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PETROGRAPHY OF THE ATHOL QUADRANGLE, MASSACHUSETTS

By

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This report is preliminary and
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for conformity with Geological
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Abstract

The Athol quadrangle of north-central Massachusetts is underlain by high-grade metamorphosed amphibolites, gneisses, schists, calc-silicate gneisses, quartzites, and orthogneisses. These include the Monson Gneiss of Middle Ordovician or older age, the Partridge Formation of Middle Ordovician age, and the Middle to Late Devonian Hardwick Granite of the New Hampshire Plutonic Series.

The Monson Gneiss is a series of interlayered biotite and hornblende gneisses and amphibolites. They were originally felsic to mafic tuffs and minor flows that were deposited in shallow seas. The light-gray gneisses are characterized by uniform bedding and minor magnetite and hornblende. The amphibolites generally show bedding and contain quartz, some of which is thought to have been introduced during deposition and consolidation in their marine environment.

The Partridge Formation includes schists generally having graphite, sillimanite, cordierite, and a lack of potash feldspar; fine-grained, equigranular calc-silicate gneisses; minor quartzites; and minor amphibolites similar to those of the Monson Gneiss.

The Hardwick Granite is an undifferentiated igneous complex which includes the Bethlehem Gneiss, Kinsman Quartz Monzonite, Spaulding Quartz Diorite, and Concord Granite of the New Hampshire Plutonic Series. In general there are two distinctive rock types: granite and tonalite. The granite is characterized by red-brown biotite and zoned apatite crystals; the tonalite is finer grained, has dark-olive or green-brown biotite, and has relatively large amounts of sphene and allanite. A non-foliated, cross-cutting, sulfidic mafic dike is thought to belong to the Late Devonian Plutonic Series of Page (in preparation).

Introduction

The Athol quadrangle comprises an area of about 55 square miles in the upland region of north-central Massachusetts; the town of Athol is about 60 miles west of Boston (Plate I, lower right-hand corner). A series of north-south ridges attaining a maximum elevation of 1383 feet dominates the topography. Maximum relief is about 875 feet; local relief is rarely more than 400 feet. The entire area is underlain by Paleozoic igneous and metamorphic rocks covered by Pleistocene overburden (Eschman, 1966).

The first bedrock geology map was made by Emerson (1898, 1917); in 1952-1955 Eschman mapped the area in more detail. The western sixth of the quadrangle was remapped by Robinson (1963) who extended the New Hampshire terminology initiated in adjacent areas by Hadley (1949) and Fitzgerald (1960).

The writer worked with Eschman on the petrography of rocks collected during his mapping and spent a month in 1964 examining the rocks in the field. As a result of this work, the writer has extended into north-central Massachusetts some of the nomenclature of the New Hampshire area (Billings, 1937), particularly that of the igneous rocks.

Acknowledgments

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The assistance of colleagues at the Geological Survey is appreciated; Dr. Lincoln R. Page, Chief of the Branch of Regional Geology in New England, was particularly encouraging through all stages of the project. Dr. Donald F. Eschman, now professor at the University of Michigan, made the initial geologic map, collected the rock samples, had the thin sections made, and suggested the petrographic topic to the writer; he also critically reviewed the geology of the manuscript. Dr. E. Wm. Heinrich, professor at the University of Michigan, directed the petrographic work and critically reviewed the manuscript. Dr. Peter ~~R~~ Robinson, of the University of Massachusetts, acquainted the writer with his work through field work and supplementary personal communications.

General Lithology

The Monson Gneiss of Middle Ordovician or older age, a series of interlayered gneisses and amphibolites, underlies most of the western third of the Athol quadrangle. Conformably overlying the Monson Gneiss are the predominantly argillaceous, high-grade metamorphosed schists of the Partridge Formation of Middle Ordovician age. The Partridge Formation was intruded by the Hardwick Granite which includes the Bethlehem Gneiss, Kinsman Quartz Monzonite, and Concord Granite of the New Hampshire Plutonic Series of Billings (1937). Concordant and discordant pegmatites are prevalent throughout the area. Mafic dikes intruded a small portion of the Hardwick Granite.

The distribution of these rocks can be seen on the geologic map (Plate I). Both megascopic and microscopic studies were made and are chronologically described below, generally in the text and individually in the Appendix. Estimated mineral percentages which appear in the tables following each section and grain sizes which appear in the Appendix were determined microscopically. Locations of the specimens used for microscopic study are given on Plate I.

Monson Gneiss

Introduction. The Monson Gneiss, or Monson Granodiorite (Emerson, 1898), consists of two distinct lithologies. The first is a feldspar-quartz-biotite gneiss which occurs in two large masses. The second occurs as narrow bands of interlayered feldspar-quartz-biotite gneiss and amphibolite roughly paralleling the two large bodies and separated from them by a thin band of gneisses, schists, and amphibolites.

Geographic description. The more prominent of the Monson bodies in the Athol quadrangle is the Tully dome, an oval body approximately 9 miles long exposed in the Royalston, Athol, and Mt. Grace quadrangles. Tully Mountain in the Royalston quadrangle provides the best outcrop areas of the gneiss. The southern part of the dome is exposed in the northwestern portion of the Athol quadrangle. It is in a topographic low due to the Athol fault which longitudinally bisects the dome. The best exposures of Monson Gneiss are along the ridges on either side of the depression. The Tully dome has been described by Fitzgerald (1960), Robinson (1963), and Pike (in preparation).

The other body occurs in a topographic low in the southwestern part of the quadrangle. It is a small part of the Monson anticline which extends from the Mt. Grace quadrangle southward into Connecticut. This body has been described in detail by Robinson (1963) and Peper (1966). Both the Tully dome and the Monson anticline are considered part of the extensive New England Oliverian domes (Billings, 1937).

The second lithology of the Monson Gneiss occurs in thin bands surrounding the Tully dome and Monson anticline. The bands consist of feldspar-quartz-biotite gneiss interbedded with feldspar-quartz-hornblende gneiss and amphibolite. The bands, designated as moa on the map (Plate I), are separated from the main bodies of Monson Gneiss by a thin band of Partridge schists, gneisses, and amphibolites. The best cross-sectional exposures through the Partridge-Monson layers are in the cliff to the northwest of Mt. Pleasant Cemetery. Specimens from this cliff include thin sections 67-52, 1 through 5 (Tables 1 and 2b).

Megascopic description. The Monson Gneiss, or Granodiorite, is, in general, a fresh-looking, light-gray, medium- to coarse-grained, feldspar-quartz-biotite gneiss. It is usually granodioritic with oligoclase and magnetite. Both fresh and weathered surfaces are similar looking; both are light gray to white. It is non-layered to layered, poorly- to well-foliated.

Slight variations of the feldspar-quartz-biotite gneiss occur in the two bodies. Coarser varieties in the Tully dome have small microcline phenocrysts and, more rarely, magnetite crystals up to 0.5 cm in diameter. The biotite gneisses in the Monson anticline are more varied. Microcline phenocrysts are more common and attain dimensions of 2.5 to 4 cm by 1 to 2.5 cm. Southwest of Ward Pond is an augen feldspar-quartz-biotite gneiss (32-53, Table 1). It is similar to the augen gneiss exposed along Rte. 2-202 on the eastern edge of the Orange quadrangle. Magnetite crystals up to 2 cm were found southwest of the intersection of Parker and Flat Rock Roads.

Medium- to coarse-grained, plagioclase-quartz-hornblende gneisses and plagioclase amphibolites occur interlayered with the biotite gneisses near the contact of the Monson Gneiss and Partridge Formation and in the thin Monson bands adjacent to the Partridge. The hornblende gneisses and amphibolites comprise about 15 percent of the total Monson Gneiss. The amphibole rocks vary greatly in appearance; they are medium- to coarse-grained, massive, 'salt-and-pepper,' or thinly bedded with varying ratios of mafics to felsics.

Estimated mineral percentages of the gneisses and amphibolites appear in Table 1, individual specimen descriptions appear in the Appendix, and specimen locations are on the geologic map, Plate I.

Microscopic description. In general microscopic study of the Monson Gneiss reveals predominantly granoblastic textures. Some elongation of grains parallel to the foliation and bedding is present. Undulatory extinction of quartz and feldspar grains, bent plagioclase twin lamellae, and micaceous laths are slight cataclastic effects. The rock shows well-developed mortar structure in only one thin section, 32-53. Megascopically the rocks are medium- to coarse-grained, but microscopic examination reveals fracturing and recrystallization of grains to form coarse-grained aggregates.

The mineralogy of the rocks is similar, although relative amounts of the minerals vary considerably. Quartz occurs in all sections. Microcline is present in the more felsic rocks. Antiperthite blebs appear only in larger crystals of plagioclase. Plagioclase, oligoclase to andesine, displays well-developed albite, pericline, and Carlsbad twinning; zoning, where present, is oscillatory with a more calcium-rich core. Some sericitization occurs in the core and along twin lamellae.

Hornblende is generally light to medium olive to medium to dark blue green, olive. A few grains are twinned, zoned. Biotite is generally light yellow brown to dark olive brown or black. In the felsic rocks the biotite is generally darker and more olive; in the more mafic rocks it is generally lighter and yellow brown. Chlorite is variable in color, but usually pale to light shades of olive blue green; interference colors are commonly anomalous Berlin blue and gray.

Clinozoisite and epidote are distinguished from one another by their optical sign. Both clinozoisite and epidote occur in the same slide, particularly where zoned clinozoisite-epidote rims zoned, yellow-orange-red allanite crystals. Allanite is commonly euhedral and variable in size. The largest allanite crystal is a partial crystal at the edge of a slide; its partial dimensions are 0.7 by 1.5 mm. In some of the intermediate rocks apatite is zoned with centrally located black inclusions. Sphene commonly occurs as overgrowths on magnetite crystals. Some hematite and magnetite has been exsolved along the cleavage planes of biotite and hornblende.

The Monson Gneiss underwent high-grade metamorphism with resultant recrystallization. Deuteric and retrograde effects are also apparent. Perthite has developed along the rims of larger microcline crystals. A deuteric, fine-grained, mortar-like aggregate of quartzo-feldspathic minerals, including myrmekite, commonly occurs between larger felsic grains of the felsic rocks. Vermicular symplectites also occur between muscovite-biotite-epidote-clinozoisite and quartz-plagioclase. Diopside is uralitized by hornblende, and biotite and chlorite are retrograde after hornblende and biotite. Commonly epidote or clinozoisite has replaced biotite or hornblende.

Origin. The gneisses and amphibolites of the Monson Gneiss are interlayered, poorly to well-bedded, and commonly have angular to rounded feldspar fragments thought to have been pumice fragments (Page, personal communication). Hence, they are thought to be a series of felsic to mafic volcanic tuffs and, more rarely, flows. The central portions of the Tully dome and Monson anticline have biotite gneisses of predominantly quartz latite composition. In the upper part of the stratigraphic section, towards the periphery of the large bodies, the quartz latites are interbedded with increasing amounts of intermediate volcanics of predominantly andesitic composition; in general, foliation also becomes more pronounced. The thin bands of Monson, designated on the geologic map as moa, have up to 50 percent hornblende gneiss and amphibolite. Some of these were basaltic tuffs and flows, others were dacites and andesites. Interbedding of the tuffs can be seen both megascopically and microscopically. Many of the tuffs were reworked and contaminated by sedimentary marine processes, particularly with the addition of quartz (68-52). Later the sequence was domed and, in the Tully dome, overturned.

Age. The Monson Gneiss is Middle Ordovician or older. Whole rock isochron ages of two samples from the Orange quadrangle are 470 million years. Mineral isochrons indicate strong metamorphism took place during the Appalachian orogeny 255 million years ago (Brookins, 1965).

Correlation. Most of the thin Monson Gneiss bands were mapped by Emerson (1917) as Dana Diorite, a 'ribbon gneiss' of alternating black diorite and white aplite. Eschman continued to use the term Dana Diorite during his mapping. Hadley (1949) extended the New Hampshire nomenclature southward into the Mt. Grace quadrangle, Massachusetts, substituting Ammonoosuc Volcanics (Billings, 1937) for most of the Dana Diorite. Hadley's work was accepted for the most part by Fitzgerald (1960) and

Robinson (1963). Although the Ammonoosuc amphibolites and gneisses are very similar to the Monson, the present author has found no anthophyllite or cummingtonite and no brownish garnet quartzites which occur in the Ammonoosuc. Hence, these amphibolites and gneisses have tentatively been grouped into the general map unit moa.

Specimens from Table 1

67-52-2	Microcline-quartz-oligoclase gneiss
32-53	Microcline-oligoclase-quartz-biotite augen gneiss
19-54	Oligoclase-microcline-quartz-biotite augen gneiss
67-52-1	Oligoclase-quartz-microcline-biotite gneiss
55-6	Oligoclase-quartz-microcline-biotite gneiss
45-54	Andesine-quartz-biotite-microcline gneiss
21a-54	Andesine-quartz-biotite gneiss
67-52-3	Oligoclase-hornblende-quartz-biotite gneiss
55-R-2b	Quartz-hornblende-oligoclase gneiss. Designated on map as moa
68-52	Quartz-labradorite-hornblende gneiss. Designated on map as moa
55-79c	Hornblende-andesine-quartz gneiss. Designated on map as moa
30-54	Andesine amphibolite
55-R-2a	Plagioclase-hornblende-quartz-biotite gneiss. Designated on map as moa
67-52-4	Andesine-biotite amphibolite

Table 1.—Estimated mineral percentages of the Monson Gneiss

Mineral	Specimen 67-52-2	32-53	19-54	67-52-1	55-6	45-54	21a-54	67-52-3	55-R-2b	68-52	55-79c	30-54	55-R-2a	67-52-4	Mineral
Quartz	30	15	25	35	20	30	20	15	55	40	10	2	10	3	Quartz
Microcline	60	50	29	25	10	9	2	T *							Microcline
Plagioclase(An)	10(20)	30(20)	31(30)	35(10)	60(25)	50(40)	60(40)	55(10)	20(10)	30(60)	30(40)	35(45)	45(15-40)	45(45)	Plagioclase(An)
Biotite	1	5	8	5	7	11	15	10	1	2	1	T	10	5	Biotite
Hornblende		2	3				2	15	25	25	50	50	25	45	Hornblende
Diopside												4			Diopside
Muscovite	T			T	T								T	T	Muscovite
Clinozoisite			1	T			T				2				Clinozoisite
Epidote	T	1			1	T		T		T		6		T	Epidote
Allanite	T	T	T	T		T	T	T		T	T		T		Allanite
Garnet	T			T									T		Garnet
Sphene		T			T			T		2	2	3		1	Sphene
Zircon	T	T	T	T	T	T	T	T	T	T			T	T	Zircon
Apatite	T	T	T	T	T	T	T	T	T	T	1	T	T	T	Apatite
Chlorite	T			T	T				T				5	T	Chlorite
Carbonate									T				T		Carbonate
Iron oxide	T	T		T	1		T	T		T	T	T		1	Iron oxide
Pyrite				T	T					1	T	T	3		Pyrite
Magnetite	T	T	T		0.5	T	T	T	T	T	2	0.5	1	1	Magnetite

* Orthoclase

* Orthoclase

Partridge Formation

Introduction. The Partridge Formation of Middle Ordovician age (Billings, 1937) is a unit of varied lithologies (Tables 2a-d) which have undergone high-grade metamorphism throughout the quadrangle. This formation was called the Brimfield Schist by Emerson (1898) and Eschman. Predominant rock types include metamorphosed volcanics, schists, biotite gneisses, calc-silicate gneisses, marbles, and quartzites. Pegmatites came from the Hardwick Granite complex. Stratigraphically the Partridge lies conformably over the Ammonoosuc Volcanics of Middle Ordovician age or older and under the Clough Formation of Silurian age, which is predominantly a quartzite or conglomerate that is exposed in the Mt. Grace quadrangle (Robinson, 1963).

Geographic distribution. The Partridge Formation forms thin bands (Plate I, Opsfa) paralleling the Monson Gneiss in the western part of the quadrangle and forms a much thicker unit elsewhere (Opg). These metasediments generally have a northerly strike with moderate to steep dips to the west. The top of the Hardwick batholith is close to the surface, and Partridge sediments occur in patches throughout the area that has been mapped as Hardwick. Some of these Partridge areas are shown on the geologic map as red and orange diagonal lines.

Hornblende gneisses and amphibolites. Well-bedded, feldspar-quartz-biotite-hornblende gneisses and amphibolites (Table 2a) occur at the base of the Partridge in the thin bands (Opsfa) paralleling the Monson bodies. The gneisses and amphibolites are interbedded and interfingered with each other, sulfidic schists, sillimanite schists, and rarely calc-silicate gneisses. These gneisses are generally well-foliated and fine- to coarse-grained. One blade of hornblende 2.5 cm in diameter was found north of Flat Rock Road. The gneisses and amphibolites are similar in varied appearance and composition to those of the Monson Gneiss. Detailed descriptions appear in the Appendix.

Schists. Megascopic description. By far the most widespread of the metasediments are the schists (Table 2b). The predominant schist is a gray quartz-feldspar-/feldspar-quartz-mica schist which is fine- to coarse-grained. Garnet, sillimanite, cordierite, and graphite are commonly present. Sillimanite takes the form of bluish-silver to gray-white fibrolite. Crystals as much as 7.5 cm long and 2 cm wide, similar to those of the Littleton Formation of Lower Devonian age described by Fowler-Billings (1949) on Mt. Monadnock, are abundant in the boulders near Reservoir No. 2 and the Bates Power Reservoir. The sillimanite crystals, although altered to muscovite, resist weathering and characteristically stand out in relief as elongate pods generally parallel to each other and the foliation. This type of rock crops out at the eastern edge of the roadcut along Rte. 2-202 just west of the Highland Avenue overpass. Sillimanite also appears in a rusty weathering, sulfidic, graphitic, feldspar-quartz-mica-garnet schist. This rusty schist is commonly in the unit designated as Opsfa on the geologic map. The rusty appearance has resulted from chemical weathering of pyrite or pyrrhotite.

Schists. Microscopic description. The texture is variable. Most of the specimens have an overall schistose appearance; some specimens have gneissic banding; and one specimen has a fine-grained, equigranular appearance similar to the calc-silicate gneisses mentioned below. Quartz-feldspar-rich layers in some specimens are granoblastic.

Bedding and foliation, which are determined from mineralogic banding and alignment, are generally parallel. Grain size is generally fine to medium. Average grain length is about 0.5 mm; three sections have an average grain length of 1 mm or greater.

All the thin sections are mineralogically similar, but relative amounts of the minerals vary. Quartz and plagioclase are present in all sections except 91-52. Quartz has undulatory extinction. Potash feldspar is rare and then is present only as a trace. One specimen (55-50d) has 5% microcline. The only occurrence of orthoclase (?) is in 67-52-5; this specimen came from the Opsfa map unit. Plagioclase is generally oligoclase. Specimens R9-54 (calc-silicate texture), 55-89c, 69-53, and 101-52 have andesine; these sediments were probably originally limey. Myrmekite and twinned plagioclase seem associated with quartz-poor specimens. Cordierite appears very similar to plagioclase, having gray interference colors and similar twinning. Cordierite was identified by lower index of refraction and characteristic irregular random fractures filled with iron oxide.

Biotite is generally yellow brown to medium reddish brown or brown. Chlorite, commonly retrograde after biotite, is pale to light green; interference colors are gray or, more commonly, anomalous in brown, purple, or blue. In some thin sections and hand specimens its crosscutting or radial character indicates a post-foliation retrograde metamorphism. Muscovite flakes occur in all specimens. Some appear to be retrograde after biotite and in one section muscovite cuts across the bedding. Sericite is present in some sections (15% in 67-52-5); much of the sericite appears to be after plagioclase and sillimanite. Sericite after sillimanite occurs in felted, lens-shaped, pod-like masses with sillimanite inclusions (67-52-5). Quartz and muscovite commonly have reacted with each other to form vermicular symplectites. Graphite, characteristically found in all specimens, occurs in and among the micaceous minerals as elongate flakes with ragged edges.

Sillimanite is ascicular to prismatic; it occurs alone or in bundles, fibrolite, or radial aggregates along the foliation. Three sections have essential sillimanite. R9-54 has small basal sections in quartz. 55-89c and 69-53 have larger prisms which are remnants of the large sillimanite crystals described above. The sillimanite occurs in pod-like masses with biotite, muscovite, quartz, and plagioclase surrounded by a muscovite or sericite halo. One sillimanite pod is embayed by the matrix. Garnet commonly is fractured, has central inclusions, and is corroded by quartz. Garnet growth did not always deflect the foliation of the matrix.

Magnetite and pyrite are anhedral to euhedral. Iron oxide occurs interstitially and in fractures; bright red hematite occurs between biotite cleavage planes in some specimens. In section 101-52 epidote granules are retrograde after biotite. Rutile forms a reticulate network in the biotite and chlorite of a couple of sections. Zircon forms radioactive reaction rims in biotite and chlorite. Apatite is commonly corroded by quartz and rarely has zoned dusty inclusions (91-52).

Calc-silicate gneisses. Megascopic description. The most massive exposures of calc-silicate gneiss occur in two roadcuts along Rte. 2-202, one just west of Highland Avenue, the other south of Reservoir No. 1. Calc-silicate gneisses or granulites, which comprise less than 10% of the Partridge Formation, are fine-grained rocks varying in shades of gray, the lighter shades having more quartz and feldspar. A pinkish tinge is caused by garnet, a greenish tinge by abundant diopside, hornblende, or epidote-clinozoisite, and a brownish tinge by biotite. Color variation within different mineralogic bands imparts a gneissic, well-bedded character to the rock. In some areas the calc-silicate gneisses occur as beds generally less than 30 cm thick within the schist. In other areas calc-silicate material forms lenses or concretions within the schist. These vary in size from a football to about one meter long.

Two other types of calc-silicate rock were found; both were rare. One is a vitreous-looking, quartz-feldspar-hornblende-garnet gneiss. The hornblende occurs as straight pod-like stringers which attain a maximum width of 1 mm. This rock is found at the intersection of a brook with the bend in the Millers River approximately 1200 feet southwest of the intersection of Townsend and Royalston roads. The other type of calc-silicate gneiss is similar but has a granular, sugary texture and feel. The hornblende stringers form discontinuous wisps. Garnets are most striking; they protrude as much as 1 mm from the weathered rock surface as round resistant bumps. One occurrence of this rock is found approximately 700 feet northeast of the immediately preceding one. This particular calc-silicate is also rare in the Monadnock quadrangle (Robinson, personal communication).

Some marble interbedded with green, gray, pink, to cream, graphitic calc-silicate gneisses occurs at the eastern edge of the railroad cut at the northern end of Bearsden Road. The marble comprises less than 5% of the calc-silicate section exposed there. The white to cream marble beds are generally 3 to 5 cm thick. Each bed weathers to a depressed area; the mineral grains have a sugary texture and can be easily rubbed from the surface.

Calc-silicate gneisses. Microscopic description. The calc-silicate gneisses (Table 2c) are fine-grained, equigranular rocks with a mosaic, granular texture. Cataclastic effects are not evident. Where biotite is relatively more abundant, the rock becomes schistose and the felsic minerals are more elongate. Mineralogic banding is common; some of this has been noted in the individual thin section descriptions in the Appendix. All sections from 55-NH-5 and 55-NH-6 are from two hand specimens.

Quartz grains commonly have undulatory extinction, but do not show much fracturing. Orthoclase occurs only as a trace mineral near quartz-rich bands in a few thin sections. Plagioclase is commonly quite calcic, being in the andesine-labradorite-bytownite range; plagioclase composition varies among laminae in some sections. Some laminae contain well-twinned plagioclase; others have little or no twinning. Twinning is albite, Carlsbad, and/or pericline.

Diopside, hornblende, garnet, and epidote-clinozoisite are poikiloblastic to skeletal. These minerals and plagioclase occur interstially or as coarse grains, usually strung out parallel to the bedding. Diopside is colorless to very pale green. Very pale green to olive hornblende is primary or retrograde after diopside. Some of the hornblende may be actinolite, but extinction angles are generally more in the hornblende range. Biotite is primary or retrograde after hornblende. Most of the biotite is light to medium yellow red brown; some is very pale and may be phlogopite. Garnet is colorless to a pink or brown tinge. Epidote and clinozoisite were distinguished by optical sign; dull anomalous interference colors in a mottled blue to yellowish green to gray are characteristic. Allanite is rarely present; it is yellow to orange to red and rimmed by epidote-clinozoisite.

Sphene occurs as rounded pink, golden pink, or gray brown pellets; some have been altered slightly to leucoxene. Magnetite occurs as blebs and pyrite is euhedral to anhedral. Both have very little alteration to hematite. Graphite occurs as flakes with ragged edges. Apatite and zircon grains are tiny.

Quartz-feldspar gneisses. Two types of quartz-feldspar gneisses are present. In the band designated as Opsfa on the map, the amphibolites are interlayered with feldspar-quartz-hornblende and/or biotite gneisses similar to those found in the thin bands of Monson designated as moa. The other gneisses are feldspar-quartz- or quartz-feldspar-biotite gneisses interlayered with schist. They are fine- to coarse-grained and seem more common near pegmatitic material. Textures are granitic.

Pegmatites. Pegmatitic material occurs throughout the quadrangle in all lithologic formations. Pegmatites are described in this section only because thin sections of them were taken from the Partridge Formation. Pegmatites are discordant to concordant, foliated and gneissic to non-foliated, medium- to coarse-grained. They were intruded before, during, and after regional metamorphism. They commonly weather as gray to white resistant knobs or masses in outcrop. Specimens are white to buff and have feldspar, quartz, and mica (Table 2d). A rare white, coarse-grained, quartz-feldspar-muscovite rock dotted with pink garnets 2 mm in diameter is quite striking in appearance (55-NH-2).

The pegmatites are microscopically fine- to coarse-grained with a sutured texture. Deuteric myrmekite is present. Some muscovite probably has formed at the expense of alkali feldspar; sericite has replaced oligoclase. Further descriptive material appears in the Appendix.

Quartzites. Vitreous-looking, white- to cream- to reddish-brown quartzites occur as minor beds in several places. These quartzites are generally about 30 cm thick. Specimen R9-54 bears the closest megascopic resemblance to the quartzites, but it is included with the schists in Table 2b because of its mineralogy (e.g., 10% sillimanite).

Origin. The Partridge Formation is a varied lithologic unit because of different environmental conditions. The basal part has some interlayered hornblende gneisses and amphibolites. They are generally well-bedded and commonly have feldspar fragments thought to have been pumice fragments (Page, personal communication). They were probably volcanic tuffs and rarely flows of felsic to mafic composition deposited in a marine environment. These are interlayered with sediments which were predominantly clays or silts. Some beds were more limey and others were more siliceous resulting in the extremes of limestone and sandstone.

All lithologies of the Partridge Formation underwent high-grade metamorphism during the Acadian orogeny and syntectonic intrusion of the Hardwick Granite. Calc-silicate gneisses and schists having large sillimanite crystals are relatively abundant near sharp contacts between the Partridge and Hardwick. Where calc-silicate gneisses and schists with large sillimanite crystals are absent, the contacts between the Partridge schists and Hardwick Granite are gradational.

Age and correlation. Some of what is mapped as Partridge Formation of Middle Ordovician age may actually be the Littleton Formation of Lower Devonian age (Billings, 1937). Lithologically the two are similar. Elsewhere the Partridge schists are characteristically sulfidic and the Littleton has graded bedding (Page, personal communication). Because graded bedding has not yet been found in the Athol quadrangle the schists have been called Partridge. They were called Partridge in the Orange quadrangle (Robinson, 1963), both in the Mt. Grace quadrangle (Hadley, 1949; Robinson, 1963), and Littleton in the Royalston (Fitzgerald, 1960) and Monadnock quadrangles (Fowler-Billings, 1949). Some of the quartzites of the Athol quadrangle may belong to the Clough Formation of Silurian age (Billings, 1937); if they do, then some of the schists may be Littleton. Clearly more field work needs to be done to justify the age and correlation of the Partridge Formation in the Athol quadrangle.

Table 2a.--Estimated mineral percentages of the Partridge Formation - hornblende gneisses and amphibolites

Mineral	Specimen 11-54	31-54	109-52
Quartz	6	9	2
Plagioclase$_{(An)}$	$50_{(40)}$	$60_{(45)}$	$45_{(45)}$
Biotite	0.5	T	T
Hornblende	40	30	50
Sphene		T	
Zircon		T	
Apatite	T	T	T
Chlorite	T	T	T
Carbonate	T		
Iron oxide	T		T
Magnetite	T	T	2

Specimens from Table 2a

11-54 Andesine-hornblende-quartz gneiss

31-54 Andesine-hornblende-quartz gneiss

109-52 Andesine amphibolite

Specimens from Table 2b

R9-54	Biotite-sillimanite-muscovite quartzite
55-70	Oligoclase-muscovite-biotite quartzite
91-52	Muscovite-biotite-chlorite-cordierite quartzite
20-52	Quartz-muscovite-biotite-oligoclase-chlorite-garnet schist
39-52	Oligoclase-quartz-muscovite-biotite gneiss
126-52	Quartz-biotite-muscovite-chlorite-oligoclase-cordierite-graphite schist
12-54	Quartz-oligoclase-muscovite-cordierite-chlorite-biotite-porphyroblastic gneiss
55-89c	Muscovite-quartz-biotite-sillimanite-garnet schist
17a-54	Biotite-muscovite-quartz-garnet schist
85-52	Cordierite-quartz-biotite-muscovite-oligoclase gneiss
66-54-2	Oligoclase-quartz-muscovite-biotite-garnet schist
15-54	Oligoclase-quartz-muscovite-biotite schist
12-53	Muscovite-quartz-biotite-chlorite-cordierite-graphite-iron oxide-oligoclase schist
78-52	Biotite-muscovite-oligoclase-quartz-garnet schist
55-50d	Biotite-oligoclase-quartz-muscovite-garnet-microcline schist
55-92d	Muscovite-biotite-quartz schist
69-53	Muscovite-biotite-andesine-sillimanite-quartz schist
101-52	Andesine-biotite-quartz schist
67-52-5	Muscovite-oligoclase-biotite-chlorite-quartz-graphite-garnet schist

Table 2b.--Estimated mineral percentages of the Partridge Formation - schists

	Specimen																			
Mineral	R9-54	55-70	91-52	20-52	39-52	126-52	12-54	55-89c	17a-54	85-52	66-54-2	15-54	12-53	78-52	55-50d	55-92d	69-53	101-52	67-52-5	Mineral
Quartz	70	60	50	35	35	30	25	20	20	20	20	20	15	15	15	10	10	10	6	Quartz
Microcline					T		T				T	T			5			T	T(?) *	Microcline
Plagioclase$_{(An)}$	$1_{(40)}$	$15_{(20)}$		$7_{(15)}$	$45_{(15)}$	$9_{(15)}$	$25_{(15)}$	$T_{(30?)}$	$T_{(20)}$	$5_{(15)}$	$35_{(15)}$	$45_{(20)}$	$5_{(15?)}$	$20_{(15)}$	$20_{(15)}$	$3_{(15)}$	$15_{(40)}$	$53_{(40)}$	$25_{(15)}$	Plagioclase$_{(An)}$
Biotite	10	8	15	15	7	20	8	20	35	15	15	15	15	25	35	20	25	30	20	Biotite
Muscovite	5	15	20	35	10	15	15	25	30	15	20	20	25	25	15	60	30	T	35	Muscovite
Sillimanite	10	T	T	T	T	T	T	20	0.5		T		T	T	T	T	15	T	T	Sillimanite
Cordierite		T	5		2	6	10			40	T		10		3	4	T	T	T	Cordierite
Epidote																		T		Epidote
Allanite				T																Allenite
Garnet	0.5		T	5		3		15	5		5		4	6	8		3	3	5	Garnet
Zircon	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	Zircon
Apatite		T	T	T	T	T	T		T	T	T	T			T		T	3	T	Apatite
Chlorite	2	T	8	7		15	10		4		2		15	T			T	T	7	Chlorite
Iron oxide	T	T	1	T	1		3	T	1	2	T	T	7	T	T	2	T	T	1	Iron oxide
Pyrite	T	T			T	T					T			0.5				T		Pyrite
Magnetite	1	T	T	T	T	T	T	1	T	T	T	T	T	0.5	T	1	2	3	0.5	Magnetite
Graphite	1	T	1	1	T	5	2	1	2	T	1	T	8	2	1	T	T	T	6	Graphite
Rutile								T(?)	T											Rutile
Leucoxene								T									T			Leucoxene

* Orthoclase

* Orthoclase

Specimens from Table 2c

55-15	Clinozoisite-hornblende-pyrite quartzite
55-83	Quartz-bytownite-diopside-hornblende gneiss
52-91a	Quartz-labradorite-garnet-hornblende-biotite gneiss
105b-54	Quartz-bytownite-garnet-hornblende gneiss
66-54-1	Quartz-hornblende-bytownite-clinozoisite gneiss
55-NH-5a	Diopside-quartz-bytownite gneiss
55-NH-5b	Quartz-diopside-bytownite-garnet gneiss
55-NH-5c	Quartz-diopside-bytownite-garnet gneiss
55-NH-5d	Quartz-diopside-bytownite-garnet gneiss
55-NH-5e	Quartz-bytownite-diopside gneiss
55-NH-6a	Quartz-biotite-plagioclase-muscovite schist
55-NH-6b	Quartz-plagioclase-biotite-muscovite schist
55-NH-6c	Quartz-labradorite-bytownite-biotite-garnet-clinozoisite schist
55-NH-6d	Diopside-garnet-clinozoisite quartzite
55-NH-6e	Diopside-quartz-garnet gneiss

Table 2c.--Estimated mineral percentages of the Partridge Formation - calc-silicate gneisses, or granulites

Specimen

Mineral	55-15	55-83	52-91a	105b-54	66-54-1	55-NH-5a	55-NH-5b	55-NH-5c	55-NH-5d	55-NH-5e	55-NH-6a	55-NH-6b	55-NH-6c	55-NH-6d	55-NH-6e	Mineral
Quartz	70	45	45	45	35	25	40	45	20-70	65	40	40	40	65	40	Quartz
Microcline						T					T *	T *	T *			Microcline
Plagioclase (An)	T (75)	25 (70)	30 (70)	30 (75)	20 (70-80)	20 (75)	20 (75)	15 (85)	10 (65-80)	15 (65-85)	20 (35,70)	25 (40, 70)	25 (70)		0.5 (70)	Plagioclase (An)
Biotite			5		1	1					25	25	10		T	Biotite
Hornblende	6	10	7	10	30	1 #			T #				3	T	T	Hornblende
Diopside		15				50	25	30	60-20	15			1	20	45	Diopside
Muscovite		T	T						T		15	10				Muscovite
Clinozoisite	20		T		10				2		T	T	5	5	2	Clinozoisite
Epidote						T	3	T		3						Epidote
Allanite			T		T	T					T					Allanite
Garnet		2	10	15			10	10	10	1	T	T	10	10	10	Garnet
Sphene	1	1	T	0.5	3	2	0.5	T	T	T			T	T	T	Sphene
Zircon		T	T	T		T					T	T				Zircon
Apatite	T	0.5	T	T	T						T	T	T			Apatite
Chlorite			T		T											Chlorite
Carbonate							T	T	T	T			T	1	3	Carbonate
Iron oxide	T	1	T	1	T	T										Iron oxide
Pyrite	5	T	T	T	3	1	T			T	T	T	T	T	T	Pyrite
Magnetite	T	T	0.5	2	T	T					T	T	0.5	T	T	Magnetite
Graphite					T	T	T	T	T	T	T	T	0.5	T	T	Graphite
Leucoxene		0.5														Leucoxene
Antigorite		T														Antigorite
Pyrrhotite(?)											T					Pyrrhotite(?)
Schorl											T	T	T			Schorl
Andalusite(?)											T					Andalusite(?)
Rutile											T					Rutile

*Orthoclase
#Actinolite

*Orthoclase
#Actinolite

Table 2d.--Estimated mineral percentages of the Partridge Formation - pegmatites

Mineral	Specimen 78a-52	70-54	55-NH-2
Quartz	50	30	30
Microcline		10	
Plagioclase$_{(An)}$	25$_{(20)}$	25$_{(20)}$	35$_{(15)}$
Biotite			1
Muscovite	20	30	25
Sillimanite		T	T
Cordierite		1	
Garnet	T	2	5
Zircon	T		T
Apatite	T		T
Chlorite			T
Carbonate			T
Iron oxide	T	T	T
Pyrite			1
Magnetite	T	T	T
Leucoxene			T

Specimens from Table 2d

78a-52 Quartz-oligoclase-muscovite pegmatite

70-54 Quartz-muscovite-oligoclase-microcline pegmatite

55-NH-2 Oligoclase-quartz-muscovite-garnet pegmatite

Hardwick Granite

Introduction. The Hardwick Granite is a poorly known intrusive complex mapped by Emerson (1917) as a narrow sinuous belt extending north-south across central Massachusetts. Extensive mapping is needed to better understand the interrelationships of the various rock types in this complex. In the Monadnock quadrangle of southern New Hampshire Fowler-Billings (1949) noted a definite similarity and possible correlation of the Hardwick Granite to the south with the Spaulding Quartz Diorite and Bethlehem Gneiss of the New Hampshire Plutonic Series. Fitzgerald (1960) mapped the western edge of Hardwick Granite in the Royalston quadrangle as the Spaulding Quartz Diorite and, thus, conformed with the Monadnock mapping due north.

Geographic description. Most of the eastern half and half of the southwestern quadrant of the Athol quadrangle is underlain by the Hardwick Granite complex. A couple of smaller Hardwick bodies occur in the north-central part of the quadrangle. The southwestern body is similar to the main body; the two are separated by the metasediments of the Partridge Formation. Inclusions of Partridge schist and calc-silicate gneiss are present throughout the Hardwick Granite. The foliation of the Hardwick in all bodies generally strikes north with moderate dips to the west.

Megascopic description. In general typical Hardwick Granite closely resembles the description of Spaulding Quartz Diorite. It is light to dark gray, medium- to coarse-grained, poorly to well-foliated with feldspar, quartz, and biotite. Weathered surfaces are usually stained yellow brown by iron oxide. The Hardwick Granite commonly has a blotchy, spotted appearance caused by dark spots and stringers of biotite wrapping around quartz-feldspar-rich areas several mm in diameter. It is commonly porphyritic with indistinct phenocryst boundaries.

There are several notable exceptions to this Hardwick description. The first is a fresh-looking, gray to dark-gray, medium- to coarse-grained, quartz-feldspar-biotite gneiss. The second is a gray, medium- to coarse-grained, quartz-feldspar-biotite gneiss which is characterized by distinctly outlined microcline phenocrysts with Carlsbad twinning. These phenocrysts are generally 1 to 4 cm long. A third variation is represented by a light-gray, fine- to medium-grained, equigranular, binary granite. Pegmatites and aplites are also abundant; both are concordant to discordant, foliated to non-foliated. Along the contact of Partridge schist and Hardwick Granite is a complete gradation from biotite schist to gneiss with the two mutually contaminating one another.

The composition of the Hardwick Granite varies from granite to granodiorite to tonalite. Estimated mineral percentages of the Hardwick Granite appear in Table 3. The granites are generally lighter colored and coarser grained than the tonalites; the tonalites are gray to dark gray and finer grained. The granodiorites bear a resemblance to either the granites or the tonalites.

Microscopic description. Microscopic examination reveals granitic textures. A few samples are sutured or mortared. Slight cataclastic effects are evident; these include strain shadows and fracturing of felsic minerals and bending of micaceous laths. Larger felsic grains are set in finer grained, deuteric aggregates of felsic minerals. In general the felsics of the granites are coarser grained and equigranular with biotite and myrmekite strung around the felsic grains. The tonalites are finer grained. Microfoliation is more evident in the tonalites; both felsics and mafics are elongate parallel to the foliation. Megascopically the rocks are medium- to coarse-grained, but microscopic examination reveals fracturing and recrystallization.

Quartz commonly shows undulatory extinction. Orthoclase occurs only as a trace in some of the tonalites. Carlsbad phenocrysts are more commonly microcline than oligoclase. Plagioclase is commonly oligoclase in the felsic rocks, whereas oligoclase or andesine occurs in the tonalites. Myrmekite, perthite, antiperthite, and sodium-rich rims on oligoclase are present in the felsic rocks. Albite, pericline, and Carlsbad twinning and normal oscillatory zoning are better developed in the tonalites. Sericitization occurs in the core and along twin lamellae of plagioclase. Muscovite is in all specimens and commonly forms at the expense of plagioclase. Quartz and feldspar have reacted with muscovite laths to form vermicular intergrowths.

Mafic minerals are present in all specimens. Hornblende occurs only as an accessory mineral in the more mafic tonalites. Hornblende is blue green to bluish olive; some twinning is present. Yellow to red-brown to olive biotite is retrograde after hornblende. The felsic rocks generally have yellow to reddish-brown biotite with bright interference colors, whereas the tonalites characteristically have olive-brown biotite with more subdued dull pink and green interference colors. Biotite is rarely corroded by quartz. Chlorite, retrograde after biotite and hornblende, is generally light yellow brown to blue green with gray to anomalous blue, purple, or brown interference colors.

Common accessories include magnetite, zircon, apatite, sphene, and members of the epidote group. Of these, only the last three will be mentioned. All specimens contain apatite and it is almost an essential mineral in specimen 55-71. Apatite is commonly euhedral to anhedral and rarely up to 1 mm long. Zoned apatite, with centrally located black inclusions oriented normal or parallel to the c-axis, commonly occurs with the reddish-brown biotite of the more felsic rocks. Sphene occurs in all seven tonalite specimens and is an essential mineral in one. The sphene is euhedral to anhedral and up to 1 mm long. It commonly forms overgrowths on magnetite. It is faintly pleochroic gray brown with a more golden core. The epidote family also occurs in all the tonalites. Members present include epidote, clinozoisite, and allanite. Epidote and/or clinozoisite (distinguished by optical sign) occur alone in zoned euhedral to anhedral crystals or form a rim on the yellow to orange to red allanite crystals. Allanite is commonly euhedral and well-zoned with distinct internal rims and darker cores. Allanite crystals greater than 1 mm long are present.

In summary the granites are characterized by a coarser, rounded texture, yellow to reddish-brown biotite, and relatively large zoned apatite crystals. The tonalites are finer grained with felsic minerals elongated parallel to the foliation, dark-olive or green-brown biotite, and relatively high amounts of sphene and allanite. The granodiorite specimens bear a resemblance to either the granites or tonalites, not both.

Age. The Hardwick Granite was syntectonically intruded into the older sediments. Time of intrusion was during the Late Devonian during the regional folding, intrusion, and metamorphism associated with the New Hampshire Plutonic Series. The Hardwick Granite underwent prograde and retrograde metamorphism.

Correlation. Billings described the New Hampshire Plutonic Series in 1937. The present author feels the Hardwick Granite is a catch-all term for several different rock types in the New Hampshire Plutonic Series (Mook, 1967). Chronologically from oldest to youngest, several members include the Bethlehem Gneiss or Granodiorite, the Kinsman Quartz Monzonite (Billings, 1937), the Spaulding Quartz Diorite (Fowler-Billings, 1949), and the Concord Granite (Fowler-Lunn and Kingsley, 1937). The Bethlehem Gneiss is a gray to dark-gray, medium- to coarse-grained, biotite granodiorite gneiss (first variation, p. 29). The Kinsman Quartz Monzonite is characterized by distinctly outlined microcline phenocrysts with Carlsbad twinning; it is also a gray, medium- to coarse-grained, biotite gneiss (second variation, p. 29). The Spaulding Quartz Diorite is a blotchy gray, medium- to coarse-grained, biotite rock similar to typical Hardwick in appearance. The youngest member is the Concord Granite which is a light-gray, fine- to medium-grained, equigranular, binary granite (third variation, p. 29).

Roadcuts along Rte. 2-202 have exposed several rock types bearing a close resemblance to the Bethlehem, Kinsman, and Concord, all in the time sequence mentioned above. Preliminary field work by the author has revealed several exposures and numerous boulders of rocks of the Kinsman type in the Athol quadrangle. Some of the areas of rocks bearing a close resemblance to the members of the New Hampshire Plutonic Series appear on the geologic map (Plate I) as black, blue, and green diagonal lines. More exposures of rocks resembling those of the New Hampshire Plutonic Series will undoubtedly be found through further field work.

Some of the felsic rocks with red-brown biotite and zoned apatite bear a close resemblance to the Kinsman Quartz Monzonite. The tonalites with dark-brown-olive biotite, sphene, and epidote members are similar to the Bethlehem Gneiss. Further field and petrographic work needs to be done to substantiate this similarity.

Mafic dikes. Megascopic description. An area of diagonal yellow lines on the geologic map appears in the roadcut between two hills towards the northern end of Bearsden Road; the rocks here are mafic with a dioritic to diabasic composition. They are massive, poorly- to non-foliated, fine- to coarse-grained, dark green-brown-black, crosscutting, andesine-biotite amphibolite dikes. Estimated percentages are given in Table 4. Some other specimens are richer in biotite, but still others contain up to 90% hornblende. Pyrite cubes up to 0.5 cm are present.

Mafic dikes. Microscopic description. Thin sections reveal decussate to diabasic textures. The grain size is variable within each section. Black oriented dust and needles are finely disseminated throughout the andesine and hornblende. This material is probably magnetite or ilmenite which was exsolved forming a herringbone latticework. Laths of andesine are commonly crosscut by mafic minerals. Traces of interstitial myrmekite are present.

Hornblende is olive to blue green, sometimes twinned. Some vermicular intergrowths have formed from the reaction of quartz with hornblende. Yellow-brown biotite is retrograde after hornblende; brownish to bluish-green chlorite with anomalous gray interference colors is retrograde after biotite and hornblende.

Grayish-brown sphene forms overgrowths on magnetite. Section 12-52-1 has aggregates of more or less euhedral, rusty-golden to bright-yellow sphene. Pyrite cubes are commonly rimmed by magnetite and hematite. Apatite up to 2 mm long commonly has tube-like structures and black inclusions parallel to the c-axis; some apatite is faintly radioactive. Radioactive epidote-clinozoisite rims allanite. A reticulate herringbone pattern has been formed by several small aggregates of zircon.

Mafic dikes. Age and correlation. The dikes underwent retrograde metamorphism. They are post-Hardwick and pre-Triassic. The dikes may be related to the mafic members of the Late Devonian Plutonic Series described by Page (~~in preparation~~ 1967, oral communication).

Specimens from Table 3

55-75d	Microcline-quartz-oligoclase gneiss
55-86c	Microcline-quartz-oligoclase-biotite gneiss with microcline-quartz vein
55-31a	Porphyritic microcline-quartz-oligoclase-biotite gneiss
55-92b	Porphyritic microcline-quartz-oligoclase-biotite gneiss
55-38d	Porphyritic microcline-oligoclase-quartz gneiss
17-54	Porphyritic microcline-quartz-oligoclase-mica gneiss
55-30	Microcline-quartz-oligoclase-biotite gneiss
55-50a	Porphyritic quartz-microcline-oligoclase-biotite gneiss
55-38c	Quartz-microcline-oligoclase gneiss
P-10	Porphyritic microcline-oligoclase-quartz-biotite gneiss
43-52	Porphyritic microcline-oligoclase-quartz-biotite gneiss
106-54	Oligoclase-microcline-quartz gneiss
88-52-2	Porphyritic oligoclase-microcline-quartz-biotite gneiss
55-71	Biotite-oligoclase-quartz-microcline-sphene gneiss
55-95a	Oligoclase-quartz-biotite gneiss
12-52-2	Oligoclase-quartz-biotite gneiss
70-53	Oligoclase-quartz-biotite gneiss
55-85f	Andesine-biotite-quartz gneiss
55-NH-4a	Oligoclase-biotite-quartz gneiss
88-52-1	Andesine-biotite-quartz gneiss conformably cut by pink andesine-quartz dike
55-88d	Andesine-biotite-quartz-sphene gneiss

Table 3.--Estimated mineral percentages of the Hardwick Granite

Mineral	55-75d	55-86c	55-31a	55-92b	55-38d	17-54	55-30	55-50a	55-38c	P-10	43-52	106-54	88-52-2	55-71	55-95e	12-52-2	70-53	55-85f	55-NH-4e	88-52-1	55-88d	Mineral
	Specimen																					
Quartz	30	25	25	20	20	30	30	45	40	25	10	20	20	15	25	25	25	15	10	15	8	Quartz
Microcline	60	60	60	55	50	40	40	35	35	35	40	30	20	10	3	T *	T *	T *				Microcline
Plagioclase (An)	10 (20)	10 (20)	10 (20)	15 (15)	25 (15)	20 (10)	20 (15)	15 (15)	25 (10)	30 (15)	35 (15)	40 (20)	45 (10)	30 (15)	40 (15)	70 (15)	60 (20)	50 (35)	60 (20)	50 (40)	65 (40)	Plagioclase (An)
Biotite	2	5	5	10	2	5	5	5	T	10	10	2	8	35	25	5	10	30	25	30	20	Biotite
Hornblende																			4	T	T	Hornblende
Muscovite	T	T	1	2	1	5	4	1	0.5	3	3	3	0.5	T	T	T	T	0.5	T	T	T	Muscovite
Sillimanite																	T					Sillimanite
Cordierite										T							T					Cordierite
Clinozoisite		T					T		T								T			T		Clinozoisite
Epidote														T	T	T		T	T		T	Epidote
Allanite		T	T			T	T							T	T	T	0.5	T	T	T	T	Allanite
Garnet	T																					Garnet
Sphene		T												5	1	T	2	4	2	3	5	Sphene
Zircon	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	Zircon
Apatite	T	T	T	T	T	T	T	T	T	T	0.5	T	0.5	4	2	2	1	2	2	1	2	Apatite
Chlorite	T	T	0.5	T	T	T	0.5	T	2	T	T	2	2	T		T	T		T			Chlorite
Carbonate										T						T						Carbonate
Iron oxide	T	T	T	T	T	T	T	T	T	T	T	1	T	T	T	T	T	T	T	T	T	Iron oxide
Pyrite		T	T							T			T	T			T				T	Pyrite
Magnetite	T	T	1	T	T	T	0.5	T	T	T	1	T	0.5	T	2	0.5	2	T	T	T	2	Magnetite
Graphite				T		T																Graphite
Rutile		T	T(?)		T(?)	T	T(?)	T(?)	T(?)		T	T(?)	3(?)				T					Rutile
Zeolite														T				T				Zeolite

*Orthoclase
(?) Ilmenite

*Orthoclase
(?) Ilmenite

Table 4.--Estimated mineral percentages from diorite-diabase dike in Hardwick Granite

Mineral	Specimen 12-52-1	55-85c	55-85h
Quartz	3	T	T
Plagioclase (An)	30 (40)	30 (45)	60 (45)
Biotite	30	20	10
Hornblende	35	40	25
Clinozoisite			T
Epidote	T	T	
Allanite	T		T
Sphene	0.5		T
Zircon	T	T	T
Apatite	1	2	T
Chlorite	T	5	T
Iron oxide	T	T	1
Pyrite	0.5	T	
Magnetite	0.5	2	2
Rutile	T		
Ilmenite		T(?)	T(?)
Chalcopyrite		T(?)	

(?) Mineral in question

Specimens from Table 4

12-52-1 Hornblende-biotite-andesine amphibolite

55-85c Hornblende-andesine-biotite-chlorite amphibolite

55-85h Andesine-hornblende-biotite amphibolite

Geologic History

All the bedrock geology of the Athol area is Paleozoic. During the Middle Ordovician volcanism from shield volcanoes was prevalent throughout much of New England. The volcanics were predominantly tuffs and rarely flows of felsic to mafic composition (Monson Gneiss) deposited in shallow seas where they were partially reworked, particularly with the introduction of silica. Then the volcanic province became a sedimentary one with the interlayering of more and more silty sediments. The silty sediments (Partridge Formation) were interlayered with minor limey and siliceous sediments as the sea level fluctuated. The Partridge sedimentation was followed by the deposition of the Clough and Fitch Formations of Silurian age (Billings, 1937) and the Littleton Formation of Lower Devonian age. The Clough, characterized by quartzites and conglomerates, represents the near shore and shore facies; the Fitch and Littleton, similar to the Partridge, were deposited in deeper water. The Clough, Fitch, and Littleton Formations are tentatively thought to be absent in the Athol quadrangle.

The New Hampshire Plutonic Series (Hardwick Granite) of Middle to Late Devonian age was intruded before, during, and after the main Acadian orogeny. High-grade regional metamorphism was associated with the orogeny. The volcanics were then transformed to gneisses and amphibolites and the sediments became sillimanite schists, diopside calc-silicate gneisses, and quartzites. Aplites and pegmatites of several ages but associated with the Hardwick intrusion are foliated or non-foliated, concordant or discordant. A minor mafic, non-foliated dike may be a member of the Late Devonian Plutonic Series of Page (~~in preparation~~ 1967, oral communication).

Folding and faulting have affected the structure of the area. Most bedding strikes to the north with moderate to steep dips to the west. Crossbedding, channeling, and graded bedding generally indicate tops to the west except to the east of the Tully dome. Doming of the Monson Gneiss and Partridge Formation occurred before the intrusion of the Hardwick Granite, because the intrusives all over New England wrap around the Oliverian domes (Page, 1967, oral communication ~~in preparation~~) and, in most places, the Hardwick crosscuts steeply dipping sediments. The Athol area is at the top of the Hardwick batholith because, in places, the Hardwick and Partridge have flat-lying foliations and the sediments form a thin patchy skin throughout the Hardwick area.

The Athol fault is the most extensive fault. It is a normal fault that extends the length of the western part of the quadrangle. Best exposures are along Rte. 2-202 and in the Tully Dam Spillway along the West Royalston Road in the Royalston quadrangle. The general trend, silicification, and brecciation (Table 5) are similar to the faults in other areas which are thought to be of Triassic age (Robinson, 1963; Norman Herz, personal communication to Eschman). The faults in other areas cut Devonian and Triassic units.

During the Pleistocene glacial deposits were left over the entire area (Eschman, 1966). Erosion has continued intermittently from the Paleozoic to Recent times.

Table 5.--Estimated mineral percentages from fault gouge from Rte. 2-202

Mineral	Specimen 35-52	Specimen 55-98b
Quartz	60	30
Microcline	10	3 *
Plagioclase$_{(An)}$	30$_{(10)}$	55$_{(15?)}$
Biotite		T
Muscovite	T	2
Garnet		T
Sphene		3
Zircon		T
Apatite		T
Chlorite		T
Iron oxide	1	
Pyrite		T
Magnetite		T
Ilmenite		T
Leucoxene	T(?)	7

* Orthoclase

Specimens from Table 5

35-52 Fault gouge

55-98b Fault gouge

Appendix

Specimens of the Monson Gneiss in Table 1

Specimen	Name, Location, Description, Origin
67-52-2	Light-gray, fine-grained, microcline-quartz-oligoclase gneiss. West of North Orange Road, north of Mt. Pleasant. Granoblastic. Felsics slightly elongate, generally 0.5 to 1 mm. Finer grained (0.06 to 0.08 mm) deuteric myrmekite and felsic grains are present interstitially. Oligoclase poorly twinned. Light-yellow-olive to olive-black biotite being replaced by light-yellow-olive to medium-blue-green chlorite. Medium-yellow-orange-red, zoned, anhedral to subhedral allanite has clinozoisite rim. Rhyolite.
32-53	Light-gray, fine- to medium-grained, microcline-oligoclase-quartz-biotite augen gneiss. Southwest of Ward Pond, western edge of quadrangle. Granoblastic and mortared. Grain size variable; generally 0.5 to 1.5 mm. Deuteric myrmekite developed along edge of oligoclase grains. Most of the microcline is present as augen, up to 14 mm long, which have perthite blebs along boundaries and inclusions of quartz, biotite, and hornblende. Olive to blue-green hornblende is being replaced by light-yellow-brown to dark-brown biotite. Mafic minerals are decussate. Rounded sphene crystals are associated with biotite. Reddish-orange allanite is rimmed by epidote. Rhyolite.
19-54	Light-gray, fine- to medium-grained, oligoclase-microcline-quartz-biotite augen gneiss. North of Rte. 122, east of Turnpike Road. Granoblastic. Grain size varies from 0.05 to 2 mm. Perthite veins and blebs in microcline and interstitial deuteric myrmekite are present. Biotite light yellow brown to dark olive black, replacing light-olive to dark green-brown, blue-green hornblende. Zoned allanite has clinozoisite-epidote rim. Allanite is yellowish orange, being darker in the core. Largest, yet incomplete and corroded, allanite crystal at edge of slide is 0.7 by 1.5 mm.

19-54 (Cont.)	Quartz latite.
67-52-1	Light-gray, fine-grained, oligoclase-quartz-microcline-biotite gneiss. West of North Orange Road, north of Mt. Pleasant. East of 67-52-2. Similar to 67-52-2 but oligoclase is better twinned. Feldspar phenocrysts as long as 5 mm occur in several layers. Quartz latite.
55-6	Light-gray, fine- to medium-grained, oligoclase-quartz-microcline-biotite gneiss. West of Old Keene Road. Granoblastic. Grain size approximately 1 mm; slightly elongate. Finer grained (0.06 to 0.2 mm) felsics present interstitially. Oscillatory zoning of oligoclase. Biotite light olive brown to dark olive brown; being replaced by epidote and pale-yellow-olive to light-blue-green chlorite. Sphene overgrowths on larger magnetite crystals. Pyrite euhedral; some has magnetite rim. Quartz latite.
45-54	Light gray, fine- to medium-grained, andesine-quartz-biotite-microcline gneiss. North of Rte. 122, west of Turnpike Road. Granoblastic. Grain size commonly 0.3, 0.6, or 1 mm. Finer grained interstitial myrmekite occurs as deuteric alteration. Antiperthite blebs. Lepidoblastic biotite pale yellow olive to olive black. Yellowish-orange allanite has epidote-clinozoisite rim. Quartz latite.
21a-54	Banded light-gray and white, fine- to medium-grained, andesine-quartz-biotite gneiss. North of Rte. 122, west of Turnpike Road. Granoblastic. Grain size generally 0.3 to 0.6 mm. Antiperthite and interstitial myrmekite present at microcline side of slide. Andesine has oscillatory zoning; phenocryst present at microcline edge. Medium olive to blue-green hornblende being replaced by biotite. Biotite is light yellow brown to dark reddish brown;

21a-54 (Cont.) medium olive brown on one edge of slide. Apatite zoned with centrally located black inclusions. Zoned, yellow-orange to red, euhedral allanite has clinozoisite overgrowth.

Dacite.

67-52-3 Banded white and dark-gray, fine-grained, oligoclase-hornblende-quartz-biotite gneiss.

West of North Orange Road, north of Mt. Pleasant. West of 67-52-1 and 67-52-2.

'Salt-and-pepper' rock. Ca-Fe-rich bands. Some bands have yellow-brown limonitic stain. Mosaic texture. Felsics slightly elongate. Grain size generally 0.2 to 0.5 mm. Oscillatory zoning of plagioclase. Biotite retrograde after medium-olive to dark blue-green, olive hornblende. Biotite light yellowish brown to dark reddish brown. Sphene present mostly in one band; occasionally forms overgrowths on magnetite. Yellow-red allanite rimmed by epidote.

Interbedded Ca-rich tuff and Fe-rich sandstone.

55-R-2b Banded light- and dark-gray, fine- to medium-grained, quartz-hornblende-oligoclase gneiss.

Rte. 2-202, west of Athol fault. Designated as moa on geologic map, Plate I.

Folded, fine-grained, amphibole gneiss cut by medium-grained, sutured quartz vein which covers 20 percent of the slide. Variable grain size generally 0.05 to 0.6 mm. Oligoclase granoblastic. Interbedded layers include quartz-oligoclase, quartz-hornblende-oligoclase, quartz, and quartz-oligoclase. Biotite pale to medium brown; replacing light olive to green-olive, blue-green, decussate hornblende. Pale-green chlorite replacing biotite and hornblende.

Interbedded impure sandstone and reworked andesite.

68-52 Gray, yellow-brown stained, fine-grained, quartz-labradorite-hornblende gneiss.

West of North Orange Road. Designated as moa on geologic map.

Mosaic quartz and feldspar. Grain size varies from 0.05 to 0.7 mm. Weakly banded, decussate hornblende is pale yellowish green to brownish green. Biotite, replacing hornblende, is pale to light yellow brown.

68-52 (Cont.) Gray-brown sphene is slightly radioactive. Anhedral allanite is zoned with a red core and orange rim. Magnetite often rims pyrite.

Reworked basaltic tuff.

55-79c Dark-gray, fine-grained, hornblende-andesine-quartz 'salt-and-pepper' gneiss.

East of Townsend Road. Designated as moa on geologic map.

Mosaic texture. Grains elongate; generally 0.05 to 0.9 mm. Oscillatory zoning of andesine. Lepidoblastic biotite pale to medium brown; replacing light-yellow-olive to medium olive, blue-green hornblende. Magnetite usually rimmed by sphene. Sphene also occurs as pellets. Red and orange allanite occurs as spots in some clinozoisite crystals. Pyrite rimmed by hematite and magnetite.

Dacite.

30-54 Green to white banded, greenish gray, fine- to medium-grained, andesine amphibolite.

East of intersection of Flat Rock and Cummings Roads.

Granoblastic. Grains elongate. Felsics generally 0.5 to 1 mm. Oscillatory zoning of andesine. Diopside up to 5 mm long, 2 mm wide; retrograde uralization with hornblende. Olive-brown to brown-green, blue-green hornblende being replaced by epidote-clinozoisite and biotite, both retrograde. Biotite light yellow olive to brownish black. Centrally located black inclusions occur in apatite. Pyrite core in magnetite crystals.

Andesite.

55-R-2a Banded light-gray, pinkish-gray and greenish-gray, fine-grained, plagioclase-hornblende-quartz-biotite gneiss.

Rte. 2-202, west of 55-R-2b. Designated as moa on geologic map.

Felsic minerals granoblastic. Mafics irregularly distributed around randomly oriented feldspar grains. Variable grain size generally 0.2 to 1 mm. Oscillatory zoning of plagioclase. Biotite pale brown to light yellow brown; replacing hornblende which is light to medium bluish olive with brown tinge in central portions. Hornblende well-zoned. Pale-green chlorite retrograde after both hornblende and biotite. Zoned apatite and yellow-orange allanite have small radioactive decay

55-R-2a (Cont.) halos in hornblende. Mineralogy varies with banding. Interbedded layers include hornblende-andesine-chlorite, andesine-hornblende-chlorite, oligoclase-quartz-biotite, oligoclase-biotite-chlorite. Plagioclase more abundant and Ca-rich in hornblende layers. Muscovite occurs only in hornblende layers.

Interbedded diorite and dacite.

67-52-4 Dark-gray, fine- to medium-grained, andesine-biotite amphibolite.

West of 67-52-3.

Mosaic. Planar grains generally 0.5 mm wide and 1 mm long. Normal oscillatory zoning of andesine. Biotite light yellow to reddish brown; replacing decussate, elongate, light-yellow-olive to dark blue-green, olive hornblende. Very pale-yellow-brown to pale-olive chlorite retrograde after biotite. Some epidote euhedral and zoned. Magnetite commonly included in sphene.

Andesite.

Specimens of the Partridge Formation in Table 2a -

hornblende gneisses and amphibolites

Specimen	Name, Location, Description, Origin
11-54	Banded, light-gray, fine- to medium-grained, andesine-hornblende-quartz gneiss. North of Rte. 122, between Athol and Turnpike Roads. Felsics granoblastic. Mafics decussate in randomly oriented feldspar. Grain size averages 0.5 mm, but up to 1.8 mm. Andesine well-twinned; normal oscillatory zoning. Lepidoblastic hornblende light greenish brown to medium brownish green; up to 1.5 mm. Biotite retrograde after hornblende; light yellow brown to medium reddish brown. Pale-green chlorite retrograde after biotite; chlorite occurs between biotite lamellae. Dacite.
31-54	Light-gray, fine- to medium-grained, andesine-hornblende-quartz gneiss. North of Flat Rock Road, west of Turnpike and New Sherborn Roads. Crosscutting, sutured quartz vein is normal to foliation. Mafics irregularly distributed in randomly oriented feldspar. Mosaic feldspar and quartz. Oscillatory zoning of andesine; generally 0.5 to 1 mm. Hornblende light to medium olive brown; size variable up to 2.6 mm long. Biotite light yellow brown to medium reddish brown; retrograde after hornblende. Pale- to light-green chlorite in large, plumose, radiating aggregates retrograde after hornblende and biotite. Pleochroic gray-brown-pink sphene occasionally forms overgrowths on magnetite; sphene euhedral when occurs alone. Andesite.
109-52	Gray, fine- to medium-grained, andesine amphibolite. North of South Main Street (Rte. 2a), west edge of quadrangle.

109-52 (Cont.) Mosaic texture. Mafics irregularly distributed in randomly oriented feldspar grains. Andesine well-twinned; generally 0.3 to 0.6 mm. Hornblende light to medium olive and twinned; grain size varies from 0.05 to 3.2 mm long. Biotite light to medium yellow brown or light to medium reddish brown; retrograde after hornblende.

Andesite.

Specimens of the Partridge Formation in Table 2b - schists

Specimen	Name, Location, Description, Origin
R9-54	Greenish-pinkish-brownish-dark-gray, fine- to medium-grained, biotite-sillimanite-muscovite quartzite. Northern edge of quadrangle at railroad tracks. Megascopically similar to calc-silicate gneisses, Table 2c. Granoblastic. Quartz grains are lenticular; up to 1.6 mm long. Average grain size 0.4 mm. Andesine poorly twinned. Biotite pale yellow brown to medium yellow reddish brown; being replaced by retrograde pale-green chlorite having Berlin blue to gray interference colors. Vermicular intergrowths of muscovite and quartz. Sillimanite ascicular to prismatic; being replaced by muscovite. Sillimanite occurs alone, in bundles, as fibrolite, or radial aggregates. Elongate bundles generally 1 to 2 mm long. Zircon size variable. Garnet xenoblastic. Aluminum-rich sandstone. Probably adjacent to calc-silicate beds to the east.
55-70	Light-gray-silvery-yellow brown, poorly foliated, fine- to medium-grained, oligoclase-muscovite-biotite quartzite. South of Reservoir No. 2. Granoblastic. Maximum grain size 5 mm; average about 1.5 mm. Some quartz corrosion of muscovite, biotite, apatite. Very thin rim of more sodium-rich plagioclase surrounding oligoclase. Biotite light yellowish brown to medium yellowish reddish brown. Retrograde chlorite is grayish green with Berlin blue interference colors. Muscovite occasionally occurs in radial clusters; some muscovite forming at expense of oligoclase. Sillimanite occurs as tiny prisms in muscovite. Pyrite unaltered. Size of zircon variable; as long as 0.3 mm. Shaley sandstone.
91-52	Banded brownish-white to silvery-light-gray, fine- to medium-grained, muscovite-biotite-chlorite-cordierite quartzite. West of Bearsden Road. Schistose. Average size about 0.5 mm. Quartz corrosion of muscovite. Biotite light yellow brown

91-52 (Cont.) to medium reddish brown; being replaced by muscovite up to 5.5 mm long and pennine up to 3 mm long. Some muscovite and pale yellow olive to light olive pennine are post-foliation. Chlorite interference colors are tobacco brown to Berlin blue. Garnet fractured, poikiloblastic. Tiny aggregates of sillimanite needles. Dusty inclusions in apatite are parallel to the c-axis. Zircon appears concentrated in micaceous bands. Zoned, twinned cordierite and iron oxide stain occur on one edge of slide, probably result of Cl-Fe-rich veinlet.

Shaley sandstone.

20-52 Banded white and gray, fine- to medium-grained, quartz-muscovite-biotite-oligoclase-chlorite-garnet schist.

West of Chase Road.

Grains lenticular, sutured. Grain size varies according to bed; up to 3 mm long but most average 0.5 mm. Quartz and oligoclase form vermicular intergrowths with muscovite. Oligoclase poorly twinned. Biotite light to medium yellow brown; some quartz corrosion. Pale green chlorite retrograde after biotite; tobacco brown interference colors. Larger garnets (1.5 mm) have centrally located inclusions and thin birefringent outer rims. Their growth has deflected the surrounding micas. Small aggregate of sillimanite needles parallel to foliation. Iron oxide alteration of magnetite. Zircon enclosed by radioactive halos; size varies. Apatite occurs as single unzoned crystals as well as aggregates of zoned anhedral crystals. Allanite is probably an igneous contaminate.

Black shale.

39-52 Rusty to white to light-gray, poorly foliated, fine- to medium-grained, oligoclase-quartz-muscovite-biotite gneiss.

East of Bearsden Road.

Granoblastic to sutured. Maximum grain size 3 mm; average about 1 mm. Quartz and muscovite form vermicular intergrowth. Oligoclase zoned, twinned. Some secondary myrmekite. Biotite light yellow brown to red brown; being replaced by retrograde muscovite. Dusty inclusions in apatite. Cordierite and microcline appear only on one edge of slide; the

39-52 (Cont.) latter is perthitic with oligoclase. Sillimanite occurs as a few needles or tiny ascicular aggregates.

Impure quartzo-feldspathic sediment possibly contaminated by Hardwick Granite.

126-52 Light-gray, fine-grained, quartz-biotite-muscovite-chlorite-oligoclase-cordierite-graphite schist.

East of Rte. 32, south of Briggs Road.

Lenticular to granoblastic. Maximum length 2 mm; average about 0.5 mm. Little twinning in oligoclase. Biotite light to medium brown. Very pale-yellow-olive to pale-green, decussate chlorite is post-foliation; interference colors are dark tobacco brown to Berlin blue. Mixtures of biotite, muscovite, chlorite, and opaques. Garnet fractured, corroded. Cordierite fractured.

Black shale.

12-54 Brownish-pinkish-white to dark-gray, fine- to medium-grained, quartz-oligoclase-muscovite-cordierite-chlorite-biotite porphyroblastic gneiss.

Junction of Rte. 32 and Tom Swamp Road.

Granoblastic. Maximum grain size 1.6 mm long with average about 0.7 mm; micas finer grained. Felsic minerals occur in iron oxide stained areas with micaceous minerals wrapping around. Poorly twinned oligoclase easily confused with cordierite as in 12-53. Some myrmekite. Biotite light brown to dark reddish brown. Muscovite occurs in pod-like aggregates or as vein work in felsic minerals. Chlorite pale yellowish olive to light green; interference colors Berlin blue; retrograde after biotite. Sillimanite needles in quartz. Cordierite fractured. Graphite most abundant in biotite-chlorite. Some hematite pseudomorphic after pyrite cubes. Dusty inclusions in apatite.

Black shale.

55-89c Light-gray-pinkish-brown, fine- to medium-grained, muscovite-quartz-biotite-sillimanite-garnet schist.

South of Millers River, west of Thousand Acre Brook.

Granoblastic and schistose bands. Quartz and skeletal garnet present mostly in medium-grained band; grain size in this band averages about 1 mm with largest grain 7.5 mm long. Grain size in schistose portion

55-89c (Cont.) averages about 0.2 mm. Plagioclase untwinned. Biotite pale yellow brown to medium reddish brown; some quartz corrosion. Muscovite, sericite, and quartz occur in masses between sillimanite crystals. Sillimanite occurs as massive prisms with biotite in pod-like masses surrounded by sericite halo. Sillimanite fibers and fibrolite are also present. Highly corroded garnets up to 2.7 mm have pushed some of the micas aside. Graphite and magnetite more finely disseminated in sillimanite mass than in matrix. Iron oxide probably pseudomorphous after pyrite cubes. Rutile(?) needles in garnet and biotite forming a reticulate pattern.

Aluminum-rich black shale.

17a-54 Pinkish-silvery-light-gray, fine- to medium-grained, biotite-muscovite-quartz-garnet schist.

West of Rte. 32, southern edge of quadrangle.

Good schistosity. Maximum grain size 1.6 mm; average length about 0.5 mm. Occasional quartz lenses present. Oligoclase poorly twinned; composition variable. Biotite light to medium yellow brown. Sillimanite generally in tiny prisms parallel to foliation. Muscovite often has inclusions of sillimanite; some muscovite is post-foliation. Pods of muscovite are probably pseudomorphous after sillimanite. Radial cluster of light brownish-green to green chlorite indicates it was post-foliation, retrograde after biotite; Berlin blue interference colors. Garnets slightly larger than 1 mm with micas deflected around xenoblastic crystals; poikiloblastic cores. Rutile present as tiny reticulate needles in biotite. Iron oxide stain. Graphite parallel to bedding.

Black shale.

85-52 Brownish-pinkish-white-light-gray, fine- to medium-grained, porphyroblastic cordierite-quartz-biotite-muscovite-oligoclase gneiss.

West of Bearsden Road.

Granoblastic, gneissic. Micaceous banding. Maximum grain size 2 mm; average 0.7 mm. Quartz has corroded oligoclase and muscovite. Oligoclase zoned, twinned. Biotite pale brown to medium golden brown; central band light yellow brown to deep red brown. More magnetite than graphite present. Magnetite in mica cleavages. Iron oxide replacing magnetite; also as interstitial stain. Zircon size variable, the largest being about 0.1 mm.

85-52 (Cont.) Shale.

66-54-2 Banded, white to gray, fine- to medium-grained, oligoclase-quartz-muscovite-biotite-garnet schist.

South of Tom Swamp Road.

Lenticular to granoblastic. Maximum grain length 3.5 mm; average about 0.6 mm. Mica segregated in bands. Zircon more abundant in some bands than in others. Biotite very pale to medium brown. Chlorite, retrograde after biotite, is very pale yellow brown to light green; Berlin blue interference colors. Some muscovite present in fine-grained pods and stringers; quartz corrosion. Garnet has centrally located inclusions. Micas undisturbed by garnet growth. Tiny aggregates of a few sillimanite needles. Cordierite twinned.

Black shale.

15-54 Finely-bedded white to gray, fine- to medium-grained, oligoclase-quartz-muscovite-biotite schist.

South of Tom Swamp Road.

Lenticular. Maximum grain length 2.6 mm; average about 0.5 mm. Some secondary myrmekite in oligoclase. Biotite light yellow brown to reddish brown, some of which is being replaced by muscovite. Muscovite forms vermicular intergrowths with quartz. Some iron oxide probably after pyrite.

Feldspathic shale.

12-53 Brownish-pinkish-light-gray, fine- to medium-grained, muscovite-quartz-biotite-chlorite-cordierite-graphite-iron oxide-oligoclase schist.

North of Tom Swamp Road.

Granoblastic. Average grain size 0.5 mm. Oligoclase poorly twinned and easily confused with cordierite which has similar looking albite-pericline-type twinning. Light- to medium-brown biotite and muscovite are decussate to lepidoblastic. Very pale-yellow-brown to light-green, dirty chlorite up to 2 mm long is retrograde after biotite. Chlorite crosscutting; interference colors are dark tobacco brown to Berlin blue. Garnet has centrally located inclusions; growth has not deformed micas. Sillimanite blebs in muscovite. Graphite flakes and magnetite blebs particularly abundant in micaceous areas.

Black shale.

78-52 Banded, white and gray, fine- to medium-grained, biotite-muscovite-oligoclase-quartz-garnet schist.

West of South Main Street.

Schistose texture with granoblastic quartz-feldspar-rich bands. Grain size varies with bed; maximum 5 mm long and average about 1 mm. Quartz and oligoclase lenticular; some very fine-grained. Quartz and oligoclase form vermicular intergrowths with muscovite. Rare retrograde myrmekite developed in oligoclase. Biotite pale to medium yellow brown. Pale- to light-green chlorite is retrograde after biotite; tobacco brown interference colors. Micas deformed around euhedral to anhedral garnet and quartz-feldspar grains. Garnet zoned with centrally located inclusions. Sillimanite in felted ascicular aggregates or alone. Zircon characterized by black radioactive decay halos in biotite. Graphite common in micas. Pyrite rimmed by magnetite; both have hematite alteration.

Black shale with impure arenaceous layers.

55-50d Banded and highly contorted, white and dark-gray, fine- to medium-grained, biotite-oligoclase-quartz-muscovite-garnet-microcline schist.

South of New Sherborn Cemetery.

Schistose. Maximum grain length 3 mm; average about 1 mm. Oligoclase poorly twinned; Na-rich rim present. Myrmekite and perthite. Biotite light yellow to medium yellow to reddish brown; some has vermicular intergrowth with quartz. Muscovite decussate and has magnetite along cleavage; quartz corrosion. Matrix unaffected by growth of garnets, which have centrally located inclusions and, rarely, a slightly birefringent outer edge. Tiny prisms of sillimanite occur in clusters or stringers in muscovite. Zircon size varies up to 1 mm.

Black shale.

55-92d Silvery-light-gray to reddish-brown, fine- to coarse-grained, muscovite-biotite-quartz schist.

North of Thousand Acre Swamp, northern edge of quadrangle. Occurs as 7 m band in schistose Hardwick Granite.

Granoblastic. Average grain size 0.2 to 0.5 mm. Oligoclase poorly twinned. Biotite light to medium brown. Muscovite occurs as sericitic pods and large

55-92d (Cont.)

plates up to 5 mm long. Muscovite forms vermicular to skeletal intergrowths with quartz. Sillimanite occurs as prismatic to fibrous subparallel aggregates in muscovite; some decussate needles in oligoclase. Iron oxide present mostly as interstitial stain and replacement of magnetite.

Shale.

69-53

Light- to dark-gray, fine- to medium-grained, muscovite-biotite-andesine-sillimanite-quartz schist.

Boulder north of Reservoir No. 2.

Sillimanite boulders common in this area. Sillimanite crystals 1 to 4 cm by 0.5 to 1 cm protrude from the weathered surface. Sillimanite embayed with biotite, muscovite, quartz, and andesine. Fracturing present. Growth of sillimanite has deflected other matrix minerals. Sillimanite crystals surrounded by (0.1 mm) muscovite. Biotite commonly rims each porphyroblast. Average grain size between 0.5 to 0.7 mm. Sillimanite needles also present in matrix. Biotite light yellow brown to brown; some quartz corrosion of biotite and muscovite. Chlorite pale yellow brown to grayish green; tobacco brown interference colors. Most quartz present in one band or lens. Myrmekite present near quartz-rich zone. Leucoxene (?) occurs only as large smudgy-looking cloud in muscovite.

Pelitic shale.

101-52

Pinkish-white-light- to dark-gray, fine- to medium-grained, andesine-biotite-quartz schist.

North of Main Street and Lake Ellis.

Schistose. Rock consists of two portions separated by a biotite-rich zone. The coarser grained portion has about 15% quartz, 60% andesine, 20% biotite, 5% garnet, and a trace of muscovite and sillimanite. Maximum grain size 2.5 mm; average about 0.7 mm. The finer grained portion has 5% quartz, 45% andesine, 40% biotite, no garnet, no muscovite, 5% apatite, and 5% magnetite. Average grain size about 0.2 mm. Andesine zoned, twinned. Biotite pale brown to orange brown in finer grained portion and pale yellow brown to red brown in coarser part. Some quartz and andesine corrosion of biotite, especially along contact of finer and coarser grained portions. Biotite wraps around quartz-feldspar grains. Garnet has central inclusions. Muscovite, epidote, and chlorite are

101-52 (Cont.) forming at expense of biotite. Epidote retrograde after biotite; occurs as interlamellar granules with dusty magnetite. Chlorite is colorless to pale green with Berlin blue interference colors. Sillimanite occurs as tiny ascicular aggregates. Apatite euhedral to anhedral with the c-axis parallel to the foliation. Pyrite corroded by iron oxide; some pyrite occurs in core of magnetite crystals.

Limey shale.

67-52-5 Light-gray, fine- to medium-grained, muscovite-oligoclase-biotite-chlorite-quartz-graphite-garnet schist.

West of North Orange Road, west of 67-52-5, Table 1.

Schistose texture. Maximum length 2 mm; most grains less than 1 mm. Larger grains of oligoclase well-twinned; slightly myrmekitic in finer grained interstitial aggregates. Myrmekite probably retrograde. Sericite present in felted, pod-like masses; probably retrograde after sillimanite. Nodular light-gray micaceous stringers can be seen in hand specimen. Biotite pale yellow brown to reddish brown. Light-yellow-brown to medium-blue-green pennine is retrograde after biotite. Micaceous minerals strung out between quartz-feldspar layers and grains. Cordierite has gray interference colors and twinning similar to feldspar, but is characterized by irregular fractures stained with iron oxide. Fractured garnet has not deformed micaceous laths. Sillimanite appears as needles in quartz and oligoclase. Zircon readily distinguished by dark-gray to black radioactive decay halos in biotite and chlorite. Graphite common in micaceous minerals.

Black shale.

Specimens of the Partridge Formation in Table 2c -

calc-silicate gneisses, or granulites

Specimen	Name, Location, Description, Origin
55-15	Light-grayish-brown, fine- to medium-grained, clinozoisite-hornblende-pyrite quartzite. North of Rte. 101. Grain size varies in bands; average about 0.6 mm. Mineralogic banding due mostly to the presence or absence of clinozoisite. Quartz is mosaic. Poikiloblastic clinozoisite is twinned and has anomalous, dull, mottled blue, gray, and greenish-yellow interference colors; up to 3 mm long. Poikiloblastic hornblende is very pale olivish green. Euhedral to anhedral pyrite occurs in some beds. Slight replacement of pyrite and magnetite by hematite. Magnetite present in one band, twinned bytownite in a couple. Apatite banded also. Rounded sphene pellets are pleochroic golden pink. Limey sandstone.
55-83	Purplish-yellow-brown and gray, fine- to medium-grained, quartz-bytownite-diopside-hornblende gneiss. West of New Sherborn Road, north of Riceville Road. From boulder nearly in place. Near contact between calc-silicate gneiss and quartzite. Fine-grained, equigranular, mosaic rock. Average grain size about 0.5 mm. Mafic minerals, especially diopside, up to 2.5 mm. Mineralogic banding present in mafic and felsic layers. Some of the felsic layers have up to 75% labradorite-bytownite; average grain size 0.3 to 0.8 mm in different layers. Greater sericitization of plagioclase near mafic bands. Diopside has a greenish-gray tinge and is highly poikiloblastic. Poikiloblastic light-yellowish-olive to medium bluish-green to olive hornblende has uralitized the diopside. Rounded pellets of pleochroic pinkish-gray-brown sphene are variable in size, weakly radioactive, and partially altered to leucoxene. Pinkish garnets are poikiloblastic. Magnetite is mostly present in one band. Pyrite occurs in this band and in others. Apatite occurs mainly with quartz and feldspar. Muscovite is forming at the expense of plagioclase predominately near the mafic bands. Yellow-olive antigorite and iron oxide occur in diopside fractures and iron oxide, probably limonite, is a cavity filler in one place.

55-83 (Cont.) Siliceous dolomite.

52-91a Rusty-brown-gray, fine-grained, quartz-labradorite-garnet-hornblende-biotite gneiss.

West of Bearsden Road, northern portion. Contains medium- to fine-grained, quartz-labradorite bed.

Quartz-labradorite layer at edge of slide is granoblastic. Some labradorite grains in this layer are poikiloblastic, contain myrmekite blebs, and are up to 4.5 mm. Other layers are fine-grained (most grains between 0.1 to 0.5 mm), mosaic, and banded, progressing from biotite-rich to garnet-rich to hornblende-rich laminae with the plagioclase becoming progressively more calcic, extending into the bytownite range. Some of the pinkish garnet appears zoned and occurs in stringers. Biotite is pale beige to medium orange brown, retrograde after hornblende in intermixed areas. Hornblende is light green to light blue green and poikiloblastic; it occurs only on one edge of slide. Pale-green-brown-yellow chlorite is retrograde after biotite; some up to 2 mm long; tobacco brown interference colors; occurs in radial clusters. Apatite present in biotite-chlorite zone. Pyrite occurs on hornblende side of slide. Sphene slightly radioactive and altered to leucoxene on hornblende side. Zircon present mostly in biotite zone. Muscovite occurs with chlorite-biotite. Yellowish-orange allanite rimmed by clinozoisite probably due to igneous contamination; occurrence is close to Hardwick body.

Siliceous dolomite.

105b-54 Rusty-brown-gray, fine- to medium-grained, quartz-bytownite-garnet-hornblende gneiss.

South of Conant Road, west of New Sherborn Road.

Fine-grained, equigranular, mosaic rock. Average grain size about 0.4 mm. Bytownite well-twinned, zoned. Poikiloblastic hornblende occasionally larger than 1 mm; xenoblastic and pleochroic from light yellow green to green. Highly poikiloblastic almost skeletal pinkish garnet crystals are over 2 mm. Core of larger garnets is slightly yellow brown. Magnetite occurs as anhedral blebs; some have quartz inclusions. Pyrite anhedral; some occurs with magnetite. Hematite replaces magnetite and is present as interstitial stain. Gray-brown to pink, pleochroic sphene is poikiloblastic, slightly radioactive, and rims magnetite.

Siliceous dolomite.

66-54-1 Brownish-gray, fine- to medium-grained, quartz-hornblende-bytownite-clinozoisite gneiss.

South of Tom Swamp Road.

Fine-grained, equigranular, mosaic rock. Average grain size about 0.5 mm. Mafic minerals, particularly hornblende and clinozoisite, occur as elongate poikiloblastic masses up to 2.5 mm. Mafic and felsic laminae are present; within the mafic laminae are biotite-hornblende-, hornblende-, and clinozoisite-rich layers. Bytownite occurs in bands optically positive or negative. Clinozoisite is colorless with anomalous, dull, blue-gray or yellow-green interference colors. Hornblende is pleochroic pale green. Sphene occurs as rounded, pleochroic, gray-brown pellets which are slightly radioactive; some occurs as overgrowths on magnetite. Pyrite is mostly anhedral; some surfaces are striated. Trace of magnetite occurs with pyrite. Biotite is pale to light to medium brown with a trace of olive black. Yellow allanite occurs as core in clinozoisite.

Siliceous dolomite contaminated by intrusives.

All 55-NH-5 sections came from successive bands of the same hand specimen.

55-NH-5a Light-greenish-gray, fine-grained, diopside-quartz-bytownite gneiss.

South of Reservoir No. 1.

Fine-grained (average 0.2 mm), equigranular, mosaic matrix with larger (up to 0.6 mm) poikiloblastic diopside grains. Some diopside twinned; colorless with slight suggestion of greenish tinge. Very pale-olive actinolite present in one band as replacement of diopside; it, in turn, is being replaced by very pale-beige to light-yellow-brown biotite. Quartz has very poorly developed undulatory extinction. Plagioclase twinned. Sphene occurs as pleochroic pink pellets. Anhedral to euhedral pyrite occurs throughout the slide. Magnetite occurs predominately in biotite band; graphite flakes are scattered throughout. Hematite replaces magnetite. Twinned epidote occurs in biotite band; anomalous dull blue interference color. Orange-red allanite occurs in epidote.

Siliceous dolomite.

55-NH-5b

Light-brown to greenish-gray, fine-grained, quartz-diopside-bytownite-garnet gneiss.

South of Reservoir No. 1.

Fine-grained, equigranular, mosaic rock. Average grain size between 0.1 and 0.2 mm. Bytownite more calcic in quartz-diopside band; little twinning present. Diopside and epidote poikiloblastic. Diopside colorless with greenish tinge; some twinned. Calcite secondary after diopside. Colorless garnet and epidote easily confused with diopside in plain light. Garnet distinguished by isotropic character and epidote by mottled, anomalous, dull blue or greenish interference colors. Garnet relatively abundant in non-opaque band. Epidote more abundant in opaque band; some epidote is twinned. Anhedral pyrite, graphite, and rounded pellets of pleochroic, golden-pink sphene occur together in one band.

Siliceous dolomite.

55-NH-5c

Cream to light-brown, fine-grained, quartz-diopside-bytownite-garnet gneiss.

South of Reservoir No. 1.

Fine-grained (average size 0.1 to 0.2 mm), equigranular, mosaic matrix with laminae of mafic minerals. Felsic band 0.2 to 0.3 mm. Diopside colorless with greenish tinge; some grains poikiloblastic, twinned, up to 1 mm long. Poikiloblastic garnet and trace of epidote resemble diopside in plain light. Epidote occurs between quartz grains in felsic band. Sphene occurs as pleochroic pink pellets. Calcite secondary replacement.

Siliceous dolomite.

55-NH-5d

Cream to light-brown to light-gray, fine-grained, quartz-diopside-bytownite-garnet gneiss.

South of Reservoir No. 1.

Fine-grained, equigranular, mosaic matrix of quartz and bytownite; mafics granular. Grain size varies from less than 0.1 mm to 0.8 mm. Felsic vein up to 1.7 mm. Quartz and diopside vary in abundance from about 20 to 65% depending upon the band. In general, two types of bands are present: clinozoisite-An_{65}-quartz-diopside and garnet-diopside-quartz with An_{80}. Diopside, garnet, and clinozoisite are

55-NH-5d (Cont.) colorless and poikiloblastic. Sphene occurs as pleochroic pink pellets. Pleochroic pale-olive actinolite is replacing diopside. Only one flake of muscovite appears; it is in felsic vein. Graphite flakes present. Calcite secondary replacement.

Siliceous dolomite to dolomitic sandstone.

55-NH-5e Cream to light-brown to light-gray, fine-grained, quartz-bytownite-diopside gneiss.

South of Reservoir No. 1.

Fine-grained, equigranular, mosaic matrix with granular mafics between quartz-feldspar grains. Grain size varies according to band from less than 0.1 mm to 0.5 mm. Abundance and composition of plagioclase vary according to mineralogic band. Diopside, epidote, and garnet are colorless and slightly poikiloblastic. Diopside twinned. Pyrite and graphite are gradational with each other in one band. Pleochroic golden-pink sphene most abundant in pyrite-diopside band. Calcite secondary. Laminae are mineralogically similar, but relative amounts of the minerals vary except for opaques, epidote, and sphene.

Limey sandstone.

All 55-NH-6 sections came from successive bands of the same hand specimen.

55-NH-6a Light-gray, fine-grained, quartz-biotite-plagioclase-muscovite schist.

South of Reservoir No. 1.

Textural and mineralogic banding present. Grain size generally between 0.1 and 1 mm. Equigranular felsic minerals are mosaic or granoblastic. One medium-grained (up to 1.5 mm long) granoblastic quartz band present. Myrmekite present in biotite-muscovite-rich band. Plagioclase more calcic in biotite band (An_{70}) but more sodic elsewhere (An_{35}). Biotite light yellow brown to medium yellow to reddish brown; biotite present throughout the slide. In a probable metasomatic vein an anhedral pyrite grain is rimmed by pyrrhotite (chalcopyrite?). A few other pyrrhotite(?) grains occur nearby. A couple of schorl grains are present in the same vein. One euhedral schorl grain is pale yellow brown to medium yellow brown olive with a

55-NH-6a (Cont.) medium olive gray rim. Biotite up to 1.5 mm long and a couple of andalusite(?) grains also occur in this metasomatic vein. Poikiloblastic garnet and clinozoisite mostly present in biotite band. Allanite, rimmed by clinozoisite, occurs in biotite-muscovite band. Orthoclase, bissected by graphite flakes, appears near quartz band. Rutile present as reticulate pattern in biotite; it is near the metasomatic vein in the biotite-muscovite band. Tiny grains of zircon and apatite are present.

Limey shale.

55-NH-6b Light- to medium-gray, fine-grained, quartz-plagioclase-biotite-muscovite schist.

South of Reservoir No. 1.

Grain size varies among laminae from less than 0.1 mm to 0.8 mm. This section has two distinct textures. One is a normal biotite-muscovite schist; the other, except for the foliated biotite, has an equigranular, mosaic texture with finer grained, circular masses. These masses are composed of remnant garnets with the matrix material; presumably the masses were once garnet crystals. More calcic plagioclase (An_{70}) is present in biotite band. Myrmekite present in the biotite-muscovite band where biotite is light to medium yellow brown. Biotite is a darker reddish brown in the equigranular biotite band. Quartz has corroded some biotite and muscovite. Garnet is anhedral and fractured in the biotite-muscovite band. Poikiloblastic and sometimes porphyroblastic remnants of larger garnet crystals appear in the biotite band. Clinozoisite is anhedral, slightly metamict, and replaces biotite. Rim on clinozoisite may be epidote. Orthoclase, which occurs in biotite band, is dissected by graphite stringers as in 55-NH-6a. Schorl is also similar to that in 55-NH-6a; it is pale yellow brown to medium yellow brown olive with medium olive gray rim. Pyrite appears in remnant garnet porphyroblast in the biotite band.

Limey shale.

55-NH-6c Cream to pinkish to greenish-gray, fine-grained, quartz-labradorite-bytownite-biotite-garnet-clinozoisite schist.

South of Reservoir No. 1.

Felsic minerals equigranular, mosaic; size variable depending upon band from less than 0.1 to 0.7 mm.

55-NH-6c (Cont.) Mineralogic bands vary as follows: plagioclase-biotite-garnet-clinozoisite, plagioclase-garnet-clinozoisite-hornblende, plagioclase-clinozoisite-hornblende, clinozoisite-diopside, clinozoisite-diopside-garnet, and garnet-carbonate-diopside. Very little twinning apparent in plagioclase. Large poikiloblastic garnet crystals and remnants of skeletal garnet crystals appear from hornblende to biotite bands; matrix material deflected around garnets. Very pale-yellow-brown to medium-yellowish-brown biotite replaces very pale-green hornblende. Some hornblende is twinned. Clinozoisite skeletal and slightly radioactive. Poikiloblastic diopside is colorless, possibly having a greenish tinge. Pyrite not present in coarser grained, garnet-carbonate-diopside band; secondary calcite is present there. Pleochroic, pinkish-gray-brown sphene slightly radioactive; some occurs as overgrowths on magnetite. Small euhedral apatite crystals present only in biotite band. Orthoclase, as in the two previous sections, is dissected by graphite flakes in biotite band. Subhedral schorl is in hornblende and biotite bands. It is very pale green to medium brownish olive; it has a yellower brown center and a grayer rim. Garnet, clinozoisite, and diopside are similar in plain light.

Sandy carbonaceous shale.

55-NH-6d Banded cream, light-brown, gray, fine-grained, diopside-garnet-clinozoisite quartzite.

South of Reservoir No. 1.

Quartz equigranular, mosaic. Grain size varies from less than 0.1 to 0.7 mm; average 0.1 to 0.2 mm. Mineralogic banding characterized as follows: diopside, garnet, clinozoisite-garnet-diopside, diopside-clinozoisite-quartz, diopside, clinozoisite-quartz-carbonate, diopside, diopside-quartz, diopside-quartz-garnet, diopside-quartz-garnet-carbonate, graphite-clinozoisite-garnet-diopside-quartz, clinozoisite-hornblende-quartz. Garnet, diopside, clinozoisite, and hornblende are all colorless, poikiloblastic, and have similar indices of refraction; hence, they are easily confused in plain light. Some clinozoisite and carbonate twinned. Carbonate secondary after diopside. Graphite as much as 3% in graphite-clinozoisite-garnet-diopside-quartz band. Color of sphene pellets varies slightly among laminae, but generally pleochroic pinkish gray brown.

Limey sandstone.

55-NH-6e

Banded cream, light-brown, light- to medium-gray, fine-grained, diopside-quartz-garnet gneiss.

South of Reservoir No. 1.

Grain size varies from less than 0.1 mm to 0.9 mm; average from 0.1 to 0.2 mm. Mineralogic banding is as follows: biotite-quartz-plagioclase, hornblende-quartz-plagioclase, quartz, diopside-clinozoisite-garnet-hornblende, diopside-carbonate-garnet, diopside-carbonate-garnet-clinozoisite, garnet-carbonate-diopside. Quartz is equigranular, mosaic. Labradorite-bytownite poorly twinned. Diopside, garnet, clinozoisite all colorless and poikiloblastic. Poikiloblastic hornblende slightly pleochroic pale olive with browner core. Biotite pale to medium yellowish brown. Some carbonate twinned; secondary. Sphene slightly radioactive and pleochroic in golden pink gray brown; it occurs as rounded pellets and as partial overgrowths on magnetite. Opaque minerals are banded.

Siliceous dolomite.

Specimens of the Partridge Formation in 2d - pegmatites

Specimen	Name, Location, Description, Origin
78a-52	White, fine- to medium-grained, quartz-oligoclase-muscovite pegmatite. West of South Main Street, crosscutting specimen 78-52, Table 2b. Suturing well-developed. Grain size up to 3 mm; largest grains are felsic. Oligoclase highly sericitized, poorly twinned. Some deuteric myrmekite blebs. Muscovite probably formed at expense of alkali feldspar. Muscovite wraps around and among larger quartz and plagioclase grains. Muscovite cleavages are dirty looking with dusty (magnetite?) inclusions; muscovite and quartz form vermicular intergrowths. Garnet fractures contain quartz veins and have iron oxide alteration. Apatite alone or in aggregates. Pegmatite.
70-54	Buff to light-gray, fine- to coarse-grained, quartz-muscovite-oligoclase-microcline pegmatite. North of Tom Swamp Road, west of Rte. 32. Lenticular to granitic. Maximum grain size 12 mm; average about 1 mm. Coarse grains of oligoclase have up to 50% antiperthite. Alkali feldspar occurs only in plagioclase. Muscovite is corroded extensively by quartz. Muscovite is replacing garnet; much has formed at the expense of microcline. Some sericite present. Sillimanite needles; in one muscovite sheet sillimanite occurs as an ascicular helical arrangement. Cordierite fractured. Limonitic interstitial stain. Magnetite dust. Pegmatite cutting schist which has contaminated pegmatite.
55-NH-2	White to light-gray-purple, fine- to coarse-grained, oligoclase-quartz-muscovite-garnet pegmatite. Fault zone alone Rte. 2-202. Granitic. Maximum grain size 6 mm in coarser portion; most under 1 mm. Quartz veins present. Sericite replacing oligoclase. Deuteric myrmekite. Muscovite has two generations, one is primary, the other

55-NH-2 (Cont.) probably formed at the expense of alkali feldspar. Biotite, present in one aggregate, is pale brown to medium yellow brown. Pale yellow-brown to olive chlorite retrograde after biotite; Berlin blue interference colors. Garnet corroded by quartz; micas deflected around garnets. Sillimanite occurs as ascicular to short stubby prisms in tiny subparallel aggregate in oligoclase. Pyrite rimmed by magnetite and carbonate.

Pegmatitic material within shale.

Specimens of the Hardwick Granite in Table 3

Specimen	Name, Location, Description, Origin
55-75d	Dirty-white to dark-gray, fine- to medium-grained, microcline-quartz-oligoclase gneiss. North of Rte. 2a (Main Street), east of Bearsden Road. Granitic. Grain size generally 0.6 to 1 mm; range from about 0.07 to 3.2 mm. Perthite irregularly distributed throughout microcline grains. Myrmekite dendritic to plumose; most occurs interstitially as finer grains. Myrmekite also occurs on boundary of oligoclase grains, although one 0.6 mm plagioclase grain is myrmekitic throughout. Parallel antiperthite blebs are in oligoclase. Na-rich rim developed at edge of oligoclase grains. Biotite light yellow olive to olive black; some laths bent. Chlorite light yellowish olive to medium bluish green with Berlin blue interference colors; retrograde after biotite. Slight quartz corrosion of muscovite and apatite. Granite.
55-86c	Light-gray, fine- to medium-grained, microcline-quartz-oligoclase-biotite gneiss with fine- to coarse-grained, microcline-quartz vein. Southeast of Pratt Hill. Sutured. Grain size in gneissic portion averages about 0.5 by 1 mm; range from 0.05 to 3.5 mm. Microcline-quartz vein coarser grained, ranging from 0.2 to 5.3 mm. Microcline porphyritic in vein. Perthite blebs and trace of myrmekite present. Myrmekite deuteric, occurring along larger grain boundaries and interstially. Light-yellow-brown to medium-blue-green chlorite retrograde after light-yellow-brown to medium-olive-brown to dark-brown biotite. Chlorite has anomalous purple interference colors. Portions of the thin section have 10 to 15% biotite. Muscovite forms vermicular intergrowths with quartz. Magnetite exsolved from biotite; some has sphene overgrowths. Euhedral pyrite has rim of hematite and outer rim of magnetite. Gray-brown, slightly pinkish sphene appears lensoid in biotite cleavages. Rutile ascicular in chlorite; some leucoxene alteration of rutile. Allanite anhedral with ill-defined outer boundary of clinozoisite-epidote, some of which is brownish bluish olive.

55-86c (Cont.) Granite.

55-31a Pinkish-light-gray, fine- to medium-grained, porphyritic microcline-quartz-oligoclase-biotite gneiss.

South southeastern edge of quadrangle. Occurs with porphyritic granite and pegmatite.

Granitic. Average grain size about 0.6 mm; range from 0.1 to 3.5 mm; microcline phenocrysts from 5.5 to 10 mm. Perthite blebs occur in microcline phenocrysts. Deuteric myrmekite developed interstitially; some grains up to 0.6 mm. Myrmekite rims and some antiperthite patches occur in oligoclase. Distinct Na-rich overgrowth on oligoclase. Strain shadows well-developed in larger quartz grains. Light yellow-brown to green chlorite retrograde after light- to medium-yellow-brown to dark-brown biotite. Chlorite has anomalous Berlin blue and purple interference colors. Muscovite forms vermicular intergrowths with quartz. Pyrite occurs as anhedral remnants in hematite-magnetite mass. Dark inclusions in apatite rare but present. Unzoned euhedral allanite is light yellow brown with slightly darker core; almost 1 mm long.

Granite.

55-92b Black streaked, pinkish-white to light-gray, fine- to coarse-grained, porphyritic microcline-quartz-oligoclase-biotite gneiss.

Same as 55-92d, north of Thousand Acre Swamp, north edge of quadrangle.

Sutured to granitic. Grain size highly variable from about 0.2 to 7 mm. Some finer grained interstitial grains present. Largest phenocrysts is microcline. Microcline and oligoclase crystals about 3 mm are common. Central portion of larger microcline crystals have perthite blebs and stringers oriented parallel to cleavage planes. Oligoclase has Na-rich rim and some myrmekite. Biotite is generally pale to medium yellow brown, although some is light yellow brown to dark medium red brown. Latter is intermixed with orange to medium-yellowish-brown biotite. Some quartz corrosion of biotite. Chlorite pale olive to light green; Berlin blue interference colors; retrograde after biotite. Muscovite corroded by quartz. Zircon size variable; dark metamict rings present. A zoned blade of apatite present.

Granite.

55-38d

Pinkish-white, black flecked, fine- to medium-grained, porphyritic microcline-oligoclase-quartz gneiss.

West of Petersham Road.

Granitic to sutured; embayment. Grain size varies from 0.1 to 5.4 mm; average about 1 mm. Microcline occurs as phenocrysts and matrix. Parallel perthite blades are more abundant in phenocrysts. Some myrmekite and albite rims developed on edge of albite-oligoclase crystals. Light-yellowish-olive to light-medium-blue-grayish-green chlorite retrograde after biotite, which is light yellow brown to dark reddish brown. Chlorite has Berlin blue interference colors. Muscovite forming at expense of plagioclase; some muscovite laths have been corroded by and have formed vermicular intergrowths with quartz. Radiate to decussate needles of rutile(?) altered to leucoxene are present in chlorite and biotite. Apatite has pitted-looking surface; a couple of aggregates are present.

Granite.

17-54

Pinkish-yellowish-white, black and silver streaked, fine- to coarse-grained, microcline-quartz-oligoclase-mica gneiss with microcline phenocrysts.

West of Rte. 32, south edge of quadrangle.

Granitic. Grain size from 0.07 to 8.7 mm; average about 0.6 mm. Microcline phenocrysts have rectangularly oriented perthite blebs. Exsolution patches of more Na-rich plagioclase appear in oligoclase. Fine-grained, deuteric myrmekite occurs predominantly between medium-sized felsic grains. Biotite light to medium yellow brown to dark reddish brown. Chlorite, retrograde after biotite, is light brownish green to olive or bluish green; some is plumose; interference colors are Berlin blue to tobacco brown. Muscovite has been corroded by quartz and has formed vermicular intergrowths with quartz. Rutile, being altered to leucoxene, occurs as ascicular to radiate fibers in chlorite. Apatite attains maximum length of 1 mm and has zoned, centrally located smudges normal to the c-axis. Size of zircon variable. Part of an orange-brown, zoned, subhedral allanite crystal 1 mm long is metamict in biotite.

Granite.

55-30 White to light-gray, black flecked, fine- to coarse-grained, microcline-quartz-oligoclase-biotite gneiss.

West of Bakers Lane, southeastern part of quadrangle.

Granitic. Grain size varies from 0.05 to 4.5 mm; average from 0.5 to 1 mm. Coarser grained felsic minerals are almost porphyritic. Perthite blebs present in larger microcline crystals. Deuteric myrmekite grains present. Myrmekite rims and Na-rich overgrowths common on oligoclase. Light-yellow-brown to medium-bluish-green chlorite retrograde after light-yellow-olive-brown to dark-olive to olive-black biotite. Chlorite has anomalous Berlin blue to purple interference colors; some rutilated. Some biotite corroded. Bright-red hematite exsolved from biotite-muscovite lamellae. Muscovite has formed vermicular intergrowths with quartz and feldspar. Apatite pitted-looking, has slightly cloudy cores, and is slightly radioactive. Zoned pale-yellow-brown allanite occurs with and without clinozoisite rim. Some clinozoisite replacing biotite.

Granite.

55-50a Light-gray to white, yellow-brown stained, poorly foliated, fine- to medium-grained, quartz-microcline-oligoclase-biotite gneiss with small microcline phenocrysts.

South of New Sherborn Cemetery.

Granitic. Grain size from 0.05 to 4.3 mm; average about 0.6 mm. Perthite blebs in center of microcline phenocrysts; rounded quartz grains also present. Some deuteric myrmekite present interstitially and in smaller grains of oligoclase. Thin Na-rich rim on oligoclase. Biotite pale yellow brown to medium reddish brown; being replaced by pale-yellowish-green to light-grayish-green chlorite which has Berlin blue interference colors. Abundant biotite clusters associated with anhedral magnetite grains which are up to 1 mm in diameter. Biotite slightly corroded. Muscovite corroded by and forms vermicular intergrowths with quartz. Muscovite also forming in oligoclase cleavage planes. Layered botryoidal iron oxide fillings, zircon, and zoned apatite are present. Black smudgy-looking inclusions in apatite are normal and parallel to the c-axis. Largest apatite crystal almost 1 mm long.

Granite.

55-38c

Light pink and gray striped, fine- to medium-grained, quartz-microcline-oligoclase gneiss.

West of Petersham Road.

Sutured. Fair foliation. Grain size from 1 to 3.5 mm; average about 0.5 mm. No myrmekite, perthite, or antiperthite. Light yellow-olive to bluish-grayish-green chlorite has almost totally replaced light-medium yellow-brown to yellowish-red-brown biotite. Chlorite has anomalous Berlin blue to purple interference colors. Quartz corrosion of muscovite; most muscovite forming at expense of albite. Ilmenite(?), or rutile(?), altered to leucoxene; occurs in micaceous minerals. Clinozoisite dirty-looking, replacing biotite.

Granite.

P-10

Purplish-gray, fine-grained, porphyritic microcline-oligoclase-quartz-biotite gneiss.

Southeast of Brooks Pond, Petersham quadrangle.

Atypical rock. Matrix equigranular with mosaic texture; moderately well-foliated. Matrix grain size up to 1 mm; averages about 0.1 mm. Coarser grained quartz is strung out in lenses parallel to foliation. Microcline phenocrysts are larger (generally up to 4 mm) and contain some reticulate, exsolved plagioclase. Oligoclase phenocrysts are smaller (about 1 mm). Oligoclase twinning poorly developed. Some myrmekite present, especially in fine-grained matrix surrounding microcline phenocrysts. All phenocrysts are parallel to the foliation and have micaceous-rich rims. Growth of phenocrysts pushed aside finer grained matrix minerals. Biotite light yellow brown to dark reddish brown; being replaced by light-yellow-green to light-bluish-green chlorite with Berlin blue interference colors. Muscovite most abundant around edges of phenocrysts; some quartz corrosion. Euhedral to anhedral zircon is about the size of surrounding matrix material. Apatite euhedral. Carbonate replacement after porphyritic oligoclase. Pyrite occurs as anhedral remnants in hematite.

Granite (?). Contaminated schist (?).

43-52

Flesh with light- to dark-gray wisps, fine- to medium-grained, porphyritic microcline-oligoclase-quartz-biotite gneiss.

43-52 (Cont.) West of Bearsden Road.

Granitic. Cataclastic; microfaulting and bending of grains evident. Grain size highly variable from 0.05 to 19.8 mm; average about 1 mm. Microcline present mostly as phenocrysts which have patches and blebs of perthite and inclusions of other minerals. Finer grained matrix and deuteric myrmekite wrap around microcline phenocrysts. Carlsbad twinning well-developed. Biotite pale yellow brown to yellow brown, reddish brown. Pale-brown-green to light-green chlorite retrograde after biotite; Berlin blue interference colors. Quartz corrosion of muscovite. Apatite zoned with centrally located dark smudges. Some zircon euhedral. Rutile ascicular and has leucoxene alteration.

Granite.

106-54 Orangish-brown to cream, fine- to medium-grained, oligoclase-microcline-quartz gneiss.

South of Conant Road, west of New Sherborn Road.

Granitic. Grain size from 0.1 to 4.5 mm; generally over 1 mm. Microcline has centrally located, strung out, lens-shaped perthite. Deuteric, interstitial myrmekite present. Na-rich rims on oligoclase. Biotite light yellow brown to reddish brown. Chlorite pale yellow brown to light olive with Berlin blue interference colors. Muscovite corroded by quartz and feldspar forming vermicular intergrowths. Some muscovite has replaced biotite. Iron oxide replaces magnetite and occurs as interstitial stain.

Granodiorite.

88-52-2 Beige to light-gray, fine- to medium-grained, porphyritic oligoclase-microcline-quartz-biotite gneiss.

West of Bearsden Road.

Granitic. Grain size 0.1 to 3.5 mm; average about 0.8 mm. Largest partial microcline phenocryst 9.5 mm. Microcline phenocrysts have rounded quartz inclusions and perthite. Perthite is aligned with grid twinning of microcline. Phenocrysts of oligoclase have highly sericitized central portions; more Na-rich member has exsolved forming rims or veined networks in oligoclase. Growing phenocrysts have pushed aside micas. Biotite generally light to medium orange brown.

88-52-2 (Cont.) Retrograde chlorite is pale green to olive with Berlin blue interference colors. Muscovite is both crosscutting and parallel to biotite-chlorite aggregates; some quartz corrosion evident. Zircon and apatite size variable. Apatite has dark, cloudy, central zoning, the individual inclusions being normal to c-axis and slightly curved. Magnetite unaltered. Pyrite occurs as specks in center of anhedral iron oxide.

Granodiorite.

55-71 White to gray, fine- to medium-grained, biotite-oligoclase-quartz-microcline-sphene gneiss.

Northwest of Phillipston.

Granitic. Grain size 0.05 to 1.4 mm long; most grains about 0.5 mm. Twinning poorly developed in microcline. Trace of deuteric myrmekite. Irregular Na-rich rim on oligoclase. Light-yellow-olive to dark-olive-black biotite has sphene developed along cleavage. Biotite rarely corroded by plagioclase. Chlorite light yellow olive to medium bluish green with anomalous purple interference colors. Sphene varies in size from tiny rounded grains to subhedral twinned crystals over 1 mm long; larger grains often poikilitic; pleochroic golden gray brown with central portion more golden; good cleavage and parting. Allanite zoned in light yellow olive colors; rimmed by epidote. Largest anhedral allanite crystal over 1 mm; some have inclusions. Clinozoisite may be present. Radial clusters of zeolite, possibly scolecite, occur as cavity filler.

Granodiorite. Similar in appearance to tonalites described below.

55-95a White to gray, fine- to medium-grained, oligoclase-quartz-biotite gneiss.

Northeastern corner of quadrangle.

Granitic, some mortaring. Grain size 0.05 to 4.5 mm; average about 0.5 mm. Trace of deuteric myrmekite present as interstitial grains and rims on oligoclase. Perthite blebs in microcline. Biotite light yellow brown olive to dark brown olive black. Slight quartz corrosion of biotite and muscovite. Sphene slightly pleochroic, gray brown. Sphene overgrowths on much of the magnetite. Bright-red hematite exsolved from biotite. Zoned allanite cores in epidote are mostly orange; some red or, rarely, brown. Clinozoisite is generally yellow brown olive.

55-95a (Cont.) Tonalite.

12-52-2

White to light-gray, black specked, fine- to coarse-grained, oligoclase-quartz-biotite gneiss.

Roadcut northern part of Bearsden Road.

Granitic. Grain size 0.1 to 5.4 mm; most about 1.5 mm. Some deuteric myrmekite present. Carbonate in oligoclase. Slight Na-rich rim apparent on some oligoclase grains. Very pale-brown to light-green chlorite retrograde after pale-yellow-brown to medium- to dark-greenish-brown biotite. Chlorite has tobacco brown interference colors. Epidote retrograde after biotite. Zoned epidote-clinozoisite forms rim on zoned allanite. Fractured sphene is dirty-looking, dark golden brown. Some quartz corrosion of apatite.

Tonalite.

70-53

Light-gray, yellow-brown, fine- to coarse-grained, oligoclase-quartz-biotite gneiss.

North of Reservoir No. 2.

Granitic. Grain size 0.1 to 6 mm; average over 1 mm. Oligoclase has exsolved Na-rich patches. Orthoclase occurs as rectangular bleb in oligoclase. Light yellow-brown to gray-green chlorite retrograde after light-yellow-brown to dark reddish-brown to brown biotite. Blue-green chlorite appears near sphene; anomalous Berlin blue interference colors. Sphene forms overgrowth on magnetite. Sphene dirty-looking, brown gray with well-developed cleavage; commonly poikilitic with opaques, quartz, apatite, and allanite. Some apatite dirty-looking. Clinozoisite zoned, forms rim on some allanite. Allanite yellow orange red with darker core. Rutile ascicular in biotite and chlorite. Small prisms of sillimanite occur mostly as single crystals in oligoclase. Cordierite has characteristic fractures and twinning.

Tonalite, contaminated by schist.

55-85f

Light- to medium-gray, fine- to medium-grained, andesine-biotite-quartz gneiss.

East of Bearsden Road.

Granitic. Grain size 0.05 to 3.3 mm; average about 0.5 mm. Trace of deuteric myrmekite. Biotite light yellow olive to dark olive. Apatite more euhedral than anhedral. Sphene has well-developed cleavage; central part more golden than outer part, which is

55-85f (Cont.) pleochroic golden gray brown. Largest sphene over 1 mm long. Light- to medium-orange-brown allanite rimmed by epidote. Zeolite, possibly scolecite, occurs in radial clusters.

Tonalite.

55-NH-4a Pinkish-brown, white, light- to dark-gray, fine- to medium-grained, oligoclase-biotite-quartz gneiss.

West of Bearsden Road.

Granitic. Grain size 0.1 to 2.5 mm long; average about 0.5 mm. Oligoclase well-twinned and zoned. Light-yellow-brown to medium-yellow-brown, decussate biotite replacing light-yellowish-olive to medium olive to bluish-olive hornblende. Some twinning present in hornblende. Colorless to pale-green chlorite is retrograde; anomalous Berlin blue to tobacco brown interference colors. Muscovite formed at expense of oligoclase. Pleochroic gray-brown sphene with magnetite cores and anhedral to euhedral apatite are relatively abundant. Some apatite is slightly radioactive. Zircon common appears as aggregated pellets. Radioactive allanite is zoned, being redder in the center and orange at the rim; epidote forms overgrowths on allanite.

Tonalite.

88-52-1 Pink, light- to dark-gray, fine- to medium-grained, andesine-biotite-quartz gneiss cut by conformable pink andesine-quartz dike.

West of Bearsden Road.

Granitic to mosaic. Grain size varies from 0.1 to 2 mm. Quartz and andesine in dike are coarser grained than in matrix, the largest andesine crystal being about 3 mm long. Andesine has zoned twinning and oscillatory extinction. Some of the muscovite replacing feldspar is oriented parallel to the twin and cleavage planes. Biotite light to medium yellow brown. Light-olive to medium-blue-green hornblende is being replaced by biotite. Magnetite is generally associated with biotite and has large overgrowths of sphene. Sphene pleochroic pink golden to gray brown, the center being more pink golden. Largest sphene crystal is about 1 mm long; some euhedral; sphene is almost an essential mineral. Apatite slightly radioactive; quartz corrosion. Clinozoisite forms overgrowths on most of the yellow-orange-brown allanite, some of which is euhedral. Some zircon euhedral.

88-52-1 (Cont.)	Tonalite. Similar to 55-NH-4a but slightly coarser grained.
55-88d	Light- to medium-gray, fine- to medium-grained, andesine-biotite-quartz-sphene gneiss.

South of Millers River, west of Thousand Acre Brook.

Granitic. Grain size from 0.05 to 2.8 mm; average about 0.5 mm. Andesine has slightly cloudy black inclusions in central portion. Trace of blue-green hornblende present. Light-yellow-olive to dark-olive, decussate biotite retrograde after hornblende. Magnetite euhedral to anhedral, varying in size; magnetite occurs alone, exsolved from biotite, as rim on pyrite cubes, or as core in sphene. Pyrite euhedral. Iron oxide replaces pyrite and magnetite. Sphene pleochroic golden gray brown. Reddish-orangish-brown anhedral allanite has irregular rim of epidote. Some twinned clinozoisite present; slight quartz corrosion. Muscovite formed at expense of andesine. Apatite euhedral to anhedral.

Tonalite.

Specimens from diorite-diabase dike in Hardwick Granite in Table 4

Specimen	Name, Location, Description, Origin
12-52-1	Gray, fine- to coarse-grained, hornblende-biotite-andesine amphibolite. Roadcut, northern end of Bearsden Road. Decussate. Grain size highly variable from 0.1 to 7.5 mm. Black oriented dust and needles finely disseminated throughout andesine and hornblende; probably exsolved ilmenite or hematite. Andesine commonly occurs as large crystals up to 7.5 mm which are dissected by mafic minerals. Trace of myrmekite present. Hornblende pale beige to light olive, blue green; some corrosion and vermicular intergrowths with quartz. Hornblende being replaced by pale-yellow-brown to light-medium-olive-brown biotite, which, in turn, is being replaced by light-green chlorite. Chlorite has anomalous gray interference colors; some is rutilated. Biotite plates are up to 5 mm long; smaller laths are mixed with hornblende and andesine; some quartz corrosion. Sphene is dark golden to bright yellow or rusty; it occurs in aggregates or alone as more or less euhedral crystals in mafic minerals, although it is more commonly found in biotite than hornblende. Sphene also occurs as overgrowths on magnetite. Euhedral pyrite crystals about 1 mm in diameter have rims of magnetite and hematite. Apatite zoned with dark dusty inclusions oriented along the c-axis. Apatite occurs alone or in aggregates; some euhedral. Epidote zoned and radioactive; some has allanite core. Zircon size variable and metamict. In one area zircon aggregate forms reticulate herringbone pattern. Diorite.
55-85c	Dark blackish- to light-gray-green, fine- to medium-grained, hornblende-andesine-biotite-chlorite amphibolite. Roadcut, northern end of Bearsden Road. Decussate texture. Grain size varies from 0.1 to 3.2 mm. Poikilitic andesine distinctly zoned; laths up to 2.5 mm. Clouds of black magnetite-ilmenite(?) inclusions form herringbone pattern in andesine and mafic minerals. Trace of myrmekite present. Twinned poikilitic hornblende up to 3.2 mm long is light olive to medium brownish olive, bluish green. Hornblende is being replaced by pale- to medium-yellow-brown biotite which occurs in plates up to 2.8 mm long.

55-85c (Cont.) Biotite is being replaced by very pale-yellow-brown to light-bluish-green chlorite which has anomalous gray interference colors. Apatite weakly metamict in biotite. Tube-like and black inclusions are parallel to the c-axis of apatite. Largest apatite crystal is about 2 mm long. Epidote-clinozoisite is metamict. Several clusters of zircon appear, one of which has almost a herringbone pattern. Quartz corrodes other minerals. Some smaller magnetite grains occur in clusters. Pyrite commonly rimmed by hematite and magnetite.

Diorite to diabase.

55-85h Yellow-brown-blackish to light-green, fine- to medium-grained, andesine-hornblende-biotite amphibolite.

East of northern portion of Bearsden Road.

Decussate texture; some grains granoblastic. Grain size 0.05 to 4 mm. Poikilitic andesine, up to 3.5 mm long, is well-zoned and has central dusty magnetite (?) inclusions. Trace of myrmekite. Hornblende is up to 4 mm, poikilitic, and twinned; exsolution latticework of magnetite-ilmenite (?) present. Hornblende is light yellow brown to olive to medium olive, bluish green. Light- to medium-yellow-brown poikilitic biotite retrograde after hornblende. Quartz corrosion of hornblende and biotite. Very pale- to light-green chlorite retrograde after biotite and hornblende; anomalous gray interference colors. Some magnetite has grayish-brown overgrowths of sphene; sphene rarely present alone. Iron oxide, present as interstitial stain and replacement of magnetite; may have replaced pyrite. Apatite slightly zoned with dusty black inclusions. Quartz occurs as clustered, parallel lenses. Allanite occurs with clinozoisite rim. Some brownish-bluish-olive clinozoisite-epidote is associated with apatite. Several parallel clusters of zircon present.

Diorite to diabase.

Specimens from fault gouge, Rte. 2-202 in Table 5

Specimen	Name, Location, Description, Origin
35-52	Light-gray to tan, fine- to medium-grained fault gouge. Fault zone on Rte. 2-202. Mortar structure, angular fragments. Average grain size about 1 mm; up to 3.3 mm long. Microfaulting and brecciation present. Feldspars highly sericitized. Albite-oligoclase zoned and twinned. Quartz-feldspar corrosion of muscovite. Muscovite occurs as small flakes. Hematite probably pseudomorphous after pyrite cubes. Limonite occurs along cleavage planes of muscovite and as interstitial stain. Fault gouge.
55-98b	Light-gray, fine- to medium-grained fault gouge. Fault zone on Rte. 2-202. Granitic to angular, minor mortar structure. Crosscutting veins and microfaulting apparent. Average grain size about 0.7 mm, up to 2.7 mm. Plagioclase almost entirely sericitized; orthoclase unaltered. Biotite light yellow brown to dark reddish brown. Muscovite forms vermicular intergrowths with plagioclase. Garnet and sphene strung out with muscovite. Sphene and ilmenite altered to leucoxene. Pyrite unaltered. Recrystallized fault gouge.

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