Geology and Petrology of The Greenville Quadrangle Piscataquis and Somerset Counties, Maine

By G. H. ESPENSHADE *and* E. L. BOUDETTE

CONTRIBUTIONS TO GENERAL GEOLOGY

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Description of metasedimentary, mafic, and granitic rocks of Paleozoic age

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GEOLOGY AND PETROLOGY OF THE GREENVILLE QUADRANGLE, PISCATAQUIS AND SOMERSET COUNTIES, MAINE

By G. H. Espenshade and E. L. Boudette

ABSTRACT

In the Greenville quadrangle, west-central Maine, slate, siltstone, and sandstone (calcareous and noncalcareous) of probable Silurian to Early Devonian age are intruded by a large mafic pluton and two granitic stocks of probable Early Devonian age. Ages of the sedimentary rocks are based upon tentative correlations with fossiliferous beds in adjacent quadrangles because the few fossils in the Greenville quadrangle are nondiagnostic; ages of the intrusive rocks are based upon radiometric age determinations. The sedimentary rocks are tightly folded about northeast-trending axes and have strong slaty cleavage. Widespread graded bedding is very useful in determining the tops of beds and thus the location of fold axes. The sedimentary rocks are in the chlorite zone of metamorphism except in the contact aureoles where the metamorphism ranges from the biotite zone, through the andalusite-amphibole zone, to the sillimanite-cordierite zone adjacent to the intrusions; retrograde metamorphism is a minor local feature.

The mafic rocks are part of the Moxie pluton, which extends southwest and northeast of the Greenville quadrangle for a total distance of about 45 miles. Troctolite and norite are the principal rock types; gabbro is less common. Plagioclase is the dominant mineral; it usually makes up 50–75 percent of the rock. Olivine and orthopyroxene are widespread, clinopyroxene is uncommon and biotite and hornblende are generally present in small amounts. The rocks can be separated into magnesium-rich and iron-rich varieties; magnesium-rich olivine and orthopyroxene are usually accompanied by plagioclase containing from 57 to 77 percent anorthite, and iron-rich olivine and orthopyroxene are associated with plagioclase containing about 50–62 percent anorthite. Compositional layering is rare, but flow structure is very common. Flow structure generally dips northward to eastward, whereas geophysical data indicate that the contacts of the pluton dip southeastward. The granitic stocks are discordant pipelike bodies that range from granodiorite to quartz monzonite in composition. Both the mafic and the felsic intrusions are undeformed and unmetamorphosed.

Slate quarrying was once an important industry in the region, but in 1965 only one quarry was active at Monson just east of the report area. Slate is a potential source of raw material for lightweight concrete aggregate. There are several possible sites for stone quarries in the intrusive masses. Sand and gravel resources seem to be limited. Small amounts of sulfides that have low copper and nickel values are known at a few places in the mafic pluton.

INTRODUCTION

The Greenville quadrangle is a little west of the center of the State and just south of Moosehead Lake, the largest lake in Maine (fig. 1). The quadrangle is near the southern edge of the extensive forest that covers northern Maine; it contains only a few square miles of open farmland.

The region is mountainous, the highest point being Big Squaw Mountain (3,196 ft). Other peaks just east and northeast of the quadrangle range from 2,500 to 3,500 feet in altitude. The watershed between the Piscataquis and Kennebec Rivers is in the northern part of the quadrangle. Most of the drainage, therefore, is southward into the Piscataquis; Moosehead Lake and the streams in the mountainous region to the west drain into the Kennebec.

Summers are cool and winters severe in this part of Maine; the mean temperature for July is 66°F and for January 12°F (Fobes, 1946). Annual precipitation is about 45 inches; annual snowfall averages about 100 inches. Slightly more precipitation falls in the summer than during the rest of the year.

Most of the quadrangle is in Piscataquis County, but a narrow strip along the western edge is in Somerset County. Greenville, Greenville Junction, and Monson are the principal settlements of the area. The town of Greenville had a population of 2,025 and Monson, Shirley, and Blanchard together had 1,123 persons in 1960, a total of 3,148; the population of these four places in 1930 was 3,097. Monson and Blanchard were settled about 1815 and Shirley and Greenville about 1825.

State Highway 15 passes northward through the quadrangle and gives access to the country east and west of Moosehead Lake. There are few permanent secondary roads and much of the area is accessible only by trails and by temporary roads built for lumbering operations. The main line of the Canadian Pacific Railway that traverses Maine between Quebec and New Brunswick passes through Greenville. Charter floatplane service is available in Greenville at the south end of Moosehead Lake and is widely used to reach lakes in northern Maine and Canada. Good facilities for wheeled aircraft also exist at the Greenville airfield.

Lumbering is the principal industry of the region, and pulpwood is the main product. Local industries include a plywood factory in Greenville and a furniture factory and slate quarry in Monson. Fishing, hunting, boating, and other outdoor recreation attract many visitors to the region.

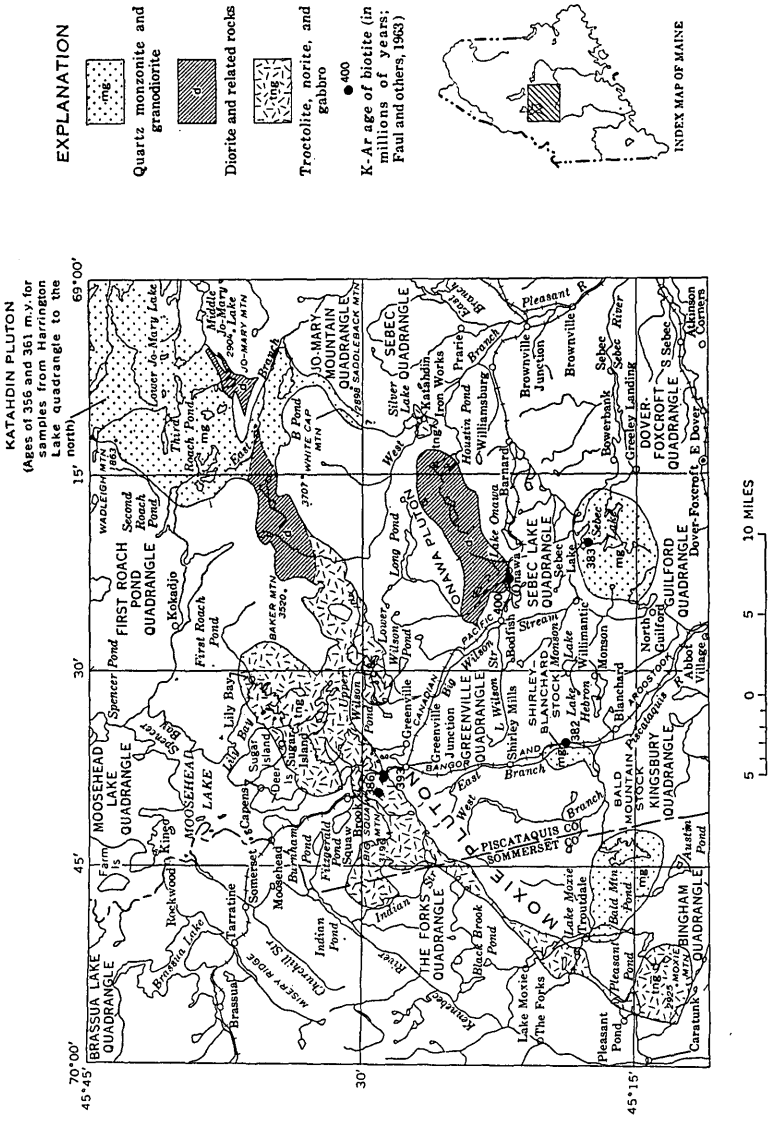


FIGURE 1.—Index map of central Maine showing location of the Greenville quadrangle, the Moxie pluton and other igneous intrusions, and radiometrically dated samples.

The earliest geologic investigations in the region were those of Jackson (1839) and Hitchcock (Hitchcock and Holmes, 1861, 1862). Geologic studies of general interest in recent years have been made by Hurley and Thompson (1950), Boucot (1961), and Boucot, Griscom, and Allingham (1964). Slate was investigated by Dale (Dale and others, 1914), contact metamorphism by Philbrick (1936, 1940), Bowin (1957), and Moore (1960), and the Moxie mafic pluton, which crosses the northern part of the Greenville quadrangle, by Visher (1960). The principal study of glacial geology of the region is by Leavitt and Perkins (1935). Detailed geophysical surveys of several areas in the quadrangle have recently been made by the Maine Geological Survey (Stickney and others, 1965). An aeromagnetic map of the Greenville quadrangle has recently been published by the U.S. Geological Survey (Bromery and others, 1963). The results of geochemical prospecting in the quadrangle have been reported by Post and Hite (1964).

The Greenville quadrangle was mapped in 1957–61 as part of the U.S. Geological Survey's program of geologic investigations in northern Maine. This geologic map, published in 1964 (Espenshade and Boudette, 1964), does not accompany this bulletin; reference to it is needed in order to understand this report fully. Geologists participating in the field studies included W. E. French, D. S. Harwood, J. B. Hunt, Harry Klemic, and D. A. Nellis of the U.S. Geological Survey and George M. Eaton of the Maine Geological Survey.

Many colleagues on the Geological Survey have contributed to our work through field visits, discussions, analytical services, and assistance with laboratory studies. Discussions with L. R. Page about the problems of the Moxie pluton have been especially fruitful. E. V. Post and F. C. Canney, who have mapped the geology and done extensive geochemical prospecting in The Forks quadrangle, adjacent to the west, have cooperated closely with us in our mutual geological and geochemical problems. Interpretations of geophysical surveys by R. W. Bromery and M. F. Kane have aided in the understanding of the structure of the Moxie pluton. Various geologists outside the Geological Survey have contributed information and ideas, particularly G. S. Visher, who spent 2 days in the field examining parts of the Moxie pluton with us during our first field season. The use of the single variation optical system at Dartmouth College for measurement of mineral refractive indices is gratefully acknowledged.

The present report has been largely prepared by Espenshade, who is also responsible for much of the petrographic work (thin-section study, modal analyses, and density measurements). Composition of plagioclase, orthopyroxene, and olivine from samples of the Moxie pluton were determined by Boudette.

PRINCIPAL GEOLOGIC FEATURES

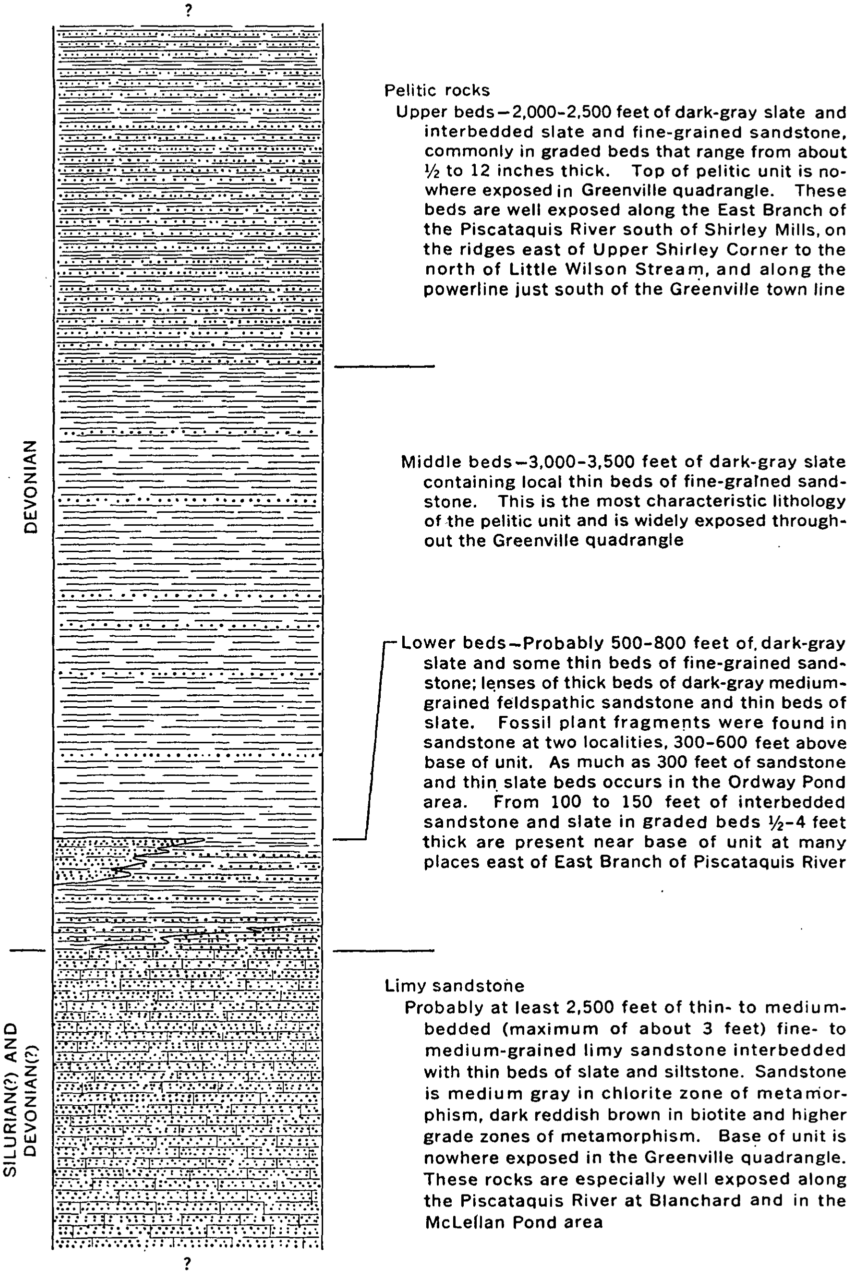
Much of the Greenville quadrangle is underlain by slate, siltstone, and fine-grained sandstone (fig. 2) that are judged to be of Silurian and Devonian age because of similarities to fossiliferous rocks farther north (Espenshade and Boudette, 1964). These rocks are folded about northeast-trending axes and are intruded by the large mafic Moxie pluton in the northern part of the quadrangle and by smaller felsic stocks in the southern part. The central part of the quadrangle, between the intrusive bodies, is underlain by rocks in the chlorite zone of metamorphism. The intrusions in the northern and southern parts of the quadrangle are surrounded by a contract metamorphic aureole in which biotite, andalusite, sillimanite, cordierite, and calc-silicate minerals were formed. Strictly speaking, siltstone and sandstone in the chlorite and biotite zones should be called metasiltstone and metasandstone, but the former terms are used herein for simplicity's sake and because original sedimentary textures are characteristically preserved in these rocks.

The Moxie pluton is one of the major intrusive masses of central Maine and extends for about 45 miles in a northeasterly direction (fig. 1; Boucot and others, 1964). Sedimentary rocks of Silurian and Devonian age crop out in a belt as much as 5 miles wide just north of the pluton. These are succeeded to the north by sedimentary and volcanic rocks of Ordovician and possibly Cambrian age. These rocks form a belt about 5 miles wide that extends for more than 50 miles southwest from Moosehead Lake. A thin sequence of Silurian beds and a great thickness of Lower Devonian rocks are exposed in the Moose River synclinorium over a wide area north of these older rocks (Boucot, 1961). The strata of the Moose River synclinorium differ from the Silurian and Devonian rocks south of the Moxie pluton in that they are very fossiliferous at certain horizons, they are coarser grained (thick sandstone beds occur in several formations), and they contain moderate amounts of interbedded volcanic rocks.

SILURIAN(?) AND DEVONIAN(?) SEDIMENTARY ROCKS

LIMY SANDSTONE

The older of the two sedimentary rock units in the Greenville quadrangle is a limy sandstone which is exposed mainly in three tight anticlines in the southern part of the mapped area (Espenshade and Boudette, 1964). The unit is well exposed at many places in these anticlines. Some of the best and most easily accessible outcrops are in the southern anticlines along the Piscataquis River at Blanchard



Pelitic rocks

Upper beds—2,000-2,500 feet of dark-gray slate and interbedded slate and fine-grained sandstone, commonly in graded beds that range from about ½ to 12 inches thick. Top of pelitic unit is nowhere exposed in Greenville quadrangle. These beds are well exposed along the East Branch of the Piscataquis River south of Shirley Mills, on the ridges east of Upper Shirley Corner to the north of Little Wilson Stream, and along the powerline just south of the Greenville town line

Middle beds—3,000-3,500 feet of dark-gray slate containing local thin beds of fine-grained sandstone. This is the most characteristic lithology of the pelitic unit and is widely exposed throughout the Greenville quadrangle

Lower beds—Probably 500-800 feet of dark-gray slate and some thin beds of fine-grained sandstone; lenses of thick beds of dark-gray medium-grained feldspathic sandstone and thin beds of slate. Fossil plant fragments were found in sandstone at two localities, 300-600 feet above base of unit. As much as 300 feet of sandstone and thin slate beds occurs in the Ordway Pond area. From 100 to 150 feet of interbedded sandstone and slate in graded beds ½-4 feet thick are present near base of unit at many places east of East Branch of Piscataquis River

Limy sandstone

Probably at least 2,500 feet of thin- to medium-bedded (maximum of about 3 feet) fine- to medium-grained limy sandstone interbedded with thin beds of slate and siltstone. Sandstone is medium gray in chlorite zone of metamorphism, dark reddish brown in biotite and higher grade zones of metamorphism. Base of unit is nowhere exposed in the Greenville quadrangle. These rocks are especially well exposed along the Piscataquis River at Blanchard and in the McLellan Pond area

FIGURE 2.—Generalized stratigraphic section of the sedimentary rocks exposed in the Greenville quadrangle.

and at places on the shores of Lake Hebron, and in the northern anticline at localities along the Blanchard-Lower Shirley Corner road and on State Highway 15 at the Shirley-Monson town line. Thin beds of lithologically similar rocks are interbedded with pelitic schist at various places along Little Squaw Mountain in the andalusite and sillimanite-cordierite zones of contact metamorphism adjacent to the south side of the Moxie pluton but are not shown separately on the geologic map (Espenshade and Boudette, 1964).

The unit is characterized by abundant thin- to medium-bedded fine-grained sandstone and limy sandstone and subordinate thin beds of shale, slate, and siltstone. Sandstone is probably three to five times as abundant as shale and siltstone. Sandstone beds range from a few inches to about 3 feet in thickness and commonly grade into shaly beds a few inches thick. This graded bedding is a widespread feature that is very useful in determining the tops of beds. Ellipsoidal calcareous concretions as much as 6 inches long are common in the sandstone, and beds of silty or sandy dolomite occur locally.

The limy sandstone unit is in the biotite or higher grade zones of metamorphism in much of the area, and the fine-grained sandstone has a very distinctive dark-reddish-brown color caused by an abundance of tiny biotite flakes. Sandstone within the chlorite zone, which composes only a small part of the total outcrop area of the unit, is generally medium gray. Limy sandstone commonly has a punky weathered rind about one-fourth inch thick where the carbonate content is appreciable. Most of the shale, slate, or siltstone beds is dark-gray to brown gray on both sides of the biotite isograd. Grain size of the sandstone generally ranges from about 0.1 to 0.4 mm and only rarely reaches 2 mm in the coarsest sandstone. Quartz, feldspar, carbonate (ankeritic dolomite), white mica, and chlorite are the dominant minerals; accessory minerals are zircon, tourmaline, and opaques. One thin section contained about 43 percent (by volume) quartz and feldspar, 32 percent carbonate, and 25 percent white mica. However, much of the sandstone contains only a few percent carbonate, and thin shale and siltstone interbeds contain even less. Quartz and feldspar grains are generally poorly sorted. They are angular in rocks within the chlorite zone where deformation is least and are flattened in rocks in higher grade zones of metamorphism where deformation is greater. Rocks in the biotite and higher grade zones are described in "Contact metamorphism" (p. F43).

Chemical analyses of composite samples of limy sandstone (252) and interbedded slate (253) are given in table 1. Although these two samples come from rock in the biotite zone of metamorphism, the analyses are considered representative of the sandstone and shale of this unit. The content of about 2 percent carbonate mineral for the sandstone (252) seems typical of much of the sandstone.

Variations in the bulk density of samples of calcareous sandstone and siltstone from the limy sandstone in the chlorite and biotite zones and calc-silicate hornfels from higher grade zones are given in table 2.

TABLE 1.—*Chemical analyses of sandstone and slate from the Greenville quadrangle, compared with average composition of shale and slate of the Littleton Formation, N.H.*

Samples from Greenville quadrangle analyzed by methods similar to those described in USGS Bull. 1036-C. Analysts: P. L. D. Elmore, S. D. Botts, I. H. Barlow, and G. W. Chloe]

Lithology sample	Limy sandstone	Sandstone	Slate	Slate	Shale and slate
	252	299	253	298	Littleton Formation
SiO_2	70.4	73.0	57.6	62.0	62.58
Al_2O_3	12.7	13.2	19.8	19.1	18.09
Fe_2O_3	.7	.7	1.6	.4	1.60
FeO	3.7	4.4	5.3	6.4	5.07
MgO	2.3	1.3	3.6	1.7	2.18
CaO	2.4	.16	.74	.18	.16
Na_2O	2.0	1.0	1.2	1.1	.81
K_2O	2.3	2.2	4.8	3.5	3.68
H_2O	1.6	2.7	3.9	3.9	4.18
TiO_2	.61	.76	.96	.94	.87
P_2O_5	.14	.11	.15	.14	----------
MnO	.07	.05	.06	.08	----------
CO_2	.83	$<.05$	$<.05$	$<.05$	.03
Total	100	100	100	99	99.25
Total sulfur as S	.02	.01	.02	.02	----------
Density (powder)	2.74	2.76	2.79	2.77	----------
Density (bulk)	2.74	2.75	2.81	2.78	----------

252: Limy sandstone from outcrop at Monson-Shirley townline, State Highway 15, Greenville quadrangle. Sandstone part of chip samples taken at 6-in. intervals; equivalent to total thickness of about 110 ft. Locality is in biotite zone of metamorphism.

299: Sandstone from outcrop at sharp road bend of State Highway 15 near mouth of Spectacle Ponds, about 3½ miles north of Monson, Greenville quadrangle. Sandstone part of chip samples taken at 3- to 5-ft intervals; equivalent to total thickness of about 90 ft. Locality is in chlorite zone of metamorphism.

253: Slate from same locality as 252. Slate part of chip samples taken at 6-in. intervals; equivalent to total thickness of about 35 ft.

298: Slate from same locality as 299. Slate part of chip samples taken at 3- to 5-ft intervals; equivalent to total thickness of about 340 ft.

Shale and slate, Littleton Formation: Average chemical composition of seven samples of shale and slate of low metamorphic grade from Littleton quadrangle, New Hampshire. (Shaw, 1956.)

The top of the limy sandstone unit grades into the base of the overlying pelitic unit by alternation of the two lithologies through a thickness of 100–200 feet. This gradation is evident where exposures are good, as along the Blanchard-Lower Shirley Corner road on the south limb of the northern anticline and at Monson on the south limb of the southern anticline. Where outcrops are not abundant, the change in lithology on crossing the contact seems rather abrupt. The contact between the two units is located within a few hundred feet at many places.

TABLE 2.—*Frequency distribution of densities and average densities of samples of limy sandstone and siltstone and calc-silicate hornfels, Greenville quadrangle*

Range of density	Limy sandstone and siltstone from chlorite and biotite zones	Calc-silicate hornfels from andalusite-amphibole zone	Calc-silicate hornfels from sillimanite-cordierite zone
	Number of samples		
2.62–2.65	4	0	0
2.66–2.70	1	1	0
2.71–2.75	6	2	0
2.76–2.80	0	3	2
2.81–2.85	0	3	0
2.86–2.90	0	0	1
2.91–2.93	0	1	1
Average density	2.69	2.78	2.84

The limy sandstone unit seems to be of uniform character throughout its thickness except that the dominant color of sandstone beds in the chlorite zone is medium gray, whereas dark reddish brown is the dominant color in the biotite zone. The base of the unit is nowhere exposed within the Greenville quadrangle, and hence the total thickness of the limy sandstone cannot be determined here. Presumably the lowest beds are exposed along the axis of the northern anticline adjacent to the Shirley-Blanchard stock and in the southern anticline. Although the structure of the southern anticline is complicated by a probable fault on its northern limb and by subsidiary folds, a minimum thickness of about 2,500 feet of the limy sandstone unit is probably exposed here.

No fossils have been found in the limy sandstone unit within the Greenville quadrangle. The age of the unit is conjectured to be Silurian(?) and Devonian(?) because of similarities in lithology and stratigraphic position to certain limy beds in nearby quadrangles. The overlying pelitic unit in the Greenville quadrangle is lithologically similiar to the Seboomook Formation of Early Devonian age in the Moosehead Lake quadrangle and the nearby region (Boucot, 1961). The limy sandstone unit of the Greenville quadrangle somewhat resembles limy slate and sandstone of Silurian or Devonian age that lie several hundred feet beneath the Seboomook Formation on Deer Island and vicinity, Moosehead Lake quadrangle, and that are separated from the Seboomook by the Whisky Quartzite and the Capens Formation (Boucot, 1961). Limy silty and sandy beds underlying slates equivalent to the pelitic unit of the Greenville quadrangle have been mapped in The Forks quadrangle (adjacent to the west) by E. V. Post. He found fossils of Silurian age (Wenlock?) at one locality and of Early Devonian age at another locality in these rocks (E. V.

Post, written commun., Jan. 2, 1964). We think that the limy sandstone of the Greenville quadrangle correlates with these limy beds of Silurian and Devonian age in The Forks quadrangle.

DEVONIAN SEDIMENTARY ROCKS

PELITIC ROCKS

Pelitic rock (slate and siltstone) with some interbedded sandstone makes up the younger sedimentary unit and underlies about half the quadrangle. These rocks are widely exposed in low ledges, roches moutonnées, and pavement outcrops on the uplands, and they form low cliffs at places along both branches of the Piscataquis River and on Big Wilson Stream.

Much of the pelitic unit is composed of slate and siltstone and subordinate fine-grained sandstone in thin beds a few inches thick. However, sandstone is very common at several stratigraphic positions, especially in the lower part of the unit. In a few places it is more than 100 feet thick and is shown as a separate unit on the geologic map (Espenshade and Boudette, 1964). Sandsone beds commonly range from less than an inch to 4 feet in thickness and grade into shale (now slate). Stratigraphic intervals consisting of sequences of repeated beds of sandstone grading to shale are as much as several hundred feet thick. These graded beds range in thickness from about one-half inch to about 8 feet. Either sandstone or shale may be dominant within a bed and one lithology may be as much as five times as abundant as the other. Shale is generally more abundant than sandstone where the beds are less than 8 inches thick. The graded bedding is a widespread, characteristic feature of the pelitic unit, and in many places shows unequivocally the tops of beds with the same top direction repeated many times throughout a thick sequence of graded beds. Crossbedding is commonly evident in the sandy layers and in wispy streaks of sand in shaly layers.

Slate and siltstone of the pelitic unit are uniformly dark gray. Abundant quartz and some feldspar occur as very fine grains in a fine schistose matrix of muscovite and chlorite and moderate amounts of fine opaque material. Sandstone also is dark gray where fresh but, in contrast to slate, weathers light gray to greenish gray. Quartz is the dominant material; feldspar makes up about 10 percent of the rock. Quartz and feldspar grains generally are less than 0.5 mm in size and have a maximum size of about 2 mm in the coarsest sandstone. The coarser quartz grains commonly appear black and glassy on a freshly broken rock surface. Feldspar in similar slate from the Sebec Lake quadrangle was judged to be potassium-free albite by Moore (1960), on the basis of X-ray diffraction analyses of several whole-rock samples. Fine chlorite and white mica make a micaceous matrix that amounts to not more than 10–20 percent of the sandstone. Fine chert grains occur in small amounts in some rock, and small slate fragments are occasionally present. Tourmaline is the principal accessory mineral; zircon is less common. Carbonate is rare and weathers to leave small slit-shaped cavities. Pyrite occurs locally. Quartz and feldspar grains are generally poorly sorted and are undeformed where micaceous matrix is abundant, athough these grains may form a mosiac texture having sutured grain boundaries in rock that has little micaceous matrix. Some grains are flattened in the plane of schistosity. Flattening is more pronounced in the biotite zone than in the chlorite zone of metamorphism. Much of the exposed area of the unit is within the chlorite zone, and the rocks here are not distinguishable in megascopic appearance from rocks witin the biotite zone.

Densities of sandstone, siltstone, and slate are given in table 3. Chemical analyses of composite samples of sandstone (299) and slate (298) from the pelitic unit are given in table 1. Note that the chemical composition of the slate sample (298) is very similar to the average composition of seven samples of shale and slate from the Littleton Formation in the Littleton quadrangle, New Hampshire. The pelitic unit of the Greenville quadrangle probably was deposited at about the same time (Early Devonian) as the Littleton Formation and in a similar environment.

TABLE 3.—*Frequency distribution of densities and average densities of samples of nonlimy sandstone, slate and siltstone, and pelitic hornfels, Greenville quadrangle*

Range of density	Sandstone from chlorite and biotite zones	Slate and siltstone from chlorite and biotite zones	Pelitic hornfels from andalusite-amphibole zone	Pelitic hornfels from sillimanite-cordierite zone
	Number of samples			
2.62–2.65	1	1	0	2
2.66–2.70	4	2	2	4
2.71–2.75	7	2	4	11
2.76–2.80	0	5	4	5
2.81–2.85	0	0	2	2
2.86–2.90	0	0	1	1
Average density	2.70	2.73	2.76	2.74

Individual beds within the pelitic unit are not shown separately on the geoligic map (Espenshade and Boudette, 1964), except for the sandstone lenses that are exceptionally thick and persistent. Thick sandstone is more abundant in the lower and upper parts of the unit than in the middle (fig. 2). Sandstone beds several feet thick alternate with slate for 100 feet or more near the base of the unit at many places in the quadrange. Thin beds (generally less than 12 in. thick) of sandstone grading into slate are common through the uppermost several thousand feet of the unit (fig. 2). Well-cleaved slate is best formed where there are appreciable thicknesses of alternating slate and sandstone. Slate has been quarried from such beds in the lower part of the unit on the south flanks of the northern anticlines (Espenshade and Boudette, 1964). The southernmost line of quarries, however, is about a mile south of the contact of limy sandstone and pelitic rock and may be in sandstone-slate beds of the upper part of the unit.

The top of the pelitic unit is not exposed in the Greenville quadrange. The total thickness of exposed beds cannot be determined exactly because of close folding and faulting and the absence of widespread marker beds. The generalized estimates of thickness given in figure 2 are based on calculations of thicknesses of parts of the unit made at places where bedding tops show uniform directions for a considerable distance. The minimum thickness of the unit in the quadrangle is judged to be 5,500–6,800 feet.

Very poorly preserved fossil plant fragments were found in fine-grained sandy beds at three localities in the Greenville quadrangle: (1) on the southeast bank of Big Wilson Stream a few hundred feet upstream from the railroad bridge, (2) on the northeast roadbank of State Highway 15 about 4,500 feet southeast of Lower Shirley Corner, and (3) in low ledges by the roadside about 6,600 feet N. 12° E. from the mouth of Little Ordway Pond. These localities are shown on the geologic map (Espenshade and Boudette, 1964). The fossils at the second and third localities come from about the same stratigraphic position, within 300–600 feet above the base of the pelitic unit; the stratigraphic position of the rocks at the first locality is not known. The material has been studied by S. H. Mamay, who found none of it preserved well enough for identification. Mamay (written commun., Dec. 2, 1957) reported as follows on the best preserved material, sample M93 from the locality on State Highway 15:

> There are several long, slender axes preserved as compressions, one of which shows a dichotomous forking. Some of the fragments contain very vague surface markings that may represent epidermal spines. This material is suggestive of, although not positively identifiable as, *Psilophyton* or a similar type of primitive vascular plant.

In 1956, Espenshade and J. W. Allingham found two small brachiopods in dark-gray fine-grained sandstone in the railroad cut 0.4 mile northwest of Bodfish station in the Sebec Lake quadrangle. The rocks at this locality resemble and are on strike with beds of the pelitic unit in the Greenville quadrangle, about 3 miles to the west. These brachiopods are *Howellella* or *Acrospirifer* according to A. J. Boucot (written commun., 1957).

Although the age of the pelitic unit cannot be determined from the poorly preserved fossil plant fragments and brachiopods, the lithology of the unit and its cyclic bedding at certain horizons resemble the Seboomook Formation in the Moosehead Lake region north of the Greenville quadrangle (Boucot, 1961). It seems likely that the pelitic unit correlates at least in part with the Seboomook and hence is of Early Devonian age.

DEVONIAN IGNEOUS ROCKS

TROCTOLITE, NORITE, AND GABBRO

GENERAL FEATURES

Mafic rock, consisting of varieties of troctolite, norite, and gabbro, underlies about 23 square miles in the northern part of the Greenville quadrangle (Espenshade and Boudette, 1964). The two separate areas of mafic rock shown on the geologic map are parts of the same pluton and are joined about a mile north of the guadrangle. The pluton, about 45 miles long, extends about 18 miles southwest and about the same distance northeast of the Greenville quadrangle and underlies a total area of about 140 square miles (fig. 1). The outline of the pluton is rather irregular and its width ranges from less than 1 mile to about 9 miles; the widest part is just north of the Greenville quadrangle. This large mafic intrusion, one of the most significant geologic features of the region, has been called the Moxie pluton by Visher (1960), the first geologist to study it in some detail.

Much of the pluton underlies lowlands and valleys that are bordered by hornfels ridges because the mafic rocks have been less resistant to weathering than the surrounding hornfels. The pluton underlies part of Moosehead Lake and the two Wilson Ponds, its presence being indicated by outcrops on islands, glacial boulders, and by aeromagnetic anomalies. Exposures of mafic rock are fairly well distributed in the quadrangle, but the area covered by glacial drift, talus, and water greatly exceeds the exposed area.

Outcrops of mafic rocks are commonly rounded or blocky, and the rock is generally little weathered. Normal varieties of mafic rock are dark gray or brownish gray on fresh surface; the weathered rock may be somewhat lighter in color or slightly iron stained from weathered olivine, pyroxene, or small amounts of sulfides and may be rather friable because of weathering between plagioclase crystals.

The rock is mostly medium grained. Plagioclase crystals are less than 5 mm in length and mafic minerals are a little smaller; poikilitic pyroxene crystals 1–2 cm in diameter are common. Plagioclase is characteristically the dominant mineral and makes up as much as 50–75 percent of most of the rock. Olivine, orthopyroxene, and clinopyroxene are the principal mafic minerals; hornblende and biotite are widespread but generally occur in amounts of less than 5 percent each.

The proportions of the major minerals range widely throughout the pluton in the Greenville quadrangle but are generally fairly uniform within single outcrops or small areas. Layers of differing composition from a few inches to several feet thick can be seen locally but are not common. Although compositional layering is uncommon, flow structure marked by the planar orientation of plagioclase crystals is widespread. The laminated flow structure and the compositional layering are parallel and generally dip northward (pl. 1*A*).

It is usually difficult to estimate the relative amounts of olivine and the two pyroxenes by visual inspection, and hence difficult to classify the mafic rock in the field except for some fine-grained norite in which orthopyroxene is practically the sole mafic mineral. Determination and classification of the varieties of mafic rock were accomplished mainly by microscopic examination of about 125 thin sections; modal analyses were made of about half these samples by the point-count method. This information provides much of the basis for the generalized distribution of major rock varieties that is shown on plate 1.

ROCK-CLASSIFICATION SYSTEM

The nomenclature used here for the mafic rocks of the Moxie pluton is a modification of the system of classification of basic rock proposed by Drysdall and Stillman (1960). Their system is based upon the relative amount of the four mafic minerals: olivine, orthopyroxene, clinopyroxene, and hornblende. These minerals are represented at the four corners of a tetrahedron, and the relative amounts of the four mafic minerals are plotted within the tetrahedron, which is divided into four equal volumes to represent the major rock types. (See fig. 3.) Thus, the rock type is determined by the dominant mafic mineral: olivine-rich rock is troctolite, orthopyroxene-rich rock is norite, clinopyroxene-rich rock is gabbro, and hornblende-rich rock is hornblende gabbro. (We substitute here the name "hornblende gabbro" for the rarely used name "bojite" proposed by Drysdall and Stillman.) The rock name may be modified by the names of the mafic minerals that occur in subordinate but significant amounts, such as olivine-augite norite. Rocks with more than 70 percent plagioclase are called feldspathic varieties.

MODAL COMPOSITION OF ROCKS

Modal analyses of samples from the Moxie pluton are arranged in table 4 according to the relative amounts of mafic minerals, following the reaction series. Olivine-rich rocks (troctolite) are generally listed first, then those rich in orthopyroxene, clinopyroxene, and hornblende. The proportions of mafic minerals in these samples are shown in the expanded tetrahedron diagram of figure 3. Distribution of the major minerals is shown by histograms in figure 4. Olivine and orthopyroxene are the dominant mafic minerals in the majority of samples. Hence, most of the samples fall within the troctolite and norite fields. There seems to be a fairly uniform progression in the olivine-orthopyroxene ratio through the troctolite-norite fields. The samples range from those in which olivine makes up nearly 100 percent of the mafic minerals to those in which orthopyroxene constitutes nearly 100 percent (table 4 and fig. 3). Clinopyroxene is present in significant amounts in a small number of samples, of which only a few fall in the gabbro field. Plagioclase content is 50–75 percent in most of the sam-

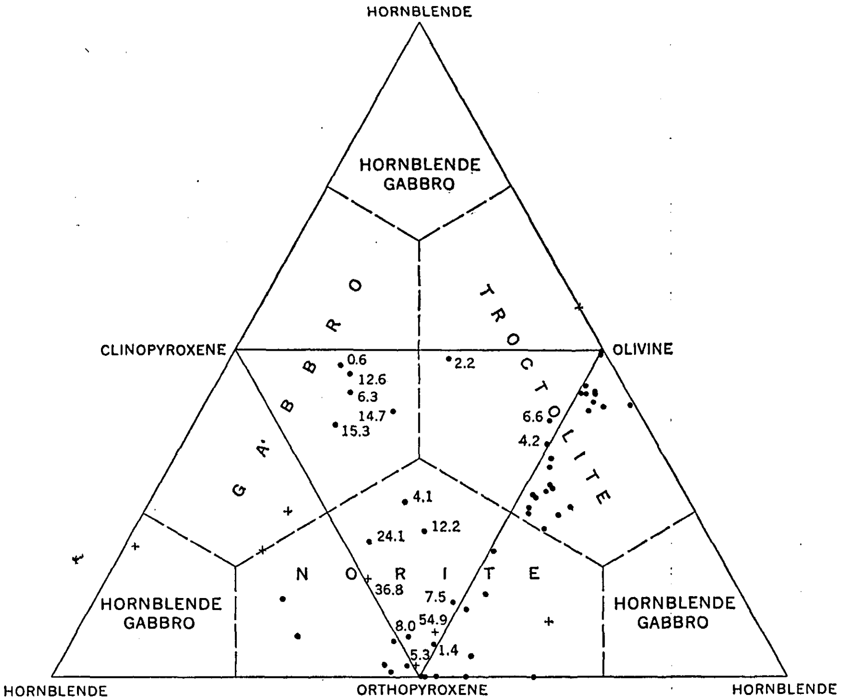


FIGURE 3.—Expanded tetrahedral diagram showing modal olivine, orthopyroxene, clinopyroxene, and hornblende in samples from the Moxie pluton, Greenville quadrangle. Rock classification scheme is modified from Drysdall and Stillman (1960). Data plotted are mafic mineral ratios from table 4. Samples with all four mafic minerals are projected to base of tetrahedron (central triangle) and the hornblende ratio is shown by adjoining number. •, cummingtonite-free rock; +, cummingtonite-bearing rock (cummingtonite calculated as hornblende).

TABLE 4.—*Modes, mafic mineral ratios, mineral compositions, and bulk densities of samples from the Moxie pluton, Greenville quadrangle*

[Asterisk indicates chemically analyzed sample. See table 6]

Sample	Modes (volume percent) [1]										Mafic mineral ratio [2]				Mineral composition (molecular percent)			Bulk density
	Plagioclase	Olivine	Orthopyroxene	Clinopyroxene	Hornblende	Biotite	Opaque minerals	Apatite	Quartz	Cummingtonite	Olivine	Orthopyroxene	Clinopyroxene	Hornblende	An content of plagioclase	Fo content of olivine	En content of orthopyroxene	
Troctolite (normal varieties) [3]																		
372*	56.7	41.2	0.1	0	0	0	2.1	0	0	0	99.8	0.2	0	0	64	55	--------	3.19
344	46.4	48.8	.5	0	.1	.6	3.6	0	0	0	98.9	1.0	0	.2	58	31	--------	3.09
366	53.6	34.3	.3	0	6.6	.2	5.0	0	0	0	83.2	.8	0	16.0	--------	--------	--------	3.30
Hypersthene troctolite (normal varieties)																		
373	61.2	29.3	2.8	0	1.4	1.5	3.9	0	0	0	87.5	8.4	0	4.1	--------	--------	--------	3.26
190	54.9	35.5	3.6	0	1.6	1.6	2.9	0	0	0	87.2	8.8	0	3.9	58	42	47	3.28
28	67.6	19.9	2.7	0	.5	1.8	5.2	2.4	0	0	86.1	11.7	0	2.2	59	--------	--------	3.09
324	60.9	27.6	3.5	0	1.8	1.1	3.6	1.5	0	0	84.0	10.6	0	5.4	--------	--------	--------	3.13
323	62.0	26.0	4.3	0	1.7	1.8	3.5	.6	0	0	81.2	13.4	0	5.4	60	42	41	3.19
92	58.5	28.5	8.3	1.3	2.7	.5	.2	0	0	0	69.9	20.3	3.2	6.6	76	74	80	2.94
193	65.0	17.8	7.2	.1	1.1	3.9	3.7	1.1	0	0	67.9	27.5	.4	4.2	--------	--------	--------	3.05
332	53.9	24.5	11.2	0	1.0	2.6	4.9	1.7	.1	0	66.8	30.5	0	2.7	--------	--------	--------	3.18
56	64.2	16.5	8.3	0	1.0	4.1	3.3	2.5	0	0	64.0	32.2	0	3.8	62	37	--------	3.04
30	63.0	[4] 21.9	11.6	0	2.0	.9	.5	0	0	0	58.7	35.2	0	6.1	--------	--------	--------	2.93
345 [5]*	[6] 64.9	[4] 16.8	12.7	0	4.6	.3	.6	0	0	0	49.3	37.2	0	13.5	69	71	79	2.91
314	65.1	18.7	11.5	0	2.4	1.3	1.0	0	0	0	57.4	35.3	0	7.3	--------	--------	--------	2.96
349*	54.0	18.9	12.6	0	2.1	4.7	5.0	2.7	0	0	56.3	37.5	0	6.2	53	28	44	3.15
32	57.5	12.0	11.4	0	3.1	6.8	4.8	4.4	0	0	45.3	43.0	0	11.7	55	--------	--------	3.12
320	63.4	14.0	10.5	0	.7	4.8	5.1	1.7	0	0	55.6	41.6	0	2.8	--------	--------	--------	3.04
363	[6] 65.3	[4] 13.7	8.6	0	4.1	2.8	4.2	1.2	0	0	51.9	32.6	0	15.5	53	34	41	3.06

Hypersthene troctolite (feldspathic varieties) [7]																	
33	70.8	17.7	2.0	0	0.1	2.8	4.7	1.8	0	0	89.4	10.1	0	0.5	61	--------	--------	3.03
342	77.4	17.0	2.6	0	.1	2.5	.4	0	0	0	86.3	13.2	0	.5	76	80	--------	2.92
347	73.9	19.5	2.1	0	2.0	1.4	1.0	0	0	0	82.6	8.9	0	8.5	--------	--------	--------	2.97
331	71.1	[4] 11.1	8.3	0	.9	4.6	3.0	.9	0	0	54.7	40.9	0	4.4	--------	--------	--------	2.92
36	74.5	12.9	11.0	0	1.0	.4	.2	0	0	0	51.8	44.2	0	4.0	76	--------	--------	2.80
471	73.9	[4] 13.7	10.7	0	1.1	.1	.3	0	0	0	50.0	45.3	0	4.7	--------	--------	--------	2.89
Augite troctolite (feldspathic variety)																	
498	77.5	[4] 12.3	0.6	8.9	0.5	0.1	0	0	0	0	55.2	2.7	39.9	2.2	--------	--------	--------	2.80
Olivine norite (normal and feldspathic varieties)																	
241*	} 62.0	12.0	19.0	0	0.3	3.4	2.3	1.1	0	0	38.3	60.7	0	1.0	52	28	43	3.02
27	} [6] 72.1	3.4	11.2	0	1.4	3.4	3.2	1.0	0	4.1	16.9	55.7	0	27.4	--------	--------	--------	2.98
530	[6] 74.2	6.5	17.7	0	1.3	.1	.1	0	0	0	25.5	69.4	0	5.1	--------	--------	--------	2.84
478	54.6	8.0	30.2	0	.8	1.0	5.4	0	0	0	20.5	77.4	0	2.1	--------	--------	--------	3.10
369	67.2	6.0	22.8	.6	2.6	.5	.3	0	0	0	18.9	71.7	1.9	7.5	76	--------	72	2.92
Norite (fine grained, normal varieties)																	
339	70.5	2.6	26.1	0.3	0.4	0.1	0.1	0	0	0	8.8	88.8	1.0	1.4	--------	--------	--------	2.90
340	66.5	0	33.2	0	.2	0	.1	0	0	0	0	99.4	0	.6	--------	--------	--------	2.89
368*	63.4	0	35.9	0	.5	.1	0	0	0	0	0	98.6	0	1.4	77	--------	63	2.97
547	64.5	0	28.2	0	1.3	1.8	4.0	.2	0	0	0	95.6	0	4.4	50	--------	44	3.02
328	62.1	0	24.2	.9	.3	3.7	4.7	2.9	1.3	0	0	95.3	3.5	1.2	54	--------	48	2.97
52	65.2	0	24.3	.5	1.8	4.2	2.2	.7	1.0	0	0	91.4	1.9	6.7	57	--------	49	2.99
322	66.0	0	29.8	1.3	2.6	0	.2	0	.1	0	0	88.4	3.9	7.7	--------	--------	--------	2.97
313	64.0	0	31.2	0	4.3	.2	.2	0	0	0	0	87.9	0	12.1	73	--------	67	2.93
466	63.8	0	31.8	4.0	.5	0	0	0	0	0	0	87.6	11.0	1.4	--------	--------	--------	2.93
509	48.6	0	33.4	0	15.0	0	3.0	0	0	0	0	68.9	0	31.1	--------	--------	--------	3.01
Norite (fine to medium grained, normal and feldspathic varieties)																	
91	83.8	1.0	13.1	0	1.7	0.3	0	0	0	0	6.3	82.9	0	10.8	75	--------	72	2.83
467	75.0	.6	20.2	2.2	2.0	.1	0	0	0	0	2.4	80.8	8.8	8.0	74	--------	73	2.86
76	55.6	.3	37.7	1.0	1.6	.8	2.4	0	0	.6	.7	91.5	2.4	5.3	74	--------	73	2.99

TABLE 4.—*Modes, mafic mineral ratios, mineral compositions, and bulk densities of samples from the Moxie pluton*—Continued

Sample	Modes (volume percent)[1]										Mafic mineral ratio[2]				Mineral composition (molecular percent)			Bulk density
	Plagioclase	Olivine	Orthopyroxene	Clinopyroxene	Hornblende	Biotite	Opaque minerals	Apatite	Quartz	Cummingtonite	Olivine	Orthopyroxene	Clinopyroxene	Hornblende	An content of plagioclase	Fo content of olivine	En content of orthopyroxene	
Olivine-augite norite (normal and feldspathic varieties)																		
67	38.3	13.5	27.5	18.1	2.5	0	0.2	0	0	0	21.9	44.6	29.4	4.1	72	--------	--------	3.13
462	77.9	3.9	9.2	3.4	2.3	2.8	.3	.1	0	0	20.7	48.9	18.1	12.2	--------	--------	--------	2.78
69*	55.4	2.4	19.4	11.3	10.5	.2	1.0	0	0	0	5.5	44.5	25.9	24.1	57	68	74	2.95
Augite norite (normal varieties)																		
458	50.6	0	28.0	12.6	5.9	0.3	2.4	0.3	0	0	0	60.2	27.1	12.7	--------	--------	--------	2.98
71	58.2	0	20.8	9.9	10.4	.3	0	0	.5	0	0	50.6	24.1	25.3	--------	--------	--------	2.92
Olivine-hypersthene gabbro (normal varieties)																		
31	40.1	17.0	9.5	24.1	8.7	0	0.5	0	0	0	28.7	16.0	40.6	14.7	72	77	77	3.00
336	[6] 65.1	9.1	1.7	23.8	.2	.1	0	0	0	0	26.1	4.9	68.4	.6	--------	--------	--------	2.98
74	54.0	[4] 10.1	2.8	23.9	5.3	0	3.8	0	0	0	24.0	6.6	56.8	12.6	74	67	--------	3.06
70	64.9	8.1	4.4	20.1	2.2	.1	.1	0	0	0	23.3	12.6	57.8	6.3	61	--------	--------	2.91
61	53.5	6.0	9.1	23.5	7.0	.5	.2	0	0	0	13.2	20.0	51.5	15.3	57	68	78	2.96
Hypersthene gabbro (normal varieties)																		
479	53.6	0	17.2	21.8	2.7	0.5	2.5	0.1	0	1.7	0	39.6	50.2	10.1	69	--------	60	2.98
310	61.2	0	3.0	30.7	4.7	.1	.3	0	0	0	0	7.8	79.9	12.2	--------	--------	--------	2.87

Cummingtonite-bearing varieties

695	0	70.8	0	0	0.7	0	18.3	0.1	0	10.0	87.3	0	0	12.7	--------	42	--------	3.91
27 [8]	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
114	54.4	1.5	11.4	.3	7.4	11.0	2.7	1.2	1.3	8.7	5.1	38.9	1.0	54.9	51	--------	35	3.05
194	47.9	.2	15.2	6.2	3.5	12.0	5.5	.5	0	9.1	.6	44.4	18.1	36.8	56	--------	42	3.02
96	[6] 70.8	0	10.6	10.6	2.8	1.3	0	0	.4	3.6	0	38.4	38.4	23.2	62	--------	72	2.83
539	45.0	0	1.7	20.8	21.6	0	2.1	0	0	8.7	0	3.2	39.4	57.4	--------	--------	--------	2.93

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[1] Modal analyses made by point-counting method; 1,000–1,600 points counted per section.

[2] Mafic mineral ratio is the content of olivine, orthopyroxene, clinopyroxene, and hornblende recalculated to 100 percent; cummingtonite is grouped with hornblende. Samples are generally listed in table in order of decreasing olivine and increasing pyroxene ratios.

[3] Normal rock varieties contain 30–70 percent plagioclase.

[4] Includes 1–3 percent of altered olivine.

[5] Samples from same locality bracketed.

[6] Includes 1–5 percent of altered plagioclase.

[7] Feldspathic rock varieties contain more than 70 percent plagioclase.

[8] Listed under olivine norite with sample 241 from same locality.

ples and exceeds 40 percent in all samples but one. The presence of hornblende and biotite in small to moderate amounts is a characteristic feature of all varieties of mafic rocks of the Moxie pluton. Cummingtonite occurs in moderate amounts in some rocks. A few percent of opaque minerals is present in nearly all varieties. Apatite is widespread in small amounts but is absent from some varieties of rocks.

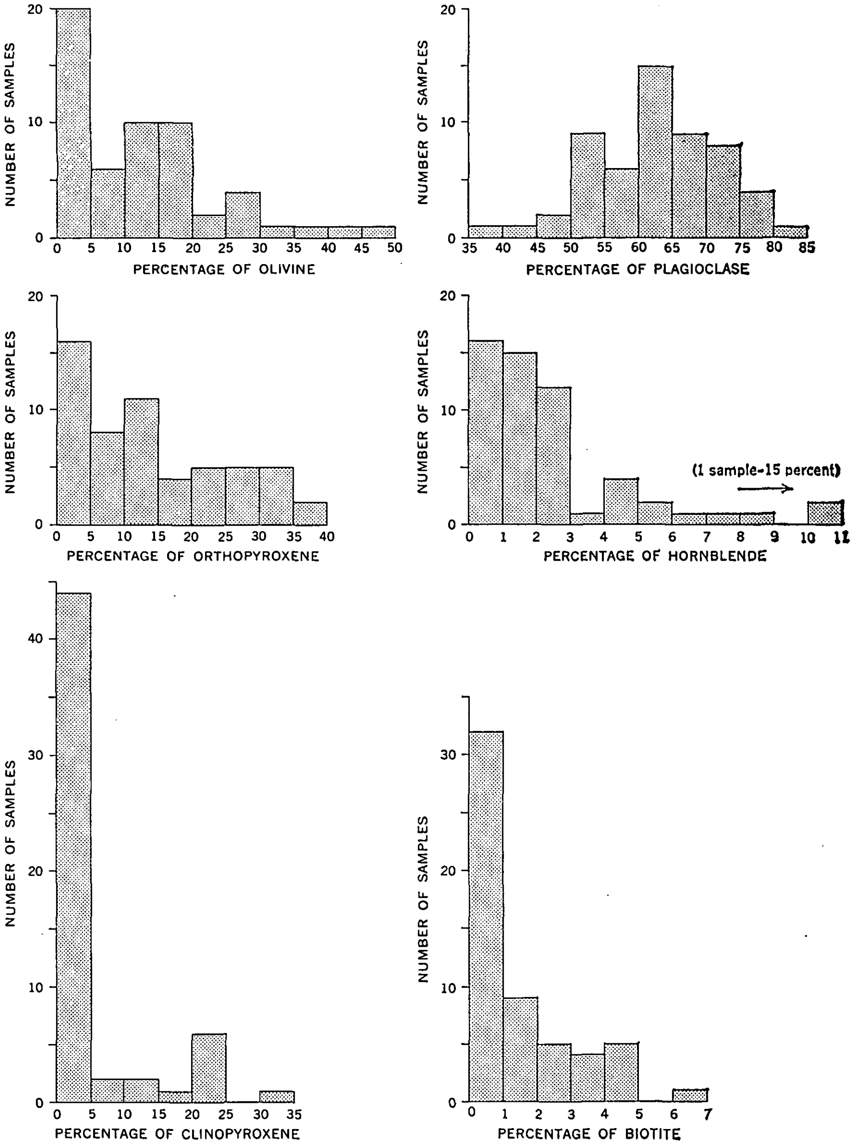

FIGURE 4.—Distribution of major mineral content (volume percent) in 56 samples from the Moxie pluton, Greenville quadrangle.

Quartz is very rare and is present mainly in fine-grained norite and in cummingtonite-bearing rocks.

The frequency distribution of densities and the average densities of samples of the major varieties of mafic rocks from this part of the Moxie pluton are given in table 5.

TABLE 5.—*Frequency distribution of densities and average densities of samples of troctolite, norite, and gabbro from the Moxie pluton, Greenville quadrangle*

Range of density	Normal troctolite	Feldspathic troctolite	Normal norite	Feldspathic norite	Normal gabbro
	Number of samples				
2.78–2.80	0	2	0	1	0
2.81–2.85	0	0	0	2	1
2.86–2.90	0	1	1	2	1
2.91–2.95	3	2	5	0	2
2.96–3.00	1	1	6	1	4
3.01–3.05	3	1	5	0	0
3.06–3.10	3	0	1	0	1
3.11–3.15	3	0	1	0	0
3.16–3.20	3	0	0	0	0
3.21–3.25	0	0	0	0	0
3.26–3.30	3	0	0	0	0
Average density	3.10	2.90	2.99	2.86	2.95

Average density, 60 samples of troctolite, norite, and gabbro 2.99

CHEMICAL COMPOSITION OF ROCKS

Chemical and spectrographic analyses and norms and modes of six samples of troctolite and norite from the Moxie pluton are given in table 6. The analyses are arranged in order of increasing FeO content (which is also the order of decreasing CaO content) because this probably approximates the trend of differentiation, that is, from low to high FeO. Some other elements also show progressive change. K_2O, TiO_2, P_2O_5, MnO, Ce, La, Mo, Nb, Sn, V, Y, Yb, and Zr generally increase with increase in FeO, whereas Cr and Cu decrease. The density of the rock also increases as the FeO content increases. However, sample 372 is anomalous in that features of early stages of differentiation (large amounts of MgO and Ni and low contents of Na_2O, K_2O, P_2O_5, Ba, B, Ce, La, Nb, Y, and Yb) are associated with late-stage features (very high FeO and relatively high Sn and Zr). These anomalous associations are possibly the result of the unusual composition of sample 372 (41 percent olivine of composition Fo_{55}); this rock may be a mixture of gravity-accumulated olivine formed at an intermediate stage of differentiation and other minerals formed at a later stage.

TABLE 6.—*Chemical analyses, semiquantitative spectrographic analyses, CIPW norms, and modes of samples from the Moxie pluton, Greenville quadrangle*

[Samples 241, 345, and 349 analyzed by methods similar to those described in USGS Bull. 1036-C; sample 69, 368, and 372 analyzed by X-ray fluorescence supplemented by methods described in USGS Bull. 1144-A. Analysts: Lowell Artis, I. H. Barlow, S. D. Botts, G. W. Chloe, and P. L. D. Elmore. The following elements were looked for in all six samples but not detected: As, Au, Bi, Cd, Eu, Ge, Hf, Hg, In, Li, Nd, Pd, Pr, Pt, Re, Sb, Sm, Ta, Te, Th, Tl, U, W, Zn. Gd, Tb, Dy, Ho, Er, Tm, and Lu were looked for but not found in samples 241, 345, and 349. Results are reported in percent to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, and 0.1; which represent approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results will include the quantitative value about 30 percent of the time]

Sample	345	69	368	241	349	372
Chemical analyses						
SiO_2	46.7	50.1	50.1	47.6	41.8	41.1
Al_2O_3	20.9	18.7	19.8	18.8	15.9	15.1
Fe_2O_3	3.2	2.2	1.4	.9	1.0	1.2
FeO	3.1	5.9	8.2	13.2	18.2	20.6
MgO	10.5	7.9	8.3	4.5	5.7	11.1
CaO	12.2	11.1	9.5	8.7	7.9	6.6
Na_2O	1.9	2.2	1.3	2.8	2.4	1.3
K_2O	.10	.24	.21	.32	.32	.18
H_2O	1.0	---------	---------	.63	.44	---------
H_2O^-	---------	.16	.25	---------	---------	.09
H_2O^+	---------	.63	.56	---------	---------	.50
TiO_2	.26	.43	.14	1.5	3.5	2.0
P_2O_5	.06	.05	.02	.82	2.2	.31
MnO	.12	.12	.18	.27	.32	.24
CO_2	.12	.06	$<.05$	$<.05$	$<.05$	.08
Total	100	100	100	100	100	100
Density (powder)	2.89	2.98	2.98	3.00	3.11	3.25
Density (bulk)	2.91	2.95	2.97	3.02	3.15	3.19
Semiquantitative spectrographic analyses [Analyst: H. W. Worthing]						
Ag	0.00002	0.00002	0.00002	0.00003	0.00003	0.00003
B	.0015	0	0	.005	.003	0
Ba	.002	.003	.002	.015	.01	.0015
Be	$<.0001$	0	0	$<.0001$	0	0
Ce	0	0	0	.007	.01	0
Co	.005	.005	.002	.003	.005	.01
Cr	.05	.03	.02	.015	.005	.015
Cu	.007	.005	.003	.003	.002	.0003
Ga	.001	.0015	.002	.002	.002	.0015
La	0	0	0	.005	.007	0
Mo	.0003	.0003	.0003	.0005	.0007	.0005
Nb	0	0	0	.0007	.0007	0
Ni	.03	.015	.005	.007	.007	.02
Pb	.0002	.0015	.001	.0003	.0003	0
Sc	.002	.005	.003	.003	.002	.0005
Sn	0	0	0	0	.0003	.0003
Sr	.02	.03	.03	.05	.03	.03
V	.01	.02	.03	.03	.03	.02
Y	.001	.002	.001	.005	.007	.003
Yb	.0001	.0002	.0001	.0005	.0007	.0003
Zr	.001	.003	.002	.015	.015	.01

See footnotes at end of table.

TABLE 6.—*Chemical analyses, semiquantitative spectrographic, etc.*—Continued

Sample	345	69	368	241	349	372
CIPW Norms						
Quartz	0	0.28	2.71	0	0	0
Orthoclase	.59	1.42	1.24	1.89	1.89	1.06
Albite	16.07	18.61	10.99	23.68	20.30	10.99
Anorthite	48.21	40.44	47.00	37.79	24.81	30.20
Corundum	0	0	.21	0	2.51	1.70
Diopside:						
$CaSiO_3$	4.66	5.81	0	0	0	0
$MgSiO_3$	3.72	3.77	0	0	0	0
$FeSiO_3$	.40	1.64	0	0	0	0
Hypersthene:						
$MgSiO_3$	7.33	15.90	20.66	7.51	7.34	6.58
$FeSiO_3$	.80	6.89	14.00	14.42	14.18	8.09
Olivine:						
Mg_2SiO_4	10.58	0	0	2.59	4.80	14.76
Fe_2SiO_4	1.27	0	0	5.48	10.21	19.99
Magnetite	4.64	3.19	2.03	1.31	1.45	1.74
Apatite	.14	.12	.05	1.94	5.21	.73
Ilmenite	.49	.82	.27	2.85	6.65	3.80
Calcite	.27	.14	0	0	0	.18
Modes (volume percent)						
Plagioclase	63.6	55.4	63.4	62.0	54.0	56.7
Plagioclase alteration minerals	1.3	0	0	0	0	0
Olivine	15.4	2.4	0	12.0	18.9	41.2
Olivine alteration minerals	1.4	0	0	0	0	0
Orthopyroxene	12.7	19.4	35.9	19.0	12.6	.1
Clinopyroxene	0	11.3	0	0	0	0
Hornblende	4.6	10.5	.5	.3	2.1	0
Biotite	.3	.2	.1	3.4	4.7	0
Opaque minerals	.6	1.0	0	2.3	5.0	2.1
Apatite	0	0	0	1.1	2.7	0
Total	99.9	100.2	99.9	100.1	100.0	100.1

See footnotes at end of table.

TABLE 6.—*Chemical analyses, semiquantitative spectrographic, etc.*—Continued

Sample	345	69	368	241	349	372
Mineral composition						
Plagioclase, molecular percent An	69	57	77	52	53	64
Olivine, molecular percent Fo	71	68	---------	28	28	55
Orthopyroxene, molecular percent En	79	74	63	43	44	---------

345: Medium-grained dark-gray hypersthene troctolite containing poikilitic hypersthene crystals 1–1.5 cm in diameter. From east side of State Highway 15 about 100 ft south of town line between towns T. 2, R. 6 and T. 3, R. 5; 2,900 ft east of 69°40′W. and 7,300 ft south of 45°30′N.

69: Medium-grained medium-gray olivine-augite norite containing poikilitic pyroxene crystals as much as 1 cm in diameter. From 1,360-ft contour on steep slope about 2,500 ft northeast of sample 345; 5,000 ft east of 69°40′W. and 5,900 ft south of 45°30′N.

368: Fine-grained medium-brown norite containing plagioclase and hypersthene in laminar orientation. From west slope of knob 2380 about 0.8 mile east of Trout Pond; 6,500 ft east of 69°45′W. and 13,200 ft south of 45°30′N.

241: Medium-grained dark-brown gray olivine norite. From west side of State Highway 15 about 500 ft northwest of contact of pluton; 8,200 ft east of 69°40′W. and 8,100 ft south of 45°30′N.

349: Medium-grained dark-gray hypersthene troctolite containing some disseminated pyrrhotite. From west side of State Highway 15 at 2,100 ft north of Middle Squaw Brook; 600 ft west of 69°40′W. and 2,200 ft south of 45°30′N.

372: Fine-grained dark-gray troctolite containing plagioclase in laminar orientation. From southwest shore of Trout Pond at 900 ft east of 69°45′W. and 14,200 ft south of 45°30′N.

MINERALOGY

Plagioclase.—Plagioclase typically forms subhedral to euhedral crystals several millimeters long that are twinned, commonly unzoned, and quite fresh. These are generally oriented in pronounced laminae. Some samples contain two sizes of plagioclase crystals. One size ranges from 3 to 5 mm, and the other is less than 2 mm; these probably represent two generations of crystals. Color of unaltered plagioclase in the hand specimen is medium to dark gray, whereas altered plagioclase is white to light gray. Grain boundaries are generally scalloped against olivine; this fact suggests that the two minerals were about contemporaneous. Plagioclase is replaced by orthopyroxene and biotite in some rocks. Anorthite content of plagioclase from different varieties of mafic rock ranges from 50 to 77 percent.

Olivine.—Olivine mainly forms anhedral to subhedral grains or is clustered in elongated aggregates, some of which are oriented in planes parallel to the plagioclase laminae. Olivine crystals are typically about 1–2 mm long, unzoned, and unaltered; alteration to serpentine occurs only locally. Color ranges from yellow green to dark metallic brown. Olivine commonly has a thin mantle or reaction rim (0.02–0.1 mm thick) of orthopyroxene or pale-brown hornblende. The composition of olivine in this part of the Moxie pluton falls into two groups; one group ranges from 28 to 42 percent forsterite, the other from 55 to 80 percent.

Orthopyroxene.—Orthopyroxene occurs in several forms. In norite, where it is most abundant, it is generally in elongated euhedral to subhedral crystals as much as 3 mm long, or in elongated clusters of grains, and it appears to be about contemporaneous with plagioclase. Where less abundant, as in some troctolite and gabbro, it commonly forms poikilitic crystals as much as several centimeters in diameter, which may enclose olivine, plagioclase, and opaque minerals. Where present in very small amounts, orthopyroxene may simply form thin mantles on olivine crystals. Thin lamellae parallel to the (100) plane are common and probably represent exsolution of clinopyroxene. Orthopyroxene with this feature is called orthopyroxene of the Bushveld type by Hess (1960). Some orthopyroxenes are nonpleochroic, and others have distinct pink to green pleochroism. The orthopyroxene in this part of the Moxie pluton also has two compositional groups, one ranging from 35 to 49 percent enstatite and one from 60 to 80 percent.

Clinopyroxene.—Clinopyroxene also occurs in subhedral grains as much as a few millimeters long or in poikilitic crystals that are a centimeter or two in diameter and that may enclose plagioclase, olivine, and orthopyroxene. It is very commonly intergrown in an irregular mottled fashion with brown hornblende. Fine parallel banding which is probably due to exsolution of orthopyroxene lamellae is present. No determinations were made of the composition of clinopyroxene; it seems to be most abundant in rocks having magnesium-rich olivine and orthopyroxene.

Hornblende.—Hornblende is light to medium brown or green and occurs most commonly as thin mantles on olivine, orthopyroxene, or clinopyroxene crystals. It is also intergrown very irregularly with clinopyroxene. In some specimens it forms poikilitic crystals and encloses olivine, plagioclase, pyroxene, and opaque minerals. Hornblende appears to be a late magmatic mineral in most places.

Cummingtonite.—The monoclinic amphibole, cummingtonite, occurs as colorless crystals that have very pale blue-green borders and as pale-tan crystals. It is commonly twinned and forms large irregular prisms or clusters of fine radiating prisms having fibrous texture. Cummingtonite is very commonly in optical continuity with normal hornblende. It is commonly intergrown with chlorite and replaces plagioclase, orthopyroxene, clinopyroxene, biotite, and hornblende; it tends to replace orthopyroxene more completely than it does clinopyroxene. Carbonate may also be associated with cummingtonite. Cummingtonite is a late mineral that in some places appears to have formed deuterically from residual liquids. It also has formed as an alteration mineral along shear zones or joints.

Biotite.—Biotite is widespread but occurs only in minor amounts. It is obviously one of the late-formed minerals because it locally replaces plagioclase. It is commonly clustered with opaque minerals and apatite and is locally poikilitic. Biotite encloses olivine, pyroxene, plagioclase, and opaque minerals.

Opaque minerals.—The opaque minerals are mostly irregular to subhedral grains that are very commonly clustered together with biotite and apatite. Ilmenite is the dominant opaque minerals in the nine polished surfaces examined. A little hematite occurs with ilmenite in several specimens. Small grains of pyrrhotite containing minute blebs of chalcopyrite are present in about half the specimens examined. In one thin section, the sulfide grains are partly mantled by biotite and hornblende, which seem to be younger than the sulfides.

Apatite.—Apatite generally forms euhedral to subhedral prisms that average 0.3 mm in length, and reach a maximum length of about 1 mm. It occurs with the opaque minerals and is most abundant where the opaques are abundant.

Quartz.—Quartz is a very rare mineral in these rocks and seldom exceeds 1 percent in amount. It is a late-formed mineral and is interstitial to plagioclase.

Other minerals.—The chlorite that is characteristically associated with cummingtonite is pale green and has an olive-green birefringence. Chlorite also occurs without cummingtonite and replaces biotite or plagioclase to a small degree. Zoisite, kaolinite (?), and carbonate also replace plagioclase to a minor extent. Serpentine and talc (?) locally replace olivine in the pluton, but olivine is generally quite fresh. Garnet occurs with cummingtonite at several places very near the outer edges of the pluton. Sphene occurs in trace amounts in some rock.

VARIATIONS IN COMPOSITION OF PLAGIOCLASE, OLIVINE, AND ORTHOPYROXENE

In order to get some measure of the variations in composition of plagioclase, olivine, and orthopyroxene in this part of the Moxie pluton, samples were chosen so as to give wide geographic distribution and good representation of the different varieties of mafic rocks. Concentrates of the three minerals were made from crushed samples by means of a magnetic separator, and compositions of plagioclase and orthopyroxene were determined by index of refraction measurements and composition of olivine from X-ray data. For plagioclase, the temperature-compensated single-variation method with monochromator was used to determine α, and the anorthite composition was then estimated using the curve of Smith (1960). The same method was used to determine γ of (210) cleavage plates of orthopyroxene. The pyroxene composition was then estimated using the curve of Deer, Howie, and Zussman (1963, p. 28). For olivine, d_{130} was determined by X-ray diffractometer and the composition estimated using the curve of Agterberg (1964). The compositions of the three minerals and their optical and X-ray data are given in table 7 where the samples are listed in the order of decreasing anorthite content.

As would be expected, the magnesium content of olivine and orthopyroxene generally decreases as the anorthite content of plagioclase decreases (fig. 5). Although there seems to be a continuous range in

TABLE 7.—*Compositions of coexisting plagioclase, olivine, and orthopyroxene in samples from the Moxie pluton Greenville quadrangle*

Sample	Plagioclase		Olivine		Orthopyroxene	
	α	An (molecular percent)	d_{130}	Fo (molecular percent)	γ	En (molecular percent)
368	1.5658	77	-------	----------	1.7103	63
92	1.5657	76	2.784	74	1.6894	80
36	1.5657	76	-------	----------	-------	----------
369	1.5656	76	-------	----------	1.6984	72
342	1.5654	76	2.780	80	-------	----------
91	1.5653	75	-------	----------	1.6994	72
74	1.5648	74	2.789	67	-------	----------
76	1.5646	74	-------	----------	1.6980	73
467	1.5645	74	-------	----------	1.6982	73
313	1.5643	73	-------	----------	1.7050	67
67	1.5638	72	-------	----------	-------	----------
31	1.5636	72	2.782	77	1.6924	77
345	1.5626	69	2.786	71	1.6901	79
479	1.5623	69	-------	----------	1.7138	60
372	1.5602	64	2.797	55	-------	----------
96	1.5595	62	-------	----------	1.6994	72
56	1.5593	62	2.810	37	-------	----------
33	1.5590	61	-------	----------	-------	----------
70	1.5590	61	-------	----------	-------	----------
323	1.5586	60	2.806	42	1.7371	41
28	1.5581	59	-------	----------	-------	----------
344	1.5578	58	2.814	31	-------	----------
190	1.5578	58	2.806	42	1.7302	47
61	1.5573	57	2.788	68	1.6913	78
69	1.5573	57	2.788	68	1.6969	74
52	1.5573	57	-------	----------	1.7279	49
194	1.5569	56	-------	----------	1.7363	42
32	1.5563	55	-------	----------	-------	----------
328	1.5558	54	-------	----------	1.7285	48
349	1.5557	53	2.816	28	1.7339	44
363	1.5555	53	2.812	34	1.7372	41
241	1.5549	52	2.816	28	1.7351	43
114	1.5546	51	-------	----------	1.7449	35
547	1.5543	50	-------	----------	1.7332	44
695	-------	----------	2.806	42	-------	----------

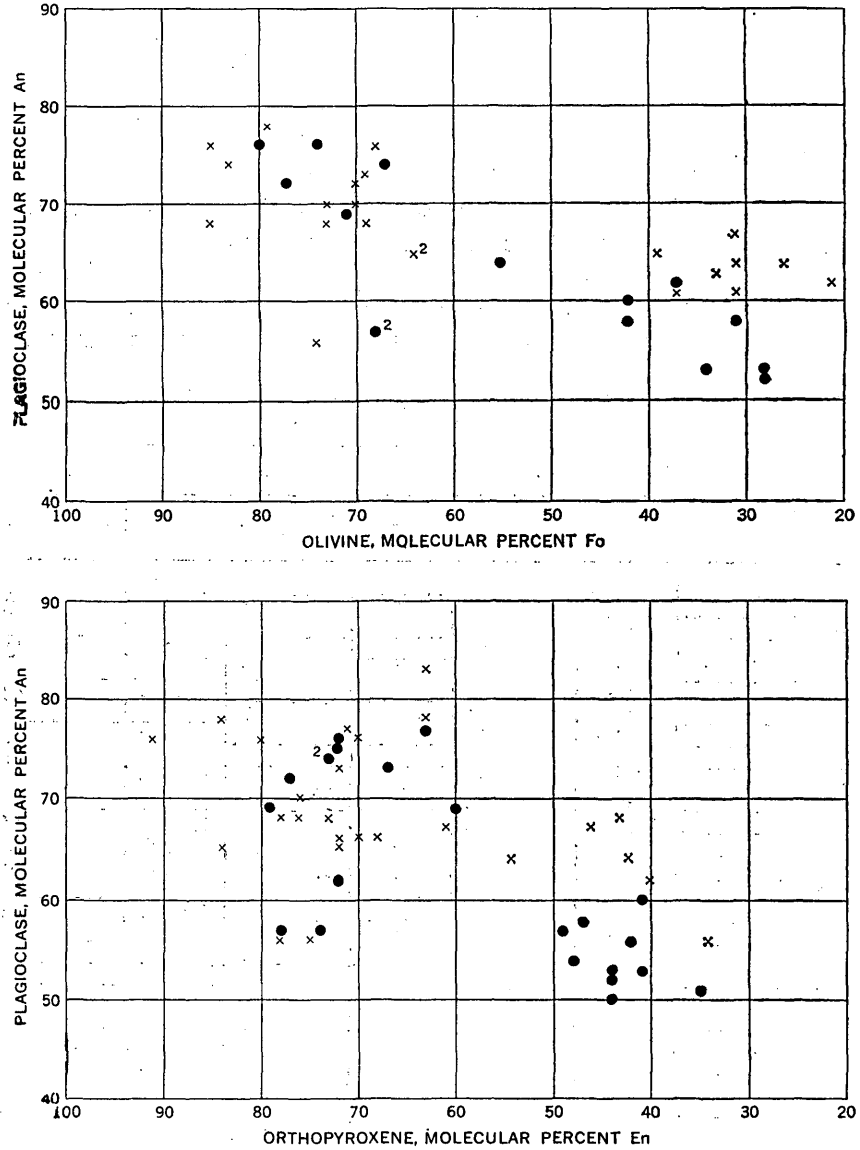

FIGURE 5.—Relations of olivine and orthopyroxene composition to plagioclase composition in samples from the Moxie pluton, Greenville quadrangle. ●, data by Espenshade and Boudette; × data from Visher (1960).

plagioclase composition, most samples of the mafic minerals are clustered into magnesium-rich groups and iron-rich groups. Visher's compositions are not strictly comparable with ours, because he used different methods of determination, but his data do show a similar clustering of magnesium-rich and iron-rich olivines and orthopyroxenes (fig. 5). However, he does not point out the existence of this situation.

COMPARISON OF MAGNESIUM-RICH AND IRON-RICH ROCKS

There are distinct differences in mineralogy and chemical composition between those rocks in which the olivine and orthopyroxene are magnesium rich and those in which these minerals are iron rich. Modes of the two groups of rocks are shown in table 8. These data suggest that in the iron-rich rocks olivine is more abundant and clinopyroxene is less abundant than in the magnesium-rich rocks. The late-stage minerals, biotite, opaques, and apatite, are far more abundant in the iron-rich rocks. Biotite is very commonly clustered in poikilitic clots from ½ to 1 cm in diameter in the iron-rich rocks. These clots form a very distinctive megascopic feature. On the other hand, poikilitic pyroxene crystals, 1–2 cm in diameter, are much more common in the magnesium-rich rocks. Apatite is present in all the iron-rich rocks, except in two samples of olivine-rich troctolite, and it is practically absent from the magnesium-rich rocks. Quartz and cummingtonite may be a little more abundant in some iron-rich rocks. The iron-rich rocks have a distinctly higher density than the magnesium-rich rocks. Although flow structure is very common in both varieties, it seems to be better formed in the iron-rich rocks.

The differences in chemical composition between the magnesium-rich rocks (samples 345, 69, and 368) and the iron-rich rocks (241 and 349) are evident in table 6 and have already been pointed out (p. F22). The nearly identical compositions of plagioclase, olivine, and orthopyroxene in samples 241 and 349 suggest that the magma at these two localities, each near opposite sides of the pluton (pl. 1), was at the same point in the differentiation trend. The high iron content of sample 372 suggests that it might belong to the iron-rich group, but inasmuch as this high iron content is accompanied by a high magnesium content, it mainly reflects the large olivine content (41 percent) of the rock. Sample 372 seems to fall between the magnesium-rich and iron-rich groups on the basis of its intermediate content of some of the minor elements (K_2O, P_2O_5, and MnO) and the intermediate composition of the olivine (Fo_{55}).

ROCK TYPES AND THEIR DISTRIBUTION

Troctolite and norite are the most abundant rock types of the Moxie pluton. Most rocks are medium grained and contain plagioclase and mafic minerals about 3–5 mm in length. The color of the rocks ranges from medium gray to very dark gray; the troctolite is commonly dark,

TABLE 8.—*Comparison of modes, mineral compositions, and densities of magnesium-rich and iron-rich rocks from the Moxie pluton, Greenville quadrangle*

Sample	Rock type [1]	Modes (volume percent)										Mineral composition (molecular percent)			Bulk density
		Plagioclase	Olivine	Orthopyroxene	Clinopyroxene	Hornblende	Biotite	Opaque minerals	Apatite	Quartz	Cummingtonite	An content of plagioclase	Fo content of olivine	En content of orthopyroxene	
Magnesium-rich rocks															
368 [2]	N	63.4	0	35.9	0	0.5	0.1	0	0	0	0	77	----	63	2.97
342	T	77.4	17.0	2.6	0	.1	2.5	.4	0	0	0	76	80	----	2.92
92	T	58.5	28.5	8.3	1.3	2.7	.5	.2	0	0	0	76	74	80	2.94
369	N	67.2	6.0	22.8	.6	2.6	.5	.3	0	0	0	76	----	72	2.92
91	N	83.8	1.0	13.1	0	1.7	.3	0	0	0	0	75	----	72	2.83
467	N	75.0	.6	20.2	2.2	2.0	.1	0	0	0	0	74	----	73	2.86
76	N	55.6	.3	37.7	1.0	1.6	.8	2.4	0	0	.6	74	----	73	2.99
74	G	54.0	10.1	2.8	23.9	5.3	0	3.8	0	0	0	74	67	----	3.06
313	N	64.0	0	31.2	0	4.3	.2	.2	0	0	0	73	----	67	2.93
31	G	40.1	17.0	9.5	24.1	8.7	0	.5	0	0	0	72	77	77	3.00
345 [2]	T	64.9	16.8	12.7	0	4.6	.3	.6	0	0	0	69	71	79	2.91
479	G	53.6	0	17.2	21.8	2.7	.5	2.5	.1	0	1.7	69	----	60	2.98
372 [2]	T	56.7	41.2	.1	0	0	0	2.1	0	0	0	64	55	----	3.19
96	N-G	70.8	0	10.6	10.6	2.8	1.3	0	0	.4	3.6	62	----	72	2.83
61	G	53.5	6.0	9.1	23.5	7.0	.5	.2	0	0	0	57	68	78	2.96
69 [2]	N	55.4	2.4	19.4	11.3	10.5	.2	1.0	0	0	0	57	68	74	2.95
Iron-rich rocks															
695	D	0	70.8	0	0	0.7	0	18.3	0.1	0	10.0	----	42	----	3.91
56	T	64.2	16.5	8.3	0	1.0	4.1	3.3	2.5	0	0	62	37	----	3.04
323	T	62.0	26.0	4.3	0	1.7	1.8	3.5	.6	0	0	60	42	41	3.19
190	T	54.9	35.5	3.6	0	1.6	1.6	2.9	0	0	0	58	42	47	3.28
344	T	46.4	48.8	.5	0	.1	.6	3.6	0	0	0	58	31	----	3.09
52	N	65.2	0	24.3	.5	1.8	4.2	2.2	.7	1.0	0	57	----	49	2.99
194	N	47.9	.2	15.2	6.2	3.5	12.0	5.5	.5	0	9.1	56	----	42	3.02
328	N	62.1	0	24.2	.9	.3	3.7	4.7	2.9	1.3	0	54	----	48	2.97
363	T	65.3	13.7	8.6	0	4.1	2.8	4.2	1.2	0	0	53	34	41	3.06
349 [2]	T	54.0	18.9	12.6	0	2.1	4.7	5.0	2.7	0	0	53	28	44	3.15
241 [2]	N	62.0	12.0	19.0	0	.3	3.4	2.3	1.1	0	0	52	28	43	3.02
114	N	54.4	1.5	11.4	.3	7.4	11.0	2.7	1.2	1.3	8.7	51	----	35	3.05
547	N	64.5	0	28.2	0	1.3	1.8	4.0	.2	0	0	50	----	44	3.02

[1] D, dunite; T, troctolite; N, norite; G, gabbro.
[2] Chemically analyzed sample; see table 6.

and feldspathic varieties are considerably lighter. One of the most distinctive rocks is medium- to dark-brown fine-grained norite; it consists mainly of plagioclase and orthopyroxene in a ratio of about 2 to 1. In this rock, plagioclase crystals are commonly less than 1 mm long and orthopyroxene less than 0.5 mm. Olivine- or pyroxene-rich rocks may occur locally in layers a few inches to 2 feet thick. Troctolite and norite may be either magnesium rich or iron rich, but gabbro is generally magnesium rich. Most of the fine-grained norite seems to be magnesium rich.

Some rocks weather to small nodules or ellipsoids which may contain small irregular interstitial gobs of pegmatitic material. Quartz-bearing pegmatite in layers as much as 1 foot thick also occurs in a few places. Fine-grained granodiorite or quartz monzonite composed mostly of quartz, plagioclase (about An_{10-15}), perthitic microcline, and biotite is very uncommon.

Inclusions of hornfels less than 1 foot long occur in some places near the edges of the pluton, and a few large slabby inclusions of hornfels as much as 20 feet across were noted.

Distribution of the major rock types of the Moxie pluton in the Greenville quadrangle as determined from microscopic study of thin sections is shown on plate 1. The trends of boundaries between the different rock units has been mainly determined from the trends of flow structures, aeromagnetic anomalies, and topographic features. Troctolite underlies much of the area and appears to be the dominant rock along the northern and western edges of the pluton. These edges probably form the floor of the pluton. Much of the ground underlain by troctolite is topographically lower than that underlain by norite and gabbro. Fine-grained norite underlies much of the high country between Trout Pond and Big Squaw Pond. Medium-grained norite, containing pyroxene somewhat altered to cummingtonite in places, seems to be continuous along the southeast edge of the pluton, which is probably the hanging wall of the intrusion. The largest area of gabbro underlies hill 1568 between State Highway 15 and Harfords Point. Troctolite, norite, and gabbro all occur in the lobe of the pluton around Lower Wilson Pond, though gabbro is perhaps dominant in the western part.

On the south slope of hill 1568, hypersthene gabbro and augite norite are well exposed. Samples were collected at intervals along a traverse trending north about at right angles to the trend of flow structure to determine if there were progressive changes in composition from the base to the top of the section (pl. 1 and fig. 6). Variations in modal composition, anorthite content, and density are shown in figure 7. The number of samples is probably too few to demonstrate the changes adequately, but the results do suggest that olivine disappears somewhere between a stratigraphic height of 360 and 670 feet above the base and that quartz occurs in very small amounts in the upper part of the section where olivine is absent. The absence of pyroxenes from sample 72 at the top of the section may be a very local feature caused by the alteration associated with a quartz vug.

Sample 695, from one of the few occurrences of dunite found in the quadrangle, was collected about 1,000 feet S. 35° W. from bench mark 1116 on State Highway 15 (pl. 1*B*). Greenish-black resinous-appearing dunite in blocks as much as 1 foot thick extends for about 500 feet N. 30° E. The rock is composed of olivine, opaque minerals, and cummingtonite (table 4). Strong magnetic and self-potential anomalies occur here (Stickney and others, 1965, p. 60–64). Similar dunite, in which olivine is accompanied by considerable opaque minerals and apatite, occurs at a point about 4,200 feet S. 19° W. from bench mark 3196, Big Squaw Mountain, at an altitude of about 2,110 feet.

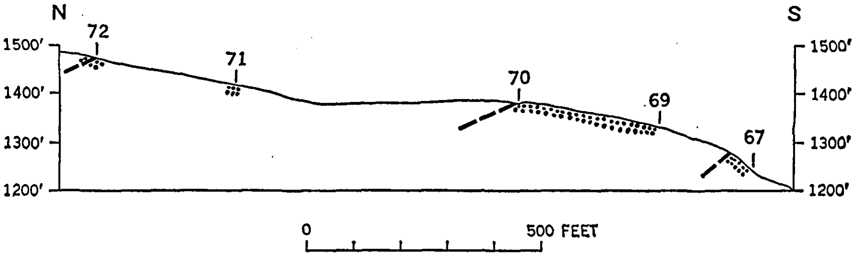

FIGURE 6.—Section on south slope of hill 1568 in southeast corner of T. 2, R. 6, from a point on the 1,200-foot contour about 2,600 feet northeast of State Highway 15, Greenville quadrangle. Dots indicate exposures of gabbro and norite; dashed lines show dip of plagioclase lamination and compositional layering; numbers show locations of samples. Position of section is shown on plate 1A.

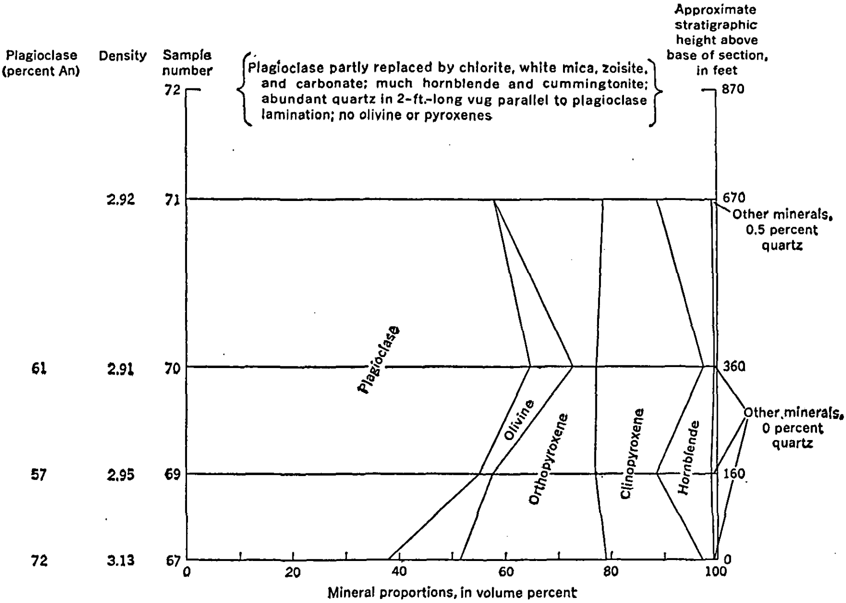

FIGURE 7.—Diagram showing variations in mineral proportions, plagioclase composition, and density in some samples from the Moxie pluton, south slope of hill 1568, T. 2, R. 6, Greenville quadrangle.

Fine-grained felsic rock forms dikes cutting the mafic rock at Rum Cove and at Lower Wilson Pond. Felsic rock also occurs on Trout Pond and north of Moore Bog, but here the contacts with the mafic rock are not exposed.

Iron-rich rocks are distinguished from magnesium-rich rocks (pl. 1*B*), on the basis of the presence of apatite in amounts greater than about 0.1 percent. That quantity of apatite is judged to be a reliable index to the iron-rich rocks for samples for which there is no data on olivine or orthopyroxene composition. This conclusion is based on the data given in table 9. On plate 1*B*, samples of apatite-bearing rocks are distinguished from rocks lacking apatite. The approximate boundary drawn between the two groups of rocks suggests that iron-rich rocks prevail entirely across the pluton between Big Squaw Pond and Big Squaw Mountain and that from here they extend northeast as two separate belts parallel to the edges of the pluton (pl. 1*B*). Visher (1960) also found a very similar distribution of iron-rich olivine and orthopyroxene in samples that he took along State Highway 15 and Little Squaw Brook. Some iron-rich rocks do occur in the area north of Moore Bog in the northwest corner of the quadrangle. The rocks in the lobe of Lower Wilson Pond are nearly all magnesium rich.

The distribution patterns of the major rock types and of the magnesium-rich and iron-rich groups are complex in this part of the Moxie pluton and do not resemble the patterns found in some large layered mafic complexes. Visher (1960) has shown that the south end of the Moxie pluton in the Bingham and The Forks quadrangles (fig. 1) is uniformly high in CaO and MgO and low in FeO. Preliminary work by Espenshade in the northeastern part of the pluton (Moosehead Lake and First Roach Pond quadrangles) shows that iron-rich rocks are very abundant there. Thus, it appears that magnesium-rich rocks are dominant in the southern part of the pluton, and iron-rich rocks are abundant in the central and northeastern part.

STRUCTURE OF THE MOXIE PLUTON

The external and internal structures of the Moxie pluton are not altogether clear. Kane (1961) has concluded from the results of gravity surveys across the pluton just west of Moosehead Lake that the southeastern and northwestern contacts both dip about 60° SE. (fig. 8). By this interpretation, the pluton here would have the structure of an enormous irregular dike and the hornfels mass of Big Squaw Mountain would be in the footwall of the pluton. The Moxie pluton widens to the northeast in the Moosehead Lake quadrangle (fig. 1), and structural features there support the view that the hornfels of Big Squaw Mountain lies beneath the pluton. This wide northeastern part of the

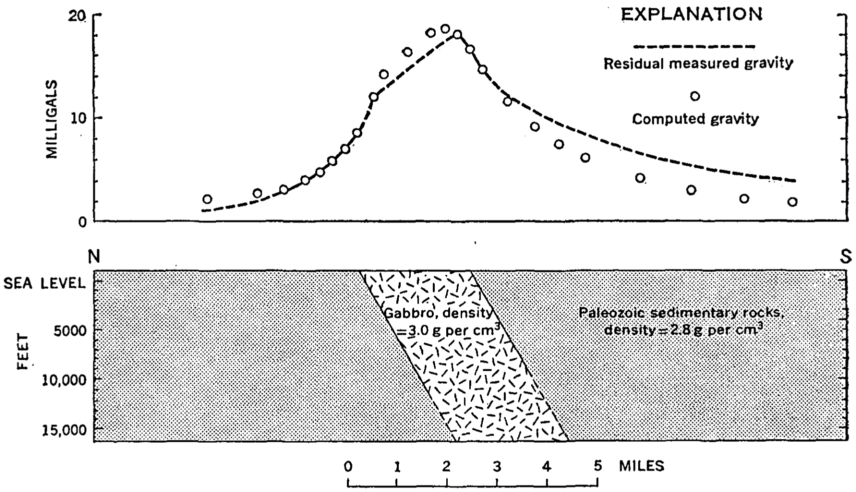

FIGURE 8.—Gravity profile and section over Moxie pluton near south end of Moosehead Lake. From Kane (1961).

pluton perhaps is an irregular undulating sheet. The narrow part of the pluton southwest of the Greenville quadrangle may have a dikelike shape, and the large rounded southern end may be pipelike. Thus, the gross structure of the pluton seems to vary in a complex manner from place to place.

Internal structure of the pluton is best displayed by the flow structure or lamination which is marked by subparallel plagioclase crystals. The flow structure is widespread and generally dips in directions ranging between north and east at angles from 20° to 60°. Compositional layering (mainly concentrations of mafic minerals) is not common in the quadrangle, but where present, it is conformable to flow structure or lamination.

No linear orientation of the plagioclase crystals in the lamination plane is evident in outcrops or in hand specimens. However, Visher (1960, fig. 8) found a weak linear orientation of the plagioclase crystals within the plane of igneous lamination from a statistical study of plagioclase orientation in several thin sections cut parallel to the lamination. This weak linear orientation suggests to Visher (written commun., 1961) that convection currents were important during fractional crystallization of the magma.

We feel that the lamination was formed principally by gravitational settling, which may have been accompanied by convection currents that caused the linear orientation found by Visher. Our view seems to be essentially the same as Visher's. If gravitational settling was more important than flow in the formation of the laminated structure, then our use of the term "flow structure" on the geologic map (Espenshade and Boudette, 1964) is not a good choice; "igneous lamination" is a preferable term.

The considerable variation in composition of plagioclase and mafic minerals suggests that some form of differentiation took place during crystallization. In the Skaergaard complex of Greenland, cryptic layering is expressed by gradual and systematic changes in mineral compositions because of progressive upward crystallization and differentiation within the magma reservoir (Wager and Deer, 1939). However, in this part of the Moxie pluton the pattern of chemical changes of the constituent minerals is complex, as are the patterns of distribution of rock types.

Flow structures near the sides of intrusive masses are commonly nearly conformable with the contacts, but the flow structures within the Moxie pluton are highly discordant with the presumed southeast-dipping contacts. Fault surfaces having gently plunging slickensides are exposed at two places on the gabbro contact on the 2,200-foot knob near the west side of the geologic map (Espenshade and Boudette, 1964). Faulting is also suggested by the zigzag trend of the contact northeast of Little Squaw Pond. The anomalous relation of the flow structure of the contacts may possibly have been caused by faulting, but it is not evident to us how this could have happened.

DIFFERENTIATION OF THE MOXIE PLUTON

The Moxie pluton has numerous characteristics (flow structure, compositional changes of rock and constituent minerals, and minor compositional layering) that resemble features of large layered mafic complexes like the Skaergaard (Wager and Deer, 1939), the Stillwater (Hess, 1960), and other stratiform mafic complexes (Thayer, 1960). However, the irregular distribution patterns of rock types (pl. 1) and the compositional clustering of the mafic minerals (fig. 5) suggest that the course of differentiation, at least in this part of the Moxie pluton, has been interrupted in some way. These irregularities can perhaps be explained as resulting from several intrusive pulses of differentiated magma from a large deep reservoir. Each pulse of magma could then have become differentiated more completely within the chamber. Taylor (1964) has described multiple intrusions within the Duluth Gabbro Complex of Minnesota where intrusive relations of younger rock varieties are well displayed. Such features have not been found in this part of the Moxie pluton.

The analytical data for MgO, FeO, and Na_2O+K_2O for the six analyzed samples taken in the Greenville quadrangle from the Moxie pluton (table 6) are plotted in figure 9. The points indicate a trend toward iron enrichment during differentiation that is similar to the trends occurring in the Skaergaard, Bushveld, Stillwater, and Duluth mafic intrusions (Hess, 1960, pl. 11). The data of figure 9, however, pertain only to the part of the Moxie pluton that lies in the Greenville quadrangle and probably do not represent the complete course of differentiation within the pluton.

Visher (1960) has concluded, on the basis of spectrographic analyses of 21 samples and his petrographic studies, that there was a general increase in the amount of iron in the magma as differentiation progressed. He also concluded that major factors in the differentiation processes were crystal fractionation and currents resulting from convection, intrusive action, or both. Our studies support these conclusions. Visher also thought that the patterns of flow structure in the Bingham and Greenville quadrangles are suggestive of funnel structures in these two areas.

Many problems remain concerning the intrusive and differentiation history and the structure of the Moxie pluton. Study now in progress of the northeastern part of the pluton may clarify some of these problems.

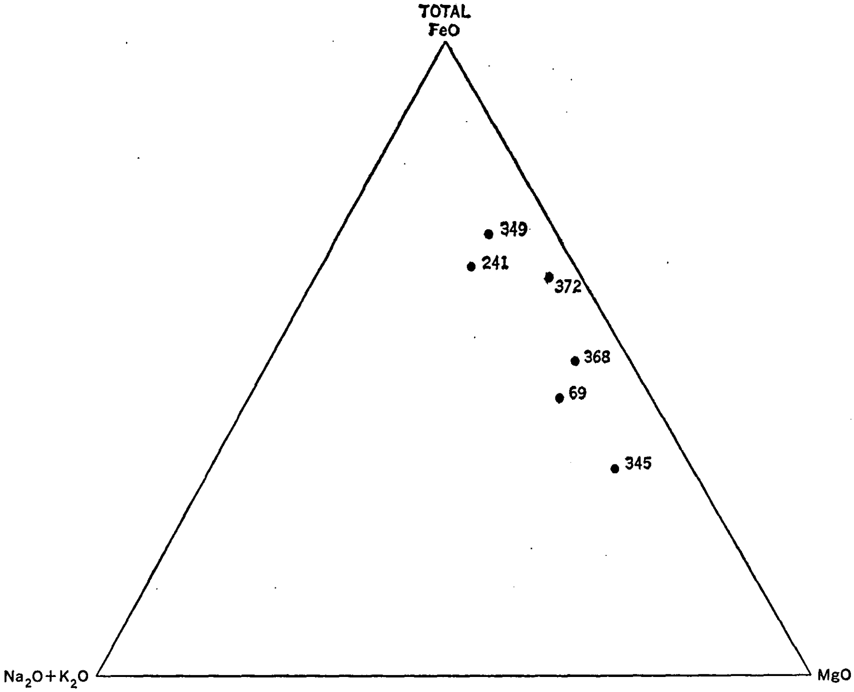

FIGURE 9.—MgO, FeO, and Na_2O+K_2O in samples from Moxie pluton, Greenville quadrangle.

QUARTZ MONZONITE AND GRANODIORITE

Two stocks that range from diorite to quartz monzonite in composition intrude slate, siltstone, and sandstone in the southern half of the quadrangle. The smaller stock, about 1½ by 4 miles, is called the Shirley-Blanchard stock because it occurs in the towns of Shirley and Blanchard. The other stock crops out on all sides of Bald Mountain Pond in the southwestern corner of the quadrangle and is called the Bald Mountain stock. It is an elliptically shaped body, about 7 miles long in a west-northwest direction and has a maximum width of about 4 miles (fig.1).

The Shirley-Blanchard stock comprises two distinct facies of rock. A mafic facies consisting of pyroxene- and amphibole-bearing granodiorite and diorite predominates in the western and southwestern part of the stock. A felsic facies consisting of granodiorite and quartz monzonite makes up the eastern and northern part of the stock (Espenshade and Boudette, 1964). Exposures are poor in much of the area, and it was not possible to determine the location or nature of the contact between the two varieties. Although the age relation of the two facies is not established, they likely were emplaced during separate intrusive pulses because they are distinctly different in composition.

The mafic variety is a medium- to dark-gray medium-grained rock of gabbroic appearance, but in a few places it is a fine-grained rock resembling diabase. Plagioclase, average composition about An_{50}, is the dominant mineral and forms euhedral to subhedral twinned and zoned crystals that reach a maximum length of about 1 cm and commonly are crudely oriented. Pyroxene and amphibole are next in abundance. Orthopyroxene is widespread and is accompanied locally by clinopyroxene. The pyroxene forms grains several millimeters in size clustered together in irregular aggregates. Pale-green to colorless amphibole (probably cummingtonite) commonly occurs with pyroxene and partly replaces it. Quartz and microcline occur together in about equal amounts, commonly in graphic intergrowths between plagioclase crystals. Biotite is always present and forms flakes as large as 2 mm. Opaque minerals and small amounts of apatite are the main accessories. Opaque minerals are considerably more abundant in the mafic facies than in the felsic facies of the stock (table 9). Locally, plagioclase is altered to fine cloudy mixtures of sericite and kaolinite(?) in the cores and to zoisite-epidote, chlorite, and calcite along veinlets. Biotite and hornblende are partly altered to chlorite, and some pyroxene is cut by thin veinlets of talc(?).

TABLE 9.—*Modes,* An *content of plagioclase, and bulk densities of samples from Bald Mountain and Shirley-Blanchard stocks, Greenville quadrangle*

Sample	Rock name	Modes (volume percent) [1]											
		Quartz	Plagioclase	Plagioclase alteration minerals [2]	Potassium feldspar	Pyroxene and amphibole	Biotite	Chlorite [3]	Muscovite	Nonopaque accessory minerals [4]	Opaque accessory minerals	An content of plagioclase [5]	Bulk density
						Bald Mountain stock							
439	Quartz monzonite	23.3	31.9	0	31.8	0	8.8	0.7	3.1	0.2	0.2	C-35, B-15	2.71
398	Granodiorite	29.8	34.1	0	17.3	0	13.2	.6	4.5	.4	0		2.62
422	do	29.9	42.5	0	10.4	0	11.8	0	4.9	.5	0	C-30, B-23	2.68
146	do	32.3	37.9	0	12.2	0	12.5	1.5	2.8	.8	0		2.66
160	do	33.2	35.9	0	18.7	0	.8	1.6	8.9	.4	.5	10	2.66
						Shirley-Blanchard stock							
274	Diorite	2.6	55.7	0	2.0	26.5	12.3	0	0	0	0.8		2.88
262	Pyroxene-amphibole granodiorite	7.9	54.8	1.7	7.6	24.0	3.1	0	0	0	1.0	50	2.80
278	do	8.8	60.6	0	7.6	15.0	5.0	0	0	.2	2.7		2.79
276	do	9.9	52.8	8.6	8.6	13.3	5.9	0	0	0	.9		2.83
280	do	11.7	57.8	0	12.5	12.1	4.9	0	0	.1	.9	52	2.78
261	do	13.9	45.6	3.4	10.0	14.4	10.9	1.6	0	0	1.0		2.77
266	do	15.7	49.4	0	8.3	8.0	18.4	0	0	0	.3	52	2.76
176	Granodiorite	24.0	42.3	0	9.9	0	23.3	0	0	.2	.2	L-52, S-32	2.68
386	do	26.8	41.8	0	8.4	0	22.1	.4	.4	.1	.1	L-47, S-27	2.69
277	do	32.0	19.3	19.0	12.7	0	12.0	4.4	.7	0	0		2.70
175	Quartz monzonite	32.3	32.3	0	27.0	0	6.5	.1	1.6	.1	.1	12	2.64
273	do	33.3	31.5	(6)	27.1	0	0	3.4	4.7	0	0		2.62
382	do	34.2	30.3	0	26.9	0	7.2	.4	1.0	0	0	15	2.62

[1] Modes made by point-counting method: 1,000–1,600 points counted per thin section.

[2] Mostly sericite, kaolinite(?), and zoisite-epidote.

[3] Mostly as alteration product of biotite.

[4] Apatite, zircon, and sphene.

[5] Anorthite contents are approximate; determinations made by Tsuboi method except for extinction-angle measurements of borders of zoned crystals. Where more than one value of anorthite content is listed for a single sample, the relationships are indicated by letters, as follows: zoned plagioclase crystals, C=core, B=border. Plagioclase crystals occur in two distinct sizes, L=large crystals (maximum size about 7 mm), S=small crystals (maximum size about 1 mm).

[6] Plagioclase alteration products are abundant and are included with plagioclase.

The mafic facies varies considerably in mineral composition, as shown by the modal analyses in table 9, Locations of the analyzed samples are given in figure 10. The quartz content of the rock generally varies directly with the potassium feldspare content and inversely with the amount of plagioclase and of pyroxene and amphibole. All the samples of mafic rock are grouped on an area near the plagioclase corner of the triangular composition diagram (fig. 11). Bulk densities of diorate and mafic granodiorite samples are given in tables 9 and 10.

The felsic facies of the Shirley-Blanchard stock is characteristically a light-gray granitic rock having a grain size of several millimeters and microcline phenocrysts 1–2 cm long. Plagioclase, in euhedral to subhedral crystals as much as 7 mm long, commonly shows albite and

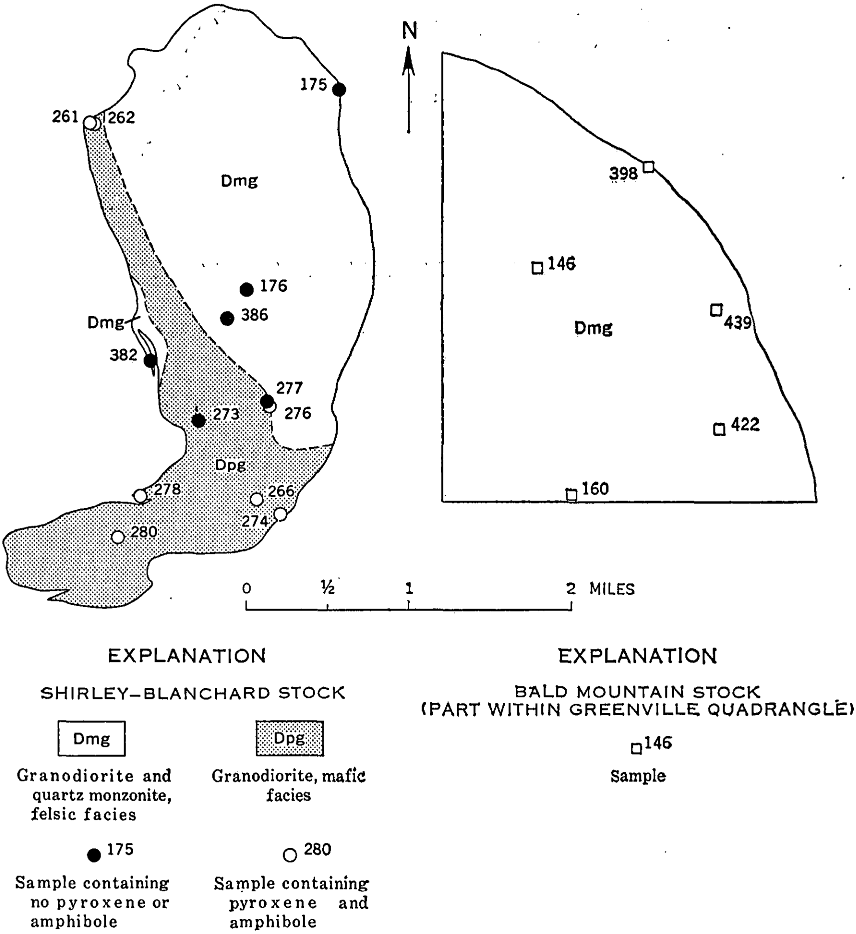

FIGURE 10.—Index maps of Shirley-Blanchard and Bald Mountain stocks showing locations of samples taken for modal analyses.

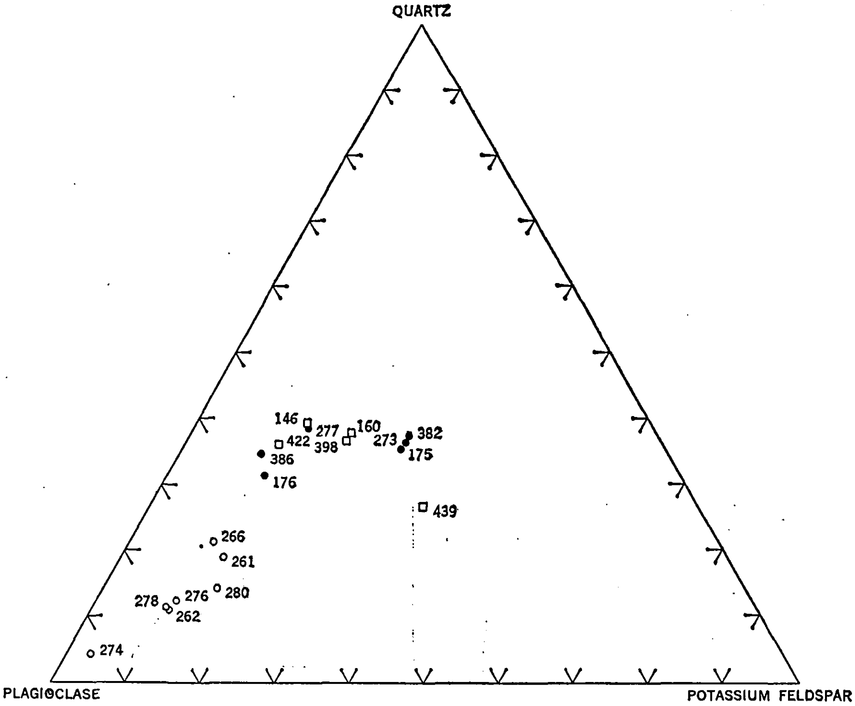

FIGURE 11.—Modal quartz, potassium feldspar, and plagioclase in samples of quartz monzonite, granodiorite, and diorite from Bald Mountain and Shirley-Blanchard stocks, Greenville quadrangle, Maine. ○, Shirley-Blanchard stock, mafic facies; ●, Shirley-Blanchard stock, felsic facies; ☐ Bald Mountain stock. Numbers are sample numbers.

TABLE 10.—*Density (range and average) of samples of diorite, granodiorite, and quartz monzonite, Greenville quadrangle*

Rock type	Samples	Density		
		Minimum	Maximum	Average
Diorite and pyroxene granodiorite	7	2.76	2.88	2.80
Granodiorite (free of pyroxene and amphibole)	7	2.62	2.70	2.67
Quartz monzonite	4	2.62	2.71	2.65

carlsbad twinning, and the crystals are zoned. The plagioclase crystals locally have a poor flow orientation. Microcline is commonly interstitial and contains poikilitic inclusions of quartz, plagioclase, and biotite, but it may also occur as subhedral phenocrysts that have carlsbad twinning. Microperthite forms scattered irregular streaks. Plagioclase seems to be partly replaced by the potassium feldspar in some rock. Quartz occurs as anhedral grains generally less than 1 mm in size that are clustered together. Quartz grain boundaries are lobate to sutured, and undulatory extinction is characteristic. Biotite is nearly always present in flakes having a maximum size of about 1.5 mm. Muscovite occurs as large flakes in some rock and also as small oriented flakes in plagioclase. Accessory minerals are opaques, zircon, apatite, and sphene. Some plagioclase is considerably altered to sericite, kaolinite(?), zoisite, and a little calcite. Biotite is partly to completely altered to chlorite in much of the rock.

Two samples (176 and 386) from the center of the stock near the boundary between the two facies have characteristics of both varieties. They contain about the same amount of potassium feldspar as the mafic granodiorite, but have an abundance of biotite rather than pyroxene and amphibole. These rocks contain plagioclase crystals in two distinctly different sizes and compositions; the larger crystals are An_{47-52} and the smaller An_{27-32}. The larger crystals have the same composition as the plagioclase in the mafic granodiorite and were probably derived from the same magma.

Modal composition of samples of the felsic facies ranges from rocks in which the plagioclase content exceeds the combined amount of quartz and potassium feldspar to rocks having about half as much plagioclase as the sum of quartz and potassium feldspar (table 9). Potassium feldspar and biotite vary inversely in amount. These samples fall in a group on the triangular composition diagram (fig. 11) with samples of granodiorite and quartz monzonite from the Bald Mountain stock. Bulk densities are somewhat less than those of the mafic granodiorite facies (tables 9 and 10).

The rocks in the part of the Bald Mountain stock within the Greenville quadrangle are similar in appearance and composition to the felsic facies of the Shirley-Blanchard stock. Samples from the Bald Mountain stock show a comparable range of mineral composition and bulk density (table 9) and fall in the same area on the triangular composition diagram (fig. 11) as samples of the felsic facies of the Shirley-Blanchard stock. Muscovite and nonopaque accessories are somewhat more abundant in the rocks of the Bald Mountain stock than in those of the Shirley-Blanchard stock. Fine-grained dark-gray ellipsoidal inclusions are fairly common in the the Bald Mountain stock. The inclusions are commonly less than 6 inches long and have a maximum length of about 3 feet. The rock is generally massive and has no evident structure, but locally there is a crude parallel orientation of inclusions. Microcline phenocrysts (2–3 cm long) may have a uniform strike within the outcrop or have a swirling pattern. Strong joints or sheeting occurs in places. Thin dikes (less than 1 ft) of aplite and pegmatite are scarce.

DIKES AND SILLS

Dikes and sills are rare in the region and are known only in the southern part of the quadrangle; none are associated with the Moxie pluton. Diorite to quartz diorite dikes and sills are most common, and several were found within a few miles of the Shirley-Blanchard stock (Espenshade and Boudette, 1964). Most of them are less than 5 feet thick; the thickest one found, about 25 feet, is exposed in Gully Brook just upstream from the old Bangor and Aroostook railroad grade. A well-exposed vertical dike, about 4 feet thick, cuts slate and sandstone on both sides of State Highway 15 at the road bend south of the east end of Spectacle Ponds.

The diorite and quartz diorite are mostly dark gray and have a fine-grained diabasic texture. Plagioclase, commonly about An_{10}, is partly altered to zoisite and epidote. Considerable pale-green amphibole is present in some rock. Pale-brown biotite, partly altered to chlorite occurs locally with or without amphibole. Quartz is present in amounts ranging from a few percent to about 10 percent. Carbonate and pale-green chlorite commonly form irregular aggregates, and are present in amounts ranging from a few percent to 15 percent. Sericite, sphene and fine opaque grains are also present.

Aplite dikes, a few feet thick, are exposed at two places in the old railroad cuts within 1,500 feet northwest of Bunker Stream and 1,000 feet east of the Shirley-Blanchard stock. (Espenshade and Boudette, 1964). Several lamprophyre dikes, 2–6 feet thick, crop out in a small tributary of Blackstone Creek near the southern edge of the quadrangle. Perfectly fresh dark-brown biotite occurs in the lamprophyre, but other constituents are much altered. Plagioclase is altered to fine cloudy kaolin(?), olivine to talc(?) and carbonate, and pyroxene to zoisite, epidote, and carbonate; opaque grains are abundant.

The dikes and sills are probably genetically related to the large intrusions nearby. Cleavage occurs in some of the dikes, but not in the stocks. This occurrence appears to be the result of selective formation of cleavage in the narrow dikes and sills but not in the stock.

METAMORPHISM

REGIONAL METAMORPHISM

The sedimentary rocks underlying a strip 5 miles or more wide extending northeast across the central part of the quadrangle are in the chlorite zone of metamorphism (Espenshade and Boudette, 1964). Rocks of chlorite grade are widely distributed through northern and northeastern Maine and are probably the result of extensive low-grade regional metamorphism. The chlorite grade of regional metamorphism was probably attained in the Greenville area prior to the emplacement of the Moxie pluton on the north side of the chlorite zone and the two granitic stocks to the south.

Petrography of the slate, siltstone, and standstone of the pelitic rock unit and limy sandstone unit in the chlorite zone has been described (p. F5, F10). Steeply dipping slaty or axial plane cleavage is present in all the argillaceous rocks, and parting parallel to bedding is rare in these rocks, although it does occur in the sandstone.

CONTACT METAMORPHISM

The sedimentary rocks have been thermally metamorphosed for distances of several miles from the mafic pluton and felsic stocks. Biotite formed farthest from the instrusions. Andalusite formed in argillaceous rocks and tremolite-actinolite in limy rocks generally within several thousand feet of the intrusive contacts. Sillimanite and cordierite occur with andalusite in pelitic hornfels and diopside in calc-silicate hornfels nearest to the intrusions. Isograds representing the first appearance of biotite, andalusite, and sillimanite-cordierite are shown on the geologic map (Espenshade and Boudette, 1964).

The isograds adjacent to the southern contact of the Moxie pluton are about parallel to the contact and define rather broad zones, possibly due to a southerly dip of this contact. There is less uniformity in the trace of the isograds around the felsic stocks in the southern part of the quadrangle. The biotite zone extends east of the Shirley-Blanchard stock for a considerable distance. This extension suggests that unexposed felsic intrusive rocks underlie this area. The andalusite-amphibole isograd just south of Blanchard may be related to a granitic intrusion exposed on Russell Mountain, a few miles to the south in the Kingsbury quadrangle (R. B. Coyle, oral commun., August 1961).

The biotite isograds south of the Moxie pluton and north of the Bald Mountain stock probably join 3–5 miles to the southwest in The Forks quadrangle because the Moxie pluton extends southwest across the quadrangle and is less than a mile from the western corner of the Bald Mountain stock at one point (fig. 1). The biotite isograds may also join to the east in the Sebec Lake quadrangle because of the Onawa dioritic pluton and the felsic stock of Sebec Lake in that area. If the biotite isograds join both to the west and to the east, the chlorite zone would be 15–20 miles long and would define a thermal sink lying between these various mafic and felsic intrustions.

The andalusite schist and the hornfels are more resistant to weathering than the parent slate, siltstone and sandstone, or the igneous rocks, and at many places they have formed hills or ridges adjacent to the intrusions. These hornfels ridges and highlands are best formed on Little Squaw Mountain on the south side of the Moxie pluton and on Big Squaw Mountain on the north side.

The contact metamorphic aureole of the Moxie pluton between Moxie Mountain and Moosehead Lake was studied by Bowin (1957) in conjunction with Visher's (1960) investigation of the Moxie pluton. Contact metamorphism of the same character as that in the Greenville quadrangle has been thoroughly studied by Philbrick (1936) and by Moore (1960) in the aureole of the Onawa pluton (ranging from gabbro to granite) in the Sebec Lake quadrangle. In this aureole the same pelitic rocks are metamorphosed to andalusite schist within a few thousand feet of the contact and to hornfels and injection hornfels containing andalusite, sillimanite, cordierite, potassium feldspar, and tourmaline nearer to the contact. Philbrick apparently did not extend his studies far enough from the contact to pick up the biotite isograd in the slaty rocks.

BIOTITE ZONE

The dark-gray slate, siltstone, and fine sandstone of the pelitic unit within the biotite zone are generally not distinguishable megascopically from the same rocks in the chlorite zone. On the other hand, abundant fine biotite imparts a distinctive dark-red-brown to brown-gray color to the siltstone and fine sandstone of the limy sandstone unit in the biotite zone. Primary sedimentary features such as bedding and graded bedding are as well preserved in the sandstone within the biotite zone as in the chlorite zone, but are obscured by cleavage in the thin slaty beds.

Sandstone that has little argillaceous matrix commonly has mosaic textures of recrystallized interlocking grains of quartz and feldspar. In rocks that have more abundant matrix, quartz and feldspar typically form flattened to lenticular grains parallel to the schistose matrix of chlorite and white mica. The maximum dimension of such flattened grains is commonly 1¼–2 times the minimum dimension.

Biotite is generally more abundant in limy sandstone (as much as 20 percent of the rock) than in noncalcareous sandstone (generally less than 10 percent). Biotite flakes are commonly less than 0.05 mm in size, but they may reach a size of about 0.2 mm.

Biotite occurs at a greater distance from the Shirley-Blanchard stock in the limy sandstone unit than it does in the pelitic unit. Because biotite seems to have started to form at a lower temperature in the limy sandstone unit, there are probably compositional differences between this biotite and that formed in the pelite. This situation posed a problem in drawing the biotite isograd adjacent to the Shirley-Blanchard stock. Should it represent an isotherm or should it be determined solely by the presence of biotite (of differing composition)? The decision was made to draw the isograd on the geologic map (Espenshade and Boudette, 1964) to show the presence of biotite. Thus, the biotite isograd is shown as zigzagging back and forth east of the Shirley-Blanchard stock, extending about 2 miles farther from the stock in the limy sandstone unit than in the pelitic unit. This extension results in a peculiar-looking pattern.

Chemical analyses of a sample of sandstone(252) and one of slate (253) from the limy sandstone unit within the biotite zone are given in table 1. Bulk densities of various rock samples from the biotite zone are included in tables 2 and 3.

ANDALUSITE-AMPHIBOLE ZONE

Andalusite occurs in pelitic rocks in a zone ranging from less than a thousand to several thousand feet wide around the intrusions. Actinolite and tremolite occur in the calcareous rocks of the limy sandstone unit in about the same zone, and the isograd on the geologic map bounding the outer part of this zone is called the andalusite-amphibole isograd (Espenshade and Boudette, 1964). This isograd is generally farther from the contact of the mafic pluton than from the felsic intrusions, presumably because of the greater heat supplied by the mafic pluton and probably also because of the southerly dip of the south contact of the pluton. The andalusite-amphibole zone around the Shirley-Blanchard stock ranges from about 1,000 to 4,000 feet in width, probably because of subsurface irregularities in the shape of the body. On the other hand, this zone adjacent to the Bald Mountain stock has a rather uniform width of about 1,500 feet which suggests that the edge of this part of the stock dips uniformly.

The andalusite schist and hornfels range in color and texture across the andalusite-amphibole zone from the fine grained light-gray schist containing andalusite prisms as much as 2 cm long in the outer part of the zone to granular or gneissic dark-brownish-gray hornfels in the inner part of the zone containing andalusite crystals only a few millimeters long. In the outer part of the zone, andalusite occurs as well-formed chiastolite crystals that contain fine dusty inclusions in cross-shaped concentrations which have a thin mantle of graphitic material on the crystal boundaries. The chiastolite is nonpleochroic. The crystals characteristically are randomly oriented within the cleavage plane. Minerals in the matrix of the schist—quartz, feldspar, biotite, muscovite, and opaques—are very similar to the same minerals in slate and have about the same grain size. The cleavage of the schist is not so closely spaced as it is in the rocks of lower grade metamorphisms. The andalusite schist is a little lighter gray than slate and has a slight sheen. In the inner part of the andalusite zone all the essential minerals (quartz, feldspar, biotite, and muscovite) except andalusite are coarser grained than in the outer part. Here the andalusite forms stubby pleochroic crystals a few millimeters long that have irregular shapes and a spongy appearance because of abundant tiny inclusions of quartz, feldspar, and biotite. The andalusite content throughout the zone ranges from a few percent to about 10 percent. Original compositional differences of interbedded shale and sandstone are preserved as alternating thin layers of andalusite hornfels and hornfels free of andalusite. Such rock has the aspect of "reversed graded bedding" because the andalusite porphyroblasts make the argillaceous layers appear coarser than the sandy layers.

Limy sandstone is metamorphosed to dense hornfels of variable composition within the andalusite-amphibole zone. The rock is dark reddish brown where biotite is abundant but is green or gray green where calc-silicates are abundant and biotite is absent. Some biotite-free hornfels is streaked or mottled and is very dense and tough. Quartz is generally the major constituent. Actinolite or tremolite form fine needlelike crystals generally less than 0.1 mm long that are intergrown with quartz and feldspar grains of about the same size. The amphiboles form a few percent to more than 50 percent of some rocks. Biotite commonly constitutes more than 10 percent of the rock. Zoisite or epidote are commonly present in fine grains in amounts less than 10 percent. Calcite is widespread and is a major constituent in some rock. Muscovite is uncommon. Sphene is locally present in amounts of several percent. Chlorite is occasionally present and partly replaces biotite. Garnet is a very rare constituent.

Bulk densities of andalusite schist and hornfels are given in table 3 and calc-silicate hornfels in table 2. The average densities of both types of hornfels are somewhat greater than the average densities of the parent rocks within the chlorite and biotite zones, because of the formation of denser minerals such as andalusite and amphibole.

SILLIMANITE-CORDIERITE ZONE

Sillimanite and cordierite occur at many places in a zone as much as several thousand feet wide adjacent to the Moxie pluton, but they seem to be absent at some places near the contact of the pluton (Espenshade and Boudette, 1964). They are much less common near the Shirley-Blanchard stock and were not found adjacent to the Bald Mountain stock.

Pelitic hornfels in the sillimanite-cordierite zone is gneissic to granoblastic and locally shows vestiges of original bedding. Cleavage is generally poorly formed. The color is dark gray to dark brown gray, depending upon the biotite content. Grain size is commonly about one-half mm in diameter, but may be as much as 2 mm in hornfels near or adjacent to the intrusions. Quartz and feldspar have typically recrystallized to mosaic texture. Perthitic potassium feldspar, some of which shows microcline grid twinning, is widespread. Zoned plagioclase ($An_{20\text{-}30}$) that displays albite twinning is much less common. Biotite is commonly abundant in the hornfels and in most specimens forms flakes coarse enough to be visible to the naked eye. Muscovite generally accompanies biotite but is less abundant. The micas typically are in crisscross or decussate texture.

Andalusite, sillimanite, and cordierite occur in varying amounts in the hornfels, and any or all of these minerals may be present or absent depending on the bulk composition of the rock. Andalusite generally forms very irregular crystals no more than 2 mm long and commonly contains abundant inclusions of quartz and biotite, although some andalusite is quite free of inclusions. In hand specimen, the andalusite porphyroblasts are pink and in thin sections are pleochroic from colorless to pink. Sillimanite typically occurs as fine needles distributed through quartz and biotite or as fibrolite veinlets between grains of quartz and feldspar, although in some specimens it forms large prismatic crystals. Sillimanite rarely replaces andalusite. Cordierite forms small rounded grains, commonly 0.1–0.4 mm in size, that contain inclusions of quartz, biotite, and opaque minerals. Where most abundant, it composes about 25 percent of the rock and may give the rock a dark blue color. Spinel occurs with cordierite and orthopyroxene in some hornfels inclusions in the Moxie pluton. Tourmaline is a common accessory mineral, but it probably was introduced into the hornfels metasomatically because it is rare in rocks of lower metamorphic grade. Small opaque grains are abundant in some hornfels. Moore (1960) X-rayed heavy-mineral concentrations from hornfels in the aureole of the Onawa pluton and determined that the heavy opaque mineral was mainly ilmenite, accompanied by a little pyrrhotite in several samples. Tiny zircons surrounded by radioactive halos are occasionally present in biotite. Garnet is very rare.

Hornfels within the sillimanite-cordierite zone commonly has wavy or highly contorted layering which suggests that the rock was once in a plastic state. The rock contains a network of thin veinlets, a few millimeters thick, of quartz and microcline. Philbrick (1936) has called such rock "injection hornfels." Small veins and lenses of pegmatite, a few inches thick and a maximum of several feet long, occur in the hornfels; and are composed of quartz, feldspar, biotite, and commonly andalusite and tourmaline.

An attempt was made to estimate the andalusite content of hornfels which has excellent relict graded bedding and which is exposed just east of State Highway 15, a few hundred feet south of the north edge of the quadrangle. A tape was stretched across the outcrop, and the minerals adjacent to each $\frac{1}{16}$-inch scale division were recorded as andalusite or as matrix. Two persons working independently across the same outcrop made the following estimates: (a) a content of 14 percent andalusite across a thickness of 47 feet and (b) a content of 8 percent andalusite over 34 feet. The andalusite content of the hornfels at this locality probably is between these two values.

Calc-silicate hornfels in the sillimanite-cordierite zone is very fine grained and similar to that in the andalusite-amphibole zone except that diopside is abundant instead of actinolite or tremolite. Quartz and feldspar are also abundant. Zoisite and calcite are generally present, and sphene is a common accessory mineral. Garnet is very rare.

Bulk densities of calc-silicate and pelitic hornfels from the sillimanite-corderite zone are listed in tables 2 and 3. The average density of samples of calc-silicate hornfels from this zone is greater than that of samples from the andalusite-amphibole zone, and even larger than for samples from the biotite and chlorite zones. Progressive increase in density with increasing grade of metamorphism must be mainly due to expulsion of carbon dioxide and change from actinolite to diopside in the zone of highest grade metamorphism. On the other hand, the average density of samples of pelitic hornfels from the sillimanite-cordierite zone is a little less than that of samples from the andalusite-amphibole zone. This difference may have no real significance because of the few samples, but it may be due to the introduction of feldspar and quartz into the high-grade hornfels.

CHANGE IN COMPOSITION OF CARBONATE MINERAL

The approximate ordinary-ray index (N_0) of the carbonate mineral was measured in several samples of limy sandstone taken at different distances from the Shirley-Blanchard stock to see if carbonate composition changes with increasing metamorphism (table 11). As the stock is approached, the index decreases steadily from a value suggesting ferroan dolomite composition in the chlorite zone to a value near calcite in a sample about 250 feet from the stock. Thus, it seems that iron and magnesium are expelled from the carbonate mineral with rising temperature. These ions possibly enter into biotite.

TABLE 11. *Approximate value of the ordinary-ray index (N_0) of carbonate from samples of limy sandstone taken at various distances from the contact of the Shirley-Blanchard stock*

Distance of sample from contact, in miles	Metamorphic zone	N_0 of carbonate
4.1	Chlorite	1.705
3.7	Biotite	1.683
2.7	do	1.670
.6	Andalusite-amphibole	1.670
.5	do	1.667
.05	do	1.661

RETROGRADE METAMORPHISM

The pelitic rocks in the contact aureoles were locally affected by retrograde metamorphism in which andalusite and cordierite were altered to sericite and chlorite. These localities are shown on the geologic map (Espenshade and Boudette, 1964). Such alteration occurs only sporadically in the aureole of the Moxie pluton, except west of Lower Wilson Pond where it may be rather widespread. Andalusite in the aureole of the Bald Mountain stock is very commonly altered; this alteration is easily recognized in the field because the andalusite crystals can be scratched by a knife point.

Moore (1960) found similar retrograde metmorphism of cordierite and postassium feldspar to sericite and chlorite in hornfels within 100 feet of the contact of the Onawa pluton. This retrograde metamorphism is doubtlessly due to alteration by solutions given off by the intrusions at late stages in cooling.

In thin section, alteration of andalusite to fine sericite is seen to range from partial to complete. Chlorite occurs locally in the outer part of the replaced andalusite porphyroblast and sericite in the core. Abundant small round areas of fine sericite are probably completely altered cordierite or potassium feldspar. Biotite is locally partly replaced by chlorite and quartz by sericite. Chlorite and sericite are abundant in the matrix of some hornfels. The only retrograde metamorphism observed in the calc-silicate hornfels was scattered chloritization of biotite.

QUATERNARY FEATURES

The extensive continental glaciers that covered Canada and the northern United States during Pleistocene time have formed abundant erosional and depositional features in the region. These features have been somewhat modified by stream erosion and deposition in postglacial (Recent) time. The nature of the preglacial land surface can only be conjectured, but it seems likely that present-day major topographic forms—ridges, hills, and valleys (but not lakes)—existed then and were not greatly changed during Quaternary (Pleistocene and Recent) time. No evidence for more than one stage of glaciation has been found in the region.

Ice erosion has accentuated former topographic irregularities in some places by steepening the slopes and has subdued irregularities in many places by rounding and smoothing the rock surfaces. Roches moutonnées and smooth pavements are especially common in slate terrane. Glacial scratches and grooves are found everywhere in slate, siltstone, and fine-grained sandstone and hornfels. Postglacial weathering has obliterated these striae in the coarser sandstone and hornfels and in the felsic and mafic rocks. The striae uniformly indicate southeasterly ice movement; about 75 of 100 measurements of striae direction were between S. 25° E. and S. 40° E.

Ground moraine or deposits of glacial till composed of compact clay, sand, pebbles, cobbles, and boulders cover most of the land area. Exposures of ground moraine are not common and are only found where the moraine has been cut by streams or artifical openings. The glacial till in these exposures is generally a tough tan to tan-green clay that contains abundant sand, gravel, and pebbles as much as several inches in diameter and scattered boulders; the clay has subhorizontal parting. The coarser material very commonly is of the same lithology as the underlying or nearby bedrock. The ground moraine is probably thickest in those areas of scarce or nonexistent outcrops, which are distinguished from areas of abundant outcrops on the geologic map (Espenshade and Boudette, 1964). Thickness of ground moraine in these areas of scarce outcrops is not known, but at least locally it exceeds 25 feet, for ground moraine of this thickness is exposed at several places in roadcuts and stream channels.

Water-laid materials (stratified sand and gravel) occur at several places, but the extent of these deposits is not known. Such material is exposed in roadcuts on State Highway 15 just north of Shadow Pond and north of Middle Squaw Brook and in a gravel pit on the north side of Lake Hebron, about a mile from the west end of the lake. Ice-channel fillings (eskers or crevasse fillings) of stratified sand and gravel that are now sinuous ridges about 30 feet high and 15 feet wide at the top are present along two valleys. The longer ridge extends with interruptions from the West Cove of Moosehead Lake south to Shirley Pond (about 7 miles), and the other extends from near Oakes Bog on the West Branch of the Piscataquis River about 2½ miles south to the westward bend of Marble Brook. These deposits are not distinguished separately on the geologic map (Espenshade and Boudette, 1964), but parts of them are evident on the topographic map as low, narrow ridges.

The lakes and ponds of the region were formed in postglacial time. Some were formed by damming of stream channels by glacial deposits. Others were probably formed by beaver dams. Many swamps in the region were once ponds that have been filled with organic material, clay, silt, and sand.

Postglacial erosion has steepened the stream gradients and reworked the glacial deposits in the lower reaches of the large stream valleys. Some material has been redeposited as alluvium in the flood plains of the large streams, such as along the Piscataquis River above and below Blanchard. Stream gradients are fairly steep, and glacial material is largely removed from the stream channels of both branches of the Piscataquis River below an altitude of about 1,030 feet and from Big Wilson Stream and Little Wilson Stream below about 1,100 feet; above these altitudes, stream gradients are gentle and swampy stretches occur along the streams. Small streams that have steep gradients near Big Squaw Mountain, Little Squaw Mountain, and elsewhere generally contain abundant boulders because the finer material has been winnowed out and carried off.

STRUCTURE

The sedimentary rocks of the region are tightly folded about northeast-trending axes that are locally bent toward the north or east near the intrusions (Espenshade and Boudette, 1964). Closely spaced cleavage is always present in the argillaceous beds and, except on the noses of folds, it strikes about parallel to bedding and dips 80° or more, presumably about parallel to the dip of the axial planes of the folds. Bedding is well displayed where sandstone beds are abundant, but is largely obliterated where slate predominates.

Stratigraphic relations within the sedimentary rocks and interpretations of the structures of these rocks are based entirely upon top directions as indicated by sedimentary and structural features. Top directions were determined principally from graded bedding, and to a minor degree from the relation of cleavage to bedding.

Three major anticlines, locally complicated by minor folding (Espenshade and Boudette, 1964), expose the older limy sandstone unit in the southern part of the quadrangle. Numerous folds have been recognized within the pelitic unit, some of which seem to extend for more than 10 miles. Other major folds may be present in the pelitic unit but were not recognized in the large areas where bedding is too scarce for widespread top determinations, such as in the northern part of the quadrangle. Axes of the larger folds probably plunge rather gently, because some of these folds persist for 5–10 miles. Minor fold axes that have a plunge of 30°–80° occur locally.

Slaty cleavage is formed most uniformly in the argillaceous and silty beds that are interbedded with sandstone. Formation of good slaty cleavage evidently requires appreciable sandstone interlayered with pelitic beds in order to impart the necessary competence. Where little or no sandstone is present, a persistent major cleavage is commonly sliced at low angles by one or more minor cleavages. In some places the intersecting cleavages form steeply plunging lineations, and the slate breaks into large, splintery fragments. Cleavage is poorly formed in thick sandstone beds, except near the nose of folds where it cuts across the strike of the bedding; thin seams of interlayered slate are commonly sheared into the cleavage in such places. Sandstone beds are broken by boudinage structure in many places. Boudins of sandstone more than a few inches thick may be separated by quartz veins. Very thin sandstone may be sliced into numerous small lenticular fragments that are strung out like beads through the slate.

Cleavage in andalusite schist in the outer part of the contact metamorphic aureoles is distorted somewhat by the andalusite porphyroblasts. Cleavage or schistosity is poorly formed in hornfels of higher metamorphic grade, and those rocks containing little biotite have very poor cleavage.

Joints that commonly strike at about right angles to bedding and cleavage and that dip steeply are very abundant in the sedimentary rocks and hornfels. Northwest trending joints are common in the mafic rocks of the Moxie pluton. Conspicuous joints also occur in the felsic rocks.

Steep reverse faults are inferred to be present on the northern flanks of the two southernmost anticlines. No faults are exposed, but it is necessary to infer their existence to construct a structure section (Espenshade and Boudette, 1964) that is consistent with observed top directions and minor folds. Quite possibly there are numerous faults within the sedimentary rocks that cannot be detected because of lack of marker beds and insufficient exposures. The amplitudes of some folds in slaty beds have probably been increased by shearing movements along cleavage planes.

The felsic stocks are partly discordant to the structural features of the sedimentary rocks. Cleavage and bedding adjacent to the Bald Mountain stock strike at high angles to the contact, but away from the stocks at a distance of half a mile the strike is more nearly conformable to the stock boundaries. Gneissic structure is absent in the felsic stocks, but irregular flow structures of feldspar phenocrysts or inclusions are present locally. Most of the Shirley-Blanchard stock intruded and markedly distended the core of an anticline. The southern part of the stock cut into another anticline and is elongated along its axis.

The dips of the contacts of both felsic stocks are indicated by the relation of isograd trends to these contacts. The Shirley-Blanchard stock appears to dip outward at variable angles and may be considerably wider at depth along the axis of the northern anticline; the contact of the part of the Bald Mountain stock within the quadrangle apparently dips rather uniformly. The presence of the andalusite-amphibole isograd south of Blanchard suggests that granite lies less than a mile beneath the surface here, as shown in section *B–B′* of the geologic map (Espenshade and Boudette, 1964).

The complexities of the external and internal structures of the Moxie pluton were discussed on pages F33–F35. The pluton must have had an original volume of some hundreds of cubic miles of mafic magma and must occupy a major structural break. The speculation is offered here that the pluton is the remnant of an enormous magma reservoir that fed a volcano or chain of volcanoes in Early Devonian time.

The mafic pluton and granitic stocks show very little sign of deformation. This fact indicates that the sedimentary rocks were probably folded and deformed before their intrusion. Some shear zones and associated cataclastic structure are present in the Moxie pluton, but these features are rare and suggest that deformation of the pluton has been negligible. Solidification of magma must have taken place subsequent to all significant deformation. Faults are exposed on the southeast contact of the pluton at two places south of Big Indian Pond (Espenshade and Boudette, 1964), but have not been recognized elsewhere in the pluton in the Greenville quadrangle. The Moxie pluton appears to have exerted considerable outward force during its intrusion. This force caused tight folds in the hornfels. The felsic stocks seem to be pipelike bodies that have been punched up into the folded sedimentary rocks, and they have distorted these folds somewhat in the process. Some dikes or sills are cleaved and, therefore must have been intruded before deformation ceased.

GEOPHYSICAL INVESTIGATIONS

Gravity and aeromagnetic surveys were made in the Greenville quadrangle and vicinity as part of the Geological Survey's program of geophysical investigations in central and northern Maine (Kane and Peterson, 1961; Bromery and others, 1963; Boucot and others, 1964). The gravity survey by Kane and Peterson (1961) showed that the part of the Moxie pluton within the Greenville quadrangle is near the southwestern end of a conspicuous linear positive gravity anomaly that extends more than 25 miles northeast of this quadrangle. Much of this positive anomaly must be related to the eastern part of the Moxie pluton, which widens northeast of the Greenville quadrangle (fig. 1).

The strongest aeromagnetic anomalies of the Greenville quadrangle (Bromery and others, 1963) are also closely related to the Moxie pluton, and these anomalies continue northeast through the Moosehead Lake quadrangle (Henderson and others, 1963) and southwest through The Forks quadrangle (Bromery and Natof, 1964). The steep magnetic gradient at the south edge of the pluton at the northeast site of the gravity profile (fig. 8) also indicates that the contact dips steeply south (R. W. Bromery, oral commun., January 1965). However, the magnetic gradient becomes more gentle to the southwest along the south slope of Little Squaw Mountain, and a strong positive anomaly is present in an area underlain by pelitic hornfels about half a mile southeast of the pluton near the Dyer road. Bromery (oral commun., January 1965) suggests that the contact dips more gently southeast here, and that there may be a small buried cupola of gabbro beneath the Dyer road anomaly. It is possible, however, that this anomaly is related to magnetic beds in the pelitic hornfels. E. V. Post (written commun., October 1964) points out that a linear magnetic anomaly continues through The Forks quadrangle (Bromery and Natof, 1964) and crosses from the southeast side of the Moxie pluton to the northwest side of Pleasant Pond, where he found pyrrhotite-bearing slate along Holly Brook.

Some small magnetic irregularities occur with the gabbro underlying Lower Wilson Pond, and become stronger a mile or so east of the quadrangle (Bromery and others, 1963).

Very little magnetic relief is found in the slate, siltstone, and sandstone south of the Moxie pluton, except for a few small anomalies in the southern part of the quadrangle. One anomaly occurs above mafic granodiorite at the south end of the Shirley-Blanchard stock. Small anomalies just east of Hatch Falls, on the north shore of Lake Hebron, and at the west end of McLellan Pond may be related to buried intrusions, because dioritic dikes are exposed near the Hatch Falls and McLellan Pond anomalies (Espenshade and Boudette, 1964).

Three magnetic anomalies in the Greenville quadrangle have been investigated in detail by the Maine Geological Survey (Stickney and others, 1965). These anomalies are on Scammon Ridge, Little Squaw Mountain, and Big Squaw Pond. The bedrock is andalusite schist and hornfels at the first locality and mafic rock at the last two localities. Self-potential anomalies were also found at each locality, but their causes are not evident.

RADIOMETRIC AGE DETERMINATIONS

Radiometric age determinations of samples from the Greenville and Sebec Lake quadrangles have been made by Faul and others (1963).

Slightly older ages were obtained from mafic intrusions than from granitic bodies. Ages of both are concluded to be Early Devonian.

A potassium-argon (K-Ar) date of 393 m.y. (million years) was obtained from biotite in norite (Faul's sample Me31) from an outcrop on State Highway 15, several hundred feet north of the southern border of the Moxie pluton in the Greenville quadrangle (fig. 1). Biotite from another sample of mafic rock, diorite from the southern edge of the Onawa pluton (Me35) about 15 miles southeast in the Sebec Lake quadrangle, gave a K-Ar age of 400 m.y. A small pegmatite dike about 1 foot thick (Me32) that cuts gabbro in an exposure on State Highway 15 at the townline between T. 3, R. 5, and T. 2, R. 6, Greenville quadrangle, gave biotite ages of 386 m.y. (K-Ar) and 360 m.y. [rubidium-strontium (Rb-Sr)].

Ages obtained from biotite in a quartz monzonite sample (Me33) from a small quarry on Bunker Stream, just inside the eastern edge of the Shirley-Blanchard stock, are 382 m.y. (K-Ar) and 361 m.y. (Rb-Sr). A sample of similar quartz monzonite (Me34) collected about 13 miles southeast from the Shirley-Blanchard stock at the west end of Sebec Lake, Sebec Lake quadrangle, gave ages of 383 m.y. (K-Ar) and 368 m.y. (Rb-Sr). A sample of the Katahdin granite from the Harrington Lake quadrangle, northeast of the area shown in figure 1, gave an age of 356 m.y. (K-Ar), whereas a diorite stock cutting the Katahdin granite gave an age of 361 m.y. (K-Ar).

A K-Ar age of 360 m.y. was obtained from a whole-rock sample of slate (Me36) taken from the Farm quarry, just east of Monson in the Sebec Lake quadrangle. As this slate is older than any of the intrusive rocks, its younger radioactive age is anomalous.

ECONOMIC GEOLOGY

SLATE

Slate quarrying began in central Maine in the 1840's at Brownville, about 23 miles east of Monson. Between 1871 and 1879, three slate quarries were opened near Monson, and in 1880 a slate quarry was opened 3 miles north of Blanchard. Slate quarrying has continued in the region to the present. The only company that has produced slate since 1944 is the Portland-Monson Slate Co., which operates an underground quarry about 1½ miles southeast of Monson in the Sebec Lake quadrangle. The slate is milled into various sizes and shapes, mainly for electrical switchboard use. Roofing slate was the sole product until the early 1890's when production of millstock was started. Millstock rapidly became the principal product, and roofing-slate production declined; no roofing slate has been produced in recent years. Total value of recorded production of slate from Maine between 1889 and 1942 is a little more than $16 million; production values have not been published since 1942. The most productive decade was 1920–29, when Maine slate production had a total value of $5,768,000. Practically all of the slate produced in Maine has come from quarries between Blanchard and Brownville and probably at least two-thirds of the recorded production, or more than $10 million worth, has come from quarries in the vicinity of Monson and Blanchard.

Fourteen abandoned slate quarries were found in the Greenville quadrangle, all between Monson and the Piscataquis River (Espenshade and Boudette, 1964). Many of the quarries are several hundred feet long along strike, about a hundred feet wide, and a few hundred feet deep; most of them are now filled with water. The quarries are alined in three different groups. The northern group of quarries about 3 miles north of Blanchard and the central group at Parrot and Monson are at virtually the same stratigraphic position in alternating beds of slate and sandstone in the lower part of the pelitic unit. The southern group of quarries is in interbedded slate and sandstone that may be several thousand feet above the base of the pelitic unit.

Detailed descriptions of the slate at some of the quarries and the physical properties of the slate have been given by Dale (1914). In the large quarries, alternating beds of slate and sandstone ranging from less than a foot to about 20 feet thick were all quarried. The slate from the different slate beds was processed, and the sandstone (exceeding slate in amount) was sent to waste dumps. At present, the Portland-Monson Slate Co. is mining from a single thick vertical slate bed several hundred feet underground; less waste rock is handled by underground mining than by the former open-quarry methods. Bowles (1922) described the method of underground mining of a 10-foot-thick slate bed at Monson.

In recent years, crushed slate has been used in the slate districts of Pennsylvania and Virginia for the manufacture of lightweight concrete aggregate. It seemed possible that slate from the Greenville quadrangle would be suitable for lightweight aggregate; therefore, a large sample representing about 280 feet across the strike was taken from the prominent exposure on State Highway 15 on the hilltop about 0.6 mile southeast of Lower Shirley Corner. This sample was tested by H. P. Hamlin of the U.S. Bureau of Mines and was found to make good-quality lightweight aggregate from which satisfactory lightweight concrete was made. Results of the various tests are given by Espenshade and Hamlin (1961).

The sample of slate tested was taken from a stratigraphic interval where sandstone beds are practically absent. Several sets of cleavage are present in this slate, which make it unsuitable for roofing slate or millstock, but it does appear to be satisfactory lightweight aggregate material. Many square miles of the region are underlain by such slate. Likewise, beds of well-cleaved slate alternating with sandstone are abundant in the region. Future prospecting for this type of slate should be directed toward sequences of alternating beds of slate and sandstone in the lower and upper parts of the pelitic unit.

STONE

Some granite was quarried many years ago on Bunker Stream near the eastern edge of the Shirley-Blanchard stock. It was probably used locally, apparently some of it in the construction of the railroad bridge over Bunker Stream. Sizable quarries could probably be developed in this granitic stock at various places along both valley sides of the East Branch of the Piscataquis River. The granitic rock of the Bald Mountain stock is similar and should be suitable for various uses, but this part of the quadrangle presently is rather inaccessible. Some varieties of mafic rock in the Moxie pluton should be suitable for crushed stone. One locality in the Moxie pluton that has good accessibility and favorable topography for a quarry site is the steep hillside east of State Highway 15 and just north of the south boundary of T. 2, R. 6.

GRAVEL

Although the entire quadrangle is covered with glacial deposits, stratified sand and gravel deposits suitable as sources of very large amounts of gravel are not abundant. Some roadside gravel pits have been dug in glacial till, but this material is generally unsatisfactory because of its high clay content. The principal known stratified sand and gravel deposits are in the two esker systems already described and on the north side of Lake Hebron; gravel has been taken from pits in each of these areas. The largest supplies have come from pits dug at intervals over a distance of somewhat more than a mile in the esker south of Shadow Pond. In 1961, excavation for road gravel was started near Hatch Falls in the other esker.

SULFIDE MINERALS

Small amounts of sulfide minerals, mainly pyrrhotite and chalcopyrite, occur at various places in the mafic rock of the Moxie pluton and in hornfels adjacent to the pluton. The most abundant sulfides found in mafic rock in the quadrangle are near the north edge of the pluton in troctolite exposed along State Highway 15 about half a mile south of the north edge of the quadrangle. A grab sample of gossan exposed in the east roadbank contained 0.12 percent copper and 0.2 percent nickel. Another mineralized mafic rock locality is near the south edge of the pluton, about 500 feet north of lat 45°25′ and 450 feet east of long 69°45′. A grab sample of sulfide-bearing rock taken from float and ledges across a width of 50 feet contained 0.06 percent copper and 0.06 percent nickel. This locality is about 1.6 miles N. 26° E. from the 600 ppm cobalt and 300 ppm nickel anomaly shown by Canney and Post (1963) in the Burnt Nubble area of The Forks quadrangle. Stream-sediment samples were taken throughout the Greenville quadrangle, but most of these proved to be rather low in heavy-metal content (Post and Hite, 1964); several slightly anomalous samples were taken just east of the Burnt Nubble area, mentioned above.

ANDALUSITE AND SILLIMANITE

Andalusite is widespread in pelitic rocks in the contact metamorphic aureoles of the intrusions, but whether it is sufficiently pure (free of inclusions of other minerals) or abundant enough to be a potential source of aluminous refractory material is doubtful. The chiastolite variety in the outer parts of the aureoles does reach lengths of several centimeters, but these crystals generally have inclusions and coatings of micaceous minerals and graphite. Andalusite in hornfels of the inner parts of the aureoles forms crystals a few millimeters long that have inclusions of quartz, feldspar, and biotite. Beneficiation tests would be needed to determine if enough inclusions and coatings could be removed from either variety of andalusite to yield a concentrate suitable for refractory purposes. An area that can be suggested for sampling lies on either side of State Highway 15, adjacent to the north edge of the pluton. The andalusite content of the hornfels exposures just east of the highway was estimated to range from 8 to 14 percent, as already pointed out.

Sillimanite has even less promise than andalusite for refractory materials, because it is less abundant, is distributed very irregularly within the aureole, and typically occurs as felty aggregates of minute fibrous crystals that would be very difficult to separate from associated minerals.

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