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PETROGRAPHY AND PETROLOGY OF THE MIDDLEFIELD GRANITE [MASSACHUSETTS]

By

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OF THE
MIDDLEFIELD GRANITE

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ABSTRACT

PETROGRAPHY AND PETROLOGY
OF THE
MIDDLEFIELD GRANITE

by Russell Gould Clark, Jr.

The Middlefield Granite is a small elliptical body, roughly three miles long and one and a half miles wide, enclosed in a series of eugeosynclinal metasediments and located in the Chester quadrangle in west central Massachusetts.

The purpose of the study was to map and describe the Middlefield Granite and to determine through field and petrographic studies as much as possible about the history, origin, mode of formation of the rock, and its relation (time and space) to the surrounding country rocks.

A geologic map of the granite and surrounding rocks, based on the author's field investigations, is presented.

As a result of the petrographic examination of granite thin sections, the minerals present are described, with estimated modes tabulated: plagioclase, averaging An_{12}, (38.7%); perthitic microcline (24.0%); quartz (24.1%); biotite (6.0%); muscovite (4.0%); epidote (2.5%); and other accessories (0.8%).

INTRODUCTION

Purpose of Study

The purpose of this study was to map and describe the Middlefield Granite and to determine through field and petrographic studies as much as possible about the history, origin, mode of formation of the rock, and its relation (time and space) to the surrounding country rocks.

Geographic Setting

The Middlefield Granite is an irregular but roughly elliptical body located in the northwest ninth of the Chester quadrangle in west central Massachusetts. The body underlies about three square miles of the Town of Middlefield. (see Figures 1,2)

Method of Study

Field work was done during the summer of 1967, while the author was working under the direction of Norman Hatch of the United States Geological Survey, Branch of Regional Geology in New England, in a cooperative mapping project with the Massachusetts Department of Public Works. Traverses were run along stream valleys and ridge

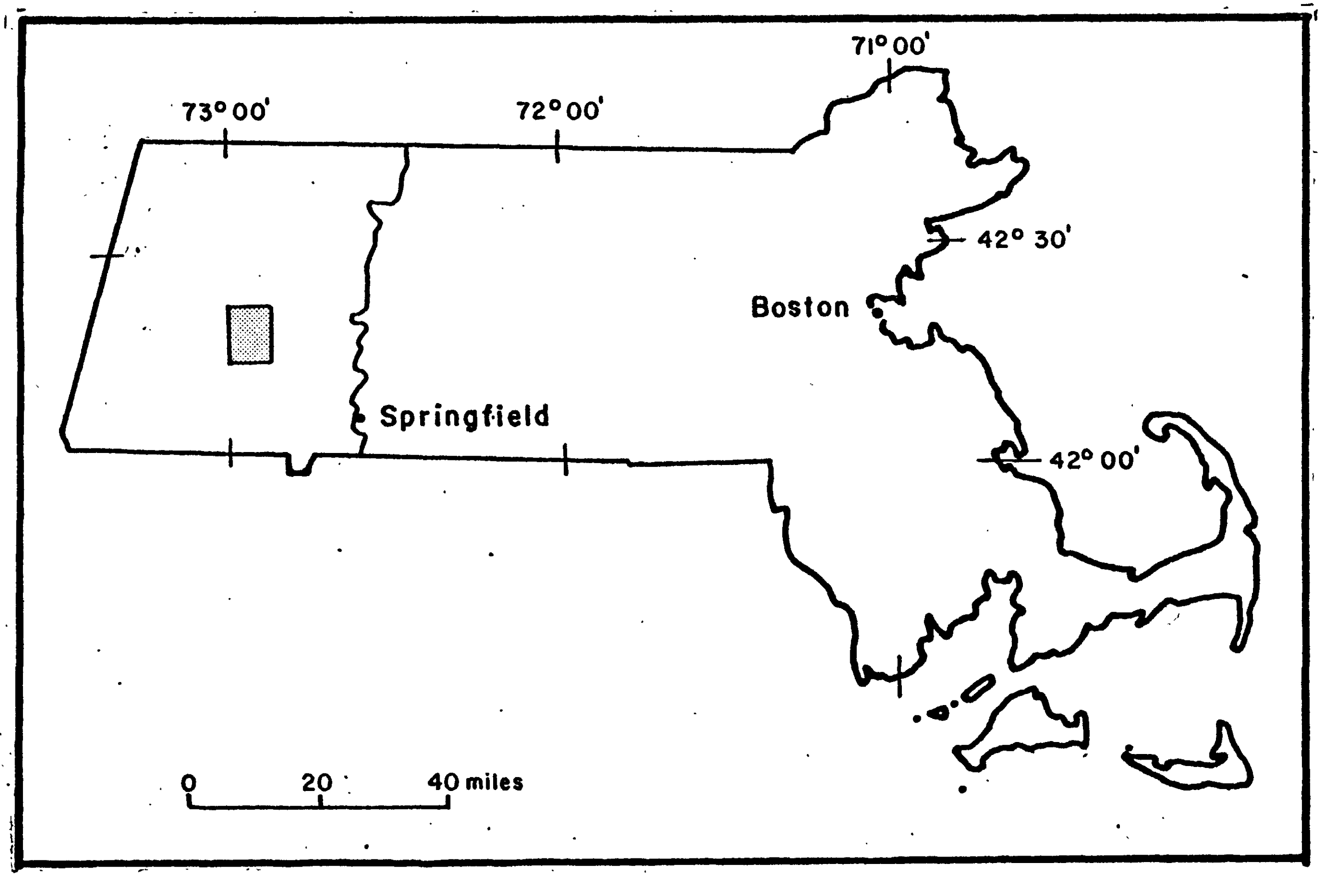

Figure 1. -- Map of Massachusetts, showing location of Chester quadrangle (shaded area).

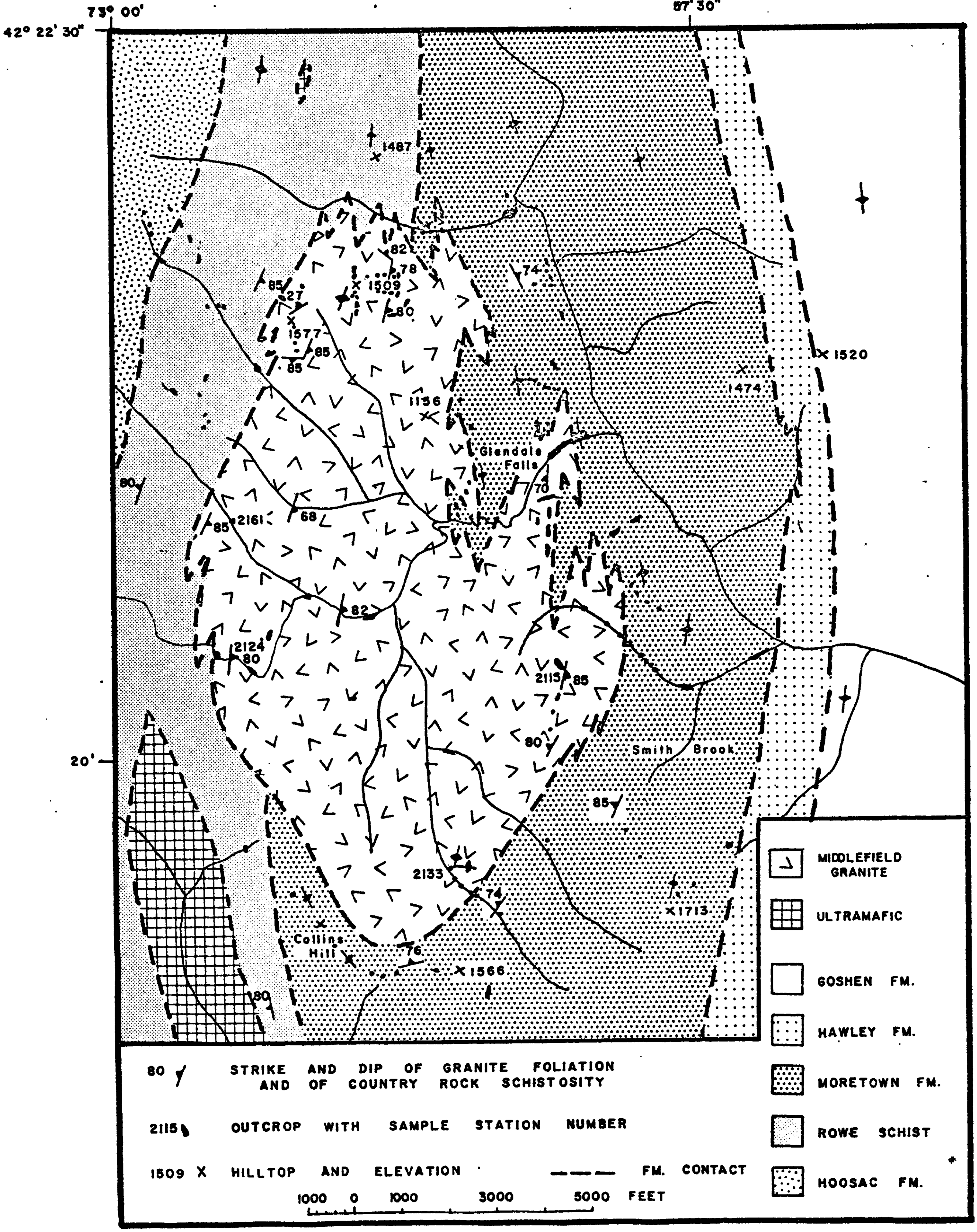

Figure 2. -- Geologic map of the northwestern part of the Chester quadrangle; showing outcrops, sample stations and locations referred to in the text.

crests, with a traverse spacing, in so far as possible, of no more than 1000 feet. Location of supplementary traverses was determined by the amount of outcrop seen on the ridges and streams and by the complexity of the geology. Field data were plotted on a 1:24,000 topographic sheet. Detailed studies on a scale of 1:120 were made at Glendale Falls.

Laboratory work and writing were done during the period September, 1967, to May, 1968, at Michigan State University under the supervision of Dr. J. W. Trow. Thin sections were observed through a Leitz petrographic microscope. Estimated modes were made from point counts using a Chayes stage. Feldspar identification was facilitated by using the technique for selectively staining plagioclase and potash feldspar described in the Appendix.

Previous Work

The author was unable to locate any detailed descriptions of the Middlefield Granite in any previous literature. The earliest mention of the granite is by Emmons (1824) and also Dewey (1824).

The most recent mention of the Middlefield Granite in the literature is by B. K. Emerson in a monograph on old Hampshire County (1898). Since it is the most recent account of the granite and it is brief, Emerson's description of the "Middlefield Porphyritic Granite" is here quoted in its entirety:

> The great dike of granite in Middlefield, about 6 miles long, is widely separated from all other outcrops, and is unlike all other masses of granite in the region. It is purely a biotite-granite, small porphyritic in its central portions. The feldspars are about three-fourths of an inch long, rarely show Carlsbad twinning, and are microcline without albite bands. A few rounded spots, apparently of albite, break the continuity of the cleavage surface. These feldspar crystals are at times bounded by a layer of secondary muscovite plates, and this is the only appearance of muscovite in the granite.
>
> The biotite is aggregated in groups of rather dull-black plates, with epidote, garnet and rarely white apatite needles accompanying it. The yellowish-white background is a somewhat friable mixture of much granular othorclase and a little bluish quartz, which is characterized by the presence of small, elongate cavities. At the border the porphyritic feldspars and the biotite aggregates disappear, and the friable ground with small distinct spots of biotite and the small cavities remain unchanged.

Regional stratigraphic and structural studies are recently completed or currently underway by the United States Geological Survey in many of the neighboring quadrangles.

REGIONAL SETTING

The Chester Quadrangle is geologically located in the Northern Appalachian Mountains on the east limb of the Green Mountain-Berkshire Anticlinorium. The anticlinorium trends north-south and has Precambrian crystalline gneisses at its core. The west limb of the anticlinorium is composed of a sequence of miogeosynclinal Paleozoic quartzites and carbonates. These rocks have most recently been studied in north western Massachusetts by Herz (1958,1961) and Norton (1967). The Middlefield Granite is on the east limb, which is composed of a sequence eugeosynclinal Paleozoic schists and gneisses. These rocks have been studied most recently in north western Massachusetts by Hatch and Hartshorn (in press), Osberg, Hatch, and Norton (unpublished map), and Hatch (in press).

Regional Structure

Description of the structural features found in the Chester Quadrangle (and in the Worthington and Plainfield Quadrangle just to the north) is summarized in Hatch, *et al.*, (1967). The description by Hatch is quoted in part here:

> (1) Deformation in pre-Goshen time produced north-west trending tight or isoclinal folds. These folds are assumed originally to have had near-horizonal or horizonal axes. . . .
>
> (2) The next deformation, which affected all the rocks, produced isoclinal folds with north-trending, vertical or steeply east-dipping axial surfaces. Axes are generally steeply plunging in pre-Goshen rocks and gently plunging or horizonal in Goshen rocks. The prominent regional schistosity is parallel to the axial surfaces of these folds.
>
> (3) Schistosity and the axial surfaces of the folds produced in stage-2 deformation are locally warped into open folds a few inches to a few feet in amplitude. Axial surfaces of these stage-3 folds strike northeast and dip moderately to steeply to the northwest; axes plunge moderately to the north. . . .
>
> (4) The doming of the gneiss around Hallockville Pond (north of Chester Quadrangle) produced minor folds with an axial plane slip cleavage in the rocks in and immediately around the dome. . . .
>
> (5) Folds with north-trending subvertical axial planes and associated slip cleavage and gently plunging axes are present along the western edge of the area. . . . This stage of folding is interpreted as being synchronous with the formation of the present Berkshire anticlinorium.

According to Hatch, stage 1 is probably Taconic (Ordovician) in age, whereas stages 2,3,4, and 5 are probably all related to the Acadian Orogeny. Hatch also believes that the regional metamorphism is Acadian, as is true in most of the rest of New England. (personal communication, April, 1968).

Metamorphic Units

Five formations of metamorphic rocks older than the Middlefield Granite occur in the Chester Quadrangle. (see Figure 1) All of these were sedimentary units originally except for the smaller amphibolites, some of which were probably intrusive dikes and sills. Two of these formations are in contact with the Middlefield Granite: 1) the Cambrian and Ordovician Rowe Schist; and 2) the Ordovician Moretown Formation.

The Hoosac Formation which is the oldest unit in the area, consists largely of light- to dark-grey quartz-albite-biotite-muscovite-garnet schist.

The Rowe Schist (Hatch *et al*., 1966) includes three distinctive lithologic types: black; green; and amphibolite.

The Black Schist member of the Rowe Schist is primarily dark grey carbonaceous quartz-feldspar-muscovite-biotite schist. It commonly weathers rusty brown or a yellow sulfidic color. The rock is moderately well-bedded in relatively more schistose and granulose beds. Quartz pods up to 4 centimeters wide and 8 centimeters long are present locally. The carbonaceous material occurs in thin layers parallel to schistosity and is a distinctive feature of this member.

The Green Schist member of the Rowe Schist is a light green fine-grained muscovite-quartz-chlorite-feldspar-garnet-magnetite schist. Fresh surfaces are light grey green to silvery green. It weathers grey-green to brown. The rock varies somewhat in proportions of micas and quartz, but is generally highly schistose. Stringers and blebs of quartz as much as 5 centimeters long are common. Bedding is generally not evident.

The amphibolite member of the Rowe Schist is a fine- to medium-grained hornblende-plagioclase schist. Fresh surfaces are greenish black with lighter plagioclase layers in some places. It weathers to a dark green-grey with a characteristic lineation. Local banding (1-2 millimeters) results from the alternation of hornblende-rich and plagioclase-rich layers.

The Moretown Formation is predominantly grey fine- to medium-grained quartz-plagioclase-muscovite-biotite granulite* and schist. The rock in many places approaches quartzite in composition. The layers or partings of mica-rich rock between 1-3 millimeter layers of quartz-feldspar-rich rock impart to the rock a characteristic thin-laminated

* The term granulite is used here purely in the textural sense to indicate a rock composed predominantly of even-sized interlocking granular minerals. No implication as to the grade of metamorphism is intended by this usage. (Hatch and others, in preparation)

appearance commonly known as "pinstripe" structure. Many garnets are 1/2 inch in diameter. The Rowe-Moretown boundary is gradational by interbedding of Rowe and Moretown lithologies. The Rowe-Moretown boundary is mapped at base of the first granulite bed more than about 6 inches thick. Many small fine-grained amphibolites, similar in composition to the Amphibolite member of the Rowe Schist, occur near the top of the Moretown Formation. Some of these are cross-cutting and thus intrusive.

Stratigraphically above the Moretown Formation is the Hawley Formation of Ordovician age and the overlying Goshen Formation of Silurian and Devonian age.

Generally, the mica-quartz rich Green Schist member of the Rowe Schist is in contact with the granite on the west, and the quartz-plagioclase rich Moretown Formation is in contact with the granite on the east.

THE MIDDLEFIELD GRANITE

General Statement

The Middlefield Granite is a roughly elliptical body about three miles long and one and a half miles wide. It is a light- to medium-grey, or buff, medium grained gneissic granite composed predominantly of microcline (commonly perthitic), plagioclase, and quartz, with lesser amounts of biotite, muscovite, epidote, sphene, allanite, and opaques. Microcline commonly forms Carlsbad twinned phenocrysts as much as 3 centimeters long that may constitute as much as 36 percent of the rock. The parallelism of individual flakes of biotite and small lenses of biotite, epidote, and sphene give the rock a prominent foliation that parallels the regional schistosity of the country rock.

The modal composition of the rock (see Tables 1,2) is that of a granodiorite according to Johannsen (Vol. II, p. 320.), but is that of a granite according to Moorehouse (p. 256). The term "granite" is herein retained to conform with Emerson's (1898) description of the body.

Microscopically, the texture is porphyritic and hypidiomorphic-granular, but in most places a cataclastic

Table 1. -- Estimated modes across a granite sill at Glendale Falls*

	G	H	I	J	K	L	M	N	Average
Microcline	2.9	9.1	31.5	24.8	20.7	36.8	34.0	20.2	25.3
Plagioclase	40.6	39.7	37.3	47.0	38.1	39.5	46.5	57.0	43.6
Quartz	23.6	25.3	20.4	13.5	19.7	9.3	5.3	0.1	13.4
Biotite	27.6	12.8	4.7	6.4	4.9	4.8	6.0	14.4	7.7
Muscovite	3.8	11.2	3.8	5.3	10.1	6.2	6.6	4.9	6.9
Epidote	1.0	0.3	1.8	2.2	4.1	2.3	1.1	1.3	1.9
Apatite	0.3	0.3	0.6	0.2	0.4	0.1	0.2	0.6	0.3
Sphene	tr		tr	0.6	0.5	0.3	0.2	1.0	0.4
Allanite						0.1		0.4	0.1
Opaque		0.3						0.1	0.1
Total	99.8	99.0	100.1	100.0	98.5	101.2	99.9	100.0	100.1

Sample G is schist.
Samples H - N are granite.
The average is for granite samples only.

* See figure 4 for location of samples

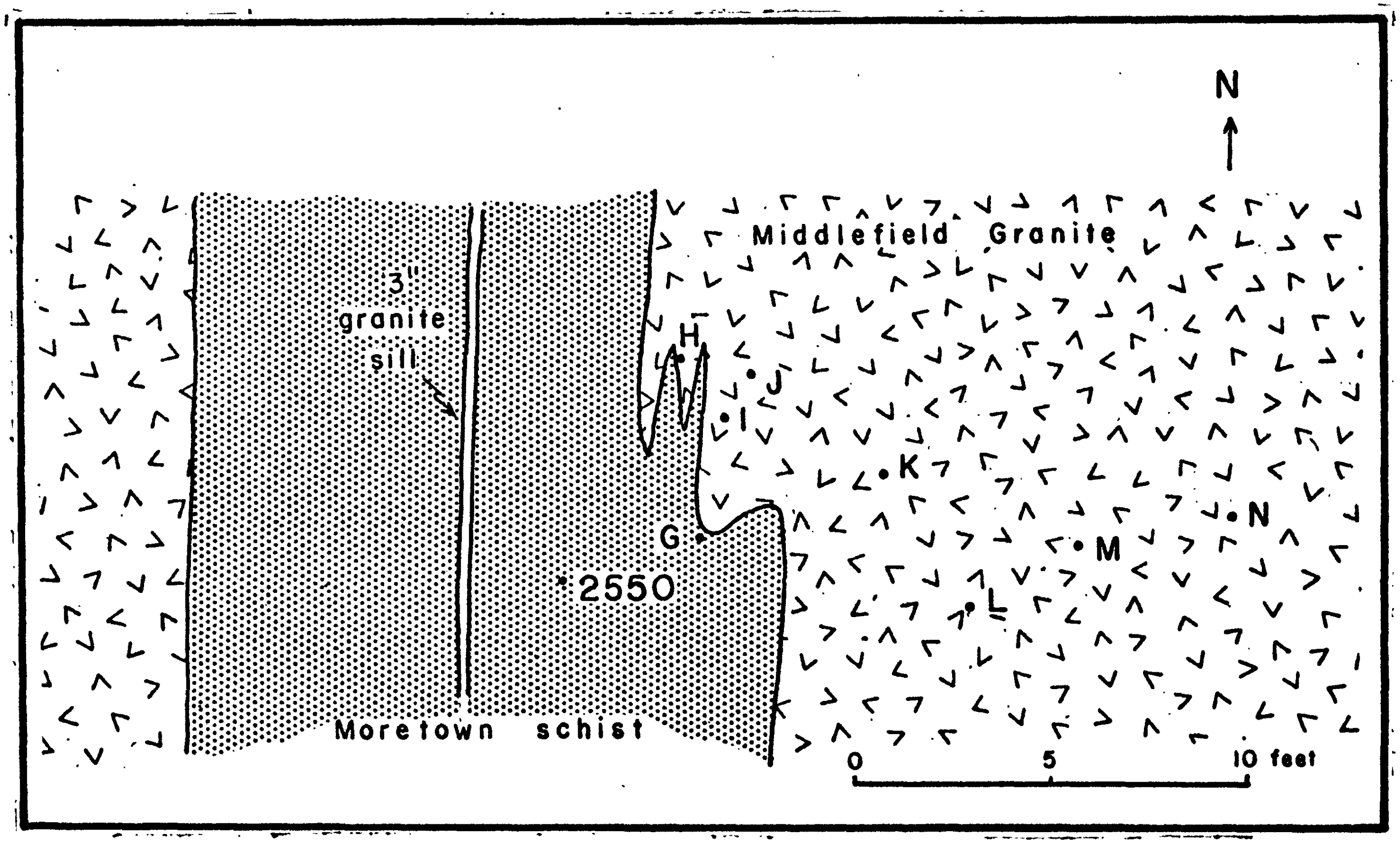

Figure 3. -- Sketch from the author's field notes showing location of samples listed in Table 1. (see Figure 4 for location of station 2550).

Table 2. -- Estimated modes of granite samples

	(1)	(2)	(3)	(4)	(5)	Average
Microcline	24.0%	29.9%	24.6%	16.2%	25.3%	24.0%
Plagioclase	34.7	38.5	32.8	43.8	43.6	38.7
Quartz	26.3	23.8	33.4	23.8	13.4	24.1
Biotite	7.1	4.5	3.9	6.7	7.7	6.0
Muscovite	3.0	1.2	2.7	6.2	6.9	4.0
Epidote	3.9	2.2	1.7	2.7	1.9	2.5
Apatite		0.3	0.2	0.4	0.3	0.2
Sphene	0.3	0.1	0.6	0.3	0.4	0.3
Opaque	0.3			tr	0.1	0.1
Allanite	0.5		0.2		0.1	0.2
Total	100.1	100.5	100.1	100.1	99.8	100.1

1. Granite Sample Number 2161*
2. Granite Sample Number 2124
3. Granite Sample Number 2133
4. Granite Sample Number 2115
5. Average of Granite Sill from Table 1.

* See figure 2 for location of samples

gneissic texture has been superimposed on this to varying degrees. Only a few of the outcrops located by this present author were entirely lacking gneissosity.

Areas of Outcrop

The actual outcrops located by the author during field work are shown on Figure 2. Outcrops are scarce in the center and along the northeastern and southwestern edges of the granite body. The largest single outcrop is at Glendale Falls, a Massachusetts State Reservation, near the eastern edge of the body. Here there is almost continuous exposure of alternating bands of granite and Moretown Schist for about 1200 feet along Glendale Brook (see Figure 4).

The shape of the body was roughly determined from the locations of the outcrops of granite and country rock. Although the granite contacts with the country rock were not located precisely, the author feels that with the exception of the northeastern portion of the body, the contacts as shown on the map (see Figure 2) are fairly accurate.

Contacts with Older Rocks

The contact of the main granite body with the surrounding rocks is very poorly exposed. The exact contact was never observed. The contact at 1) the base of Glendale Falls was determined to within 10 feet, 2) the northwest side of hill 1577 was determined to within 125 feet, and 3) the north fork of Smith Brook was determined to within 120 feet. (see Figure 2) The contact at each of these three places is thought by the author to be sharp, since at no place was there any sign of texturally or compositionally gradational contact between the granite and the country rock.

The contact at the southern end of the body is not located with any precision by the outcrops but is based on the attitude of the schistosity in the adjacent country rock (see Figure 2). Assuming that the schistosity here smoothly wraps around the granite (as is apparently the case) the southwestern contact of the granite truncates the Moretown Formation-Rowe Schist boundary.

The nature of the contact at the extreme northern end of the granite body is uncertain due to lack of outcrops. From the available field evidence, however, two possibilities can be suggested: 1) one sill of granite was located in the brook north of the granite (see Figure

2); if more sills like this exist, the granite may have an interfingering contact with the country rock; or 2) if the obscure foliation of biotite flakes found on the northern sides of hills 1509 and 1577 is primary (see page 19), it may indicate a smooth curved contact similar to one inferred at the southern end of the granite. The author favors the second possibility, since this would give the granite body similar contacts at both ends, and such a smooth contact would also be parallel to the schistosity of the two Moretown outcrops found in the brook just northeast of hill 1509. On the geologic map (Figure 2) this contact is shown as a group of jagged sills with a generally curved northern outline. This is an attempt by the author to show that this may be either a smooth or interfingering contact.

Many pieces of country rock are included or partly included in the granite, particularly along the eastern margin of the body. Only two such large inclusions, which may be roof pendants, were noted in the western half of the granite. These inclusions are best seen at Glendale Falls, where they range in width from a few feet to several tens of feet (see Figure 4). Most are exposed along their length for less than a hundred feet but may extend for thousands of feet. The contacts of the granite

and the inclusions parallel the schistosity in the coun-
t
try rock and are sharp (see Figure 5). Foliation observed in the granite is parallel both to the contacts and the schistosity in the wall rocks, except locally where the granite cuts across the schistosity of the inclusions (see Figure 6). One gradational contact between the granite and a small inclusion is shown in Figure 7.

Foliations

Almost every outcrop seen by the author was foliated. Most outcrops had only one foliation, but some had two. In the field the two foliations were distinguished as 1) a relatively weak foliation consisting of a subparallel alignment of individual biotite flakes, and 2) a relatively stronger foliation consisting of a subparallel alignment of elongate packets of biotite, individual flakes of biotite, microcline phenocrysts, or any combination of these three. Microscopically, the elongate packets of biotite were seen to also generally contain epidote, sphene, and muscovite.

Where only one foliation was observed at an outcrop, it was invariably the second type, and was parallel or subparallel to the regional schistosity in the country rock. Where both types of foliation were present in an outcrop, the second type was parallel or subparallel to the regional schistosity and the weaker first type of foliation was at an angle to this.

Figure 5. -- Negative print of a thin section showing sharp nature of the contact between a granite sill (top) and slab-like inclusion of schist at Glendale Falls (X4)

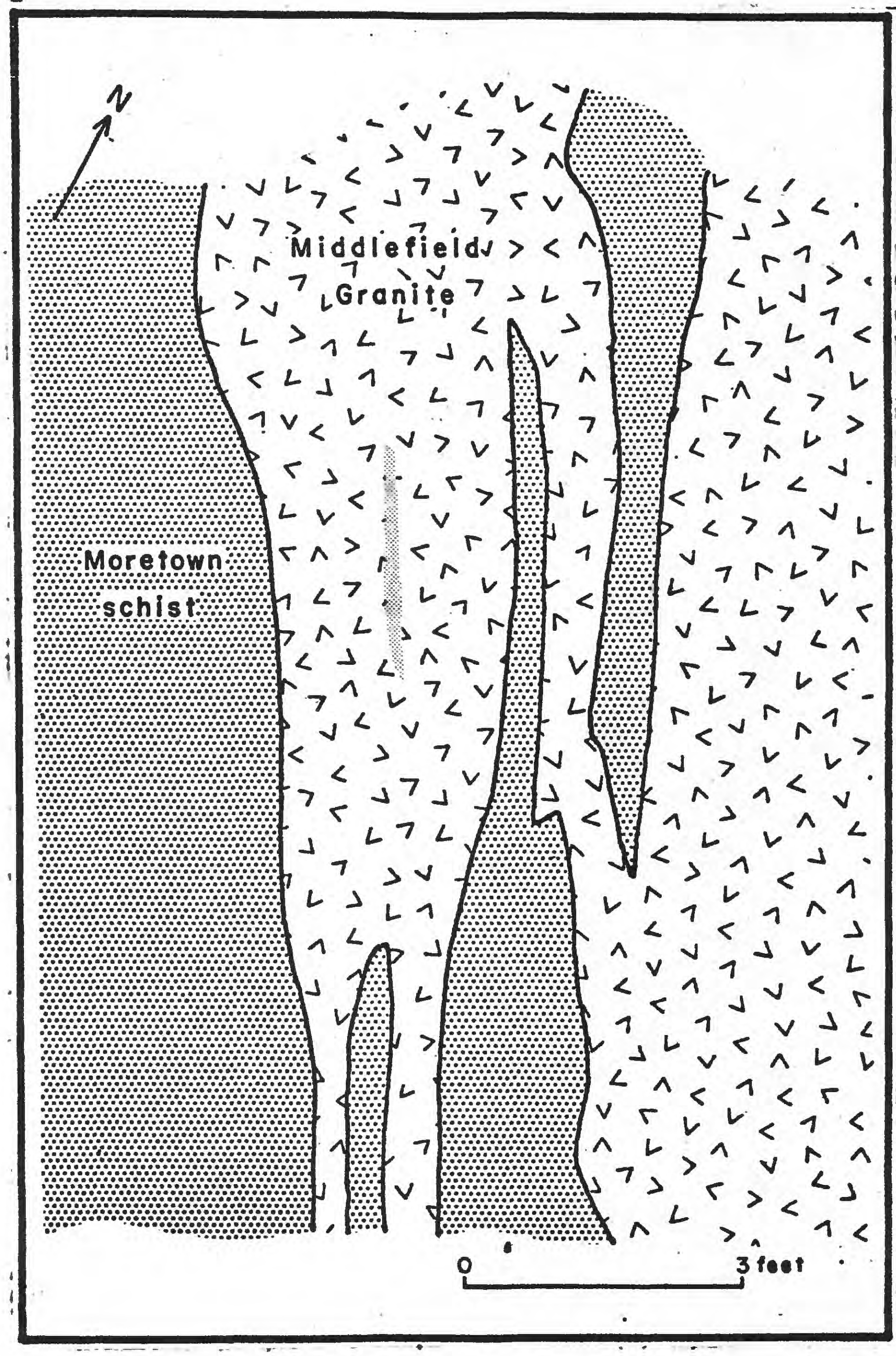

Figure 6. -- Sketch from the author's field notes showing granite cutting through a schist inclusion.

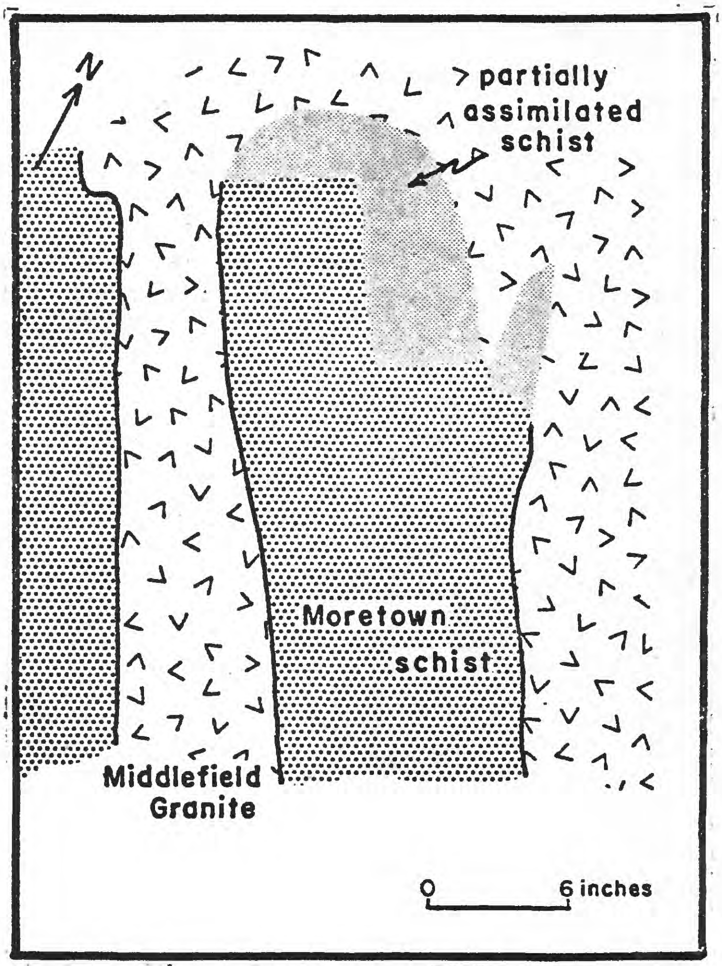

Figure 7. -- Sketch from the author's field notes showing a small schist inclusion which has been partially assimilated by the granite.

The location and orientation of these foliations are noted on the accompanying geologic map (see Figure 2).

Petrography of the Middlefield Granite

Two types of microcline are present: 1) large grains, the white phenocrysts seen in hand specimen, are typically perthitic (vein and patch types of perthite), commonly exhibit the characteristic gridiron twinning, and generally contain inclusions of plagioclase (other inclusions of biotite, sphene, and epidote may also be present); these large grains generally have a subhedral rectangular shape with irregular borders; and 2) small approximately equidimensional, well-twinned grains, containing few or no inclusions, commonly in aggregates, composed solely of microcline, elongated parallel to the secondary foliation of the granite; these aggregates are commonly seen near, or in contact with, the larger first type of microcline. (See Figures 8, 9, and 10)

Plagioclase occurs in three forms as: 1) inclusions in microcline phenocrysts; 2) grains in, but not part of, the groundmass; and 3) myrmekitic intergrowths of quartz and plagioclase. Plagioclase in the first two forms is subhedral with corroded borders generally albite-twinned,

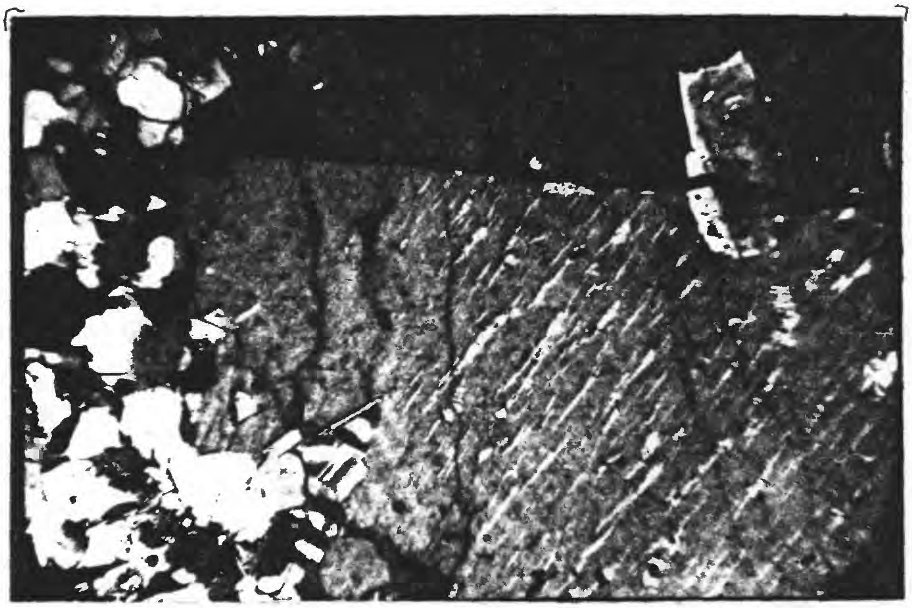

Figure 8. -- Photomicrograph of a Carlsbad twinned, perthitic microcline phenocryst; an epidote veinlet fills the twin plane and cuts through a zoned plagioclase inclusion (upper right).
(X80) (crossed nicols).

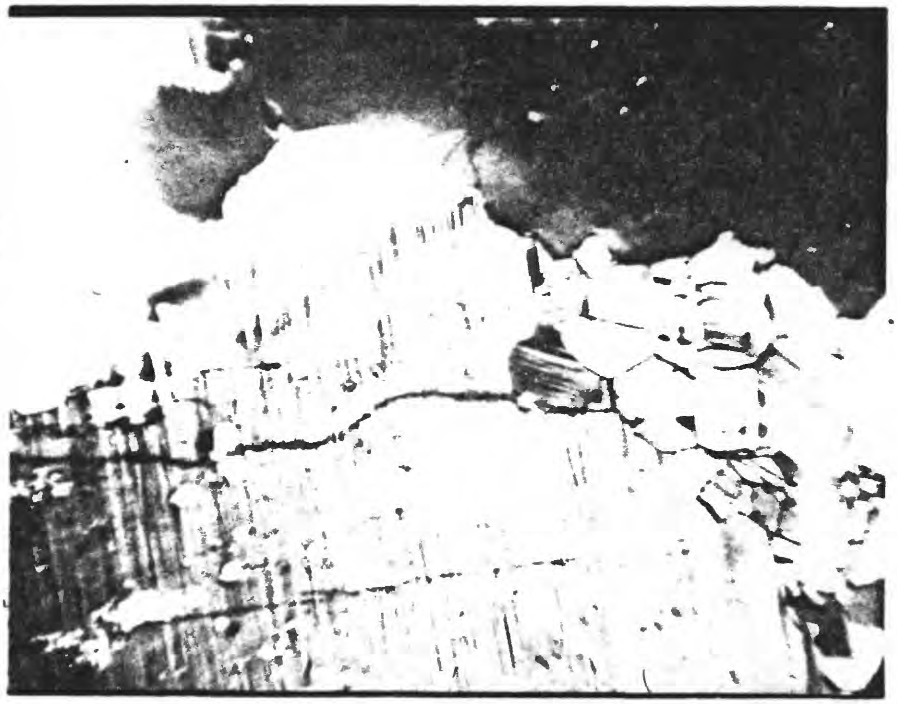

Figure 9. -- Photomicrograph of a group of small microcline grains (right center) adjacent to, and presumably fractured from the larger microcline phenocryst. (X80) (crossed nicols).

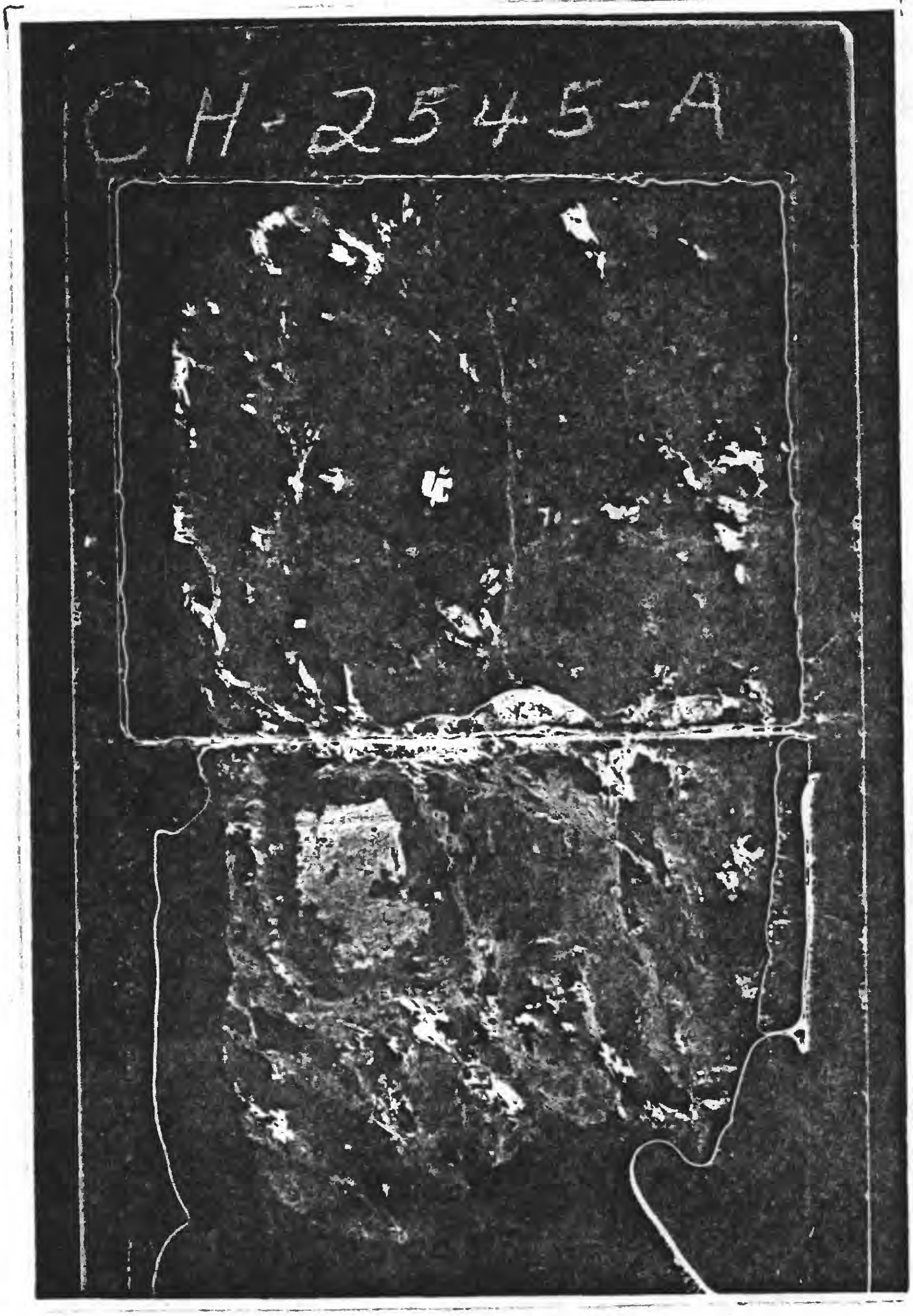

Figure 10. -- Negative print of a granite thin section: unstained (top) and stained (bottom). In stained half: Quartz is black; plagioclase is dark-grey; microcline and muscovite are light-grey; and biotite is white. A corroded phenocryst of microcline with a myrmekitic border is located at the upper left in the stained half. (X4)

and commonly contains muscovite (and/or paragonite?), epidote, and, in some places, quartz inclusions. The third (myrmekitic) form of plagioclase is commonly found 1) as partial rims on microcline phenocrysts, and 2) in the cataclastic groundmass. The composition of the plagioclase in the first two forms was found, using the Michel-Levy method, to be approximately An_{12}.

Quartz occurs in 1) elongate lenses, the sides of which are generally smooth and sharp against adjacent minerals and the groundmass; the long directions of these lenses parallel the regional secondary foliation of the granite ~~gneiss~~, and the quartz within the lenses is fractured, with individual grains showing undulating extinction; 2) myrmekitic intergrowths with plagioclase, 3) inclusions in plagioclase and microcline, and 4) small distinct grains in the cataclastic groundmass. The first type of quartz described is distinctive and the most abundant type. 10,13 In this first type, bubble trains are common and generally cross boundaries between individual fractured grains within the lenses; and in some places epidote, biotite, or sphene occur in fractures within these lenses.

Biotite occurs as 1) individual flakes with ragged ends in the groundmass, and 2) inclusions in plagioclase and microcline, but its most common occurence is as 3)

Figure 11. -- Photomicrograph showing slightly zoned inclusion of plagioclase, with myrmekite border in microcline. Plagioclase twinning continues through zoning.
(X330) (crossed nicols).

Figure 12. -- Photomicrograph showing part of the myrmekite border on the microcline phenocryst shown in Figure 10.
(X80) (crossed nicols).

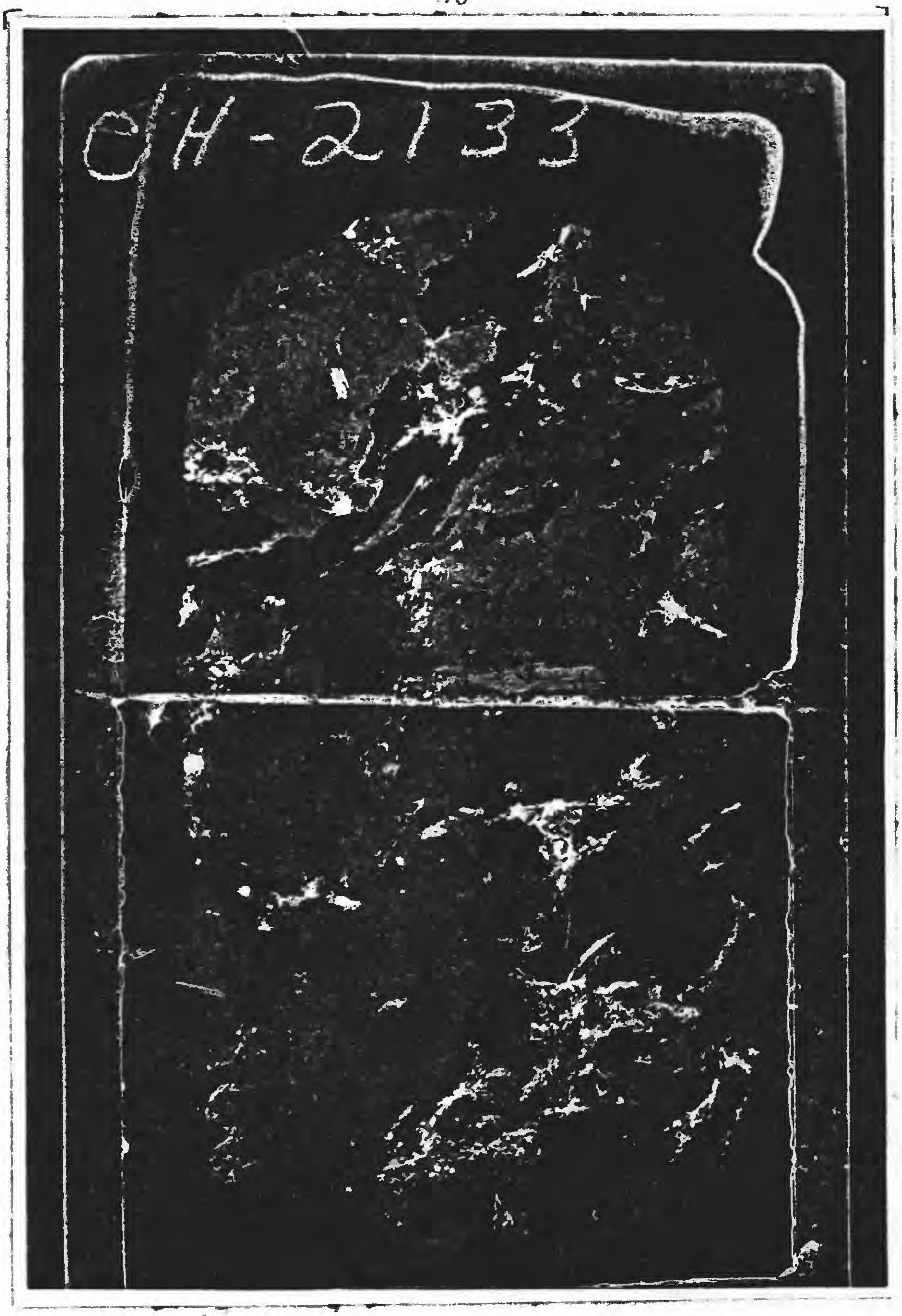

Figure 13. -- Negative print of a granite thin section: unstained (bottom) and stained (top). Quartz is black; plagioclase is dark-grey; microcline and muscovite are light-grey; and biotite is white. (X4)

elongate packets of flakes, associated with epidote, sphene, and muscovite and other accessories. This third form (elongate packets) commonly appears vein-like and wraps around larger grains of feldspar. The subparallelism of these elongate packets forms the predominant foliation of the granite which parallels the regional schistosity. The biotite in all three forms is generally brown, although the pleochroism tends toward olive-green when the flakes are viewed normal to the cleavage. "Bird's-eye" extinction is commonly strong. Biotite may alter to muscovite or chlorite. (see Figures 10,13,14,15)

White mica occurs as 1) flakes associated with the elongate packets of biotite mentioned above, 2) ragged flakes in the groundmass, 3) small flakes included in plagioclase, often oriented along plagioclase cleavage planes, and 4) symplectic intergrowths with plagioclase. The first three types are muscovite. The fourth type of white mica, which may be paragonite has a 2V of about 20°. "Bird's-eye" extinction is common in the first two forms of muscovite. (see Figures 10, 13, 14)

Epidote occurs as 1) anhedral to subhedral grains associated with biotite in the elongate packets mentioned above and included in plagioclase and in some microcline, and 2) green cryptocrystalline veinlets filling fractures through other grains, spaces between other grains, and

Figure 14. -- Photomicrograph shewing elongate packet of biotite, muscovite, epidote, and other accessories. (X80) (uncrossed nicols).

Figure 15. -- Photomicrograph showing euhedral sphene (left), and epidote replacing biotite (right). (X330) (uncrossed nicols).

some twin planes in both plagioclase and microcline. In some places this second (veinlet) form of epidote appears to be iron-stained. (see Figures 8, 14, 15)

Sphene generally occurs as dirty-brown anhedral to euhedral grains associated with biotite and epidote in the elongate packets (described above), but it may occur as euhedral inclusions in microcline or quartz, or anhedral grains in the groundmass. (see Figure 15)

Apatite occurs as anhedral to subhedral grains in the cataclastic groundmass.

Subhedral to anhedral, red-brown to orange allanite is found intimately associated with epidote, commonly in the elongate packets of biotite, epidote, and sphene. Normally, allanite shows little extinction, but rather transmits polarized light in all orientations and has a blotchy appearance; other crystals are zoned and show more extinction, or are botryoidal.

The few opaques observed were 1) magnetite included in muscovite, and 2) ilmenite included in sphene.

SUMMARY

Origin of the Middlefield Granite

Several field observations point toward the conclusion that the Middlefield Granite was forcefully injected into its present position as a small elliptical stock.

1) The attitude of the wall rocks, as shown on Figure 2, bulge outward on both the east and west sides of the body. Just east of Collins Hill, at the southern end of the granite, the foliation in the country rock appears to wrap around the end of the body; the strike changes from N.43°W. on the southwest side to N.46°E. on the southeast side.

2) The granite appears to cut across the Moretown Formation-Rowe Schist boundary on the southwest side of the body and possibly at the north end.

3) The contacts between granite and the large slab-like inclusions of Moretown are sharp. The three contacts between the main granite body and the enclosing schists described on page 17 gave every indication of being sharp; no evidence of large scale gradational contacts were seen.

4) Alternating bands of granite and schist at Glendale Falls are probably sills of igneous rock between

roof pendants of the overlying country rock.

5) A few partially assimilated xenoliths of schist were observed. (see Figures 6, 7, 16)

6) A weak biotite foliation, which may be primary, is visible, where it does not parallel the regional schistosity, but has the stronger secondary foliation superimposed upon it. On hill 1509 primary (?) foliation dips to the north on the top of the hill and dips to the south on the south side of the hill, indicating that hills 1509 and 1577 are probably cupolas of an originally igneous body projecting into the overlying country rock.

7) At Glendale Falls, within one of the sills of granite, a partially assimilated xenolith of schist about 15 feet long and 6 inches wide is present. The xenolith is elongated perpendicular to the bands of schist on either side of the granite sill and is straight except that the ends bend to the north on the west end and to the south on the east end, so that the xenolith forms an elongate S (see Figure 16). This may indicate that the flowing granite magma rotated the xenolith with a right lateral strike-slip movement.

Several lines of evidence pointing to a magmatic origin for the granite have been found by studying the thin sections:

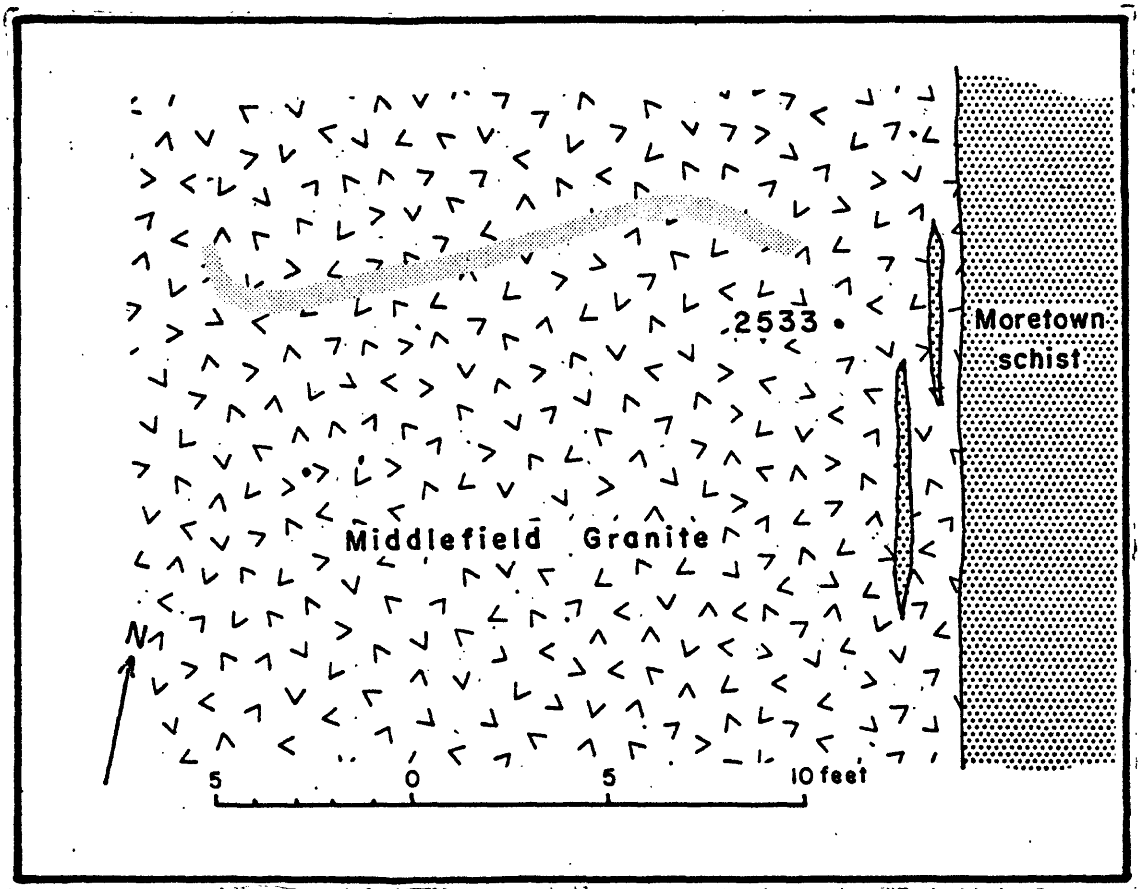

Figure 16. -- Sketch from the author's field notes showing S-shaped schist inclusion which has been partly assimilated by the granite. (see Figure 4 for location of station 2533).

1) Several plagioclase grains were zoned with the highest anorthite content in the center; the zoning was fuzzy, and in a few places twinning was superimposed on the zoning. (see Figures 8, 11)

2) Several plagioclase grains have inclusions of muscovite and quartz in zones, indicating that the crystallization of the plagioclase may have been interrupted temporarily.

3) Plagioclase inclusions in microcline grains have been rotated.

All of the above field and microscopic observations are believed to point toward a magmatic origin and forceful intrusion of the granite body. The origin of the magma itself cannot be determined from the available evidence.

Crystallization History

In view of the complex regional tectonics it is not surprising that very little can be inferred about the crystallization history of the Middlefield Granite.

The body most likely crystallized from a granitic magma, or from a quartz monzonitic magma if the anorthite content of the plagioclase was much higher than it is now (i.e., about An_{12}).

Since at least some of the plagioclase present has included biotite flakes and both plagioclase and biotite are found in the groundmass, plagioclase and biotite crystallization probably overlapped. Microcline has included plagioclase, so it probably crystallized later than plagioclase. Most, if not all, of the white mica appears to be secondary after biotite and plagioclase. Epidote also appears to be secondary.

Most of the perthite appears to be of the exsolution vein type and probably formed as the body cooled. Myrmekite probably formed as the body cooled apparently resulting from the reaction between plagioclase and microcline.

Subsequent Metamorphic Effects

The regional schistosity of the country rocks appears to have been imparted during Hatch's second (early Acadian) stage of folding (N. L. Hatch, personal communication, 1968) (see page 7). Since the granite body warps this schistosity outward on both the east and west sides of the body (~~see Figure~~ [illegible]), its emplacement could not have been before the folding. But since the granite also contains a foliation parallel to this regional schistosity, it too must have been affected by this stage of folding. The granite is therefore presumed to have been emplaced syntectonically with the second stage of folding.

After the body cooled another tectonic event occurred which caused most of the myrmekite to be broken off from the microcline phenocrysts. This event cannot be definitely correlated with any subsequent stage of folding, but must have occurred before stage 5. This can be reasoned as follows: the regional metamorphism of the area (which produced staurolite in other areas of the quadrangle) occurred after Hatch's stage 3, but before his stage 5 (N. L. Hatch, personal communication, 1968); both forms of epidote (vein and grain) present in the rock appear to have formed by decalcification of the plagioclase which probably took place during the regional metamorphism. Since veins of epidote cut through both grains and groundmass alike, it followed any cataclasis of the rock.

Conclusions

Three reasonably certain conclusions may be reached from the field and petrographic descriptions assembled in this paper: 1) the Middlefield Granite was originally emplaced in a liquid or partially liquid state; 2) the body was emplaced during the early stages of the Acadian

Orogeny; and 3) subsequent to its emplacement, the body underwent further deformation, which imposed gneissic and cataclastic textures upon the granite. This deformation most likely also occurred during the Acadian Orogeny.

The conclusions reached in this paper concerning the crystallization history and the precise order and number of metamorphic events which affected the granite are at best only tentative, but are believed by the author to be the best approximations which can be currently made from the available evidence.

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APPENDIX

Procedure for Uncovering Thin Sections in Preparation for Staining

In most cases, one will want to uncover only half of a thin section, so that part of the slide may be retained for comparison purposes, or for the study of textures or structures which might possibly be obscurred by the stain.

Apparatus:
- ice box (or an inhospitable climate)
- diamond pencil
- straight edge
- acetone
- lint-free cloth or paper
- razor blade
- masking tape

Procedure:

1. Freeze the thin section, by placing it outdoors if it is cold enough, or in an ice box. Fifteen minutes should be sufficient, but longer freezing, even for days, apparently will not hinder the preparation of the section.
2. Using a diamond pencil and a straight edge, make a groove across the cover glass on the frozen thin section.
3. Insert the edge of a razor blade (at a low angle) under the edge of the cover glass which is most nearly parallel to the groove which has been made.

4. Pry up the edge of the cover glass using a quick flipping motion. The portion of the cover glass to be removed will (hopefully) fly off in one piece.

5. If part of the cover glass does not come free, repeat the action with the razor blade on another free edge of the cover glass until all of the glass is completely removed.

6. When the desired portion of the cover glass has been completely removed, the rock chip will still be covered by the mounting medium. This may be removed by washing the slide with acetone, and a slight amount of rubbing with a lint-free cloth (or paper). Now the rock chip itself is exposed.

7. Assuming that only part of the cover glass has been removed, it is necessary to cover the remaining portion with masking tape (or something similar) to prevent the remaining portion of cover glass from being frosted by the hydrofluoric acid.

8. It may also be convenient to form a handle for the thin section by placing a piece of folded masking tape on the back of the thin section.

Selective Staining of Potassium Feldspar and Plagioclase in Thin Sections*

Reagents and Apparatus:

Hydrofluoric acid, concentrated, 52% HF, Caution: HF can cause painful burns.
Barium chloride solution, 5%.
Sodium cobaltinitrite solution, saturated.
Rhodizonate reagent. Dissolve 0.05 grams of rhodizonic acid potassium salt in 20 milliliters of distilled water. Make fresh in a small dropping bottle, as the reagent solution is unstable.
Etching vessels. Plastic vessels of about 3/4 inches in depth and various diameters slightly less than those of the specimens to be etched.
Plastic cover vessels, large enough to cover the etching vessels and specimens placed on them for etching.
Ribbed vessel to hold the cobaltinitrite solution.
Plastic or paraffin etching vessel to fit thin sections.

Procedure:

1. Etch the rock surface by leaving it face down for only ten seconds over hydrofluoric acid at room temperature. Note: Rinsing the slide after etching causes the stains to be uneven.

2. Immerse the slide in the saturated sodium cobaltinitrite solution for 15 seconds. The potassium feldspar is evenly stained light yellow.

3. Rinse the slide briefly in tap water to remove all of the cobaltinitrite.

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* Reference: E. H. Bailey and R. H. Stevens, 1960, "Selective Staining of K-Feldspar and Plagioclase on Rock Slabs and Thin Sections," Am. Min., Vol. 45, p. 1020.

4. Dip the slide quickly in and out of the barium chloride solution.
5. Rinse the slide briefly with tap water and then with distilled water.
6. Cover the rock surface with the rhodizonate reagent from the dropping bottle. When the plagioclase feldspar has become pink, rinse the slide in tap water.
7. Allow the slide to dry and cover it in the usual way.

In the stained thin sections under the microscope, the potassium feldspar can be seen to be stained a pale yellow and the plagioclase pink.** The mineral borders may be outlined by tiny spots of amber red, which seem to be a reaction product of rhodizonate with residual barium chloride left in the cracks between the mineral grains. This defect is not sufficient to interfere with study of the thin section. It was thought that longer washing after the barium chloride treatment would eliminate these amber spots, but after three minutes in tap water the potassium feldspar was also stained red by the rhodizonate.

** Pure albite does not become stained by the treatment with barium ion and rhodizonate, but albite with calcium corresponding to only 3 percent of anorthite was stained red. Apparently sodium in the etch residue from albite is not readily replaced by barium; however, it may be replaced by potassium. After immersing etched albite in a solution of potassium chloride, it may be stained yellow with cobaltinitrite, showing that potassium ion has substituted for sodium in the etch residue. By this method plagioclase, except perhaps for nearly pure anorthite, as well as the potassium feldspar, can be stained yellow with the cobaltinitrite.

Revised Staining Technique

The technique described on the previous two pages is the one described by Bailey and Stevens (1960). Through a trial and error method the author found that better staining was achieved by using the following method, which is basically like that of Bailey and Stevens, but has a few minor differences.

Reagents and Apparatus:

It was found that ~~by~~ diluting the rhodizonate reagent solution by four times (i.e., use 0.05 grams of the salt in eighty milliliters of distilled water). ~~This~~ gives better control over the quality of the stain, since it slows down the staining process.

Procedure:

1. Etch the rock surface by leaving it face down for 15-20 seconds at one-quarter inch above the hydrofluoric acid at room temperature.
2. Immerse the slide in the saturated sodium cobaltinitrite solution for 1 minute.
3. Rinse the slide briefly in distilled water to remove all of the excess cobaltinitrite.
4. Dip the slide quickly in and out of the barium chloride (1 second of complete submersion is sufficient).
5. Rinse the slide briefly with distilled water.

6. Cover the rock surface with the rhodizonate reagent from the dropping bottle.

7. Then, immediately dip the slide in distilled water to stop the staining. The plagioclase will be slightly pink. Repeat steps 6 and 7 until the desired shade of pink is obtained. (If the slide is not immediately rinsed after applying the rhodizonic acid for the first time, the staining will be uneven and perhaps too strong. When reapplying the rhodizonic acid, wait just a few seconds before washing the slide.)

8. Allow the slide to dry and cover it in the usual way.

The major differences between this technique and that of Bailey and Stevens are 1) the immersion times for various reagents; 2) the use of distilled water, wherever rinsing is called for; and 3) the repeated application of rhodizonic acid followed by immediate rinsing.

Procedure for Covering Stained Thin Sections

Apparatus: Permount (or some similar mounting medium)
glass rod
cover glasses
pencil, with eraser end
lamp with 60-watt bulb

Procedure:

1. After staining section let it dry completely. Be careful not to touch the stained portion of the slide.

2. In a well-ventilated area, dip the glass rod into the mounting medium and let one drop fall on the uncovered stained area of the slide. (Note: one drop will cover approximately a 22 millimeter by 22 millimeter area.)

3. Take a cover glass and hold it at a 45° angle to the thin section with one end of the cover glass resting on the section. Let the other end of the cover glass fall slowly, spreading the drop of mounting medium beneath it, so that it now completely covers the rock chip.

4. With the eraser end of a pencil, press lightly on the cover glass, so that the mounting medium spreads evenly over the rock chip.

5. Place the covered thin section under a gentle heat source for about 12-15 hours. (A lamp with a 60-watt bulb placed 12 inches away should be sufficient.) Note: Overheating may cause bubbles to form in the mounting medium.

6. After the mounting medium has hardened, excess medium on the slide may be scraped off, and the slide may be cleaned with an appropriate solvent.