. Also present is a large amount of amphibolite. Within the quadrangle the Manhattan has been invaded on a grand scale by younger granite.

The Manhattan formation overlies the Inwood marble, which in turn overlies the Fordham gneiss; these three units comprise the New York City group.

HISTORICAL REVIEW

The Manhattan formation was named by Merrill (1890, p. 390) from Manhattan Island, New York City. Within the quadrangle Percival (1842, p. 84) designated it as Micaceous ranges and called it H(2 and 3).

It is called Becket gneiss on the State Geological Map of 1906, and Balk 1936, pl. 1) uses Hudson River pelite. The term Manhattan formation is used in this report because of the apparent physical continuity with the type locality.

The belt of Manhattan just west of the Still River valley extends northward into the New Milford quadrangle. Percival (1842, p. 95 and geol. map) designated this terrane as H(3) and extended it to Lake Waramaug where it includes part of the material that has been called Waramaug formation by Gates (1952, p. 10 and geological map).

AREAL DISTRIBUTION

The Manhattan formation underlies two separate areas within the Danbury quadrangle. The largest of these is 5.9 square miles and forms two belts that extend from the middle of the quadrangle northward into the New Milford quadrangle. This terrane has been invaded extensively by younger granite within the quadrangle. Areas were mapped as granite or Manhattan according to which is present in amounts over 50 percent; therefore much granite is included in the Manhattan formation. To the south is a second area of 2.4 square miles; this is part of a belt that extends into New York State and can be followed to the type locality.

Amphibolite associated with the Manhattan formation crops out in two mappable areas in the central and northern parts of the quadrangle. It underlies 0.03 square miles on the eastern shore of Danbury Bay of Lake Candlewood and 0.07 square miles in the northern part of Candlewood Isle.

APPEARANCE IN OUTCROP

The Manhattan formation is generally exposed in closely spaced outcrops; it forms both hills and valleys and is best exposed in drumlins. Along the tops of drumlins it makes flat pavements. On the lee it forms cliffs up to 30 feet high, but outcrops are rare on the stoss ends. The scarp slopes (relative to the foliation) are marked by low overhangs, whereas on the dip slopes the surfaces of the outcrops are generally parallel to the foliation.

Original bedding is apparent only where there are quartzitic layers. Quartz lenses and stringers are common, and near plutons of younger granite there are many pegmatites.

Amphibolite in the Manhattan formation is exposed on the sides of valleys flooded by Lake Candlewood. This topographic position suggests that the valleys themselves may also be underlain by amphibolite. Jointing is generally well-developed in the amphibolite; as a consequence the exposures are craggy. There is little tendency for the joints to slope parallel to the surface of the ground.

In the northern area there are excellent exposures on Candlewood Isle and at the east base of the hill west of Brookfield. In the southern area typical exposures may be seen on the two small knobs between

Rogers Park and U.S. Route 202. Typical amphibolite is exposed on the eastern shore of Danbury Bay of Lake Candlewood.

PETROGRAPHY

The principal rock type of this unit is sillimanite-garnet-biotite gneiss. The rock is designated *gneiss* because it exhibits alternating dark and light layers. This layering, however, is in general so poorly defined that the name *schist* might be used. Barth (1936, p. 810), working in Dutchess County, New York, with rock probably of this unit, arbitrarily set the boundary between schists and gneisses as the sillimanite isograd. The character of the rock in the Danbury quadrangle militates in no way against this generalization. The presence of silimanite, of course, does not make a gneiss out of a schist, but if the sillimanite developed from muscovite, the rock would thereby lose some of its schistose character.

The rocks of the northern area are composed principally of sodic plagioclase, quartz, and biotite; microcline is rare. Garnet and sillimanite are characteristically present almost everywhere in this formation except on the eastern side of the hill northwest of Brookfield, where muscovite is present. Muscovite also occurs locally on the western side of Candlewood Isle and just southeast of the southern tip of Lake Candlewood. A small amount of chlorite is found in the central and southern part of Candlewood Isle. Zircon, apatite, and black iron ores are present as accessories.

The rocks in the southern area differ from those to the north by having microcline as well as plagioclase, and this difference certainly raises a question as to the correlation of the two terranes. The basis for the correlation, however, is structural; it is described below.

Sillimanite-garnet-biotite gneiss. The principal constituents of this rock are quartz, andesine, biotite, garnet, and sillimanite. It is strongly foliated and moderately layered; biotite-rich septa alternate with more sialic material.

Quartz ranges in grain size from 0.1 to 0.5 mm. The grain boundaries are generally straight; they show no interlocking. In section about half the grains are equant and half show elongation (3:2) parallel to the foliation.

Plagioclase ranges in grain size from 0.5 to 1 mm. The grains have irregular boundaries and tend to wrap around contiguous grains of quartz. In section most grains are elongate (3:2) parallel to the foliation. Twinning is poorly developed in most grains; in many, however, it is clearly defined. Zoning is absent. The composition in all rocks examined is between An_{30} and An_{35}.

The grain size of microcline ranges from 0.5 to 1 mm. Like plagioclase it occurs as grains that are elongate (3:2) parallel to the foliation. Twinning is very poorly developed; it resembles more the strain shadows of moderately deformed quartz. Exsolution lamellae are on the average about 0.01 by 0.002 mm.; they make up 5 to 10 percent of the grains. Lobes of myrmekite invading the microcline are common.

Biotite is commonly reddish in hand specimen. The flakes range from 0.05 by 0.1 mm. to 0.1 by 1 mm. Pleochroism is from light yellowish brown to opaque; it is dirty greenish gray just before becoming opaque. Radiohaloes have developed around included zircon.

The average grain size of garnet is 1 mm. although in some rocks it ranges up to 15 mm. Generally the grains are equant; grains elongate in section are very common, however, and elongation is parallel to foliation. Straight fractures, perhaps (110) partings, are characteristically present, and these also parallel foliation. In section, grains commonly wrap around or wholly surround biotite, quartz, plagioclase, or sillimanite.

Sillimanite occurs as slender needles, which range in size from 0.02 by 0.001 mm. to 0.1 by 0.01 mm. It occurs in elongate patches that are about the same size as the biotite flakes. These patches are generally embedded in biotitic layers but are also common along the boundary between grains of plagioclase; they appear to be pseudomorphous after mica, probably muscovite. In those rocks that are very high in sillimanite, the needles compose individual layers. The larger needles generally lie parallel to the foliation; the smaller ones occur as a felt of matted needles, and only the outline of the patch is parallel to the foliation.

Rosiwal analyses of typical gneisses of the Manhattan formation are given in Table VI.

Amphibolite. The amphibolite associated with the Manhattan formation has a distinctive appearance. First, the hornblende is platy, and the rock thereby has a strong foliation. Further, the rock characteristically contains scattered lenses of quartz and plagioclase. These sialic lenses are typically 1 by 5 cm. in the cross-section of the outcrops and are parallel to the foliation; they make up 1 to 10 percent of the rock.

Table VI (values in percent)

	1	2	3	4	5	6
Plagioclase	34	55	12	35	43	46
Quartz	29	20	34	40		54
Biotite	32	20	44	23		
Garnet	4	3				
Sillimanite	1	2	10			
Muscovite				2		
Hornblende					57	

1 and 2 Sillimanite-garnet-biotite gneiss.

3 Sillimanite-biotite gneiss.

4 Muscovite-biotite gneiss.

5 Amphibolite.

6 Sialic lens in amphibolite.

Hornblende occurs as equant to elongate grains that average 0.5 mm. in diameter. The pleochroic formula is: X=light brownish yellow, Y=dark brownish green, Z=dark brownish green.

The plagioclase is labradorite (An_{55}) in both the amphibolite and the sialic lenses. The grain size ranges from 0.5 to 2 mm.

Quartz is abundant in the sialic lenses but only sparingly present in the amphibolite; the average grain size is 0.1 to 0.2 mm.

Black iron ore occurs as irregular patches between grains of hornblende.

Rosiwal analyses of an amphibolite and of a sialic lens are given in Table VI.

STRUCTURE

The foliation of the rocks of the Manhattan formation is produced by a parallelism of the long dimension of the component minerals. Biotite is by far the most important in this respect; also, the feldspar, quartz, and garnet, and the patches of sillimanite are commonly tabular and thereby add to the foliation. In addition, there is a poorly developed gneissic structure; the flakes of biotite are aggregated in thin, discontinuous layers, and both quartz and plagioclase tend to form elongate layers. Individual dark and light layers are 1 to 2 mm. wide.

Indications of original bedding were found only on Candlewood Isle; some layers are quartzitic, and the foliation parallels them rigidly. All other original bedding has been completely obscured by transposition or recrystallization.

The foliation is in general not disturbed by crinkling or by drag folds. On the hill west of Great Plains Road just northeast of the Danbury city limit, however, there is a strong development of chevron folds; this marks a sharp change in the regional trend of the foliation. Large, open drag folds are common in many places.

Lineation is produced by a streaking of the biotite flakes, and in all cases observed it is parallel to the axes of drag folds and crinkling.

The original thickness of the Manhattan formation is obscure. If it had been but a few hundred feet thick, it certainly would tend to pinch out in places. Its persistence throughout a terrane of such complex deformation indicates a substantial original thickness; several thousand feet is certainly indicated.

The correlation of the two physically separated terranes is based principally on the structure. In both areas the gneisses here designated as Manhattan are physically above the Inwood marble, and the same side of the marble is in contact with both gneiss terranes. Therefore the two gneiss terranes ought to be the same. In addition, the rocks of the two terranes have the same physical appearance, which is distinctive and different from that of the other units in the region. Further, the amphibolite associated with both terranes is very distinctive and not at all like that of the Hartland formation or the Precambrian Highlands.

There is no concrete evidence within the quadrangle that indicates whether the Manhattan or the Inwood is younger. If traced in either direction along strike, however, the Manhattan so consistently overlies the Inwood that there is little doubt that it is the younger.

In New York State the Inwood marble commonly grades into the Manhattan formation by apparent interbedding (Fettke, 1914, p. 196). This relationship could reflect tight isoclinal folding. Although no such gradation was observed in the Danbury quadrangle, it does occur just to the west at Mill Plain in the Brewster quadrangle.

The amphibolite occurs as lens-shaped bodies that are conformable to the foliation of the surrounding gneiss; the foliation within the amphibolite is also parallel to that of the gneiss. The amphibolite is quite uniform in composition and carries neither xenoliths nor screens of gneiss.

GENESIS

The rocks of the Manhattan formation belong to the sillimanite-almandite subfacies of the amphibolite facies (Turner, 1948, p. 85); they are typical of pelites of the sillimanite zone throughout the world.

The steps in the progressive metamorphism of these rocks are obscure save one; this is the formation of sillimanite. Sillimanite develops from the Al_2O_3 produced in excess by a mineralogical adjustment that has taken place at high temperature and under great pressure. Since the sillimanite occurs in patches that have the same shape as biotite flakes, it could have developed as a residuum from the destruction of a mineral similar to biotite. The biotite, however, shows no indication of alteration; besides, it is relatively low in Al_2O_3 (generally about 17 percent). Muscovite is a much more satisfactory source. It is high in Al_2O_3 (generally 30 to 35 percent), is absent in those rocks where sillimanite is present, and characteristically occupies a position in the fabric of metamorphic rocks now occupied by the patches of sillimanite.

The occurrence of the amphibolite as well defined bodies of uniform composition indicates that it developed from basaltic sills or lava flows.

Hartland Formation

INTRODUCTION

The Hartland formation is an extensive terrane of non-uniform lithology. If it were unmetamorphosed and fossiliferous, it would probably be described as a group and be divided into two or more formations. North of U.S. Route 6 a quartzitic sillimanite-biotite schist makes up the greater part of the formation; amphibolite and metaspilite are also present. Well defined plutons were emplaced in this part of the terrane. To the south the rock is more schistose and includes extensive areas of injection gneiss.

HISTORICAL REVIEW

The Hartland formation was named by Gregory (1906, p. 96) from the town of Hartland, Connecticut. According to Wilmarth (1938, p. 918), however, the United States Geological Survey does not recognize the name Hartland but calls the unit Hoosac schist. The terrane mapped here as Hartland extends northeastward into the Newtown, New Milford, Roxbury, New Preston, Woodbury, and Litchfield quadrangles. No recent work has been done beyond Litchfield, however, and the correlation on northward to Hartland and to Hoosac Mountain, Massachusetts, is in doubt. Detailed descriptions of the Hartland formation have been published by Gregory (1906, pp. 96-100), Cameron (1951, pp. 9-12), and Gates (1951, pp. 5-9; 1952, pp. 16-21; 1954, pp. 7-11). Within the Danbury quadrangle Percival (1842, p. 58) designated this unit as formation F7.

AREAL DISTRIBUTION

The Hartland formation underlies two separate areas within the quadrangle. In the northern corner there is a small area of 0.1 square miles. A larger area ramifies through the eastern and southern portions of the quadrangle and underlies 9.3 square miles. Within this terrane are many small bodies of the Brookfield plutonic series and of younger granite; also, screens of Hartland are included in the areas mapped as Brookfield and as younger granite.

Two masses of amphibolite associated with the Hartland formation were mapped. The one at Brookfield Center underlies about 0.1 square miles and the one on the northern quadrangle boundary 0.02 square miles.

APPEARANCE IN OUTCROP

The Hartland formation is in general poorly exposed in the quadrangle; it is covered by extensive glacial deposits. In the eastern part of the quadrangle just north of U.S. Route 6, however, the formation is exposed in closely spaced outcrops over an area of about half a square mile. Here the outcrops are large and craggy, and thirty-foot cliffs are common. Original bedding is distinguishable in a few exposures; it is parallel to the foliation.

Exposures of typical sillimanite-biotite schist may be seen where U.S. Route 6 leaves the eastern edge of the quadrangle, and also just west of the top of the hill on the road that crosses Shelter Rock. The contact between the Hartland formation and the Inwood marble is exposed in the town of Bethel in the valley of Limekiln Brook at a point 600 feet west of the junction of Plumtrees Road and Rockwell Road.

PETROGRAPHY

The principal rock type of the Hartland formation within the Danbury quadrangle is garnet-sillimanite-biotite schist. It is not as highly foliated as some schists, and perhaps might better be called a mica quartzite or granulite.

In the northern part of the quadrangle, the rock is less schistose and the intrusives are well defined plutons. In the south it was originally more schistose, and it has been invaded more intimately by younger granite. The more schistose material may represent strata that are either higher or lower stratigraphically.

Where little or no granite is present, quartz stringers are extensively developed. They are generally about 2 cm. thick and 10 to 20 cm. long.

Amphibolite occurs in the northern part of the quadrangle but only in small amounts. It bears the same structural relation to the Hartland formation as the Mt. Tom hornblende gneiss described by Agar (1927, p. 32). A hornblende-quartz-bytownite granulite occurs at the eastern margin of the amphibolite mass north of Brookfield. A small body of albitic amphibolite is exposed on the western bank of the Hoosatonic River at the northern margin of the quadrangle; it is regarded as a metaspilite.

Garnet-sillimanite-biotite schist. The principal constituents of this rock are quartz, andesine, biotite, sillimanite, garnet, and muscovite. Kyanite and microcline are present locally, and tourmaline is common at the contact with younger granite. The accessories are apatite, zircon, and black iron ore. Along the contact with the Inwood marble, chlorite has developed at the expense of garnet and biotite; sericite has replaced feldspar and biotite. The fabric is crystalloblastic schistose; all planar elements are parellel.

The quartz grains are generally equant and 0.1 to 0.2 mm. in diameter. Many, however, are elongate (2:1 to 4:1) in section. In general the grain boundaries are straight, but in some places they are partially interlocking.

Plagioclase ranges in grain size from 0.1 to 0.5 mm. Large porphyroblasts up to 10 mm. are present in some blocks that have been included as xenoliths in the Brookfield plutonic series. It is sodic andesine in composition. Near the contact with the Inwood marble it is in places strongly sericitized.

The grain size of the microcline ranges from 0.1 to 0.5 mm. Grid-twinning is well developed in some rocks but only poorly defined in others.

Biotite occurs as flakes 0.02 by 0.1 mm. to 0.1 by 0.5 mm. It is pleochroic from pale brown to dark brown or opaque. Near the contact with the Inwood marble it has altered in part to chlorite and in part to a streaked mass of sericite and opaque material.

The flakes of muscovite are generally 0.1 by 1 mm. Sericite is common near the contact with the Inwood marble; it forms at the expense of feldspar and biotite.

Sillimanite occurs typically as clean, unaltered needles 0.01 by 0.1 mm.; in some rocks, however, prisms as much as 1 mm. in diameter have developed. It is abundant in the formation and makes up as much as 50

The grains of garnet are generally equant and subhedral; they range in diameter from 0.1 to 1 mm. Many grains, however, are elongate (3:1) in section, and the elongation is parallel to foliation. In places near the contact with the Inwood marble it has altered in part or fully to chlorite.

Kyanite occurs as elongate (2:1) grains that range in size from 0.1 to 0.5 mm. It is present in the same thin-section with sillimanite in apparent equilibrium.

Tourmaline is present in rock that lies next to bodies of younger granite. It occurs as prisms, generally about 0.1 by 0.3 mm. The pleochroic formula is: fast=pale brown, slow=dark brown. In cross-section normal to the c axis it is zoned; from the core outward it changes successively from pale blue-green to brown and then to green. These cross-sections have the typical bulging triangular habit of tourmaline.

Chlorite replaces biotite and garnet as noted above. It was also observed with sericite in a veinlet about 0.05 mm. wide along a small fault.

Rosiwal analyses of typical schists are given in Table VII.

Amphibolite. The amphibolite associated with the Hartland formation is composed of labradorite, hornblende, biotite, and a small amount of sphene. The fabric is granoblastic foliated but does not exhibit layering.

Plagioclase is labradorite, An_{50}. The grains are about 0.1 to 0.5 mm. in diameter and in section are commonly somewhat elongate parallel to the foliation.

The average grain size of the hornblende is 0.5 by 1 mm. The pleochroic formula is: X=light yellowish green, Y=dark green, Z=dark green. It has numerous opaque inclusions.

Biotite occurs in flakes about 0.05 by 0.1 mm. and is pleochroic from light yellowish brown to opaque.

Sphene occurs in diamond-shaped crystals about 1 mm. in size.

A Rosiwal analysis of an amphibolite of the Hartland formation is given in Table VII.

Metaspilite. One body of amphibolite carries albite rather than labradorite. On this basis the rock is interpreted as being a metaspilite.

Hornblende-quartz-bytownite granulite, a calc-silicate rock. Along the eastern margin of the amphibolite body north of Brookfield is a granulite composed of bytownite, quartz, hornblende, and a small amount of garnet and black iron ore. In hand specimen the rock shows a weak foliation. In thin section, however, a stronger foliation becomes apparent; it is produced by the flat tabular to discoid habit of hornblende, bytownite, and quartz.

Injection gneiss. The injection gneiss in the southern part of the main Hartland area is composed of discontinuous dark septa about 2 mm. thick separated by light layers about 5 mm. thick. The septa are well defined and are composed of biotite, sillimanite, and quartz. The light layers have the composition of granite. Within the septa the needles of sillimanite are parallel to the foliation and occur in compact masses. Along the margins, however, they fray out into the granitic material and show no preferred orientation; they seem to have been unraveled by the injection of the granitic material.

Table VII (values in percent)

	1	2	3	4	5
Quartz	25	28	60	27	
Plagioclase	23	22	16		51
Microcline	3	2		6	
Biotite	28	26	21	33	11
Sillimanite	12	10		30	
Garnet	9	8	1	4	
Muscovite			2		
Tourmaline		4			
Hornblende					38

1 Garnet-sillimanite-biotite schist.
2 Garnet-sillimanite-biotite schist next to contact with intrusive granite.
3 Biotite quartzite (plagioclase-biotite-quartz granulite).
4 Garnet-sillimanite-biotite schist.
5 Amphibolite.

STRUCTURE

Bedding is visible in several places in the Hartland formation. It is particularly evident in the more quartzitic material, which in many places shows a well preserved lamination.

The foliation is pronounced and is parallel to the bedding where the latter is distinguishable. It is commonly crinkled and contorted. Streaking of the mica flakes produces a strong lineation, which is parallel to the fold axes of the crinkles. Where vein quartz is present it occurs as flattened pencils, which are typically 1 cm. by 2 cm. by 20 cm. The long dimension of these pencils is parallel to the other lineations.

The western portion of the Hartland formation has a general north-south strike and a steep dip to the west. In the eastern part just north of U.S. Route 6 there is a great fold; proceeding northward the foliation swings clock-wise over 90°. To the east of Brookfield the dip of the foliation in both the Hartland metasediments and the Brookfield plutonic series becomes more gentle and in the northeast corner of the quadrangle it is horizontal.

GENESIS

The rocks of the Hartland formation have been metamorphosed to a rank that corresponds to the sillimanite-almandite sub-facies of the amphibolite facies (Turner, 1948, p. 85). Like the Manhattan formation they are typical of pelites of the sillimanite zone.

There are no unstable relict minerals nor are there pseudomorphs to indicate the course of progressive metamorphism of these rocks. The course of retrogressive metamorphism along the western border, however, is quite apparent. Chlorite has developed at the expense of biotite and garnet, and sericite has formed by alteration of feldspar and biotite. This mineral assemblage corresponds to the muscovite-chlorite sub-facies of the greenschist facies (Turner, 1948, p. 96). Since the diaphthoresis is restricted to a belt along the contact, it is regarded as having been produced by a thrust fault.

The amphibolites within this unit differ in no way from the metasediments either in their determinable metamorphic history or in their structural relation to the Brookfield plutonic series and younger granite. This developmental and structural similarity permits the interpretation that both rocks types were present before the advent of the first orogeny to affect them. If so, the amphibolites, particularly the metaspilite, were probably geosynclinal basalts.

Brookfield Plutonic Series

INTRODUCTION

The Brookfield plutonic series is a distinctive series of igneous rocks that occurs in well defined plutons. Four of these plutons crop out within the Danbury quadrangle. The rock type ranges from diorite to granite and from equigranular to porphyritic. Three of the plutons appear to be single intrusive masses marked by internal facies changes. The fourth is composite; at least two intrusives compose it.

The plutons appear to occupy marked flexures in the invaded rocks. The intrusives may have been localized by the flexures; on the other hand they may have acted as competent masses around which the host rocks were folded.

HISTORICAL REVIEW

The Brookfield plutonic series was named the ***Brookfield diorite*** by Gregory (1906, p. 107) from the development of these rocks in Brookfield; the town is apparently the type locality rather than the villages of Brookfield or Brookfield Center. On the State Geological Map accompanying the 1906 report, the two northernmost plutons of the Danbury quadrangle are mapped as Brookfield diorite. The Shelter Rock mass and the mass in the southeastern corner are mapped as Danbury granodiorite. Percival (1842, p. 58) denoted these rocks as 7F; Balk (1936, pl. 1) uses the terms Brookfield diorite, Bethel pyroxene diorite, and diorite and related intrusives for this unit.

Other descriptions of the Brookfield are found in the reports of Agar (1927, pp. 28-31), Cameron (1951, pp. 13-24), and Gates (1951, pp. 10-11, and 1952, pp. 25-26).

The Harrison diorite of southeastern New York State is apparently the same as the Brookfield.

AREAL DISTRIBUTION

Four plutons of the Brookfield series crop out within the Danbury quadrangle; they are small, concordant, lobate masses. Several similar plutons are located to the south and southeast, and a large mass, part of the Mt. Prospect complex (Cameron, 1951), lies in the New Preston and Litchfield quadrangles.

The largest mass in the Danbury quadrangle lies east of Brookfield. It underlies 2.65 square miles within the quadrangle and extends northward into the new Milford quadrangle. The mass north of U.S. Route 6 underlies 1.14 square miles and extends into the Newton quadrangle. The Shelter Rock mass underlies 0.60 square miles and extends into the Bethel quadrangle. Part of a large mass of Brookfield rocks underlies 0.51 square miles in the southeastern corner of the quadrangle. This mass extends into the Newton, Botsford, and Bethel quadrangles.

APPEARANCE IN OUTCROP

Outcrops are very well distributed over most of the area underlain by the Brookfield plutonic series. These rocks are more resistant to weathering than the surrounding schists and mica quartzites, and consequently they form hills. Individual outcrops are commonly more than one hundred feet long. Overhangs and cliffs are not unusual on the scarp or dip slopes; they are up to 50 feet high. Exposures on the tops of the hills range from flat pavements to convex masses that rise 5 to 10 feet above the surrounding ground. At exposures along the sides of hills, large joint blocks, typically 3 by 5 by 10 feet, have drifted away from the outcrops. These boulders are common as glacial erratics on drumlins to the southeast.

There are several outcrops of granite belonging to the series on or near the unimproved dirt roads in the northeastern corner of the quadrangle. Quartz monzonite and granodiorite may be observed just east of the junction of Stony Hill Road and Bound Swamp Road (1 mile north of U.S. Route 6), on the road that crosses Shelter Rock, and on U.S. Route 202 just west of where it enters the Newton quadrangle. Good exposures of quartz diorite crop out on Long Meadow Hill Road at the northern edge of the quadrangle; it is also exposed at the northwestern end of the Shelter Rock mass. Diorite crops out on the western edge of Shelter Rock in the cliff just northeast of the junction of Still River and Sympaug Brook.

PETROGRAPHY

The petrographic types of this series range from diorite to granite and from equigranular to porphyritic. They are grouped together because they occur as facies of the same plutons. The Brookfield plutonic series is therefore a mappable structural unit rather than a particular type of igneous rock. The rock types do, however, form a petrographic series.

The pluton east of Brookfield grades from quartz diorite along the western and southern margins to granite in the central and eastern portions. These rocks do not contain prominent megacrysts[1].

The mass north of U.S. Route 6 ranges from quartz diorite to quartz monzonite. The most common type is a quartz monzonite that is studded with megacrysts of microcline and/or plagioclase.

The Shelter Rock pluton grades from quartz diorite to quartz monzonite. Although equigranular varieties are widespread, those carrying megacrysts of microcline and/or plagioclase predominate. The rock commonly grades in a single outcrop from an equigranular variety to one that contains scattered megacrysts and finally to one with abundant megacrysts.

In the mass in the southeastern corner of the quadrangle the predominant rock type is a quartz monzonite that is crowded with megacrysts of microcline and plagioclase. Quartz diorite is also abundant. The two types are interlayed as thick sills, and no structural evidence was found within the quadrangle that indicates the sequence of emplacement. About two miles to the southwest in the Bethel quadrangle, however, the foliation of a similar quartz diorite is cut by a similar quartz monzonite. This pluton is therefore regarded as composite; an earlier intrusive of quartz diorite was later invaded by quartz monzonite.

Andesine granite. The granite is composed of quartz, microcline, plagioclase, biotite, epidote, allanite, sphene, apatite, and zircon. It is equigranular and strongly foliated; no megacrysts are present.

Quartz occurs as equant grains, which range from 0.1 to 1 mm. in diameter.

Microcline ranges in grain size from 0.1 to 1 mm. and exhibits a well developed grid twinning. A few grains are invaded by lobes of myrmekite. Exsolution lamellae are not abundant; they are about 0.01 by 0.002 mm.

Plagioclase occurs as equant grains about 0.5 to 1 mm. in diameter; it is andesine, An_{35}.

Biotite is pleochroic from pale brownish green to nearly opaque. The grain size ranges from 0.1 by 0.05 mm. to 1 by 0.5 mm.

Epidote occurs as colorless to faintly green grains that range from 0.1 to 0.5 mm. in diameter.

Allanite occurs as six-sided prisms that are about 0.1 mm. in diameter and 0.5 mm. long. It is brown, only weakly pleochroic, and commonly twinned. Zonal growth is marked by very fine growth lines and an uneven distribution of color. Most crystals are enclosed by a layer of epidote, which ranges from 0.1 to 0.01 mm. in thickness.

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[1]Megacryst is defined above in the Introduction to the section on the Danbury augen granite.

Sphene occurs as wedge-shaped crystals that range from 0.1 to 1 mm. in length.

The andesine granite underlies the central and eastern portion of the mass east of Brookfield. A Rosiwal analysis of a typical specimen is given in Table VIII.

Quartz monzonite. The quartz monzonite is composed of quartz, microcline, plagioclase, hornblende, biotite, magnetite, apatite, sphene, and zircon. It is strongly foliated and almost everywhere carries stout, blocky megacrysts of microcline. Plagioclase megacrysts are also common.

Quartz occurs as equant grains and ranges from 0.1 to 0.5 mm. in diameter.

The microcline megacrysts are about 10 by 20 mm. Some parts are crowded with exsolution lamellae whereas other parts are free of them. Grid twinning is poorly developed. Microcline occurs more commonly as megacrysts than as a constituent of the groundmass.

Plagioclase occurs in the groundmass as anhedral to subhedral grains, which range from 0.2 to 1 mm. in diameter. Megacrysts are up to 10 mm. in length; they are generally not as large as those of microcline. The plagioclase is andesine, An_{40}.

Biotite is pleochroic from yellowish brown to opaque. The flakes range from 0.1 by 0.05 to 1 by 0.5 mm.

Hornblende occurs as equant grains about 0.5 mm. in diameter. The pleochroic formula is: X=yellowish green, Y=dark green, Z=dark green.

Quartz monzonite comprises about half the rock of the Brookfield series. It is the principal type present in the pluton north of U.S. Route 6, in the Shelter Rock mass, and in the mass in the southeastern corner. The most common variety is porphyritic hornblende-biotite quartz monzonite. A Rosiwal analysis of a typical specimen is given in Table VIII.

Granodiorite. Many specimens are petrographically granodiorite. These differ from the quartz monzonite only because the microcline is subordinate in amount to the plagioclase. A Rosiwal analysis is given in Table VIII.

Quartz diorite. The principal constituents of this rock are plagioclase, quartz, hornblende, biotite, and augite. Foliation is but poorly developed; it is due to the parallel orientation of some of the flakes of biotite.

Megacrysts of plagioclase are common; they generally show a moderate development of (010) and hence are tabular. The average grain size is 3 by 6 mm. Masses that appear in hand specimen to be single megacrysts are commonly composed of two or more grains in random orientation. Plagioclase of the groundmass occurs as anhedral grains that are about 0.5 mm. in diameter. The composition is An_{45} for both megacrysts and that of the groundmass.

Hornblende occurs as equant to irregular grains; it commonly wraps around plagioclase. The pleochroic formula is: X=light greenish brown, Y=dark green, Z=dark green.

The flakes of biotite are 0.5 to 1 mm. in length. The sides are straight, but the ends are commonly concave, thereby accomodating rounded grains of plagioclase. The pleochroism is from light yellowish brown to opaque.

Augite occurs as pale green, slightly pleochroic, equant grains, which are about 0.5 mm. in diameter. There are numerous inclusions, which are long and slender in section; they are about 0.01 by 0.001 mm.

Magnetite and a very small amount of apatite are also present.

Quartz diorite occurs at several places along the western margin of the Shelter Rock mass and on the western and southern margins of the mass east of Brookfield. The most common variety is biotite-hornblende quartz diorite; a Rosiwal analysis is given in Table VIII.

Diorite. The diorite is composed of plagioclase (An_{45}), hornblende biotite, augite, and minor magnetite and apatite. It differs from the quartz diorite only by the absence of quartz. Only one specimen of this type was studied; it is a biotite-hornblende diorite. A Rosiwal analysis is given in Table VIII.

Table VIII (values in percent)

	1	2	3	4	5
Quartz	26	22	22	8	
Microcline	40	30	19		
Plagioclase	10	26	36	33	47
Biotite	21	18	23	24	18
Hornblende		4		35	35
Epidote	3		tr		
Augite				tr	tr

1 Andesine granite.

2 Hornblende-biotite quartz monzonite.

3 Biotite granodiorite.

4 Biotite-hornblende quartz diorite.

5 Biotite-hornblende diorite.

STRUCTURE

The rocks of the Brookfield series are moderately to strongly foliated, and in many places they have been affected by a post-crystalization shearing. The later deformation is marked by streaking and fluting within the planes of foliation. There has been no crinkling of the foliation planes, however, nor is there any sign that the movement picture was rotational. The later deformation was parallel to the earlier.

Xenoliths are very common and are lithologically similar to the rock types that make up the Hartland formation. They are elongate and blocky in the cross-section presented by flat outcrops. They are small; typical ones average 20 to 30 cm. in length and 2 to 3 cm. in width. The long dimension is everywhere parallel to the foliation. Screens of metasediment are present in some places; they are 2 to 10 feet thick and of indefinite length along strike.

All the plutons with the exception of the one in the southeastern corner appear to be single intrusions; variations in petrographic character are interpreted as facies changes. These single intrusives displace the foliation around them in the manner of a forceful injection; they "shoulder aside" the host rock and are chiefly conformable, although in detail they are cross-cutting. There is no predilection for any type of host rock; sillimanite mica schist, mica quartzite, and amphibolite are invaded.

Cameron (1951, p. 25) has noted that the Mt. Prospect complex "appears to occupy the position of a marked flexure in the regional strike." This is certainly true for two of the plutons of Brookfield rock within the Danbury quadrangle. The mass north of U.S. Route 6 occupies the crest of a flexure of over 90° in the regional strike. The Shelter Rock mass is interpreted as the core of a large isoclinal fold. The mass east of Brookfield does not coincide with a change in the regional strike of the foliation; it nevertheless does occupy a strong flexure. This flexure has a horizontal axis and can be appreciated only by noting the decrease in the angle of dip from west to east across the mass. The other occurrence of Brookfield rocks within the quadrangle is too limited in extent to determine whether it occupies a flexure. Cameron (1951, p. 28) suggests that the coincidence of Brookfield rocks with flexures may be due to "dilatation during the early stages of development of the flexure", which afforded channels for the invading magma. This writer feels a second hypothesis worthy of consideration is that the Brookfield rocks acted as competent masses in later deformation, and that they became cores around which the surrounding rocks were flexed. Both these processes may have been important.

GENESIS

The Brookfield series is regarded as igneous; this conclusion is based on two lines of evidence. First, Brookfield rocks cut across and push apart the foliation of the metasediments of the Hartland formation. Second, the Brookfield rocks contain abundant inclusions and screens of metasediment and amphibolite that are recognizably from the Hartland formation. Contacts with country rock and inclusions are sharp, and the invaded rocks have had no recognizable influence on the composition of the Brookfield rocks.

Several petrographic types comprise the Brookfield series. Their close association in space and their petrographic similarity indicate a close genetic relationship. These several types could be a comagmatic series, igneous facies, or variants due to later hydrothermal activity. Structural evidence in the Mt. Prospect complex indicates a cogmatic series; a biotite pyroxenite cuts the foliation of diorite gneiss and in turn is found as xenoliths in quartz monzonite porphyry (Cameron, 1951, p. 24). Although the biotite pyroxenite is out of place for such a series, it is not abundant enough to affect the general picture; it is significant only for determining order of intrusion. The diorite and the porphyry do, however, appear to be earlier and later members of a cogmatic series. Within the Danbury quadrangle, on the other hand, the several rock types in all but one pluton grade into one another; the composite pluton in the southeastern corner of the quadrangle is described above under Petrography. Although there may have been several pulses to intrusion, and the several plutons may be of slightly differing ages, most of the plutons have the characteristics of single intrusives; the several petrographic types appear to be either igneous facies or variants of hydrothermal origin.

Microcline megacrysts extending from Brookfield rocks out into metasediments of the Hartland formation were observed in only one place; they occur as much as 3 feet away from the contact. This is just west of Bound Swamp Road at the southern margin of the pluton that lies north of U.S. Route 6. Many xenoliths have a few scattered plagioclase megacrysts. These megacrysts are similar to those of the Brookfield. The occurence of megacrysts in country rock and in xenoliths is certainly indicative of a hydrothermal origin for at least part of the megacrysts of the Brookfield. Any hydrothermal activity must, however, have been an autometamorphic process because there is no later igneous activity or independently demonstratable hydrothermal activity that is related in space to the rocks that carry megacrysts. If the megacrysts are hydrothermal, they may represent a reconstitution *in situ* of the consolidated rock, or they may be composed of material from a lower part of the pluton that was somewhat later in consolidating. The megacrysts could, however, be largely true phenocrysts. There is no real evidence one way or the other on this point.

An hypothesis of origin of the Brookfield rocks must account for the great range in composition and for the presence of facies. None of the rock types is as mafic as amphibolite, but many approach it. The Brookfield magma may have been developed at great depth by fusion of amphibolite that was associated with varying amounts of metasediment. These metasediments would have rendered certain portions of the magma more silicic. Further, the high calcium content of the plagioclase (An_{35}) in the andesine granite may be due to limestone present in the source rock for the magma.

Since amphibolites are widespread in regions of metamorphic rocks and predominate in many places, they are certainly subject to the same palingenic development that is common for metasediments. A high temperature, of course, would be necessary to effect this melting. The factors that would produce the necessary environment for development of such a magma are obscure. That this environment is probably not a common one is reflected by the relative scarcity of rocks of the Brookfield type.

Another hypothesis is that the rocks of the Brookfield plutonic series developed from primary basaltic material that was contaminated by different amounts of the granitic crust.

The Brookfield plutonic series appears to have been emplaced before the last orogeny. There is nothing implicit here, however, as to whether there has been more than one orogeny.

Younger Granite

INTRODUCTION

A younger granite is intrusive into the Manhattan formation, Inwood marble, Hartland formation, and Brookfield series. Typically it forms small, concordant plutons, which have marginal pegmatites. For the most part the rock is a true granite; in some places, however, it grades into alaskite. It is a strong ridge-maker; the trend of the ridges is controlled more by jointing than by foliation.

The younger granite is regarded as having consolidated from a magma. It was intruded after the peak of the regional metamorphism that has affected the invaded rocks.

HISTORICAL REVIEW

The younger granite of the Danbury quadrangle was first mapped by Percival (1842, p. 95), who designated it as formation H (1). On the State Geological Map of 1906 it is called *Thomaston granite.* It was subsequently mentioned by Agar (1934, p. 368) and by Balk (1936, p. 1). Younger granite in Western Connecticut has generally been designated Thomaston granite. Gates (1954, p. 6) has named a special type of younger granite the *Nonewaug granite.* Since correlation of the granite of this quadrangle with either the Thomaston or the Nonewaug granite is not conclusive, the unit is designated simply as younger granite in this report.

AREAL DISTRIBUTION

Intrusives of younger granite are scattered throughout the region east and south of the Precambrian Highlands. Eleven separate masses were mapped; they underlie a total of 5.7 square miles. There are many additional smaller bodies, particularly in the marble. The largest single mass extends from Beaver Brook Mountain northward into the New Milford quadrangle and underlies 5.0 square miles. West and south of Brookfield many small plutons are intrusive into the Inwood marble, and a large lens of 0.5 square miles extends north and south from Brookfield Center. Several small plutons are intrusive into the Manhattan formation both in the west between Beaver Brook Mountain and Lake Candlewood and in the south on Thomas Mountain; these underlie a total of 0.2 square miles.

Many of the granite bodies contain much country rock. They were mapped as granite only if the granite constitutes over 50 percent of the total.

APPEARANCE IN OUTCROP

The younger granite is the principal ridge-maker to the east and south of the Precambrian Highlands. It stands as high above the gneisses of the

Manhattan formation as it does above the Inwood marble. The scarp slopes (relative to foliation) are very steep and in many places are marked by vertical cliffs up to 50 feet high. Outcrops are generally few on the other slopes. The tops of the ridges exhibit excellent exposures. Individual outcrops are typically rounded masses 50 to 200 feet long, 20 to 100 feet wide, and 5 to 30 feet high. Where screens of metasediment are present on the ridge tops, deep road-like trenches cut through the topography. The long dimension of the outcrops is in general parallel to the foliation. The actual shape, however, is determined by joints, and in many places the trend of the outcrops is 20° to 40° from that of the foliation. Also, the joints tend to dip steeply in the same direction as the topographic surface. The discordance in the regional grain of the topography in the area just east of Beaver Brook Mountain is due for the most part to this joint control; there is no discordance in the foliation.

Excellent exposures may be seen on the eastern slope of both Beaver Brook Mountain and the large hill west of Brookfield. Granite is intrusive into marble 300 feet southwest of the junction of Laurel Hill Road and the unnamed road that leads into Brookfield; also 100 feet west of where the road to the east of Thomas Mountain leaves the quadrangle.

PETROGRAPHY

The younger granite is indeed a true granite; it grades into alaskite rather than into quartz monzonite and granodiorite. Quartz and microcline are the essential minerals, and plagioclase is generally present in small amounts. The varietal minerals are biotite and muscovite; either may predominate. The accessories are zircon, apatite, and black iron ore.

The fabric is generally equigranular. Foliation is everywhere present; it is produced by a parallelism of mica flakes, tabular microcline, and tabular quartz.

The microcline grains range in size from 0.1 to 2 mm. In section they are elongate (3:2); their boundaries are rounded to straight but exhibit no crystal faces. Grid twinning is well developed everywhere, but exsolution lamellae as well as myrmekite are rare. The color in hand specimen ranges from white to buff to pink. Where granite invades marble the color is white without exception. The pink color is found only where a terrane of biotite gneiss or schist is invaded, and it is particularly strong where pegmatite has replaced the host rock. Where granite has invaded biotite gneiss or schist and has shouldered it aside with no replacement, the microcline shows little or no color. Percival (1842, p. 87) also noted this correlation of the color of feldspar with the type of rock invaded.

The quartz grains range in size from 0.1 to 1 mm. and are commonly elongate (3:2 to 4:1). The grain boundaries are smooth and generally straight; there is no tendency to interlock or to wrap around other minerals.

The pleochroism of the biotite is from light brown to dark green or opaque. The flakes are generally 0.1 by 0.3 mm.

Muscovite occurs as individual flakes about 0.1 by 1 mm. and also as aggregates of sericite.

Rosiwal analyses of typical specimens of younger granite are given in Table IX.

The margins of the plutons are marked by the extensive occurrence of pegmatites; they are generally 1 to 10 feet wide and 10 to 100 feet long. Microcline and quartz are the principal constituents. Septa of biotite and muscovite are common; they are generally parallel to the foliation of the wall rock but may be twisted or contorted. Black tourmaline is common; it occurs as prisms, which range from 1 mm. up to 20 cm. in length, and makes up as much as 5 percent of some pegmatites. Beryl was observed at only one place, about 600 feet south of a point on the New York, New Haven, and Hartford Railroad 0.35 miles west of where it leaves the eastern margin of the quadrangle.

Danburite was first described as a mineral species from a specimen found in pegmatite at Danbury (Shepard, 1838, p. 137). The original locality could not be located, nor was any danburite found in any of the pegmatites.

Table IX (values in percent)

	1	2	3
Microcline	57	60	74
Quartz	32	28	26
Biotite	6	10	
Muscovite	5	tr	
Plagioclase		2	

1 Muscovite-biotite granite.
2 Biotite granite.
3 Granite aplite.

STRUCTURE

The younger granite everywhere exhibits some foliation; it is produced by micas as well as by flat grains of both microcline and quartz. That the quartz is flat suggests protoclastic development, that is, the deformation of a rock in the last stages of consolidation. In some places a range in grain size produces a layering; the grains are commonly from 1 to 20 mm. This structure is also characteristic of the Nonewaug granite (Gates, 1954, p. 15). The foliation of the granite is in general parallel to that of the country rock. At a distance from the contacts, however, there is some tendency for the foliation to dip less steeply. Lineation is either poorly developed or not megascopically apparent.

The foliation of the country rock generally spreads out around the bodies of granite; in detail, however, cross-cutting is very common. Septa of more schistose metasediment fray out into the granite. Apparently unsupported xenoliths of metasediment occur in the granite; some of these exhibit chevron folds.

The pegmatites are more pronouncedly cross-cutting than the granite. They show little tendency to thrust aside the country rock, and even where narrow dikes cross-cut for several feet, the foliation is not disturbed. Also, pegmatites in places ramify the country rock in the aimless manner of ptygmatic veins. This cross-cutting without disturbance suggests a replacement origin.

Pegmatites of the younger granite cut discordantly across the foliation of the rocks of the Brookfield plutonic series.

GENESIS

The younger granite is considered magmatic. The following points form the basis for these conclusions:

(1) *In general the granite shoulders aside the older rock.* That the surrounding rock spreads out around the granite indicates either that the granite has pushed its way in or that it formed by a complete selective granitization of sill-like bodies within the metasediments. All important metamorphic rock types are represented in the invaded terrane; yet none save amphibolite has the structural habit of the granite plutons. It is indeed unlikely that there should have been some unusual rock type present that has now been completely replaced. On this basis the granite has the appearance of a foreign material that has pushed its way in. There is no structural evidence for emplacement in the solid state. Therefore magmatic origin alone accounts for the structural position of the granite. Note: the pegmatites associated with this granite are believed to be hydrothermal replacement bodies.

(2) *Contacts are generally sharp rather than gradational.* The contacts of granite with biotite gneiss and schist and with marble are generally knife-sharp; only the contacts with amphibolite are marked by hybrid rocks. If granitization had been more active in formation of these granites, other gradational rocks should be present along the margins of the plutons.

(3) *Some apophyses and dikes show chilled borders.* Chilled borders were observed only where marble is the host rock. Probably the marble yielded to magmatic pressure with enough fracturing to allow injection over a great enough distance to reach cooler wall rock. In the biotite gneiss and schist, however, the magma probably worked its way gradually up the more yielding foliation planes and never burst forth into a cooler environment.

(4) *In detail the granite cuts across the foliation of the invaded rocks.* Where the contacts cut across the foliation of biotite gneiss and schist, septa of biotite fray out into granite. Some xenoliths exhibit chevron folds. These structures could be cut by or included within the granite only after they had fully developed; therefore granitic emplacement post-dates the peak of the metamorphism of the invaded rocks.

(5) *The granites effect diaphthoresis in the marble.* That olivine in the marble has altered to serpentine in the contact zone of the granites demonstrates a disharmonic relationship between contact aureole and invaded rock; the thermal energy level of the aureole was below that at which the metasediments reached equilibrium, and diaphthoresis has taken place. The criterion of harmony (Walton, 1955, p. 11) is therefore applicable for petrogenesis even in terranes of strong regional metamorphism. The disharmonic relationship demonstrates further that regional metamorphism had passed its peak before the granite was emplaced.

STRUCTURE

INTRODUCTION

The rocks of the Danbury quadrangle belong to three regional structural units. The Precambrian Highlands in the northwest portion are overthrust onto the metasediments of the New York City group to the east and south. The New York City group in turn stands apart from the Hartland formation to the east.

Igneous intrusions are superposed on the regional structure. The Danbury augen granite is intrusive into the Precambrian Highlands. The Brookfield plutonic series is confined to the Hartland formation. Younger granite is widespread in both the Hartland formation and the New York City group.

PRECAMBRIAN HIGHLANDS

The hornblende gneiss and amphibolite, the gneissic granite and trondhjemite, and the Danbury augen granite compose the Precambrian Highlands. In some places the hornblendic gneisses occur as lenses within the gneissic granite and trondhjemite; elsewhere the gneissic granite and trondhjemite form lenses in the hornblendic gneisses .These two units are interlayered on a large scale. The Danbury augen granite occurs as conformable plutons and is largely confined to hornblendic host rock.

The regional foliation is characterized by broad sweeps; there are no large mappable isoclinal or drag folds. Small isoclinal and drag folds, however, are common and may be seen in outcrops only 10 feet wide. The dip of the foliation is nearly everywhere very steep or vertical.

Postcrystalline shearing is pronounced throughout the Precambrian Highlands. The quartz in most rocks exhibits undulose extinction or is granulated. The twinning lamellae of plagioclase are bent in some rocks. No mylonite was found, however.

NEW YORK CITY GROUP

The New York City group is a structural unit separated by structural discordances from the adjoining units. On the west the Highlands fault marks the boundary with the Precambrian Highlands. The boundary on the east with the Hartland formation is probably also a fault. The dip of the foliation of the New York City group is not as steep as that of the Precambrian Highlands.

The rocks of the New York City group may be divided into two parts on the basis of their deformational behavior; the structural boundary or structural front between these two parts extends in an east-west direction through the northern part of the city of Danbury. North of this line the foliation is in general north-south, and there are no mappable isoclinal folds. Small isoclinal folds are common but do not affect the regional picture. The persistence of the north-south structure of these rocks probably reflects the buttressing effect of the Precambrian Highlands to the west. South of this structural front the rocks are characterized by large mappable isoclinal folds, and these folds are further deformed by axial plane folding (Scotford, 1955, p. 1614). This type of structure extends southward into the Bethel quadrangle and thence westward into New York State. The irregularity of the structure here probably reflects a complex movement picture that obtained in the rocks to the south of the Precambrian Highlands as the Highlands moved eastward along the Highlands fault.

Hartland Formation

The foliation of the Hartland formation has a generally persistent regional strike. There is a large mappable drag fold to the north of U.S. Route 6 in the eastern portion of the quadrangle, and other mappable drag folds occur to the south in the Bethel quadrangle. Rocks of the Hartland formation are also involved in the axial plane folding of the isoclinal fold that extends through Shelter Rock into the city of Danbury. In general, however, the Hartland formation is characterized by large drag folds and not by axial plane folding.

Passing from the village of Brookfield eastward to the Housatonic River the dip of the foliation of the Hartland formation and of the Brookfield series becomes progressively more gentle; at the river the foliation is indeed horizontal. This undulation in regional dip suggests a drag fold of monoclinic symmetry, the b-axis of which is horizontal. This fold occurs about opposite the mid-point of the eastern front of the Precambrian Highlands mass. The movement sense of the drag is that of west overriding east; this conforms to the structural picture to the west where the Precambrian Highlands override the eastern rocks from the west.

Highlands Fault

The gneisses of the Precambrian Highlands have been thrust eastward and southward over the formations of the New York City group. The actual fault plane is nowhere exposed in the Danbury quadrangle.

Intense cataclasis was found in but one outcrop; there is no mylonite, however. This outcrop is on Still River 300 feet upstream from Old Mill Pond, and the rock is younger granite. A few feet north of U.S. Route 6 at a point 0.2 miles from the western quadrangle boundary, gneisses of the Highlands crop out within 20 feet across strike from gneiss of the Manhattan formation. No significant cataclasis is evident in either of these outcrops. Mylonite along this fault does occur, however, a few miles to the west near Brewster, New York.

Thus the Highlands fault is marked in some places by strong post-crystalline deformation; in others this deformation is not significant. Such an uneven display of cataclasis suggests small movement. The deformational behavior of the New York City group and Hartland formation, however, indicates that the Precambrian Highlands moved a great distance to the east. The rocks east of this mass have been folded on a large scale according to a simple monoclinic symmetry. To the south the folding is irregular and axial plane folding is common, reflecting the lack of a buttress. If the deformation of the New York City group and the Hartland formation is closely related to the eastward movement of the Precambrian Highlands block, then most of the movement must have been precrystalline or paracrystalline. The cataclasis now evident is probably a post-crystalline renewal of movement.

Hartland Formation-New York City Group Contact

In some respects the structure of the Hartland formation is parallel to that of the New York City group, in others it is discordant. The parallelism is found in the Shelter Rock area where both units are involved in isoclinal folding. Discordance is demonstrated by the large flexure in the Hartland formation north of U.S. Route 6 east of Danbury, to which there is no parallel disturbance in the New York City group.

The writer believes that the New York City group has been thrust from the west onto the Hartland formation. This conclusion is based on the following arguments: (1) From north to south along the western margin of the Hartland formation, the rock becomes less quartzitic and more schistose. Apparently the western contact is cutting across stratigraphic units within the Hartland formation. (2) The contact also makes a low angle with the regional trend of the structure of the Hartland. (3) Where the contact is actually exposed, the Inwood marble truncates the schistosity of the Hartland formation at an angle of about 10°. This exposure is in Bethel on Limekiln Brook at a point 600 feet west of the junction of Plumtrees Road and Rockwell Road. (4) There is a zone of diaphthoresis along the western margin of the Hartland formation (See Genesis under Hartland Formation). These four points indicate that the Hartland formation is bounded on the west by a fault along which the Inwood marble has been thrust from the west.

About 20 miles to the southwest in the Pound Ridge quadrangle, New York, the boundary between the New York City group and the Siscowit granite is definitely a thrust fault, a well developed mullion structure marking the contact (D. M. Scotford, personal communication). The Siscowit granite is a younger granite that is probably intrusive into the Hartland formation. It seems reasonable that the contact marked by this thrust fault in the Pound Ridge quadrangle is an extension of the contact being discussed here in the Danbury quadrangle.

MINERAL RESOURCES

In evaluating the mineral resources of the Danbury quadrangle, factors other than geological are very important. The attitude of the people toward an industry that requires blasting is justifiably cautious. The Danbury area is growing rapidly, and nearly every part of it is potential residential property. For this reason a deposit must be of great value in order to offset the detrimental effect that its mining would have on the surrounding property.

Limestone and Dolomite

The Inwood marble (limestone, dolomite) ranges in composition from entirely calcite to entirely dolomite. The areal distribution of calcitic and dolomitic varieties is shown on the accompanying geological map.

The Danbury area was once the scene of an active lime industry; dolomitic rock was calcined to make plaster. Production was for a local market, and as the economy of the country expanded, these operations became uneconomic. The lime kilns are now in ruins or have been removed to make way for new housing developments. Limekiln Brook in Brookfield and Limekiln Brook in Bethel and Danbury, however, will always be permanent reminders of this activity.

The Inwood marble is quarried just east of U. S. Route 7 two miles north of the Danbury city limit. The stone, almost pure $CaCO_3$, is crushed on the premises and sold for agricultural lime. This is the only commercial operation in bedrock within the quadrangle. The material where the quarry is located may be part of a belt of high-calcium limestone extending northward under the valley fill of Still River. The nearest exposures of similar rock occur between Still River and Pocono Road both north and south of Silvermine Road. Field observations indicate that this last area contains a large reserve of high-calcium material suitable for cement.

Feldspar and Beryl

An extensive development of pegmatite is located along the eastern base of the large ridge west of Brookfield. Microcline occurs as light pink masses up to several inches in diameter. Quartz is the only other important constituent. These deposits do not appear to have commercial possibilities.

Beryl occurs in pegmatite in southern Brookfield about 600 feet south of a point on the New York, New Haven, and Hartford Railroad 0.40 miles west of where it leaves the quadrangle.

Sand and Gravel

Sand and gravel of glacial origin are widespread in the Danbury quadrangle. The writer, however, is not in a position to evaluate the reserves of this material because his study was confined to the bedrock and did not include the surficial deposits.

REFERENCES CITED

Agar, W. M., 1927, The geology of the Shepaug aqueduct tunnel, Litchfield County, Connecticut: Connecticut State Geol. and Nat. History Survey Bull. 40, 38 pages.

———— 1933, Danbury granodiorite gneiss of Connecticut: Am. Jour. Sci., 5th Ser., v. 25, pp. 1-19.

———— 1934, The granites and related intrusives of western Connecticut: Am. Jour. Sci., 5th Ser., v. 27, pp. 354-373.

Balk, Robert, 1936, Structural and petrologic studies in Dutchess County, New York, part I: Geol. Soc. America, Bull., v. 47 pp. 685-774.

———— 1949, Structure of Grand Saline salt dome, Van Zandt County. Texas: Am. Assoc. Petrol. Geol., Bull., v. 33, pp. 1791-1829.

Barth, T. F. W., 1936, Structural and petrologic studies in Dutchess County, New York, part II: Geol. Soc. America, Bull., v. 47, pp. 775-850.

Cameron, E. N., 1951, Preliminary report on the geology of the Mt. Prospect Comlex: Connecticut State Geol. and Nat. History Survey Bull. 76, 44 pages.

Dale, T. N., 1912, The commercial marbles of western Vermont: U. S. Geol. Survey Bull. 521, 170 pages.

Fettke, C. R., 1913/14, The Manhattan schist of southeastern New York State and its associated igneous rocks: Annals N. Y. Acad. Sci., v. 23, pp. 193-260.

Gates, R. M., 1951, A report on the bedrock geology of the Litchfield quadrangle: Connecticut State Geol. and Nat. History Survey Misc. Ser. no. 3 (Quadrangle Rept. 1, 13 pages.

———— 1954, The bedrock geology of the Woodbury quadrangle: Connecticut State Geol. and Nat. History Survey, Quadrangle Rpt. 3, 23 pages.

Gates, R. M., and Bradley, W. C., 1952, The geology of the New Preston quadrangle: Connecticut State Geol. and Nat. History Survey Misc. Ser. no. 5 (Quadrangle Rept. 2) 46 pages.

Gregory, H. E., 1906, The crystalline rocks: Connecticut State Geol. and Nat. History Survey Bull. 6, pp. 41-156.

Gregory, H. E., and Robinson, H. H., 1906/7, Preliminary geological map of Connecticut: Connecticut State Geol. and Nat. History Survey Bull. 7.

Merrill, F. J. H., 1890, On the metamorphic strata of southeastern New York: Am. Jour. Sci., 3rd Ser., v. 39, pp. 383-392.

Moore, F. H., 1935, Marbles and limestones of Connecticut: Connecticut State Geol. and Nat. History Survey Bull. 56, 56 pages.

Percival, J. G., 1842, Report on the geology of the State of Connecticut: New Haven (Osborne and Baldwin, Printers) 495 pages.

Prucha, J. J., 1955, Stratigraphic relationships of the Fordham gneiss in southeastern New York (Abstract): Geol. Soc. America, Bull., v. 66, p. 1606.

Rice, W. N. and Gregory, H. E., 1906, Manual of the geology of Connecticut: State Geol. and Nat. History Survey Bull. 6, 273 pages.

Scotford, D. M., 1955, Axial-plane folding (Abstract): Geol. Soc. America, Bull. v. 66, p. 1614.

Shepard, C. U., 1838, Notice of danburite, a new mineral species: Am. Jour. Sci., 1st Ser., v. 35, pp. 137-139.

Turner, F. J., 1948, Mineralogical and structural evolution of the metamorphic rocks: Geol. Soc. America, Memoir 30, 342 pages.

Vogt, J. H. L., 1898, Der Marmor in Bezug auf seine Geologie, Structur, und seine mechanischen Eigenchaften: Zeitschr. f. prakt. Geol. pp. 4-16, 43-52.

Walton, Matt, 1955, The emplacement of "granite": Am. Jour. Sci., v. 253, pp. 1-18.

Wilmarth, M. G., 1938, Lexicon of geologic names of the United States: U. S. Geol. Survey Bull. 896, 2396 pages.