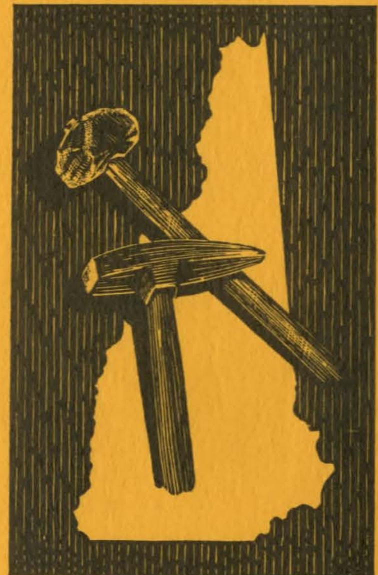
The Geology of the PETERBOROUGH QUADRANGLE NEW HAMPSHIRE

Bulletin No. 4

By Robert C. Greene



PUBLISHED BY THE STATE OF NEW HAMPSHIRE
DEPARTMENT OF RESOURCES AND ECONOMIC DEVELOPMENT

Frontispiece
Pack (to right) and North Pack Monadnock (to left) mountains, looking east from Old Town Farm, Near Peterborough Village.

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Published by the NEW HAMPSHIRE
DEPARTMENT OF RESOURCES AND ECONOMIC DEVELOPMENT
CONCORD, NEW HAMPSHIRE
1970

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NEW HAMPSHIRE
DEPARTMENT of RESOURCES and ECONOMIC DEVELOPMENT
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TABLE OF CONTENTS

D

E

ILLUSTRATIONS

F

TABLES

G

ABSTRACT

The Peterborough Quadrangle, covering 220 square miles in south-central New Hampshire, is a region of wooded rolling hills and mountains. The topography is dominated by the north-trending Wapack Range, the highest point of which is Pack Monadnock Mountain, 2310 feet above sea level. The total relief in the area is slightly less than 2000 feet.

The Quaternary surficial unconsolidated deposits, consisting of till, sand, gravel and silt, are mostly of glacial origin. This report is not concerned with them.

The bedrock consists of metamorphic rocks of Lower Devonian age and plutonic rocks largely of Middle Devonian age.

All the metamorphic rocks have been assigned to the Littleton Formation. For convenience this has been divided into four informal members, the Souhegan, Peterborough, Francestown, and Crotched Mountain. The Souhegan and Peterborough Members consist largely of mica schist and feldspar-quartz granulites, which were originally shales and graywackes. Small amounts of lime-silicate rocks and rocks of volcanic origin are also present. The Crotched Mountain Member contains beds with sillimanite crystals as much as an inch long. The Francestown Member, although very thin, makes a good marker horizon as it is composed of distinctive white to light gray pyrite-quartz-plagioclase granulite and white lime-silicate rock. The Littleton Formation is about 24,000 feet thick in the Peterborough Quadrangle and is probably entirely Lower Devonian.

The plutonic rocks belong to the New Hampshire plutonic series: they include the Massabesic Gneiss, Spaulding Quartz Diorite, Kinsman Quartz Monzonite, and binary quartz monzonite. The Massabesic gneiss is a mixed rock, containing remnants of the Littleton Formation as well as sills of pink granite and pegmatite. The Spaulding is a gray massive quartz diorite. The Kinsman is characterized by large phenocrysts of microcline one inch long and generally has a good foliation. The binary quartz monzonite, which is massive to well foliated and light-colored, has been quarried.

Basaltic dikes may be late Triassic and a small body of diorite may be early Jurassic.

A synclinal axis runs through the northwest corner of the quadrangle. The rest of the quadrangle is on the southeast limb of this syncline. Subsidiary and minor folds complicate this limb. The folds plunge gently north-northeast. The Kinsman Quartz Monzonite is a syntectonic sill-like body that thickens toward the southwest. The other plutons are somewhat irregular bodies that were intruded by forceful injection and perhaps permissive injection. The metasedimentary rocks have been regionally metamorphosed in the sillimanite zone.

Whereas the Bronson Hill anticline to the west was a positive area

during the Siluro-Devonian, so that only a relatively thin sequence of strata was deposited, further east a great basin developed in which 45,000 feet of Silurian and Devonian rocks accumulated.

Pleistocene glaciers modified the landscape by erosion and the deposition of till and outwash. Granite and soapstone have been quarried in the area in the past; sillimanite and pegmatites have a potential value. Recently silicified rocks have been quarried and crushed to add to concrete to give it a sparkle.

INTRODUCTION

The Peterborough quadrangle covers an area of approximately 220 square miles in south-central New Hampshire (Fig. 1). The southern border of the quadrangle is 2.5 miles north of the Massachusetts state line. Peterborough, the principal village, is 59 airline miles northwest of Boston, Massachusetts.

This quadrangle lies in the heart of the intensely deformed Appalachian tectonic belt. Underlying it are Middle Paleozoic schists and related rocks of high metamorphic grade invaded by Middle Paleozoic plutonic rocks. The strike of the bedding, foliation, and fold axes exhibit a predominant northeasterly trend, in accordance with the general plan of Appalachian structure.

The area was chosen specifically in order to unravel the stratigraphy and structure of the mica schists and associated rocks southeast of the Bronson Hill anticline of western New Hampshire (Billings, 1956). Although these rocks have been mapped in numerous quadrangles to the north, in those areas the stratigraphy and structure have been solved in only a general way. The present study has been successful in this effort. It has been demonstrated that the Bronson Hill anticline was a positive area during Silurian and Devonian, but that tens of thousands of feet of sediment were deposited into a rapidly subsiding basin to the east.

For base maps copies of the original compilation sheets for the Peterborough 15 minute quadrangle at a scale of 1:8,000 were used. These provided a base with excellent detail. Also useful were aerial photographs at a scale of 1:21,600 on which probable areas of outcrop were spotted in advance of field work.

Previous work in the Peterborough quadrangle consists of three reconnaissance surveys, made at widely spaced intervals over the past century and a quarter.

The first survey was that of C.T. Jackson (Jackson, 1844). He was looking primarily for mineral deposits. Minerals in the Peterborough area mentioned in the survey were plumbago, bog iron ore, and soapstone. Only the latter was found by the present writer.

The survey of C.H. Hitchcock (Hitchcock, 1874, 1877, 1878) resulted in a geologic map of the state and regional descriptions of the rocks and structure. His map shows considerable insight in the Peterborough area, with the boundaries of (translated into modern terms) the Kinsman Quartz Monzonite, the Spaulding Quartz Diorite, and rusty and non-rusty schists fairly well shown.

The most recent survey was that of M.P. Billings, for the modern state geologic map (Billings, 1955). Billings visited the Stony Brook roadcuts in Wilton, Pack Monadnock and Crotched Mountains and a few other localities, recording lithologic and fold data. The resultant state geologic

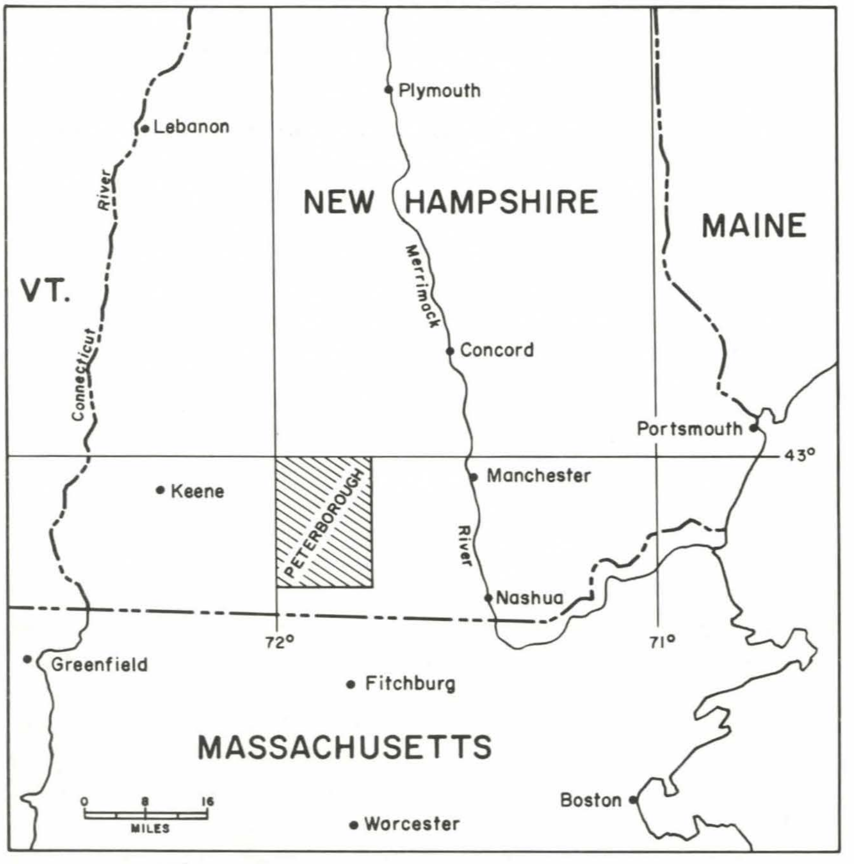


Figure 1.
Index Map — Shows location of Peterborough Quadrangle.

map needs modification in the Peterborough area only in the enlargement of some of the plutonic bodies.

The Monadnock quadrangle, adjacent to the Peterborough quadrangle to the west, has been mapped (Fowler-Billings, 1949), as has the Lovewell Mountain quadrangle to the northwest (Heald, 1950). No detailed mapping has been done in the contiguous quadrangles to the north, east, and south. The Manchester quadrangle, the second one to the east at the same latitude as Peterborough, has been mapped (Sriramadas, 1966).

Much of the Peterborough quadrangle is a hilly area of no great relief. The general upland surface lies at 700 to 1200 feet above sea level. Above this level rise prominent monadnocks, most of them aligned in a discontinuous ridge known as the Wapack Range. The highest point is Pack Monadnock Mountain, slightly over 2300 feet above sea level, with

North Pack Monadnock Mountain second at 2278 feet. South of Pack Monadnock lies Temple Mountain, a long north-south ridge on which the highest peak is 2084 feet above sea level. Farther south, a number of disconnected hills constitute the southern part of the Wapack Range; the highest is Barrett Mountain, 1853 feet.

Northeast from North Pack Monadnock, Winn, Rose, Lyndeborough and Piscataquog Mountains form an extension of the Wapack Range (Figure 2). The highest peak is the summit of Rose Mountain at approximately 1730 feet. Crotched Mountain, 2020 feet, lies near the north boundary of the quadrangle.

On either side of the Wapack Range, the rough, hilly surface is broken

Figure 2.
Mountains in Lyndeborough — Looking northeast from North Pack Monadnock Mountain. Middle distance, from left to right: Rose, Lyndeborough, and Winn Mountains. Piscataquog Mountain is low hill to right of Winn Mountain. Twin peaks in distance are Uncanoonuc Mountains, to right of which is Joe English Hill.

only by occasional low-lying swamps and lakes. Though the general pattern of hills and valleys is quite irregular, a number of elongate hills, whose axes trend slightly west of north, are present. These are drumlins and other types of ice-shaped hills. An area of exceptionally low relief lies in the north-east part of Peterborough and adjacent parts of Greenfield.

Most of the Peterborough quadrangle drains into the Contoocook, Souhegan, and Piscataquog Rivers, all of which are tributary to the Merrimack River. Small areas near the southeast and southwest corners of the quadrangle drain, respectively, into tributaries of the Nashua and Millers Rivers.

The largest settlement is Peterborough (population 2,556); Greenville (population 1,280) is second largest. The other towns contain one or more settlements or centers for which they are named. The populations of most are very small (cf. Sharon, 62).

The land in the Peterborough quadrangle was formerly extensively used for pasture and farm land. Stone walls and decayed barbed wire fences are common on land that is now covered with second growth timber and brush. While it appears that 65% or more of the land was at one time cleared, scarcely 5% was cleared in 1961.

Small patches of white pine of marketable size are present in the Peterborough quadrangle, but these are rapidly being cut. Agriculture is largely confined to three industries — orchard, dairy, and chicken. Lyndeborough and Wilton are noted for apples and peaches, and New Ipswich for chickens. Dairy cows are raised in Peterborough and Francestown. Wild blueberries are extensively harvested from "blueberry pastures" located on exposed summit and ridge areas on Crotched, Winn, Lyndeborough, and Piscataquog Mountains.

There is a ball-bearing plant at Peterborough. Several old textile mills, some of which have been modernized and are still in operation, are located at Greenville. An important current industry is the sale of real estate for country homes.

The writer gratefully acknowledges the support of the New Hampshire Department of Resources and Economic Development and of the Louise H. Daly fund of Harvard University, without which the geologic mapping of the Peterborough quadrangle would not have been possible. Base maps, aerial photographs, and thin sections were generously provided by the Department of Geological Sciences, Harvard University. The writer also wishes to express his gratitude to his advisor, Dr. M.P. Billings, who suggested the problem, visited the area with him, and in many ways stimulated his efforts.

GENERAL LITHOLOGIC FEATURES

The Peterborough quadrangle is underlain chiefly by metamorphic and plutonic rocks of Devonian Age (Fig. 3 and 4). The metamorphic rocks are mainly mica schists, with lesser amounts of quartz-feldspar granulite and lime-silicate granulite. These metamorphic rocks are assigned to the Lower Devonian Littleton Formation. The plutonic rocks are assigned to the Spaulding Quartz Diorite, Kinsman Quartz Monzonite, and binary quartz monzonites, all three of which belong to the New Hampshire plutonic series. The Massabesic Gneiss is a mixed rock, partly metamorphic, partly plutonic. Basaltic dikes are probably Triassic; a small body of diorite is probably Jurassic.

LITTLETON FORMATION

General.

The rocks in a large area in central New Hampshire, including the Peterborough Quadrangle, are mica schists that have been correlated with the fossiliferous Lower Devonian Littleton Formation in the type area near Littleton, New Hampshire (Billings, 1956).

The Littleton Formation occupies about 75 percent of the Peterborough Quadrangle. The formation consists of mica schists with variable amounts of such minerals as garnet and sillimanite. Distinctly subordinate rocks are quartz-feldspar granulites and lime-silicate granulites. The quartz-feldspar granulites are composed mostly of quartz and plagioclase, with considerable biotite and muscovite. Some are metamorphosed graywackes, others are of volcanic origin. Sulfides are abundant in some of these rocks, causing a very rusty weathering.

For descriptive purposes the Littleton Formation has been subdivided into four informal members, which from southeast (also oldest) to northwest (also youngest) are the Souhegan, Peterborough, Francestown and Crotched Mountain Members. The general characteristics of the Littleton Formation are shown in Fig. 3.

Souhegan Member.

The name Souhegan Member is introduced here for a group of rocks that underlies an area about 3 miles wide in the southeast corner of the quadrangle. The type locality is in roadcuts along Route 31 just north of the village of Greenville.

This member consists of mica schist with minor beds and lenses of quartz-feldspar granulite and lime-silicate granulite. The mica schist commonly contains thin pods, lenses, and stringers, seldom over a few inches long, composed of plagioclase and minor quartz (Fig. 5). The schists are gray, medium-grained, and evenly foliated. In places a slight compositional

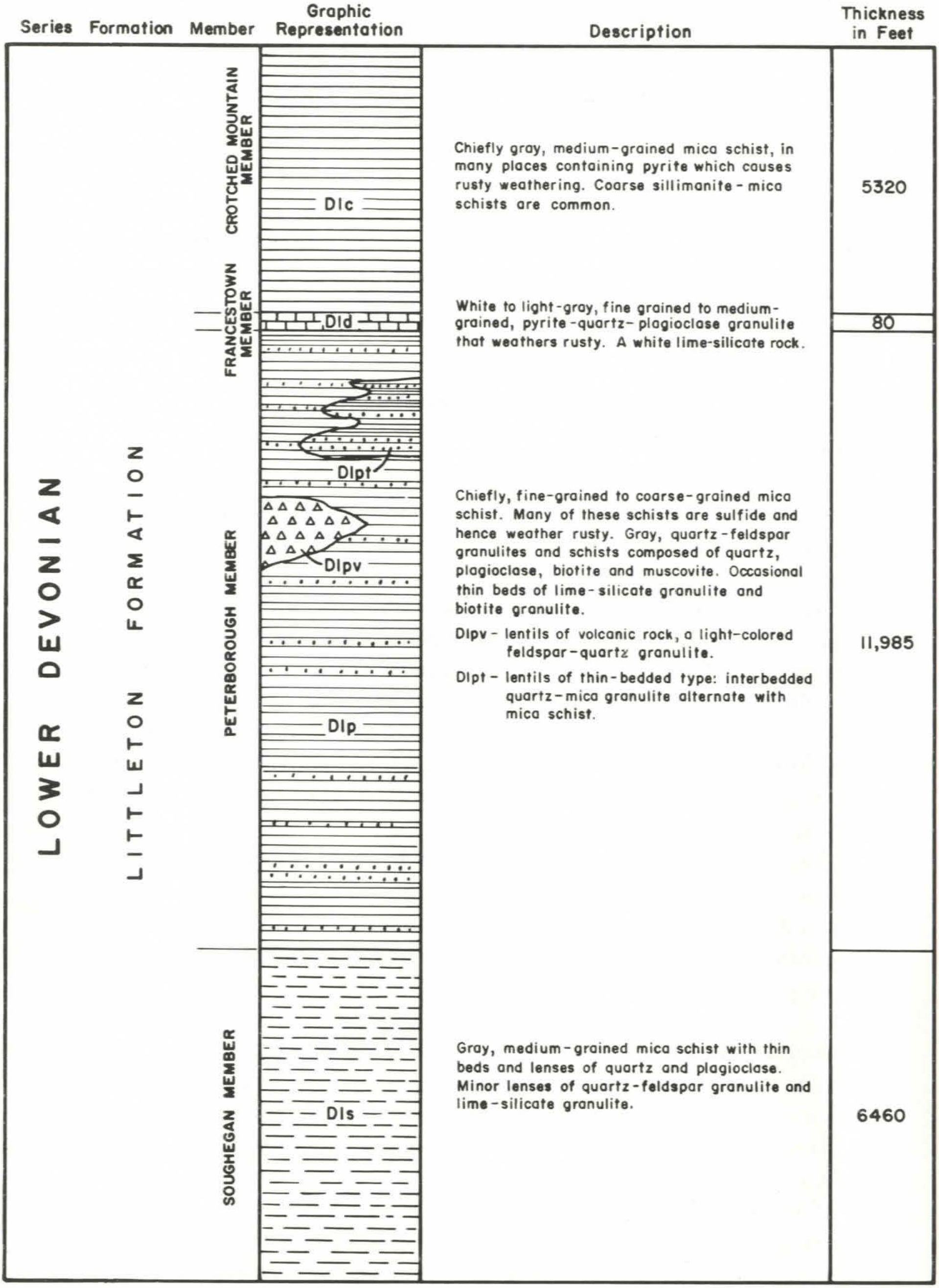


Figure 3.
Columnar Section of Littleton Formation in Peterborough Quadrangle — Errors in thickness may be as great as 20%.

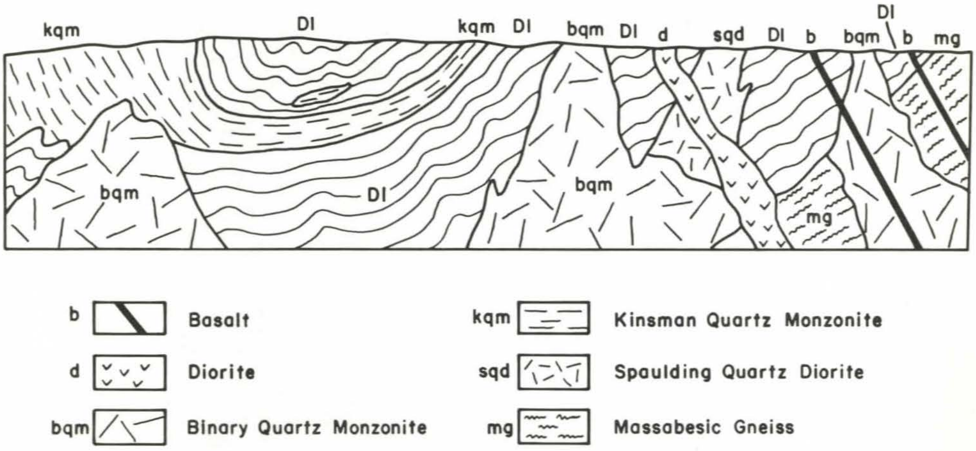


Figure 4.

Sequence of Igneous Rocks in Peterborough Quadrangle — A diagrammatic representation of presumed sequence of plutonic rocks and basalt.

Figure 5.

Souhegan Member of Littleton Formation — Mica schist with abundant quartz-feldspar pods. From type locality of member in Route 31 road cuts, Greenville.

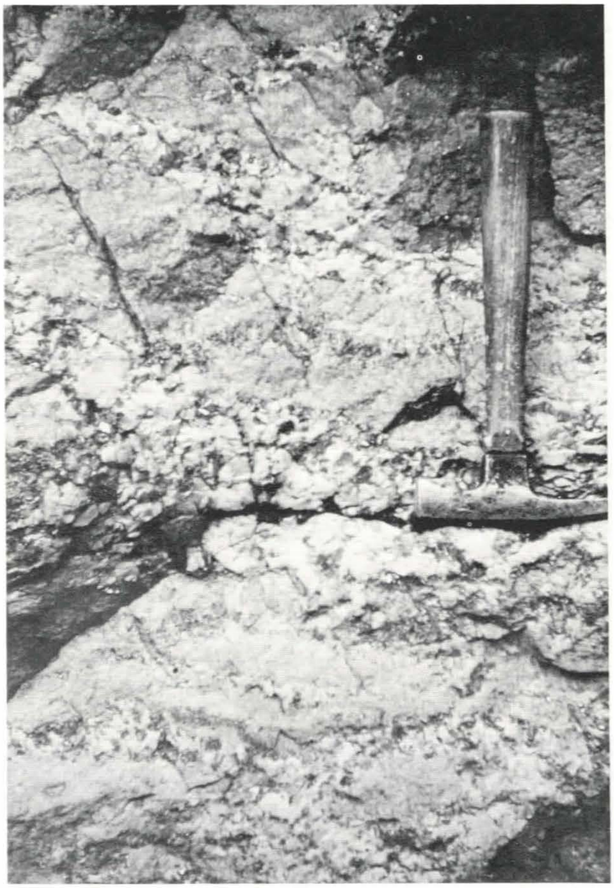


Figure 6.

Pegmatite — Intruding Souhegan Member of Littleton Formation, Route 31 road cuts, Greenville.

layering results from a differential concentration of the various minerals. Splitting is along mica-rich layers, which exhibit a characteristic sheen due to the orientation of the micas. This sheen helps to distinguish the schists of the Souhegan Member from the schists in the other members of the Littleton Formation. A spotted appearance results from the concentration of biotite into patches. Pegmatite bodies, containing a distinctive ivory-colored perthitic microcline abound in the Souhegan Member (Fig. 6), but granitic rocks are rare, except in the larger plutons that are separately mapped. As will be shown later, this member is about 6500 feet thick.

Typical modes* of the mica schists are given in Table 1, columns 1-7. It is obvious that these rocks are composed largely of mica and quartz, with some plagioclase; other minerals are rare. Column 8 is a quartz-feldspar granulite, commonly incorrectly called quartzite in the field. Column 9 is one of the lime-silicate granulites. Column 10 is a rare variety unusually rich in magnetite.

Peterborough Member.

The name Peterborough Member is here introduced informally for the mica schists that comprise most of the Littleton Formation in the Peterborough quadrangle. The type locality is in the southeast corner of the township of Peterborough, in an area covering about one square mile northwest of Pack Monadnock and southeast of Old Mountain Road.

This member consists chiefly of mica schists, with some interbedded feldspathic granulite. In addition there are several lentils of a thin-bedded type and one lentil of volcanic rocks; these lentils will be described separately.

The mica schists constitute about 50 percent of the Peterborough Member, but there are minor differences. Representative modes are given in Table 2, columns 1-8. The most common rocks are mica schists consisting largely of quartz, biotite, and muscovite (Table 2, columns 1 and 2). These rocks are gray and generally well foliated (Fig. 7). In the finer grained rocks the foliation is even, but in the coarser rocks it is commonly crinkled (Fig. 8). In many places these schists assume a greener hue, due to the partial or complete conversion of biotite to chlorite (Table 2, columns 3 and 4). Some of the schists contain small amounts of garnet and/or sillimanite (Table 2, columns 5-7) and locally these minerals become very abundant (Table 2, column 8). The mica schists were originally shale.

About 25 percent of the Peterborough Member is a sulfidic schist (Table 2, column 9). These rocks are very conspicuous in the field because of the rusty weathering. These rocks were sulfidic shales that were deposited in a reducing environment.

Rocks that, for want of a better name, may be called quartz-feldspar granulites and quartz-mica granulites constitute about 25 percent of the Peterborough Member. Composed chiefly of quartz, plagioclase, and mica, they are gray fine-grained to medium-grained rocks, characterized by a granular to weakly schistose texture. In the field they have often been called quartzite, but this is a misnomer, as the amount of quartz only occasionally exceeds 60 percent. They are interbedded with the mica schists and generally

*Nearly all the modes are based on a point count of 200 or more points on a standard thin section. In a few cases, where the rock is very coarse grained, or the mineralogy is simple, a visual estimate was used. M= minor (0.5 to 1.0%), tr = trace (present but less than 0.5%). All Tables (1-17) are in the Appendix, p.00-00.

range in thickness from a fraction of an inch to several feet. Outcrops showing interbedding are exposed in Jaffrey near the Contoocook River. Representative modes are given in Table 2, columns 10-13. These rocks were deposited as graywackes.

The lime-silicate granulites constitute less than one percent of the Peterborough Member, but they contrast sharply with the monotonous mica schists and feldspathic granulites. They occur as thin beds or lenses, a few inches or feet thick. Generally fine-grained, they are gray to greenish gray and possess little or no foliation. They are composed mostly of quartz and plagioclase of intermediate composition, but with small amounts of such lime-silicate minerals as actinolite, clinozoisite, and diopside (Table 2, columns 14 and 15). These rocks were originally dolomitic arenaceous shales. Associated with the lime-silicate rocks, as elsewhere in New Hampshire, are purplish-brown biotite granulites with considerable quartz and intermediate plagioclase (Table 2, column 16). Such rocks were originally calcareous shales.

Four lentils of thin-bedded rocks have been mapped within the Peterborough Member. Three of these are in a belt that trends northeasterly through the central part of the quadrangle. A fourth is in the northeast corner. These are areas in which thin beds of quartz-mica granulite (Table 2, column 17) alternate with beds of mica schist (Table 2, columns 18 and 19). The beds range in thickness from a fraction of an inch to several inches. But contacts with the surrounding schists are very gradational and not readily located with precision.

A small lentil of volcanic rocks has been separately distinguished in the northeast corner of the quadrangle, just southeast of Haunted Lake in Francestown. The rock is a light-colored feldspar-quartz granulite with minor amounts of mica imparting a weak foliation. Bedding is shown by contrasting light-colored and dark layers. Plagioclase crystals give the lighter layers a speckled appearance. Representative modes are given in Table 2, columns 20 and 21. These highly feldspathic rocks are believed to have been dacitic tuffs, by analogy to similar rocks in the Littleton-Moosilauke area, where such rocks are found in various grades of metamorphism (Billings, 1936). Darker layers are quartz-biotite schist and probably represent admixed sedimentary material.

Sills and dikes of binary quartz monzonite and pegmatite, from a few inches to several tens of feet thick, are commonly present in the Peterborough Member. They are especially well exposed in Winn and Piscataquog Mountains, the Pack Monadnocks, and the southwest corner of the quadrangle. On Rose and Lyndeborough Mountains quartz veins, many with tourmaline, are abundant.

The topography suggests that a belt of more resistant mica schists and feldspathic granulites underlies the Wapack Range from the south

Figure 7.

Thin-bedded schist, Peterborough Member — Near summit of Rose Mountain. Lighter colored beds are quartz-mica schist, darker beds are coarser mica schist.

Figure 8.

Folded Schist — Peterborough Member of Littleton Formation. North slope of North Pack Monadnock Mountain.

end of the quadrangle to North Pack Monadnock. Moreover, the same rocks presumably extend northeasterly to Winn, Lyndeborough, and Piscataquog Mountains.

The Peterborough Member is about 12,000 feet thick. Of this total, about 5300 feet are east of the Wapack Range, 2000 feet are in the Wapack Range, and 4700 feet are west of the Wapack Range.

Francestown Member.

The name Francestown Member is here introduced for a thin but very distinctive unit which is exposed as a narrow band in the northern part of the Quadrangle. The type locality is along Quarry Road about 1 1/2 miles northeast of the village of Francestown. Exposures extend from about 2000 feet south of the quadrangle boundary along Quarry Road to about 1000 feet north of the boundary on the Hillsborough quadrangle.

In the Monadnock Quadrangle to the west, this unit was called the Rusty Quartzite Member (Fowler-Billings, 1949, pp. 1258-1261). This was a field term and subsequent petrographic work showed that the so-called quartzites were lime-silicate-granulites and plagioclase quartz granulites. In the Monadnock quadrangle, the member consists of actinolite granulite, pyrite-quartz-plagioclase granulite, and purple-brown biotite granulite (Fig. 41).

In the Peterborough Quadrangle, the Francestown Member consists chiefly of two types of rocks. The pyrite-quartz-plagioclase granulite is fine- to medium-grained, and, where fresh, is white to light-gray. In outcrop the rock breaks into rectangular blocks, is very rusty because of weathering, and may exfoliate sheets of impure limonite from its surface, and gives off a sulfurous odor. The calc-silicate rocks are white, tough, compact, and resistant; weathered surfaces are also rusty. Small porphyroblasts of actinolite are typical. Representative modes are given in Table 3, columns 1 and 2.

This unit, originally dolomitic feldspathic sandstone and pyritiferous calcareous sandstone, ranges in thickness from zero to 500 feet.

Crotched Mountain Member.

The name Crotched Mountain Member is here introduced for mica and sillimanite schists that occur in the north-central part of the Peterborough Quadrangle, stratigraphically above the Francestown Member. The type locality is on the summit area of Crotched Mountain (west part of township of Francestown), less than 1/2 mile south of the quadrangle boundary. The Crotched Mountain Member differs from the other members of the Littleton Formation in that large sillimanite crystals are conspicuous in some of the rocks.

Mica schist is the most abundant rock. These are gray, medium-

Figure 9.

Sillimanite Porphyroblasts — Weathering out on surface of schist. North of summit of Crotched Mountain.

grained rocks with fair foliation. Representative modes are given in Table 4, columns 1 and 2. Sillimanite schists are characteristic of the higher parts of Crotched Mountain; gray, tough and resistant, they lack foliation, but the sillimanite porphyroblasts, which weather out in relief (Fig. 9) impart a strong lineation to the rocks. A mode is given in Table 4, column 3. Similar rocks are found elsewhere in the area (Table 4, columns 4 and 5). A rock unusually rich in sillimanite is represented by the mode in Table 4, column 6. Some pyritiferous schists also occur, notably east of Bullard Hill near the quadrangle boundary. Occasional lime-silicate granulites are also found (Table 4, column 7).

Granite and pegmatite admixed with the schist are rare in the Crotched Mountain Member. But such rocks are found near Bullard Hill. The Crotched Mountain Member is estimated to be about 5300 feet thick.

Age of the Littleton Formation.

The Littleton Formation is considered to be Lower Devonian, but no fossils are known from the Peterborough Quadrangle. On the east side of the Westmoreland-Swanzey (Keene) dome (Fig. 41) the mica schists assigned to the Littleton Formation overlie the Clough and Fitch Formations. The former is Llandovery C-3 to C-5 (Lower Silurian), whereas the latter is Ludlow (Upper Silurian) (Thompson et al., 1968, pp. 206-

207). In the Littleton area the Littleton Formation contains Lower Devonian fossils (Billings and Cleaves, 1934; Boucot and Arndt, 1960). The protolith of the rocks in the Monadnock syncline (Fig. 41) was very similar to the upper fossiliferous part of the Littleton Formation of the type area (Billings, 1936). Similarly, the Crotched Mountain Member is presumably Lower Devonian.

The Francestown, Peterborough, and Souhegan Members are thus Lower Devonian or older. In the Manchester area the Littleton Formation overlies the Berwick Formation of the Merrimack group (Sriramadas, 1966, p. 9). This is also true in southern Maine (Hussey, 1962). In the Waterville area of Maine the correlatives of the Merrimack group contain fossils of Late Llandovery (Lower Silurian) and Wenlock or Ludlow age (Middle and Upper Silurian) (Osberg, 1968, pp. 32 and 33).

Although the correlations are long range, the Francestown, Peterborough, and Crotched Mountain Members lie between Lower Devonian and Upper Silurian strata. Silurian fossils in northern New England are confined to slightly calcareous assemblages, such as those from which the Merrimack group was derived, whereas Lower Devonian fossils are confined to noncalcareous assemblages such as those from which the Littleton Formation was derived. Thus the entire Littleton Formation in the Peterborough Quadrangle is probably Lower Devonian. Moreover, arguing about the Silurian-Devonian boundary is a little futile inasmuch as there is no agreement on its location in the type areas of Europe (Rickard, 1962, pp. 113-114).

General statement.

The Littleton Formation in the Peterborough Quadrangle is extensively invaded by plutonic rocks. They are assigned to four units and are considered to be Middle Devonian. The Massabesic Gneiss is a mixed rock. The Spaulding quartz diorite, the Kinsman quartz monzonite, and the binary quartz monzonite, as well as the pegmatites, belong to the New Hampshire plutonic series.

Massabesic Gneiss.

The Massabesic Gneiss underlies a few square miles in the extreme southeast corner of the quadrangle. This area is along the northwest edge of a large body that extends southwest for 90 miles from Rochester, New Hampshire, to near Worcester, Massachusetts. This body, which ranges in width from 4 to 10 miles, has been called the Fitchburg pluton (Billings, 1956). In the Peterborough Quadrangle a small discontinuous body, 2 miles long, lies just east of Greenville.

The name is taken from Massabesic Lake, the reservoir for Manchester, New Hampshire (Sriramadas, 1966). The Massabesic Gneiss is a gray to pink heterogeneous rock, composed primarily of quartz, plagioclase, microcline, biotite and minor amounts of muscovite. Modes of the more homogeneous variety are given in Table 5, columns 1, 2, and 3. But the gneiss is commonly layered, so that mica-rich layers a fraction of an inch thick to several feet thick alternate with granitic layers that are only slightly foliated. The heterogeneity is further emphasized by the presence of inclusions of the Souhegan Member in the gneiss. Elsewhere, granite sills intrude the gneiss. The contacts with the Souhegan Member are not sharp, but are transitional, a feature best observed in the adjacent Ashby Quadrangle.

The Massabesic Gneiss is a mixed rock. The schists of the Souhegan Member have been subjected to alkali metamorphism accompanied by the intrusion of granitic sills.

Spaulding Quartz Diorite.

The Spaulding Quartz Diorite composes much of the Lyndeborough pluton in the east-central part of the quadrangle, all of the New Ipswich pluton in the south-central part, and five smaller bodies in the southeast part. Good exposures may be seen along Highway 31 between Wilton and South Lyndeborough. The Spaulding Quartz Diorite, the type locality for which is in the Monadnock Quadrangle (Fowler-Billings, 1949), is a dark-gray medium-grained to foliated rock. There is a distinct spotted appearance due to the segregation of biotite on the one hand and quartz and feldspar on the other; the resulting spots are several millimeters in diameter.

Representative modes are given in Table 6, columns 1-9. It is apparent that the rock is a quartz diorite, composed chiefly of plagioclase (oligoclase and andesine), quartz and biotite. Quartz is generally between 10 and 30 percent of the rock, but one specimen has only a trace of quartz. Microcline is present in a few specimens, muscovite is present in one. The relative abundance of sphene is striking.

Other rocks are associated with the Spaulding Quartz Diorite in the Lyndeborough pluton. Most of them have a fairly large amount of potash feldspar. Some (Table 6, columns 10 and 11) would be classified as biotite-quartz monzonite. Others (Table 6, columns 12 and 13) would be called leucocratic quartz monzonite or even granite. Sufficient field data were not obtained to determine the extent and relations of these quartz monzonites and granites. They may be segregations within the Spaulding or they may be later intrusions.

A rather unusual rock, composed largely of andesine, quartz, muscovite and small amounts of tourmaline was found in Lyndeborough in a railroad cut 13,000 feet northwest of South Lyndeborough village. This is probably the product of hydrothermal alteration, as needles of tourmaline are common in the vicinity.

South of Winn and Lyndeborough Mountains tongues of the Spaulding Quartz Diorite intrude the schists of the Littleton Formation. This relationship is interpreted to indicate a magmatic origin for the Spaulding.

Kinsman Quartz Monzonite.

A large area of Kinsman Quartz Monzonite in the northwest part of the Peterborough Quadrangle is the southeastern end of the Cardigan pluton, the northern end of which is 60 miles to the north. The type locality is at Kinsman Notch, New Hampshire.

The Kinsman is perhaps the most striking rock in the state. Phenocrysts of microcline, as much as 2 inches long, and commonly in parallel alignment, are the dominating feature. The matrix consists of plagioclase, microcline, quartz, biotite, muscovite, and chlorite. The plagioclase grains, which are oligoclase, are somewhat larger than the other minerals. Representative modes are given in Table 7, columns 1 and 2.

At Halfmoon Pond the Kinsman is intensely sheared, and exposures are especially good at the spillway. Vertical shear planes strike north to northeast. Feldspar crystals, normally more or less rectangular in outline, have been fractured and crushed. Commonly the corners have been sheared off so that the crystals are elliptical in outline. Chlorite and muscovite flakes wrap around the ends of the phenocrysts (Fig. 10). Representative modes from the sheared area are given in Table 7, columns 3 and 4.

Daly (1897), citing mainly structural criteria, believed that the Kinsman was an intrusive rock and that the foliation, expressed primarily by the

Figure 10.

Sheared Kinsman Quartz Monzonite — Moderately sheared; note "boat-shaped" phenocrysts. Spillway at Halfmoon Pond, Hancock.

alignment of the microcline phenocrysts, was a flowage phenomenon. The writer agrees with Daly. Feldspar phenocrysts, both microcline and plagioclase, must have formed slowly at depth in a semi-fluid environment near enough the feldspar liquidus so that nucleation was slow and precipitation of large crystals favored. The whole mass was intruded, probably digesting metasedimentary rocks on the way, as shown by the presence of garnet and cordierite in the Kinsman in the Lovewell Mountain Quadrangle (Heald, 1950).

Binary quartz monzonites and related rocks.

Light-colored granitic rocks, in some instances of sufficient quality to have been quarried in the past, are found in numerous parts of the quadrangle. Some bodies are sufficiently large to be separately shown on the geological map. Several of these bodies have been named (Plate 1): Peterborough, Whitcomb Peak, and Pratt Pond plutons. Several other bodies, separately mapped but not named, are located as follows: (1) southeast corner of Francestown; (2) south of Temple Mountain; and (3) south of Greenville. Moreover, some of these rocks occur as dikes, sills, and irregular bodies that are too small to map separately; some quarries are in such bodies.

These rocks are all similar in that they are relatively light-colored, medium-grained, and massive to weakly foliated. Biotite is the only dark mineral, and muscovite is present in variable amounts. It has long been known that these rocks are quartz monzonites, that is, potash feldspar and plagioclase present in about equal amounts. But the term "granite" was so firmly entrenched in the quarry industry, that they have been termed binary granites. In this paper they will be called quartz monzonite.

In some of these rocks biotite is distinctly dominant over muscovite (Table 8, columns 1-5). Others contain both biotite and muscovite (Table 8, columns 6 and 7), and in still others muscovite is the principal mica (Table 8, columns 8-14).

Pegmatites.

The pegmatites of the Peterborough Quadrangle, though abundant, were little studied. They occur both as sills and dikes, generally a few feet to a few tens of feet wide. Pegmatite is nowhere quarried and roadcut exposures for sampling are rare. One good exposure is in Francestown, 6000 feet south of the southeast corner of Haunted Lake. Additional exposures are in roadcuts on Route 31, 3000 feet northeast of the village of Greenville. The pegmatites are coarse-grained rocks composed of large crystals or masses of perthitic microcline, with smaller crystals of interstitial quartz, plagioclase, microcline, and muscovite, occasionally biotite or tourmaline.

Age of New Hampshire Plutonic Series.

In the Peterborough quadrangle the only direct evidence on the age of the New Hampshire Series is that it is younger than the Littleton Formation and older than the Pleistocene glacial deposits. No direct radiogenic ages are available, but regional data suggest a Middle Devonian age (Lyons and Faul, 1968, pp. 309-310).

BASALT AND DIORITE

Basalt.

The only basaltic dikes found in the Peterborough Quadrangle are located in a small belt southeast of the contact of the Souhegan and Peterborough Members of the Littleton Formation. The dikes, which range in width from 2 inches to several tens of feet, generally strike parallel to the strike of the local foliation and dip nearly 90°. The dikes are composed of aphanitic to fine-grained dark-gray to black basalts. Representative modes are given in Table 9, columns 4-8. Olivine, which is found in all except one of the modes, is corroded and rimmed by pyroxene. The basalts are probably Late Triassic, essentially contemporaneous with the basalts of the Upper Triassic rocks of the Connecticut Valley. They may however, belong to the Early Jurassic White Mountain volcanic-plutonic series.

Diorite.

A small body of diorite in Francestown, just east of Poor Farm Road, is about 1500 feet in maximum dimension. It is a dark-gray hornblende-biotite diorite, fine-grained to coarse-grained, and massive to weakly foliated. Representative modes are given in Table 9, columns 1-3. It apparently cross-cuts the adjacent Kinsman Quartz Monzonite.

The correlation of this diorite presents a problem. It strongly resembles the Moulton Diorite of the New Hampshire plutonic series (Billings, 1936). But the Moulton is considered to be older than the Kinsman and the regional metamorphism. In the Peterborough Quadrangle the Moulton would have been regionally metamorphosed to amphibolite. The diorite is tentatively considered to belong to the Early Jurassic White Mountain volcanic-plutonic series (Billings, 1956, pp. 71-72).

STRUCTURE

General Statement.

The analysis of the geological structure of the Peterborough quadrangle is concerned with three subjects: (1) the Littleton Formation, (2) the plutonic rocks, and (3) such late features as the basalt, diorite, and silicified zones.

Littleton Formation

General statement.

Inasmuch as the Littleton Formation consists chiefly of metamorphosed sedimentary rocks, the methods of investigation are those customarily utilized in such studies, that is, features related to the original sedimentation and those features superimposed on them during deformation. The structural characteristics are of two magnitudes: minor features that are visible in single outcrops, and major features that are deduced from the map pattern and data obtained at outcrops.

Minor structural features.

The minor features include bedding, foliation, folds, and lineation.

Bedding is shown by compositional layering, that is, by alternating layers of differing mineralogy, and, less commonly, by differences in color or texture. Most commonly the alternating layers are mica schists and quartz-feldspar granulites. The beds range in thickness from a fraction of an inch to many feet. But in many places bedding is difficult or impossible to recognize because the rock is a homogeneous mica schist. In the Francestown Member bedding is shown by differences in the amount of actinolite, feldspar, and quartz. Graded bedding was rarely observed and cross-bedding was never seen.

Foliation here consists of two types — a schistosity and slip cleavage.

Schistosity results from the parallel alignment of platy and ellipsoidal minerals such as biotite, muscovite, and quartz. Sillimanite may form mats lying in parallel planes. In many places small lenses of quartz, with or without feldspar, are parallel to the schistosity. In this area the schistosity is universally parallel to the bedding, at least wherever the two occur together. This fact may be observed on Crotched Mountain, North Pack Monadnock, in Jaffrey, Peterborough and elsewhere. This parallelism of bedding and schistosity is readily demonstrated in the thin-bedded lentils within the Peterborough Member.

A slip-cleavage, approximately vertical and trending north-south, was observed over much of the northern part of North Pack Monadnock Mountain. This slip-cleavage cuts across the bedding and schistosity.

The minor folds, a few inches to a few feet across, range from open gentle flexures through moderately tight folds to, in a few cases, isoclinal folds. Examples of gentle and moderate folds may be seen in Greenfield: one near the road junction at elevation 941 feet south of Russell, and several others in the stream directly north of that point. A superb example of an isoclinal fold, 4 feet in amplitide, may be seen on the northeast side of Piscataquog Mountain, just east of the quadrangle boundary. Another small isoclinal fold was observed on Rose Mountain.

A point diagram, Fig. 11, shows the direction and amount of plunge of the observed fold axes for the entire quadrangle, plotted on the lower hemisphere of a Schmidt equal-area net. It is immediately apparent that most of the folds plunge at angles of 30° or less. Moreover, the points are concentrated in the northern and southern sectors. About 70 percent of the folds plunge at low angles toward the north-northeast or south-southwest (the direction of plunge rarely deviating more than 30° from this average). About 20 percent plunge northwest at an average angle of 15°, and about 10 percent plunge southeast at an average angle of 15°.

The folds plunging north-northeast and south-southwest are considered to be genetically related to the regional structure; they thus indicate that the regional structure is plunging gently, and that the average regional plunge is 0° in a north-northeast-south-southwest direction. It will be shown later that the larger structural features are consistent with this concept. In general, the minor folds plunging northwest and southeast are believed to be cross folds. They may have formed later than the regional structure, although some may result from heterogeneity in the rocks.

At many places in the Peterborough Quadrangle the bedding or schistosity are severely contorted, that is, the strike and dip are not systematic over even a few square feet of outcrop, and systematic fold data can not be obtained. Notable examples of such contortion are on Pack Monadnock Mountain, Fisk Hill, Wildcat Mountain, Kidder Mountain, Barrett Mountain, and New Ipswich Mountain (Fig. 8).

Fabric lineation in the plane of the bedding or schistosity is common in the schists of the Peterborough Quadrangle. Lineation is generally shown by aligned muscovite and biotite flakes; sillimanite may also be aligned. A plot of the mineral lineation is given in Figure 12. Most of the lineations plunge at angles of less than 30° in a direction that ranges from S.60°W. through west and north to northeast.

On the higher parts of Crotched Mountain the lineation is shown by sillimanite porphyroblasts an inch long. Most of these lineations plunge in a westerly direction nearly perpendicular to the fold axes. They are thus *a* lineations, related to bedding-slip during folding.

On Winn, Rose, Lyndeborough, and Piscataquog Mountains most of the lineations plunge northwest. Here muscovite and biotite, and, to a lesser

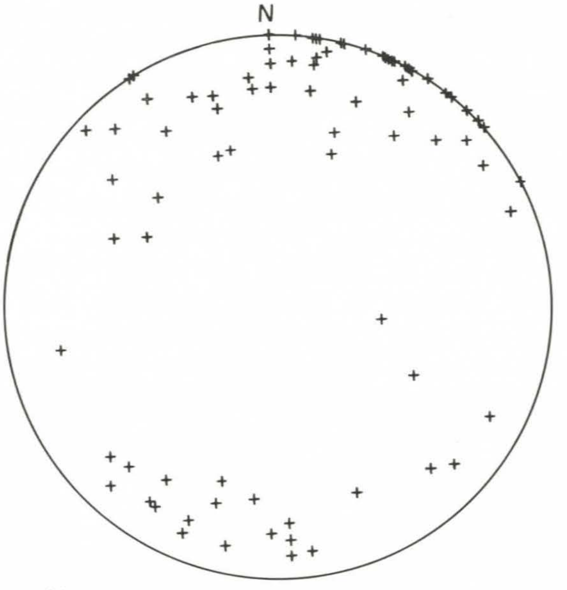


Figure 11.

Point Diagram of Lineations — Excludes fold axes. Entire quadrangle, except Souhegan Member. Schmidt net, lower hemisphere.

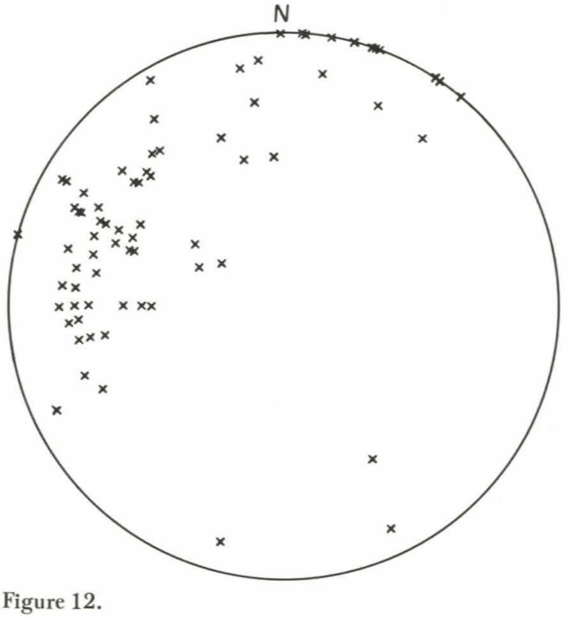


Figure 12.

Point Diagram of Fold Axes — Entire quadrangle. Schmidt net, lower hemisphere.

extent, sillimanite, produces the lineation. Thus again the *a* direction prevails.

On Kidder Mountain and Conant Hill the lineation, shown by muscovite flakes, is essentially parallel to the fold axes. This is a *b* lineation.

Muscovite and biotite show a good lineation in the schists of the Souhegan Member. Whereas the schistosity dips in a N.30°W. direction, the lineation plunges in a N.50°W. direction. It is presumably an *a* lineation, with slip diagonal to the fold axes.

Major structural features.

Whereas the minor structural features are observed in outcrops, the major structural features are inferred from the map pattern and the integration of the minor features.

The geological map, Plate 1, shows that the Peterborough Quadrangle, excluding the plutonic rocks, is underlain by a series of lithologic belts trending north-northeast. Six successive belts are recognized. From southeast to northwest they are: (1) Souhegan Member; (2) southeast part of the Peterborough Member; (3) middle part of the Peterborough Member, that is, the resistant rocks comprising the Wapack Range and its northeast continuation into Winn and Piscataquog Mountains; (4) northwest part of the Peterborough Member; (5) Francestown Member; and (6) Crotched Mountain Member. Such a non-repetitive sequence suggests a homoclinal structure. The fact that the bedding dips northwest suggests, but does not prove, that the sequence is on the southeast limb of a syncline and thus gets younger to the northwest. Moreover, the structure in the Monadnock quadrangle (Fig. 41) demonstrates that this concept is correct. This interpretation has been incorporated into the structure sections on Plate 1.

Although the major structure may be deduced from the broader features, a more detailed analysis is necessary to obtain a more precise interpretation. That is, how much of the section is repeated by folds that are any size from a few feet to many hundreds or thousands of feet across. To facilitate this investigation twenty-one structural diagrams have been prepared (Fig. 14-34). The method of preparing such diagrams is described in Billings (1954, 108-115). Each diagram is for a separate area, called a domain (Fig. 13). A domain is an area in which, in the author's opinion, the structure is relatively homogeneous. In these diagrams the following pertinent data are shown. Bedding (and foliation) are shown by dots. Each dot represents the pole of the perpendicular to a measured bedding. Lineation is represented by a cross; each cross represents the pole of a measured lineation. Fold axes are represented by a plus sign; each plus sign represents the pole of a measured fold axes.

The bedding is the most common feature represented in these diagrams. One or many folds lie within a single domain. If a single fold — an anticline or a syncline — is present in a domain and if this fold is strictly

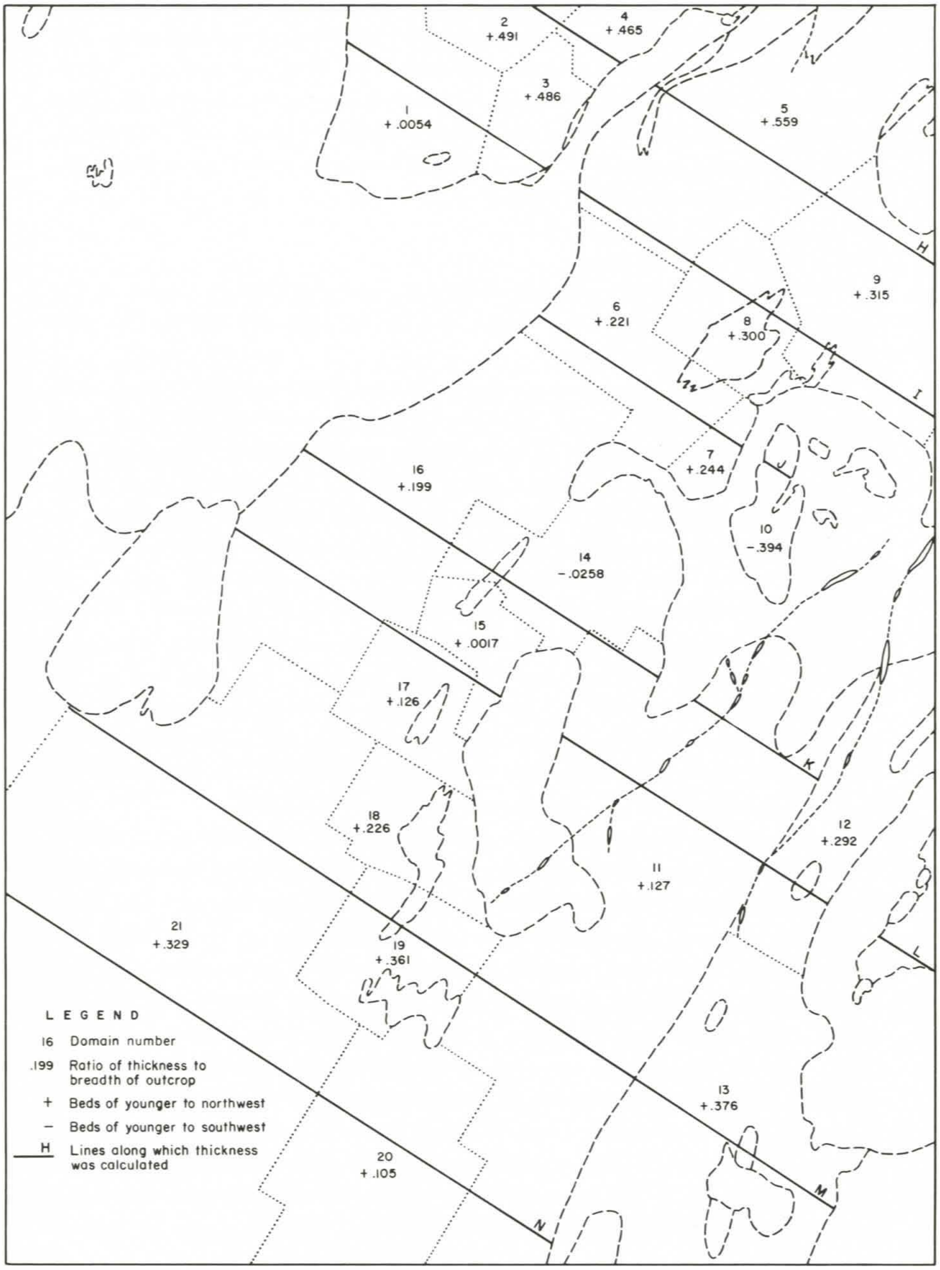
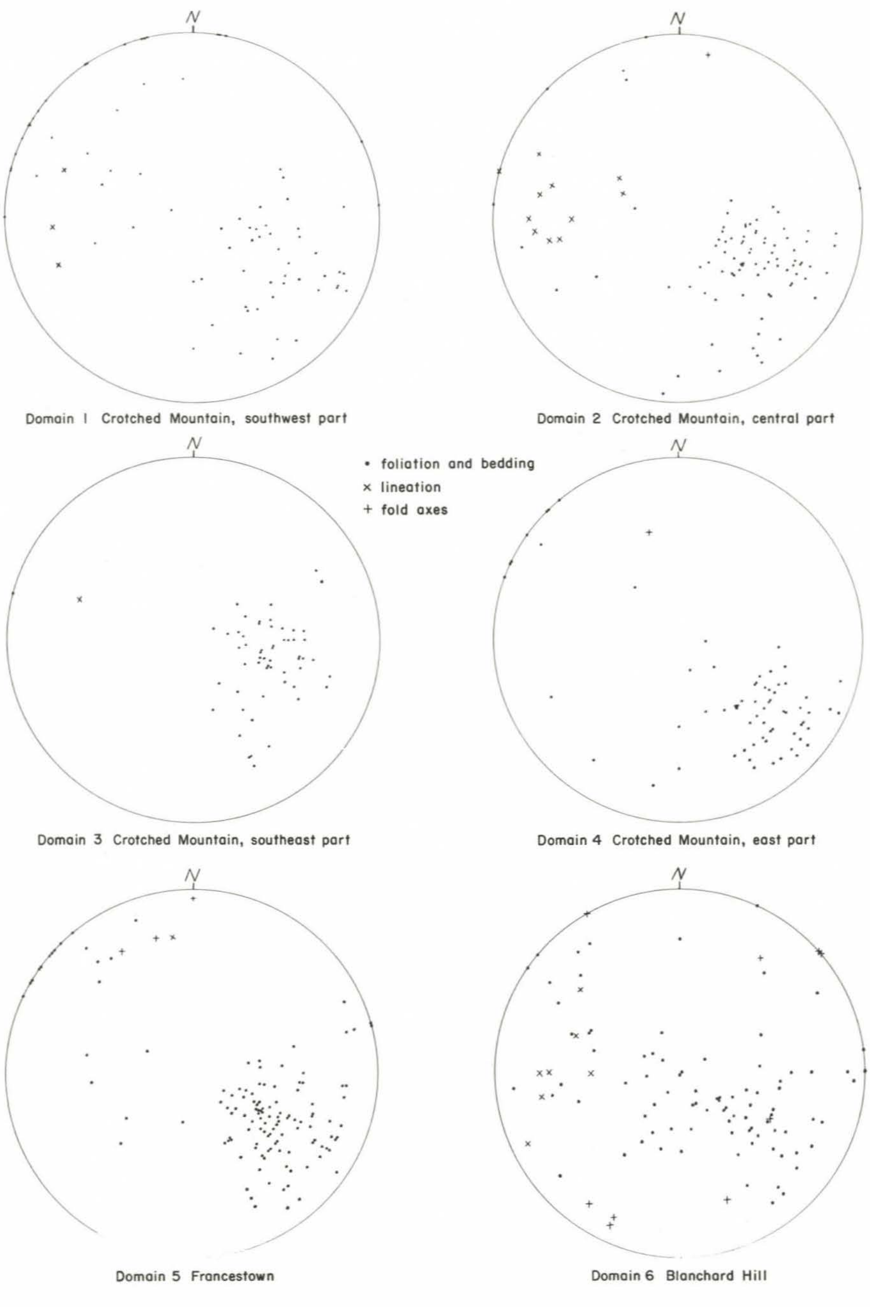


Figure 13.

Domains used in Structural Analysis.

cylindrical, all the points representing bedding would lie on a single arc (girdle). The chord connecting the ends of the girdle passes through the center of the diagram. The fold would plunge at right angles to the chord of this arc and in the direction in which the arc is concave. The distance between the chord and the arc (girdle) is a measure of the plunge of the fold. If the plunge of the fold is zero, the girdle is a straight line through the center of the diagram. If the girdle lies on the circumference of the diagram, the plunge of the fold is vertical.

In the diagrams the dots representing bedding show more or less scatter — that is, the points do not lie on a single girdle. There are many reasons for such scatter. (1) Many folds may be present within the domain and their axes may not be parallel in either strike or plunge. (2) The fold axes may have a constant strike, but the value of the plunge may change, from say, northeast to southwest, passing through the horizontal; in this case the points would lie on a broad band through the center of the diagram. (3) Cross folding will produce two sets of fold axes. (4) Faulting may locally warp the structure. The scatter shown in these diagrams may be explained in these various ways. Consequently nothing is to be gained by considering in detail the scatter in each diagram; only the general relations will be considered. For example, beds that strike northwest and dip steeply — represented by points on or near northeast or southwest circumference of the diagram, may result from cross folding or very steeply plunging folds. Moreover, at this stage we are not concerned with whether beds are overturned. This point will be discussed later.



Figures 14-19.
Structural Diagrams, Domains 1 to 6 — Schmidt net, lower hemisphere.

Domain 1, Crotched Mountain, southwest part. Crotched Mountain Member. The average strike of the bedding is N.30°E., the average dip is 40°NW. The beds appear to be mostly in the southeast limbs of synclines. A few northeast strikes, with dips ranging from 10° to 90° SE, represent beds on the northwest limbs of synclines. The broad girdle trending northwest through the center of the diagram indicates that the fold axes trend northeast and plunge at low angles. The lineation, shown by sillimanite crystals, plunges, on the average, 25°W. It is an *a* lineation.

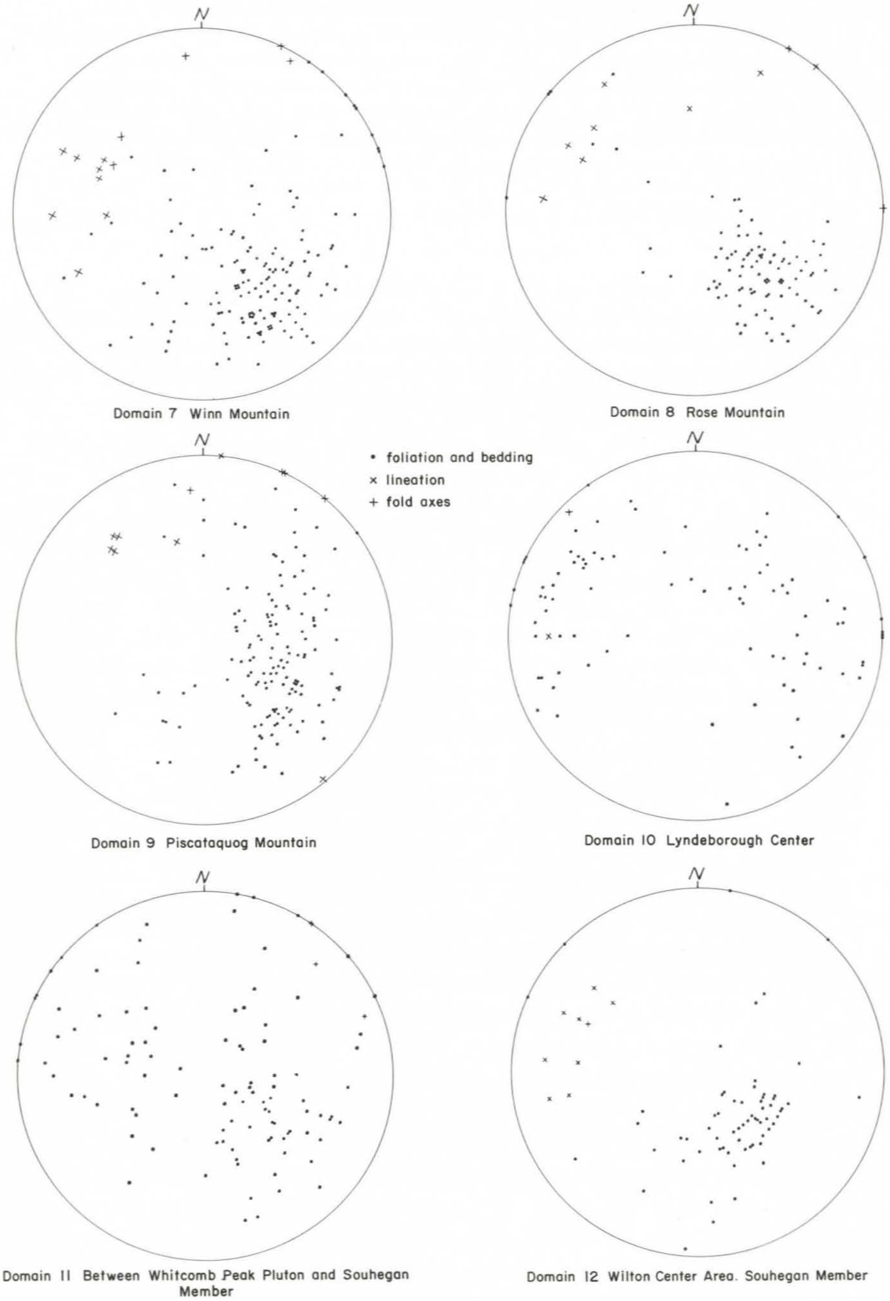
Domain 2, Crotched Mountain, central part. Crotched Mountain Member. The average strike is N.30°E., the average dip is 40°NW. Unless there is a lot of overturning, for which, as will be shown later, there is no evidence, the area is on the southeast limb of a syncline. The lineation, caused by sillimanite porphyroblasts, plunges 30° in a direction N.80°W; it is an *a* lineation.

Domain 3, Crotched Mountain, southeast part. Crotched Mountain Member. The average strike is N.25°E., the average dip is 35°NW. This domain, like area 2, is on the southeast limb of a syncline.

Domain 4, Crotched Mountain, east part. Crotched Mountain Member. The average strike is N.40°E., the average dip 60°NW. This area is also on the southeast limb of a syncline.

Domain 5, Francestown. Francestown and Peterborough Members. The most common average strike is N.30°E., with a dip of 45°NW. However, a faint girdle convex toward the southwest suggests that the fold axes plunge 35°NE. The few minor folds plunge at an angle of 15° in a direction slightly west of north.

Domain 6, Blanchard Hill. Upper part of Peterborough Member. A broad girdle convex toward the southwest suggests folds plunging on the average 25°NE. But the minor folds plunge gently NNE and SSW. The *a* lineation plunges gently toward the west.



Figures 20-25.
Structural Diagrams, Domains 7 to 12 — Schmidt net, lower hemisphere.

Domain 7, Winn Mountain. Lower part of the Peterborough Member. The greatest concentration of points indicates a northeast strike and dip of 60°NW. However, as will be shown later, many of the beds dipping northwesterly more steeply than 65° may be overturned. Points in the northwest sector indicate beds dipping southeast. Points in the inner parts of the southwest and northeast sectors are presumably due to plunging folds; points in the outer parts of these sectors represent either steeply plunging folds or cross folds. Some of the minor folds seem to reflect the normal northeast trend. Others reflect the cross folding. The westerly plunging lineations may be either **a** lineations related to the regional folding or *b* lineations related to the cross folding.

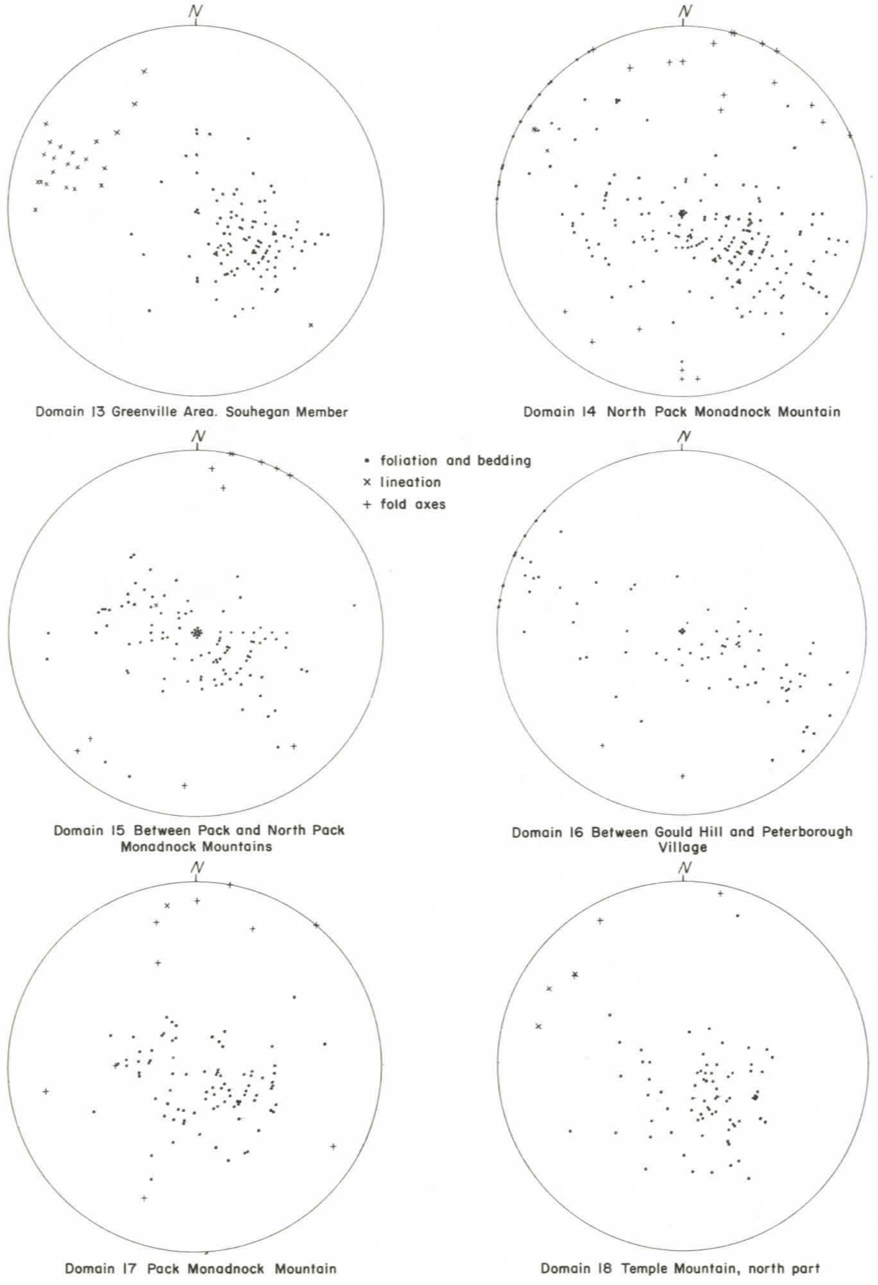
Domain 8, Rose Mountain and vicinity. Middle part of the Peterborough Member, including lentil of thin-bedded schist. A strong concentration of points indicates an average strike of N.40°E. and a dip of 40°NW. As will be shown later the beds in the outer part of the southeast sector may be overturned. A weak girdle suggests folds plunging gently north-northeast. The *a* lineation plunges west-northwest.

Domain 9, Piscataquog Mountain. Peterborough Member. There is a great deal of scatter, but most of the dips are northwest, west, and southwest. As will be shown later, the points in the outer part of the southeast sector are probably overturned. The points in the inner parts of the southwest and northeast sectors probably represent beds on the noses of plunging folds. The points in the outer part of these sectors, meaning northwest strikes and steep dips, suggest cross folding. The topography suggests the Piscataquog Mountain may be on the nose of a large fold, about two miles across and plunging northeast. It is here that the hogback ridge constituting the Wapack Range and its northeasterly extension suddenly bends back on itself to trend southeast. But the attitude of the bedding shows this is not a broad open fold — which would be characterized by northwest strikes and northeasterly dips — but is composed of many minor tight folds. The four minor folds recorded are consistent with a very gentle north-northeasterly plunge.

Domain 10, Lyndeborough Center. Lower part of the Peterborough Member. The distribution of the points suggest folds trending north-northeasterly, plunging mostly southwesterly, but some plunging northeasterly.

Domain 11, Between Whitcomb Peak pluton and Souhegan Member. Peterborough Member. The scatter here is so great that no single interpretation is possible. But this area covers 30 square miles, and smaller areas might permit a better analysis.

Domain 12, Wilton Center Area. Souhegan Member. The greatest concentration of points indicate an average strike of N.50°E., with a dip of 45°NW. The few points in the southwest and northeast sectors are presumably related to the noses of plunging folds. The lineations are *a* lineations.



Figures 26-31.
Structural Diagrams, Domains 13 to 18 — Schmidt net, lower hemisphere.

Domain 13, Greenville Area. Souhegan Member. The relations are similar to those in area 12.

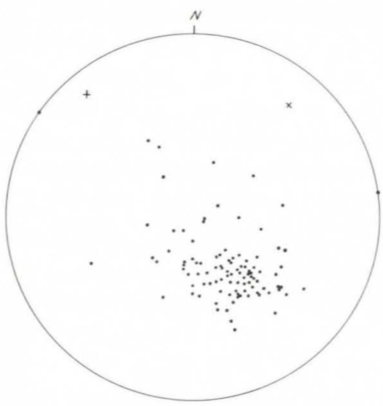
Domain 14, North Pack Monadnock Mountain. Peterborough Member, including a lentil of thin-bedded schist. The greatest concentration of points indicates a dominant northeast strike with dips ranging from 0° to 90°. However, southeasterly dips are common, and a broad girdle slightly convex toward the southwest indicates a gentle plunge toward the north-northeast. Fourteen of the minor folds plunge, on the average, 25°NNE; six others have an average plunge of 20°SSW. The net average plunge of all the minor folds is 10°NNE.

Domain 15, Between Pack and North Pack Monadnock Mountains. Peterborough Member. A broad girdle trending northwest indicates folds that plunge about 15° NNE. The average plunge of most of the minor folds is 10°NNE.

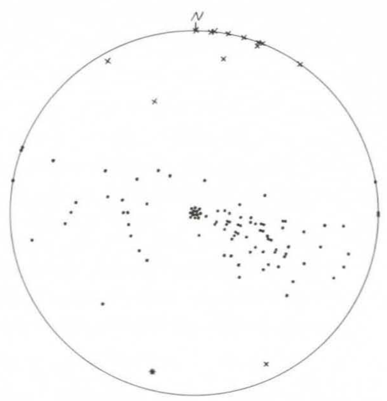
Domain 16, Between Gould Hill and Peterborough Village. Peterborough Member. A broad girdle trending about N.60°W., but slightly convex to the southwest, indicates folds plunging about 10°NNE.

Domain 17, Pack Monadnock Mountain. Peterborough Member, including lentil of thin-bedded schist. There is a great deal of scatter in this diagram, but the dips are generally low. Seven of the ten minor folds plunge, on the average, 20°NNE; one of the folds plunges 10°SSW. These minor folds thus suggest a gentle north-northeast plunge of the major structural features. The point diagram is consistent with this. Two of the minor folds appear to be cross folds.

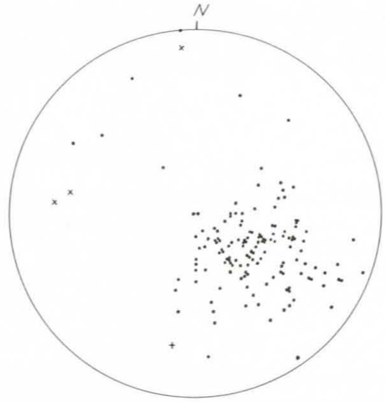
Domain 18, Temple Mountain, northern part. Peterborough Member, also lentil of thin-bedded schist. This area may be interpreted in the same way as area 17, except that the few minor folds plunge north-northwest.



Domain 19 Temple Mountain, south part



Domain 20 South part of Wapack Range



Domain 21 Southwest part of the quadrangle

• foliation and bedding
× lineation
+ fold axes

Figures 32-34.

Structural Diagrams, Domains 19 to 21 — Schmidt net, lower hemisphere.

Domain 19, Temple Mountain, southern part. Peterborough Member, also lentil of thin-bedded schist. The great concentration of points indicates an average strike of N.60°E., a dip of 40°NW.

Domain 20, Southern part of Wapack Range. Peterborough Member. A girdle trending N.70°W. indicates horizontal fold axes that trend N.30°E. The lineation is parallel to the fold axes.

Domain 21, Southwest part of the quadrangle. Peterborough Member. The great concentration of points in the southeast sector indicates beds dipping, on the average, about 45°NW. An *a* lineation is present.

The following generalizations may be made from the twenty-one diagrams.

(1) In seventeen of the diagrams the most prominent dip is toward the northwest (ranging from WNW to NNW) at angles averaging 45°, but ranging from 0° to 80°.

(2) In four of these seventeen diagrams there is also a dip toward the southeast, averaging 40° but ranging from 10° to 80°.

(3) Ten of the diagrams, despite considerable scatter, show broad girdles that indicate fold axes that plunge at low angles (0° to 10°) toward the north-northeast or south-southwest, but in a few instances plunge north-northeast at angles of 25° to 50°.

(4) The minor folds, although not numerous, are sufficiently abundant in nine of the diagrams to warrant some conclusions. In seven of these diagrams the folds plunge north-northeast at angles ranging from 0° to 10°. In two of the diagrams the minor folds plunge 10°NNW.

(5) Some cross folding is indicated in six diagrams, either by beds that strike northwest and dip steeply, or by a few minor folds.

(6) In ten of the diagrams the lineation plunges in a northwesterly direction, almost at right angles to the strike of the fold axes. It can be either an *a* lineation, parallel to the direction of slip while the beds were folding, or a *b* lineation, parallel to the axes of the drag folds.

In two diagrams a *b* lineation, parallel to the regional fold axes is present.

This analysis demonstrates that the dominant dip of the bedding and schistosity parallel to the bedding is northwest, averaging 45°. The fold axes, both major ones deduced from the diagrams and the minor observed axes, strike north-northeast and plunge at low angles, generally north-northeasterly. Coupled with the stratigraphic data already given, most of the Peterborough quadrangle is on the southeast limb of a syncline in which the subsidiary folds plunge NNE.

Subsidiary folding and thickness of the Littleton Formation. Subsidiary folds are those that are larger than the minor folds observed in outcrop but smaller than such folds as the Monadnock syncline. The purpose of this section is to deduce the extent of subsidiary folding, and, as a corallary, the thickness of the Littleton Formation.

The thickness of the strata between the top and bottom of a stratigraphic unit may be calculated along a line (traverse) **oriented in any direction** by the equation (Billings, 1954, pp. 431-438).

$$t = s \sin \delta \sin \alpha$$

where t is thickness, δ is angle of dip of bedding, and α is the angle between the line of the traverse and the strike of the bed.

If several different attitudes (strikes and dips) have been measured along the line of the traverse, the thickness may be calculated piecemeal:

$$t = s_1 (\sin \delta \sin \alpha_1) + s_2 (\sin \delta_2 \sin \alpha_2) + \cdots s_n (\sin \delta_n \sin \alpha_n)$$

where the terms represent each individual dip-strike measurement. $s_1 + s_2 + \ldots s_n$ should equal s, the total length of the traverse. One method is to assume that the influence of each dip-strike symbol extends halfway to the next one (Billings and Tierney, 1964, p. 147).

Another method is to calculate the average value of sin δ sin α for an entire domain, that is

$$A = \frac{\Sigma \sin \delta_1 \sin \alpha_1 + \sin \delta_2 \sin \alpha_2 + \cdots \sin \delta_n \sin \alpha_n}{n}$$

where **A** is average value of $\sin\delta \sin\alpha$.

In effect this gives equal weight to each dip-strike symbol. This is essentially the method used in this paper. A more elaborate method would be to weight each symbol by area, but this would be far more complicated than the method adopted.

However, the direction in which the beds "top" or "young" must be taken into account. In a traverse trending northwest, for example, the term sin δ sin α could be treated as positive if the dips (more precisely, the apparent dip) is northwest and as negative if the dip is southeast.

Thus the basic equation may be written:

$$t = s \frac{\Sigma (\sin \delta_{nw} \sin \alpha_{nw} - \sin \delta_{se} \sin \alpha_{se})}{n}$$

where the subscripts **nw** and **se** refer to the direction of apparent dip along the line of traverse. A similar proceedure can be followed regardless of the azimuth of the line of traverse. All the dip-strike symbols within the domain are utilized in the calculation. The question of accuracy will be discussed below.

The importance of knowing the direction in which the beds "top" or "young" has been mentioned. Regional considerations demonstrate that in general the strata in the Peterborough Quadrangle become younger toward the northwest. But we are now interested in the direction of "topping"

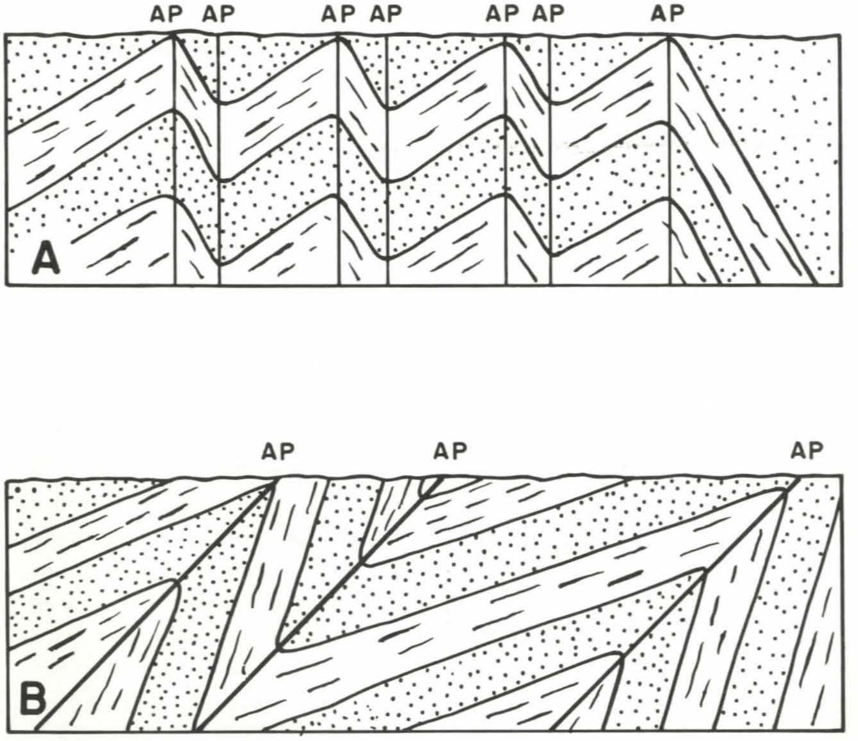


Figure 35.

Relation of Dip of Beds to Axial Planes of Folds — A. Vertical axial planes; all beds top in direction of dip. B. Inclined axial planes; beds that dip in same direction as axial plane but more steeply, top in opposite direction of dip of bedding.

at each outcrop. Methods of telling top and bottom of beds by sedimentary and volcanic features are well known to geologists (Billings, 1954, pp. 70-78). But few, if any, of these criteria are available in the Peterborough Quadrangle. Drag folds (Billings, 1954, pp. 78-83) were used by Freedman (1950, p. 476) in the Mt. Pawtuckaway Quadrangle and by Sriramadas (1966, pp. 40-41) in the Manchester Quadrangle. But significant data were not obtained in the Peterborough Quadrangle.

In principle, another very simple criterion may be used, based on the dip of the beds and the dip of the axial planes of the folds (Billings, 1954, p. 40, Fig. 24). If the dip of the axial planes are vertical, all beds are right-side-up and "young" in the direction of dip. But if the axial plane is inclined, beds that dip in the same direction as the axial plane, but more steeply, are overturned, that is "young" in the opposite direction to that in which they dip (Fig. 35).

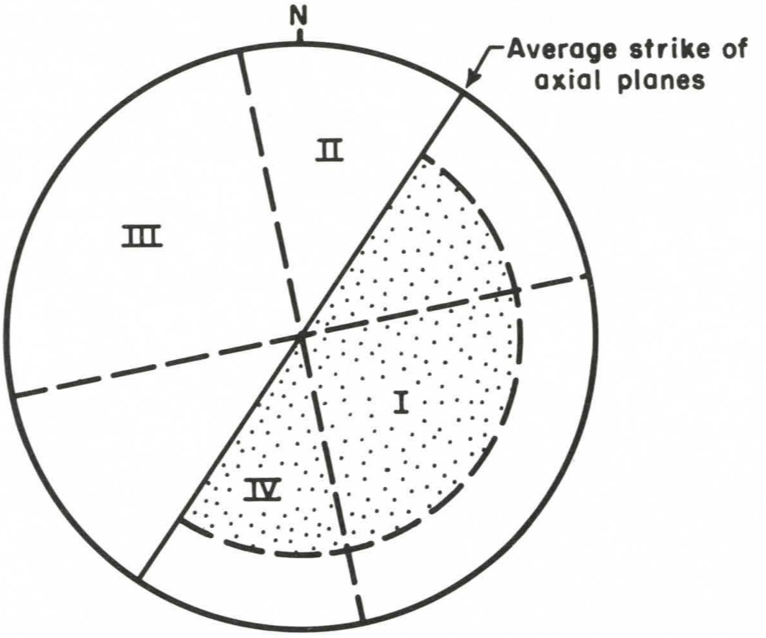


Figure 36.

Quadrant Method for Determining Structural Position of Outcrops — For folds in which axial plane is inclined. Dashed semi-circle in trace on lower hemisphere of axial plane dipping 63° NW. If pole of bedding lies in stippled area, the beds top ("young") toward the northwest. If pole of bedding lies elsewhere, the bed tops southwest.

The method was applied to each of the 21 domains (Fig. 13). For each of these areas it was necessary to obtain the average attitude of the axial planes. The average strike of all the axial planes is N. 33°E. In eight of the diagrams the axial planes are essentially vertical (domains 1, 2, 3, 4, 5, 6, 11, and 16). In the other thirteen the axial planes have an average dip of 63°NW. That is, in these diagrams beds that dip northwest at angles more steeply than 63° are considered to be overturned and to "young" toward the southeast.

The structure diagrams were used for the thickness calculation in the following manner. A template giving the value sin δ sin α is placed over the diagram. The axis of the template is placed parallel to the strike of the axial planes of the folds. The value of sin δ sin α is read from the template for each dip and strike and recorded. Horizontal beds and any beds striking at right angles to the strike of the fold axial planes will give a value of 0. Vertical beds striking parallel to the axial planes give a value of 1 if the axial planes are inclined. Any beds whose apparent dip is parallel to the axial planes are indeterminate, and must be ignored. All other beds give values between 0 and 1.

For the eight domains in which the axial planes are essentially vertical, it was assumed no overturning occurred; that is, the beds "top" in the direction in which they dip. Fig. 36 illustrates the procedure for those domains in which the axial planes have an average strike of N.33°E. and an average dip of 63°NW. Points in the diagrams (Fig. 14-34) that lie within the stippled areas top northwest, all others top southeast.

The pertinent data for the Peterborough Quadrangle are summarized in Table 10. The 21 domains are listed separately. In column 2 are listed the average dip of the axial planes in each domain, assuming the average strike of the axial planes is N.33°E. Columns 3 to 10 are calculated on the basis of traverse lines that trend at right angles to the strike of the axial planes, that is, in a N.57°W. direction. Column 3 lists the number of observations in which the beds top northwest; more precisely those observations in which the apparent dip is in a direction N.57°W. Column 4 lists the number of observations in which the beds top southeast, more precisely those in which the apparent dip is in a direction S.57°E. Column 5 lists the total number of observations. Column 6 is the total value of $\sin \delta \sin \alpha$ for all the observations topping northwest; is measured from the traverse direction, N.57°W. Column 7 is the similar summation for all those beds topping southeast. Column 8 is the difference, column 7 subtracted from column 6. Column 9 is the value in column 8 divided by the value in column 5, it is the ratio of thickness to breadth of outcrop, that is, the factor by which breadth of outcrop is to be multiplied to get thickness.

In Table 11 the thickness has been calculated along seven lines (Fig. 12), but separate calculations have been made for each domain crossed by the line. Column 1 lists the line along which the calculations are made. Column 2 lists the members that the line crosses. Column 3 gives the number of the domain, column 4 is the breadth of outcrop within that domain, column 5 is the factor for that domain, and column 6 gives the calculated thickness within that domain (that is, column 4 multiplied by column 5). Column 7 summarizes the thickness for each member, and column 8 summarizes the total thickness calculated along each traverse line.

Table 12 lists the best value for the thickness of each member. Only a limited amount of data in Table 11 could be utilized, either because the traverse line did not cross the entire member or because plutons interrupted the section.

The source of errors in the preceding calculations may now be discussed.

(1) Equation (2) may be used to calculate the thickness along a traverse line where the attitude is measured at intervals. The influence of each dip-strike is assumed to extend half-way to the next symbol in both directions. This is what Billings and Tierney (1964, p. 147) did in

the City Tunnel Extension in the Boston area. But this assumes a sharp change in the dip-strike at each half-way point, whereas the dips actually change gradually. But geometric reconstructions show that a serious error is not introduced by such calculations.

(2) The method of summation, as done in equation (2) and (4) introduces no errors.

(3) As in most other regions, the calculations are plagued by an irregular distribution of outcrops.

(4) Tectonic factors, such as thickening and thinning of beds, faults, and shear zones may introduce further complications. But there is no evidence of large faults that would introduce a large systematic error.

(5) The errors introduced by the items listed above would be presumably compensatory.

The greatest uncertainty, of course, is due to the difficulty in ascertaining the top and bottom of beds. About eight percent of the beds dipping northwest are considered to be overturned. If in fact all these beds were right-side-up, the thickness would be increased by about 15 percent or 3700 feet. Conversely, if some of the northwesterly dipping beds that have been assumed to be right-side-up were overturned, the thicknesses would be decreased. All things considered, it seems that the probable error in calculating the thicknesses is not greater than 10 percent. The thickness may then be expressed as 24,000 ± 2500 feet.

As shown in Table 13, the Littleton Formation in the Monadnock Quadrangle has a "middle member" that is 5400 feet thick and an "upper member" that is 6000 feet thick (Fowler-Billings, 1949, p. 1254). The middle member may be correlated with the Crotched Mountain Member. The upper member is thus younger than the Crotched Mountain Member. The total thickness of the Littleton Formation in the two quadrangles is about 30,000 feet.

Such a great thickness for Lower Devonian in New England is not unusual. In the Moose River synclinorium of Maine the thickness of the fossiliferous Lower Devonian is of this order of magnitude; the Seboomok Formation alone is as much as 20,000 feet thick (Boucot, 1961, p. 170, Bull. 1111E).

New Hampshire Plutonic Series

General statement.

A study of the structure of the New Hampshire plutonic series is concerned with the shape, relations to adjacent rocks, internal structural features and mechanics of emplacement of the plutons. (Billings, 1945; 1956, pp. 121-135).

Lyndeborough Pluton.

The Lyndeborough Pluton is an irregular body underlying about 10 square miles of the quadrangle. Irregular patches of the Littleton Formation, as much as two miles long, lie within the pluton. It is composed mainly of Spaulding Quartz Diorite, but with small associated bodies of granodiorite and quartz monzonite (Table 6). Most of the rock is massive, but in places it is characterized by a weak foliation that generally strikes north-northeast but dips both northwest and southeast.

The external contacts generally strike parallel to the strike of the adjacent schists, despite the broadly cross-cutting appearance of the body as a whole. The contacts are generally poorly exposed but appear to be steep.

The foliation is considered to be a primary foliation that formed as the magma was being intruded. The magma apparently made room for itself largely by forceful injection after much of the folding of the Littleton Formation had been completed.

New Ipswich and related plutons.

Six oval-shaped bodies, including a New Ipswich Pluton, intrude the Souhegan member in the southeast part of the quadrangle. One-half to one mile long, and 1/4 to 1/2 mile wide, they are structurally similar. The rock is a well-foliated gneiss. Dips are gentle to moderate northwesterly, parallel to those in the adjacent schists. The foliation, primarily due to magmatic flow, may have been intensified by plastic flow in the solid state.

Cardigan Pluton.

The Kinsman Quartz Monzonite in the northwest part of the quadrangle is the south end of the Cardigan Pluton, which extends 60 miles to the north, and ranges in width from six to fourteen miles. This pluton has generally been considered to be a sill or lens injected as magma into the Littleton Formation (Billings, 1945, p. 62).

In the Peterborough Quadrangle large phenocrysts of microcline are commonly parallel to one another. Where the phenocrysts are euhedral and undeformed, as is commonly the case, the foliation is considered to be a primary magmatic flow structure. In the main part of the pluton in the Peterborough Quadrangle — that is, the part west of a line joining Otter Lake and Happy Valley, — a foliation strikes north to northeast and dips steeply. At the west margin of the quadrangle the foliation, which is vertical, strikes slightly west of north. In the long narrow belt extending northeasterly toward Francestown, the foliation dips 50° to 75°NW.

The attitude of the southern contact may be considered first.

North of West Peterborough, extending eastward from the quadrangle boundary to the Peterborough Pluton, the contact forms a big loop convex toward the north. The fact that the schists of the Littleton Formation strike into the contact suggests a cross-cutting contact. But the foliation of the Kinsman also strikes into the contact. It seems much more likely that we have here a folded concordant contact.

The contact is not exposed along the northern border of the Peterborough Pluton. Between North Village and Greenfield the foliation in the Kinsman and Littleton is parallel to their mutual contact. Dips are chiefly vertical or steeply northwest. But northeast of Greenfield the dips in the Kinsman and Littleton are gentle northwest, indicating that the contact similarly dips northwest.

The upper contact of the Cardigan Pluton extends southwest from north of Francestown to Otter Lake, whence it trends north to the north border of the quadrangle. In general the contact is concordant as far as Otter Lake and dips 50°NW. Although locally the foliation of the Kinsman strikes into the contact, this is probably due to folding, inasmuch as the Francestown Member is discontinuously present along this contact. In an exposure north of Francestown the contact dips 60°NW, parallel to the dip of the adjacent schist. Between Francestown and Sunset Lake the contact, which may be located within a few feet, is relatively sharp. But directly north of Sunset Lake there are mixed exposures of Littleton and Kinsman. The latter appears as sills in the former; contacts are parallel to foliation with very little cross-cutting. Phenocrysts persist in the Kinsman to the margins of the sills, although reduced in size. Contacts are generally sharp, but may be transitional over one-half inch.

In the northwest corner of the quadrangle, in and north of the village of Hancock, there are two mappable inclusions in the Cardigan Pluton. The northern one is composed of poorly exposed outcrops of the Francestown Member. The southern one contains schists and lime-silicate rocks cut by stringers of Kinsman.

That part of the Cardigan Pluton extending southwest from Francestown to Greenfield is a sill-like body, dipping about 60°NW. It is 1500 to 2000 feet thick. It lies very close to the Francestown Member. In the Monadnock Quadrangle the bottom of the Cardigan Pluton climbs above the Francestown Member (Fig. 41). Moreover, west of Greenfield the band of Kinsman greatly widens. Along latitude 43°00'N. it is nine miles wide (Fig. 41). The sill appears to have widened greatly, but much of this may be due to folding.

Daly (1897) concluded that the Kinsman was injected as a magma and that the foliation was a primary flow structure. He pointed out that in places the foliation of the Kinsman parallels the contact but transgresses the foliation of the schist. Moreover, he argued that lack of granulation of the phenocrysts favored flowage.

There is also some evidence bearing on the time of intrusion relative to folding. Daly's observation that foliation in places cuts across the foliation of the schist indicates that intrusion followed at least some of the folding. Moreover, Fig. 41 suggests that the Kinsman cuts across the Monadnock syncline. On the other hand, the upper contact of the pluton participates in the Crotched Mountain syncline; thus significant folding followed intrusion. The Cardigan Pluton is truly syntectonic.

Peterboro Pluton.

This pluton, composed of binary quartz monzonite, in which muscovite is more abundant than biotite (Table 14, column 7 and 9), is elliptical in plan and is three miles long, two miles wide. The quartz monzonite is highly foliated. Ovoid feldspar grains and granulated muscovite show that this rock was deformed before final consolidation. Foliation along the western flank is parallel to the contact and to the foliation of the country rock. Foliation in the quartz monzonite along the eastern contact is parallel to the contact, but the dips are opposite to that of the schists. The southern contact appears to be cross-cutting. In the bed of the Contoocook River at Noone steeply dipping sheets of quartz monzonite are parallel to the foliation of the schists.

The pluton is a miniature gneiss dome, conformable in the west, cross-cutting in the east. It is probably the result of forceful injection, with continued movement after consolidation was nearly complete.

Whitcomb Peak Pluton.

This elliptical body east of Pack Monadnock Mountain is four miles long and one mile wide. It is composed of muscovite granite (Table 8, columns 10 and 11), characterized by a faint flow structure shown by aligned muscovite and biotite. Such a foliation may be seen on Route 101, 3700 feet east of B. M. 1020. Because of poor exposures the contacts can not be accurately mapped. The foliation dips northwest at steep angles. The Whitcomb Peak Pluton is probably largely the result of permissive injection, possibly aided by stoping.

Pratt Pond Pluton.

This pluton consists of two parts, a southern circular portion two and one-half miles in diameter, and an elongate northeasterly projection that is three miles long and one mile wide. The southern part consists of biotite-quartz monzonite (Table 8, columns 3 and 4). It is cross cutting, and the foliation dips very gently, suggesting proximity to the roof of the body. This part may have been emplaced by stoping. The northwest contact of the northerly projection is parallel to the structure of the adjacent schists. Roadcuts on Route 101, 7000 feet southeast of Wilton Center, exhibit a striking display of dikes and sills of the quartz monzonite intruding the Spaulding Quartz Diorite. Foliation is faint or absent in this northern part of the pluton.

Joints.

A limited number of observations of the strike and dip of jointing in the plutonic rocks were made. In the Cardigan Pluton a system of vertical joints consisting of two sets is found. These are nearly at right angles and strike about N.30°E. and N.60°W. Jointing is well displayed in the Whitcomb Peak Pluton (Route 101 cuts). Best developed sets in the vertical joint system strike about N.45°E., due N, and N.75°W. Jointing is also well displayed in the pluton south of Greenville, and the southern part of the Pratt Pond Pluton. Strike directions of the two sets of vertical joints are quite consistent at approximately N.30°E. and N.60°W. Little can be said regarding the significance of these joint directions, except that it seems a curious feature that the pluton south of Greenville, which is least foliated, should have joints well aligned parallel and perpendicular to the regional strike.

Faults and Silicified Zones

Many minor faults and shear zones may be observed in roadcuts and outcrops. The displacement is usually only a few feet. But such small faults are not sufficiently important to show on an inch-to-a-mile scale. There is no stratigraphic evidence to suggest large faults.

But two silicified zones are shown on Plate 1. One extends for six miles northeasterly from West Wilton. The second extends north-easterly from Whitcomb Peak. Each of these two zones consists of aligned patches of silicified rock. These patches are usually a few hundred to 2500 feet long and at most 100 feet wide. The silicified rocks consist largely of quartz, with minor amounts of pyrite and magnetite. The most completely silicified areas are fine-grained chert-like quartz. Associated with such rock are breccias consisting of partially silicified rock cut by small quartz veins. The margins of the silicified zones are slightly silicified country rock cut by quartz veins.

Such silicified zones are found elsewhere in New Hampshire (Billings, 1956, p. 120). They are believed to have developed along fault zones. In the Keene-Brattleboro area (Moore, 1948) the silicified zones are obviously related to the Triassic border fault. The silicification is the result of hydrothermal activity. Hot silica-saturated waters rose from depth along fracture zones.

METAMORPHISM

Progressive Metamorphism

Aluminous schists.

Regional metamorphism has converted the sediments of the Peterborough quadrangle to metamorphic rocks of high grade. The mineral assemblages indicate that most of the quadrangle is in the sillimanite zone of metamorphism. Only the small inclusion of schist in the Kinsman Quartz Monzonite at Halfmoon Pond is in the K-feldspar-sillimanite zone. Sillimanite is by no means an abundant mineral; however, as seen in the phase diagrams (Figs. 37-40), there are large bulk composition fields where there would be no sillimanite no matter how high the grade; moreover much sillimanite has probably been destroyed by retrograde metamorphism. Applying negative evidence, neither kyanite nor andalusite, which would indicate lower grades, are present. Staurolite is also absent, indicating that the rocks of the Peterborough quadrangle are in the upper part of the sillimanite zone. Mineral assemblages in the pelitic schists of the Peterborough quadrangle are listed in Table 14. This is reduced to simpler form in Table 15, for plotting on Thompsons AMF projection (Thompson, 1957). In Table 15 plagioclase is disregarded and only assemblages with quartz and muscovite are listed. A single phase diagram (Fig. 37) accounts qualitatively for the assemblages of the upper sillimanite zone present in the Peterborough quadrangle, as none of the other minerals that can be represented thereon are present (except chlorite, which is retrograde). Not present are sillimanite-almandine (with quartz and muscovite) nor are any assemblages involving K-feldspar (without sillimanite). This indicates lack of magnesia-poor or potassium-rich bulk composition in the metasediments.

For the K-feldspar-sillimanite zone, the one assemblage reported can be represented in the phase diagram, Fig. 38. This is an AMF projection for this zone where muscovite is present. Obviously, the AMF projection is not suitable for K-feldspar-sillimanite assemblages without muscovite.

Calc-silicates.

Calc-silicates are uncommon in the Peterborough quadrangle. The calc-silicate assemblages are listed in Table 16. Each assemblage was observed in one or two samples only. An ACF diagram (Fig. 39) has been prepared to illustrate the calc-silicate assemblages. This diagram shows phases in equilibrium with quartz projected on a triangular base with Al_2O_3 at one corner, CaO, at another, and the combined oxides FeO and MgO at the third corner. This diagram is not nearly as satisfactory as those employed for the aluminous schists because FeO and MgO must be combined, no alkalis are included as components, and anorthite may be shown on the diagram but not albite.

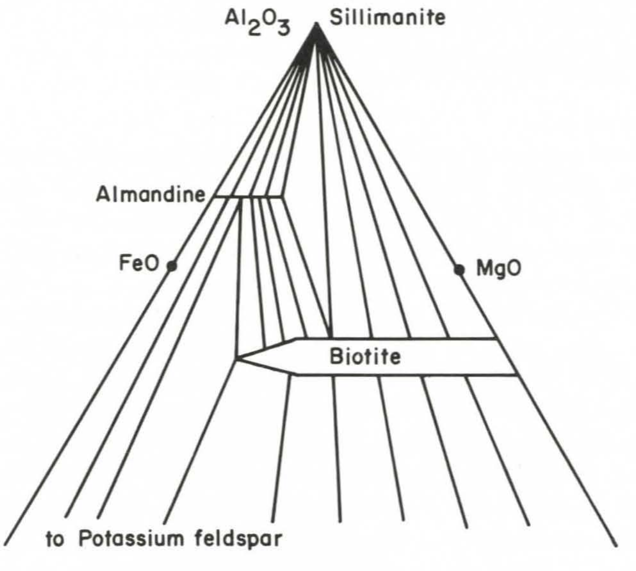


Figure 37.

Phase Relations, Upper Sillimanite Zone — For Peterborough Quadrangle. Thompson's AMF projection, quartz and muscovite present.

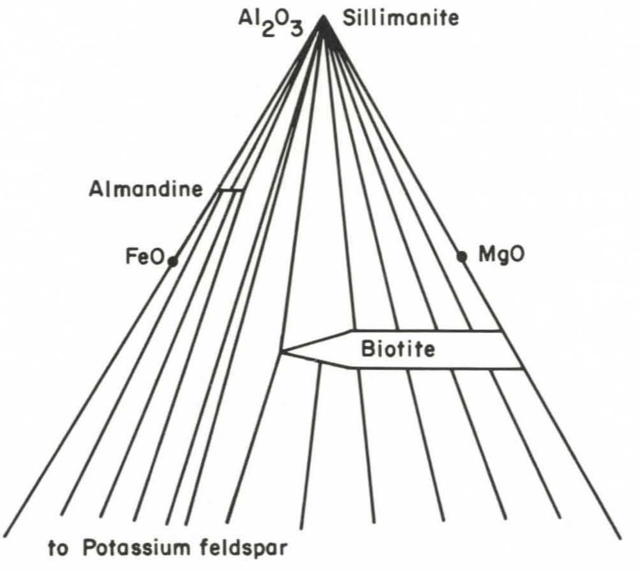


Figure 38.

Phase Relations, Sillimanite-Potassium Feldspar Zone — For Peterborough Quadrangle. Thompson's AMF projection, quartz and muscovite present.

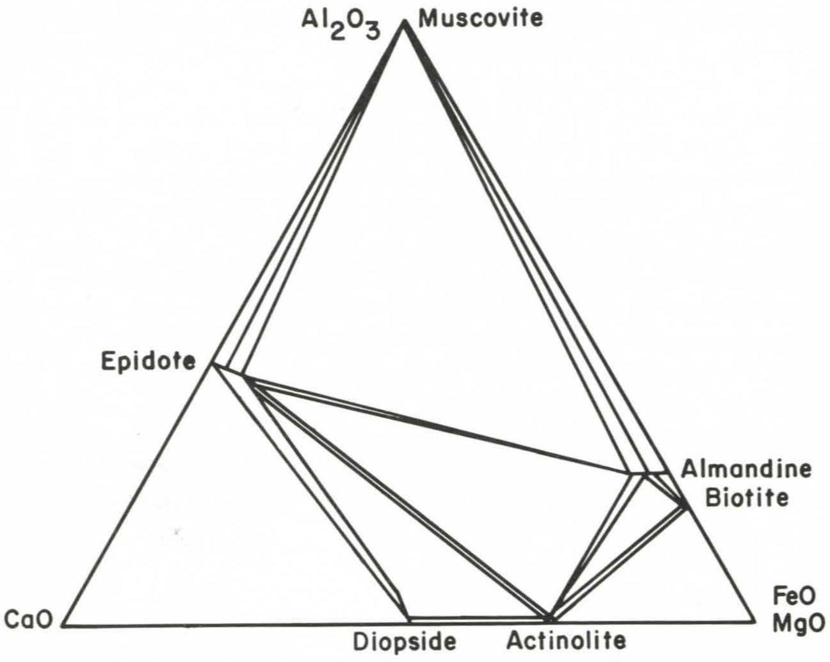


Figure 39.
Phase Relations in Calc-Silicate Rocks — For Peterborough Quadrangle. Tentative.

In view of the foregoing, it is not surprising that in two assemblages, more than three phases may be plotted on the diagram, a violation of the phase rule. Nevertheless, the diagram gives the best possible representation of the compatible assemblages in this system in the upper sillimanite zone.

Limiting conditions.

The aluminum silicate minerals andalusite, kyanite, and sillimanite (Al_2SiO_5) provide the best available clue to temperature-pressure conditions in pelitic schists. The one component aluminum silicate system has received much deserved study (Clark, Robertson, and Birch, 1957; Clark, 1961; Bell, 1963; Newton, 1966; Richardson, Gilbert, and Bell, 1969). Unfortunately different methods of determination of the stability fields of the andalusite, kyanite, and sillimanite polymorphs have led to quite different results (Fig. 41). Accepting the most recent value for the triple point (about 622°C and 5.5kb) it is seen that the sillimanite field lies to the right of curves A and C in Fig. 40.

Turning now to the system SiO_2-$KAlSi_3O_8$-$NaAlSi_3O_8$-H_2O (Tuttle and Bowen, 1958) in search of an upper limit, we find that the highest pressures considered are only 4000 kgm/cm^2, approximately 4 kilobars. However, the curves (Tuttle and Bowen, 1958, Fig. 26, pg. 56) are very flat at the highest pressure considered, and may be extrapolated with slightly decreasing slope to higher pressures. Since the compositions of some of the schists under consideration lie close to the compositions used in the melting experiments, these curves may be taken as practical upper limits, since the schists have not been melted. This gives a permissible pressure-temperature range defined by curves A, C, and G, figure 40. This range is disturbingly small, and certainly suggests that there are problems yet to be solved in the aluminum silicate system. Tuttle and Bowen's experiments were done with a water saturated system, and this limits the applicability of their curves to metamorphic rocks where these conditions may not have obtained. However, because many small dikes and sills of granite with hydrous minerals such as muscovite and biotite have intruded the schists, it seems likely that water was available at least locally, and moreover, that the rocks were heated to temperatures close to the ternary minimum.

Retrograde Metamorphism

Metasedimentary Rocks.

Nearly all of the metasediments in the Peterborough quadrangle have undergone retrograde metamorphism to a greater or lesser degree. This is shown principally by the alteration of biotite, and to a lesser extent by the alteration of garnet and the presence of sericite.

In many thin sections the biotite is seen to be more or less altered. Taking examples from Table 2, in some rocks the biotite is seen to be bleached, and partly converted to chlorite (cols. 3, 4, 13, 19). The bleached biotite is pale-brown to gray under the microscope, and with crossed nicols the birefringence is considerably reduced. Commonly, higher order interference colors show the center of the grains to be less affected. Where completely converted to chlorite, the characteristic green color of this mineral is seen. Under crossed nicols the color is gray, rarely with ultra-blue in certain orientations. Commonly, fine grains of magnetite pepper the chlorite. In many cases conversion from biotite to chlorite is direct, i.e., without the intermediate stage of bleaching, so that fresh-looking biotite and chlorite — rimming it and in separate grains — may be seen in the same slide. Examples are Table 2, cols. 3 and 10. Finally, many rocks contain no biotite, but abundant chlorite, some with magnetite, indicates that alteration of biotite has been complete. Such rocks commonly contain abundant sericite (included with muscovite in modes).

In many of the rocks from the Peterborough quadrangle containing garnet, this mineral is partly altered to chlorite and sericite. In some specimens the garnet is perfectly fresh, whereas in others garnet in several

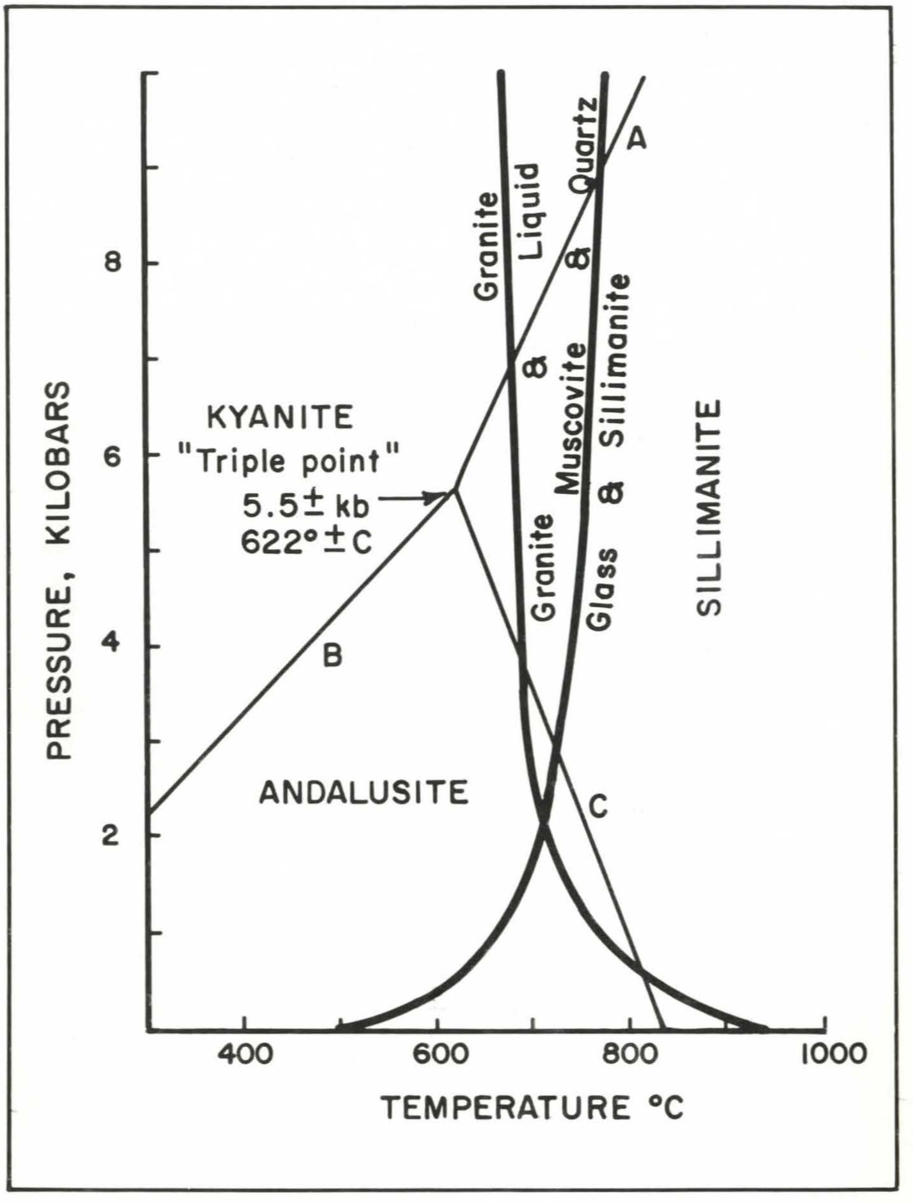


Figure 40.

Limiting Conditions of Metamorphism in the Peterborough Quadrangle — Triple point after Richardson et al (1969). Curve G, minimum melting in granite system, after Luth et al (1964).

stages from 20-90% alteration may be seen. In still other specimens round patches of chlorite are obviously products of the complete alteration of garnet.

Plutonic Rocks.

Most of the plutonic rocks, like the metasediments, have undergone retrograde metamorphism in some degree. This appears as alteration of biotite and of plagioclase.

Alteration of Biotite.

This effect is as previously described for the metasediments. Most commonly, fresh-appearing biotite is rimmed with chlorite and some grains are completely converted. (Table 7, cols. 1 and 2 and Table 6, cols. 1 and 4). In rare cases, only chlorite remains. (See Table 7, col. 4).

Alteration of Plagioclase.

Much of the plagioclase is partially saussuritized. Various stages in this process may be observed in the plutonic rocks, starting with cloudiness in the plagioclase grains and progressing to the appearance of detectable muscovite flakes, and more rarely, epidote and calcite. The most altered plagioclases are generally albite or sodic oligoclase, as is to be expected.

The Kinsman Quartz Monzonite is the most severely retrograded plutonic rock. Much of the Spaulding Quartz Diorite also shows the effects of severe retrograding. The Binary Granite and Massabesic Gneiss are less affected.

DEFORMATION, METAMORPHISM, AND INTRUSION

The rocks of the Peterborough quadrangle, as we see them today, are obviously the result of a major orogenic episode. A thickness of Early Devonian sediments, almost certainly in excess of 30,000 feet, had accumulated over the area. Compression along northwest-southeast lines began, probably in Middle Devonian time. The rocks we now see at the surface, then deeply buried, were folded and sheared, and heated to high temperatures, converting them to high-grade schists and granulites.

It is very likely that the intensity of the folding is directly related to the intensity of the compressional stress operative at the time the folds were formed. Early folding under intense stress resulted in tight and isoclinal folds, with axial planes overturned to the southeast; possibly also in the major downwarp forming the Merrimack Synclinorium.

As the intensity of the compression diminished, so did the intensity of folding, so that in later stages gentle folds were formed, some of these aligned normal to the stress, and some at an angle to the stress, reflecting adjustments of rock masses along northwest-southeast lines.

Intrusions of magma occurred, though their precise timing relative to the climax of orogeny, and to each other, are difficult to determine. Spaulding Quartz Diorite and Kinsman Quartz Monzonite were probably early, with binary quartz monzonite in several different stages.

As the time of maximum stress passed, the temperature dropped, and the final intrusions of binary quartz monzonite and pegmatite occurred. With the lowering of the temperature, retrograde metamorphism set in. This was accompanied by further shearing and slippage of the rocks, commonly parallel to the principal foliation, but rarely cross-cutting it. Retrograded rock samples, from Pack Monadnock Mountain in particular, show the results of late deformation in the form of slip planes and abundant fine, mashed muscovite. Cross-folding and cross-shearing, particularly noted on Winn, Lyndeborough, and Piscataquog Mountains, occurred at this time. The most extremely retrograded schists in the area occur in a cross sheared area just south of the body of granite in Francestown. The development of a cross-cutting crinkling or slip cleavage, particularly noticeable on the north slope of North Pack Monadnock Mountain occurred during this stage. Quartz veins were deposited, conformable at first, later cross-cutting. Finally, retrograding affected the intrusives as temperatures lowered, stress ended, and the orogeny was completed, probably before the close of Devonian time.

At a later time, probably during the Triassic, limited local intrusion of basalt dikes, normal faulting, and silicification occurred.

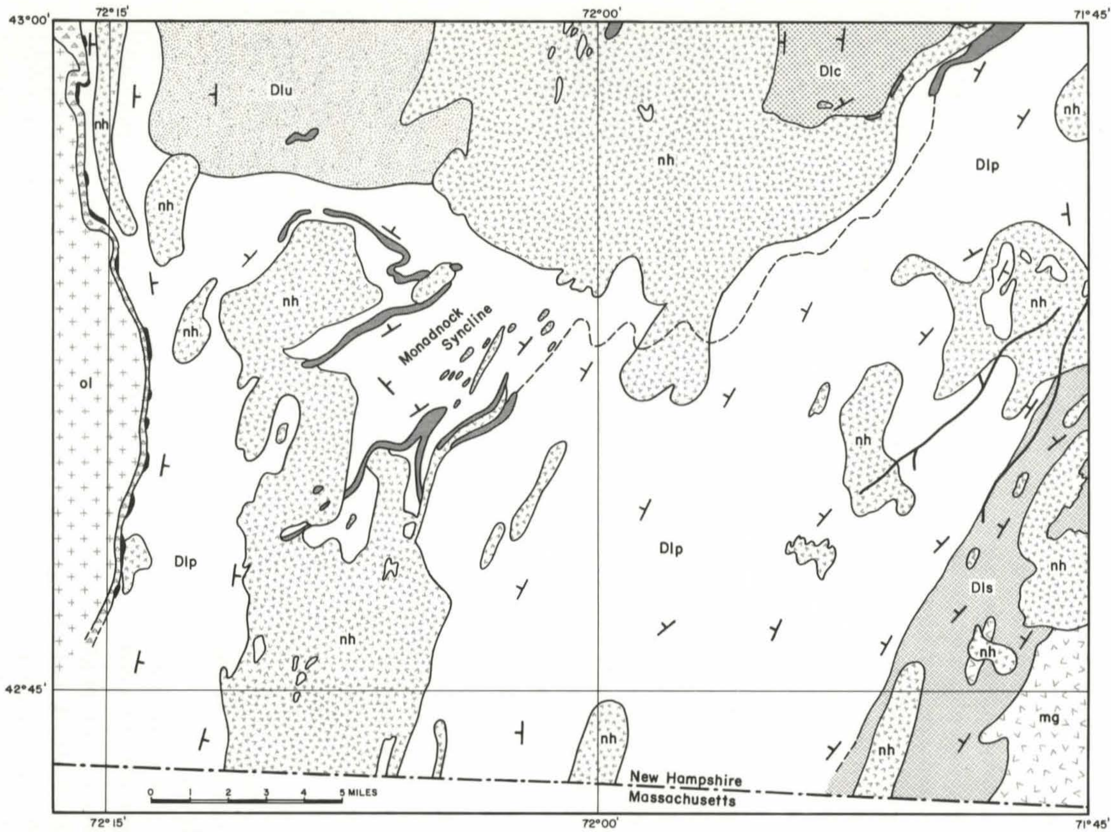
These events brought the deformational and intrusive history of the Peterborough quadrangle to a close, and erosion, interrupted only by glaciation, has ensued to this day.

REGIONAL RELATIONSHIPS

The Peterborough Quadrangle lies across the central and eastern parts of the Merrimack Synclinorium, a broad structural belt extending from central Connecticut across Massachusetts and New Hampshire into Maine (Billings, 1956, p. 114).

In Connecticut, Massachusetts, and New Hampshire the Merrimack Synclinorium is bounded on the west by the Bronson Hill anticline (Fig. 41). On the east it is bounded by the Massabesic Gneiss of the Fitchburg Pluton. The Rockingham Anticlinorium lies southeast of the Fitchburg Pluton (Billings, 1956, p. 112). But the crest of this anticline is at the New Hampshire coast, where it is called the Rye Anticline. Thus southern New Hampshire, between the Bronson Hill Anticline on the west and coast on the east is underlain by a broad synclinorium approximately 60 miles wide. Subsidiary and minor folds are associated with this synclinorium.

The axis of the Merrimack synclinorium is very asymmetrically located. It extends through Mount Monadnock and Crotched Mountain. The west limb is about ten miles across, whereas the east limb is fifty miles across. According to Fowler-Billings (1949, p. 1254) on the west limb the Silurian, represented by the Clough Formation, attains a maximum thickness of 100 feet. The Devonian Littleton Formation below the Francestown Member is 5000 feet thick. But on the southeast limb of the Merrimack Synclinorium the Littleton Formation below the Francestown Member is about 18,500 feet thick in the Peterborough Quadrangle. Moreover, the Silurian (Merrimack group) in the southeastern limb of the Merrimack Synclinorium is at least 18,000 feet thick; Billings, (1956, p. 9) gives 18,000 feet in southeastern New Hampshire; Hussey (1962) gives 13,000 to 17,000 feet in southern Maine; and in the Manchester area of New Hampshire Sriramadas (1966, p. 9) gives 17,500 feet, excluding the lower part of the group. For those who question the possibility of such great thicknesses of Silurian, we may refer to the Gaspe′ Peninsula, where the unmetamorphosed Silurian is at least 16,000 feet (Lajoie et al, 1968, p. 615). Thus the Silurian rocks thicken from 100 feet on the Bronson Hill Anticline to 18,000 feet in southeastern New Hampshire. Similarly, the lower part of the Littleton Formation thickens from 5000 feet on the flanks of the Bronson Hill Anticline to 18,500 feet further east. For those who are unhappy about the difficulty in locating the Siluro-Devonian boundary, we can say that the Siluro-Devonian thickens from 5000 feet to 36,500 feet toward the east. Similarly, in eastern Vermont the Siluro-Devonian is much thicker than on the Bronson Hill Anticline. The Bronson Hill Anticline was thus a positive area during Siluro-Devonian times, with deep basins both east and west of it sinking much more rapidly. This same relationship is recognized further north in New Hampshire and Maine, where this positive area has been called the Somerset Geanticline (Cady, 1968, p. 159).



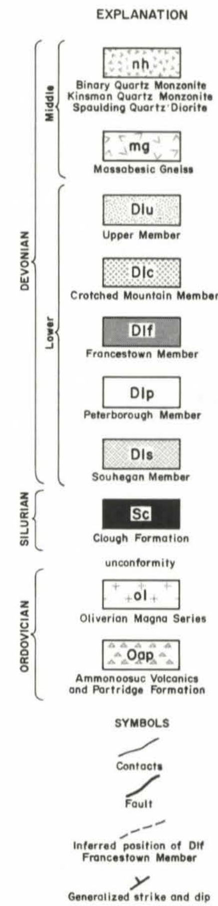


Figure 41.

Regional Sketch Map — Geological map of Monadnock and Peterborough Quadrangles.

GEOMORPHOLOGY AND SURFICIAL GEOLOGY

The surficial geology of the Peterborough quadrangle was not mapped for this report. However, some features of the surficial deposits were noted, as well as the relationship between bedrock and topography. Considerable information on the surficial deposits in the Peterborough quadrangle is included in the Geology of New Hampshire by Hitchcock (1874, 1877, 1878) and in the Geology of New Hampshire by Goldthwait (1925). Goldthwait discusses the glacial-fluvial deposits of the Contoocook valley. He describes some of the Pleistocene lakes and drainage routes.

Topography and Bedrock

Topography seems related in only a very general way to the lithology of the bedrock in the Peterborough quadrangle. Plutonic rocks of all types generally underlie lowlands, but there are exceptions, such as Whitcomb Peak in Temple, the hill north of Halfmoon Pond, and the hill northwest of Otter Lake, both in Hancock. The schists outcropping on the Pack Monadnock Mountains and other mountains are commonly of quartz-rich types that appear to be resistant, but just as commonly they are mica-rich types that appear to be weak. The thin-bedded facies, as developed on Rose and Temple Mountains, would appear to be resistant; however, rocks of this facies also underlie low ground in Francestown. A glance at the geologic map shows that only locally does strike parallel the crest of a ridge. However, Temple, Pack and North Pack Monadnock, Winn and Lyndeborough Mountains appear to constitute a cuesta on northwest dipping beds of generally greater resistance than those underlying the adjacent lowlands (Fig. 42).

Glaciation

The effects of glaciation on the topography of the Peterborough quadrangle are readily apparent. Figure 43 is a map showing the directions of ice movement in various parts of the Peterborough quadrangle, as indicated by striae and streamline features. The streamline features represent drumlins and ice-shaped hills. Most of the more symmetrical elongate hills, particularly in the Rand Brook area (Greenfield, Francestown, and Lyndeborough) are drumlins; others are in part drift and in part shaped bedrock.

The effect of the Wapack Range in diverting the ice may be seen by the alignment of the streamline features. The glacier, in turn has had profound effects on the topography. In addition to the smooth shape of drumlins and minor bedrock hills, the gentle northwest slopes and steep southeast slopes of the mountains are the result of glacial action. The ice flowed generally southeast, in riding up over pre-existing highs, it deposited quantities of

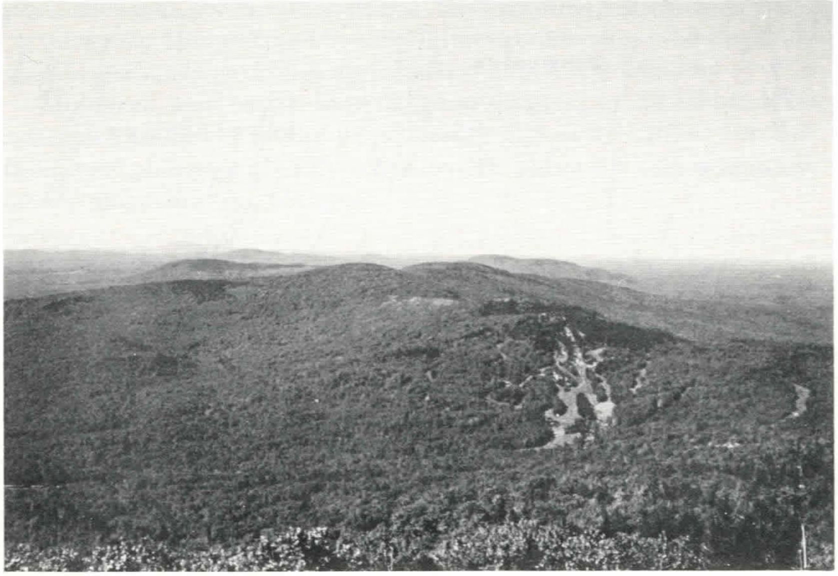


Figure 42.

Temple Mountain and Southern Peaks of Wapack Range — Looking south from summit of Pack Monadnock; peak in the far distance is Wachusett Mountain, near Leominster, Massachusetts.

till on the northwest slopes, then in spilling over the crests, broke off great blocks and oversteppened the southeast slopes. That this occurred is apparent in Winn, Lyndeborough, North Pack Monadnock, and Temple Mountains in particular. The same effect may be seen on Fisk Hill (Temple), Kidder Mountain (New Ipswich) and Blanchard Hill (Greenfield).

Retreat of the last glacier left much of the Peterborough quadrangle mantled with till. Till is thickest on the north slopes of the mountains, but covers also much of the lowlands as ground moraine. Superposed on the till in many areas are deposits of stratified drift.

Resumption of the normal drainage is as yet incomplete, as is indicated by the numerous lakes and swamps.

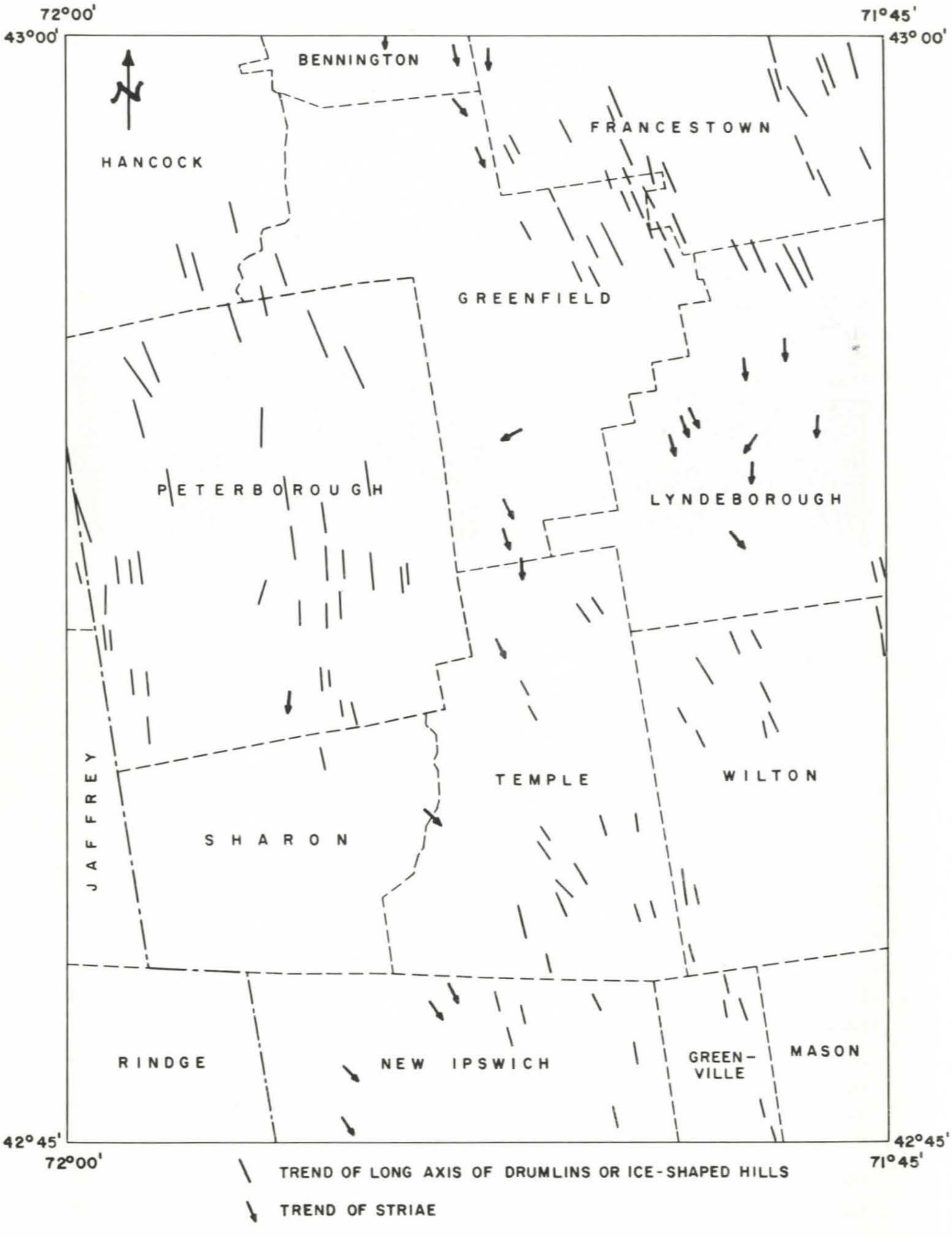


Figure 43.

Linear Features Related to Glaciation — Glacial striae and stream-lined features (drumlins and ice-shaped hills).

ECONOMIC GEOLOGY

General Statement

Rocks that have been quarried in the past or at present include granite, soapstone, silicified rock, and sand or gravel.

Granite

Eight abandoned granite quarries were found by the writer in the Peterborough Quadrangle. Most are in the binary quartz monzonite. All produced granite for dimension stone. The largest quarry was in the extreme southeast corner of the quadrangle in a body of binary quartz monzonite too small to map separately. It is surrounded by Massabesic Gneiss. Locally known as the McDonald Quarry, it apparently operated in the 1880's and 1890's. This quarry and five other small quarries in Greenville, Mason, and West Wilton are part of the Milford quarry district (Dale, 1923, p. 180-191).

The quarry near Stinson Hill in Lyndeborough is in the Spaulding Quartz Diorite. A quarry in Peterborough just across the Contoocook River from the center of the village was developed in the highly foliated binary quartz monzonite of the Peterborough Pluton. Blocks of this rock may be seen in buildings, foundations and retainer walls in Peterborough; they have taken the weather well.

The most attractive granites are those of the Pratt Pond and Greenville Plutons, which contain a lighter and more lustrous microcline than the rock of the Whitcomb Peak and Peterborough Plutons. The rock is as attractive as that currently being quarried at Barre, Vermont, and elsewhere.

Soapstone

A body of soapstone in Francestown has been extensively quarried, so that there are good exposures in the quarry wall (Fig. 44). Soapstone is a term used rather loosely for any rock rich in talc, but containing numerous other minerals as impurities.

The body of soapstone is lenticular, about 400 feet long, 100 feet wide, and dips steeply to the north parallel to the country rock, which is mica schist.

Modes are given in Table 17. Columns 1 and 2 are chloritized mica schists characteristic of the Peterborough Member of the Littleton Formation. Columns 3, 4, and 5 are biotite granulites and schists typical of those found in many places associated with lime-silicate rocks. Column 6 is typical lime-silicate rock composed of actinolite, calcic andesine, biotite, and a little quartz. Columns 7, 8, and 9 are the soapstone, all containing phlogopite and talc, and some containing actinolite and chlorite.

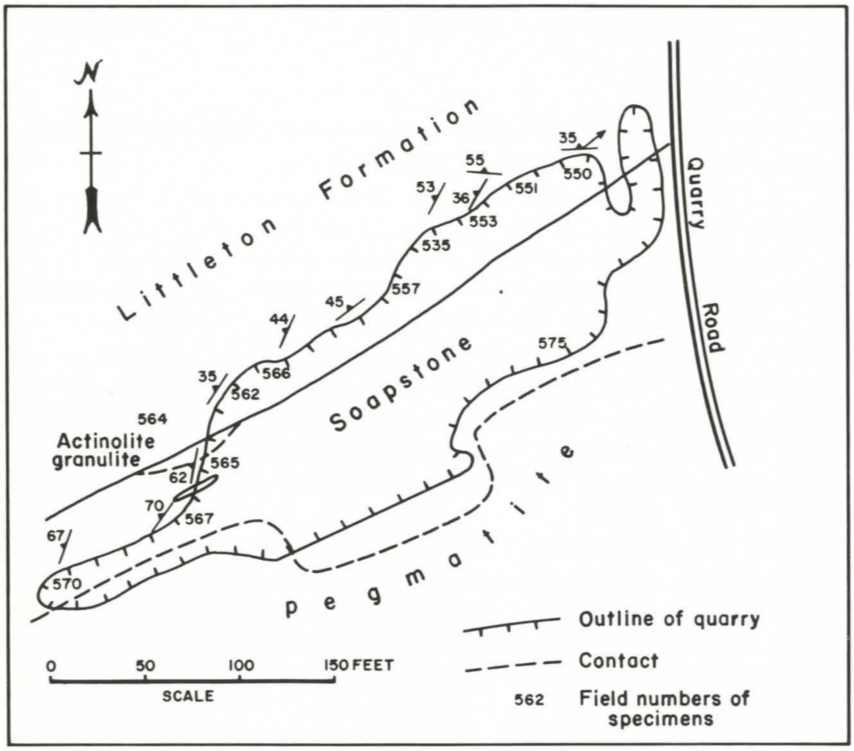


Figure 44.
Soapstone Quarry in Francestown.

Although the talc and associated rocks in Vermont are related to serpentine, there is no evidence that this soapstone is of this origin. The associated lime-silicate rocks, as well as the high percentage of potash indicated by the phlogopite in the soapstone, suggests a derivation from argillaceous dolomite. Because the mineral assemblage is indicative of lower metamorphic grade than the surrounding schists, the soapstone must have formed later than the climax of the regional metamorphism. It is most likely that the soapstone was derived from a lime-silicate rock by hydrothermal alteration.

Hitchcock (1878) reports that this deposit was discovered in 1794 and first worked in 1802. The soapstone was quarried in blocks, then sawn into slabs for use in sinks, stoves, and washboards. The material from this quarry apparently became rather famous for its high quality. The quarry was abandoned in the early 1900's, probably because most of the good material was exhausted, but perhaps in part owing to competition from cheaper cast-iron stoves and sinks. Blocks of soapstone could still be found in 1960 near the quarry, but little good material remains in place above water level in the quarry.

Silicified rock

In 1963 a quarry was opened in Lyndeborough in a silicified zone one-half mile east-northeast of B.M. 655. The rock is crushed to fine particles and mixed with concrete to give it sparkle and luster. Similar silicified zones are available elsewhere in the Peterborough Quadrangle, but care should be taken to get clean rock and especially to avoid those parts containing pyrite. The silicified rock may also have possibilities for glass manufacturing.

Pegmatite

The pegmatites are a potential source of feldspar, mica, and beryl. However, even during World War II none of these bodies was exploited (Cameron et al, 1954, p. 255).

Sillimanite

Sillimanite is used in the ceramic industry. Rocks containing 20 to 40 percent of sillimanite are available in two localities, one directly west of Winn Mountain (Table 2, column 8) and one directly west of Crotched Mountain (Table 4, columns 5 and 6). The quantity has not been determined but can be ascertained by further surface observations and diamond drilling.

Sand and Gravel

A large number of sand pits and a few gravel pits have yielded large tonnages of these materials in the Peterborough Quadrangle. They are mostly in lowland areas in Rindge, Jaffrey, Peterborough, Hancock, and Greenfield. Large quantities of clean and well-sorted sand underlie the outwash plain directly north of Happy Valley (Peterborough) and line the Contoocook River between Noone and North Village (both in Peterborough). Gravel deposits are less abundant but some are located near Squantum (Jaffrey) and near the Souhegan River in the south of Wilton.

REFERENCES CITED

Bell, P. M., 1963, Aluminum silicate system: experimental determination of the triple point: Science, v. 139, p. 1055-1056.

Billings, M. P., 1937, Regional metamorphism of the Littleton-Moosilauke area, New Hampshire: Geol. Soc. America Bull., v. 48, p. 463-566.

_________, 1954, Structural Geology, Prentice-Hall, New York, 514 p.

_________, 1955, Geologic Map of New Hampshire.

_________, 1956, The Geology of New Hampshire, Part 2, Bedrock Geology, N. H. State Planning and Development Commission, Concord, 203 p.

_________, Chapman, C. A., Chapman, R. W., Fowler-Billings, K. and Loomis, F. B., Jr., 1946, Geology of the Mt. Washington quadrangle, N. H.: Geol. Soc. America Bull., v. 57, p. 261-274.

_________, and Cleaves, A. B., 1934, Paleontology of the Littleton area, New Hampshire: Amer. Jour. Sci., 5th ser., v. 28, p. 412-438.

_________, _________, 1935, Brachiopods from mica schist, Mt. Clough, New Hampshire: Amer. Jour. Sci., 5th ser., v. 30, p. 530-536.

_________, and Tierney, F. Lyle, 1964, Geology of the City Tunnel Extension, Greater Boston, Massachusetts, vol. 51, p. 111-154.

Boucot, Arthur J., 1961, Stratigraphy of the Moose River synclinorium, Maine, U. S. Geol. Survey, Bull. 1111-E, p. 153-188.

_________, and Thompson, J. B., Jr., 1958, Late Lower Silurian fossils from Sillimanite zone near Claremont, New Hampshire: Science, v. 128, no. 3320, p. 362-363.

_________, _________, 1963, Metamorphosed Silurian brachiopods from New Hampshire: Geol. Soc. America Bull., v. 74, p. 1313-1333.

_________, MacDonald, G. J. F., Milton, C., and Thompson, J. B., Jr., 1958, Metamorphosed Middle Paleozoic fossils from central Massachusetts, eastern Vermont, and western New Hampshire: Geol. Soc. America Bull., v. 69, p. 855-864.

Cady, Wallace M., 1968, The lateral transition from the miogeosynclinal to the eugeosynclinal zone in northwestern New England and adjacent Quebec, pp. 151-162, in E-an Zen et al., Studies of Appalachian Geology: Northern and Maritime, New York, 1968.

Cameron, Eugene and others, 1954, Pegmatite Investigations, 1942-45, New England, U. S. Geol. Survey, Prof. Paper 255, 352 p.

Chapman, C. A., 1939, Geology of the Mascoma quadrangle, New Hampshire: Geol. Soc. America Bull., v. 50, p. 127-180.

_________, 1952, Structure and petrology of the Sunapee quadrangle, New Hampshire: Geol. Soc. America Bull., v. 63, p. 381-425.

Chayes, F., 1952, The finer grained calc-alkaline granites of New England: Jour. Geology, v. 60, p. 207-254.

Clark, S. P., 1961, A redetermination of equilibrium relations between Kyanite and Sillimanite: Amer. Jour. Science, v. 259, p. 641-650.

Clark, S. P., Robertson, E. C., and Birch, F., 1957, Experimental determination of Kyanite-Sillimanite equilibrium relations at high temperatures and pressures: Amer. Jour. Science, v. 255, p. 628-640.

Dale, T. Nelson, 1923, The commercial granites of New England, U. S. Geol. Survey, Bull. 738, 488 p.

Daly, R. A., 1897, Studies on the so-called porphyritic gneiss of New Hampshire: Jour. Geology, v. 5, p. 694-722, 776-794.

Emerson, B. K., 1917, Geology of Massachusetts and Rhode Island: U. S. Geol. Survey Bull. 597.

Fowler-Billings, K., 1949, Geology of the Monadnock area, New Hampshire: Geol. Soc. America Bull., v. 60, p. 1249-1280.

Fowler-Lunn, K., and Kingsley, L., 1937, Geology of the Cardigan quadrangle, New Hampshire: Geol. Soc. America Bull., v. 48, p. 1363-1386.

Freedman, J., 1950, Stratigraphy and structure of the Mt. Pawtuckaway quadrangle, New Hampshire: Geol. Soc. America Bull., v. 61, p. 449-492.

Goldthwait, J. W., 1925, The geology of New Hampshire: N. H. Acad. Science, Handbook no. 1, Concord, N. H., 86 p.

Heald, M. T., 1950, Structure and petrology of the Lovewell Mountain quadrangle, New Hampshire: Geol. Soc. America Bull., v. 61, p. 43-89.

__________, 1955, The geology of the Gilmanton quadrangle, New Hampshire: N. H. Planning and Devel. Comm., Concord, 24 p.

Hitchcock, C. H., 1874, 1877, 1878, Geology of New Hampshire, three volumes and atlas, Concord, N. H.

Hussey, Arthur M., II, 1962, Geology of southern York County, Maine, Special Geol. Studies Series, no. 4, Maine Geol. Survey, 67 p.

Jackson, C. T., 1844, Final report of the geology and mineralogy of the state of New Hampshire, Concord, N. H.

Lajoie, J., Lesperance, P. J., and Beland, J., 1968, Silurian stratigraphy and paleogeography of Matapedia-Temiscouata Region, Quebec, Am. Assoc. Petrol. Geol., v. 52, p. 615-640.

Luth, W. C., Jahns, R. H., and Tuttle, O. F., 1964, The granite system at pressures of 4 to 10 kilobars, Jour. Geophys. Research, vol. 69, p. 759-773.

Moore, G. E., Jr., 1949, Structure and metamorphism of the Keene-Brattleboro area, N. H., and Vt.: Geol. Soc. America Bull., v. 60, p. 1613-1670.

Osberg, Philip H., 1968, Stratigraphy, structural geology, and metamorphism of the Waterville-Vassalboro area, Maine, Bull. No. 2, Maine Geological Survey.

Quinn, A., 1944, Magmatic contrasts in the Winnipesaukee region, New Hampshire: Geol. Soc. America Bull., v. 55, p. 473-496.

_________, 1953, The geology of the Wolfeboro quadrangle, New Hampshire: N. H. Planning and Devel. Comm., Concord, N. H., 24 p.

Rickard, Lawrence V., 1962, Late Cayugan (Upper Silurian) and Helderbergian (Lower Devonian) stratigraphy in New York: Bull. no. 386, N. Y. State Museum and Science Service, 157 p.

Richardson, S. W., Gilbert, M. C., and Bell, P. M. (1969), Experimental determination of kyanite-andalusite and andalusite-sillimanite equilibria; the aluminum silicate triple point, Am. Jour. Sci., vol. 267, p. 259-272.

Sriramadas, A., 1955, Geology of the Manchester quadrangle, N. H.: Ph.D. thesis, Harvard University.

_________, 1966, Geology of the Manchester quadrangle, New Hampshire: New Hampshire Dept. Resources and Economic Development, Bull. no. 2, 78 p.

Thompson, J. B., Jr., 1954, Structural geology of the Skitchewaug Mountain area, Claremont quadrangle, Vermont-New Hampshire: Guidebook Forty-sixth New England Intercollegiate Geological Conference (Dartmouth College).

_________, 1957, The graphical analysis of mineral assemblages in pelitic schists: Amer. Min., v. 42, p. 842-858.

Thompson, J. B., Jr., Robinson, Peter, Clifford, Tom N., and Trask, Newell J., Jr., 1968, Nappes and gneiss domes in west-central New England, p. 203-218 in E-an Zen et al., Studies of Appalachian Geology: Northern and Maritime, New York, 1968.

Tuttle, O. F., and Bowen, N. L., 1958, Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O: Geol. Soc. America, Mem. 74, 153 p.

APPENDIX

INTERESTING LOCALITIES

Interesting localities are so numerous in the Peterborough quadrangle that only the briefest mention of them can be made here. Many have already been alluded to in the body of this report.

Littleton Formation

1. **Pack and North Pack Monadnock Mountains**

Mica schist and quartz-feldspar granulite of the Peterborough Member of the Littleton Formation. Road from route 101 up Pack Monadnock, fire tower on summit. Good trail from there to North Pack and down to Sand Hill Road.

2. **Temple Mountain**

Ridge crest exposures of thin-bedded rocks on north part, rusty weathering schists on south part, wooded peaks in central part. Good trail entire length, starts near ski area on route 101, ends near village of Sharon.

3. **Crotched Mountain**

Excellent exposures of schist of the Crotched Mountain Member in glacially truncated outcrops on ridge leading north from Crotched Mountain Center (directly above Sunset Lake). Trail continues to summit of mountain, where a fire tower is located. Schists of the summit area have abundant large sillimanite porphyroblasts weathering out on the surface. Small anticlinal fold at base of fire tower. Steep trail descends west to route 31 near Whittemore Lake, another north to Bennington-Francestown road on Hillsborough quadrangle.

4. **Winn, Rose, and Lyndeborough Mountains**

Excellent glacially truncated exposures of thin-bedded rocks on Rose Mountain, and of the Peterborough Member of the Littleton Formation on Lyndeborough and Winn Mountains, the latter containing the greatest acreage of bare rock in the Peterborough quadrangle. Good mineral collecting from quartz-tourmaline veins, particularly the south slopes of Rose and Lyndeborough Mountains. Trails faint in this area, map and compass needed.

5. **Falls of the Piscataquog**
South Branch Piscataquog River at quadrangle boundary. Excellent exposures of granite upstream from bridge, highly sheared and retrograded green schists with pink quartz veins downstream.

6. **Wilton-route 31 roadcuts**
Longest continuous cuts across the strike in the Peterborough quadrangle. Northwest part foliated Spaulding Quartz Diorite, southeast part Souhegan Member. Several basalt dikes.

7. **Greenville-route 31 roadcuts**
Type locality of Souhegan Member. Here are very fresh cuts showing the distinctive character of the Souhegan Member, also granite and pegmatite.

8. **Quarry road, Francestown**
Soapstone quarry readily accessible, best examined by boat, inquire locally for permission. Exposures of Francestown Member north of quarry are excellent.

Spaulding Quartz Diorite

9. **Lyndeborough-Stony Brook area**
Railroad and stream cuts exhibit the many varieties of this rock, best between South Lyndeborough and BM828, also near BM861.

10. **New Ipswich Center**
Roadcut in route 123-124, 2500' east of BM973 shows foliate Spaulding Quartz Diorite of the New Ipswich Pluton with a related pegmatite dike.

11. **Wilton, route 101 cut**
(2500' east of BM460) Large roadcuts show foliate Spaulding Quartz Diorite on one side of the road abundantly cross-cut with dikes of granite. Other side of road shows granite with pegmatite and aplite.

Kinsman Quartz Monzonite

12. **Halfmoon Pond spillway, Hancock**
Spillway opened by Army Engineers with glacially polished surfaces uncovered. Superb exposures of Kinsman, mostly badly sheared. Relationship of flow foliation to shear well displayed.

13. **1280 foot hill directly north of Halfmoon Pond**

Here may be seen exposures of more "typical" Kinsman with undisturbed flow foliation. No trails, map and compass needed.

14. **Sunset Lake**

Contact area (directly north of lake) with interfingering quartz monzonite and schist, mostly on grounds of Nashua Fresh Air Camp.

Massabesic Gneiss

15. **Cascade Road**

Ashby quadrangle, directly south of Mason center, 3/4 mile below south boundary of Peterborough quadrangle. Waterfall near head of Mason Brook exposes excellent section showing typical features of Massabesic Gneiss.

Binary Quartz Monzonite

16. **Peterborough**

Abandoned quarry displays the structural features of the Peterborough Pluton. Climb bank from lower road 100 yards north of southernmost bridge, east side of river.

17. **Temple, route 101 roadcut, 4000' west of BM1020**

Good display of jointing and faint flow foliation in granite of Whitcomb Peak Pluton.

18. **Temple, East spur of Pack Monadnock Mountain**

Transitional contact of granite of Whitcomb Peak Pluton and schist. Access difficult, best by descent from summit of Pack Monadnock Mountain.

19. **Greenville, route 31, and Wilton, route 101 roadcuts**

See nos. 7 and 11, respectively.

20. **Mason, McDonald Quarry, 1800' NW of SE corner of quadrangle**

Large abandoned quarry in binary granite, Massabesic Gneiss also exposed. Granite massive to faintly foliate.

Silicified Zones

21. **Temple, Kendall Ledge**

This large and smoothly polished ridge of white quartz-rock has the form of roche moutonnee.

22. **Lyndeborough, Junction 735, near east edge of quadrangle.**

Attractive specimens of red, white, and gray brecciated and veined quartz-rock may be collected from this small roadcut.

TABLES 1-17

Table 1
Representative Modes of Souhegan Member

	1	2	3	4	5	6	7	8	9	10
Quartz	52	50	56	58	42	53	64	77	71	24
Plagioclase		8	7	11	20	7	16	13	25	3
Biotite	20	24	20	11	23	28	9	9	2	
Muscovite	28	17	17	17	15	13	9			40
Chlorite										28
Garnet	tr			1	tr			tr	tr	tr
Magnetite	m	tr	tr	m	tr	m	m	1	tr	5
Pyrite	tr	1	tr	m	tr		1			
Apatite	tr	tr	tr	tr	m	tr	tr	tr	tr	
Zircon	tr	tr	tr	tr	tr	tr	m	tr	tr	tr
Actinolite									2	
Grain Size (mm)	0.05-0.7	0.05-1.0	0.1-2.0	0.1-3.0	0.1-0.7	0.1-1.0	0.05-0.5	0.1-2.0	0.1-1.0	0.01-2.0
Plagioclase*		15	15	10	15	10	15	15	60	10

*Anorthite content ± 5%

1. (273-13) Medium-coarse-grained mica schist, poor foliation, good lineation. Wilton, Route 31, 2000 feet northwest of Old Wilton Reservoir.
2. (224-3) Fine- to medium-grained mica schist, with quartz-feldspar bands, even foliation. Wilton, Old Wilton Reservoir.
3. (250-1) Medium-grained mica schist, highly foliated and banded. Greenville, Route 123, 2000 feet west of village.
4. (285-1) Medium-coarse-grained mica schist, banded, pods of feldspar, highly foliated and banded. Greenville, Route 31, 4000 feet north of village, type locality of Souhegan Member.
5. (287) Medium-grained mica schist, pods of feldspar, highly foliated. Greenville, Route 31, 5000 feet north of village.
6. (221-7) Dark medium-coarse mica schist, pods of quartz and feldspar, irregular texture, foliation uneven. Wilton, railroad cut near Stony Brook, 2200 feet northwest of B. M. 429.
7. (249-1) Light-colored medium-fine-grained mica schist, prominent fine even foliation and lineation. New Ipswich, High Bridge.
8. (285-2) Quartz-feldspar granulite, banded and foliated. Greenville, Route 31, 4000 feet north of village.
9. (286) Medium-grained lime silicate granulite, irregular texture, faint even color banding. Greenville, Route 31, 5000 feet north of village.
10. (912) Coarse-grained green muscovite-chlorite schist with magnetite; crinkled foliation. Wilton, 2000 feet northwest of Old Wilton Reservoir.

Table 2
Representative Modes of Peterborough Member

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Quartz	63	36	37	27	37	29	32	tr	18	74	30	80	32	8	49	34	70	31	9	35	29
Plagioclase		2	18		4	38	3	24	tr	4	27	38	33	55	22	36	*			46	58
Biotite	12	15	2		16	26	29	26	17	8	30	4	13	33	m	25	8	24	11	9	6
Muscovite	22	42	29	47	37	3	28	3	58	12	10	9	10			1	16	29	55	10	4
Chlorite	tr	2	16	24	3		1	tr		tr		6	10	m	1	tr	5		22		2
Garnet	tr	tr			3	2		19		tr	4				6	3		6	2		
Sillimanite		tr				1	6	27									tr	11			
Actinolite														2	9						
Diopside															8						
Clinozoisite															4						
Sphene															m						
Apatite							tr	tr			tr		tr	m		tr				tr	
Zircon	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr
Magnetite	2	3	tr	3		m	1	m	2	1	tr	1	1	3	m	2	1	tr	2	tr	m
Pyrite	tr		m			m		tr	6	1		1		tr	tr						
Calcite													1								
Tourmaline																		tr	tr		
Grain Size (mm)	0.01-0.7	0.1-1.0	0.01-0.5	0.01-1.0	0.1-0.8	0.1-2.0	0.05-0.7	0.02-1.0	0.1-1.0	0.02-1.0	0.1-0.5	0.05-0.4	0.05-2.0	0.05-1.0	0.05-0.5	0.1-0.6	0.1-1.0	0.01-1.0	0.01-1.0	0.02-1.0	0.02-2.0
Plagioclase*		10	35		15	45	25	25	10	15	25		15	35	60	45				15	25

*Anorthite content ± 5%

1. (132-1) Medium-grained light-colored mica schist, fair foliation, pronounced lineation. Lyndeborough, road 2500 feet west of summit of Lyndeborough Mountain.
2. (185-1) Fine-grained mica schist, prominent foliation, slight banding. Pack Monadnock, east spur, 1600 feet east of summit.

3. (107-2) Medium- fine-grained green chlorite mica schist, good foliation slightly contorted, porphyroblasts of plagioclase. Francestown, Rand Brook, 2000 feet west of junction with Piscataquog River.
4. (145) Medium- fine-grained green chlorite-mica schist, good foliation and lineation, altered remnants of garnet porphyroblasts. Near summit of Lyndeborough Mountain.
5. (353-2) Dark coarse-grained garnet-mica schist, feldspar pods and muscovite porphyroblasts, prominent crinkled foliation. Pack Monadnock, 600 feet north of summit.
6. (156-2) Dark very coarse garnet-sillimanite-biotite schist, foliation veryirregular. Lyndeborough, Route 31, 5000 feet west of summit of Winn Mountain.
7. (770) Medium-grained sillimanite-mica schist, foliation fair, prominent banding with dark and light layers. Lyndeborough Center.
8. (156-3) Dark very coarse garnet-sillimanite-biotite schist, foliation very irregular. Lyndeborough, Route 31, 5000 feet west of summit of Winn Mountain.
9. (266-3) Medium-coarse-grained sulfidic mica schist, prominent, even foliation. Jaffrey, near Contoocook River, 5000 feet southwest of Hadley.
10. (132-3) Medium-grained light-colored quartz-mica granulite, faint even foliation. Lyndeborough, road 2500 feet west of summit of Lyndeborough Mountain.
11. (110-3) Medium-grained quartz-feldspar, weak foliation, biotite in discontinuous bands. Greenfield, Stony Brook, 4000 feet northeast of Russell.
12. (134) Coarse-grained quartz-feldspar granulite, slight foliation. Lyndeborough, Route 31, 5000 feet west of summit of Winn Mountain.
13. (210) Medium- fine-grained green quartz-feldspar schist, well foliated,slight banding, feldspar pods. Lyndeborough, Stony Brook, 1500 feet west of South Lyndeborough.
14. (116-2) Medium-grained lime-silicate granulite, fair foliation. Lyndeborough, Stony Brook.
15. (993) Fine-grained mottled red and green lime-silicate granulite Sharon, Jarmany Hill Cemetery.
16. (381-5) Fine-grained biotite granulite, small garnet porphyroblasts, faint foliation. North Pack Monadnock, 2300 feet north of summit.
17. (614-1) Medium-grained mica-quartz granulite, faint foliation. Thin-bedded lentil. Lyndeborough, Rose Mountain, 2800 feet southeast of summit.
18. (128-1) Dark medium-grained garnet-sillimanite-mica schist, faint foliation. Thin-bedded lentil, Lyndeborough, peak between Lyndeborough and Rose Mountains.
19. (389) Medium- coarse-grained muscovite-biotite-chlorite schist, prominent foliation and lineation. Thin-bedded lentil, North Pack Monadnock, 1000 feet north of summit.
20. (81-2) Medium-coarse-grained feldspar-quartz granulite, faint foliation, mica concentrated along parting planes. Volcanic lentil, Francestown, 1200 feet south of southeast corner of Haunted Lake.
21. (604-5) Medium- coarse-grained feldspar-quartz granulite, faint foliation. Volcanic lentil, Francestown 500 feet south of southeast corner of Haunted Lake.

Table 3
Representative Modes of Francestown Member

	1	2	3
Quartz	78	45	75
Plagioclase	12	30	10
Actinolite	4	10	
Diopside	tr ?		
Clinozoisite	3	4	
Muscovite			15
Sphene	m	2	
Apatite		tr ?	
Zircon		tr	
Magnetite	tr	m	tr
Pyrite	4	7	m
Grain Size (mm)	0.05-0.4	0.02-0.4	0.02-0.7
Plagioclase*	60	60	45

*anorthite content ± 5%

1. (584) Medium-grained pyritiferous lime-silicate granulite, faint foliation, weathers very rusty. Francestown, Quarry Road, 8000 feet northeast of village.
2. (325) Fine-grained lime-silicate granulite, faint foliation, weathers very rusty. Francestown, 4300 feet east of east end of Sunset Lake.
3. (585-1) Fine-grained granulite, light gray with dark-greenish-gray splotches and muscovite flakes, weathers very rusty. Francestown, Quarry Road, 8000 feet northwest of village.

Table 4
Representative Modes of Crotched Mountain Member

	1	2	3	4	5	6	7
Quartz	50	40	4	22	38	6	42
Plagioclase		3	2	2	m		33
Biotite	15	31	53	17	31	47	tr
Muscovite	35	9	6	23	7	3	
Chlorite		2		15			
Sillimanite		8	28	18	21	43	
Garnet	1	tr	7	tr	tr		5
Actinolite							8
Clinozoisite							10
Zircon		tr	tr	tr	tr	tr	
Apatite					tr		
Magnetite	m	3	1	4	1	2	2
Pyrite		3		tr			1
Grain Size (mm)	0.1-0.8	0.1-1.0	0.1-1.5	0.1-1.0	0.1 2.0	0.1-1.5	0.05 0.3
Plagioclase*		35	20	20	25		60

*anorthite content ± 5%

1. (48-2) Coarse micaceous granulite, foliation poor. Crotched Mountain, 3000 feet north of Sunset Lake.
2. (122-4) Medium-grained to coarse-grained sillimanite-mica schist, fair but irregular foliation. Crotched Mountain, 2500 feet northeast of Sunset Lake.
3. (355) Coarse-grained sillimanite-mica granulite, coarse irregular texture, foliation poor. Crotched Mountain, peak 1500 feet southeast of summit.
4. (122-1) Coarse-grained sillimanite-chlorite-mica schist, sillimanite in masses of fibers, fairly even foliation. Crotched Mountain, 2500 feet northeast of Sunset Lake.
5. (316-2) Coarse-grained sillimanite-mica schist. Bennington, 3500 feet north of Whittemore Lake.
6. (316-3) Medium- fine-grained sillimanite-biotite schist, well foliated. Bennington, 3500 feet north of Whittemore Lake.
7. (58-2) Very fine-grained lime-silicate granulite. Crotched Mountain, saddle 4300 feet north of Sunset Lake.

Table 5
Representative Modes of Massabesic Gneiss

	1	2	3
Quartz	15	11	31
Plagioclase	64	48	24
Microcline	9	10	26
Biotite	9	30	14
Muscovite	4	tr	3
Chlorite	tr	tr	m
Apatite	m	tr	2
Zircon	tr	tr	tr
Magnetite		tr	
Pyrite		tr	
Grain Size (mm)	0.2-3.0	0.1-3.0	0.1 3.0
Plagioclase*	15	15	25

*anorthite content ± 5%

1. (246) Coarse-grained granodiorite gneiss, irregular foliation and slight compositional layering. Mason, on road 4500 feet southeast of junction at elevation 1009.
2. (493) Coarse-grained granodiorite gneiss with feldspar porphyroblasts, faint, irregular foliation. Greenville, Ashby quadrangle, Route 31, 1.3 miles south of south boundary of Peterborough quadrangle.
3. (471) Coarse-grained quartz monzonite gneiss, good foliation. Mason, Ashby quadrangle, Route 31, 2.3 miles south of south boundary of Peterborough quadrangle.

Table 6
Representative Modes of Spaulding Quartz Diorite and Associated Rocks

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Quartz	29	20	9	13	tr	13	12	29	18	28	25	29	23	39
Plagioclase	51	53	64	44	56	48	44	33	48	23	34	39	22	28
Microcline		4		6	tr	5				36	27	31	50	
Biotite	14	18	23	28	37	25	37	33	33	10	11	tr		21
Muscovite	4									tr		tr		11
Chlorite	4	m	m	3	m	2		tr	tr	1	tr	2	4	tr
Apatite	tr	2	m	tr	m	2	2	3	2	m	tr	m	tr	tr
Zircon	tr	tr						tr	tr	tr		tr	tr	tr
Magnetite	tr	m	1	tr	m	m	m	m	m	m	tr		tr	tr
Pyrite	tr	tr		tr		tr	m	tr	tr		tr		tr	m
Epidote+		m	m	3	5	1	tr	m	tr		tr	tr	m	
Sphene		3	m	5	2	5	4	tr	tr					
Garnet									tr					
Calcite		tr		tr			1							
Grain Size	0.1	0.1-	0.01-	0.2-	0.05-	0.1-	0.05-	0.1-	0.1-	0.1-	0.1-	0.1	0.1-	0.1-
(mm)	0.2	2.0	0.5	2.0	0.3	1.0	0.8	1.0	2.0	2.0	1.0	2.0	3.0	3.
Plagioclase*	15	10	35	10	40	15	25	45	45	15		10	10	35

*anorthite content ± 5%

+ Including some allanite

1. (806) Medium-coarse-grained biotite-quartz diorite, small feldspar phenocrysts, good foliation. Lyndeborough, railroad cut 4500 feet NW of South Lyndeborough Village.
2. (198-2A) Coarse-grained, non-foliated biotite granodiorite, Lyndeborough, Stony Brook, 7500 feet NW of South Lyndeborough Village.
3. (194-2) Fine-grained, dark-gray, non-foliated biotite-quartz diorite. Lyndeborough, railroad cuts 9000 feet NW of South Lyndeborough Village.
4. (198-2) Medium-coarse-grained non-foliated biotite granodiorite. Same locality as 2(=198-2A).
5. (192) Fine-grained medium-gray rock, non-foliated biotite-quartz diorite with black spots. Same locality as 3(=194-2).
6. (647) Coarse-grained non-foliated biotite granodiorite. Lyndeborough, 2300 feet southeast of summit of Winn Mountain.
7. (226-5) Medium-fine-grained non-foliated biotite-quartz diorite, splotchy coloring. Wilton, Route 101, 7000 feet SE of Wilton.
8. (226-8) Medium-grained foliated biotite-quartz diorite, same locality as 7(=226-5).
9. (248-2) Coarse-grained weakly foliated biotite-quartz diorite. New Ipswich, 3000 feet east of New Ipswich Center.
10. (932) Coarse, well foliated biotite-quartz monzonite, irregular texture with feldspar phenocrysts. Wilton, Temple Brook, 2500 feet southeast of Wilton Center.
11. (200-2) Coarse-grained biotite-quartz monzonite non-foliated. Lyndeborough, 3000 feet NW of Stimson Hill.
12. (214-3) Coarse-grained quartz monzonite, pinkish ivory with dark-green flecks, non-foliated. Lyndeborough, 1600 feet SW of South Lyndeborough County.
13. (193-1) Medium-coarse-grained gray-pink massive porphyritic granite. Lyndeborough, railroad cuts 9000 feet northwest of South Lyndeborough Village.
14. (153-2) Two mica quartz diorite, probably a hydrothermally altered rock. Lyndeborough, railroad cut 13,000 feet NW of South Lyndeborough Village.

Table 7
Representative Modes of Kinsman Quartz Monzonite

	1	2	3	4
Quartz	10	10	19	10
Plagioclase	30	30	36	30
Microcline	40	40	35	50
Biotite	15	15	4	
Muscovite	5	5	6	3
Chlorite	tr	2		5
Apatite	tr	tr	tr	tr
Zircon	tr	tr	tr	tr
Pyrite		tr		
Magnetite	tr	tr	tr	tr
Calcite	tr	tr	tr	
Epidote		tr	tr	tr
Grain Size (mm)	0.05-1.0	0.1-2.0	0.1-2.0	0.05-1.0
Size of Pheno. in mm.	10-60	10-30	10-50	10-50
Plagioclase*	15	10	15	15

*anorthite content ± 5%

1. (44 1/2) Greenfield, Route 31, 1000 feet south of Sunset Lake. Large phenocrysts of microcline and smaller phenocrysts of plagioclase in a gray matrix. Phenocrysts aligned, foliation fair.
2. (12-2) Hancock, spillway of Halfmoon Pond at Windy Row Road. Large phenocrysts of microcline and smaller phenocrysts of plagioclase in a gray matrix, good foliation.
3. (9-1) Same as 2. Altered Kinsman quartz monzonite in large shear zone. Large phenocrysts of microcline and smaller phenocrysts of plagioclase in dark-greenish matrix.
4. (12-1) Same as 2. Altered Kinsman quartz monzonite in large shear zone. Large fractured phenocrysts of microcline and smaller phenocrysts of plagioclase, very little matrix.

Table 8
Representative Modes of Binary Quartz Monzonite

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Quartz	40	29	36	30	32	29	29	35	35	49	30	32	32	30
Plagioclase	36	34	30	32	48	32	20	26	32	26	40	41	44	35
Microcline	17	30	31	33	18	27	32	31	16	13	20	21	21	27
Biotite	7	7	2	2	2	8	6	1	m				m	
Muscovite	m	tr	m	tr	tr	2	12	6	15	10	10	5	4	7
Chlorite	tr	m	m	1	tr	1	tr	1	m	3				
Apatite	tr	m	tr	tr	tr	m	m		tr	m	m			
Zircon	tr	tr	tr	tr	tr		tr	tr	tr					
Epidote							tr ?		tr ?					
Garnet					tr							2	tr	1
Magnetite	tr	tr	tr	tr		1	tr	tr	tr			tr		
Pyrite		tr	tr											
Grain Size (mm)	0.1-3.0	0.1-4.0	0.1-2.0	0.2-2.0	0.3-2.0	0.1-1.5	0.1-2.0	0.05-3.0	0.05-0.7	0.1-2.0	0.1-4.0	0.1-1.5	0.1-2.0	0.1-0.5
Plagioclase*	15	15	15	15	15	15	15	15	10	10	15	25	15	15

*anorthite content ± 5%

1. (981) Coarse-grained slightly foliated biotite-quartz monzonite, small body intruding Massabesic Gneiss, McDonald Quarry, Mason, 1500 feet northwest of southeast corner of quadrangle.
2. (226-14) Coarse porphyritic biotite quartz monzonite, non-foliated, Wilton, Route 101, 7000 feet southeast of Wilton Center.
3. (967) Coarse-grained leucocratic quartz monzonite, weakly foliated. Mason, small quarry 2600 feet southeast of Pratt Pond.
4. (242-2) Medium-coarse-grained leucocratic quartz monzonite, moderately strong foliation. Mason, small quarry 3800 feet south of Pratt Pond.
5. (257) Coarse-grained leucocratic granodiorite, faintly foliated, Greenville, 4700 feet southeast of village of Greenville.
6. (279) Medium-fine-grained binary quartz monzonite. Greenville, Route 31, 2300 feet northwest of village of Greenville.
7. (801) Coarse-grained binary quartz monzonite, fairly strong foliation, Peterborough, bed of Contoocook River at Noone.
8. (93) Very coarse-grained muscovite-quartz monzonite faintly foliated. Francestown, near east margin of quadrangle, 6000 feet south of Haunted Lake.
9. (162) Medium-coarse-grained muscovite-quartz monzonite, well foliated. Peterborough, quarry in south part of village.
10. (188-2) Coarse-grained muscovite-quartz monzonite, non-foliated. Temple, Route 101, 5800 feet north of Whitcomb Peak.
11. (1158) Very coarse-grained muscovite-quartz monzonite, non-foliated. Temple, 500 feet east of Whitcomb Peak.
12. (282-2) Coarse-grained muscovite-quartz monzonite with non-foliated. Greenville, Route 31, 2300 feet northeast of village of Greenville.
13. (277-2) Medium-grained muscovite-quartz monzonite, faint foliation, same locality as column 6(279).
14. (226-6) Fine-grained muscovite-quartz monzonite, small garnets, non-foliated, same locality as column 2(226-14).

Table 9
Representative Modes of Diorite and Basalt

	1	2	3	4	5	6	7	8
Quartz			1					
Plagioclase	36	37	46	32	45	42	40	49
Olivine				3	2	1	tr	
Augite				63	50	54	57	48
Hornblende	45	57	33					
Biotite	16	5	8					
Clinozoisite			tr					
Magnetite	4	2	11	3	4	3	3	4
Chlorite			tr					
Apatite	tr	m	1					
Zircon	tr	tr	tr					
Pyrite						tr		tr
Calcite							tr	tr
Grain Size (mm)	0.1-0.5	0.1-1.0	0.1-2.0	0.01-0.2	0.02-0.4	0.02-0.4	0.02-0.4	0.05 0.6
Plagioclase*	45	45	45	60	60	60	60	60

*anorthite content ± 5%

1. (539-2) Dark-gray fine-grained diorite, non-foliated, Francestown, directly east of Poor Farm Road.
2. (539-1) Dark-gray medium-grained diorite, faint foliation, same locality as column 1 (539-2).
3. (546) Dark-gray coarse diorite, non-foliated, black biotite and green hornblende prominent, same locality as column 1 (539-2).
4. (273-10) Black aphanitic basalt. Wilton, Route 31, east edge of quadrangle.
5. (273-16) Black aphanitic basalt. Same locality as column 4 (273-10).
6. (957) Black fine-grained basalt. Mason, 1800 feet southeast of Pratt Pond.
7. (239) Aphanitic black basalt. Wilton, 5000 feet northeast of Abbot Hill at quadrangle boundary.
8. (911) Fine-grained black basalt. Mason, 5500 feet southwest of Pratt Pond.

Table 10
Ratio of Thickness to Breadth of Outcrop

1	2	3	4	5	6	7	8	9	10
1	85°NW	42	34	76	26.05	25.64	0.41	+0.0054	NW
2	85°NW	75	10	85	47.32	5.66	41.66	+0.491	NW
3	85°NW	54	1	55	27.66	0.96	26.70	+0.486	NW
4	85°NW	57	12	69	41.88	9.75	32.13	+0.465	NW
5	90°	104	10	114	69.81	6.12	63.69	+0.559	NW
6	90°	54	25	79	29.27	11.86	17.41	+0.221	NW
7	63°NW	111	42	153	59.68	22.47	37.21	+0.243	NW
8	63°NW	79	20	99	45.22	15.53	29.68	+0.300	NW
9	63°NW	116	25	141	56.07	11.52	44.55	+0.315	NW
10	63°NW	26	65	91	10.29	46.06	-35.77	-0.394	SE
11	90°	53	36	89	28.27	16.95	11.32	+0.127	NW
12	63°NW	54	10	64	23.78	5.09	18.69	+0.292	NW
13	63°NW	101	9	110	43.57	2.22	41.35	+0.376	NW
14	63°NW	108	90	198	48.47	53.57	-5.10	-0.026	SE
15	63°NW	54	46	100	17.84	17.67	0.17	0.0017	NW
16	90°	51	22	73	27.81	13.26	14.55	0.199	NW
17	63°NW	60	28	88	19.50	8.40	11.10	0.126	NW
18	63°NW	59	14	73	20.62	4.13	16.49	0.226	NW
19	63°NW	89	13	102	40.95	4.06	36.89	0.361	NW
20	63°NW	54	28	82	24.65	16.04	8.61	0.105	NW
21	63°NW	125	15	140	57.86	11.79	46.07	0.329	NW

Column 1. Domain
2. Dip of axial planes of folds
3. Number of readings topping northwest
4. Number of readings topping southeast
5. Total number of readings
6. $\sin\delta \sin\alpha$ for beds topping northwest (positive)
7. $\sin\delta \sin\alpha$ for beds topping southeast (negative)
8. Difference between columns 6 and 7. Positive means beds get younger to northwest; negative means they get younger to southeast.
9. Factor by which breadth of outcrop along line of traverse is multiplied to get thickness
$t = f \times s$ $f = t/s$ t = thickness, f = factor s = breadth of outcrop

Table 11
Calculation of Thickness of Littleton Formation in Peterborough Quadrangle

1	2	3	4	5	6	7	8
H	Crotched Mtn.	2	5,900	0.491	2,900		
	Crotched Mtn.	4	5,200	0.465	2,420	5,320	
	Francestown*	-	---	---	80	80	
	Peterborough	5	13,400	0.559	7,490		
	Peterborough	6	15,700	0.315	4,950	12,440	17,840
I	Crotched Mtn.	1	12,000	0.005	65		
	Crotched Mtn.	3	5,100	0.486	2,470	2,540	
	Francestown	3	200	0.486	100	100	
	Peterborough	5	9,700	0.559	5,420		
	Peterborough	8	8,900	0.300	2,670		
	Peterborough	9	11,900	0.315	3,410	11,500	14,140
J	Peterborough	6	14,900	0.221	3,290		
	Peterborough	7	2,600	0.224	630		
	Peterborough	10	2,220	-0.394	-875	3,045	3,045
K	Peterborough	16	12,800	0.199	2,550		
		14	11,800	-0.026	-300		
		11	6,000	0.127	760		
		11	11,900	0.127	1,510	4,520	4,520
L	Peterborough	16	12,600	0.199	2,510		
	Peterborough	17	5,290	0.126	670		
	Peterborough	15	2,300	0.002	5		
		11	17,300	0.127	2,200	5,385	
	Souhegan	12	5,400	0.292	1,580		
		12	4,600	0.292	1,340	2,920	8,305
M	Peterborough	21	24,300	0.329	8,000		
		19	10,800	0.361	3,900		
		11	13,700	0.127	1,740	13,640	
	Souhegan	13	17,200	0.376	6,460	6,460	20,100
N	Peterborough	21	31,000	0.329	10,200		
	Peterborough	20	13,000	0.105	1,370		
	Peterborough	11	9,100	0.127	900	12,470	12,470

1. Traverse line in Figure 12
2. Member
3. Domain
4. Breadth of outcrop along traverse side.
5. Factor calculated for entire domain.
6. Thickness within each domain.
7. Thickness of Member
8. Total thickness along traverse line.

* Francestown Member in a syncline. Value for thickness assumes southwest limb dips 60° NW and is 200 feet wide.

Table 12
Thickness of Littleton Formation in Feet in Peterborough Quadrangle

Member	Traverse used	
Crotched Mountain	H	5,320
Francestown	H	80
Peterborough	M, N	11,985*
Souhegan	M	6,460
Total		23,970

* Average of data from traverses M (11,500 feet) and traverse N (12,470 feet)

Table 13
Thickness of Littleton Formation in Feet in Peterborough and Monadnock Quadrangles

Monadnock Quadrangle

Upper Member		6,000
Middle Member		5,400
Francestown		0-660
Lower		5,000
(absent)	Total	17,060

Peterborough Quadrangle

(absent)	
Crotched Mountain Member	5,320
Francestown	80+
Peterborough	11,985
Souhegan	6,460
Total	23,845

Table 14
Mineral Assemblages in Schists of the Peterborough Quadrangle, Excluding Oxides and Accessories

Assemblage	No. of Samples
quartz-muscovite-plagioclase	2
quartz-muscovite-biotite	4
quartz-muscovite-plagioclase-biotite	16
quartz-muscovite-plagioclase-garnet	1
quartz-muscovite-biotite-garnet	5
quartz-muscovite-plagioclase-biotite-garnet	8
quartz-muscovite-biotite-sillimanite	2
quartz-muscovite-plagioclase-biotite-sillimanite	2
quartz-muscovite-biotite-garnet-sillimanite	2
quartz-muscovite-plagioclase-biotite-garnet-sillimanite	10
muscovite-biotite	1
muscovite-plagioclase-biotite	1
muscovite-biotite-garnet	1
quartz-muscovite-plagioclase-biotite-microcline-sillimanite	1

Table 15
Mineral Assemblages in Schists of the Peterborough Quadrangle with Quartz and Muscovite, Excluding Plagioclase, Oxides and Accessories

biotite
garnet
biotite-garnet
biotite-sillimanite
biotite-garnet-sillimanite
biotite-microcline-sillimanite

Table 16
Mineral Assemblages in Calc-silicate Rocks of the Peterborough Quadrangle

quartz-plagioclase-biotite-garnet
quartz-plagioclase-biotite-actinolite
quartz-plagioclase-biotite-garnet-actinolite
quartz-plagioclase-biotite-garnet-actinolite-epidote
quartz-plagioclase-biotite-garnet-actinolite-epidote-diopside
quartz-plagioclase-actinolite-epidote
quartz-plagioclase-actinolite-diopside-epidote
quartz-plagioclase-biotite-garnet-muscovite-epidote

Table 17
Representative Modes of Rocks from the Francestown Soapstone Quarry

	1	2	3	4	5	6	7	8	9
Quartz	24	50	58	19	38	6			
Plagioclase	6	8	19	48		24			
Biotite	9	m	23	31	26	12			
Muscovite	46	30		m	4				
Chlorite	14	11		tr	31	1	m	11	28
Apatite	tr	tr	tr	2	tr		tr	tr	
Zircon	tr	tr	tr	tr	tr		tr		
Garnet		tr	tr						
Rutile						m			
Magnetite	1	2	tr	m		tr			
Talc							33	36	48
Actinolite						58		30	1
Phlogopite							65	23	22
Calcite					tr		1		
Grain Size (mm)	0.1-0.7	0.05-0.5	0.05-0.5	0.1-1.0	0.1-1.0	0.1-2.0	0.05-2.0	0.02-2.0	0.02 1.0
Plagioclase*	25	15	45	45		45			

*anorthite content ± 5%

See Figure 44 for location of specimens.

1. (562-2) Wall rock. Medium-grained chloritized mica schist, weakly foliated, Peterborough Member.
2. (551-1) Wall rock. Medium-grained chloritized mica schist, highly foliated, some mineral segregation; slip-cleavage cuts foliation at low angle. Peterborough Member.
3. (560) Wall rock. Fine-grained biotite granulite. Peterborough Member.
4. (555) Wall rock. Medium-grained biotite schist, good foliation. Peterborough Member.
5. (565) Wall rock. Medium-coarse-grained highly foliated chlorite-biotite schist. Peterborough Member.
6. (564) Wall rock. Coarse-grained actinolite granulite, 3 feet from contact with soapstone. Peterborough Member.
7. (575) Soapstone. Dark-green foliated talc-phlogopite schist.
8. (567) Soapstone. Coarse-grained gray-green talc-phlogopite-actinolite schist.
9. (570) Soapstone. Medium-grained gray-green talc-phlogopite schist.

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