GEOLOGY

of the

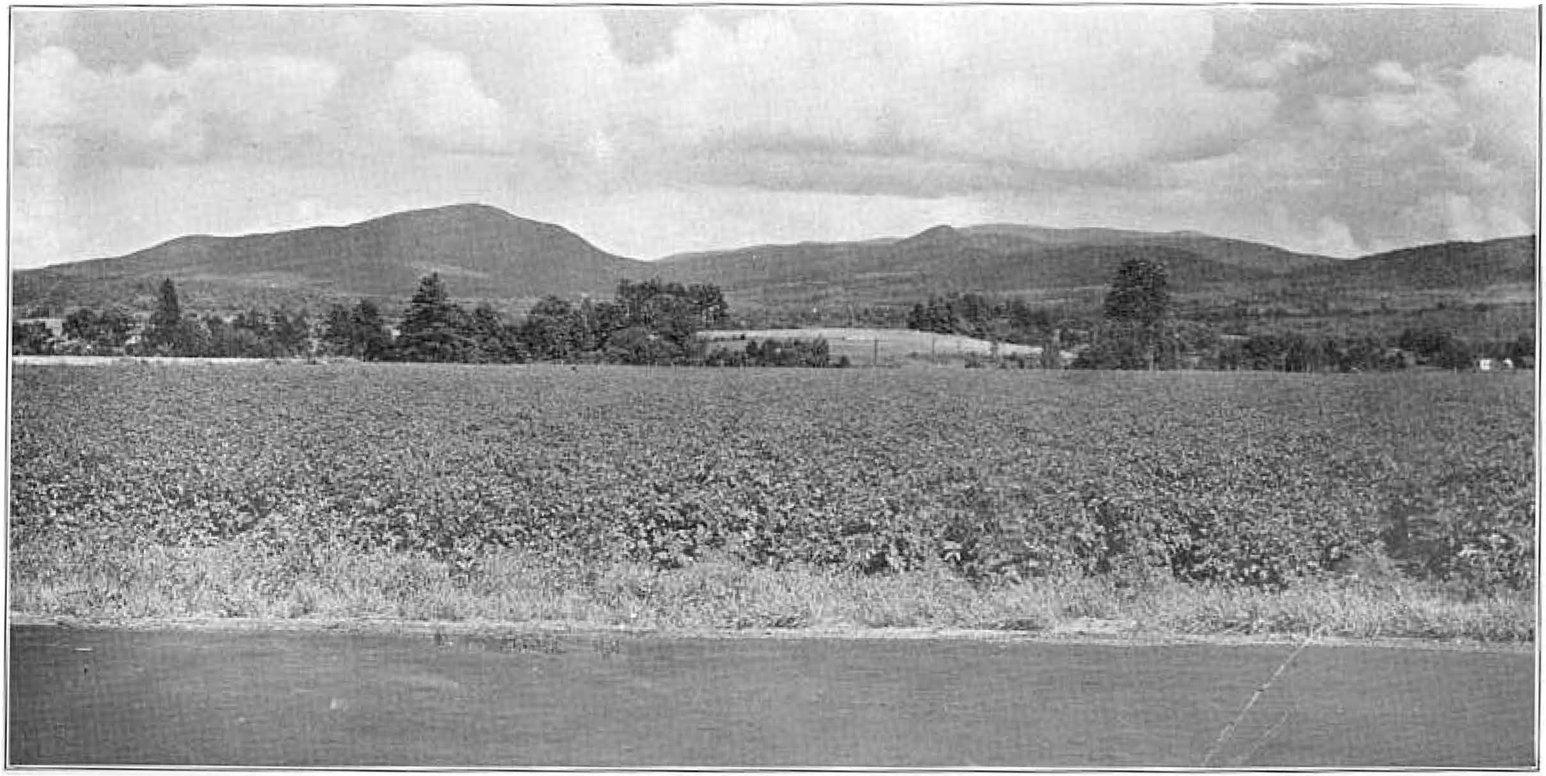
LITTLETON and MOOSILAUKE QUADRANGLES

NEW HAMPSHIRE

STATE PLANNING AND DEVELOPMENT COM.

By
MARLAND P. BILLINGS

1935



View in the Moosilauke Quadrangle, from North Haverhill: Black Mountain and Sugarloaf, left and center; Mount Moosilauke in far right background.

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Published by the

STATE PLANNING AND DEVELOPMENT COMMISSION

Concord, New Hampshire

1935

FOREWORD

This pamphlet is designed to give a general description of the geology of the Littleton and Moosilauke quadrangles, New Hampshire, but it is not intended to be a complete scientific report. It is hoped that it will appeal to both the amateur naturalist and the professional geologist. The most technical phases of the geology are not discussed. Although technical terms are of necessity used rather freely, there is a glossary at the end of the paper, which, it is believed, will enable the amateur to comprehend fully the discussion. These definitions are not always rigidly correct, due to the attempt to present a picture in as few words as possible and in non-technical language. Due to the brevity of the treatment of such a large subject, the paper is unavoidably somewhat dogmatic. The author hopes to publish a longer and more technical report elsewhere.

The field work was carried on under the auspices of the Division of Geological Sciences of Harvard University, and the geological maps and text were financed by the State Highway Department of New Hampshire.

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GEOLOGY OF THE LITTLETON AND MOOSILAUKE QUADRANGLES, NEW HAMPSHIRE

by

MARLAND P. BILLINGS

CHAPTER I. INTRODUCTION

The Littleton and Moosilauke quadrangles lie in western New Hampshire and include Littleton, Lisbon, Bath, Sugar Hill, Swiftwater, East Haverhill, Center Haverhill, and part of Franconia. Most of the area lies west of the White Mountains, but the extreme eastern and southeast portions of the Moosilauke quadrangle are occupied by some of the higher mountains belonging to this group.

The region is of particular interest to geologists, for it is possible to demonstrate here that at least some of the highly metamorphosed rocks of the White Mountains are of Paleozoic age. It is possible to tell the age of rocks from the kind of fossils which they contain, just as the antique collector can deduce when a piece of furniture was made merely by its form. The only known fossils in the State of New Hampshire are found in the Littleton and Moosilauke quadrangles, and it is only natural that the geologist, whose chief concern is with the history of the earth, should begin his extensive studies in this region.

The age of the rocks is not the only feature of interest in this district, for careful study reveals that after the fossil-bearing rocks were originally laid down, they were tremendously squeezed, as in the jaws of a great vise, and thrown into a series of gigantic folds many miles across. The recognition and reconstruction of these great folds is one of the most intriguing phases of Geology. During the folding and shortly thereafter, great masses of magma were forced up into the earth's crust, there to solidify into granites and related rocks. This was followed by a long period of erosion, during which thousands of feet and probably miles of rock were worn away and carried to the sea by streams and rivers. Very recently — during the last million are five or six feet thick. The rocks are almost invariably crumpled.

The thickness of the Albee formation is very difficult to determine, due to the intense folding which the rocks have undergone; but a rough estimate, made on the east slopes of the Gardner Mountain, gives 4000 feet. Although the base of the formation is not exposed northwest of the Ammonoosuc River in the Littleton and Moosilauke quadrangles, it has been observed two miles west-southwest of Center Haverhill, in the Woodsville quadrangle, and the figure given above is probably a fair estimate of the total thickness of the formation.

The Albee formation is the oldest exposed in the area, and is of greater antiquity than the oldest fossils as yet found in the district. Since these fossils are of middle Silurian age, the Albee formation is clearly older than this particular geological epoch. Moreover, since there is a pronounced unconformity between the Silurian and the older formations, the latter must be pre-Silurian. Finally, reconnaissance studies suggest that the Albee, Ammonoosuc, and Partridge formations of western New Hampshire are younger than the middle Ordovician of eastern Vermont. It is believed, therefore, that the Albee formation is of upper Ordovician age, although this cannot be considered to be demonstrated as yet. It is not at all impossible that someone may find fossils in the Albee formation.

Ammonoosuc Volcanics. The name Ammonoosuc volcanics is proposed for a group of volcanic rocks which overlie the Albee formation but underlie the Partridge. The type locality lies in the district bounded on the north by Slate Ledge School and Partridge Lake, and on the south by Youngs Pond (Ogontz Lake) and Tinkerville. The name is chosen from the Ammonoosuc River, which lies several miles to the southeast, and along which the formation is also well exposed, but with a different metamorphic character.

The Ammonoosuc formation is one of the most extensive in the Littleton and Moosilauke quadrangles. Two major belts may be recognized northwest of the Ammonoosuc thrust. One lies on the west side of the Littleton quadrangle, two miles west of the crest of Gardner Mountain. A second may be traced from the township of Dalton, on the east side of the Littleton quadrangle, across the townships of Littleton and Lyman into Bath, a total distance of eighteen miles.

Good exposures of the Ammonoosuc volcanics may be seen: in that square mile which has Slate Ledge School for its northeast corner; southwest and northwest of Youngs Pond (Ogontz Lake); and on the hill 1206 feet above sea level, one and one-half miles south-southwest of Pattenville. Exposures are very poor in the area west of Gardner Mountain, but outcrops may be seen in Smutty Hollow (as named on the map) at an elevation of 700 feet, or west of the church at North Monroe.

These rocks are distinctly of volcanic origin, a fact first recognized by Lahee (14)*, but very few, if any, true lava flows are present. Most of the material would be classified as tuff, breccia, or volcanic conglomerate, and was largely deposited by streams flowing westward from the active volcanoes to the east.. Some of the finer material may have been carried westward by the wind and deposited directly from the air. For descriptive purposes the Ammonnosuc volcanics may be divided into a number of types, which, however, grade into one another.

One of the most conspicuous types is soda-rhyolite volcanic conglomerate, a white to buff-colored rock in which the pebbles and boulders are fairly well rounded and range in size from a few inches to a foot in diameter. Another striking type is a white to buff-colored soda-rhyolite containing quartz and feldspar crystals from one-eighth to one-fourth inch across, the quartz, in many instances, being distinctly blue. This rock is probably a volcanic tuff in most cases, but in some localities it may represent true lava flows. There are also many fine-grained, white to buff-colored soda-rhyolites of a very dense, compact type, which are difficult to distinguish from quartzites in many instances. Some are volcanic tuffs, others are flows or shallow intrusives. Chlorite schist and chlorite-epidote

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*Numbers in parentheses refer to references at end of paper.

schist are conspicuous. They are light to dark green in color and are almost invariably schistose. They are metamorphosed andesitic and basaltic tuffs. Black slate and impure quartzite are also found in the Ammonoosuc volcanics and, locally, may comprise a considerable part of the formation.

Cleavage, generally striking northeast and dipping steeply, is more conspicuous than bedding, and over large areas the latter may be absent or very obscure. Locally, however, particularly where there are large exposures, bedding may be readily observed, and there is little question that most of the formation is water-laid.

The thickness of the Ammonoosuc volcanics cannot be accurately calculated. The great breadth of outcrop so characteristic of the formation indicates a considerable thickness, and a round figure of 2000 feet is assumed. The Ammonoosuc volcanics are believed to be upper Ordovician for the same reasons as were given in the discussion of the age of the Albee formation.

Partridge Formation. The name Partridge formation is proposed for a group of black slates which overlie the Ammonoosuc volcanics and underlie the Clough and Fitch formations. The name is chosen from Partridge Lake, in Littleton township. In the type locality the slate outcrops in a narrow belt five miles long, trending north-northeast through Partridge Lake. A very small area is exposed one-half mile southwest of Partridge Lake, and a third extends for three miles through Dodge Pond, Tinkerville, and the village of Lyman. There is a fourth area south of Lyman. The largest, however, is in the northwest corner of the Moosilauke quadrangle where it occupies several square miles northwest of Bath and west of Moulton Hill.

Good exposures may be seen: one mile south-southwest of Partridge Lake; at the south end of Dodge Pond; one-half mile northwest of Moulton Hill; and on the hills two miles northwest of Bath.

This formation consists largely of black slate, although locally it is somewhat sandy. Cleavage is always very conspicuous but one rarely sees any bedding. The lower twenty-five feet of the formation, however, is rather distinctive and has served as an excellent key bed. In some places it is composed of interbedded black slate and fine-grained, light-colored quartzite in beds from one-fourth to one inch thick. Elsewhere this basal member has thin beds of schistose soda-rhyolite tuff similar to those found in the Ammonoosuc volcanics.

The thickness of the Partridge formation is difficult to determine. The maximum breadth of outcrop, seen in the area to the west of Moulton Hill, is 7000 feet, but areal mapping demonstrates that the rocks are intensely folded here. An approximation for the thickness of the Partridge formation in this area is 2000 feet. In many places, however, the Partridge formation is completely absent, and the Silurian formations rest directly on the Ammonoosuc volcanics. The thickness is thus listed as ranging from 0-2000 feet. The formation is believed to be upper Ordovician in age for the same reasons as have already been given in the discussion of the age of the Albee formation.

Clough Conglomerate. The name Clough conglomerate is proposed for a group of interbedded quartz conglomerates and quartzites which directly underlie the Fitch formation. The name is chosen from the Clough Hill district, two and one-half miles northwest of Lisbon, where the formation is typically exposed. The formation as defined is precisely the same as Hitchcock's "auriferous conglomerate", (7, II, pp. 303-311) and the only reason for abandoning his term is that modern usage demands locality names for formations. Moreover, the amount of gold in the formation scarcely justifies the imposing name "auriferous".

The Clough conglomerate is undoubtedly the best key horizon in western New Hampshire. It is very distinctive, readily recognized, thin but resistant, and most invariably outcrops wherever it exists. A study of the geological structure of the area resolves itself, in part, into a careful mapping of the Clough. This formation apparently continues south as far as the Massachusetts boundary and thus will serve as an excellent key to the geology of western New Hampshire.

The formation has a most intricate distribution in the northwest corner of the Moosilauke quadrangle, the exact nature of which can be most satisfactorily obtained by reference to the geological map. Its irregularities are in part due to the intense folding which the rocks have undergone. Furthermore, the Clough conglomerate behaved as a very brittle formation during the folding, and, whereas the other strata were able to adjust themselves by flowage, the Clough broke up into isolated blocks. It is absent, therefore, at the base of the Silurian in many places, not because it was not deposited, but for structural reasons. Throughout most of the Littleton quadrangle, however, the formation is absent because it was never deposited.

The Clough conglomerate may be seen practically everywhere that it is shown on the map. Many of the exposures are bold, conspicuous white outcrops, which rise as cliffs from ten to forty feet high. As will be shown later, southeast of the Ammonoosuc thrust it holds up high mountains. Many of the outcrops appear to be perfectly massive, without bedding, and may be either conglomerate or quartzite; others show interbedding of these two types, with the individual beds from one to three feet thick.

The pebbles in the quartz conglomerate are chiefly vein quartz, but a few are quartzite, jasper, greenstone, and soda-rhyolite. The pebbles have generally been "stretched" into cigar-shaped bodies, in which the greatest diameter is from one-half to two inches, and in some cases, as much as three or four inches. The matrix may be a pure quartzite, or a quartz-chlorite-sericite schist. In the latter case it is greenish gray, and locally may be stained brown from iron rust.

The quartzites are white to buff, hard, resistant, vitreous rocks.

In the northwest corner of the Moosilauke quadrangle the breadth of outcrop of the Clough conglomerate varies from nothing to 400 feet within short distances. These large variations are believed to be largely structural and have little or no relation to the original thickness of the formation. One of the best places to obtain the true original thickness is one-half mile west of Pettyboro School. Since the strata here are essentially vertical, the thickness is equal to the breadth of outcrop, approximately 150 feet. Even on Black Mountain and Sugarloaf, where the Clough covers such a large area, it is believed that the original thickness was not much greater than 150 feet, and that folding and faulting have greatly thickened the formation.

The Clough conglomerate directly underlies the Fitch formation, which contains middle Silurian fossils. Moreover, the two are closely related in age, for a few beds of quartz conglomerate similar to the former occur in the latter. On the other hand, the Clough conglomerate is separated from the underlying formations by an unconformity, and it is thus apparent that it is either middle or lower Silurian. In some respects the Clough is similar to the Shawangunk conglomerate of New York. Both are quartz conglomerates, but the Clough is thinner and purer. The Clough directly underlies fossiliferous middle Silurian, and the Shawangunk carries middle Silurian fossils in its upper part. The two are thus closely related, if not identical, in age.

Fitch Formation. The name Fitch formation is proposed for the limestones and related sediments of middle Silurian age in the Littleton district. The name is chosen from the farm of G. E. Fitch, one and three-fourths miles west-northwest of Littleton, and on whose property is located the famous fossil locality known to geologists for sixty-five years.

The Fitch formation may be traced as a long narrow belt southwestward from the Fitch farm for eleven and one-half miles to the vicinity of Moulton Hill. It then turns back toward the northeast and can be traced for three miles, where it abuts against the Ammonoosuc thrust. Two small bodies are found directly northwest of the thrust, one a mile west of Sugar Hill Station and a second one-half mile east of the summit of Walker Mountain. A small area also occurs west of

Parker Mountain, and there are two small patches between Youngs Pond (Ogontz Lake) and Partridge Lake.

Good exposures of the Fitch formation are rare. At the Fitch farm only the lower and upper parts of the formation are exposed. One-half mile east of Slate Ledge School just south of the road there is a fairly continuous section about 400 feet across, and three-fourths of a mile southwest of Youngs Pond there is an excellent section 770 feet across.

The Fitch formation includes a great variety of rocks, including: white, buff, and gray marble; dark gray to black limestone; brown, dolomitic slate; brown, sandy dolomite; gray, calcareous slate; gray, sandy limestone; white, calcareous sandstone; white, fine-grained, calcareous conglomerate; gray, impure quartzite; white to grey arkose; quartz conglomerate; and gray slate.

In general the individual beds are not very thick, and range from a fraction of an inch to several feet. Cleavage is more conspicuous than bedding. The arkose, however, is massive, and locally occurs in beds several scores of feet thick without showing any signs of bedding. These arkoses are exposed in the 1400 foot hill one and one-half miles west-northwest of Littleton and in the belt extending south-southwest from Parker Mountain to the Littleton-St. Johnsbury road.

The relations are confused in places by the presence of intrusive igneous rocks, such as the diorite in the vicinity of the Fitch farm. The most troublesome of all the intrusives, however, are the soda-rhyolite dikes and sills around Parker Hill, two and one-half miles northwest of Lisbon. They are so abundant and resistant that they constitute 95 per cent of the outcrops.

The thickness of the Fitch formation can be determined most satisfactorily in the region northeast and southwest of Slate Ledge. The most complete section is one-half mile east of Slate Ledge School, where the strata are essentially vertical, and the breadth of outcrop is between 465 and 565 feet. This includes, however, an altered diorite sill 75 feet thick, and the total thickness of the sediments is thus only 390 to 490 feet.

As far as one can judge these rocks are neither repeated nor reduced by folding or faulting, and the true thickness is therefore about 450 feet. The section west of Parker Mountain is only 300 feet thick, but detailed mapping indicates that faulting has cut out some of the formation. The section three-fourths of a mile southwest of Youngs Pond is 770 feet across, but some beds are repeated by folding. The best estimate for the thickness of the Fitch formation is, therefore, 400-700 feet.

Fossils have been found in the Fitch formation at a number of localities, but the only diagnostic material is that found at the Fitch farm. The fossils found here are definitely marine and include about twenty forms of corals, brachiopods, crinoids, trilobites, and pelecypods. They have been described in detail in a recent paper by Billings and Cleaves (3). They indicate a Niagaran (middle Silurian) age for the formation. Fossils have also been found in the Fitch formation at the following localities, but they are poorly preserved: (1) in the quarry one-half mile north-northwest of the summit of Parker Mountain; (2) one and one-half miles west-northwest of Littleton about 1000 feet north of the 33° dip symbol; (3) 2300 feet S 70° E of the Slate Ledge School; (4) 4600 feet due west of the Clough Hill School; (5) 3000 feet northwest of Sugar Hill Station; and (6) 2400 feet due east of the Summit of Walker Mountain.

Littleton Formation. C. P. Ross (15, p. 284) suggested the name "Littleton argillite" for the "banded argillite" and "dark, gray sandstones with dark shale layers" previously described by Lahee (13, p. 242). The term argillite, however, is not very satisfactory, as the rocks are slates, sandstones, and volcanics. The term Littleton formation, from the township in which the rocks are typically developed, is proposed instead. More specifically, the type locality is around Slate Ledge, Walker Mountain, and the district lying a mile to the southwest.

This formation is exposed in a long belt extending for thirteen miles from Parker Mountain, two and one-half miles north of Littleton, to Moulton Hill, two and one-half miles west of Lisbon. Good exposures may be seen at the following places:

(1) at Slate Ledge quarry and along the transmission line one-fourth of a mile to the south; (2) on the cliffs on the east slope of Walker Mountain; (3) along the north-south road one-half mile west of the top of Walker Mountain; (4) along the west slope of Mormon Hill; and (5) on the hill two miles west-northwest of Lisbon, where the volcanic member is particularly well exposed.

The Littleton formation consists dominantly of black slate and black to gray sandstone, with one important volcanic member. That portion of the formation beneath the volcanic member is dominantly slate, excellently exposed in the quarry at Slate Ledge. The first thousand feet of the formation above the volcanic member is a hard, resistant, black sandstone, which holds up a conspicuous ridge to the east and northeast of Slate Ledge and forms the cliffs one and one-half miles west of Littleton. The upper part of the formation is composed of interbedded sandstone and slate, in which the individual beds are from one to six inches thick.

The volcanic member lies from 700 to 1000 feet above the base of the formation. In the vicinity of Slate Ledge the basal part of the volcanic member is a porphyritic greenstone, which is metamorphosed andesite or basalt. Above this is a white, volcanic conglomerate, in which the boulders are well rounded and range in size from one to eighteen inches in diameter. They are chiefly a light-colored soda-rhyolite with phenocrysts of albite, but a few of the pebbles are soda-trachyte. At the top of the volcanic member is a greenish-gray rock which microscopic study shows to be altered basalt and is shown on the map with the symbol Dlc.

Due east of Youngs Pond the base of the volcanic member is a greenstone, representing altered andesite or basalt, above which is a black slate. At the top is a soda-trachyte, gray in color, and full of elongated gas cavities. Two miles northwest of Lisbon the volcanic member is excellently exposed and consists of a lower greenstone — altered andesite tuff — and an upper soda-rhyolite tuff and breccia; but the two are separated by a bed of slate several hundred feet thick.

The thickness of the Littleton formation is difficult to measure throughout much of the area, for it is intensely crumpled, and the precise details of the structure are unknown. West of Littleton, however, the structure is relatively simple, with a broad, open syncline plunging 65°SW. Calculations made north of Walker Mountain give a thickness of about 5000 feet.

Fossils have been found in the Littleton formation at a number of localities. One of these is five-eighths of a mile due west of the summit of Walker Mountain, where the 80° dip symbol is shown. An equally good collecting ground is on Mormon Hill, just between the first "M" and "o" on the map. Billings and Cleaves (3) have listed fourteen forms from these two localities, mainly brachipods, but including one pelecypod and two gastropods. They have shown that these fossils are of Oriskany (lower Devonian) age, and that the Littleton formation is the same age as the Moose River sandstone of Maine, the Grand Greve formation of Quebec, and the Oriskany formation of New York. It should be noted, however, that these two collecting localities lie about 2500 feet above the base of the formation, and, actually, only the middle part of the Littleton formation has been demonstrated to be of Oriskany age. But poorly preserved brachiopods found both near the base and the top of the formation are apparently similar to those found in the best localities and suggest that the whole formation is Oriskany in age.

Chapter III. Sedimentary and Volcanic Rocks Southeast of the Ammonoosuc Thrust

The formations described above are also found southeast of the Ammonoosuc thrust, but due to greater heat and, perhaps, pressure, they have been profoundly changed or metamorphosed. New minerals have been developed, notably biotite, garnet, staurolite, sillimanite, and andesine feldspar. Hornblende, which is rare northwest of the thrust, is very abundant and has a different chemical composition. Slate has been changed to mica schist, slaty sandstone to quartz-mica schist, greenstone, chlorite schist, and chlorite-epidote schist to amphibolite, soda-rhyolite tuff to fine-grained biotite gneiss, calcareous slate to calcite-biotite schist, and sandy dolomite to actinolite and diopside-bearing granulites. The changes are so great that even the trained geologist does not realize at first that the strata on opposite sides of the thrust are the same age.

Albee Formation. The Albee formation is found in two belts southeast of the Ammonoosuc thrust, one, a narrow belt extending southwesterly in the vicinity of Littleton, a second, just west of Bath and Lisbon. Good exposures may be seen on the hills one mile north of Lisbon, one-half mile west of Bath, and along the state highway west of the junction of the Wild Ammonoosuc and Ammonoosuc Rivers.

The rocks northwest of Lisbon and Bath resemble in many respects those in the Gardner Mountain area, the chief difference being the presence of a little biotite and garnet. In the belt near Littleton, however, although some of the members may be described as biotite-bearing quartzites, others are typical mica schists, some with garnets.

Ammonoosuc Volcanics. The Ammonoosuc formation is found in three belts southeast of the Ammonoosuc thrust. One of these extends from Littleton to Center Haverhill, a second is found north of Northey Hill, and a third extends from Franconia village to Sugarloaf Mountain, where it splits into two branches, one swinging southeast to the State Sanitarium, the second southwest to Lake Constance.

Good exposures may be seen in the vicinity of Salmon Hole School, the village of Lisbon, Swiftwater, on the hill one and one-half miles southwest of Swiftwater, on Cobble Hill, and for a quarter of a mile above the mouth of Davis Brook.

Southeast of the Ammonoosuc thrust the Ammonoosuc volcanics do not superficially bear much resemblance to the same formation northwest of the thrust. Close scrutiny, however, reveals certain textural features characteristic to both regions. Chemical and microscopic studies also demonstrate the correlation which has been adopted. Some volcanic conglomerates have been observed, for example, under the bridge at Barrett, but they are not so abundant as northwest of the thrust. Well-rounded pebbles and boulders, chiefly soda-rhyolite, are set in a schistose matrix containing some biotite. There are also white, fine-grained, biotite gneisses, with conspicuous quartz and feldspar grains; they are the metamorphosed equivalent of the soda-rhyolite tuffs and breccias with conspicuous quartz and feldspar grains found northwest of the Ammonoosuc thrust. White, fine-grained, biotite gneisses are the equivalent of the fine-grained soda-rhyolites. The amphibolites are fine to medium-grained, dark-green rocks, which are locally conglomeratic, fragmental, or bedded. They are the equivalent of the chlorite and chlorite-epidote schists found northwest of the Ammonoosuc thrust, and represent metamorphosed andesitic and basaltic tuffs, breccias, and volcanic conglomerates. Some mica schists and black quartzites are present and are the equivalents of the slates and impure quartzites northwest of the thrust. Schistosity is usually conspicuous in these rocks.

Partridge Formation. A large area of the Partridge formation occurs two miles southwest of Landaff. Exposures are good throughout the whole area, and a particularly good section may be seen by going northwest from the second house northwest of B. M. 1513. The formation is composed largely of mica schist, some of which has garnet.

Clough Conglomerate. Four belts of the Clough conglomerate occur southeast of the Ammonoosuc thrust. One extends from one-half mile east of Salmon Hole School to a mile northwest of Landaff; a second is found northeast of Northey Hill; a third extends from Franconia to Sugarloaf Mountain, where it splits, one arm going southeast to The Hogsback, the other southeast to Lake Constance; and a fourth belt is found on the west slope of Mt. Clough. Large mountains are held up by this formation, notably Black Mountain, Sugarloaf, and The Hogsback. The outcrops on Black Mountain are very easy to reach by trail.

The rock does not differ essentially from that found northwest of the Ammonoosuc thrust, for it is composed of tough, resistant, white to buff-colored quartz conglomerate and quartzite. The rock as a whole is more coarsely crystalline, however, and the pebbles tend to merge with the ground-mass and lose their identity. On Black Mountain quartz-mica schists are present.

Fitch Formation. There are three belts of the Fitch formation in the area southeast of the thrust. One extends from Streeter Pond to one mile southwest of Landaff; a second is near Northey Hill; and a third goes from Franconia to Lake Constance. There are good exposures: northeast of Northey Hill; in the abandoned quarries at Sugar Hill; east of Pearl Lake; and southwest of Black Mountain.

A great variety of rock types is found, just as northwest of the Ammonoosuc thrust. Buff-colored marbles are the equivalent of similar marbles and limestones to the northwest. Yellowish biotite-calcite schists are the equivalent of calcareous slates. White to light-gray quartz-calcite schists are equivalent to calcareous sandstones and sandy limestone. One of the prettiest rocks is a light-green granulite, speckled with actinolite crystals, which locally occur in rosettes. Microscopic study shows that these rocks are composed of light-green diopside, actinolite, andesine feldspar, potash feldspar, and quartz. Diopside is found only southeast of the Northey Hill thrust, but actinolite occurs in the more northwesterly belt. Chemical considerations show that these rocks are the equivalent of sandy dolomites. Other rocks, which have more or less actinolite, usually in rosettes, are the equivalent of dolomitic slates. Buff-colored quartzite is also present, one bed in the vicinity of Northey Hill being so wide and conspicuous that it has been separately mapped as the Northey Hill quartzite member of the Fitch formation. Some arkose has also been observed, especially along the Ammonoosuc River just south of the mouth of the Gale River. Gray mica schist has also been noted and is the equivalent of the gray slates.

Fossils have been observed on the southeast bank of the Ammonoosuc River, about one-half mile southwest of the North Lisbon School, in a buff marble interbedded with calcite-mica schist. The fossils are chiefly crinoid columnals and calyxes, but the genus and species cannot be identified. (3).

Littleton Formation. There are three belts of the Littleton formation southeast of the Ammonoosuc thrust. One of these may be traced from Streeter Pond to Landaff; a second, from Franconia to Landaff, where it is cut out by a large body of Bethlehem gneiss, but reappears southwest of Black mountain; and a third, from two miles northeast of Easton to Mt. Moosilauke. Excellent exposures may be seen on Garnet Hill, on the great slides in Tunnel Ravine, on Beaver Brook, and on the lower part of the Gale River, where the lower volcanic member is particularly well displayed.

The formation consists dominantly of metamorphosed sedimentary rocks, with minor amounts of metamorphosed volcanics. The sedimentary types are various kinds of schists, particularly black to fine-grained schists and phyllites, with large crystals of garnet, biotite, or staurolite; the last may attain a length of several inches in some instances. In the Mt. Moosilauke belt, however, the large staurolite crystals are no longer present, but sillimanite, in crystals from a fraction of an inch to an inch long, is found instead. In fact, the separation of the rocks southeast of the Ammonoosuc thrust into "mesozone" and "katazone" is based on whether staurolite or sillimanite is present, but there are some complications which cannot be adequately treated here. In general these rocks are the equivalent of the slates northwest of the thrust. Light-gray, quartz-mica schists, locally carrying a few garnets, are equivalent to the sandstones. In the "katazone" (Mt. Moosilauke belt) the rocks are more coarsely crystalline than in the "mesozone."

Two volcanic members are present. One of these extends from just west of Streeter Pond in a general southwesterly direction toward Landaff. It is typically exposed on the Gale River about one-half mile above its mouth, and is composed of soda-rhyolite volcanic conglomerate and amphibolite. The former is a white to gray rock in which the pebbles and boulders range from a fraction of an inch up to eight inches. The most common are soda-rhyolite with small feldspar phenocrysts, but there are also some "dark porphyries" and a few pebbles of a white, fine-grained granite. The amphibolites are dense, dark-green, massive rocks. Locally they are composed of small, spheroidal masses about a foot in diameter and are interpreted as metamorphosed pillow lava of basaltic composition. The volcanic conglomerate dies out both to the northeast and southwest.

Southwest of Salmon Hole Brook this lower volcanic member is composed of: light-colored biotite gneiss with large grains of milky to blue quartz (orginally soda-rhyolite tuff); light-colored, fine-grained, biotite gneiss breccia (soda-rhyolite breccia); and amphibolite breccia (basaltic breccia).

An upper volcanic member composed of dark green amphibolite may be traced from Salmon Hole Brook to the Gale River. In some places it is clearly fragmental, with angular blocks several inches across, and in others is rather fine-grained and excellently bedded. It represents metamorphosed tuff and breccia of andesitic or basaltic composition.

No volcanics have been observed in the belt extending southwest from Garnet Hill, but two belts, chiefly amphibolite and interbedded mica schist, have been noted in the Mt. Moosilauke belt.

There is a very remarkable occurrence of fossils in the Mt. Moosilauke belt. They were found by Billings and Cleaves at an elevation of about 2650 feet on the more northerly of two slides on the east slope of Mt. Clough, but have not as yet been described. One, an unidentified brachiopod, is in a metamorphosed concretion. The other, belonging to the genus *Spirifer*, is in a mica schist, which microscopic study shows to be full of garnets.

Chapter IV. Intrusive Igneous Rocks

There are many intrusive igneous rocks in the Littleton and Mosilauke quadrangles. Some are in small bodies, such as dikes and sills; others are in larger masses, such as stocks or batholiths. They did not form at the same time, but are of very different ages. On the other hand, they did not develop promiscuously throughout geologic time, but were confined to very definite episodes. Usually igneous rocks intruded during a certain period of earth history have certain distinctive features and may be grouped together as belonging to a definite magma series. Thus, in western New Hampshire and the White Mountain district four magma series have been recognized: (1) Highlandcroft, certainly pre-Silurian and probably late Ordovician in age; (2) Oliverian, younger than the lower Devonian but older than the folding; (3) New Hampshire, intruded during the folding and shortly thereafter; and (4) White Mountain, which is younger than the New Hampshire magma series and separated from it by a pronounced unconformity.

Highlandcroft Magma Series

Highlandcroft Granodiorite. The name Highlandcroft granodiorite is proposed for a granodiorite and associated intrusives which are younger than the Albee, Ammonoosuc, and Partridge formations, but older than the Clough, Fitch, and Littleton formations. The name is chosen from "Highlandcroft", a large estate on the St. Johnsbury road about one and one-half miles west-northwest of Littleton. This estate is located on the largest body of this rock in the Littleton and Moosilauke quadrangles, a mass about four and one-half miles long. There are also four lesser bodies, all in the Littleton quadrangle.

In the main body the granodiorite is a greenish-gray, medium-grained, granitic-looking rock in which the individual crystals are something less than an eighth of an inch across. In the freshest specimens four minerals may be distinguished: light-green, somewhat greasy-appearing plagioclase feldspar; white, glassy potash feldspar, with good cleavage planes; black hornblende; and glassy to milky quartz. In the more sheared and altered varieties chlorite is more prominent, and east of Walker Mountain potash feldspar is abundant. Lahee (13) has shown that the Highlandcroft granodiorite intrudes the Ammonoosuc volcanics, but is overlain unconformably by the Fitch formation. It is, therefore, probably late Ordovician in age.

Oliverian Magma Series

The name Oliverian magma series, from the stream by that name in the southwest corner of the Moosilauke quadrangle, is proposed for a series of intrusive igneous rocks which are definitely younger than the lower Devonian but are older than the great period of folding. In the Moosilauke quadrangle it is represented only by the Owls Head granite, but other rock types of this series are present in the Mt. Cube and Rumney quadrangles.

Owls Head Granite. The Owls Head granite, named from the cliff by that name, occupies a semi-circular area in the southwest corner of the Moosilauke quadrangle. In the immediate vicinity of the main body numerous small sills of the granite are abundant in the overlying Ammonoosuc volcanics. It is a pink, medium-grained rock, somewhat foliated near its margins, but more massive in the interior. The essential minerals are white to pink potash feldspar, smoky quartz, white plagioclase feldspar, and biotite, with magnetite as an accessory. Although the youngest formation which it actually intrudes in the Ammonoosuc, it has domed up the Clough, Fitch, and Littleton formations and is thus younger than the Devonian. For reasons that are discussed in the next chapter it is believed to have preceded the folding.

New Hampshire Magma Series

The name New Hampshire magma series is suggested for a group of plutonic rocks which either accompanied the folding or were intruded shortly thereafter, but are separated from the overlying Moat volcanics by a pronounced unconformity. The series is characterized by the presence of muscovite in many of the members, a distinct foliation in some, and an abundance of pegmatites. The Bethlehem granodiorite gneiss and the Kinsman quartz monzonite are typical representatives. This series is definitely younger than the lower Devonian and may be either late Devonian or late Carboniferous, but at the time of writing the author is inclined to favor the former age.

Moulton diorite. The Moulton diorite is typically exposed on Moulton Hill, in the northwest corner of the Moosilauke quadrangle, but is also found in several smaller bodies in both quadrangles. It varies considerably in texture, and several varieties may be recognized. In general, however, it is a dark, greenish-gray, medium-grained rock, composed essentially of greenish plagioclase feldspar and hornblende. Since it is intrusive into the Littelton formation, it is younger than the lower Devonian.

Bethlehem granodiorite gneiss. This rock composes three different bodies, one in the southeast corner of the Littleton quadrangle, and two others in the Moosilauke quadrangle. The name was originally used by C. H. Hitchcock (7, II, pp. 104-111) for a variety of rocks exposed in the township of Bethlehem, but is now used in a more restricted sense for just one of the phases. It is generally light-gray, but locally it may be flesh-colored or green. The most conspicuous minerals are white feldspar, vitreous quartz, and biotite, and in the body in the southeast corner of the Littleton quadrangle epidote is common. The rock is usually very granular or sugary, but elsewhere it is medium to coarse-grained. In many places it is well foliated, particularly near the contacts, but southeast of Cooley Hill it is very massive. Small inclusions of schist, from a few inches to four feet long, are commonly present. The Bethlehem gneiss is definitely younger than the lower Devonian, for two miles northwest of East Haverhill small sills related to the main body inject the Littleton formation. The general distribution of the formation also indicates that it is intrusive.

Kinsman quartz monzonite. This rock is exposed along the east border of the southern two-thirds of the Moosilauke quadrangle, the name being chosen from Kinsman Notch. The maximum breadth of outcrop is two and one-half miles, but these exposures constitute only the western margin of a large igneous body exposed chiefly in the Franconia quadrangle. It is a white to gray, medium-grained rock, which in places contains large conspicuous crystals of white potash feldspar from one to two inches long. Locally the rock shows a weak foliation. The essential minerals are plagioclase feldspar, orthoclase, quartz, biotite, and muscovite. Just north of Beaver Pond, in Kinsman Notch, it is clear that the Kinsman quartz monzonite is younger than the Littleton formation, for sills and dikes of the former cut the latter.

Miscellaneous stocks. A series of small, isolated igneous bodies occur in the Littleton and Moosilauke quadrangles, but lack of space does not permit detailed descriptions. They include the Remick tonalite, Sugar Hill quartz monzonite, French Pond granite, Moody Ledge granite, Pond Hill granite, and Scrag granite. They are all briefly described in the legend accompanying the geological map. Some are definitely intrusive into the Littleton formation, and they are all considered to be younger than the lower Devonian.

White Mountain Magma Series

The White Mountain magma series includes a group of volcanic and intrusive igneous rocks with definite mineralogical peculiarities which are described in much greater detail in the pamphlet describing the geology of the Franconia quadrangle. In the Littleton and Moosilauke quadrangles the Landaff granite and certain dikes and sills are related to this series.

Landaff granite. This granite lies in the northeast part of the township of that name and in adjacent parts of Lisbon and Easton. It is a fine-grained, massive rock, which in many places is blotchy due to variations in color. It is pink to gray in color, and is spotted by needles of black hornblende, which microscopic study shows to be hastingsite.

Dikes and Sills

Dikes and sills are very abundant in the Littleton and Moosilauke quadrangles, and detailed study show that they are of many ages. The oldest are soda-rhyolites, which are represented on the geological map by a special symbol and are particularly abundant in four localities; Parker Hill; one and one-half miles northwest of Lisbon; one and one-half miles west of Pearl Lake; and one mile west of Moody Ledge. They are dense, white, hard rocks, which might readily be confused with chert or quartzite. They have been through the regional metamorphism and southeast of the Ammonoosuc thrust carry some biotite. They are never found above the lower volcanic member of the Littleton formation and are therefore believed to have been intruded during the lower Devonian volcanism.

A second group are the basic dikes and sills which have been subjected to the regional metamorphism. Just like the sedimentary and volcanic rocks their mineralogy is very different on opposite sides of the Ammonoosuc thrust. To the northwest they are generally dark green and in some instances are schistose. Irregular to rhombohedral masses of a reddish brown substance, from one-eighth to three eighths of an inch across give these rocks a distinctive appearance. Microscopic study shows that this material was originally a carbonate, ankerite, which has been weathered to iron rust. Dikes of this type are sufficiently abundant northwest of Gardner Mountain to be represented by a special symbol on the geological map. Southeast of the Ammonoosuc thrust this same group has been metamorphosed to amphibolites, which are fine to coarse-grained, dark-green rocks, in which plagioclase is usually white and the hornblende black. These rocks are so abundant in the southwest corner of the Moosilauke quadrangle and one and one-fourth miles northeast of Sugar Hill Station that they are represented by a special pattern. Some of these metamorphosed dikes and sills definitely cut the youngest sediments of the area, but none are known to intrude the Bethlehem gneiss, Kinsman quartz monzonite, or the younger intrusives. They are believed, therefore, to have been essentially contemporaneous with the Moulton diorite, although some which cut only the older formations may be of greater antiquity.

Dikes and sills of pegmatite, a very coarse-grained white rock composed of large, well-formed crystals of feldspar muscovite, and biotite, and irregular masses of quartz, with local occurrences of black tourmaline or red garnet, are common in the vicinity of the Bethlehem gneiss and the Kinsman quartz monzonite.

There are also a limited number of dikes and sills younger than the metamorphism, many of which are related to the White Mountain magma series. Some are dense black rocks, and include gabbro, diabase, quartz diabase, camptonite, and diorite; others are light-gray to white, and include syeno-diorite, syenite, and bostonite.

CHAPTER V. GEOLOGICAL STRUCTURE

GENERAL STATEMENT

The structure of the Littleton and Moosilauke quadrangles is very complicated. Very little of it is obvious from a casual inspection of the area, even to the trained geologist, and can be gleaned from the rocks only by the most detailed studies. Among the most striking features are the great folds, now deeply eroded so that only their roots remain. There are also great thrust faults, fractures which are now completely healed, but along which in the past large blocks of the crust have slid past one another. The intrusive igneous bodies are numerous and of various shapes and sizes. It is the purpose of this chapter to describe in greater detail the nature of the folds, thrust faults, and igneous intrusions.

FOLDS

After the six formations described on previous pages were deposited, they were subjected to strong horizontal compression and thrown into a series of folds. These folds are of all magnitudes, from great waves, the crests of which are many miles apart, to tiny folds, which can be seen only under the microscope. In single exposures many of the minor folds may be seen, as, for example, on the top of Black Mountain. The great major folds trend northeast in the Littleton quadrangle and the northern part of the Moosilauke quadrangle, but in the southern part of the latter they swing into the south.

In the northwestern part of the district there is a great arch following the crest of Gardner Mountain, known as the Gardner Mountain anticline. It is shown at the left end of sections DD′ and EE′ in the Littleton quadrangle. Superimposed on the major arch are countless lesser folds of various magnitudes, and of necessity these are represented diagramatically in the section. At the outcrops one actually sees many small folds a few inches or a few feet in height.

The next great fold to the southeast is a trough or syncline, the center of which may be traced from Parker Mountain through Walker Mountain, Mormon Hill, and Moulton Hill. It may be called the Walker Mountain syncline. The general nature of this fold is best displayed in section DD′ of the Littleton quadrangle, but the southeast limb has been cut off by a thrust fault, which will be described on a later page. This fold is also shown in section CC′ of the Littleton quadrangle, although in this case it is greatly complicated by faulting.

Further to the southeast the relations are considerably complicated by thrust faults. In a region of folds without faults we would expect to find anticlines and synclines alternating with one another, but due to faulting it is possible for a fold to be completely cut out. Precisely this situation exists northwest of Lisbon, where the expected anticline has been eliminated by the Ammonoosuc thrust fault, which will be described later. The center of the next syncline to the southeast may be traced from near Streeter Pond in a general southwesterly direction just west of Pearl Lake, Landaff, and Whites Pinnacle, and finally leaves the quadrangle one and one-half miles southwest of Center Haverhill. Only the northwest limb of this fold is preserved, however, and the southeast limb has been cut out by the thrust fault extending southwest from Northey Hill. The relations are shown in sections BB′ and CC′ of the Moosilauke quadrangle. This fold has been named the Salmon Hole Brooke syncline.

The next fold to the southeast is the Garnet Hill syncline, which may be traced from Garnet Hill to Landaff, where a big intrusion of the Bethlehem gneiss cut it out. It is well shown in section AA′ of the Moosilauke quadrangle and it will be observed that it is overturned so that both limbs dip in the same direction, that is, toward the northwest.

Still further to the southeast is the Bronson Hill anticline, which may be traced from Sugar Hill through Bronson Hill, Scotland School, Benton, and Long Pond to the Sanitarium at the south end of the quadrangle. This fold is best shown at the left end of section AA′ of the Moosilauke quadrangle; in the other sections igneous intrusions complicate the relations.

The great belt of schists extending from Mt. Moosilauke to Easton may be best described as a screen, for it is bounded on both sides by igneous intrusions, and in the strictest sense of the definition is neither an anticline or a syncline. That this mass is actually thrown into a series of folds, as shown on sections EE′ and FF′, can be demonstrated on the numerous slides at the head of Tunnel Brook on the west slope of Mt. Moosilauke.

Countless minor folds are superimposed on the major folds of the Littleton and Mossilauke quadrangles. Many of the smallest may be seen in individual outcrops. Others may be deduced from the ground plan of the contacts between formations. Many of those shown on the sections, however, are diagrammatic, for, although they clearly represent the nature of the structure, their precise number, size, and distribution cannot be determined by present geological field methods. The tiniest ones, even though observed, cannot be represented, due to the scale employed.

Thrust Faults

Numerous thrust faults are present in the area, but only the three major ones can be described here — the Ammonoosuc, the Northey Hill, and the Hogsback.

Ammonoosuc thrust. This thrust may be traced from Parker Mountain in the Littleton quadrangle in a general southwesterly direction, passing east of Walker Mountain, through Perch Pond, west of Lisbon, and leaving the Moosilauke quadrangle in the vicinity of Childs Brook. The average dip of the Ammonoosuc thrust is 37° NW. In the Woodsville quadrangle, about one-half mile southwest of the place where the thrust leaves the Moosilauke quadrangle, the fault plane may be seen in several places and the dip at three different localities measured as 32°, 36°, and 38° NW. One and one-fourth miles N 80° W from the bridge over the Ammonoosuc River at Lisbon the fault dips 32° NW. At a sawmill one-half mile northwest of Salmon Hole School the fault plane is exposed in Youngs Brook, and dips 50° N. W. From the mapping at Parker Mountain in the Littleton quadrangle, one may calculate the dip to be 31° N. W.

In several places the rocks adjacent to the Ammonoosuc thrust have been strongly silicified, with the development of considerable vein quartz. This silicified zone is not always wide enough to show on the geological map, but this has been done in four localities — northwest of Lisbon, east of Walker Mountain (two places), and on the east slope of Parker Mountain.

The movement along the Ammonoosuc thrust is believed to have been directly up the dip, for at the locality in the Woodsville quadrangle already mentioned there is a distinct mullion structure or ribbing extending directly down the dip of the fault plane. The fault is believed to have developed after the folding had ceased and the nature of the movement is shown elsewhere (2). The hanging wall—that is, the area to the northwest — moved upward toward the southeast and the minimum displacement was two and three-fourths miles. In all the sections the fault is shown with the same dip continuing indefinitely downward, but it is entirely possible that the dip becomes less with depth. A diagram illustrating the formation of this fault has been published elsewhere (2).

Northey Hill thrust. This fault may be traced from northeast of Northey Hill in a general southwesterly direction as far as Landaff, where it is apparently cut out by the intrusion of the Bethlehem gneiss. In general the dip of the fault is rather steep, but at the north end it appears to dip rather gently toward the northwest. This fault is believed to have developed during the folding, and the northwest side was driven upward toward the southeast.

The Hogsback thrust. This may be traced from the north slopes of Sugarloaf Mountain toward the southeast, passing just northeast of the crest of The Hogsback, and leaving the quadrangle between Owls Head and the State Sanitarium. Although the fault plane has never been observed, it is believed to dip about 45° to the north, northeast, and east. The hanging wall — the block to the northeast — has been driven southwestward relative to the foot wall. Two lesser thrusts are present on Sugarloaf Mountain, and movement along them has piled up the Clough conglomerate to a thickness of 600 feet.

Igneous Bodie

Space permits a discussion of the shape and mechanics of intrusion of only the larger igneous bodies.

Owls Head granite. Structually this granite and the adjacent sediments form a great dome, only half of which is exposed in the Moosilauke quadrangle. The structure is well shown in sections FF′, EE′ and GG′, of the Moosilauke quadrangle. The surrounding sediments and volcanics wrap around in a great semicircle and dip outward in all directions at angles of 30° to 40°, to the west on the west side, to the north on the north, and to the east on the east. The foliation of the granite has the same structure, as shown on the geological map and cross sections, and this is believed to indicate that the top of the granite conforms to the structure of the sediments. The dome is clearly due to the granite lifting its roof while being intruded. It is as yet uncertain as to whether this body has a floor, but the writer believes that the evidence in the Mt. Cube and Rumney quadrangles favors this interpretation, and that the body may be a true laccolith.

This intrusion is believed to have preceded the great period of folding. This conclusion is based primarily on the simple, domical shape of the roof. After working for two field seasons in the intensely crumpled strata of the Littleton and the northern part of the Moosilauke quadrangles, the writer was amazed to see the relatively simple structure of the Clough conglomerate extending from The Hogsback through Sugarloaf and southwest to East Haverhill. It would be absolutely impossible for such a simple structure to develop after the rocks had been crumpled. The Owls Head dome must be older than the folding. The strongly granulated character of the granite is additional evidence suggesting that it is older than the folding. During the folding the Owls Head granite dome served as a great buttress controlling the other structures.

Bethlehem Granodiorite Gneiss. Three bodies of the Bethlehem gneiss are known in the Littleton and Moosilauke quadrangles. The mass that extends southwest from Landaff, which may be considered the type example, extends about a mile into the Woodsville quadrangle, where it ends in a blunt termination. In ground plan this body is eleven miles long, and averages one mile in width, although locally it exceeds two miles. It is clearly concordant with the regional structure in plan. The manner in which its contacts cross hills and valleys without appreciable variation indicates that the contacts must be relatively steep in cross section. Moreover one and one-fourth miles ENE of Center Haverhill the northwestern contact has been observed to be vertical; one and three-fourths miles WSW of Center Haverhill this same contact dips about 80° NW. East of Green Mountain, although the exact contact could not be observed, it is clearly very steep and essentially parallel to the foliation. The body thus appears to have the shape of a gigantic sill, as shown in sections CC′, DD′, and EE′. As shown on the geological map this body is more or less foliated throughout its extent, the foliation striking parallel to the contact and dipping from 80° NW to vertical. The foliation is considered to be a primary flow structure, which, however, was utilized for additional movements after the rock had become consolidated.

The manner in which the sediments wrap around this mass of Bethlehem gneiss indicates that it made room for itself, in large part, by pushing aside the adjacent formations, and, in part, by lifting them up. A limited amount of the room now occupied by the gneiss was made by ripping fragments off the walls. There are a number of reasons for believing that the Bethlehem gneiss was intruded during the later stages of the folding.

Kinsman quartz monzonite. Only the western edge of this body is exposed in the Mossilauke quadrangle, but field work in the Franconia quadrangle indicates that it has the same general shape as the Bethlehem gneiss, although much larger. It is at least twenty miles long, averages four miles in width, and has a maximum width of six miles. In ground plan it is concordant to the regional structure. That the western contact is very steep is demonstrated by the manner in which it climbs 2000 feet just south of Kinsman Notch without any important variation in its north-south trend. The average dip of the foliation on both sides of the contact suggests that it dips 60° NW, but south of Kinsman Notch it appears to be about vertical. This body is apparently shaped like a gigantic sill or lens, dipping steeply northwest, and is believed to have been intruded during the last stages of the folding.

French Pond granite. Most of the boundaries of the French Pond granite are very poorly exposed, but the northern boundary may be traced with considerable accuracy. The schistosity of the volcanics to the north of the granite and a local, weak foliation within the granite itself strike northwest and dip about 75° to the southwest. This suggests that the contact may dip at the same angle. Moreover, the manner in which the normal northeasterly strikes are distorted around the French Pond granite implies that it forced its way in.

Chapter VI. Physiography and Glacial Geology

Physiography. The Littleton-Moosilauke area may be briefly characterized as a maturely dissected region, the principle features of which have been carved by streams and rivers working through untold centuries. Many thousands of feet and probably several miles of rock have been worn away since the period of folding. Glaciation, both continental and mountain, have modified the details of the topography both by erosion and deposition.

Consideration of the geological map reveals that there is a remarkable correlation between topography, lithology, and structure. The general northeasterly "grain" of the district, particularly noticeable in the Littleton quadrangle and the northern part of the Moosilauke quadrangle, is clearly controlled by the distribution of formations, which in turn, is controlled by the structure. Gardner Mountain is higher than its surroundings due to the resistant quartzites of the Albee formation exposed in the core of the Gardner Mountain anticline. The range of hills extending southwestward from Walker Mountain through Mormon Hill and Trevina Hill is held up by the resistant Devonian sandstones in the Walker Mountain syncline. Mt. Moosilauke stands high because of the large area of resistant Devonian sandstone, now converted to quartz-mica schist; and as this belt narrows toward the north, this range breaks down. The Hogsback owes its unusual northwesterly trend to the resistant Clough conglomerate on the northeast flanks of the Owls Head dome, and the ridge suddenly breaks down at the south end, due to the elimination of the Clough conglomerate by faulting. Sugarloaf is a mountain because the Clough has been piled up by thrust faulting to at least three times its normal thickness, but the ridge rapidly breaks down to the southwest as the Clough becomes thinner. Black Mountain owes its height to an unusual concentration of the resistant Clough conglomerate by folding and thrust faulting.

*Glacial Geology**. During the Ice Age this district, like the rest of New England, was completely covered by the continental ice sheet. Grooves and finer scratches on ice-worn surfaces of rock indicate a nearly due southward movement, except near the summit of Mt. Mossilauke, where the course was as definitely toward the southeast. Probably the difference is due to change in direction during successive stages, the southward striae generally registering later movement and the other the earlier, which is preserved only on summits high enough to have been uncovered by downward melting before the close of the glaciation.

Crescentic fractures, an unusual kind of glacial marking, appear on quartzite ledges one-half mile northeast of the sum-

*The section on glacial geology is based largely on data supplied by W. Goldthwait.

mit of Northey Hill (11). In ground plan they have the shape of a crescent, a few inches across from tip to tip, invariably occur in groups, and are convex in the direction from which the ice came. Glacial striae, wherever present, bisect the crescents.

Ice laid drift or till varies greatly in composition and in thickness. Locally, as west of Sugar Hill, it is over 100 feet thick and very compact from the pressure of over-riding ice; but more commonly it ranges from ten to twenty-five feet in thickness. It tends to become looser among the mountains, perhaps because of relatively stagnant ice during the later stages of occupancy, when much of the drift was released. Exposures and many borings at Fifteen Mile Falls during the construction of the dam and retaining wall revealed a two-fold record of the last glaciation (5), with alternating sheets of till and lake deposits which total more than 200 feet. According to detailed studies the edge of the retiring ice allowed clays and silts to accumulate in a lake for at least 119 years, and then readvanced across the deposit, picking up some of it and smearing a new till sheet over the rest, and finally wasted back toward Canada 270 years after its first retreat. Strongly crumpled bedding where the readvancing ice dragged bottom on the lake beds and jammed till into them show that here, at least, there was active movement and not stagnation in the last stages of the Ice Age.

Much of the glacial drift was deposited in bodies of standing water as the ice was melting away. Clay and some sand accumulated on the bottom of temporary lakes, and gravel and sand were deposited either as deltas built out into temporary lakes or as irregular deposits in small pools. The wasting away of the ice sheet here, as elsewhere in New Hampshire, seems to have consisted first in the downward melting of its surface for a very long period of time before there was a general northwesterly recession of the ice edge across the country. Indeed, it appears likely that in this rugged interior of New England the thinning down of the ice surface from contour to contour produced ice margins of extreme irregularity and that lingering masses of stagnant ice continued to occupy the valleys long after it had melted off the higher slopes. The principal valleys that drain southward or southeastward show kames and kame terraces where outwash gravels and sands settled in crevasses and pools which lay between the stagnant ice in the valley and the hill slopes.

Valleys which drain toward the north and west, however, appear to have held temporary lakes with outlets toward the south. One such body occupied the upper part of the Wild Ammonoosuc valley. It was held in on the southeast by the Mt. Kinsman, Mt. Wolf, and Mt. Mossilauke ranges, and on the northwest by a shifting ice front. At some stages the lake may have been very small, but when the ice front extended from the Kinsman Range to Black Mountain it was relatively large. One proof of the presence of this lake is the presence of varved clays at an elevation of 1830 feet on the middle fork of Reel Brook. The surface of this lake, since it drained to the south through Kinsman Notch, was something higher than 1870 feet. It was at this time that many of the features of Lost River evolved. Potholes of large size drilled in the bed rock appear to have been ripped up by readvancing ice and recut; but no full analysis of the phenomena has been made by the writer. Sayles has discussed the origin of Lost River (16).

Kinsman Notch was the lowest point in the shore of this lake and was the outlet until the ice began to melt back from the north slopes of Howe Hill. Eventually a stage was reached when this outlet was lower than Kinsman Notch, and the waters now drained around the north slopes of Howe Hill. Steep-sided crevasse fillings and spillway trenches cross the road less than a mile southwest of Benton Village. Later, lower escape is similarly shown by two stream-swept gaps and kames between Benton and Whites Pinnacle.

In late glacial time an arm of Glacial Lake Hitchcock occupied the Ammonoosuc Valley. Varved clays deposited in this lake are exposed in the state highway one mile east-northeast of Bath, where some two hundred annual layers were well displayed when the cut was new.

The effects of extinct mountain glaciers may also be observed in the district. Jobildunk Ravine, on the east slope of

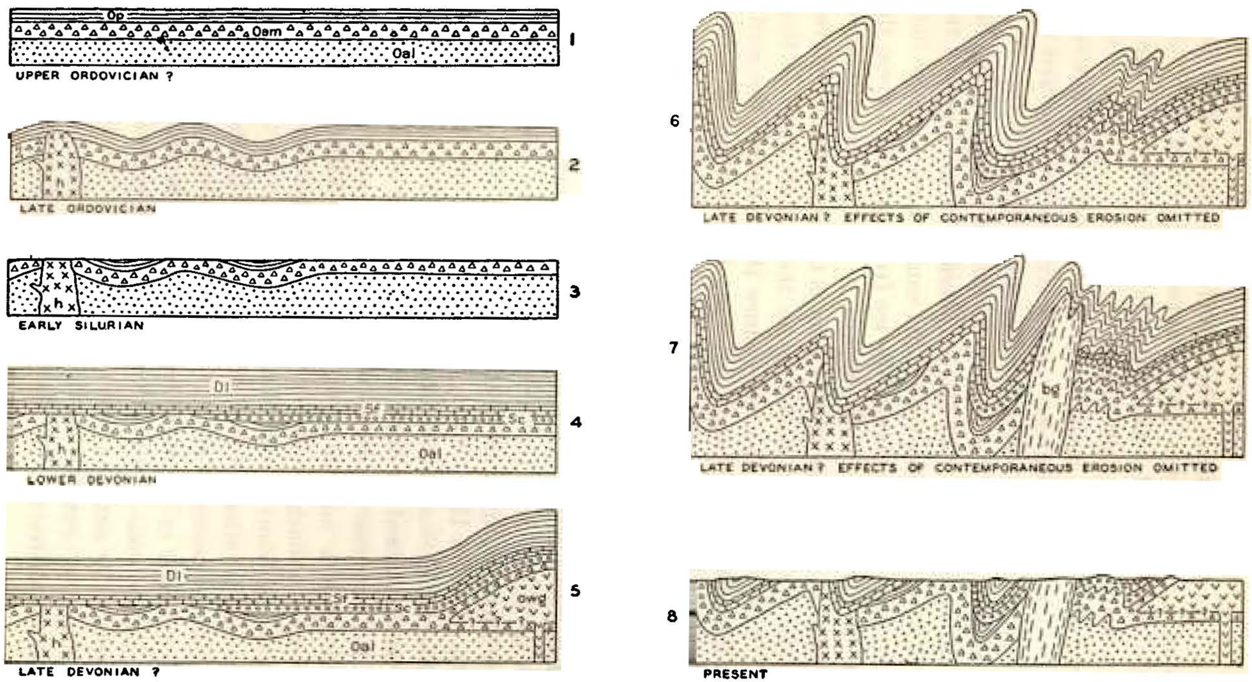

FIGURE 2. Series of diagrammatic sections to illustrate the geological history of the Littleton and Moosilauke Quadrangles. Oal=Albee formation; Oam=Ammonoosuc volcanics; Op=Partridge formation; h=Highlandcroft granodiorite; Sc=Clough conglomerate; Sf=Fitch formation; Dl=Littleton formation; owg=Owls Head granite; bg=Bethlehem granodiorite gneiss. See text for further explanation.

Mt. Moosilauke, is a good example of a glacial cirque. It was cut principally before the advance of the last ice sheet.

There is an excellent display of river terraces along the Ammonoosuc River, especially one mile west of Littleton. The highest terrace is about 890 feet above sea level, and below it are several lesser ones. These terraces have been cut in sand, clay, and gravel, but numerous outcrops of bed rock protrude through them. The whole valley may at one time have been filled with clay, sand, and gravel up to the level of the highest terrace, but river erosion since then has carried away much of the sediment.

Chapter VII. Geological History

Our story begins about 375,000,000 years ago, in the latter part of the Ordovician period. The sequence of events is represented diagrammatically in figure 2. The earliest event of which we have any record is the deposition of the Albee, Ammonoosuc, and Partridge formations, probably during the upper Ordovician (fig. 2, stage 1). The Albee formation was laid down as sand and mud in a shallow sea, and was derived from a great land mass which lay somewhere to the east and southeast in what is now the Gulf of Maine. After many thousands of feet of this sand and mud had been deposited, volcanoes went into eruption somewhere to the east, and vast quantities of volcanic debris were swept westward by streams and deposited in western New Hampshire. Very few, if any, of the lava flows extended that far west. Before activity had ceased 2000 feet of volcanic matter had accumulated. There then ensued a period during which mud to a depth of 2000 feet, the Partridge formation, was deposited.

The flat strata were now subjected to horizontal compression and thrown into a series of gentle folds. At the same time the Highlandcroft granodiorite was intruded (fig. 2, stage 2). Streams immediately began to attack the region and it was worn down to a surface of low relief (fig. 2, stage 3). These events probably occurred at the close of the Ordovician.

Then came a new invasion of the sea in Silurian time (fig. 2, stage 4). At first the shore line was not very far away and deposition was rather slow. The waves and currents were able to sort the sediments very carefully, and only the most resistant material, quartz, was preserved. A thin sheet of sand and gravel, probably nowhere more than 150 feet thick, and completely absent over much of the Littleton quadrangle, accumulated; later it consolidated to form the Clough conglomerate. As the shore line moved still further away mud, arkosic sand and calcareous ooze, mud, and sand accumulated in a warm shallow sea. This was during middle Silurian time. The sea teemed with life, and corals, trilobites, brachiopods, and crinoids flourished. About 500 feet of these sediments were deposited. During upper Silurian time western New Hampshire was apparently dry land not very far above sea level, but with the advent of the lower Devonian the great land mass in the Gulf of Maine began to rise more rapidly, and great quantities of mud and sand were carried to western New Hampshire. Periodically great volcanoes went into eruption somewhere to the east, and volcanic debris was carried westward by the streams. Occasionally lava flows reached the Littleton and Moosilauke quadrangles. Most of the deposition of the sand and mud was in a shallow sea, and marine animals, particularly brachiopods, were buried with the sediments. Five thousand feet of these sediments accumulated.

Some time later, while the strata were still flat, a mass of magma was forced into the sediments and domed them up (fig. 2, stage 5). This magma may have risen along a narrow conduit and then spread out to form a laccolith. The magma consolidated and became the Owls Head granite.

Then came the great folding (fig. 2, stage 6). The precise date is unknown, but it was either late Devonian or late Carboniferous, probably the former. The flat strata were caught as in the jaws of a gigantic vise. They were squeezed and thrown into a series of great folds, the crests of which were many miles above the troughs. The whole country was now moving southeastward, folding as it went. Great masses of molten magma began rising in the folding rocks, jamming them apart or pushing them up (fig. 2, stage 7). The sediments were now so hot and under such high confining pressures that they flowed like sticky molasses. In the later stages of the compression, when the rocks had cooled down, and the rocks yielded by rupture instead of by flowage and folding, a great fracture, the Ammonoosuc thrust developed. Along it western New Hampshire was driven southeastward several miles.

As soon as the folding rocks first rose above the sea, they were subjected to erosion and rapidly worn down (fig. 2, stage 8). Although the folds as we now reconstruct them extend many miles into the air, it does not follow that the mountains ever reached this height. Indeed, it is possible, but not probable, that erosion kept pace with the uplift of the folds, and that no mountains developed.

After considerable erosion had gone on, tremendous volcanic activity broke out all over western New Hampshire, and the Moat volcanics accumulated, but all trace of this stage of the history is lost in the Littleton and Moosilauke quadrangles. At the same time great bodies of magma, belonging to the White Mountain magma series, rose into the crust and consolidated. A detailed discussion of this phase of the history is reserved, however, for the pamphlet describing the geology of the Franconia quadrangle.

Throughout Mesozoic and Tertiary time western New Hampshire was deeply eroded. Many thousands of feet, if not miles, of rock were stripped away. It does not necessarily follow that the area ever actually stood higher above sea level than it does today, for the erosion of the rocks was accompanied by a gradual uplift of all New England. There is some evidence in the White Mountain district that the uplifts were periodic, with the development of distinct erosion surfaces, but no detailed study of this phase of the geology has as yet been made.

With the advent of the Ice Age glacial conditions set in. Local glaciers accumulated in the higher mountains, carving great amphitheatres or cirques, such as Jobildunk Ravine. Later the whole district was overwhelmed by the ice sheet from the north, which capped even the highest mountains of the Littleton and Moosilauke quadrangles. Some of the details of this epoch have been described in the section dealing with the glacial geology. Very little change has taken place in post-glacial time. The river terraces along the Ammonnosuc River were cut and the great slides developed.

Chapter VIII. Mineral Occurrences*

Early geological reports (10 and 7, vol. III, pt. V) and records (6) contain enthusiastic references to the potential mineral wealth of this part of northern New England. Various kinds of deposits have been discovered in the region, and although there are no active mines or quarries here now, the presence of numerous small shafts, tunnels, and abandoned quarries bear eloquent though silent testimony of efforts made in bygone days to establish and maintain a mining industry. Many of these old workings are merely prospect pits, others were operated for a number of years with fair success. The more interesting localities are noted on the geological maps by the conventional symbol.

Slate, granite, and soapstone have all been obtained within the area at one time or other. The largest slate quarry, abandoned sixty years ago, is at Slate Ledge, in the lower part of the Littleton formation. Granite has been obtained in the past from the French Pond granite at the summit of Pond Ledge. There is an old soapstone quarry, omitted by oversight from the geological map, one mile N 30° E of the Brier Hill School, in the west central part of the Moosilauke quadrangle. Of passing interest are the attempts on the part of early settlers to locate deposits of coal. Belief that the black graphitic slates of the Partridge formation held promise of it led to the opening of a number of test pits, some of which may still be seen along the valley of Pettyboro Brook.

Lime was formerly obtained from the limestones of the Fitch formation. A number of abandoned quarries and ruins of kilns may be seen in the district. The more important quarries are shown on the geological map. This industry flourished in

*This chapter is based largely on data supplied by Harold M. Bannerman.

the eighteen thirties and forties. The rock is not high grade over large areas, however, and when the railways brought strong competition with more highly organized and extensive producers in other places, the local industry gradually died out.

Magnetic iron ore was discovered and opened at Ore Hill, Lisbon, about 1805. By 1810 a smelter and iron foundry were built at Franconia, and a small iron industry established which persisted with reasonable success during the ensuing forty years. To the mineral collector these deposits still hold much of interest. The chief ore mineral is magnetite. In the main it is fine-grained, dull-black, and strongly magnetic, but beautiful specimens showing a more resplendent black color and well developed octahedral crystals with rounded edges are to be found by breaking open some of the quartz-rich blocks of ore lying on the dumps. Pale red to cinnamon-colored garnets, black, lathlike crystals of hornblende, and pistachio-green epidote may also be obtained.

Gold was discovered in 1864 in a small quartz vein on the south side of Trevina Hill and about two years later the Dodge Mine, one-half mile S 30° W from the Clough Hill School, and other properties were discovered. Stamp mills were erected on the Ammonoosuc River and at Youngs Pond, but the program rapidly drifted into an orgy of speculation (4, p. 438) and by 1878 mining had almost ceased. Hitchcock estimated that between 1868 and 1878 $50,000 worth of gold had been recovered from the various properties (7, vol. III, pt. V, p. 11).

The greater part of the gold-bearing deposits in this district occur as small veins in the schistose rocks of the Littleton and Ammonoosuc formations, though occasionally lenses of pyrite in the Clough conglomerate carry low values of gold. Most of the vein matter is milky quartz with which sporadic amounts of pyrite, ankerite, arsenopyrite, and pyrrhotite occur. In some localities a liberal sprinkling of chalcopyrite is also present, and on the eastern slopes of Gardner Mountain, particularly in Bath and southern Lyman, galena and smaller amounts of sphalerite appear. The veins are small. They tend to occur as irregular lenses and stringers paralleling fault or shear zones in the schists, or as discontinuous gash veins cross-cutting the walls of the fault zones. They have thus been formed since the development of the faulting. Their nature and alignment suggests that they were deposited by ore-bearing solutions circulating through channelways created by fault movements. It is of interest, moreover, to note that with few exceptions they are located on the west side (hanging wall) of the Ammonoosuc thrust to which the smaller faults may be related.

Properties that are of some interest to the mineral collector are: the "Dodge Mine", one-half mile S 30° W from Clough Hill School; the "New England Mine", near B. M. 1214, one and one-half miles southwest of Youngs Pond; a property located in the town of Bath, just west of the road near the northwest corner of the Moosilauke quadrangle; the "Granite State", northeast of the property just mentioned; and the "Paddock Mine", one mile west of B. M. 1139, which in turn is one mile northwest of Tinkerville.

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GLOSSARY

Some rock and mineral names which are not used extensively in the text are not defined.

Actinolite	A black to dark-green silicate of lime, magnesia and iron. Bounded by prisms and usually occurs as an aggregate of radiating crystals.
Albite	A white soda feldspar, harder than window glass, striated.
Amphibolite	A dark green to black metamorphic rock consisting essentially of hornblende and feldspar.
Andesite	Dark, grey lava.
Ankerite	A carbonate composed of lime, iron, magnesia and carbon dioxide, pink in color and easily scratched by a knife.
Anticline	An arch-like fold, convex upward.
Argillaceous	Containing clay or of a clayey nature.
Arkose	Sandstone containing considerable feldspar.
Arsenopyrite	A silver-white, metallic sulphide, harder than a knife.
Auriferous	Carrying gold.
Basalt	Dark, dense lava.
Batholith	A large body of igneous rock which solidified below the surface of the earth and apparently extends down at least several miles.
Bedding	The arrangement of sedimentary rock in distinctive layers.
Biotite	Black mica.
Breccia	A rock composed of various sized angular fragments cemented together; in this paper refers to fragmental volcanic rocks.
Calcareous	Containing calcium carbonate.
Carbonate	Salt of carbonic acid.
Carboniferous	Geological period extending from 175,000,000 to 290,000,000 years ago.
Chalcopyrite	Brass-yellow copper mineral, easily scratched by a knife.
Cirque	A large amphitheatre carved in rock by a mountain glacier.
Chlorite	A green, mica-like mineral.
Cleavage	A structure by virtue of which breaking is easier in certain directions than in others.
Crevasse-filling	A jumbled mass of glacial drift relatively long and narrow; accumulated in a fracture in the ice.
Devonian	Geologic period extending from 290,000,000 to 330,000,000 years ago.
Dike	A tabular body of igneous rock filling a fracture in older rocks.
Diopside	A green silicate of lime, magnesia, and iron.
Diorite	Medium to coarse-grained rock composed dominantly of plagioclase feldspar and dark minerals.
Dip	Angle of inclination from the horizontal plane.

Dolomite — Rock similar to limestone or marble but richer in magnesia.

Epidote — A yellowish-green mineral, harder than a knife.

Epizone — Region of low-grade metamorphism.

Fault — Fracture in the crust of the earth, and along which there has been relative displacement of the walls.

Feldspar — Name applied to a group of associated minerals. Harder than glass. Cleavage at right angles or nearly so. White, gray, red, bluish, or greenish usually. Essential constituent of most igneous rocks.

Flank — One of the two parts of an anticline or syncline on either side of the axis.

Foliation — A platy structure in rocks due to the parallelism of flat minerals.

Foot Wall — The underlying wall of a fault.

Formation — Any sedimentary bed or consecutive series of beds sufficiently homogeneous or distinctive to be considered a unit and given a name.

Fossil — The remains or trace of an animal or plant preserved in the rocks of the earth.

Galena — A shiny black sulphide of lead. Cleaves into cubic form.

Garnet — In this area a red mineral, a fraction of an inch across and usually bounded by crystal faces; harder than a knife; a silicate of aluminum and iron.

Gneiss — A metamorphic or igneous rock generally consisting of alternating dark and light bands.

Granodiorite — A granitic rock, intermediate in composition between granite and diorite.

Granulite — A metamorphic rock, which by recrystallization possesses a granular structure.

Greenstone — Dark-green, altered volcanic rock, found in areas of low-grade metamorphism.

Hanging Wall — The overlying wall of a fault.

Hornblende — A black silicate of lime, iron, and magnesia. Usually in needles or prisms a fraction of an inch long; slightly harder than a knife.

Igneous rocks — Rocks formed by the solidification of molten magma.

Intrusive — Rock which has congealed from the molten state beneath the surface of the earth.

Jasper — An opaque, compact, non-crystalline, variety of quartz, stained red, brown, green, or yellow.

Kame — A circular or irregular mass of glacial gravel and sand.

Katazone — Region of high-grade metamorphism.

Laccolith — A mushroom-shaped igneous mass intruded between sedimentary beds; it domes up the overlying sediments.

Limb — See flank.

Lithology — The study of the rocks.

Magma — "Molten rock" originating within the earth; when it pours out on the surface it forms lava flows.

Magnetite	Black magnetic iron ore, often in octahedrons.
Massive	Non-bedded and non-foliated.
Matrix	The natural material in which any metal, fossil, pebble, fragment, or crystal is embedded.
Mesozoic	Geologic era extending from 60,000,000 to 175,000,000 years ago.
Mesozone	Region of medium-grade metamorphism.
Metamorphism	A change in mineralogical composition of a rock due to a change in pressure, heat, or moving solutions.
Muscovite	White mica.
Ordovician	Geologic period extending from 355,000,000 to 415,000,000 years ago.
Outcrop	Locality where bed-rock is exposed.
Paleozoic	Geologic era extending from 175,000,000 to 515,000,000 years ago.
Pegmatite	A very coarse-grained rock, composed principally of feldspar, quartz, and mica.
Phenocryst	A crystal that is much larger, relatively, than the crystals of the matrix in which it is embedded.
Phyllite	A rock intermediate in character between a slate and a mica schist.
Plagioclase	That variety of feldspar rich in soda and lime.
Pleistocene	Geologic epoch extending from 25,000 to 2,000,000 years ago.
Plunge	Angle which the axis of a fold makes with the horizontal plane. Analogous to a ridge pole of a roof if building were tilted.
Porphyry	An igneous rock in which there are large crystals embedded in a finer-grained matrix.
Pyrite	Brass-yellow iron sulphide, harder than a knife; "fool's gold".
Quartz	A very hard, glassy mineral. Prominent in quartzite, granite, etc.
Quartzite	Hard, resistant rock composed dominantly of quartz.
Quartz-monzonite	A granitic rock in which the percentages of plagioclase and potash feldspars are approximately equal. Quartz is present.
Sandstone	A rock composed of more or less rounded mineral grains, usually quartz.
Schist	Any metamorphic rock with a highly foliated structure and no distinct banding.
Sedimentary rock	Usually in layers and in most cases has been deposited in water, either a sea, lake or river.
Sericite	Very fine-grained white mica.
Silicified	Impregnated with quartz or silica.
Sill	Tabular body of igneous rock intruded parallel to the bedding of the rocks.
Sillimanite	A white, fibrous mineral in crystals from one-half to two inches long.
Silurian	Geologic period extending from 330,000,000 to 355,000,000 years ago.
Soda-rhyolite	A lava, equivalent chemically to granite, but containing more soda than potash.

Soda-trachyte	Lava, chemically equivalent to syenite, but rich in soda.
Spillway	A passage-way through which a temporary lake drained.
Staurolite	A brown mineral bounded by prisms, and in many places from one to three inches long.
Stock	Similar to a batholith but generally circular in shape and less than 40 square miles in area.
Strata	See bedding.
Strike	Trend in ground plan of bedding, fault, etc.
Structure	The attitude and relative positions of rock masses.
Syenite	A granitic rock without notable quartz. Dominantly potash feldspar.
Syncline	A fold, convex downward.
Tertiary	Geologic period extending from 2,000,000 to 60,000,000 years ago.
Thrust	A fault due to compression and in which the hanging wall moves up relative to the foot wall.
Tonalite	Rock similar to diorite except for the presence of quartz.
Tuff	A rock composed of the finer kinds of volcanic detritus, usually more or less stratified.
Unconformity	An erosion surface which separates a geological formation from the underlying rocks and indicates a long lapse of time.
Varved clays	Distinctly layered clays, each pair of layers having taken one year to deposit.
Vitreous	Glassy.
Volcanic rock	Lava flow or fragmental material thrown out of a volcano.