

**GEOLOGY OF THE
NORTHERN PORTION OF THE
BELCHERTOWN INTRUSIVE COMPLEX
WEST-CENTRAL MASSACHUSETTS
BY JAMES OWEN GUTHRIE**



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THE GEOLOGY OF THE NORTHERN PORTION
OF THE
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By

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Contribution No. 8

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ABSTRACT

The Belchertown Intrusive Complex is located in the western part of the Central Upland of Massachusetts along the eastern margin of the Connecticut River Lowland. The main part of the Complex outcrops over approximately 64 square miles and is intruded into metamorphosed Paleozoic sedimentary and volcanic rocks and gneisses of uncertain age. Triassic sedimentary rocks are in fault contact with the Complex along the western border of its exposure. Pleistocene glacial debris covers much of the area.

The oldest rocks are pre-Middle Ordovician gneisses exposed in the Pelham Dome and in the main body of Monson Gneiss. The Pelham Gneiss of the area mapped is granitic gneiss with interstratified amphibolite. The Monson Gneiss is layered to massive quartz-plagioclase gneiss and amphibolite.

Between the Pelham Gneiss dome and the Monson Gneiss, there are two tight synclines and an anticline. These are, west to east, the Pelham-Shutesbury syncline, an unnamed anticline, and the Great Hill syncline. The synclines contain Paleozoic metamorphic rocks. The oldest known Paleozoic formation, overlying the Monson Gneiss, is the Middle Ordovician Ammonoosuc Volcanics composed of interbedded hornblende and anthophyllite amphibolite and quartz-feldspar gneiss. Overlying the Ammonoosuc Volcanics is the Middle Ordovician Partridge Formation of sulfidic mica schist with minor interbedded amphibolite. The Partridge Formation is exposed in the trough of the Pelham-Shutesbury syncline and on each limb of the Great Hill syncline. The middle belt forms a narrow elongate septum that extends 3 1/2 miles

into the batholith. The rocks of this septum exhibit a progressive coarsening and a more gneissic texture toward the center of the batholith. Kyanite in the Partridge Formation septum is replaced by sillimanite about 700 feet inside the batholith contact. The southern, inner 1 1/2 miles of the septum contains coarse prismatic sillimanite crystals that appear to be pseudomorphs after andalusite.

The Lower Devonian Erving Formation, overlying the Partridge Formation, is exposed in the center of the Great Hill syncline. It consists mainly of hornblende-epidote amphibolite and quartz-plagioclase-biotite granulite. Several large inclusions of amphibolite and granulite occur in the northwestern part of the intrusion and probably represent stoped blocks. One of these is clearly from the Erving Formation, and one from the Partridge Formation, but most are of uncertain correlation.

Intruding the metamorphic rocks is the Belchertown Intrusive Complex. It is composed of (1) hornblendite and meladiorite bodies a few thousand feet across, (2) a batholith of quartz diorite and granodiorite about 8 miles wide, (3) intrusive breccia, (4) subsidiary quartz diorite stocks less than 1000 feet across, and (5) aplite and pegmatite dikes. The hornblendite and meladiorite bodies, some containing diopside, are probably basic forerunners of the main intrusion. The rocks of the batholith consist of three main types arranged in roughly concentric zones. They are: (1) an outer zone of hornblende-biotite quartz diorite, (2) a middle zone of hornblende-biotite granodiorite, and (3) an inner zone of hornblende-biotite-augite granodiorite. Minor diorite and biotite-rich quartz diorite and

granodiorite occur near the country rock contacts. Contemporaneous with the intrusion of the batholith were the brecciation and injection of the metamorphic rocks along its northern borders by the magma and emplacement of two quartz diorite stocks in the Quabbin Hill area. The final stage of igneous activity associated with the Complex was the emplacement of aplite and pegmatite dikes.

The metamorphic rocks exhibit several structural features. Regionally there are the large-scale folds produced during the several stages of regional metamorphism. Locally the prominent structural features are foliation and lineation. The foliation generally strikes north-south and dips steeply to the east. The lineation trends north-south and plunges gently to the north. Within the igneous rocks the foliation and lineation vary in attitude and intensity throughout the batholith. In a narrow zone along the contacts the igneous rocks have a well foliated and lineated structure identical in character and attitude to that in the metamorphic country rock. Dikes that cut marginal parts of the batholith and adjacent country rock are highly folded in some locations. Within the batholith the foliation and lineation are not well developed and are generally discordant to the metamorphic structures of the country rock. In the inner edge of the narrow schistose zone there is an overlapping of the inner, possibly primary igneous, foliation and the outer, superimposed, secondary foliation.

The initial intrusions of the Belchertown Complex were the hornblendites. Following this the main batholith was replaced by a combination of stoping and forceful injection. The concentric zoning

of the batholith rocks is due to magmatic crystallization and/or metamorphism. Crystallization from the edge inward may account for the initial rock types. The more hydrous outer part of the batholith was formed by an influx of water either during magma crystallization or during later regional metamorphism.

The Belchertown Intrusive Complex intrudes rocks as young as the Lower Devonian Erving Formation and truncates structures formed early in the regional metamorphism. However, the similarity in structures of the narrow schistose border zone of the batholith and the metamorphic country rock and the strong deformation of late dikes show that the batholith was present during late stages of deformation and metamorphism. From this and from some tentative radiometric dates on the possibly related Prescott Complex outside the area, the age of the Belchertown Intrusive Complex is placed as Devonian.

The intrusion of the Belchertown Intrusive Complex affected the local geothermal gradient and promoted the metamorphic rocks from the kyanite zone into the sillimanite zone. In the portion of the septum of Partridge Formation closest to the center of the batholith, conditions were temporarily favorable for the crystallization of coarse andalusite, later pseudomorphed by sillimanite. Later, as the temperature fell, the more hydrous rocks of the batholith could have contributed to the retrograde metamorphism exhibited in the adjacent country rocks.

INTRODUCTION

Location

The Belchertown Intrusive Complex is located in west-central Massachusetts about 12 miles southeast of Amherst and southwest of Quabbin Reservoir (Figure 1). The northern portion of the Complex lies mostly within the town limits of Belchertown, but partly in Ware. The northern portion covers an area of approximately 30 square miles and lies within parts of the Winsor Dam, Belchertown, Palmer and Ludlow 7 1/2-minute quadrangles.

Topography and Drainage

The area mapped lies at the eastern margin of the Connecticut River Lowland in the western part of the Central Upland of Massachusetts (Davis, 1895; Alden, 1924). The topography is controlled mainly by the underlying bedrock. Metamorphic rocks in the northern and eastern portions of the area form the higher, more hilly portions, with an average elevation of 650 feet above sea level. The central more subdued area is underlain by intrusive igneous rocks with elevation averaging 450 feet above sea level. In the northwest portion, with an average elevation of 325 feet, the region is underlain by Triassic sedimentary and volcanic rocks. Pleistocene glaciation has modified the topography by erosion and by the deposition of till or ground moraine and glaciofluvial deposits.

Drainage in most of the area mapped is southward into the Chicopee River and ultimately to the Connecticut River. However, in the northwest and west portions of the area, drainage is westward

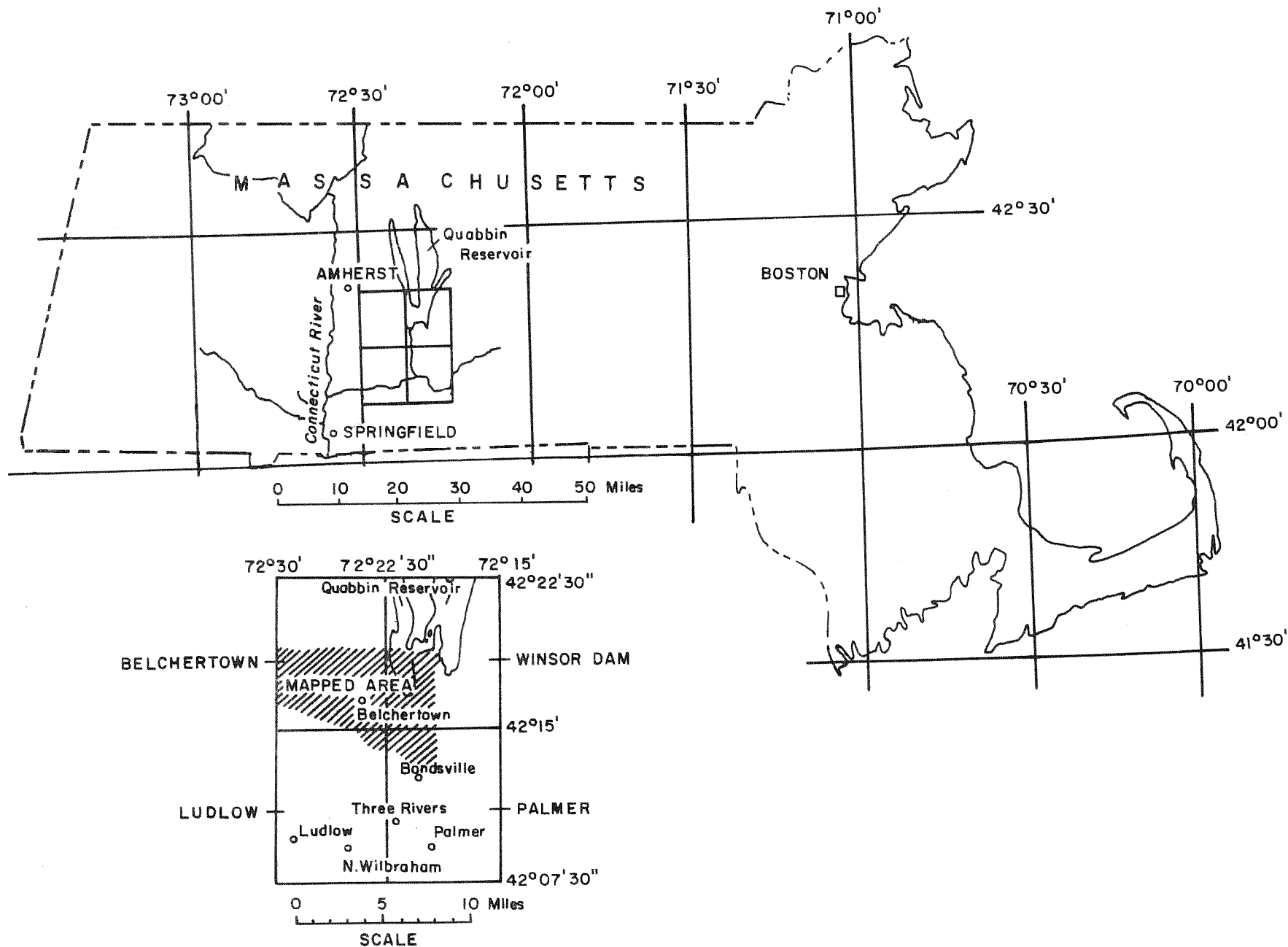


Figure 1. Map of Massachusetts showing location of the Belchertown, Winsor Dam, Ludlow and Palmer Quadrangles. Blow-up shows the area mapped.

and northwestward into the Connecticut River. Pleistocene glaciation has disturbed the drainage in the low-lying areas causing the development of local swamps.

Vegetation and Quaternary Cover

The area is predominantly mixed coniferous and deciduous woodland, much of which is secondary growth on abandoned pastures and farmlands.

The hills in the area are veneered by several inches to many tens of feet of glacial till. The lowlands contain large deposits of outwash sand and gravel, as well as kames, kame terraces and eskers. Most of the outcrops of the area occur at the summits and south-southeast or lee slopes of the hills. Some stream erosion has also exposed bedrock.

Coverage and Methods of Study

Approximately four months, from June to September of 1964, were spent doing field work. Work was concentrated mostly on the intrusive igneous rocks. Geologic mapping was done on a topographic base of portions of the Winsor Dam, Belchertown, Palmer and Ludlow 7 1/2-minute quadrangles at a scale of 1:24,000 (see Figure 1). Location was accomplished by inspection of landmarks and the use of an aneroid altimeter. Where the glacial cover is extensive, contacts between lithologic units were inferred from outcrop distribution, float, and topography.

Thin sections of 85 selected rocks were examined by conventional petrographic methods. Structural data, consisting of attitudes of

foliation, lineation, minor folds, and pegmatite and aplite dikes were plotted and analyzed in order to determine the age relations of tectonic and intrusive events in the area.

In order to gain a better picture of the intrusive rocks in relation to surrounding metamorphic and sedimentary rocks, work done outside of the mapped area by others (Balk, 1940; Bain, 1941; Halpin, 1965; Robinson, 1967b; Peper, 1967) has been included on the geologic map (Figure 2).

Geologic Setting

The Belchertown Intrusive Complex is located in the Bronson Hill anticline of the central metamorphic belt of the New England Appalachians (Billings, 1956: Figure 3). In the general area studied the belt of metamorphic rocks consists of pre-Middle Ordovician rock in the cores of gneiss domes and metamorphosed Middle Ordovician and Devonian sedimentary and volcanic rocks that are tightly folded between the gneiss domes. The main pluton of the Belchertown Intrusive Complex truncates the southern end of the Pelham gneiss dome and intrudes the metamorphosed sedimentary and volcanic rocks that occur in synclines between the Pelham dome, the Glastonbury dome, and the main body of the Monson Gneiss (Figure 3).

Along the western edge of the Central Uplands of Massachusetts lies the Connecticut Valley, a down-faulted block. The Triassic sedimentary and volcanic rocks that underlie the Connecticut Valley are in fault contact with both the metamorphic rocks and the rocks of the Belchertown Intrusive Complex.

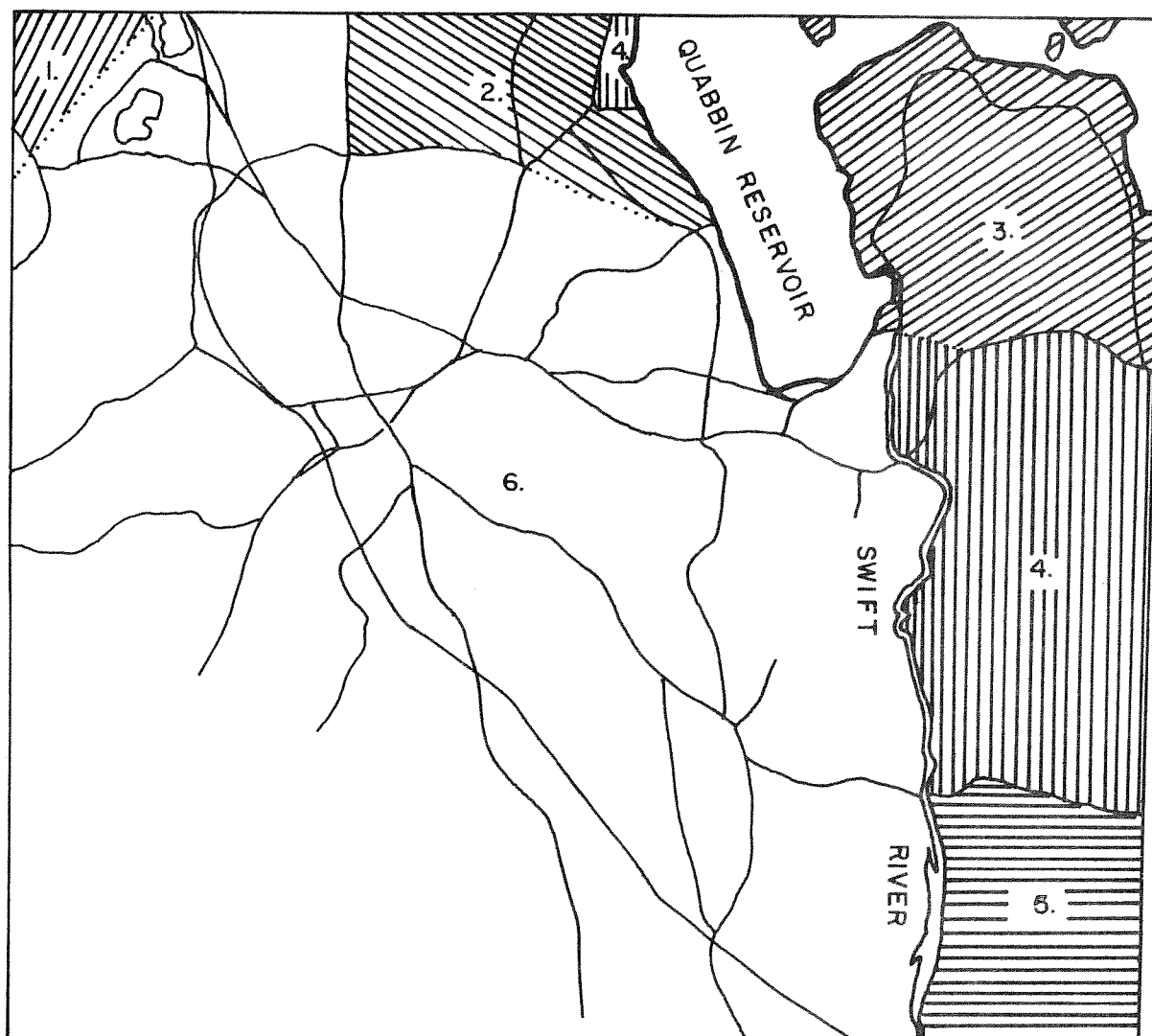


Figure 2. Reference to geologic mapping in the Belchertown area.

- | | |
|---------------------------------|--------------------------|
| 1. Bain, 1941 | 4. Robinson, unpublished |
| 2. Balk, 1940 | 5. Peper, 1967 |
| 3. Halpin, 1965; Robinson, 1967 | 6. This study |

Previous Work

The Belchertown Tonalite was described and named by Emerson (1898, 1917). Emerson (1917) mentions that Edward Hitchcock had briefly described the Belchertown Tonalite as a syenite. It is shown at a scale of 1:250,000 by Emerson (1917).

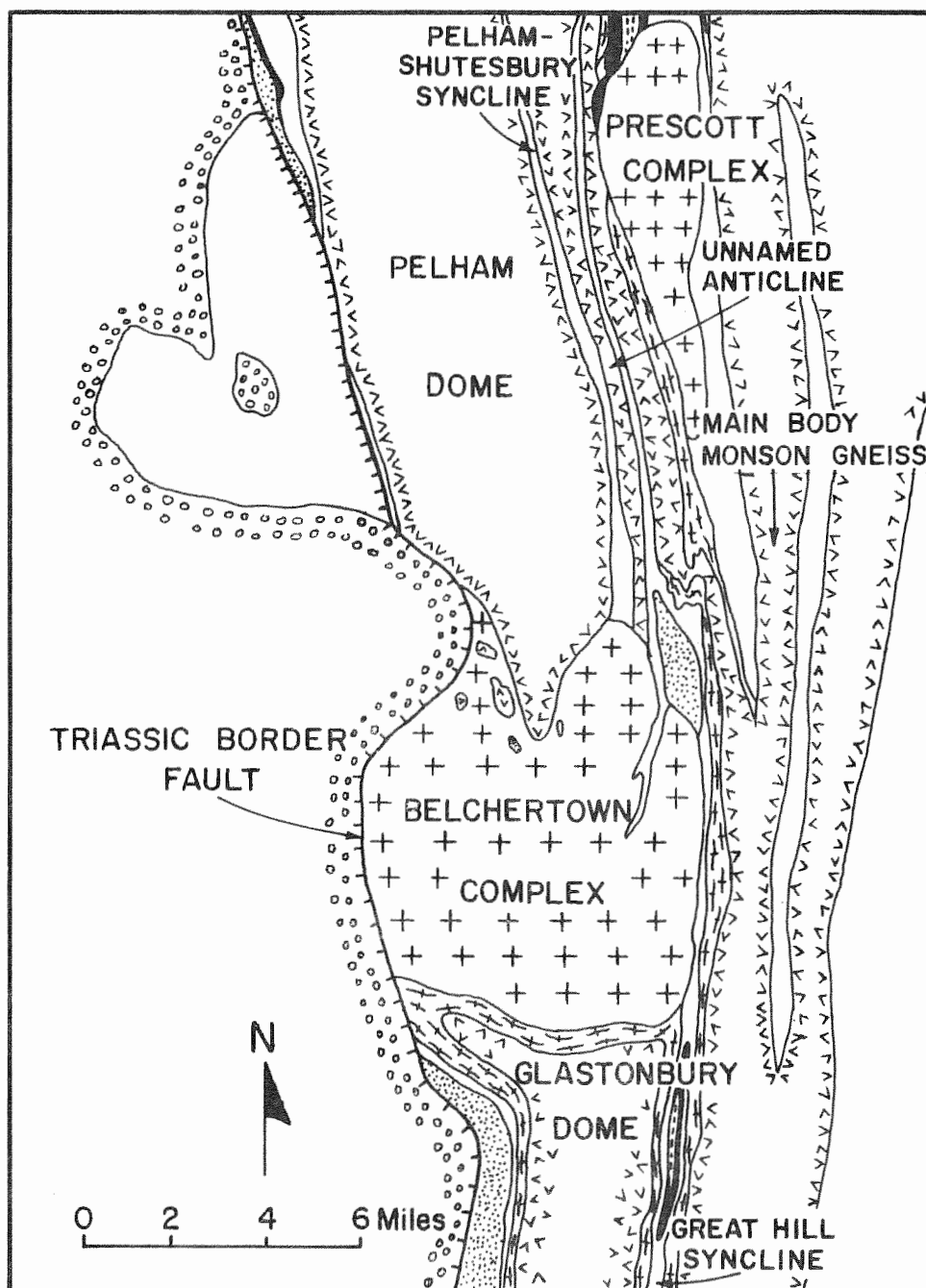


Figure 3. Geologic sketch map showing the regional structural setting of the Belchertown Intrusive Complex.

Triassic		Sedimentary and volcanic rocks.
Devonian?		Belchertown and Prescott intrusive complexes.
Lower Devonian		Erving Formation
		Littleton Formation
Silurian		Clough Formation
Middle Ordovician		Partridge Formation
		Ammonoosic Volcanics
Age Uncertain		Gneisses and related rocks.

During the construction of Quabbin Reservoir, Balk (1940) made a reconnaissance of the geology of the area. His study included a cursory examination of the northern portion of the Belchertown Tonalite.

Percy (1955) indicated that the Belchertown Tonalite is actually a complex, consisting of various rock types. She also suggested that the pluton underwent post-crystallization deformation contemporaneous with the last phases of orogenic movement; i.e., a syntectonic origin.

The areal relationship of more recent regional mapping to the present work is shown in Figure 2.

Purpose of Study

This study of the northern portion of the Belchertown Intrusive Complex has three main objectives: 1) the preparation of a bedrock map of the Complex to show the different lithologies and the contact relations with the surrounding metamorphic rocks, 2) a measurement of the internal structural features of the igneous rocks and study of their relationships to structural features of the intruded metamorphic rocks, and 3) obtaining information of the mineral and chemical composition of the igneous rocks from which implications on their origin can be drawn. It is intended that this study indicate the physical, chronological and tectonic setting of the intrusion in relation to the metamorphic rocks of the area.

Acknowledgements

The study was undertaken as partial fulfillment for a Master's degree in geology under the supervision of Professor Peter Robinson.

Professor Robinson has been most helpful, both in the field and in reviewing and criticizing the writer's ideas and work. Professors G. E. McGill, L. M. Hall, and J. H. Hartshorn were also helpful in critically reviewing this work.

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The writer would also like to acknowledge the help and support given by his wife and family.

METAMORPHIC ROCKS

The oldest rocks exposed in the area are metamorphosed sedimentary and volcanic rocks. They are the Monson and Pelham Gneisses, probably of pre-Middle Ordovician age (Robinson, 1963), Ammonoosuc Volcanics and Partridge Formation (Middle Ordovician), and the Erving Formation (Lower Devonian). These rocks are intruded by the Belchertown Intrusive Complex and are in fault contact with Triassic rocks.

The descriptions for the metamorphic rocks, except for a portion of the Pelham Gneiss, the long inclusion of the Partridge Formation and other metamorphic inclusions of unknown age in the Belchertown Intrusive Complex, are based on the literature (see Figure 2).

Monson Gneiss

The Monson Gneiss, described by Emerson (1898) and later named the Monson Granodiorite (Emerson, 1917), is located along the eastern side of the Belchertown area and is overlain by the Ammonoosuc Volcanics and the Partridge Formation of Middle Ordovician age. The Monson Gneiss consists of medium-to coarse-grained, layered to massive, well foliated quartz-plagioclase gneiss. The main minerals are quartz, oligoclase or andesine, biotite, hornblende, minor microcline, magnetite, ilmenite and, locally, small garnets. Interlayered with the gneiss are amphibolite layers that vary in thickness from less than 1/2 foot to approximately 30 feet. They are fine grained, have a very uniform texture and a well developed layering, and consist predominantly of hornblende and labradorite.

The chief distinguishing characteristic between the Monson Gneiss and the Pelham Gneiss is the composition of feldspars. Microcline, abundant in the Pelham Gneiss, is less important in the Monson Gneiss. The plagioclase in the Monson Gneiss is generally andesine as compared to albite or oligoclase in the Pelham Gneiss.

Pelham Gneiss

The name Pelham Gneiss was first used by Emerson (1917) for the gneisses that form the core of the Pelham dome. It is overlain by the Middle Ordovician Partridge Formation. Balk (1956) has further subdivided the Pelham Gneiss into the Dry Hill Gneiss and the Poplar Mountain Gneiss. The Dry Hill Gneiss consists of a fine- to medium-grained, gray- to yellow-weathering biotite granite gneiss. The Poplar Mountain Gneiss consists of a fine-grained, gray-weathering, quartz-biotite gneiss of sedimentary derivation with porphyroblasts of microcline and interbedded quartzite.

The gneiss mapped in the north-central portion of the Belchertown area is similar to the Dry Hill Gneiss, but it contains interbedded layered amphibolite. Good exposures of the Pelham Gneiss occur east and north of State Highway 9 and on the hill west of Quabbin Reservoir at the north boundary of the area (Plate 2).

The Pelham Gneiss in the Belchertown area is a medium- to coarse-grained, sugary-textured, moderately foliated brown- to gray-weathering gneiss composed of quartz and plagioclase, with lesser amounts of biotite, muscovite and microcline (Table 1). The plagioclase is calcic-oligoclase. The biotite is a dark-to light-olive green. Common accessories are apatite, zircon and magnetite.

Table 1. Estimated modes of Pelham Gneiss and the mineral assemblage of an amphibolite layer.

	Pelham Gneiss		Amphibolite
	B-66	B-72	B-60
Quartz	40	38	
Plagioclase (An %)	31 (26)	48 (24)	X (65)
Microcline	18	6	
Biotite	7	6	
Muscovite	tr	tr	
Hornblende		tr	X
Garnet	tr		
Chlorite		tr	
Epidote	tr		X
Ilmenite	tr	tr	X
Sphene	tr	tr	X
Apatite	tr	tr	X
Zircon	tr	tr	X

tr - trace, these minerals constitute 2 percent of rock.

Hand specimen descriptions and localities for Table 1.

B-66 Granitic gneiss - 2000 feet east of State Highway 9 and 2600 feet north of Allen Street, west of a dirt road in a small quarry.

B-72 Granitic gneiss - Just west of U.S. Route 202, about 800 feet north of where it crosses Allen Street.

B-60 Amphibolite - In road cut on the west side of U. S. Route 202, 2000 feet north of where it crosses State Highway 9.

Minor amounts of hornblende, epidote, garnet and secondary iron-rich chlorite may be present.

The interbedded amphibolite varies in thickness from several inches to 10 feet. The amphibolite consists of layered, fine- to medium-grained hornblende and labradorite (An_{65}) with minor epidote, sphene, ilmenite, zircon, apatite (Table 1), and, locally, quartz, biotite, garnet and chlorite (Balk, 1940). The hornblende crystals are usually oriented parallel to the layering.

Ammonoosuc Volcanics

The term Ammonoosuc Volcanics was used by Billings (1937) for a group of metamorphosed volcanic rocks exposed in the Littleton quadrangle, New Hampshire, and extending southward into southern New Hampshire. This unit has been traced from New Hampshire southward into central Massachusetts by Robinson (1963). The Ammonoosuc Volcanics are stratigraphically above the Monson Gneiss and below the Middle Ordovician Partridge Formation. Exposures of the Ammonoosuc Volcanics were found along the eastern edge of the Belchertown area and on the east and north sides of Quabbin Hill. In the general area of Quabbin Hill mapped by Halpin (1965) and Robinson (1967b), there are four distinct units of the Ammonoosuc Volcanics not shown separately on Plate 1. These units are (1) mafic lower unit of anthophyllite and hornblende amphibolite, (2) felsic upper unit of quartz-feldspar gneiss, (3) local unit of hornblende-chlorite schist, and (4) uppermost quartz-albite-muscovite schist.

Partridge Formation

The Partridge Formation was named by Billings (1937) for rocks in the vicinity of Partridge Lake, Littleton Township, New Hampshire, and has been traced discontinuously southward into Massachusetts from the type locality (Billings, 1956; Robinson, 1963).

In the Belchertown area the Partridge Formation forms three belts of rocks in narrow synclines between the Pelham dome and Monson Gneiss (Figure 3; Robinson, 1967b). The eastern belt is exposed in the vicinity of Quabbin Hill and along the eastern side of the area mapped by the writer. It consists of sulfidic mica schist with interbedded amphibolite. The Partridge Formation, in this eastern belt, lies above the Middle Ordovician Ammonoosuc Volcanics and below the Early Devonian Erving Formation. The middle belt of the Partridge Formation is exposed in the area as an elongated inclusion in the Belchertown Intrusive Complex. It consists primarily of sillimanite-garnet-mica schist and gneiss. The western belt overlies the pre-Middle Ordovician Pelham Gneiss and is cut by the intrusive complex. It consists principally of sulfidic mica schist with interbedded amphibolite.

The sulfidic schist of the eastern belt is a well foliated rock and generally exhibits a characteristic rusty-weathering color. The common minerals are quartz, albite, muscovite, red-brown biotite, garnet, optically positive and negative chlorite of retrograde origin, and minor amounts of tourmaline, apatite and staurolite (Halpin, 1965). The sulfidic mica schist of the western belt is similar, except for the retrograde chlorite, and contains kyanite (Robinson, 1967b).

From Winsor Dam southward the middle belt of Partridge Formation extends into the batholith of the Belchertown Intrusive Complex as a long thin inclusion or septum (Figure 3; Plate 1). This mass, referred to as a septum to differentiate it from the other inclusions, is 3.3 miles long and varies in width from 400 feet at the north end to over 1000 feet near the middle. The septum splits into a western prong and an eastern prong 1.65 miles from its north end. The western prong extends only 0.5 miles farther south, while the eastern prong extends 1.6 miles farther.

The Partridge Formation that forms the septum exhibits both a mineralogical and textural change as it extends into the Belchertown batholith. Near the northern edge of the batholith, just at the southwest end of the Winsor Dam (Figure 3; Plate 1), the rock is well foliated schist (B-20, Table 2) containing kyanite, sillimanite, staurolite, garnet, quartz, plagioclase, biotite, and muscovite. The sillimanite occurs as acicular mats about the kyanite and as swirling patches throughout the thin section (Figure 4). Farther south, into the batholith, the texture of the Partridge Formation becomes more gneissic and coarser grained. The sillimanite occurs as large, prismatic crystals over an inch in length (Figure 5). A sample (B-100, Table 2) from the southern portion of the septum contains sillimanite, garnet, biotite, quartz, plagioclase, and secondary sericite and chlorite. Primary muscovite seems to be lacking.

Within the septum kyanite occurs only in the northern 0.4 mile. Staurolite occurs only locally and appears to be restricted to the northern half of the septum. The sillimanite exhibits the greatest

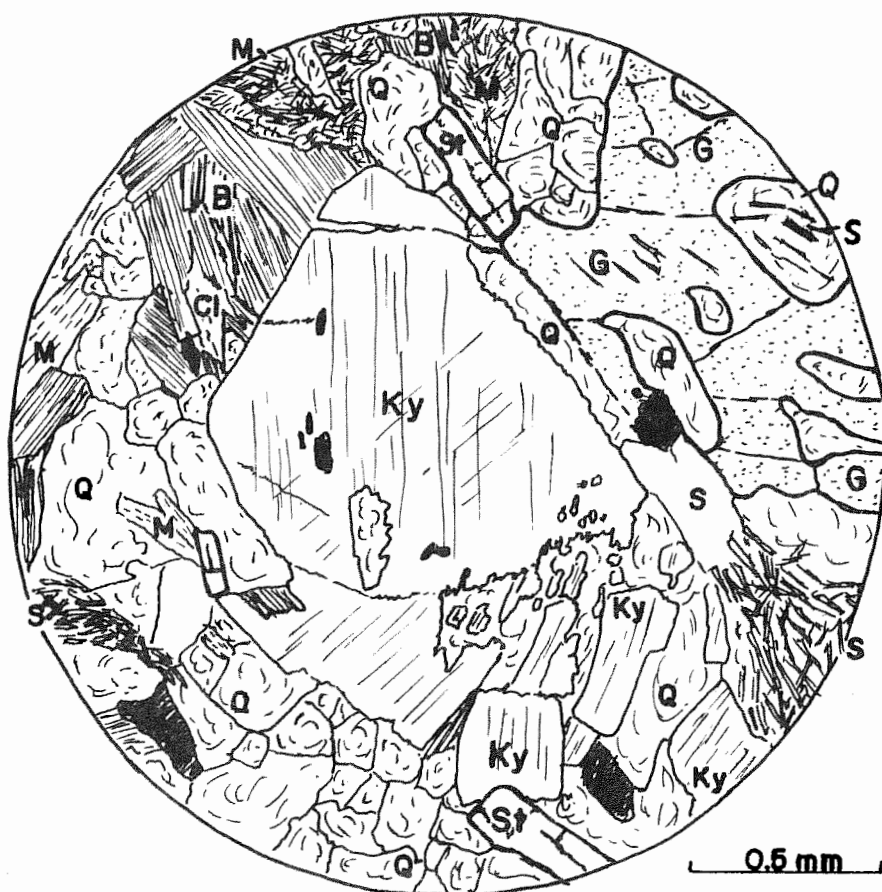


Figure 4. Beginning replacement of the original kyanite by sillimanite, specimen B-20, from the northern end of the Partridge schist septum. Ky - kyanite; S - sillimanite; St - staurolite; G - garnet; B - biotite; Q - quartz; Cl - chlorite; M - muscovite.

change in grain size. In the northern portions of the septum sillimanite occurs as acicular crystals generally in swirling mats.

Farther south the sillimanite becomes coarser until the crystals form grains over an inch in length that have the segmented habit believed to be characteristic of pseudomorphs of andalusite (Rosenfeld, 1969).

Table 2. Mineral assemblages and estimated modes of selected samples of the Partridge schist septum. Samples listed in order from north (left) to south (right).

	B-20	B-19	B-94c	B-94d	B-94e	B-26	B-29	B-24	B-40	B-44	B-42	B-96	B-98	B-99	B-100
Quartz	51	37	X	X	X	X	X	57	X	45	X	X	X	X	50
Plagioclase		1	X	X	X	X	X		X		X	X	X	X	
Muscovite	5	40	X	X	X	X	X	tr	X	10	X	X	X		tr
Biotite	12	tr	X	X	X	X	X	tr	X	5	X	X	X	X	5
Garnet	16	6	X	X	X	X	X	10	X	10	X	X	X	X	10
Chlorite			X	X	X	X	X	2	X	10	X		X	X	10
Kyanite	3														
Sillimanite	7		X		X	X	X	3	X	5	X	X	X	X	10
Staurolite	2					X			X						
Pyrrhotite	tr	tr	X	X	X	X	X	tr	X	tr	X	X	X	X	tr
Graphite	tr	tr	X	X	X	X	X	tr	X	tr	X	X	X	X	tr
Rutile						X	X		X	tr					tr
Hematite(weathering prod.)					X										
Allanite			X	X				tr	X						
Apatite			X		X	X	X	tr	X	tr		X	X		
Zircon	tr	tr	X	X	X	X	X	tr	X	tr	X	X	X	X	tr
Tourmaline		tr						tr							
Sericite	tr		X	X	X	X	X	tr	X	15	X	X	X	X	15

X - present but amount not estimated. tr - trace.

Hand specimen descriptions and localities from Table 2.

B-20 Kyanite-sillimanite-garnet-staurolite mica schist. At the southwest tip of Quabbin Reservoir, 600 feet south of the southwest end of Winsor Dam and 800 feet east of the administration building, at the 630-foot contour.

B-19 Garnet-mica schist. Same area as B-20, but 1000 feet south of the southwest end of Winsor Dam, at the 610-foot contour.

B-94 Series of samples taken from a road cut on State Highway 9, approximately 2400 feet east of the Quabbin Reservoir entrance road turn off, of the Partridge Formation. The samples begin on the east side of the septum and go westward. Stations are about 10 feet apart.

c) Sillimanite-garnet mica schist.

d) Garnet mica schist.

e) Sillimanite-garnet mica schist.

B-26 Sillimanite-staurolite-garnet mica schist. At the crest of the ridge, about 2500 feet south of State Highway 9, at the 610-foot contour.

B-29 Sillimanite-garnet mica schist. On the ridge, just west of the crest, 1600 feet south of B-26 location, at the 710-foot contour.

B-24 Sillimanite-staurolite-garnet mica schist. On the eastern slope of the ridge, 4300 feet north-northeast of the intersection of Cold Spring Road and Michael Sears Road, at the 680-foot contour.

B-40 Sillimanite-staurolite-garnet mica schist. On the east slope of the large hill formed in part by the West Fork of the septum, 3700 feet north of Cold Spring Road, at the 750-foot contour.

B-44 Sillimanite-garnet mica schist. On ridge formed by the eastern fork of the septum, 2000 feet north of Cold Spring Road, at the 510-foot contour.

B-42 Sillimanite-garnet mica schist. In the same area as B-44, only 600 feet farther south along the ridge, at the 550-foot contour.

B-96 Sillimanite-garnet mica schist. At the southern tip of the large hill formed in part by the western fork of the septum, about 375 feet north of Cold Spring Road, at the 680-foot contour.

B-98 Sillimanite-garnet mica schist. Just north 200 feet of Cold Spring Road, 400 feet east of Cold Spring at the 530-foot contour.

B-99 Sillimanite-garnet mica schist. Along the east side of Michael Sears Road, about 2900 feet south of Cold Spring Road, at the 580-foot contour.

B-100 Sillimanite-garnet mica schist. About 200 feet south of B-99, at the 550-foot contour.

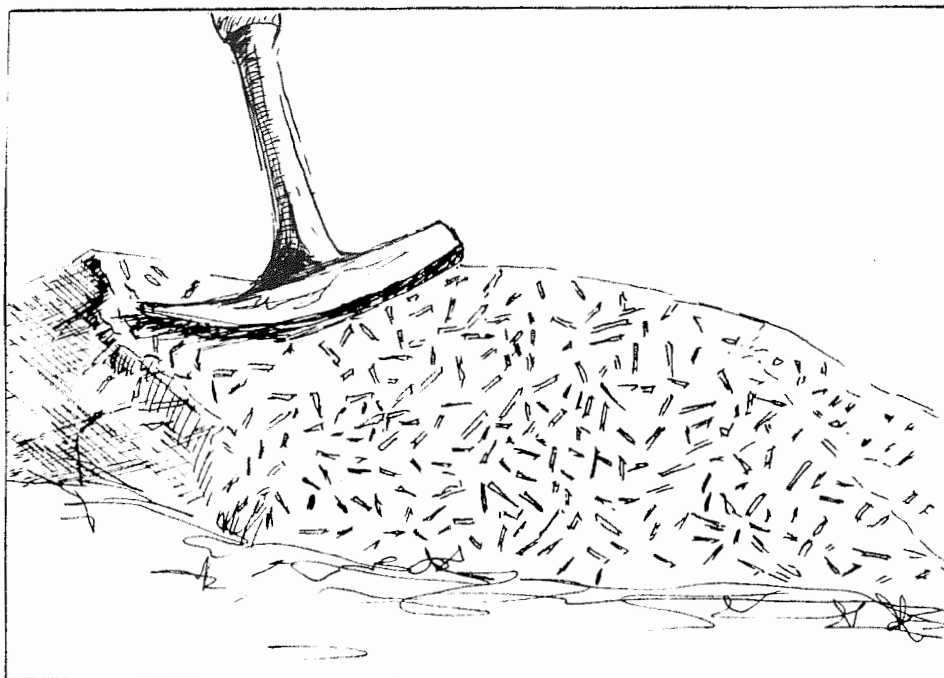


Figure 5. Sketch of the coarse sillimanite schist from the southern portion of the Partridge schist septum. The sillimanite crystals are over an inch long. Located at sample station B-100, Plate 2.

The biotite occurs as red-brown, irregular flakes. It varies in abundance from trace to about 15 percent of the rock (Table 2) depending on the amount of chlorite replacement of the biotite.

A fine-grained, mosaic-textured groundmass of quartz and plagioclase makes up 35 to 55 percent of the rocks. The plagioclase, determined as andesine by optic sign and relief, forms less than 5 percent of the groundmass.

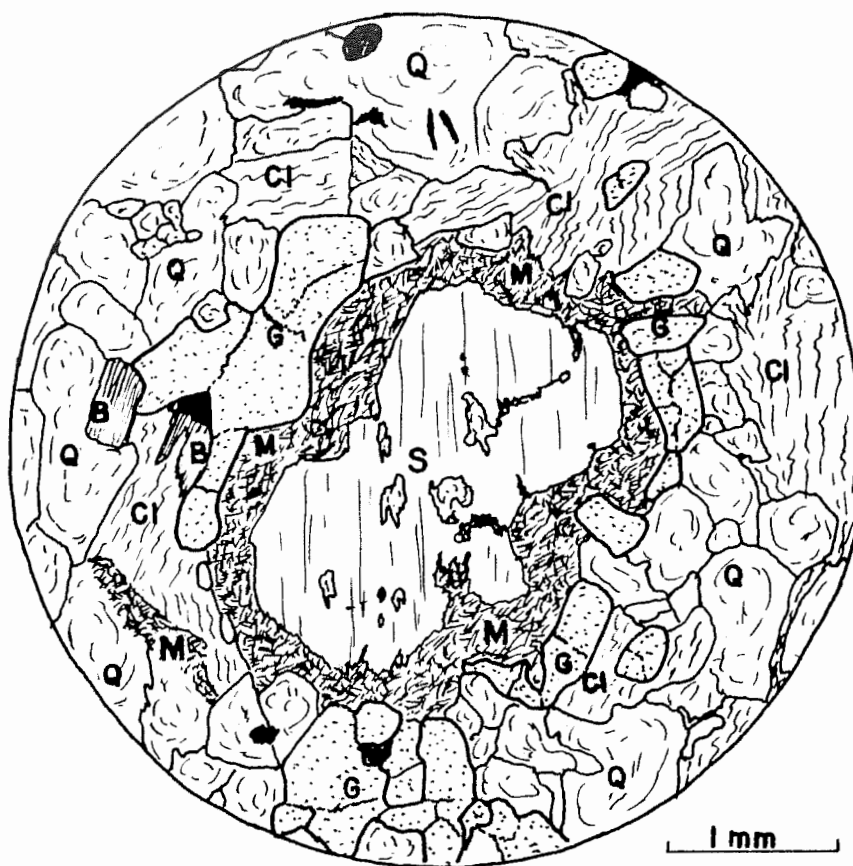


Figure 6. Coarse sillimanite, specimen B-44, developed in the southern portion of the Partridge schist septum. S - sillimanite; G - garnet; Q - quartz; B - biotite; M - muscovite; Cl - chlorite.

Muscovite appears to be of two generations. The coarser flakes are probably primary, while the finer flakes, called "sericite," are secondary. Sericite becomes more abundant and primary muscovite becomes less abundant as the septum is followed southward. Retrograde metamorphism has generally replaced the sillimanite with sericite, either completely as in the case of the finer grains, or

partially, as with the coarser crystals (Figure 6). The sillimanite in some of the samples (B-94c, 94e, 26, 29 and 24, Table 2) taken from the northern portion of the septum has survived replacement only as inclusions in the garnets.

Chlorite occurs throughout the schist in minor to major amounts. It is optically positive, negative or isotropic, and in some cases all three optical types occur within the same specimen. Chlorite forms after biotite and less commonly after garnet and staurolite. Secondary chlorite and sericite due to retrograde metamorphism appear to increase to the south in the septum.

Interbedded in the Partridge Formation at the east end of the road cut on State Highway 9, is a fine-grained, poorly foliated, green-weathering amphibolite. It consists of hornblende, biotite, andesine, secondary optically negative chlorite, and accessory sphene, zircon, magnetite, apatite, allanite and epidote.

Erving Formation

The youngest metamorphic unit in the Belchertown area is the Lower Devonian Erving Formation. It overlies the Middle Ordovician Partridge Formation and forms the core of a syncline that is plunging gently northward. In the Quabbin Hill area Halpin (1965) and Robinson (1967b) divided the Erving into a unit of hornblende-epidote amphibolite and a unit of quartz-plagioclase-biotite granulite with interbedded mica schist, coticule, calc-silicate rock, and marble. These two units are shown separately on Plate 1.

The amphibolite unit is fine- to coarse-grained, well foliated to laminated, black-weathering rock consisting of hornblende, andesine

and epidote with traces of sphene and calcite. The coarse-grained amphibolite has large, unoriented hornblende crystals in a plagioclase matrix, while the finer grained amphibolite is laminated with strongly oriented hornblende crystals.

The granulite consists of a well bedded, fine-grained, light gray weathering rock composed of quartz, brown biotite, oligoclase, clinozoisite and traces of secondary optically negative chlorite. Granulite beds range in thickness from a quarter of an inch to 1 1/2 feet. Interbedded with the granulite are layers of muscovite-biotite schist, actinolite-garnet-clinozoisite calc-silicate, and thin cotecule beds.

INCLUSIONS OF METAMORPHIC ROCKS IN THE BELCHERTOWN COMPLEX

Within and along the edge of the Belchertown Batholith are several large blocks or inclusions of metamorphic rocks. These inclusions, measuring from several thousand feet to less than one thousand feet across, were mapped northwest, west, southwest and southeast of Belchertown Center.

Of the six inclusions mapped, only two could be correlated with any of the known metamorphic formations in the Belchertown area. Of the four remaining inclusions of unknown correlation three are amphibolite and one is granulite (Plate 1).

Inclusions of Known Correlation

Granulite of the Erving Formation. An outcrop of folded, interbedded granulite and biotite schist, with some calc-silicate beds, about 10 by 30 feet, is located in the woods about 400 feet north of

Springfield Road, 900 feet west of the point where it crosses the Central Vermont Railroad (Plate 1). This rock was identified as being the granulite of the Erving Formation (Robinson, personal communication). The extent of this inclusion is unknown because of glacial cover, but it appears to be surrounded by the granodiorite phase of the Belchertown batholith (Plates 1 and 2).

Partridge Formation. An outcrop of rusty weathering schist with interbedded calc-silicate beds is exposed on the north side of the Mill Valley Road just west of South Cemetery, about a mile east of Belchertown Center (Plate 1). These rocks were identified as belonging to the Partridge Formation (Robinson, personal communication). The shape and the size of the inclusion are inferred because of poor exposure. The schist is in contact with hornblendite on the western side of the inclusion, while elsewhere it appears to be in contact with the quartz diorite phase of the Belchertown batholith.

Inclusions of Unknown Correlation

In the following section, because three of the four inclusions are amphibolite, they have been numbered to facilitate the discussions. The mineral assemblages for each of the inclusions are presented in Table 3.

A₁ amphibolite. Amphibolite outcrops in the area between the Central Vermont Railroad and State Highway 9, north of Hannum Road and south of Bay Road, specifically along the railroad and on the east side near the top of Hill 568 (Plate 1). The amphibolite, although not well exposed, appears to be bordered on the west by the quartz diorite, on the north by intrusive breccia and on the southern and

eastern sides by hornblendite. The amphibolite may be related to the Pelham Gneiss, but because of the similarities of all amphibolites of the area, regardless of age, this correlation is very uncertain.

The outcrops along the railroad are highly altered, well foliated, gray-weathering, bedded amphibolite. Chlorite and calcite are quite conspicuous in hand specimen. Transecting one of the outcrops is a silicified fault zone. Numerous veins of vuggy quartz and pink feldspar crisscross the outcrops. All of these secondary features are probably of Triassic age.

On Hill 568, east of the railroad, the exposed rock is coarse- to medium-grained, brownish-weathering, foliated and bedded amphibolite. A thin section (Sample B-74b, Table 3) contains hornblende, actinolite, albite, allanite, epidote, zircon, apatite, sphene and calcite. The actinolite is replacing the hornblende and is crystallographically continuous with the hornblende (Figure 7). This replacement and the presence of secondary epidote rimming the allanite (Figure 7) and albitic plagioclase suggest retrograde metamorphism. The retrograde metamorphism and conspicuous alteration which this inclusion has undergone are probably related to its proximity to the Triassic border fault (Plate 1).

A₂ amphibolite. The drumlin-like hill on which the town of Belchertown is built appears to be underlain by amphibolite. Exposures are very poor, but all outcrops found consist of amphibolite (Plate 2). The float found on the ground and in the fences is also predominantly amphibolite. The eastern, south and southwest portions of this amphibolite appear to be in contact with quartz diorite. Along the western

Table 3. Mineral assemblages for selected samples from the large metamorphic inclusions of unknown correlation.

	A ₁	A ₂		A ₃	Granulite		
	B-74b	B-65	B-25	B-61	B-87	B-81	B-79
Quartz		X	X		X		X
Plagioclase (An %)	X (Ab)	X (60)	X (78)	X (38)	X (40)	X (49)	X (38)
Muscovite					X		
Biotite		X			X		X
Garnet			X		X		X
Staurolite					X		
Chlorite (Opt.Sign)		X (-)		X (-)	X (±)		X (-)
Hornblende	X	X	X	X		X	
Actinolite	X						
Epidote	X		X	X		X	
Calcite	X						
Rutile		X					
Ilmenite		X	X		X		X
Sphene	X			X	X	X	
Hematite						X	
Apatite	X	X		X			X
Zircon	X				X		X
Allanite	X	X					

Hand specimen descriptions and localities for Table 3.

B-74b Bedded amphibolite. Northeast of the crest of the hill 1200 feet east of the Central Vermont Railroad and 2100 feet due south of the Bay Road and Hamilton Street intersection, at the 740-foot contour.

B-66 Bedded amphibolite. In a pipeline ditch about 400 feet east of U. S. Route 202, 1/2 mile north of the center of Belchertown, at the 550-foot contour.

B-25 Amphibolite. On the west side of State Street, about 150 feet southwest of its intersection with Jenson Street, at the 540-foot contour.

B-61 Amphibolite. 75 feet north of Hannum Street, about 1000 feet west of the Belchertown Sewage Disposal Plant, at the 450-foot contour.

B-87 Interbedded granulite and biotite-garnet schist. West-northwest of the Belchertown State School, about 1000 feet southwest of Jackson Street, at the 450-foot contour.

B-81 Amphibolite. Northeast 400 feet from the intersection of Jackson Street and the Central Vermont Railroad, at the 510-foot contour.

B-79 Granulite. Northeast of Jackson Street, about 500 feet west from where it crosses the Central Vermont Railroad, at the 450-foot contour.

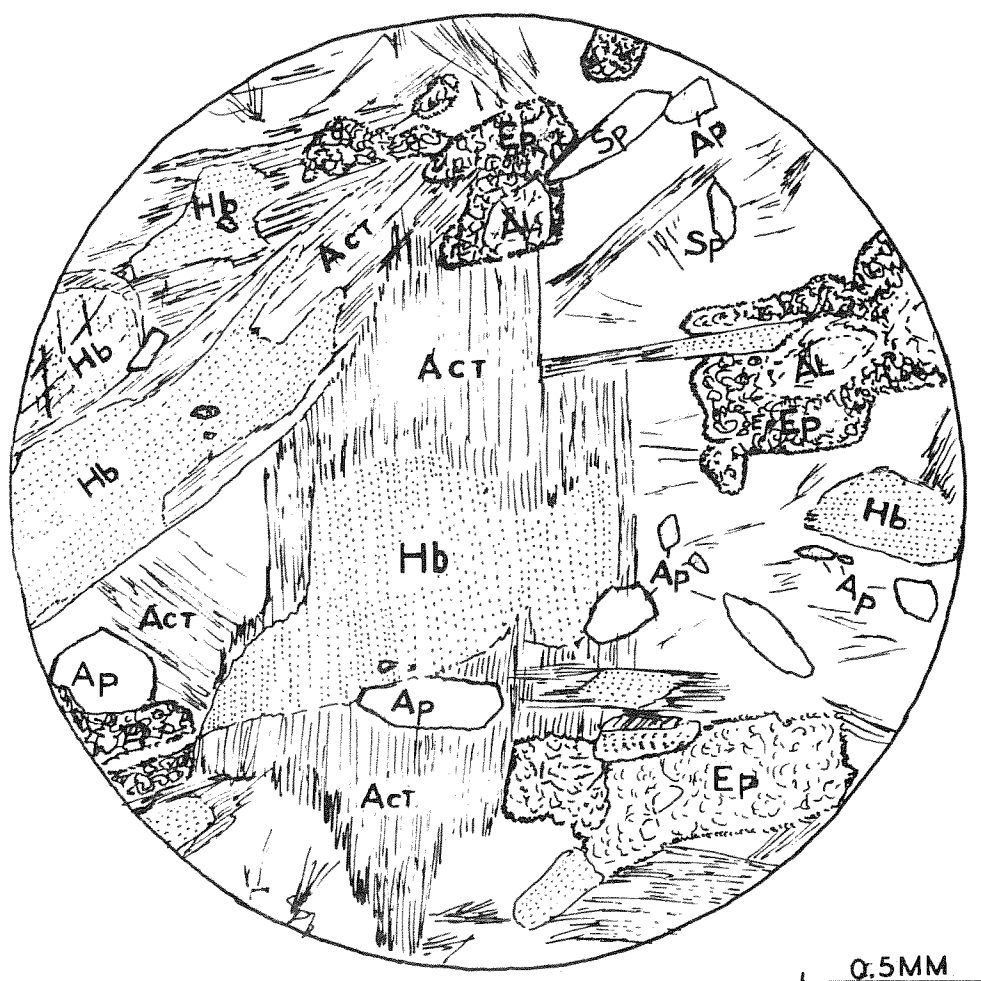


Figure 7. Retrograde alteration in an amphibolite, specimen B-74b. Hornblende is being replaced by actinolite; epidote and albite are also common secondary minerals. Hb - hornblende; Act - actinolite; Al - allanite; Ep - epidote; Ap - apatite; clear area albitic plagioclase.

side it appears to be an intrusive breccia, while the northern portion may be in contact with the Pelham Gneiss. The amphibolite may be related to the Pelham Gneiss; however, there are not enough data to be sure of this correlation.

Located just southeast of Belchertown Center on State Highway 21 is an outcrop of medium- to fine-grained amphibolite. In hand specimen the amphibolite contains conspicuous hornblende, large

garnets (up to 3/4 inch) and lenses and pods of epidote. A thin section (B-25, Table 3) contains hornblende, garnet, epidote, zoned bytownite (An_{78}), quartz and ilmenite.

To the northwest of Belchertown Center, about 1/2 mile east of State Highway 202, an outcrop of amphibolite was found in a ditch being dug for a pipeline. In hand specimen the rock is a well bedded, fine-grained amphibolite. Hornblende, plagioclase and garnet are conspicuous. Interlayered with the beds of amphibolite are very thin beds of biotite schist. A thin section (B-65, Table 3) contains hornblende, brown biotite, epidote with some allanite centers, zoned labradorite (An_{60}), quartz, secondary optically negative chlorite, ilmenite and apatite. Several other outcrops quite similar in appearance to those described above occur north, northeast and southwest of Belchertown Center (Plate 2).

A₃ amphibolite. North of Hannum Road, about 1200 feet west of the Belchertown Sewage Disposal Plant, is a small outcrop of amphibolite (Plate 1). The amphibolite is in contact with or grades into a body of diopside-bearing hornblendite, except in the northern portion where it may be in contact with granodiorite.

The outcrop is a massive to bedded fine-grained, brown-weathering amphibolite that has suffered extensive post-metamorphic fracturing, alteration and silicification, presumably due to the proximity of the Triassic border fault. A thin section (B-61, Table 3) contains hornblende, zoned andesine (An_{38}), epidote, secondary optically negative to isotropic chlorite, sphene and apatite.

Granulite. Outcrops of granulite and amphibolite are located south of Hannum Road and about 0.5 mile west of Belchertown (Plate 1). They are surrounded by quartz diorite along the western and southern portions. Along the north side they appear to be in contact with hornblendite and to the east with intrusive breccia. This granulite and amphibolite may be part of the Erving Formation, but because of the difference in appearance from granulite of the Erving Formation, the correlation is uncertain.

A large outcrop of granulite is located just northwest of the intersection of Jackson Street and the Central Vermont Railroad (Plate 1). The rocks are fine grained, foliated, lineated and weather brown. Interbedded with the granulite are a few thin beds of biotite schist. A thin section (B-79, Table 3) contains brown biotite, quartz, andesine (An_{38}), garnet, secondary optically negative chlorite, zircon, ilmenite and apatite.

On the hill just east of the granulite outcrop, in a railroad cut, are several exposures of amphibolite. In hand specimen the amphibolite is a bedded, fine-grained, greenish-brown-weathering rock with pods and layers of epidote. In thin section (B-81, Table 3) the rock consists of hornblende, epidote, andesine (An_{49}), sphene and ilmenite. The hornblende-epidote amphibolite appears to be interbedded with the granulite.

On the southwest side of Jackson Street northwest of the Belchertown State School there is a small outcrop of folded granulite and interbedded biotite schist. The outcrop is transected by numerous quartz, pegmatite and aplite dikes. This outcrop is probably related to the outcrops near the railroad but more closely resembles the

Erving Formation. A thin section (B87, Table 3) contains brown biotite, garnet, andesine (An_{40}), quartz, muscovite, staurolite, secondary optically positive and negative chlorite, zircon, sphene and ilmenite.

INTRUSIVE IGNEOUS ROCKS

Intruding the metamorphic rocks of the Belchertown area, south and southwest of Quabbin Reservoir, is a batholith of quartz diorite and granodiorite. This batholith, approximately 64 square miles in size, was named the Belchertown Tonalite by B. K. Emerson (1898). The writer has renamed it the Belchertown Intrusive Complex because the intrusive rocks of the batholith and surrounding regions exhibit wide petrographic, textural and structural variations.

The Belchertown Intrusive Complex is subdivided into five general units. These units, in probable order of age from oldest to youngest, are: 1) ultramafic bodies, 2) intrusive breccia, 3) the main batholith, 4) subsidiary stocks, and 5) marginal and peripheral aplite and pegmatite dikes. The small ultramafic intrusive masses, principally of hornblendite and diopside-bearing hornblendite, are generally associated with the metamorphic rocks and are located at the edges or outer portions of the batholith (Plate 1). The intrusive breccia consists of small to large, angular to rounded fragments of amphibolite, schist, granulite, and hornblendite in a diorite matrix, and occurs along the northern edge of the batholith. The batholith consists of zonally arranged quartz diorite to granodiorite. The outer margin is biotite-hornblende quartz diorite. This grades inward into hornblende-biotite granodiorite, and then

hornblende-biotite-augite granodiorite in the inner portion of the batholith. The subsidiary stocks consist of biotite-quartz diorite and minor hybrid rocks intruding the metamorphic rocks northeast of the batholith near Quabbin Hill. The dikes of aplite and pegmatite, of several types and age relations, formed last and fill fractures in the intrusive rocks and peripheral country rocks.

Ultramafic Rocks

Several small intrusive bodies and inclusions of ultramafic rocks were mapped in the Belchertown area. These ultramafic rocks, consisting of hornblendite; diopside hornblendite; and hornblende, hornblende-biotite, diopside-hornblende meladiorites, are probably the basic forerunners of the main intrusion of quartz diorite-granodiorite of the Belchertown Intrusive Complex. Exposures of the ultramafic rocks occur along the north and northwest borders of the main intrusive body (Plate 1) and belong to discrete bodies, generally adjacent to metamorphic country rocks. They also occur as fragments in the intrusive breccia and as xenoliths in the quartz diorite and granodiorite. Because of their variable composition and occurrence, the outcrops are described individually. The rocks are classified according to Johannsen's classification (1939).

Individual outcrops. Near the southernmost tip of Quabbin Reservoir there is an outcrop of hornblende meladiorite. The rock is massive, medium grained, and weathers greenish black (Plate 2). The outcrop is crisscrossed and brecciated by dikes of diorite and pegmatite (Figure 17). The meladiorite consists primarily of hornblende and andesine (An_{32}), with minor amounts of biotite, quartz, sphene,

apatite and zeolite (B-3, Table 4). The zeolite is almost certainly secondary and probably of Triassic age. To the west of the above meladiorite, 1600 feet north of State Highway 9 and 1 1/2 miles east of Belchertown, several outcrops of moderately foliated, medium-grained, dark green, greenish-black weathering, hornblendite-biotite meladiorite were observed (Plate 2; B-69, Table 4). Several large pegmatite dikes transect the meladiorite.

On the western edge of the small inclusion of Partridge schist, north of Mill Valley Road, west of South Cemetery, about 1 1/2 miles east of Belchertown, is a small body of hornblendite (Plate 2). The rock is dark green, massive, coarse grained (hornblende crystals over 1/4 inch in length), weathers to a greenish-black color and consists of 97 percent hornblende (B-16, Table 4). Four hundred feet north is an outcrop of the same rock that is brecciated and has a matrix of quartz diorite (B-57, Table 4).

In the northwest portion of the map area, lying between the Central Vermont Railroad and State Highway 9, is a large body of hornblendite (Plate 2). The rock is dark green, massive, medium grained, weathers greenish black and consists mostly of hornblende (B-15, Table 4). An outcrop of brecciated hornblendite, possibly related to this large body, occurs on the Central Vermont Railroad 750 south of the intersection with Hamilton Street (Plate 2; B-11, Table 4).

A body of ultramafic rocks, composed of hornblendite and diopside hornblendite, was mapped south of Hannum Street, 1000 feet west of the Belchertown Sewage Disposal Plant (Plate 2). The hornblendite

Table 4. Point-counted modes for ultramafic rocks.

	B-3	B-69	B-16	B-57	B-15	B-11	B-62	B-63	B-92	B-67	B-110
Quartz	2.4	0.2		0.2							
Plagioclase (An %)	15.3 (32)	16.5 (36)	tr	22.3 (33)	1.0	9.5 (41)	0.9 (35)	0.2	tr	9.6 (31)	18.4 (39)
Microcline		0.3									
Hornblende	78.5	50.4	96.6	66.8	92.0	87.0	98.8	55.0	74.6	59.0	64.8
Diopside								41.9	23.4	25.4	
Biotite	1.6	25.8	0.2	0.7	0.6			1.5	tr	0.2	0.5
Chlorite		tr	0.5	0.8	tr	0.5		tr		0.5	13.6
Epidote		2.2	0.9	3.0	2.6	0.5		0.2		1.9	
Allanite	tr	tr			tr			0.2	0.4		6.1
Calcite					1.3						
Rutile		tr			0.1	tr					
Sphene	1.0	2.5	0.3	1.3	1.0	1.9	0.3	0.8	0.5	3.1	1.8
Magnetite	tr		0.6	0.6	0.6		tr	0.1	tr		
Apatite	1.2	1.9	0.8	3.5	0.7	0.7		0.1	1.0	0.4	0.8
Zircon	tr	0.2	0.1	0.7			tr	tr	0.1		0.1
Zeolite	tr										
Total	100.0	100.0	100.0	99.9	99.9	100.1	100.0	100.0	100.0	100.1	100.1

Hand specimen descriptions and localities for Table 4.

B-3 Hornblende meladiorite. At the top of a small knoll at the southernmost tip of Quabbin Reservoir, just southwest of the intersection of the Quabbin Reservoir entrance road and the residential side road, about 500 feet north of State Highway 9, at the 560-foot contour.

B-69 Hornblende-biotite meladiorite. On the west-southwest slope, just below the crest of the eastern peak, of the hill north 1600 feet of State Highway 9, 1 1/2 miles east of Belchertown, at the 680-foot contour.

B-16 Hornblendite. North off Mill Valley Road, 0.9 miles east of Belchertown, on the western side of the South Cemetery (associated with the small Partridge Schist inclusion), at the 460-foot contour.

B-57 Brecciated hornblendite. The same as for B-16, only 400 feet farther north, at the 480-foot contour.

B-15 Hornblendite. South-southeast 150 feet of Hannum Road in a small stream, 425 feet east-northeast of the Central Vermont Railroad underpass, at the 460-foot contour.

B-11 Hornblende meladiorite (breccia fragment). Just east of the Central Vermont Railroad, 750 feet south of where the railroad and Hamilton Street intersect, at the 385-foot contour.

B-62 Hornblendite. Approximately 600 feet south of Hannum Street, 1000 feet west of the Belchertown Sewage Disposal plant, at the 390-foot contour.

B-63 Diopside-hornblendite. 1225 feet south of B-62, on the southwest slope of hill, at the 480-foot contour.

B-92 Diopside hornblendite. The same as B-62.

B-67 Diopside-hornblende meladiorite. Sample location is an outcrop of intrusive breccia alongside Allen Street, 150 feet west of State Highway 9, at the 460-foot contour.

B-110 Hornblende-chlorite meladiorite. Sample location is an outcrop of augite-hornblende-biotite granodiorite containing inclusions of ultramafic rocks, north on State Highway 21, west 500 feet of its junction with Springfield Road, at the 470-foot contour.

(B-62, Table 4) is dark green, massive, medium grained, weathers dark greenish-black and consists of 98.8 percent hornblende. The diopside hornblendite (B-63, B-92, Table 4) also has a massive, medium-grained texture, but its color and weathering features differ from the hornblendite. On a fresh surface it appears light green with dark-green to black blebs in it. On the weathered surface the dark grains stand out, giving the rock a knobby appearance. The light green is diopside; the dark green is hornblende. The diopside is intergrown with and surrounded by hornblende (Figure 8).

Throughout the intrusive rocks of the batholith and in the bordering intrusive breccia are xenoliths and fragments of ultramafic rocks, two of which were studied petrographically. A small outcrop of brecciated ultramafic rock (B-67, Table 4) is located on Allen Street, 150 feet west of State Highway 9 (Plate 2). The matrix appears to be silicified diorite. Dikes of pegmatite and veinlets of pinkish feldspar transect the breccia. A xenolith of hornblende-chlorite meladiorite (B-110, Table 4), about a foot across, occurs in the hornblende-biotite-augite granodiorite on State Highway 21, 500 feet west of its junction with Springfield Road (Plate 2). The xenolith is massive and medium grained.

Discussion. In general all the rocks exhibit a xenomorphic-granular texture. The rocks classified as hornblendite and diopside hornblendite are probably close to their original compositions. However, some minor retrograde metamorphism, i.e., the formation of epidote and chlorite, has occurred. The rocks classified as meladiorite are probably ultramafics into which plagioclase has been introduced due

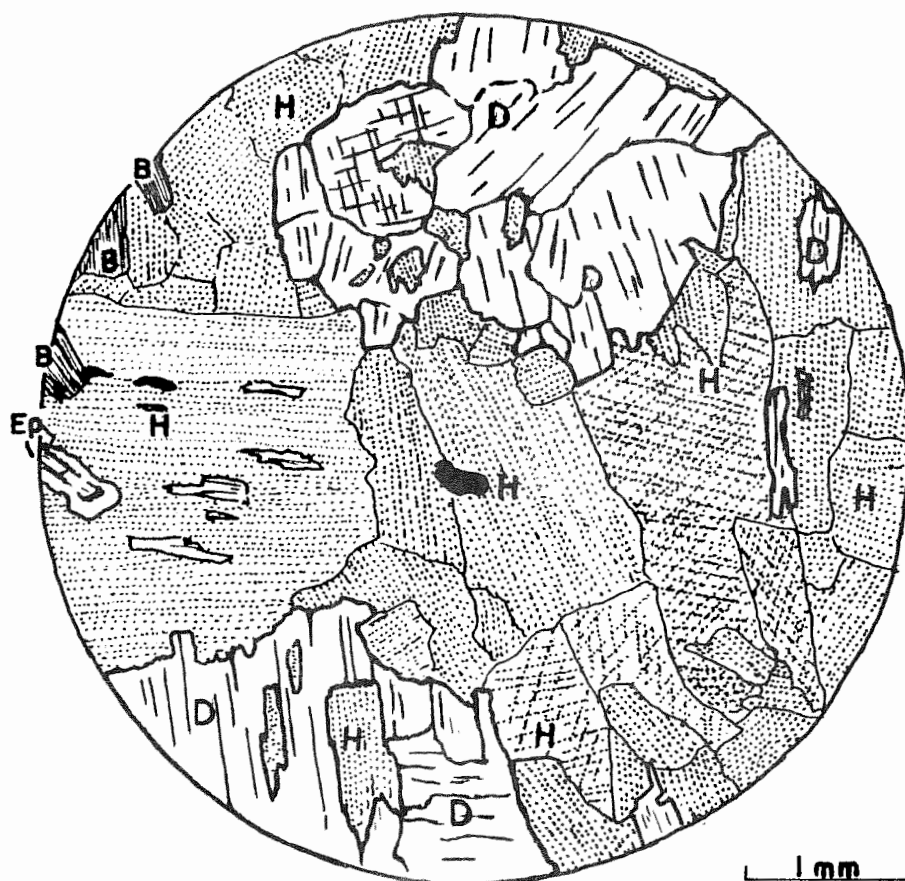


Figure 8. Diopside hornblendite, specimen B-63, showing the textural relationship of diopside and hornblende. H - hornblende; D - diopside; B - biotite; Ep - epidote.

to intrusion of dioritic liquid of the batholith. The bases for this assumption are: 1) all those samples that are meladiorites occur either in brecciated outcrops or as xenoliths; 2) plagioclases in the meladiorite are twinned whereas those in the hornblendites and diopside hornblendites are untwinned; 3) compositions of the plagioclases are too sodic for an ultramafic rock, but are, however, very similar to the composition of the quartz diorite-granodiorite which intrudes or surrounds them; and 4) minor presence of quartz and local microcline in some of the meladiorites (Table 4).

The Belchertown Batholith

The batholith of the Belchertown Intrusive Complex consists of four rock types (Plate 1). In the northern portion of the batholith these are arranged in three concentric gradational zones. The outer marginal zone is primarily hornblende-biotite quartz diorite with local patches of hornblende-biotite diorite (Table 5; Plate 2). To the south and into the batholith, the quartz diorite grades into hornblende-biotite granodiorite. The third zone, closest to the core of the batholith, consists of augite-bearing hornblende-biotite granodiorite.

In general, the rocks that form the batholith are medium grained, moderately foliated, and brownish-gray weathering and exhibit a hypautomorphic-granular texture (Figure 9). The dark crystals and clots of hornblende and biotite set in the white groundmass of plagioclase give the rocks a distinctive mottled appearance in outcrop. Locally the structures and texture of these rocks vary. Near the borders of the batholith and near the septum of Partridge schist, the quartz diorite and granodiorite are fine grained, exhibit a mosaic texture and are well lineated and foliated (Figure 10). In some places these well foliated rocks contain megacrysts of plagioclase up to 1/4 inch in length. Toward the center of the batholith the granodiorite is locally massive and coarser grained (Figure 11). Foliation and lineation are poorly developed and are related to the orientation and concentration of hornblende and biotite crystals or clots. Biotite occurs locally as poikilitic plates, 3/4 of an inch in diameter, that give the granodiorite a porphyritic appearance.



Figure 9. Hypidiomorphic-granular texture of the hornblende-biotite granodiorite, specimen B-18. Q - quartz; P - plagioclase; Hb - hornblende; B - biotite; M - microcline; Ep - epidote; Z - zircon; A - apatite; Sp - sphene.

The exposures of quartz diorite and granodiorite are generally poor. The best outcrops are found along the ridge west of the Swift River, extending from the west end of Winsor Dam to just south of Cold Spring Road. Several other good outcrops can be found west, south and south-east of Belchertown (Plate 2).

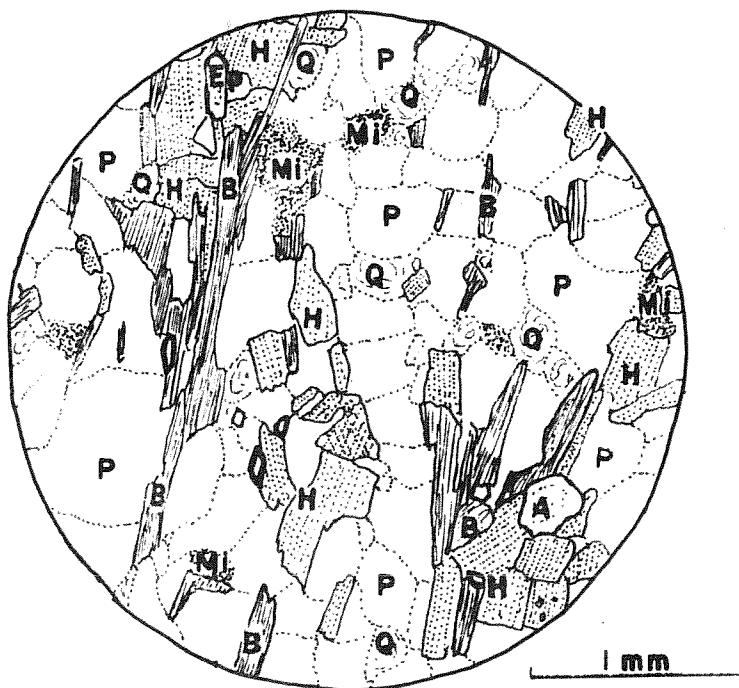


Figure 10. Characteristic metamorphic texture of quartz diorite specimen B-43, near contact of the batholith and metamorphic country rock. P - plagioclase; Q - quartz; B - biotite; H - hornblende; Ep - epidote; A - allanite.

Classification and petrography. The classification used in this paper is based on the modal mineralogy and is a modification of Johanssen's classification (1939; Bateman et. al, 1963). The basis is modal amounts of quartz, plagioclase and potassium feldspar calculated to percentages. The boundaries between the fields of the different rock types (Figure 12) are in terms of the ratios of K-feldspar to the total feldspar (10, 35 and 65 percent) and the percent of quartz of the total quartz plus feldspars (10 and 50 percent). The ferromagnesian minerals, if more than one percent, are used as modifying terms. According to the classification of the 36 modal analyses, 3 are diorites, 18 quartz diorites and 15 granodiorites.

Table 5. Point-counted modes of the Belchertown batholith. A. Diorites, contact zone, and Spillway stock.

	Diorite			Contact Zone						Stock
	B-1	B-14	B-73	Dike B-94a	← Contact B-95a	B-95b	B-95c	B-95d	B-95e	B-8
Quartz	4.9	1.6	3.8	22.5	20.9	10.4	5.2	7.6	13.7	11.4
Plagioclase (An %)	56.0 (28)	48.2 (36)	47.9 (36)	46.2 (32)	54.8 (47)	25.4 (42)	35.4 (36)	32.7 (37)	49.1 (32)	55.2 (ab)
Microcline	0.7	1.2	2.9	2.9	0.7	0.5	0.5	0.2	0.2	1.6
Hornblende	13.9	36.2	32.7	13.2		29.7	35.1	28.0	12.2	
Biotite	18.2	5.7	8.6	12.1	22.2	26.5	18.8	25.0	19.2	17.0
Epidote	2.8	0.7	0.5			3.9	0.3	2.6	2.9	0.6
Allanite	0.6			tr	0.1	0.3	0.7	0.3	0.1	tr
Rutile		0.1			tr					
Sphene	1.4	2.2	1.6	0.9		1.4	1.2	1.5	1.3	1.0
Magnetite	tr		0.2	tr	0.5		0.2		tr	tr
Apatite	1.0	1.4	1.0	0.6	0.7	1.6	2.1	1.8	1.1	0.7
Zircon	0.5		0.4	0.1	tr	0.3	0.5	0.1	0.2	tr
Chlorite		2.7	0.8	0.1	0.1			0.3		0.5
Other			Calcite	1.4				Muscovite		0.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.1	100.0	100.0

Hand specimen descriptions and localities for Table 5.

B-1 Hornblende-biotite diorite. North of State Highway 9, 1200 feet east of the turn off for the Quabbin Reservoir entrance road, at the 500-foot contour.

B-14 Hornblende-biotite diorite. On Hannum Street, 200 feet east of the Central Vermont Railroad underpass, at the 440-foot contour.

B-73 Hornblende-biotite diorite. In the stream bed west of the Central Vermont Railroad, 300 feet southeast of Hannum Street, at the 430-foot contour.

B-94a Hornblende-biotite quartz diorite. At the eastern end of the road cut across the Partfidge schist septum on State Highway 9, about 0.5 mile east of the Quabbin Reservoir entrance road turn off; the sample is from the dike in the septum.

Table 5. B. Quartz diorites.

	B-22	B-23	B-30	B-31n	B-35	B-36a	B-43	B-45	B-64	B-89
Quartz	16.5	7.8	7.5	11.5	9.2	11.1	9.2	7.6	10.8	13.7
Plagioclase (An %)	54.5 (33)	59.0 (32)	57.5 (28)	38.0 (31)	50.3 (28)	53.6 (32)	54.5 (37)	54.1 (31)	59.1 (32)	43.0 (33)
Microcline	1.6	tr	0.5	2.4	0.9	2.2	3.7	1.2	4.6	3.2
Hornblende	9.4	15.4	14.6	10.7	6.8	17.6	16.9	14.6	9.8	7.8
Biotite	12.9	12.8	13.6	27.8	24.8	13.2	10.2	16.3	12.7	24.5
Epidote	2.7	1.6	4.3	6.6	5.4	tr	0.5	2.5	0.7	3.6
Allanite	0.5	0.4	tr	0.5	0.2	0.1	0.7	0.4	0.1	0.5
Rutile		tr								0.1
Sphene	0.8	1.7	0.5	0.7	1.0	1.2	1.3	1.5	1.1	2.0
Magnetite	tr	0.1	0.5	0.1	0.3	0.1	0.1	tr	tr	
Apatite	0.6	1.1	0.6	0.8	0.7	0.6	0.6	1.5	0.9	0.8
Zircon	0.5	0.1	0.4	0.4	0.4	0.3	0.3	0.4	0.1	0.4
Chlorite				0.5			2.0		0.2	0.4
Tourmaline					tr					
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.1	100.1	100.0

B-95 a. Biotite quartz diorite; b. Hornblende-biotite quartz diorite; c. Hornblende-biotite quartz diorite; d. Hornblende-biotite quartz diorite; e. Biotite-hornblende quartz diorite. Sample locations at the western end of the road cut which crosses the Partridge schist septum on State Highway 9, 1/2 mile east of the Quabbin Reservoir entrance road turnoff. The samples were taken at 10-foot intervals from near the gradational contact between the quartz diorite, to the west, and the Partridge schist, to the east, and continued into normal appearing quartz diorite.

B-8 Biotite quartz diorite, Quabbin Reservoir Spillway stock, in the spillway 150 feet south of the bridge, at the 480-foot contour.

B-22 Hornblende-biotite quartz diorite. On the eastern side of the ridge west of the Swift River, 1600 feet south of State Highway 9, at the 470-foot contour.

B-23 Hornblende-biotite quartz diorite. 400 feet southwest of station B-22, at the 510-foot contour.

Hand specimen descriptions and localities for Table 5 continued.

B-30 Hornblende-biotite quartz diorite. On the west slope of the ridge west of the Swift River, 2400 feet due south of State Highway 9, at the 660-foot contour.

B-31n Hornblende-biotite quartz diorite. 1000 feet south of location B-22, about 50 feet from the Partridge schist septum and quartz diorite contact, at the 530-foot contour.

B-35 Biotite-hornblende quartz diorite. On the north slope of the hill west of the ridge west of the Swift River, about 900 feet due south of State Highway 9, at the 600-foot contour.

B-36a Hornblende-biotite quartz diorite. In the same area as B-35 but some 700 feet west-northwest of it, and 850 feet south of State Highway 9, at the 610-foot contour.

B-43 Hornblende-biotite quartz diorite. On the east slope of the ridge 1400 feet north of Cold Spring Road, about 1500 feet northeast of the junctions of Cold Spring and Michael Sears Roads, at the 500-foot contour.

B-45 Hornblende-biotite quartz diorite. West of Sabin Street 100 feet and about 0.95 mile north of its junction with Cold Spring Road, at the 580-foot contour.

B-64 Biotite-hornblende quartz diorite. On the east side, near the crest, of the hill just west of the Belchertown State School, about midway between State Street (U. S. 202) to the south and Hannum Street to the north, at the 520-foot contour.

B-89 Biotite-hornblende quartz diorite. In a small quarry west 2100 feet from the Swift River, about 1 1/2 miles north of Bondsville, at the 485-foot contour.

B-18 Biotite-hornblende granodiorite. On the eastern slope of the large hill formed in part by the western fork of the Partridge schist septum, about 2400 feet north-northeast of the junction of Cold Spring and Michael Sears Roads, at the 650-foot contour.

B-31s Biotite granodiorite. 1000 feet south of location B-22, within several feet of the granodiorite and Partridge schist contact, at the 550-foot contour (same location as B-31n, but closer to the contact).

B-46 Biotite-hornblende granodiorite. 400 feet west of Sabin Street, 0.9 mile south of its intersection with State Highway 9, at the 550-foot contour.

Table 5. C. Granodiorites.

	B-18	B-31s	B-46	B-47	B-49	B-54	B-58	B-85	B-86	B-88	B-90	B-91	B-97	B-105	B-110	B-114
Quartz	11.4	21.0	9.2	12.0	8.9	6.8	7.2	9.8	11.4	8.1	15.5	5.8	12.7	10.8	8.1	10.1
Plagioclase (An %)	47.5 (33)	46.1 (33)	50.8 (37)	44.7 (32)	42.0 (28)	36.3 (32)	42.7 (38)	43.0 (33)	55.2 (36)	40.6 (36)	41.8 (31)	39.3 (33)	44.0 (36)	46.8 (36)	46.5 (36)	38.3 (32)
Microcline	10.8	6.1	7.9	10.6	13.0	7.1	5.6	6.9	6.5	9.7	10.8	9.1	8.7	7.6	4.9	12.9
Augite														1.5	4.2	5.6
Hornblende	8.2	0.3	9.5	13.6	15.7	28.2	28.0	28.3	12.1	21.7	13.3	25.6	13.1	15.4	18.5	17.4
Biotite	16.7	19.5	18.4	11.9	13.5	15.4	10.0	7.5	11.2	10.5	12.7	15.5	16.1	14.8	15.5	14.9
Epidote	2.9	5.2	1.6	3.9	3.9	1.4	0.9	0.5	0.3	5.6	4.6	1.4	2.7	0.8	0.1	
Allanite		0.1	0.5	0.2	0.6	0.9	tr	1.0	0.3	0.2	0.3	0.4	0.5			0.1
Rutile												tr				
Sphene	1.4	0.8	0.9	2.1	1.0	1.9	1.9	1.7	0.8	1.9	0.6	1.1	1.5	0.9	1.4	tr
Magnetite	0.1	tr	tr	tr		0.1	1.9	tr	0.1		tr	tr	tr	0.1	tr	0.1
Apatite	1.0	0.5	1.0	0.4	1.3	1.3	1.2	1.3	0.6	1.4	0.3	1.6	0.4	1.2	0.6	1.0
Zircon	tr	0.3	tr	0.6	0.1	0.6	0.6		0.3	0.3		0.2	0.3	0.1	0.1	
Chlorite		0.1	0.2	tr				tr	1.2	tr	0.1					
Tourmaline	tr															
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100.0

Hand specimen descriptions and localities for Table 5 continued.

B-47 Hornblende-biotite granodiorite. Just east of the crest of the small hill east of Cold Spring, 1000 feet due north of Cold Spring Road, at the 550-foot contour.

B-49 Hornblende-biotite granodiorite. East off Michael Sears Road, just over 0.75 mile south of its junction with Cold Spring Road, at the 480-foot contour.

B-54 Hornblende-biotite granodiorite. On the west slope of the hill located between the Boston and Maine Railroad and State Highway 181, about 1200 feet west of the Bondsville Road, State Highway 181, at the 470-foot contour.

B-58 Hornblende-biotite granodiorite. On the east slope of the high ground west of Jabish Canal, 1000 feet south of South Cemetery on Mill Valley Road, at the 490-foot contour.

B-85 Hornblende-biotite granodiorite. On the northeast slope of the hill west of the Belchertown State School, 600 feet north of U. S. Highway 202, about 400 feet southeast of station B-64, at the 510-foot contour.

B-88 Hornblende-biotite granodiorite. In a small quarry in the highlands west of the Swift River some 2100 feet, about 1 1/2 miles north of Bondsville (same area as B-89), at the 490-foot contour.

B-90 Hornblende-biotite granodiorite. On the east slope of the highlands west 2100 feet from the Swift River, about 0.75 mile north of Bondsville, at the 450-foot contour.

B-91 Hornblende-biotite granodiorite. On State Highway 181, about 0.75 mile northwest of Bondsville, at the 390-foot contour.

B-97 Hornblende-biotite granodiorite. North 75 feet of Cold Spring Road, about 700 feet east of Cold Spring, at the 525-foot contour.

B-105 Augite-hornblende-biotite granodiorite. North off the Boston and Maine Railroad, 3200 feet southeast from where it crosses State Highway 181, at the 420-foot contour.

B-110 Augite-hornblende-biotite quartz diorite (very close to being a granodiorite, see figure 12). On State Highway 21, 500 feet west of its junction with Springfield Road, at the 470-foot contour.

B-114 Augite-hornblende-biotite granodiorite. On the west slope of a hill just east of State Highway 21, 1600 feet south of its junction with Springfield Road, at the 450-foot contour.

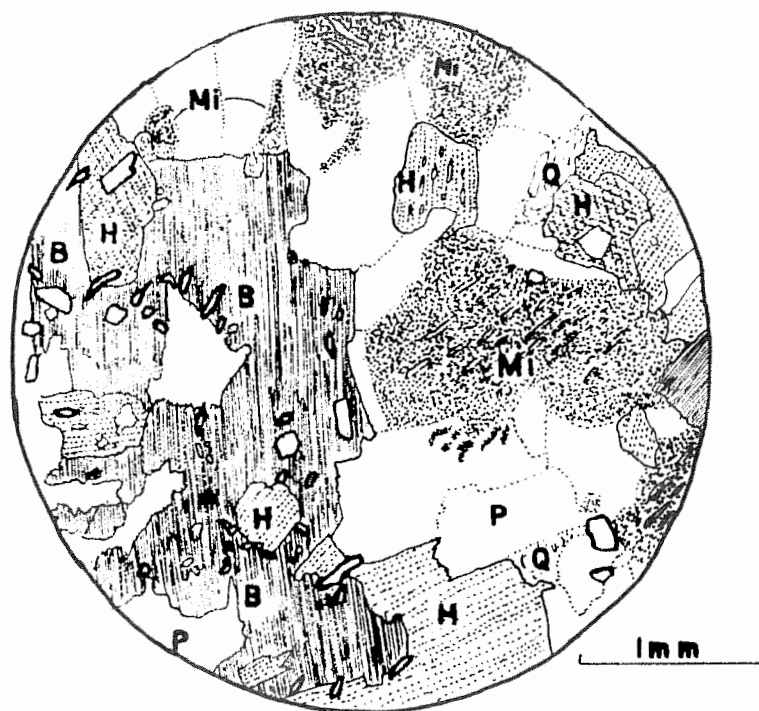


Figure 11. Hornblende-biotite granodiorite specimen B-91, showing large biotite and microcline crystals common in the central portion of the batholith. Q - quartz; P - plagioclase; Mi - microcline; H - hornblende; B - biotite.

Quartz ranges from 1.6 to 22.2 percent, with an average of about 10 percent (Table 5). Specimens with greater than 20 percent quartz all occur very close to the contact with the Partridge Formation (B-94a, B-95a, B-31s). Quartz generally occurs as fine, anhedral, interstitial grains. However, near the borders of the batholith and near the Partridge septum, the quartz occurs as groups of mosaic grains (Figure 10) generally exhibiting undulatory extinction. It also occurs as small rounded grains included in some hornblende (Figure 13, left) and locally forms a myrmekitic texture with plagioclase.

Plagioclase forms 25.5 to 59.0 percent of the rock, with an average of 46.9 percent. It occurs as subhedral to anhedral, generally

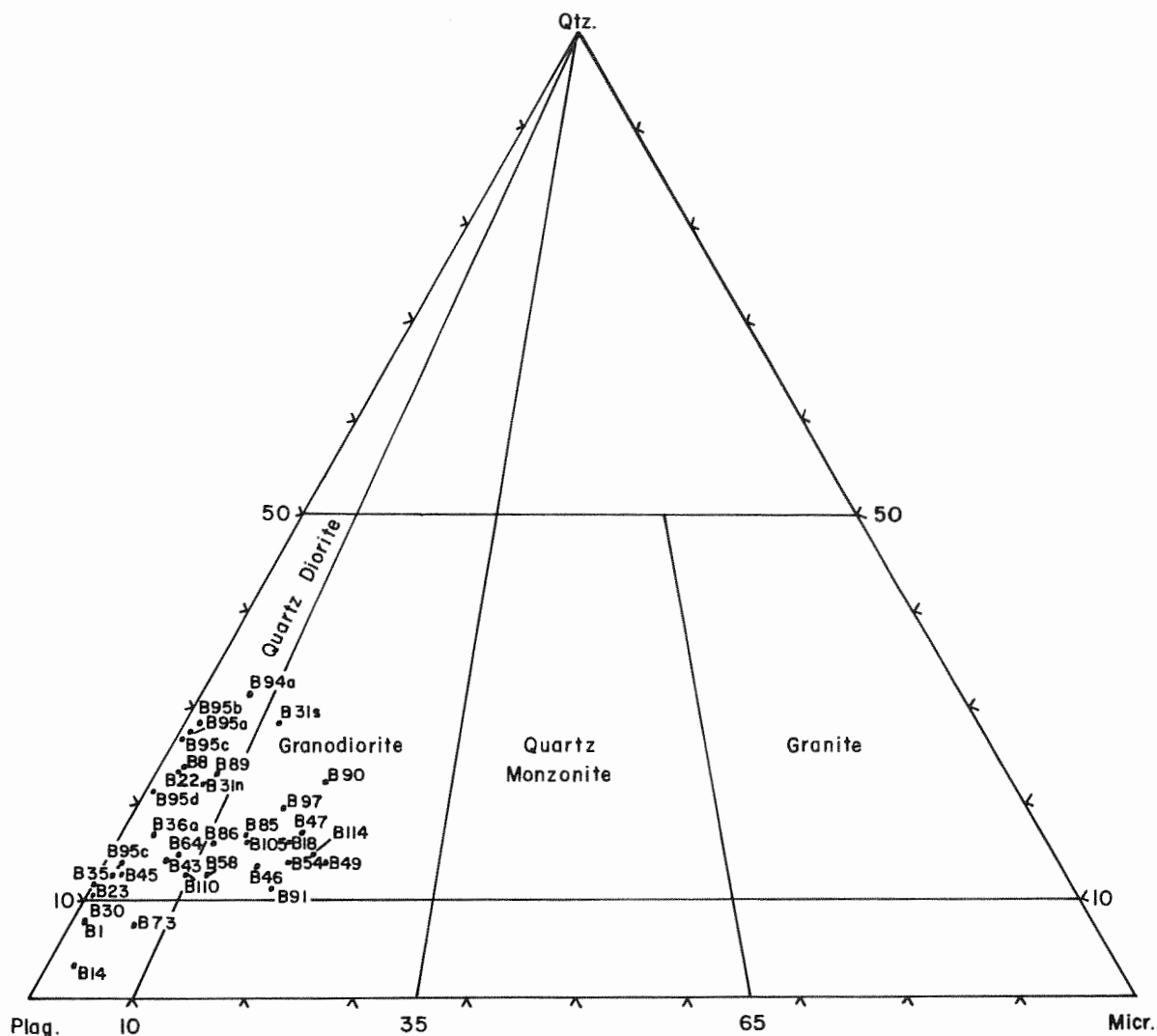


Figure 12. Plot of 31 modes of granitic rocks from the Belchertown Intrusive Complex on the classification diagram used in this paper (taken from Bateman, et al., 1963, p. D-13). Numbers correspond to thin sections.

medium-sized grains, that vary from equant to tabular in habit. The equant grains occur more toward the margins of the batholith or near the contacts with the septum of Partridge schist. Here the texture is commonly mosaic and suggests strong metamorphic deformation (Figure 10). Tabular crystals of plagioclase are present in those rocks which appear to have a more nearly igneous texture (Figure 11) and some in the granodiorite zone are antiperthitic. Although the composition of

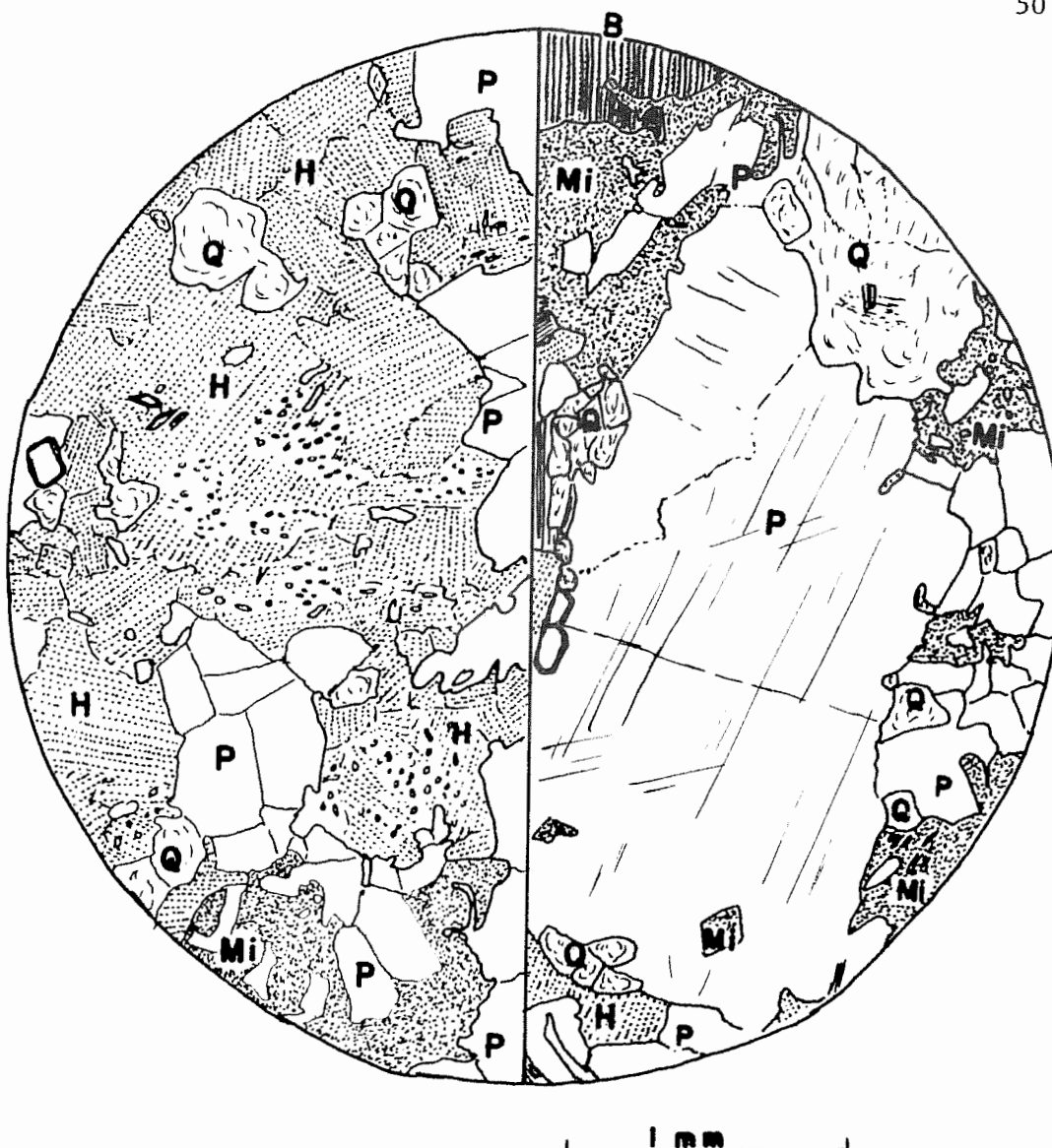


Figure 13. Sections showing characteristic textures for secondary hornblende (left, specimen B-85) and microcline (right, specimen B-54a). The secondary hornblende is intergrown, exhibits areas of lighter color and contains clusters of small quartz inclusions. The microcline exhibits a very irregular outline indicative of its late crystallization. Q - quartz; P - plagioclase; Mi - microcline; B - biotite; H - hornblende.

the plagioclase ranges from An_{28} to An_{38} (average An_{34}), there is no systematic change from the edges toward the center of the batholith (Table 5).

Microcline ranges from zero to 13 percent, averaging 4.7 percent. In the diorite and quartz diorite it is absent or present in amounts

less than 4.7 percent, and occurs interstitially as fine, anhedral grains (Figure 10). In the granodiorite zone, the anhedral microcline crystals are large, exhibit irregular embaying outlines, and show perthitic texture (Figures 10 and 13).

Hornblende and biotite are variable in amount and relative proportion. The variation in hornblende-biotite ratio is shown by comparing samples taken far from the contacts of the batholith with those close to the contact (Table 5 and Plate 2). Hornblende and biotite exhibit preferred orientation at and near the margin of the batholith (Figure 10), but lose it away from the margins (Figure 9).

Hornblende, ranging from zero to 36.3 percent of the rock (Table 5) occurs as single crystals or aggregates. Individual crystals are fine to medium, anhedral to euhedral, and generally less abundant than aggregates. The aggregates are medium to coarse, generally elongate, irregularly shaped masses formed by a number of fine anhedral to subhedral hornblende crystals (Figure 15). A poikilitic texture with inclusions of quartz is locally developed (Figure 13). In augite-bearing rocks hornblende is a common secondary mineral (Figure 14). There is also evidence of replacement of hornblende by biotite (Figure 11).

Biotite, 5.7 to 27.5 percent of the rocks (Table 5), generally occurs as fine- to medium-grained, subhedral to anhedral, ragged-appearing crystals. The texture and grain size of biotite shows a variation from the batholith margins inward. Along the outer portions it occurs as fine-grained, subhedral, well formed grains while in the inner portions it occurs as medium-sized, anhedral, poikilitic crystals.

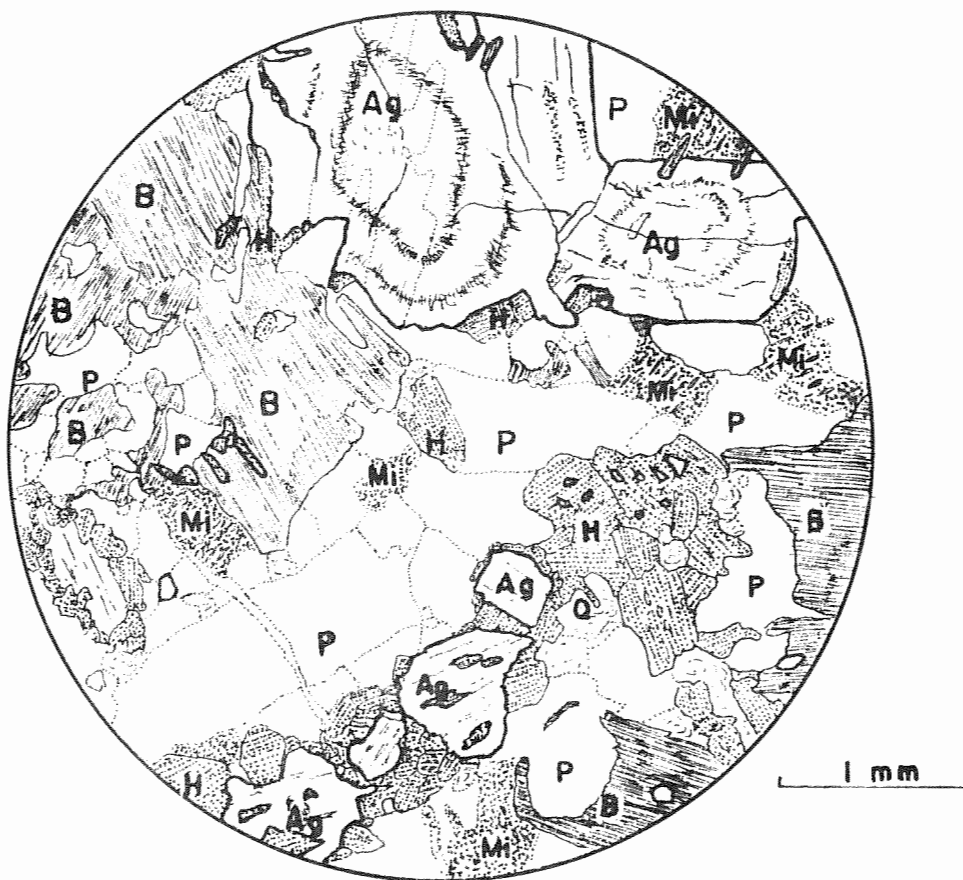


Figure 14. Textural relationships in augite-bearing granodiorite, locality B-114. The augite is subhedral and exhibits an internal structure of arranged platelets. Hornblende is partially replacing and rimming the augite. Q - quartz; P - plagioclase; Mi - microcline; Ag - augite; B - biotite; H - hornblende.

Augite is restricted to granodiorite in the central portion of the batholith. It forms 1.5 to 5.6 percent of the rock and occurs either as medium subhedral to euhedral grains, or as partially replaced grains in the cores of hornblende (Figure 14). Percy (1955) mentioned the occurrence of orthopyroxene in the granodiorite. None was found by the writer, but David J. Hall (personal communication, 1970) has found some in the center of the batholith farther south. Most of the augite crystals contain small, oriented, opaque rods or plates of uncertain mineralogy, producing what is commonly termed a saenitic texture (Figure 14).

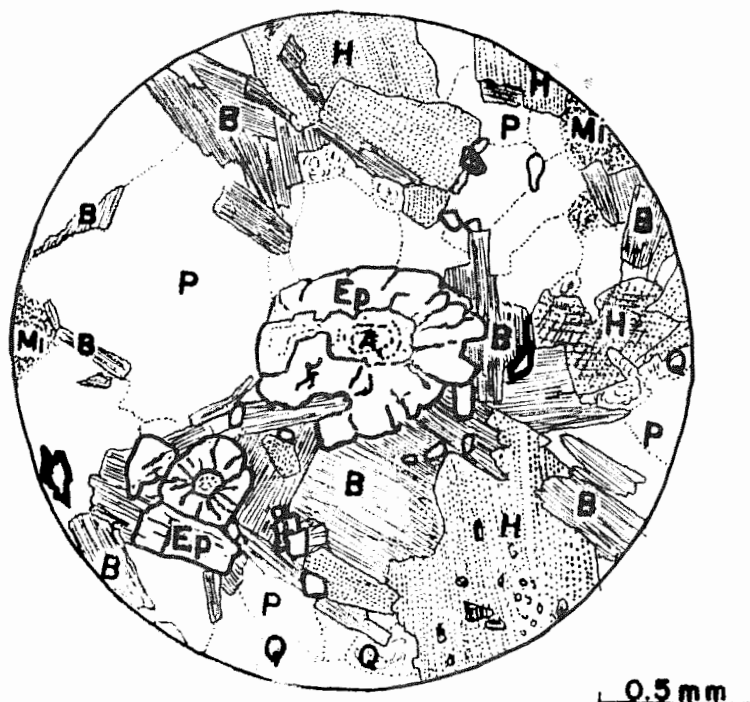


Figure 15. Example of epidote rimming allanite, locality B-54a. Q - quartz; P - plagioclase; H - hornblende; B - biotite; Ep - epidote; A - allanite; Mi - microcline.

Epidote occurs as fine, anhedral to euhedral grains associated with biotite and hornblende, and as rims about accessory allanite crystals (Figures 15 and 16). The common accessory minerals are sphene, apatite, zircon, allanite and magnetite. Some of the sphene may be secondary due to the replacement of augite by hornblende, and of hornblende by biotite, because it is commonly associated with the hornblende and biotite. Hematite replacing the magnetite is probably due to weathering. Secondary chlorite, both optically positive and negative, occurs as small patches or strips within the biotite.

Distribution of rock types. The rocks of the Belchertown Intrusive Complex Batholith are divided on the map into hornblende-biotite quartz diorite, hornblende-biotite granodiorite, and hornblende-

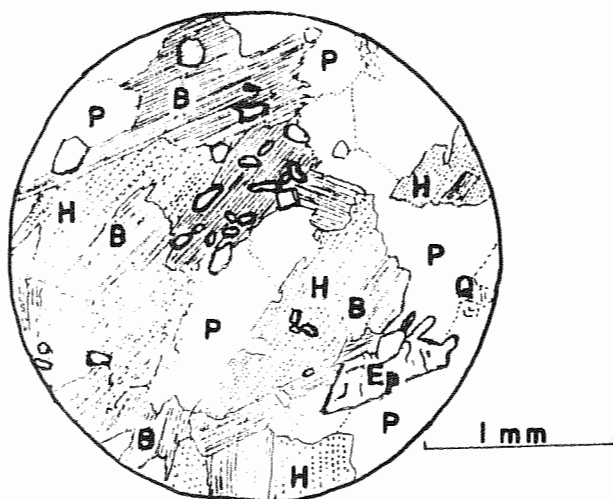


Figure 16. Characteristic intergrowth and close association of hornblende and biotite, specimen B-1, in diorite of the batholith. Q - quartz; P - plagioclase; H - hornblende; B - biotite; Ep - epidote.

biotite-augite granodiorite. These rock types are arranged in concentric zones with gradational contacts (Plate 1 and Plate 3). Hornblende-biotite quartz diorite forms the irregular zone marginal to the batholith, within which there are also areas of hornblende-biotite diorite and biotite quartz diorite. The diorite seems to be situated in the outer part of the zone, between the metamorphic rocks and the quartz diorite, but there are insufficient data to verify this relationship. The biotite quartz diorite is generally found within a few feet of contacts against the schistose country rock. On Plate 1 the main quartz diorite zone is shown extending along the east side of the batholith and around the southern end of the large amphibolite inclusion underlying Belchertown, although outcrop evidence for this distribution is scarce (Plate 2).

Inward into the batholith, and toward the south, the amount of microcline increases and the quartz diorite grades into hornblende-

biotite granodiorite (Plate 1). Local areas of biotite-hornblende granodiorite occur generally near the contacts with the septum of Partridge Formation.

An additional change is marked by the appearance of augite in the inner portion of the batholith. Although augite is not abundant, the writer believes it is important enough to warrant identification of the rocks as a separate zone. One augite-bearing rock (B-110, Table 5), is quartz diorite, but is very close to the granodiorite field boundary on Figure 12, and is not mapped separately.

Intrusive igneous rock contacts. The contacts of the Belchertown batholith with the metamorphic country rock are difficult to establish because glacial debris covers much of the area. The only visible contacts occur along the eastern side of the septum of Partridge schist, in the road cut on Highway 9 through the septum (Figure 10) and at one locality east of the Swift River (Plate 2). The contacts are generally concordant with the schist's foliation, although in some places the foliation of the schist appears to dip steeper than the foliation of the adjacent quartz diorite or granodiorite (Plate 1 and 3). Although from a distance these contacts appear to be sharp, they are in fact gradational. A zone of hybrid schistose rocks, several inches to several feet thick, is usually present. Locally present along these exposed contacts are country rock inclusions from a few inches to almost a foot in length.

The inferred contacts shown on Plate 1 were drawn on the basis of outcrops, float, topography, and logs of diamond drill cores made by the Metropolitan District Commission, prepared by Professor Peter Robinson (personal communication). It appears that the Belchertown

batholith crosscuts the metamorphic rocks along its northern border. Along the eastern border of the batholith the rocks appear to be generally concordant with the metamorphic rocks on the east limb of the Great Hill Syncline.

The contact of the quartz diorite and the hornblendite is not exposed, but several lines of evidence help establish their age relationship. Just north of Hannum Street, about 500 feet east of the Central Vermont Railroad, an outcrop of hornblendite contains several dikes of quartz diorite (Plate 2). Contacts are gradational through a thin zone. In the northeast portion of the Belchertown area there is an outcrop of intrusive breccia which consists of hornblendite fragments in a quartz diorite matrix. Elsewhere, inclusions of angular to subangular fragments of hornblendite commonly occur within the quartz diorite and granodiorite. These observations indicate that the hornblendites are older than the quartz diorite and granodiorite.

Intrusive Breccia

Along the northwest and north-central borders of the Belchertown batholith are outcrops of brecciated metamorphic rocks cemented by diorite (Plate 2). The outcrops are quite limited in size and number, and much of the delineation of the intrusive breccia zones is based on float material found in stone fences, as glacial debris, and on the general topographic expression of the area. The intrusive breccia consists of either amphibolite breccia or hornblendite breccia, of which the former is more abundant. The intrusive breccia

occurs mainly on the margins, but there are a few occurrences within the batholith.

The outcrops of intrusive breccia in the northwest portion of the batholith consist of both amphibolite and hornblendite fragments in a diorite matrix. Pegmatites and minor aplites occur as crosscutting dikes. The general locations of these outcrops are (Plate 2): east of State Highway 9, about 2400 feet north of Allen Street (amphibolite breccia); on the Central Vermont Railroad, 2500 feet north of the intersection with Allen Street (amphibolite breccia); north of Bay Road 1000 feet northwest of the intersection with Highway 9 (amphibolite breccia); in the road off Allen Street west of its intersection with State Highway 9 (hornblendite breccia); and on the Central Vermont Railroad 200 feet south of the Hamilton Street crossing (hornblendite breccia).

Amphibolite breccia in the northwest region consists of fine- to medium-grained, bedded amphibolite which is fractured and cemented by fine-grained felsic diorite. The amphibolite fragments are mostly angular in shape and variable in size. Crosscutting these are dikes of aplite and granite pegmatite (Figure 18). In the area close to the Triassic border fault the amphibolite breccia has suffered strong alteration. Most of the hornblende has been altered to chlorite and epidote, and the diorite matrix appears to be silicified and contains pink feldspar.

The hornblendite breccia consists of angular to rounded, generally oblong fragments of medium-grained, massive hornblendite and diopside hornblendite (for petrography of some fragments see section on ultramafic rocks). Outcrops near the Triassic fault exhibit alteration and shearing.

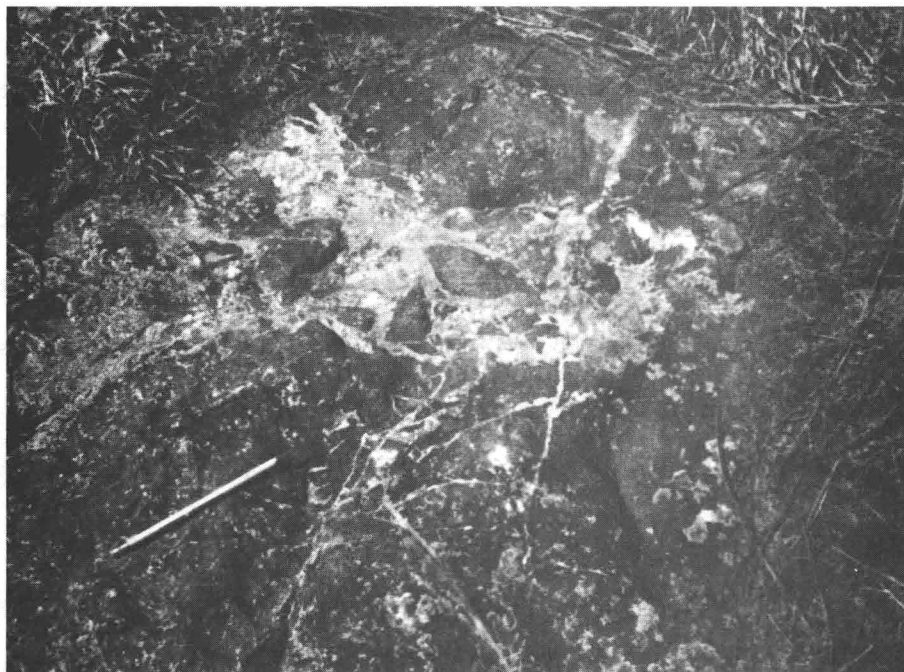


Figure 17. Outcrop of meladiorite and hornblendite cut by dikes of diorite, forming a local breccia. Location B-3, Plate 2.



Figure 18. Amphibolite brecciated by intrusion of quartz diorite, pegmatite and aplite dikes. Exposed during the construction of a house north of Bay Road, 500 feet northwest of Highway 9.

The north-central portion of the Belchertown area is considered by the writer to be underlain by intrusive breccia. The only outcrops, mostly of brecciated amphibolite, are located along the west shore of Quabbin Reservoir 2800 feet north of the power line (Plate 2). Because of the topography and the minor amount of breccia float, this area was mapped as intrusive breccia.

The intrusive breccia in the north-central area varies from very large blocks or angular fragments of amphibolite cut by dikes of diorite and granite pegmatite, to large fragments 10 to 20 inches in size, to fragments less than an inch in size set in a matrix of felsic diorite. The amphibolite is a fine- to medium-grained, bedded to massive rock that contains lenses and streaks of epidote with some thin interbeds of biotite schist. The brecciation is caused by the crosscutting prying apart and detaching of fragments by the diorite dikes (Figure 19). This results in angular, irregular or rounded fragments of amphibolite, schist, granulite and hornblendite, mixed in a hornblende-biotite diorite matrix. Veins and dikes of aplite and pegmatite transect the breccia. In some of these breccias the hornblendite occurs as fragments, while in others, or in the same rock, it occurs as a reaction rim between the fragments and the diorite (Figure 20). In a few of the outcrops the hornblendite appears to be intrusive into the metamorphic rock (Figure 20).

Near the hornblendite body located west of Quabbin Reservoir, an outcrop of quartz diorite has several large blocks of hornblendite in it. At the southern end of Quabbin Reservoir, incipient brecciation has occurred in the hornblendite (Figure 17).

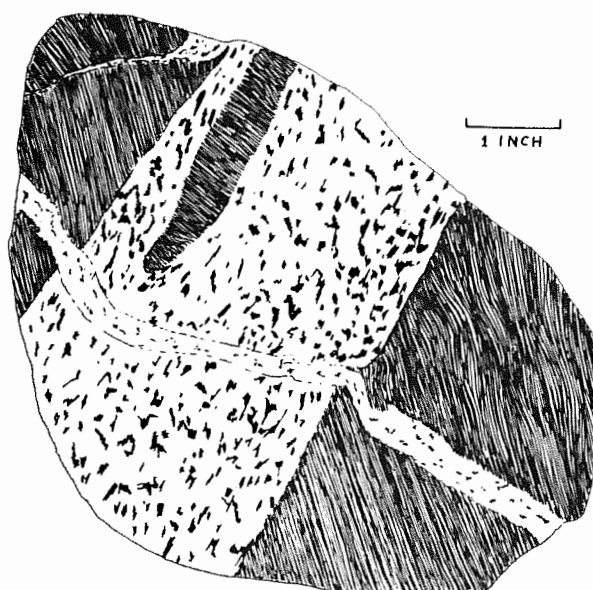


Figure 19. Tracing of amphibolite transected by dikes of hornblende-biotite quartz diorite. Note crosscutting relationships and prying apart of the amphibolite by dike material. Specimen is from the intrusive breccia zone on west shore of Quabbin Reservoir.

There is a small outcrop of breccia on Sabin Street, just north of Cold Spring Road near the southern tip of the western branch of the Partridge schist septum. This isolated outcrop consists of angular and rounded fragments of biotite schist, amphibolite, biotite, hornblendite and granulite in a matrix of granodiorite. This is the only outcrop of intrusive breccia located away from the margins of the batholith, though several glacial boulders (Figure 21) have been found (cf. Guthrie and Robinson, 1967, Stop 7).

The contact relations of the batholith rocks and the intrusive breccia are difficult to describe because there is no area showing massive intrusive rocks in contact with breccia. The writer feels that the contact is gradational. Close to the intrusive breccia xenoliths are very plentiful and are large and angular; away from the breccia xenoliths become scarcer, smaller and rounder. The contact

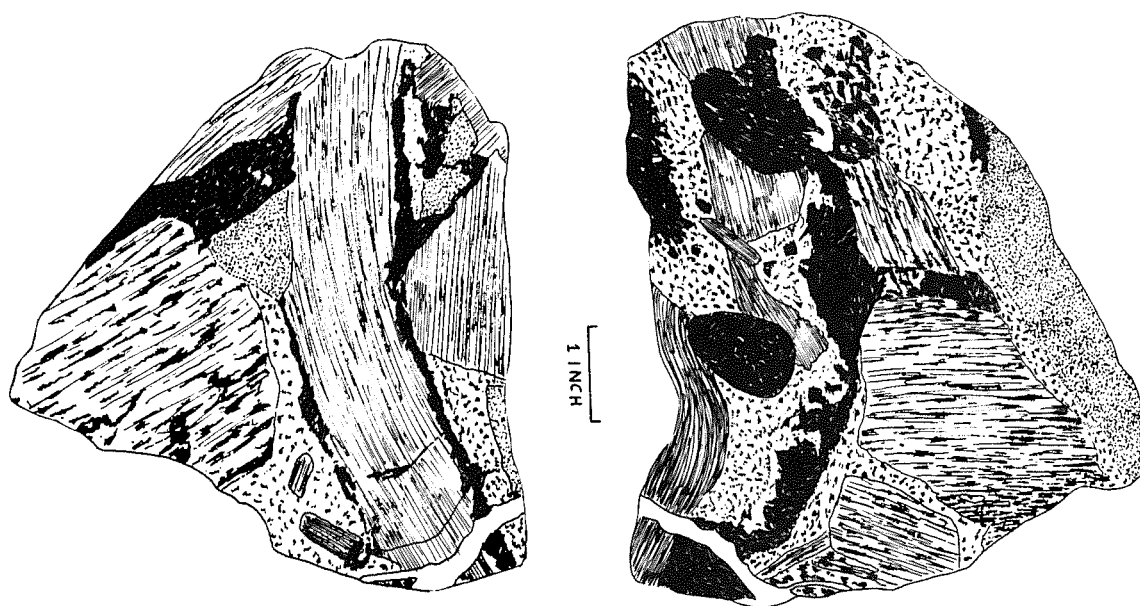


Figure 20. Tracings of intrusive breccia texture and rock types from opposite sides of a sawed block from west shore of Quabbin Reservoir. Fragments are: Hornblende (heavy black pattern), schist (closely drawn lines), amphibolite (thick-lined areas), and granulite (dotted). The matrix is hornblende-biotite quartz diorite. An aplite dike cuts one corner. Note the irregular and in some places apparently gradational contact between hornblende and quartz diorite.

shown on the cross sections (Plate 3) is based on this supposition.

The mechanism for brecciation is most likely fracturing of the rock and then invasion and prying apart by the magma.

Subsidiary Stocks

Near Quabbin Hill, in the northeast corner of the area, there are two stocks of quartz diorite. In the surrounding metamorphic rocks of the Quabbin Hill area there are also numerous small lenses of quartz diorite. Because of their small size they were not mapped by Halpin (1965). The stock in the Quabbin Reservoir spillway is the best exposed and was studied in detail by the writer (Figure 22). The second stock was mapped by Halpin (1965).

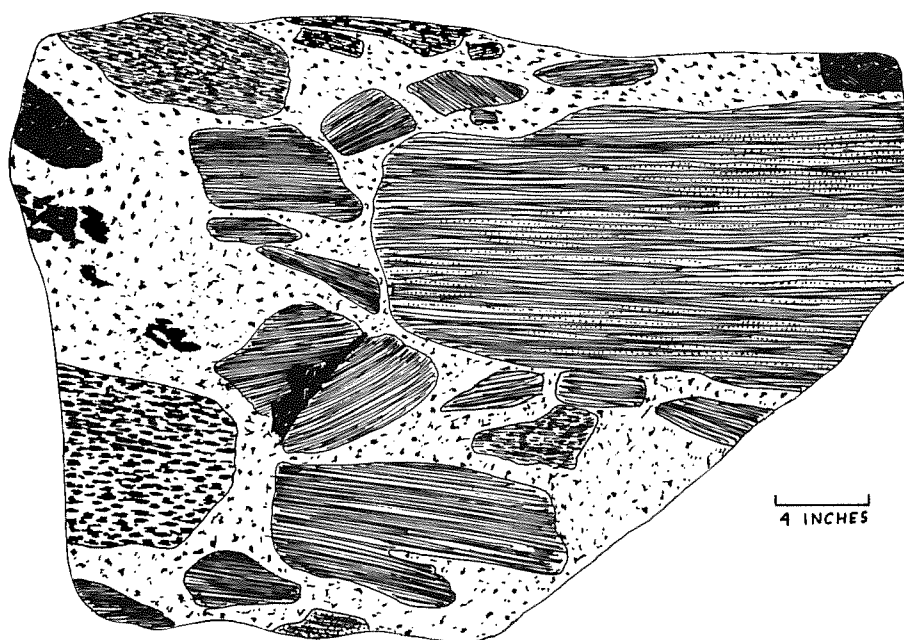
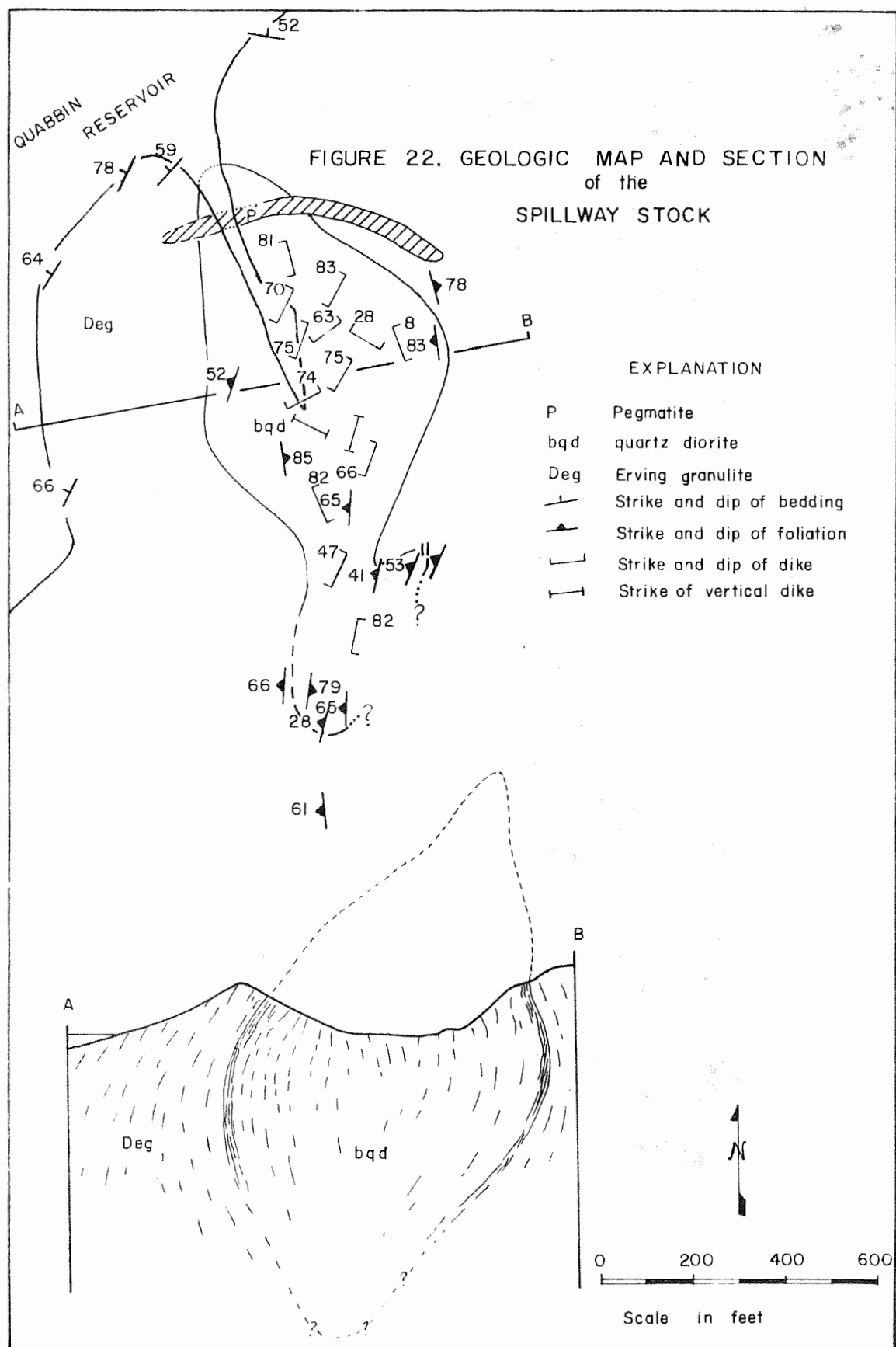


Figure 21. Sketch of a boulder of intrusive breccia showing the heterogeneous mixture of rock types and general appearance. Fragments are hornblende (heavy black pattern), schist (closely drawn lines), biotite (short lines), granulite (lines and dots), and amphibolite (short heavy lines). The matrix is hornblende-biotite granodiorite. Found near south end of west branch of Partridge schist septum, on east side of Sabin St., 300 feet north of junction with Cold Spring Road.

The rock of the Spillway stock is well foliated and has a fine- to medium-grained, sugary to porphyritic texture. It is composed of biotite, albitic plagioclase, quartz, microcline, sphene, apatite, zircon, opaque, epidote and allanite. Chlorite secondary after biotite and muscovite are also present (B-8, Table 5). The rock of the Spillway stock varies both in composition and in texture from quartz diorite to a hybrid chlorite-rich rock. The foliation of the rock is due to the concentration and orientation of biotite. The plagioclase generally occurs as anhedral, mosaic grains, but also occurs as large, subhedral megacrysts (Figure 23). Quartz, plagioclase and minor microcline form the mosaic-textured groundmass.



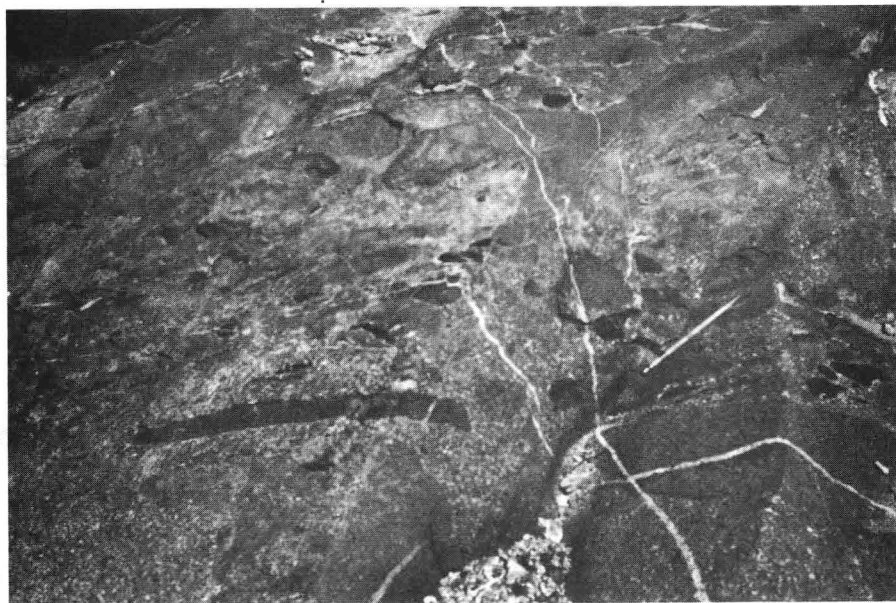


Figure 23. Porphyritic quartz diorite facies of the Spillway stock, near the contact, containing oriented inclusions of granulite, biotite schist, hornblendite and coarser grained equigranular quartz diorite. East side of the spillway road, 400 feet north of the bridge.



Figure 24. Contact of the quartz diorite of the Spillway stock and granulite of the Erving Formation. On the spillway road, 700 feet north of the bridge.

Inclusions of granulite, biotite schist, amphibolite, hornblendite and chlorite-rich rocks are fairly abundant. The inclusions are usually elongated, range from a few inches to over a foot in length, and are generally oriented parallel to the foliation (Figure 23). The inclusions become smaller and less abundant toward the center of the stock.

The contacts of the biotite quartz diorite with the granulite of the Erving Formation are generally concordant and vary from sharp to gradational (Figure 24). At the northern end of the stock the contact and foliation indicate an anticlinal structure. However, at the southern tip, the schist appears to be wrapped around the stock and dips gently northward under it (Figure 28).

Dikes

Related to the final stages of the igneous activity associated with the Belchertown Intrusive Complex are internal and peripheral dikes. These dikes are primarily pegmatite and aplite. A cursory examination of these dikes was carried out in order to determine their relation to the main intrusion and their age sequence. No petrographic work was done.

The dikes are generally thin (1 to 8 inches, although a few reach several feet, Figure 26) and are most abundant at the batholith margins and in the peripheral metamorphic country rocks. The aplite dikes appear megascopically as fine-grained, sugary textured, quartz and feldspar rocks, either grayish white or pinkish white. The pegmatite dikes in outcrop consist of coarse-grained, interlocking crystals of quartz, feldspar, and minor muscovite. A few pegmatites contain minor beryl, garnet and tourmaline. Some composite dikes exhibit an aplite core and pegmatite margin.



Figure 25. An early mafic dike in quartz diorite of the Spillway stock cut by a later pegmatite dike. A large inclusion is parallel to the foliation of the quartz diorite.

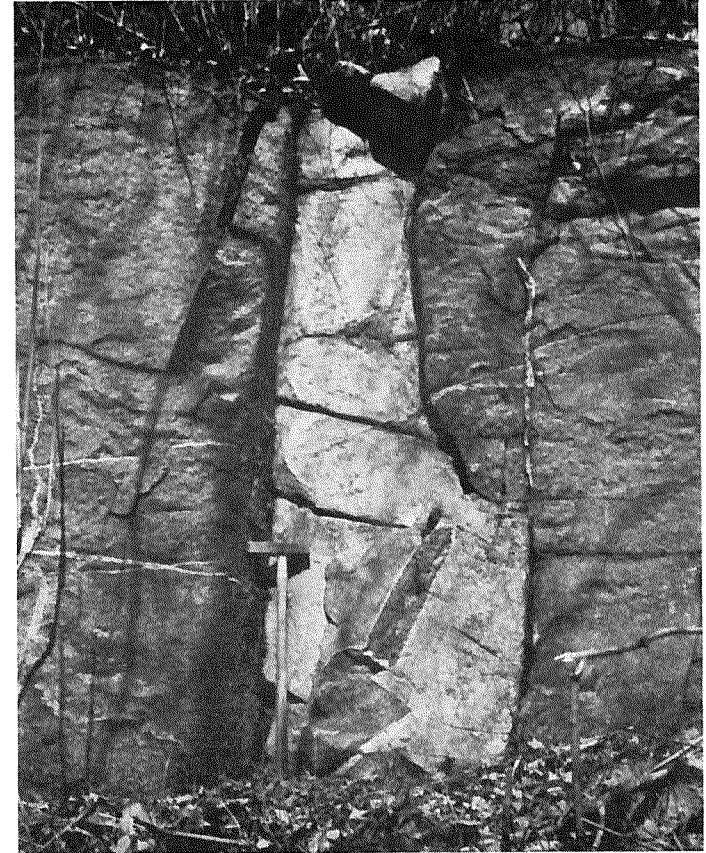


Figure 26. Large aplite dike crosscutting Partridge schist of the septum. The dike contains two blocks of plucked country rock. Located about 600 feet north of sample locality B-18, Plate 2. The hammer is 2.5 feet long.

The minority of the dikes studied consist of diorite and mafic rocks. The diorite dikes are composed of fine-grained, dark gray, aplitic-textured rocks of feldspar and biotite. The mafic dikes are fine grained and massive, and consist of hornblende and biotite with minor feldspar (Figure 25). Several mafic dikes of a composite nature with a felsic core and mafic borders were found in an outcrop of quartz diorite located at the top of the hill on Summit Street, south of U.S. Highway 202 (Figure 27). The diorite and mafic dikes are the earliest because they are cut by all the other dikes.

The last features formed are the mineralized fractures or joints. These structures, which cut all the other features, consist of quartz veins or calcite- and chlorite-coated joints. Balk (1940) reported joints coated with epidote, chlorite, muscovite, pyrite, and, locally, purple fluorite and black tourmaline in the Quabbin Reservoir spillway.

The chronological sequence of the dikes was determined near the Spillway stock and at several widely separated outcrops. The general sequence deduced was as follows: diorite and mafic dikes, composite mafic dikes, gray granite aplite, granite pegmatite, pink aplite, beryl-garnet-tourmaline pegmatite, and quartz veins and mineral-coated joints. In general the dikes are straight, although in some of the peripheral metamorphic rocks and border hybrid igneous rocks the dikes have been folded (Figure 29).

Pegmatite Bodies

Within and near the batholith are large, tabular to irregular, steep, irregularly dipping bodies of pegmatite and quartz. The pegmatite bodies (Plate 1) consist of very coarse-grained quartz,

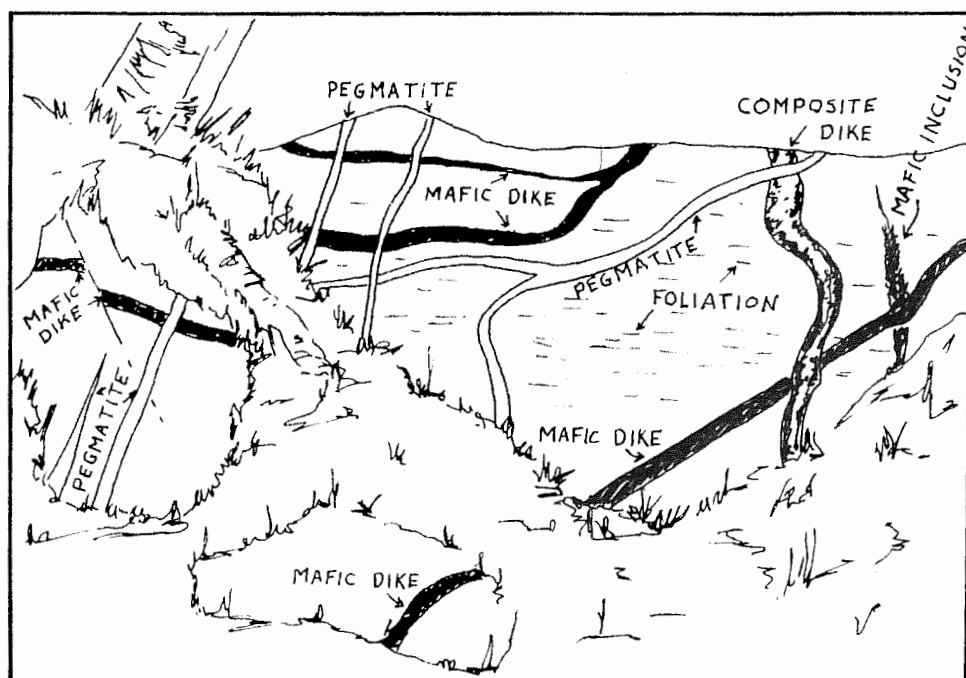


Figure 27. Sketch of an outcrop of hornblende-biotite granodiorite showing dike sequence and relationships. Location is at the crest of the hill crossed by Summit Street, 3300 feet south-southeast of Highway 202.

feldspar and minor muscovite. A quartz-rich body, located at the top of the hill on Summit Street southeast of U. S. Highway 202, contains scattered, large crystals of feldspar. Large pegmatites related to regional metamorphism are located throughout the metamorphic rocks of the Quabbin Reservoir area and those found in the Belchertown Complex are probably similar in history. It may be, however, that some pegmatites in and marginal to the Belchertown batholith are related to residual liquids of the batholith itself.

TRIASSIC ROCKS

Sedimentary and volcanic rocks of Triassic age are exposed in the northwest corner of the Belchertown area. They are in fault contact with the Belchertown Intrusive Complex and Pelham Gneiss. The Triassic rocks of this part of the Connecticut Valley have been mapped by Emerson (1917) and Bain (1941). The maps generally agree with each other except in the Metacomet-Arcadia Lakes area. Emerson (1917) shows Triassic rocks east of Bachelor Brook, whereas Bain (1941) does not. The writer located several outcrops of Triassic rocks east of Bachelor Brook.

Sedimentary Rocks

The sedimentary rocks of the Belchertown area consist mostly of pebble conglomerate with interbedded, well bedded, coarse red sandstone and cobble conglomerate that probably correlate with the Longmeadow Sandstone. The pebbles and cobbles are fairly rounded but poorly sorted. The cobble conglomerate predominates near the border fault, but farther from the fault the rocks consist of interbedded coarse sandstone and pebble conglomerate.

Examination of the pebbles and cobbles of the conglomerate showed a wide representation of metamorphic, igneous and pegmatite rocks. Rock types of the Belchertown Intrusive Complex, however, were not observed. This may mean either that the Belchertown Intrusive Complex was not unroofed at the time of deposition or that the Belchertown material in the general area was eroded, transported and deposited at another location.

The sedimentary rock unit north of the Holyoke Basalt is the Sugarloaf Formation, as shown by Bain (1941).

Volcanic Rocks

Interbedded with the sedimentary units are volcanic rocks. The Holyoke Basalt and Granby Tuff are exposed in the northwest corner (taken from Bain's map, 1941). The Holyoke Basalt consists of at least two flows (Bain, 1941) and is only about 100 feet thick in this area.

Stratigraphically above the basalt, and interbedded in the Long-meadow Sandstone, is a tuffaceous unit, the Granby Tuff. Bain (1941) described the Granby Tuff as being partly agglomerate with lava flows. In the eastern portion of the Triassic rocks, adjacent to the border fault, the Granby Tuff, as mapped by the writer, consists mostly of a fine ash with some lapilli. A small lava flow about 10 feet thick was also found interbedded with the tuff.

STRUCTURAL GEOLOGY

The principal regional structural features present in the area of the Belchertown Intrusive Complex are the Pelham and Glastonbury gneiss domes, and the main body of the Monson Gneiss (Figure 3). The Pelham dome and Monson Gneiss are separated by the Pelham-Shutesbury syncline, an unnamed gneiss anticline, and the Great Hill syncline. The Glastonbury dome is flanked on the east by the Great Hill syncline and on the west by the Wilbraham syncline. The Belchertown Intrusive Complex is intruded between the Pelham and Glastonbury domes. In its northern portion it truncates the southern end of the Pelham dome, the Pelham-Shutesbury syncline, the unnamed anticline, and the west limb of the Great Hill syncline. At the south end it is apparently concordant with mantling strata on the north end of the Glastonbury dome (D. J. Hall and Peter Robinson, personal communications, 1970).

Foliation in the Belchertown batholith is weakly developed except near the contacts and at local areas within the batholith where the rocks are highly schistose. Exposed contacts appear concordant, but map relationships show that the northern contact of the batholith is regionally discordant with the structure of the metamorphic rocks.

Several stages of deformation have been recognized in the Belchertown area by previous workers (Robinson, 1963, 1967a, b; Halpin, 1965). They are as follows:

1. An early stage of recumbent folding. This is expressed by regional nappe structures and local recumbent folds. All stratigraphic units, including the dome gneisses, were involved in the local folding. Any minor structural features formed during this stage have

been almost completely obliterated by later deformation. In the Belchertown area, the Pelham-Shutesbury syncline and the unnamed anticline were formed during this stage.

2. A main stage of deformation and regional metamorphism. At this time the north-south trending regional structures, including the Pelham and Glastonbury gneiss domes, the main body of Monson Gneiss, and the Great Hill syncline, were formed, as well as the general mineralogy and lineation of the metamorphic rocks. Structural features of the first stage were refolded. The Prescott Complex was intruded during this stage (Makower, 1964; Robinson, 1967a), while the Belchertown Intrusive Complex probably was intruded in the later part of this deformation.

3. A late stage of local deformation. In the Quabbin Hill area steep southeast-plunging folds were formed. These folds deformed lineations and minor fold axes of the second stage (Halpin, 1965; Robinson, 1967b). The retrograde metamorphism prevalent in some of the metamorphic rocks probably occurred during this period. The dikes near the Spillway stock were folded in this phase but also probably in phase two.

4. Triassic normal faulting and related hydrothermal alterations. At this stage the rocks reacted in a brittle manner, forming faults. Local retrograde metamorphism, probably due to hydrothermal activity, was produced in and near these structures.

Structural Features of Metamorphic Rocks

In the present study the structural features of metamorphic rocks were examined in three areas: east of the Belchertown Complex on Quabbin Hill and to the south; in the Partridge schist septum within the Belchertown batholith; and in the southern part of the Pelham Gneiss dome. The structural geology of Quabbin Hill has been described in detail by Halpin (1965) and will be treated only briefly here.

The belt of metamorphic rocks running through Quabbin Hill exhibits strong foliation and lineation. The foliation generally is parallel to the relict bedding and is defined by the parallel orientation of platy, acicular or flattened mineral aggregates. The lineation is formed by the parallel orientation of prismatic minerals or the smearing out of mica, quartz or feldspar clots. In general, the foliation of the metamorphic rocks east of the Belchertown Intrusive Complex strikes north-south and dips steeply east, except in the structurally complex Quabbin Hill area and in the area surrounding the Spillway stock (Figure 31c).

The Spillway stock, elongated N20E, has intruded the granulite unit of the Erving Formation. The foliation strikes roughly parallel to the stock and dips steeply away from it (Figure 22). The structure at the north end of the stock is that of a north-plunging anticline. At the southern end the granulite appears to dip under the stock, and the contact has a form similar to a syncline (Figures 28 and 29).



Figure 28. Granulite of the Erving Formation dipping gently northwest beneath quartz diorite of the Spillway stock at the south end of the spillway. The contact and foliation are parallel.

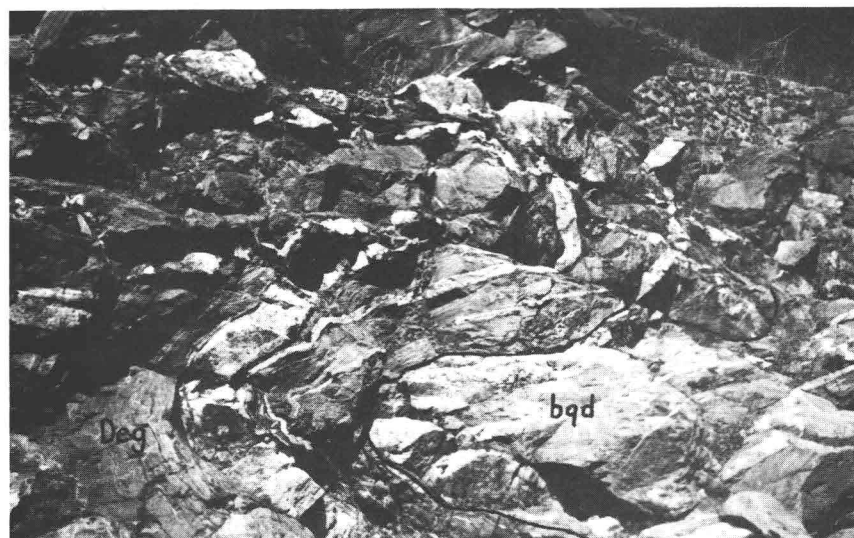


Figure 29. Folded contact between the quartz diorite of the Spillway stock and the granulite of the Erving Formation. At the southwest corner of the stock at the south end of the spillway.

The lineations developed in the metamorphic rocks east of the Belchertown Complex are fairly uniform, trend generally north-south and plunge gently northward (Figure 32c). Two sets of minor folds are present near Quabbin Hill (Halpin, 1965; Robinson, 1967b): a first set, trending north-south and plunging north, formed during the main stage of deformation with axes parallel to the lineation; and a second set, related to the third stage of deformation, consists primarily of steep southeast-plunging chevron folds west and north of Quabbin Hill. The lineations formed during the main stage of deformation are wrapped around these later folds.

The rocks of the Partridge Formation of the septum show a change in their foliation and lineation from north to south. At the north end they are well foliated and lineated. Southward the rock becomes less schistose and more gneissic, and the lineation is either obscured or absent. In the septum the foliation generally strikes N30E and dips steeply to the west (Figure 31c). The lineation trends north-south and plunges north (Figure 32c). Comparison of the foliation of the septum and the metamorphic rocks east of the complex indicate two differences: the strike of the foliation of the septum is northeast rather than north, and the dip of the foliation of the septum is west rather than east.

Balk (1940) believed that the contact of the Belchertown Complex and the Pelham Gneiss dome was concordant and that the foliation of the igneous rocks wrapped around the southern end of the dome. The writer's mapping indicates that a zone of intrusive breccia lies between the igneous rocks and the Pelham Gneiss. The foliation of the

igneous rock, in the few places where it is exposed, is concordant to the contact, but discordant to the Pelham dome structure (Plate 1). Foliation in the Pelham Gneiss generally strikes N40W along the southwest side of the dome and dips moderately southwest (Figure 30a), but there are local variations, especially near Allen Street, just west of U.S. Highway 202. Exposures of Pelham Gneiss northeast of Belchertown are very poor and the general attitude is unknown, but in one outcrop at the corner of Jabish Street and Allen Street, the foliation dips gently southeast, suggesting a closure on the south end of the dome. The equal-area plot of foliation poles (Figure 30a) does not indicate any great change in the foliation, but is probably more a reflection of the paucity of data than the true structural picture. The plot of lineation indicates variable attitudes (Figure 30b).

The inclusions of metamorphic rocks in the quartz diorite and granodiorite of the batholith exhibit most of the same structures as the country rocks. The attitudes of the foliation and lineation, when compared to the regional attitudes of the country rock (Plate 1), suggest rotation of these rocks from their original positions.

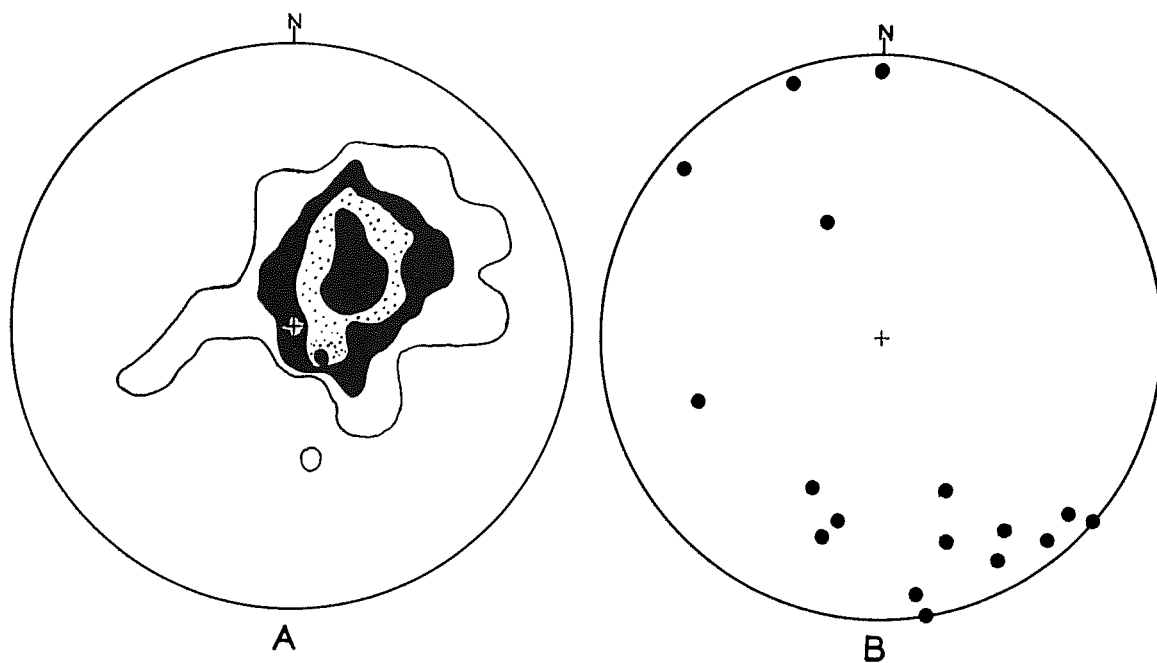


Figure 30. Lower hemisphere equal-area projections of measurements from the Pelham Gneiss.

A. 80 poles of foliation. Contours 0, 3, 6, and 10 percent per 1 percent area.

B. 17 mineral lineations.

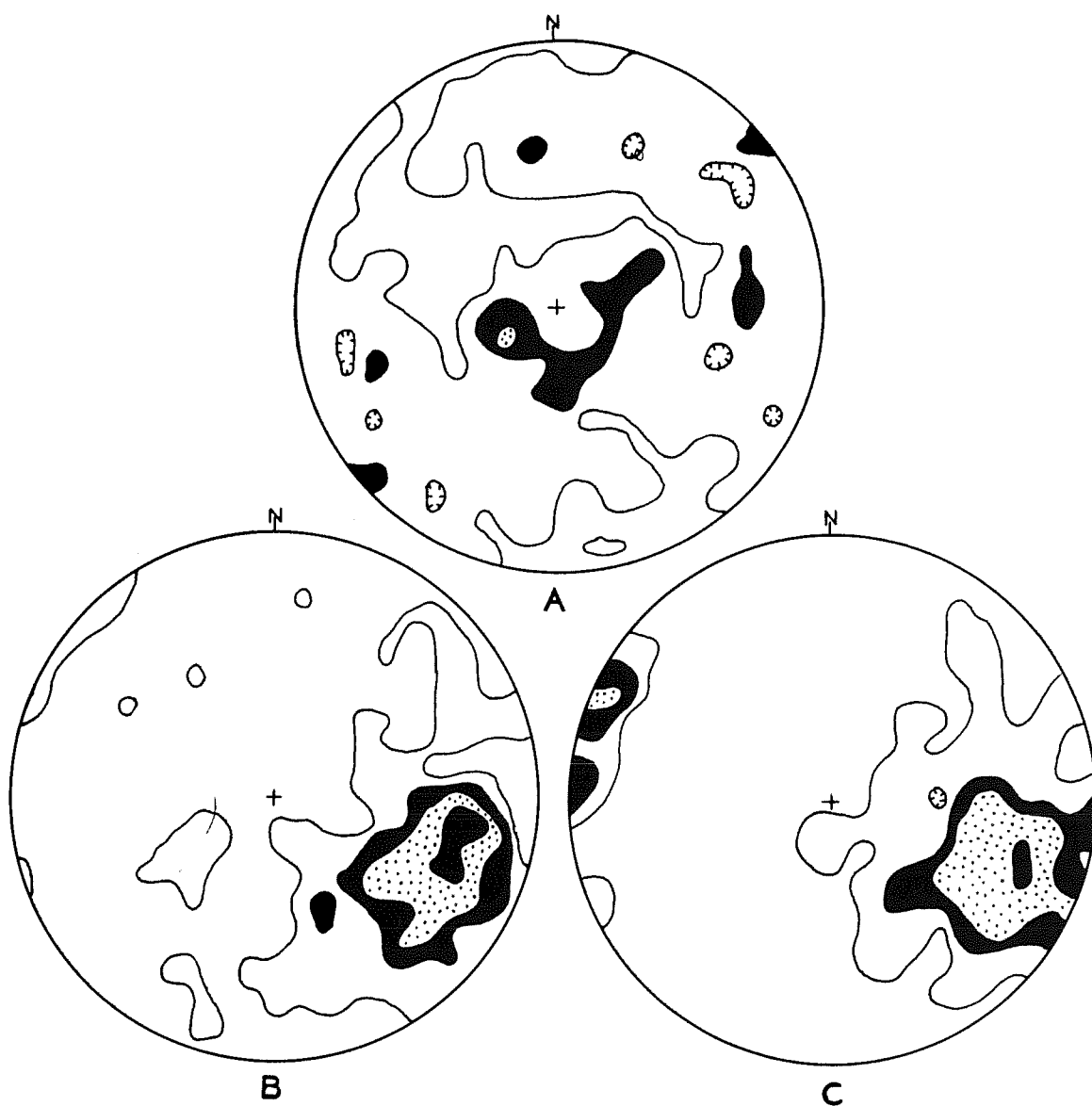


Figure 31. Contoured lower hemisphere equal-area projections of poles of foliation in batholith and country rocks. Contours 0, 3, 6 and 10 percent per 1 percent area.

A. 133 poles of foliation measured in the Belchertown batholith, excluding the schistose border zone.

B. 127 poles of foliation measured in the Quabbin Spillway stock and schistose border zone of the Belchertown batholith.

C. 103 poles of foliation measured in the Partridge schist septum and in granulite of the Erving Formation surrounding the Quabbin Spillway stock.

Note similarity between B and C.

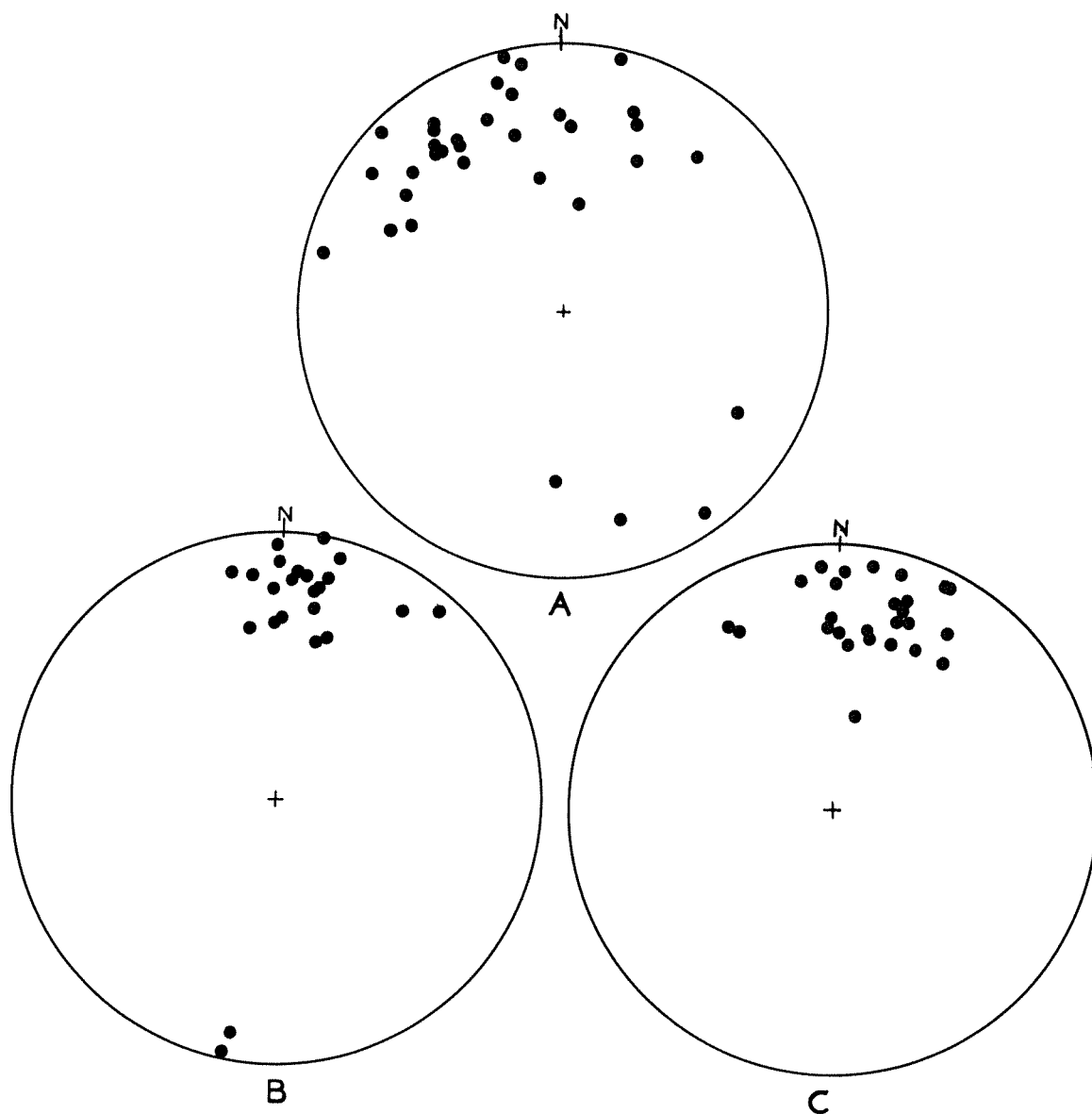


Figure 32. Lower hemisphere equal-area projection of mineral lineations in batholith and country rock.

A. 34 lineations measured in the Belchertown batholith, excluding the schistose border zone.

B. 23 lineations measured in the Spillway stock and schistose border zone of the Belchertown batholith.

C. 26 lineations measured in the Partridge schist septum and the Erving Formation surrounding the Spillway stock. Note similarity between B and C.

Structural Features of Igneous Rocks

Foliation and lineation. The quartz diorite and granodiorite of the batholith exhibit foliation and lineation developed by the preferred orientation of hornblende, biotite, aggregates of hornblende and biotite, or aggregates of quartz and feldspar. The foliation is moderately developed in most of the rocks, but ranges in character from a strong pervasive schistosity to a faint planar orientation of mineral aggregates. Well foliated rocks occur near the borders of the batholith and are best exposed on Hannum Street, just east of the Central Vermont Railroad underpass; along the Partridge schist septum; in a small stream outcrop east of Swift River; and in the Spillway stock (Plate 2). One well exposed zone of schistosity, 60 to 150 feet wide, is along the west side of the Partridge schist septum. The schistosity is defined by strong orientation of the ferromagnesian minerals, predominantly biotite, and the orientation of aggregates of quartz and plagioclase (Figure 10). Orientation decreases away from the contact and schistose rocks grade into moderately foliated rocks. The moderately foliated rocks of the outer part of the batholith grade into the more massive, poorly foliated, interior portion of the batholith. Minor areas of very well foliated rock also occur locally within the batholith, particularly in the western part. These may have been areas near inclusions or roof pendants since removed by erosion, or they may be areas of rock that were intruded earlier and suffered strong tectonic deformation (Guthrie and Robinson, 1967). Lineation caused by the orientation

of ferromagnesian aggregates is well developed in the schistose rocks, but becomes poorer in the moderately and poorly foliated rocks.

The attitudes of foliation and lineation in the quartz diorite and granodiorite are quite variable. Comparisons of these attitudes in the massive central portion, the schistose margins, and the metamorphic country rocks (Figures 31 and 32) brings out an important point: attitudes of foliation and lineation in the schistose borders of the intrusive complex are nearly identical to those in the adjacent country rock and quite different from those in the more massive part of the batholith. This difference is more striking in the case of foliation than lineation, possibly because lineation could only be measured in the most strongly foliated portion of the massive core, principally in the area west of Belchertown. At some localities between the schistose borders and the massive core there are rocks showing two foliations: a weak, possibly primary foliation parallel to the foliation of the inner igneous rocks, and a superimposed secondary foliation parallel to the foliation of the schistose borders and the country rocks.

Elongate to rounded xenoliths of metamorphic rocks, oriented parallel to the foliation, occur near the contact of the igneous and country rocks. The best example is in the Spillway stock (Figures 23 and 25). The xenoliths trend north-south parallel to the foliation, and plunge gently north. There are also small autholiths, predominantly of hornblende, generally oriented parallel to the foliation. These are not restricted to the margins, as are the xenoliths, but also occur within the batholith.

The hornblendite bodies which are peripheral to the batholith are mostly massive, but some exhibit local, moderately to poorly developed foliation.

The intrusive breccia, peripheral to the northern portion of the Belchertown Intrusive Complex, consists of fragments of metamorphic rocks in a matrix of diorite. The fragments exhibit internal layering and foliation, but these structures do not show a continuity in attitude from fragment to fragment (Figures 20 and 21), indicating the fragments have been rotated and transported. Some elongated fragments have an external preferred orientation. The diorite matrix shows little or no structure in some localities. Elsewhere the diorite shows flow foliation due to orientation of inclusions parallel to dike walls.

The generalized structural map (Figure 33) of the Belchertown batholith suggests two types of folds in the foliation of the massive central portion: 1) a large dome possibly related to the intrusion of the magma, and 2) small folds that probably are due to later tectonic events. Only one small fold, an anticline, was observed in the field.

Orientation of dikes and joints

Joints in the quartz diorite, granodiorite, and peripheral country rock are occupied either by pegmatite and aplite dikes, or by thin coatings of secondary minerals. In the batholith the dikes trend mainly northeast, dip steeply westward, and transect the foliation (Figure 34). In the Spillway stock the dikes generally trend northeast and dip fairly steeply west, nearly parallel to the foliation (Figure 22). Dikes in the country rocks occur close to the contacts and are generally

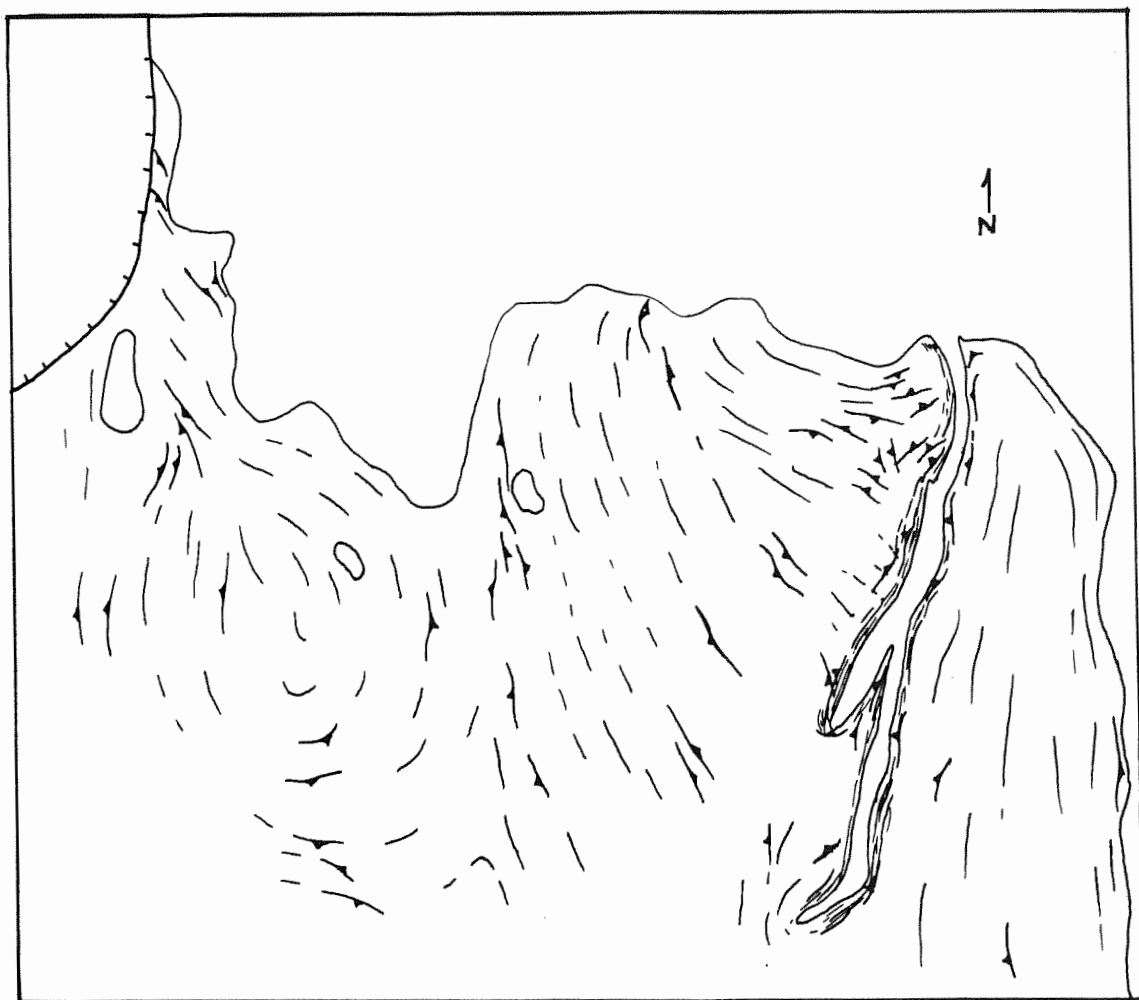


Figure 33. Sketch map of the Belchertown batholith showing the generalized strikes and dip directions of the foliation.

parallel to the strike of the foliation. The width of the dikes varies from less than an inch to several feet. Most of the dikes are structureless internally, but some of the granite pegmatites show foliation that is parallel to the dike walls.

The dikes which occur in the batholith exhibit the following trends: N10E, N30E, N60E, and N60W (Figure 35b), the last being poorly developed. The dips are primarily to the northwest, but a few are in other directions. Dike attitude appears related to location within the batholith (Figure 34). In the northeastern portion all dikes strike



Figure 34. Sketch map of the Belchertown batholith, showing the approximate attitudes of dikes.

northeast and dip west. Those dikes near the septum are generally parallel to the foliation. In the northwest portion the dikes tend to strike northwest and dip southwest. Those toward the inner portion of the batholith do not exhibit a preferred direction and are less abundant than at the margins. The dikes in the batholith occur as straight or irregular bodies, rarely folded.

Dikes are very well shown in the Spillway stock. The major trends are N10E and N30E, similar to those in the batholith (Figure 35A).

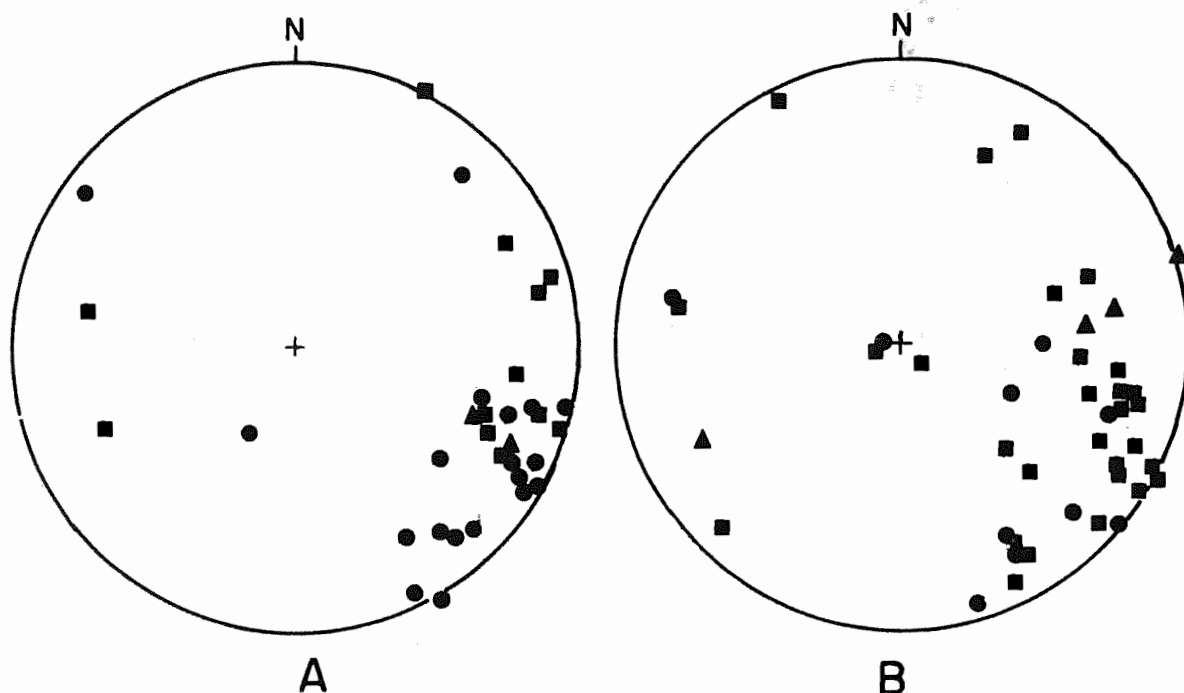


Figure 35. Lower hemisphere equal-area diagrams of dikes and joints. Circles - joints and aplite dikes, squares - pegmatite dikes; triangles - mafic and diorite-aplite dikes.
 A. 35 poles of dikes and joints from the Quabbin Spillway stock.
 B. 48 poles of dikes and joints from the Belchertown batholith and Partridge schist septum.

The N60E trend is, however, not so prevalent, and several other minor trends are also present. The dikes dip predominantly to the northwest (Figures 24 and 35A), but a minority of the dikes near the contacts dip very gently into the contact. Quartz veins and minor veneered joints which cut across all the other structural features are also present in the stock. They trend about N30E and dip steeply to the west.

In the Erving Formation granulite, which surrounds the Spillway stock, pegmatite and aplite dikes are abundant near the contact. Away from the stock the abundance of dikes diminishes. Many of the dikes

in the quartz diorite do not seem to continue into the granulite. However, the gently dipping dikes, which dip into the contact, appear to extend into the granulite. Dikes or sills in the granulite are intensely folded, whereas those in the quartz diorite show little or no folding (Figure 32), except in the immediate vicinity of the contact.

In the Partridge schist septum most of the aplites and pegmatites measured are sills. Several large sills of quartz diorite were also mapped (Plate 1). These are probably similar to but smaller than the lobe of granodiorite which splits the inclusion at Cold Spring. Several aplite dikes were found which crosscut the schist (Figure 26). They contain fragments of schist and granodiorite. Several steeply dipping pegmatite bodies trending approximately N25W crosscut the structure (Plate 1).

Structure of Triassic Rocks

The Triassic sedimentary and volcanic rocks in the northeast corner of the map west of Bachelor Brook strike N35E and dip southeast. The dip varies from almost vertical (87°) at Arcadia Lake to 47° about one mile southwest of Metacomet Lake. The rocks east of Bachelor Brook strike predominantly north-south and dip variably to the west (Plate 1).

Faulting is a dominant Triassic structural feature. The contact between the Triassic rocks and Paleozoic metamorphic and igneous rocks is the Triassic Border Fault of the Connecticut Valley. The major movement has been down on the west side relative to the east side.

From exposures farther to the north (Keeler and Brainard 1940), a 60° west dip for the fault plane is inferred (Plate 3).

The trace of the border fault in the vicinity of the Belchertown Complex is peculiar. West of the Pelham dome (Figure 3) the fault is straight and trends about N20W (Robinson, 1967a). Just north of Metacomet Lake, off the mapped area, the fault trends of N50W. At Metacomet Lake the fault trends almost north-south and about two miles farther south it trends N55E (Plate 1). West of the center of the Belchertown batholith the fault again trends north-south (Figure 3). These deviations of the fault could be controlled by the original shape of the batholith, but this is by no means certain.

A second fault, which follows the valley of Bachelor Brook, has been inferred by the writer (Plates 1 and 3). This inference is based on the differences in dips of the sedimentary rocks, the linear character of the Bachelor Brook Valley, and the occurrence of tuffaceous rock east of Bachelor Brook and its absence close to the fault on the west side.

There are several vertical faults of small right-lateral separation that cut and displace the basalt flows (Plate 1). Bain (1941) considered these faults to be related to compression and flexure caused by the southward and upward movement of the eastern portion of the Triassic Basin and believed that this movement accounts for the steepening of dip as the edge of the basin is approached.

In the igneous and metamorphic rocks the writer observed several silicified zones which are probably related to faults.

These zones could not be traced more than a few feet due to lack of exposure but are believed to be due to brittle deformation during the Triassic. These faults were also avenues for hydrothermal solutions and may be responsible for some of the alteration noted.

MINERALOGY

Minerals in Metamorphic Rocks

Muscovite. In the Partridge Formation of the septum two types of white mica were identified: primary metamorphic muscovite, and secondary sericite. The primary muscovite occurs as large single crystals or clusters of crystals, usually oriented parallel to the foliation. It is most abundant at the north end of the septum and decreases in abundance southward (Table 2). The secondary sericite occurs as aggregates of small unoriented grains. Much of the sericite appears to be altered sillimanite because it forms rims around sillimanite crystals (Figure 6) or pseudomorphs after sillimanite. A minor amount of sericite occurs in small clusters along altered shear zones.

Biotite. The biotite in the Partridge schist septum is reddish-brown in color and is partially or entirely replaced by optically positive and negative chlorite. The biotite appears to be finer grained in the southern part of the septum than in the northern part.

The biotite in the Pelham Gneiss occurs as medium, tabular, well-oriented, olive-green crystals. Very little retrograde metamorphism of the biotite to chlorite has occurred.

Garnet. Garnet is fairly abundant in the Partridge schist septum (Table 2), but is very minor in the Pelham Gneiss (Table 1). The garnets in the Partridge schist are fine to medium, clear, reddish, anhedral, poikilitic grains with inclusions of quartz, opaques and

biotite. In the northern to central portion of the septum, acicular sillimanite commonly occurs as inclusions. In some specimens this is the only place in which the sillimanite has not been replaced by sericite. In the southern portion of the septum the garnets commonly exhibit a preference for grouping around or alongside the large sillimanite crystals (Figure 6). Retrograde metamorphism has not affected the garnets very much, but some show replacement along fractures by optically positive chlorite, hematite, sericite and possibly biotite. In the Pelham Gneiss the garnets occur as fine, clear, light-brown, euhedral crystals with inclusions of quartz or feldspar.

Staurolite. Staurolite occurs as small euhedral, locally poikilitic crystals with inclusions of quartz and plagioclase in the northern half of the Partridge Formation septum. Staurolite appears to become finer grained, less abundant and more irregular in shape as far south as Station B-40, located on the west prong of the inclusion (Plate 2). It has not been found farther south. The absence of staurolite in the southern part could be due to a change in the bulk composition of the schist, but more probably it reflects a higher temperature of metamorphism.

Aluminum silicates. The Partridge Formation septum contains kyanite and sillimanite. The kyanite is restricted to the northern third of the septum, occurring as medium-grained euhedral crystals, commonly partially replaced by sillimanite (Figure 6). In the Belchertown area sillimanite occurs only in the Partridge schist septum.

In the northern part of the septum it occurs as acicular crystals, commonly in swirling, felted masses where it has not been altered to sericite. In the southern third of the septum the sillimanite occurs as large prismatic crystals up to an inch in length and about 1/5 inch in width. The peculiar mosaic pattern of these crystals, when viewed under crossed nicols in sections normal to the c-axis, has led Rosenfeld (1969) and Robinson (personal communication) to suggest that these large crystals were originally andalusite, subsequently inverted to sillimanite. The occurrence of sillimanite and possibly andalusite in what is regionally the kyanite zone indicates the role that the heat derived from the intrusion of the Belchertown batholith has played. The relations of the aluminum silicates in this one septum suggest that, at some time in their history, rocks of the septum must have undergone conditions of the aluminum silicate triple point at about 620°C and 5.5kb (Richardson et.al, 1969), but the exact sequence of events is not yet clear.

Chlorite. Chlorite, the most common retrograde mineral in the Partridge schist septum, is an alteration product of biotite, garnet and, to a lesser extent, staurolite. It occurs as fine to medium, irregularly shaped, pleochroic, pale-green crystals, commonly partially or completely replacing biotite or along fractures in garnet. The interference color varies from abnormal blue through an isotropic state to abnormal brown to gray green. Albee (1962) points out that chlorites of most associations pass through an isotropic state at an Fe/Fe+Mg ratio of 0.52. Those with a negative optic sign, positive

elongation and abnormal blue interference colors are more Fe-rich than 0.52. Those with a positive optic sign, negative elongation and abnormal brown interference colors are less Fe-rich than 0.52. The chlorites of the septum are generally close to the isotropic state, but show some abnormal blue and brown interference colors with brown predominating. Thus their Fe/Fe+Mg ratio lies close to 0.52 and may average 0.50 or lower.

Minerals in Igneous Rocks

Calcic pyroxene. Calcic pyroxene occurs in some of the hornblendite bodies and in the granodiorite in the central portion of the batholith. Optical properties of the pyroxenes in these two rock types indicate some differences in their compositions. The pyroxene in the hornblendite is colorless in thin section, has a 2V of about 60° and a $Z \angle C$ of $40-45^{\circ}$, and is believed to be diopside by the writer. The calcic pyroxenes in the granodiorite are pale green in thin section, medium to dark green in hand specimen, and appear to have a 2V around 50° . They are here referred to as augite. They are commonly rimmed or almost completely replaced by hornblende, and commonly occur as remnant fragments within the hornblende (Figure 14). Some of the augites exhibit oriented opaque inclusions (Figure 14) which may represent exsolution of ilmenite or rutile.

Hornblende. There appear to be two kinds of hornblende in the quartz diorite and granodiorite of the Belchertown batholith: primary crystals formed from the magma, and replacements of primary pyroxene. Medium-sized subhedral grains that are generally free of inclusions

and have an even, clear color are interpreted to be primary.

Aggregates of medium-sized anhedral grains of irregular shape, variable color, and containing numerous inclusions of quartz (Figure 13) are considered to be secondary. In the augite-bearing granodiorite the color of the hornblende adjacent to the pyroxene is lighter in color than the remaining hornblende. The opaque inclusions of the augite tend to disappear when hornblende has replaced the augite, although the formation of associated sphene may be related to the disappearance of the opaque inclusions.

In the hornblendites the hornblende is paler and has lower relief than hornblendes of the quartz diorite and granodiorite, suggesting a lower iron content.

Biotite. The color of biotite is generally olive green, but varies from olive to brownish green to tan and brown. Brown biotite occurs in the south-central portion of the Belchertown area, particularly in the augite-bearing granodiorite. Deer, Howie and Zussman (1966) point out that the color of biotite is related to the relative amounts of titanium and ferric iron. Reddish-brown color is due to a high relative titanium content, while green indicates a high relative ferric iron content. An intermediate proportion of titanium and ferric iron can result in greenish-brown or yellowish color. Biotite within the marginal quartz diorite and granodiorite is fine-grained and tabular, has a good preferred orientation, and is generally the only ferromagnesian mineral present within a few feet of the contact. Toward the center of the batholith, biotite becomes coarser

and occurs as ragged to tabular grains without good preferred orientation. There may be two generations of biotite, truly magmatic and post-magmatic. The truly magmatic biotite occurs as large, well-formed poikilitic flakes, while the more abundant post-magmatic biotite occurs as finer grained aggregates.

Biotite in granodiorite and, to a slight extent, in hornblendite appears to have partially replaced hornblende because it is intergrown with, surrounds, or occurs as clusters within the hornblende.

Plagioclase. The composition of the plagioclase in quartz diorite and granodiorite was obtained by using the Michel-Levy method of extinction angles in thin sections. The composition ranges from An_{23} to An_{47} with An_{34} being the average. The average An content in the central portion of the batholith is higher than at the margins (Table 5; Plate 2). Plagioclases within a few feet of the contact of the septum of Partridge Formation are more calcic (An_{42-47}) than those in the same area farther away (An_{32-37}).

The comparison of the composition of the plagioclase with the amount of epidote for a given rock (Figure 36) shows that, with a decrease in the amount of epidote present within the rock, there tends to be an increase in the calcium content of the plagioclase. This may be why the plagioclase of the outer zone is lower in calcium content than the plagioclase in the inner zone.

The untwinned plagioclases of the hornblendites are biaxial positive, have a large 2V, and have a moderate positive relief compared to balsam. Because of this they are regarded as labradorite.

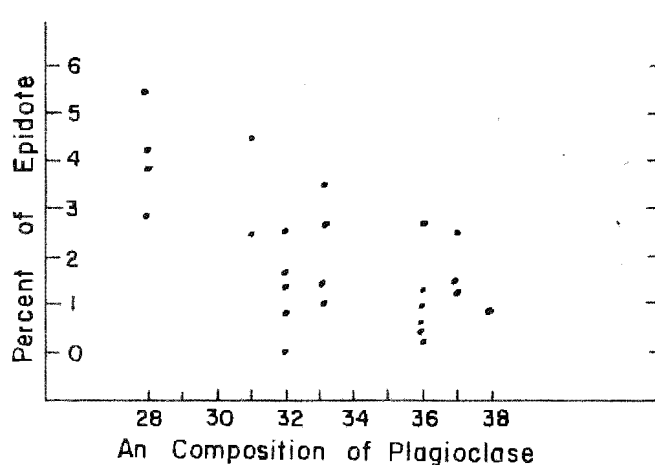


Figure 36. Plagioclase composition in mole % anorthite plotted against modal percentage of epidote in quartz diorites and granodiorites from the Belchertown batholith. Rocks with lower anorthite content in plagioclase tend to have more epidote.

In the meladiorites the plagioclases that are twinned have compositions in the andesine range.

Microcline. Microcline is variable in amount (0-13 percent, Table 5), grain size and shape. In the outer portions of the batholith the microcline occurs as minor, fine, interstitial grains. Inward, into the batholith, the microcline increases in amount. Along the outer portions of this inner zone the microcline occurs as fine to medium grains. The grains are interstitial, but the larger grains exhibit a perthitic structure (Figure 11). Farther into the batholith, microcline appears as medium grains still exhibiting a perthitic structure. It also exhibits an irregular shape, as if it may be replacing the plagioclase, since it sends lobes into and, in some cases, contains portions of the plagioclase (Figures 11, 13 and 15).

PETROGENESIS OF THE BELCHERTOWN INTRUSIVE COMPLEX

The history of emplacement of an igenous body is recorded in its relationship to the surrounding country rock, its internal fabric and its mineralogy. Modification by assimilation and later metamorphism can, however, obscure and complicate these relationships. In order to understand the petrogenesis of the Belchertown Intrusive Complex, its physical and petrographic features will be reviewed and discussed.

Emplacement Sequence

The Belchertown Intrusive Complex consists of four separate but related major rock types: hornblendite, quartz diorite and granodiorite, intrusive breccia, and dike rocks.

Hornblendites occur in small peripheral bodies. Although actual contacts were never observed the hornblendite apparently intrudes the metamorphic rocks and is in turn intruded, brecciated and partially assimilated by the quartz diorite. The pale color of the hornblende and diopside in the hornblendite suggests a high magnesium content, consistent with other indications that the hornblendite formed early in the magmatic sequence.

The quartz diorite-granodiorite batholith and subsidiary stocks followed the hornblendite and intruded a much larger area of metamorphic rocks. Some of the contacts with the metamorphic rocks are concordant, but there is gross discordance along the northern contact. The hypautomorphic-granular texture, the foliation, and the contact structures indicate that the batholith and stocks were intruded

as a magma. The rock does exhibit a strong metamorphic texture locally, especially in the stocks and in the narrow zone parallel to the contact of the batholith and country rock. At the contacts the foliation is concordant, but away from contacts it becomes discordant and less well developed (Figures 33 and 34). Autoliths and xenoliths, generally oriented parallel to the foliation, are most abundant near the contacts and decrease into the batholith.

Formation of intrusive breccia was contemporaneous with the emplacement of the batholith and stocks. It consists of angular blocks of hornblendite, granulite, bedded hornblende amphibolite (Figures 20, 22 and 23) and minor amounts of other metamorphic rocks set in a matrix of quartz diorite and cut by dikes of diorite, aplite and pegmatite. The fluid nature of the matrix and dikes is indicated by the rotated and rafted fragments (Figures 22 and 23). The inclusion of foliated metamorphic rocks as disoriented fragments is strong evidence that the intrusion occurred late in the regional metamorphism.

Following the emplacement of the batholith and stocks, dikes of fine-grained diorite, mafic rock, aplite and pegmatite were formed, generally in that order. The dikes were emplaced into the outer, solidifying portion of the magma and into the marginal country rock. The joints into which the material was emplaced were formed either by tectonic stresses of regional nature or local stresses related to the batholith (Balk, 1937). The fact that many of the dikes, including all but the latest pegmatites, have been deformed shows that the batholith, stocks, and dikes were all intruded before the end of regional deformation and metamorphism.

Mechanisms of Emplacement

The mechanisms of emplacement are believed by the writer to have been both forceful intrusion and stoping. Forceful intrusion is suggested by the outline of the Partridge schist septum, features of the Spillway stock, and regional relations (Figure 37). Stopping is indicated by the presence of the intrusive breccia.

The Partridge Formation of the septum originally lay on the west limb of the Great Hill syncline (Figure 37). During batholith intrusion it was apparently forced westward. The Erving Formation that originally formed the center of the syncline was removed. During westward bending of the septum, the dip of foliation in the schist was also changed, through the vertical, from east to west (Plates 1 and 3). The double-pronged shape at the end of the septum also indicates the forcing apart of the schist by the intrusive rocks, as do the small sills of quartz diorite within the septum.

The contacts of the Spillway stock are generally concordant and the foliation of the surrounding granulite wraps around it (Plate 1; Figure 22). The stock appears to have pushed its way into the granulite, forcing the granulite up and away from it as the stock was intruded (Plate 3, Figure 22). However, the observed structural features are also consistent with later solid-state deformation of relatively rigid intrusive rock enveloped in more plastic country rock.

The stoping mechanism is indicated by the presence of peripheral intrusive breccia and inclusions formed by the fracturing of the metamorphic rocks and the injection of magma. The magma has pried the

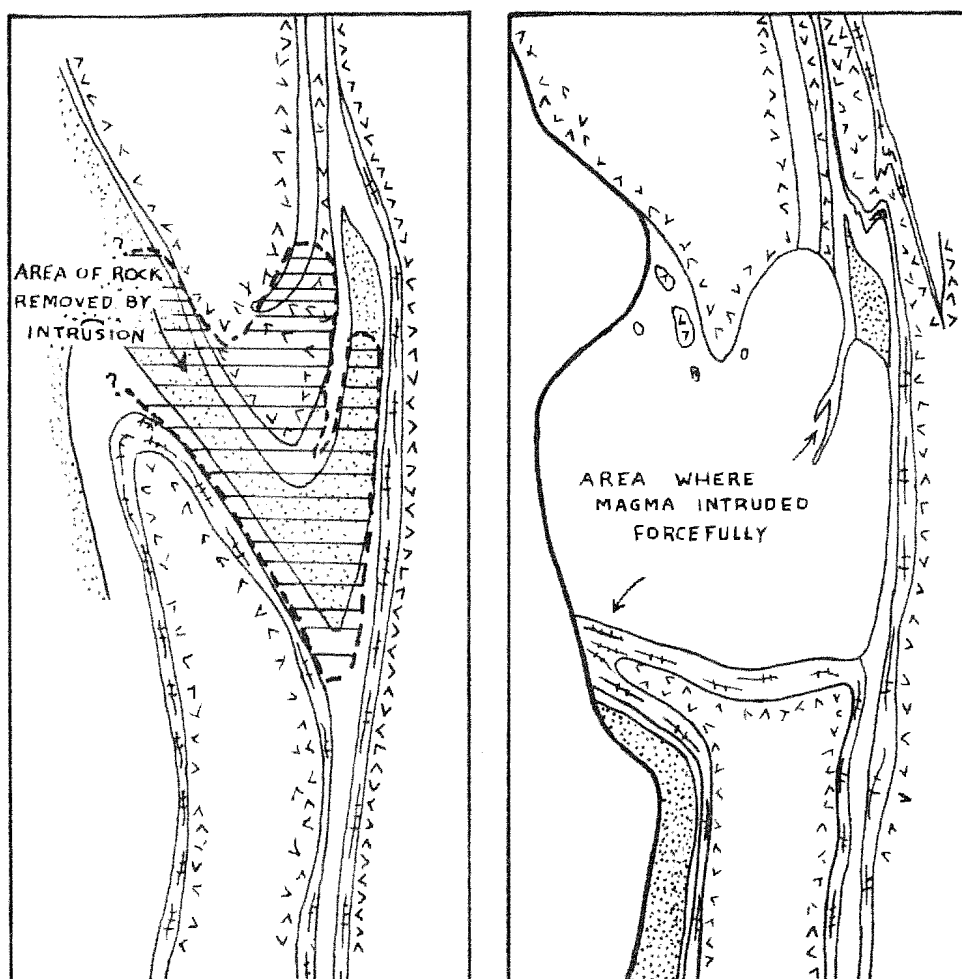


Figure 37. Sketch maps comparing reconstructed metamorphic terrain before the intrusion with the area after emplacement of the Belchertown batholith.

rocks apart and has either assimilated many fragments or they have sunk. The inclusions may represent large blocks stoped from the roof or edges of the batholith (Plates 1 and 3). Most of the intrusive breccia fragments and inclusions are amphibolites and hornblendites which seem to have been more easily broken loose and less susceptible to subsequent assimilation. The Partridge Formation schist seems to have been resistant both to brecciation and assimilation, hence best shows the effects of forceful intrusion. The granulite of the Erving Formation behaved plastically in some places, in a brittle manner in others.

but on the whole seems to have been very susceptible both to removal by stoping and strong mineralogical alteration. It may be safely assumed that granitic fragments of the Pelham Gneiss were capable of nearly complete solution in the Belchertown magma.

Mineralogic History

The batholith of the Belchertown Complex contains three crudely concentric zones of quartz diorite and diorite, granodiorite, and augite-bearing granodiorite. It would appear that the mineralogy of these rocks is the product of three different processes: direct magmatic crystallization, reactions between previously formed minerals and residual fluids, and regional metamorphism. Since it is probable that intrusion took place during regional metamorphism, the results of the different processes are extremely difficult to distinguish.

The sequence of crystallization from the magma, as described below, is based on the mineralogy and texture of the rocks from the augite-bearing granodiorite zone, because these rocks exhibit the least modification of their igneous textures. Augite and plagioclase crystallized first, with the augite probably starting just before and ending sooner than the plagioclase. The augite occurs, where unaltered, as euhedral crystals (Figure 14), and the plagioclase continued its crystallization into the last stages (Figure 9). Hornblende began to crystallize part way through the crystallization of the plagioclase, and some biotite probably crystallized concurrently with the hornblende, as is indicated by the scattered large, subhedral crystals. Hornblende and biotite are also secondary minerals.

Hornblende has replaced the augite, while biotite has replaced hornblende and, rarely, augite. Quartz and microcline occur last in this crystallization sequence. The quartz always occurs as interstitial grains. Microcline, however, occurs both interstitially and as fairly large irregular grains (Figures 9 and 11). Using this sequence as a basis, the batholith as a whole and the origin of its concentric zoning can be discussed.

Contamination by the country rock is not believed by the writer to have been important beyond a 10-to 20-foot zone adjacent to the contact. In the batholith, at two places along the septum of Partridge Formation, a series of samples was taken beginning at the contact and proceeding into the quartz diorite (Table 5, B-95, B-31; Plate 2). The mineralogical variation in these series of samples suggests that near the septum the igneous rock has been contaminated by addition of SiO_2 , K_2O , and Al_2O_3 .

The concentric zoning could perhaps be explained by fractional crystallization if the batholith began to crystallize from its edges inward. If this is the mechanism, then several mineralogical features should be present. A plot of the modes of the different igneous samples (Figure 12) on a quartz-plagioclase-potash feldspar composition diagram indicates a progressive increase in the content of quartz and microcline, consistent with early crystallization of plagioclase near the borders. Another mineralogical feature that should be present is a systematic variation in the anorthite content of the plagioclase. In fact, the average plagioclase composition for the outer zone (An_{32}) is lower than the average of the inner zone (An_{34}), the

opposite from what would be expected from a simple fractionation model. Another contrary feature is the total absence of augite in the outer zones and its occurrence only in the rocks of the central zone. If differentiation by fractional crystallization is the mechanism by which the zonal arrangement was formed, how can these last two features be explained?

The main differences between the outer rocks and the inner rocks are the absence of augite, the scarcity of microcline, the abundance of biotite, and the abundance of epidote in the outer rocks. Scarcity of microcline can be explained by fractional crystallization from the margins inward. The absence of augite suggests a more hydrous environment. The abundance of epidote seems to be tied crudely to the composition of the plagioclase (Figure 40) and could also indicate a more hydrous environment. The hydrous conditions suggested for the outer zone of the batholith could cause the replacement of the augite by hornblende, formation of biotite from microcline, and the formation of epidote. Hydrous conditions in this outer zone could have been due to magmatic processes or absorption of water from the surrounding rocks, either by assimilation or during regional metamorphism (see metamorphism section).

A further result of the suggested concentration of water in the outer portions of the batholith may actually have been the retrograde metamorphism exhibited in the septum of the Partridge Formation. As the temperature dropped, the biotite in the schist became unstable and formed chlorite. The released potash and the water present reacted with the sillimanite to form sericite. The scarcity of

chlorite after biotite in the quartz diorite in contact with the septum may be due to a compositional difference, i.e., the high aluminum environment of the schist was more favorable to formation of chlorite and sericite.

Time of Emplacement

The Belchertown Intrusive Complex was intruded late in the regional metamorphism. It crosscuts structural features formed early in the metamorphism, but was itself deformed and metamorphosed.

A narrow schistose zone, along the contacts of the batholith with the country rock, with a strong metamorphic tectonite fabric, indicates shearing or movement of these rocks after they had either solidified or were in a very viscous state. This could have been due to continued upward movement of the intrusive mass or to the effects of regional deformation and metamorphism. In his discussion of structures of igneous rocks, Balk (1937) points out that igneous bodies with gneissic or highly foliated borders produced by frictional drag have flow lines or lineations within the foliation that plunge in the steepest possible direction. However, in the schistose zone, the lineation plunges gently and parallel to the lineation in the country rock, thus indicating a metamorphic origin. The foliation of the inner part of the batholith, which is clearly crosscut by the metamorphic foliation of the schistose zone, may be either of primary igneous origin or formed during an earlier phase of the metamorphism. The folded dikes show that deformation continued long after solidification of the borders of the batholith. The hornblendites do not exhibit much metamorphic

modification, perhaps because they are more massive and less susceptible to deformation.

Apparently the intrusion was emplaced during the Devonian. It was post Early Devonian because it intrudes the Erving Formation and truncates some structural features formed in these rocks. It was also involved in the late stages of the metamorphism which is responsible for some of the metamorphic structures exhibited by the country rock. The date of metamorphism, although uncertain, is considered to be between 400 and 250 million years ago (Brookins, D. G., 1967). A tentative Rb-Sr whole rock isochron of 380 m.y. has been determined by R. S. Naylor (Robinson, 1967a, p. 20) for the Prescott Intrusive Complex, which lies north of the Belchertown Intrusive Complex. The Prescott Complex truncates early recumbent fold structures, but has itself a strongly developed later metamorphic fabric.

Metamorphism

The general area of Quabbin Reservoir was metamorphosed in the kyanite and sillimanite zones. Kyanite-bearing rocks occur in the belts of Paleozoic metamorphic rocks of the Great Hill and Pelham-Shutesbury synclines (Figure 3). Sillimanite occurs in the next schist belt to the east (outside of the mapped area). The intrusion of the Belchertown Complex, therefore, was into metamorphic rocks that regionally reached a metamorphic peak in the kyanite zone.

The intrusion of the Belchertown Complex batholith affected the metamorphic grade of adjacent and included country rock. The septum of the Partridge Formation best exhibits these thermal effects.

The septum, prior to the intrusion, apparently contained primary euhedral oriented kyanite. Early in the intrusive history andalusite appears to have formed in the southern half of the septum due to increased temperature related to the intrusion. Further heating possibly combined with increased pressure caused andalusite and kyanite to become unstable and to be wholly or partially replaced by sillimanite. Because of conduction, the outer portions of the batholith cooled faster than the inner portions, allowing the complete conversion of andalusite to sillimanite in the inner part of the septum. The northern half mile exhibits only partial conversion of the kyanite to sillimanite, especially near the north end.

The occurrence of staurolite and primary muscovite only in the northern 1 1/2 miles of the septum also may be due to the secondary thermal effects of the intrusion. At high temperatures staurolite and muscovite would break down to biotite, garnet and sillimanite; muscovite and quartz would react to form sillimanite, potassium feldspar, and water (Richardson, et. al., 1969). Although primary muscovite is absent and sillimanite is abundant in the southern part of the septum, there is no potassium feldspar to indicate that the second reaction has actually taken place. However, the extremely sillimanite-rich composition of these muscovite-free schists strongly suggests that some of the less refractory constituents may have been melted out of these rocks and assimilated into the surrounding granodiorite. Apparent contamination of the igneous rocks near contacts with the septum (B-95, B-31, Table 5) may be evidence for such a process.

The later retrograde minerals, sericite and chlorite, are important in working out the post-magmatic history of the Belchertown Intrusive Complex. The retrograde metamorphism could be related to the intrusion itself or to a later hydrothermal metamorphism. It is difficult to explain why minerals of the septum were retrograded and those of the adjacent igneous rocks were not. Possibly there was a shift in either temperature and/or H_2O activity so that the more alumina-rich schist minerals became unstable while those minerals of the igneous rock did not. Whatever the cause, the biotite and some garnet was converted to chlorite, with the released K_2O of the biotite aiding in the conversion of sillimanite to sericite.

Summary

The Belchertown Intrusive Complex is comprised of four separate but related rock types. The earliest-formed was hornblendite, which may be a basic forerunner of the main intrusion. The ultramafic intrusions were followed closely by the intrusion of the batholith of quartz diorite and granodiorite. Accompanying the intrusion of the batholith was the formation of peripheral intrusive breccia. The last intrusions were of aplitic and pegmatitic dikes.

The emplacement of the complex was by both forceful intrusion and stoping. The best evidence of forceful intrusion is the present form of the septum of Partridge Formation. Stopping is indicated by the presence of large inclusions of metamorphic rocks along the edges and within the batholith and by the intrusive breccia.

The crudely concentric zoning of the batholith could be due to several mechanisms. The inner zones of augite-bearing granodiorite and granodiorite could be due largely to normal magmatic inward crystallization of the batholith from the edges. The outer zone of quartz diorite has been modified by metamorphism and reactions between minerals and fluids. In this outer zone pyroxene is absent, microcline is minor, epidote and biotite are abundant, and the plagioclase is less calcic than predicted. These features are suggestive of more hydrous conditions, either of original crystallization or later metamorphism.

Emplacement took place late in the time of regional metamorphism of New England. The batholith truncates structures associated with the regional metamorphism but is itself modified by the metamorphism. Along the contacts of the batholith is a narrow schistose zone whose foliation and lineation correspond closely with those of the adjacent metamorphic rocks. A Devonian age is tentatively given to the complex because it intrudes the Erving Formation and cuts structural features formed during this general time.

The regional metamorphic grade of the area was in the kyanite zone. The intrusion of the batholith caused a local increase in grade, as shown by the septum of the Partridge Formation which contains sillimanite pseudomorphs after andalusite in the southern part, and sillimanite partially replacing kyanite in the northern part. In the southern half of the septum, conditions were such that staurolite was unstable, and muscovite and quartz may have reacted to form sillimanite,

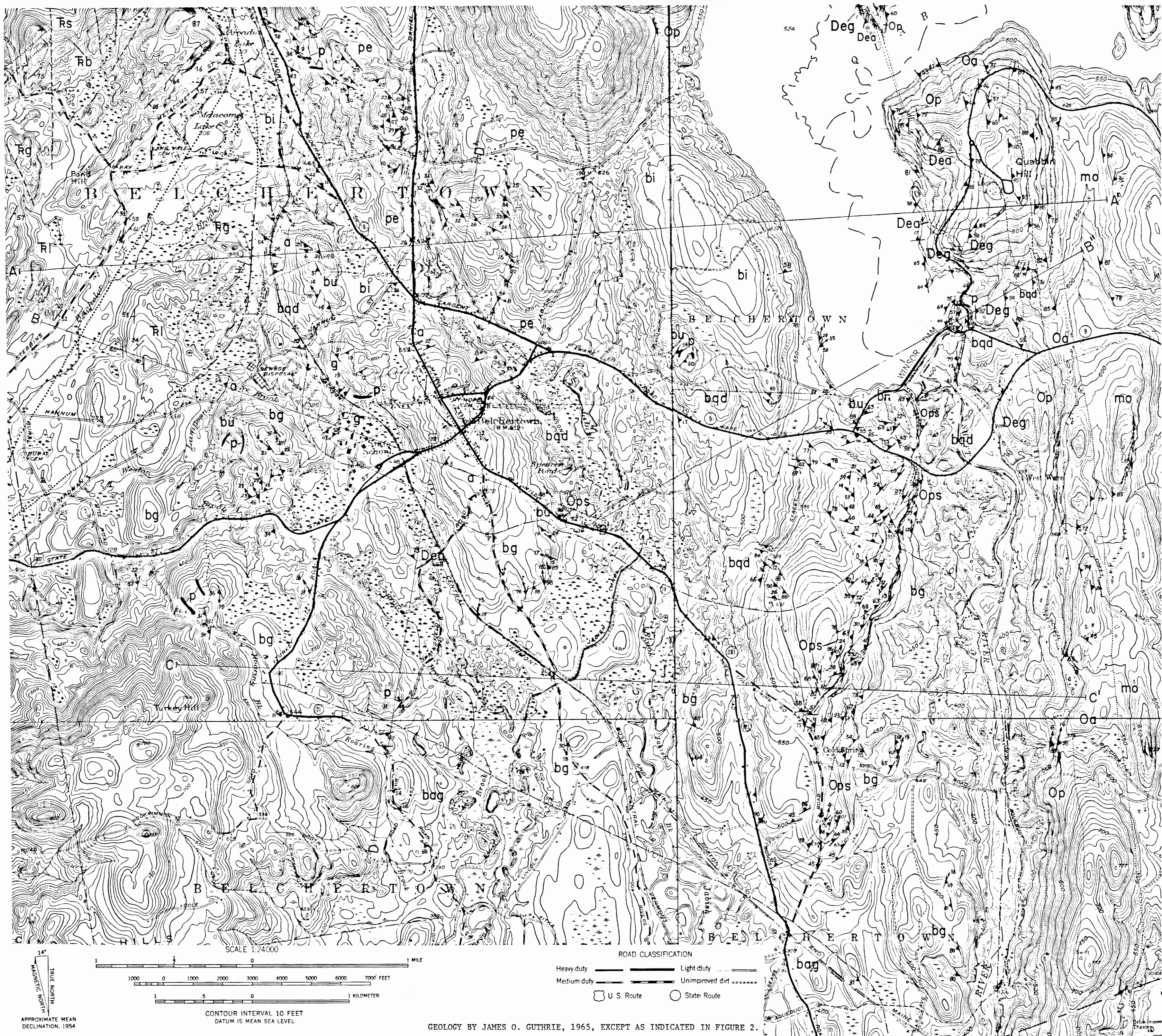
potassium feldspar and water. The high percentage of sillimanite and the absence of potassium feldspar in the southern part of the septum suggest partial melting and assimilation of less refractory constituents by the granodiorite. The retrograde metamorphism of the rocks in the septum is possibly related to bulk chemistry and a late influx of water.

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PLATE I GEOLOGIC MAP OF THE NORTHERN PORTION OF THE BELCHERTOWN INTRUSIVE COMPLEX



EXPLANATION	
SEDIMENTARY AND VOLCANIC ROCKS	
Rs	LONGMEADOW SANDSTONE
Rg	GRANBY TUFF
Rb	HOLYOKE BASALT
Ri	SUGARLOAF FORMATION
INTRUSIVE IGNEOUS ROCKS	
PEGMATITE	
p	Massive, discordant, generally tabular granitic pegmatites.
BELCHERTOWN INTRUSIVE COMPLEX	
bqd	Fine- to medium-grained, moderately to well foliated, brownish-gray weathering hornblende-biotite quartz diorite.
bg	Fine- to medium-grained, moderately to well foliated, brownish-gray weathering hornblende-biotite granodiorite.
bag	Medium- to coarse-grained, poorly to moderately foliated, brownish-gray weathering, augite-hornblende-biotite granodiorite.
bi	Intrusive breccia consisting of rounded to angular fragments of metamorphic and ultramafic rocks in matrix of hornblende-biotite quartz diorite or granodiorite.
bu	Massive medium-grained meladiorite, hornblende, and diopside hornblende.
METAMORPHIC ROCKS	
INCLUSIONS OF UNCERTAIN AGE	
a	Amphibolite
g	Granulite
ERVING FORMATION	
Deg	Well stratified, gray, fine-grained quartz-plagioclase-biotite granulite with interstratified schist and calc-silicate rock.
Dea	Well stratified fine- to coarse-grained hornblende-epidote amphibolite.
PARTRIDGE FORMATION	
Op	Rusty-weathering quartz-plagioclase-mica-garnet-pyrrhotite schist with abundant chlorite where retrograded; interbedded amphibolite.
Ops	Schist inclusion in Belchertown Complex. Northern part: quartz-plagioclase-mica-garnet-staurolite-kyanite-sillimanite schist. Southern part: coarse-grained quartz-biotite-garnet-sillimanite rock. Retrograde sericite and chlorite locally abundant.
AMMONOOSUC VOLCANICS	
Oa	Well stratified amphibolite and feldspar-quartz gneiss (differentiated in detail by others).
MONSON GNEISS	
mo	Coarse-grained layered to massive plagioclase-quartz gneiss with interstratified amphibolite.
PELHAM GNEISS	
pe	Coarse- to fine-grained granite gneiss with interstratified amphibolite.
Contact, location approximate where dashed, location inferred where dotted.	
Gradational contact	
Fault, location approximate where dashed, location inferred where dotted.	
Line of cross section	
27	Strike and dip of bedding
65	Strike and dip of foliation
13	Trend and plunge of lineation



PLATE 2

OUTCROP AND SAMPLE STATION MAP

EXPLANATION

- Triassic rocks
- Metamorphic rocks
- Igneous rocks
- Pegmatite dikes
- Contact between rock units
- Outline of rock outcrop (Small outcrops blacked in)
- B-21 Sample station

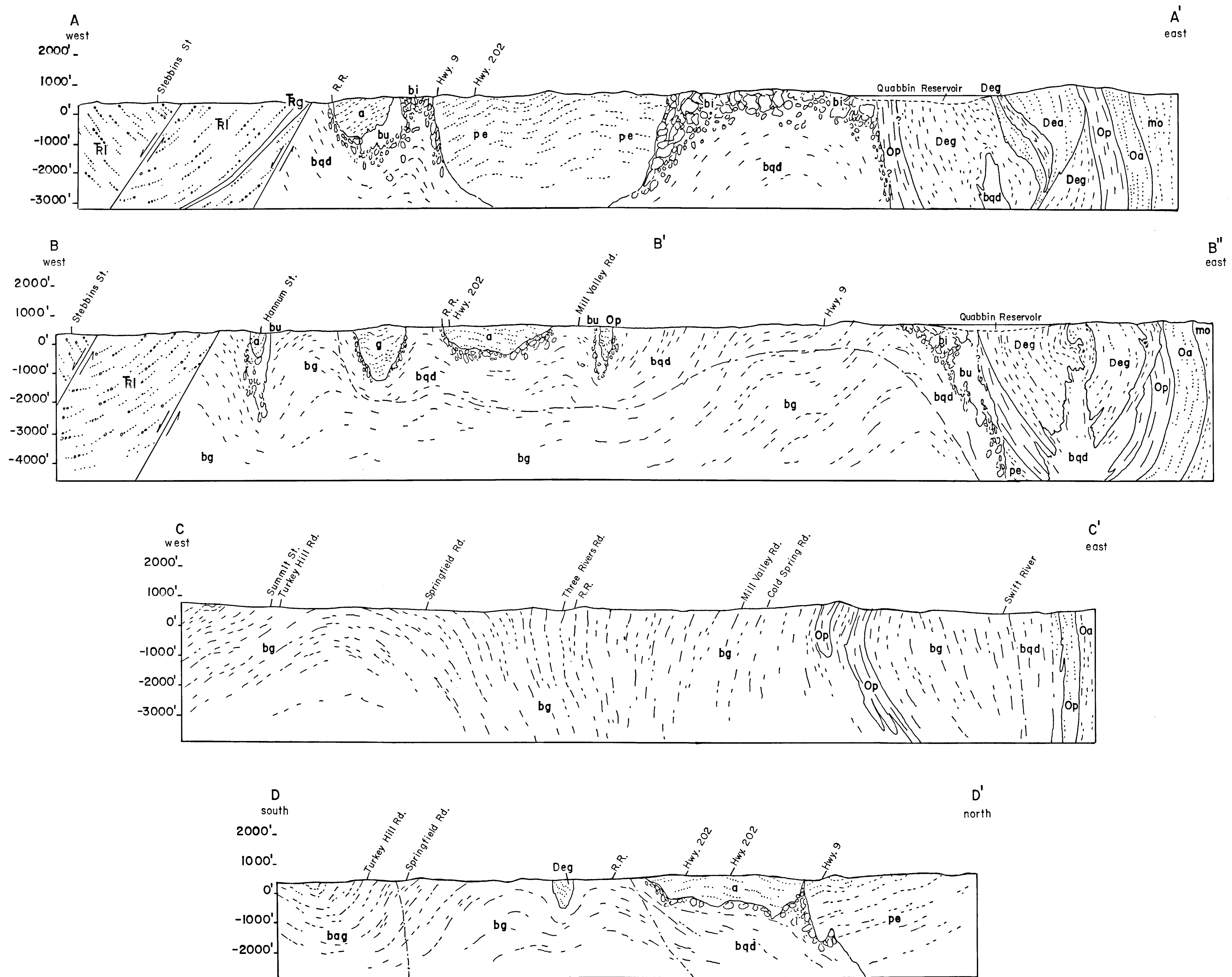


PLATE 3 GEOLOGIC STRUCTURE SECTIONS OF THE NORTHERN PORTION OF THE BELCHERTOWN INTRUSIVE COMPLEX
 BELCHERTOWN, MASSACHUSETTS

GEOLOGY BY JAMES O. GUTHRIE

