THE PETROLOGY OF THE NORTH CONWAY QUADRANGLE IN THE WHITE MOUNTAINS OF NEW HAMPSHIRE

By Marland Billings.
Harvard University, Cambridge, Massachusetts.

Presented by Esper S. Larsen.

Received April 11, 1928. Presented by title, April 11, 1928.

TABLE OF CONTENTS.

LIST OF PLATES AND FIGURES.

CHAPTER I.

Introduction.

Location. The North Conway quadrangle, mapped by the United States Geological Survey on a scale of 1 : 62,500, is in the east-central part of the State of New Hampshire and is approximately one hundred and fifty miles north of Boston, Massachusetts (see figure 1). The quadrangle is bounded by latitudes 44° 00′ and 44° 15′ and longitudes 71° 00′ and 71° 15′. The region may be reached from Boston by the Boston and Maine Railroad or from Portland, Maine, by the Maine Central Railroad, or by excellent highways from either city.

Topography and Drainage of the White Mountains. North Conway is in the southeastern part of the White Mountains section of the New England physiographic province (see figure 1). As Fenneman (1)[1] has pointed out, the boundaries between the White Mountains and the New England Upland are of necessity vague. The White Mountains physiographic section, as it is termed by Fenneman, trends northeasterly from central New Hampshire into western Maine, and the total length along the axis of the section is somewhat more than one hundred miles. The mountains comprise a glaciated and maturely dissected mountainous region of relatively high relief developed on crystalline rocks. The culminating summit of the whole section is Mt. Washington, which is somewhat southwest of the geometric center of the group. It attains an elevation of 6290 feet above sea level and of more than a mile above the valleys at its base. A number of peaks in the Presidential and Franconia Ranges exceed 5000 feet in elevation and many summits are higher than 4000 feet.

As shown in the accompanying map (Figure 1) the Presidential Range, in the southern part of the White Mountains section, is the center of a drainage system that radiates in all directions. The Saco River flows southeastward into the Atlantic Ocean, the Pemigewasset southward to the Merrimack, the Ammonoosuc westward to the Connecticut, and the Peabody northward to the Androscogin.

Although many of the major ranges, such as the Presidential, Baldface, Carter-Moriah, Carrigain, Dartmouth, and Randolph Ranges, have a general northeasterly trend, the fact that impresses one in the field is the apparent lack of definite plan in the distribution of the mountains. One range may trend northwesterly, as the Moat Range,

[1] The numbers following an author's name refer to the bibliography at the end of the chapter.

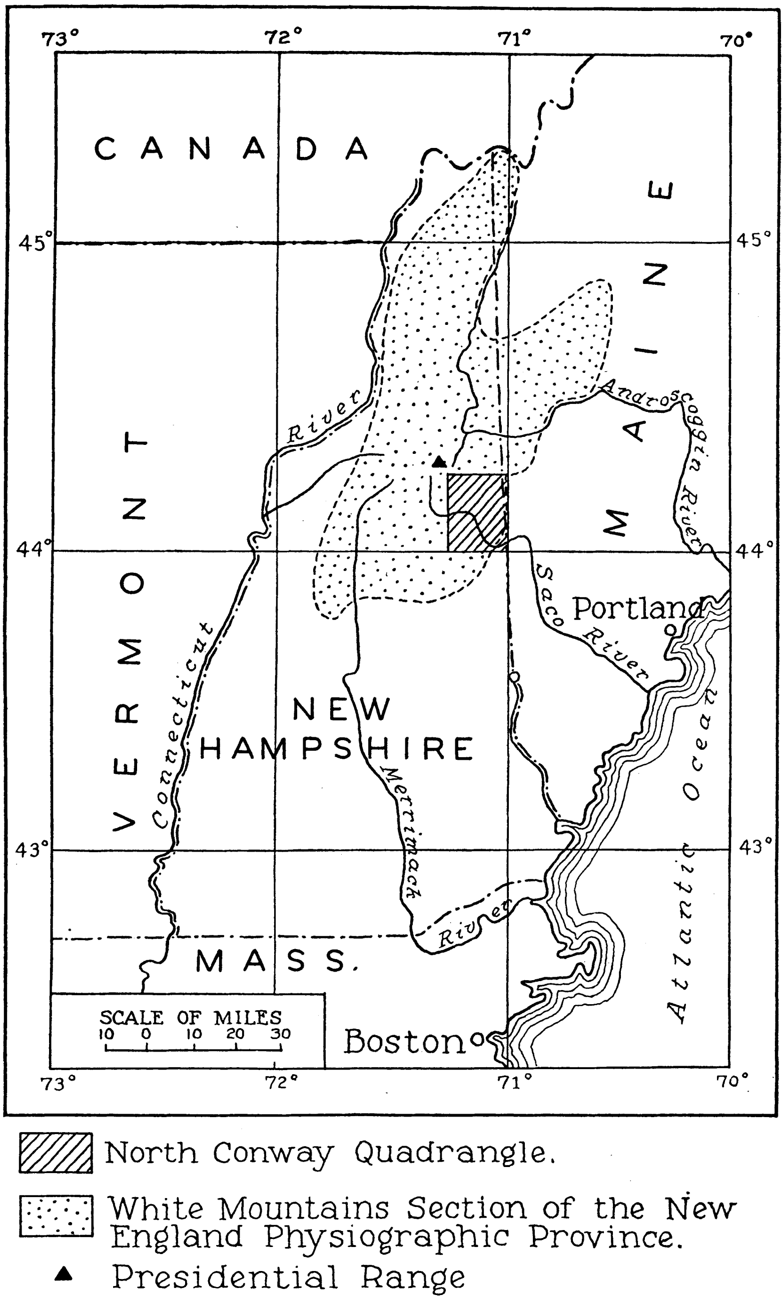


FIGURE 1. Location of the North Conway quadrangle and the White Mountains section of the New England physiographic province.

but a closely adjacent series of peaks may trend easterly, as the Sandwich Range. Some groups show no systematic arrangement as, for example, in the southern third of the Crawford Notch quadrangle, where Table Mountain, Bear Mountain, Bartlett Haystack, Mt. Tremont, Owl Cliff, Greens Cliff, Mt. Kancamagus, and Mt. Huntington have a very erratic distribution.

Many of the summits, such as Moat and Chocorua, are bare and open due to forest fires which have swept over them in the past and destroyed the soil cap. The summits of the Presidential Range are treeless because they rise above timber-line, which is at approximately 4800 feet above sea-level but varies with several factors. The peaks are not sharp pinnacles, but many of them have relatively steep slopes; others are rounded or even flat-topped.

Topography, Drainage, and Culture of the North Conway Quadrangle. The topography and drainage of the quadrangle are adequately expressed by the United States Geological Survey's topographic map of the North Conway quadrangle. The mountain masses are irregularly distributed; the summits are subdued and in the higher ranges attain elevations from 3000 to 3600 feet. The only important stream is the Saco River, which meanders across a flood-plain, incised in the sand terraces of a valley which varies from half a mile to two miles in width (see Plate IIA).

North Conway, with 1,500 inhabitants, is the largest town in the quadrangle. Good roads and trails make most portions of the quadrangle readily accessible, but Perkins Notch, Sable Mountain, and Chandler Mountain are relatively isolated and inaccessible. The chief industry of the area is catering to summer tourists. A number of hotels are located at North Conway and Jackson, and many small boarding houses are found in the valleys. The lumber industry was once important, but in 1920 the major operations ceased. Farming along the flood-plains of the rivers is a profitable business, the chief crops being hay and corn. The corn is canned each fall at Conway, North Fryeburg, and West Fryeburg; all three of these villages are just beyond the limits of the North Conway quadrangle. A large proportion of the timber land is now owned by the Federal government and is part of the White Mountains National Forest.

Previous Geological Work. The earliest work on the geology of the whole state of New Hampshire is that by C. T. Jackson (2) in 1844, but it is of no practical value for the present work. For the North Conway quadrangle the chief geological reference is C. H. Hitchcock's "Geology of New Hampshire," in five volumes, published fifty years ago. On the whole I have followed rather closely Hitchcock's classification of the formations, although some re-definition and subdividing has seemed advisable. He made a lithological classification of the granites and syenites of the White Mountains alkaline batholith. His classification of the metamorphic rocks will probably have to undergo considerable revision, but it has not been found necessary to consider that problem in the North Conway quadrangle. As for the structural and chronological relations of the various groups, Hitchcock's work is of little value. The mapping was poor in details, but, considering the conditions under which the survey was carried on, Hitchcock did a wonderful piece of work. The following table is given to facilitate a comparison of the terminology used by Hitchcock (3) with that of the present paper.

TABLE I.

COMPARISON OF FORMATIONAL NAMES.

HITCHCOCK.	THIS PAPER.	
Modified drift	Stratified drift	
Glacial till	Glacial till	
Conway granite	Biotite granite	
	Black Cap biotite granite	
Chocorua group	Riebeckite granite	
	Hastingsite granite	
	Nordmarkite	
Albany granite	Porphyritic nordmarkite	
	Certain contact phases of the Conway biotite granite.	
	Nordmarkite porphyry	
(Not recognized)	Diorite	
Pequawket breccia	Pequawket breccia	Moat volcanics
Quartz porphyry	South Moat flows	
Porphyritic gneiss	Meredith porphyritic granite	
(Kearsarge andalusite group)[2]	Intervale clay-slates	
Montalban group	Chatham granite	
	Montalban schists	

In determining the chronological sequence and the relations of the various formations, the writer found little help in the work of

[2] In the North Conway quadrangle Hitchcock mapped certain clay-slates as "Kearsarge andalusite group"; in the opinion of the present writer the clay-slates of the North Conway quadrangle do not belong to Hitchcock's "Kearsarge andalusite group" and for this reason they are mapped as a new formation.

the past. Perry's (4) analyses of the comendites from Mt. Pequawket (Mt. Kearsarge) are of value, and Daly (5) published a short paper on the Pequawket breccia. Other papers that have been of great aid, although they were concerned with areas outside of the North Conway quadrangle, are Daly's (6) paper on the New Hampshire (Meredith) porphyritic granite, the paper by Pirsson and Washington (7) on the nepheline syenite of Red Hill, and the paper by Pirsson and Rice (8) on Tripyramid Mountain. Hawes' (9) paper on the Albany contact zone is classic. The recent booklet by Goldthwait (10) on the "Geology of New Hampshire" contains a bibliography and gives a popular account of the geology.

Nothing has been written directly on the physiography of the North Conway quadrangle, but the papers by Goldthwait on the glacial geology (11) and physiography (12) of the Presidential Range are of great value. Lane (13), Johnson (14), Lobeck (15), and I. B. Crosby (16), have contributed to the studies on the glacial geology and physiography of the White Mountains.

A number of mineralogical papers have been published by Kunz (17), Eakle (18), Farrington and Tillotson (19), Schaller (20), and the present writer (21), on the topaz and phenacite from Baldface Mountain. J. L. Gillson (22) has recently published a paper on the paragenesis of the minerals in the Conway biotite granite.

Method of Study; Acknowledgments. The field work for the present paper was done during the summers of 1925 and 1926 under the direction of Dr. E. S. Larsen. Dr. Larsen was in the field with the writer for ten days during the first season. The Government topographic sheet, surveyed in 1892, was used as a base, and although grossly inaccurate in many details, it suffices for an area composed primarily of igneous and metamorphic rocks. All elevations were determined by aneroid barometer, and as a rule are probably accurate to within thirty feet. The petrographic studies were made under the direction of Dr. Larsen, the crystallography was studied under the guidance of Dr. Palache, and the physiographic studies were discussed with Dr. Mather. Dr. Daly suggested the North Conway area as a possible thesis subject. The thin sections for the petrographic study, nearly three hundred in all, and the chemical analyses by W. H. Herdsman and Mrs. S. Parker were financed from the Holden fund at Harvard University.

Advance Summary. The geological history of the North Conway quadrangle is summarized in the following table, which also indicates the various chapters in which the various sections are discussed.

TABLE II.

GEOLOGICAL HISTORY OF THE NORTH CONWAY QUADRANGLE.

Pre-Cambrian (?)	*Montalban Schists. Chapter II.* Deposition of shales, limestones, and sandstones which were later to become the Montalban schists.
Pre-Cambrian (?)	*Chatham and Meredith Granites. Chapter III.* Folding and metamorphism of the sediments to form the Montalban schists, accompanied by the intrusion of granites.
Silurian (?)	*Intervale Clay-Slates. Chapter II.* Deposition of muds and sands was followed by a mountain making movement. (This phase of the history is a little uncertain, because the clay-slates may be merely the less intensely metamorphosed equivalent of the Montalban schists.)
Devonian (?)	*White Mountains Alkaline Batholith. Chapter IV.* Lava flows, with associated tuffs and breccias, were extruded upon the surface; diorite, syenites, and granites were intruded as plutonic phases.
Mesozoic and Tertiary	*Subaerial denudation.* The region was subjected to profound subaerial denudation, with repeated uplifts.
Quaternary	*Glaciation and post-glacial erosion.* The region was subjected to glaciation, alpine glaciers in the high ranges preceding the continental ice sheet, which overwhelmed the whole area. Post-glacial erosion has been relatively slight.

REFERENCES.

1. N. M. FENNEMAN. Physiographic divisions of the United States. Annals of the Association of American Geographers, vol. 6, pp. 19–98, 1917.
2. C. T. JACKSON. Final report on the geology and mineralogy of the State of New Hampshire, 376 pages, map, Concord, 1844.
3. C. H. HITCHCOCK. The Geology of New Hampshire. Part I (1894), Part II (1877), Parts III, IV, and V and atlas (1878).
4. J. H. PERRY. Notes on the geology of Mt. Kearsarge. Jour. Geol., vol. 11, pp. 403–412, 1903.
5. R. A. DALY. The quartz porphyry and associated rocks of Pequawket Mountain, (abstract). Science, new series, vol. 3, p. 752, 1896.
6. R. A. DALY. Studies on the so-called porphyritic gneiss of New Hampshire. Jour. Geol., vol. 5, pp. 694–722, 776–794, 1897.

7. L. V. Pirsson, and H. S. Washington. Contributions to the geology of New Hampshire; no. III, on Red Hill, Moultonboro. Am. Jour. Sci., 4th series, vol. 23, pp. 257–276, 433–447, 1907.
8. L. V. Pirsson, and W. N. Rice. Contributions to the geology of New Hampshire; no. IV, Geology of Tripyramid Mountain. Am. Jour. Sci., 4th series, vol. 31, pp. 269–291, 1911.
9. G. W. Hawes. The Albany granite and its contact phenomena. Am. Jour. Sci., 3rd series, vol. 21, pp. 21–32. 1881.
10. J. W. Goldthwait. Geology of New Hampshire. New Hampshire Academy of Science, Handbook number 1 (1925).
11. J. W. Goldthwait. Glacial cirques near Mt. Washington. Am. Jour. Sci., 4th series, vol. 35, pp. 1–19, 1913. Bull. 24, Geol. Soc. Am., pp. 677–678, 1913.
12. J. W. Goldthwait. Remnants of an old graded upland on the Presidential Range of the White Mountains. Am. Jour. Sci., 4th series, vol. 37, pp. 451–463, 1914.
13. A. C. Lane. White Mountain Physiography. Am. Jour. Sci., 5th series, vol. 1, pp. 349–354, 1921.
14. D. W. Johnson. Date of local glaciation in the White, Adirondack, and Catskill Mountains. Bull. 28, Geol. Soc. Am., pp. 543–553, 1917. Also abstract, p. 136.
15. A. K. Lobeck. The position of the New England peneplane in the White Mountain region. Geog. Review, vol. 3, pp. 53–60, 1917. Also abstract in Bull. 27, Geol. Soc. Am., p. 108, 1916. Also abstract in the Annals of the New York Academy of Science, vol. 26, pp. 445–446, 1916.
16. I. B. Crosby. The physiographic history of Pinkham Notch. Appalachia, vol. 15, pp. 462–468, 1924.
Former courses of the Androscoggin River. Jour. Geol., vol. 30, pp. 232–247, 1922.
17. G. F. Kunz. Gems and precious stones of North America, p. 100, 1890.
18. A. S. Eakle. Topaz crystals in the mineralogical collection of the U. S. National Museum. Proc. U. S. Nat. Mus., vol. 21, pp. 361–369, 1898.
19. O. C. Farrington, and E. W. Tillotson, Jr. Notes on the various minerals in the museum collection. Field Columbian Museum, publications, geological series, vol. 3, pp. 131–163, 1908.
20. W. T. Schaller. Phenacite from New Hampshire. Bull. 490, U.S.G.S., pp. 53–54, 1911. Also Zeitschrift für Krystallographie, Band 48, s. 554, 1911.
21. M. P. Billings. Topaz and phenacite from Baldface Mountain, Chatham, New Hampshire. Am. Min., vol. 12, pp. 173–180, 1927.
22. J. L. Gillson. The granite of Conway, New Hampshire, and its druse minerals. Am. Min., Vol. 12, pp. 307–319, 1927.

CHAPTER II.

Montalban Schists and Intervale Clay-Slates.

MONTALBAN SCHISTS.

Distribution and General Relations. The oldest rocks exposed in the North Conway quadrangle form a group of mica schists, lime-silicate rocks, and micaceous quartzites, which were designated the Montalban group by Hitchcock (1). They are often intimately injected by granite intrusives which I have named the Chatham granite. The only large area of the Montalban group is found in the northwestern part of the quadrangle, but unfortunately the exposures are not good, because the outcrops are largely confined to a few of the streams. A second area about two and a half miles long is exposed west of Sloop Mountain, but the heavy covering of glacial drift makes it very difficult to determine the exact boundaries. Small patches of the Montalban schists have been noted on the east slopes of Baldface Mountain and elsewhere as xenoliths in the Chatham granite. Two patches were found west of Mountain Pond apparently as inclusions in the younger nordmarkites.

The best exposures of the Montalban schists are on the Ellis River west of Eagle Mountain and also along the river, just below where it flows out of the Crawford Notch quadrangle. Excellent exposures may be seen in the bed of Meserve Brook, on Tin Mountain, and on the south slopes of Black Mountain. In the bed of the stream to the west and south of Sloop Mountain the exposures are good but difficult to reach.

In general the Montalban schists of the North Conway quadrangle strike northeast and dip on the average about 45° to the northwest. The schistosity is parallel to the original bedding. The present writer has not been able to unravel any broad structures, but occasionally local folding may be detected, as for example along the Ellis River, northwest of Spruce Mountain, where a small anticline is exposed. If the major structure is a monocline dipping toward the northwest, as it seems to be, the Montalban schists must be many thousands of feet thick. There is no field evidence for close isoclinal folding, but the complications introduced by the two series of later intrusives, rock flowage, the heavy glacial drift, the forest cover, and probable faulting have prevented the solution of the structural problem.

The crystalline schists of the North Conway quadrangle may be divided into three major lithological types: (1) lime-silicate rocks, composed essentially of hornblende, white diopside, feldspar, and quartz; (2) mica schists, composed essentially of muscovite, biotite, and quartz; and (3) quartzites, composed essentially of quartz with accessory mica. Intermediate types are common. This classification is genetic: the lime-silicate rocks being metamorphosed limestones, dolomites, and calcareous sandstones; the mica schists, recrystallized shales; and the micaceous quartzites, metamorphosed impure sandstones.

Lime-silicate group. The lime-silicate rocks are rather widespread in the Montalban schists of the North Conway quadrangle and elsewhere in New Hampshire and Maine. Excellent exposures are seen on the south slopes of Black Mountain, between the 1340-foot and 1950-foot contours, where mica schists and sillimanite-mica schists are associated with them. The dip is 33° N. A second series of exposures are displayed in the bed of Meserve Brook, beginning at about 1120 feet and continuing intermittently to 1700 feet; the lime-silicate rocks are here associated with mica schists, injection gneisses, and a few granite dikes. The dip increases upstream from 32° NW to 80° NW. A third occurrence is found on the Ellis River about half a mile south of the uppermost highway bridge over the stream. The lime-silicate rocks are interbedded with mica schists and injection-gneisses, and all are cut by a twenty-foot dike of a muscovite-biotite granite with radiating crystals of black tourmaline. The strata here dip only 12° NE. On the eastern slopes of Spruce Mountain, half a mile north of the Spruce Mountain Camps and about one hundred and twenty-five feet above the valley floor, a lime-silcate rock is exposed beneath mica schists.

In general the lime-silicate group comprises pure white, greenish-gray, or greenish-black, thinly bedded rocks, with or without distinct schistosity and composed essentially of feldspar, quartz, hornblende, diopside, and titanite. Minor accessories include biotite, rutile, apatite, hematite, magnetite, and ilmenite. Both orthoclase and plagioclase feldspar are present, occasionally in the same hand specimen. Although the composition of the plagioclase feldspar is uniform for any given hand specimen, it is very variable in the group as a whole and may range from oligoclase to calcic labradorite (Ab_{28}). The feldspar occurs only in the groundmass and never as porphyroblasts. The diopside is pure white, is anhedral to subhedral in habit, and usually occurs as porphyroblasts set in a granoblastic ground mass of quartz and feldspar. The amphiboles vary in composition. At one end of the series the amphibole is black in the hand specimen:

the pleochroism is X = practically colorless, but with a slight tinge of yellow, Y = green with a brownish tinge, Z = green with a brownish tinge somewhat less noticeable than in Y; $X < Y = Z$. The indices are $\alpha = 1.649$, $\gamma = 1.678$. At the other end of the series the amphibole is green in the hand specimen and practically colorless under the microscope, with the following indices: $\alpha = 1.630$, $\gamma = 1.647$. The optical orientation for both types is $Y = b$, $Z \wedge c = 12° - 17°$. The variations in indices and pleochroism is probably due to differences in the iron content, the amphibole with the lower indices and slight pleochroism being a lime-magnesia amphibole. When the amphibole is very abundant in the rock, as in the amphibolites, it is compact and shows only a slight tendency toward sieve structure, but when it is not abundant the sieve structure is developed to the extreme, the hornblende at times being hardly more than a skeleton crystal. One of the most characteristic features of the metamorphic hornblende is the fact that it has a unique habit, quite unlike that of the typical igneous amphibole. In this metamorphic hornblende the front pinacoid (100) is often strongly developed but the side pinacoid (010) is usually suppressed. In the igneous amphiboles the side pinacoid is usually well-developed. Wherever the amphibole stalks are all parallel to the original bedding and to one another, a distinct nematoblastic structure results.

Obviously, with so many possible mineral combinations a great variety of rocks may result. One of the most striking types is a *white diopside rock*, composed of numerous white diopside porphyroblasts set in a granoblastic groundmass composed of quartz, orthoclase, and plagioclase. Titanite is relatively abundant in wedge-shaped crystals. A variety of this type carries occasional black hornblende porphyroblasts. A second type, a *speckled amphibolite*, is composed of black hornblende porphyroblasts showing pronounced sieve texture, set in a granular groundmass of quartz, orthoclase, plagioclase, and titanite. One variety contains a few diopside porphyroblasts, and another variety contains considerable biotite in the groundmass. In the third major group are found *amphibolites*, composed of abundant stalks of amphibole, with or without distinct parallel arrangement, set in a fine groundmass composed of orthoclase, plagioclase, and quartz. A subtype carries biotite.

Mica schists. The mica schists are platy rocks, composed essentially of mica and quartz with variable amounts of andalusite, sillimanite, garnet, feldspar, and minor accessories. The *andalusite schists* are found in only two localities in the North Conway quadrangle: one at the southern end of Black Mountain, the other in the stream west of Sloop Mountain. They are composed essentially of porphyroblasts of andalusite, often associated with sheaves of sillimanite and flakes of muscovite, set in a groundmass of quartz, muscovite, and biotite. The groundmass is generally lepidoblastic but varies in grain. Accessories include orthoclase, albite, red garnet, black tourmaline, chlorite, magnetite, apatite, and zircon. The *mica schists* are similar except that macroscopic andalusite and sillimanite are lacking. *Garnetiferous mica schists* are rare; they have been noted on North Baldface Mountain.

Hornfels. Hornfelses are relatively wide-spread. They are dense, compact, brittle, purplish-gray rocks without schistosity or cleavage. They may show well-defined bedding planes, particularly on weathered surfaces. The individual strata vary widely in composition, but the essential minerals are biotite and quartz, with important quantities of pyrite, sericite, andalusite, and plagioclase.

Quartzites. Pure white quartzites are practically lacking in the White Mountains; *micaceous quartzites* and *quartzose mica schists* are common.

Character of the original Sediments. From the preceding descriptions it is apparent that the original sediments from which the Montalban schists have been derived were impure limestones and dolomites, calcareous sandstones, shales, arenaceous shales, and sandstones.

Age of the Montalban schists. The age of the Montalban schists is not well determined. In the literature they are generally supposed to be Paleozoic (2), on the basis of a supposed correlation with the dubiously Paleozoic schists of western Massachusetts. No one has actually traced the Montalban schists southward. Recent work by E. B. Knopf (3), moreover, casts doubts on the Paleozoic age of the Massachusetts crystalline rocks. Evidence in the North Conway quadrangle demonstrates clearly that the Montalban schists are older than the Moat volcanics, which are probably Devonian. The present writer has traced the Montalban group eastward to Lewiston, Maine. The work of Perkins and Smith (4) suggests that these gneisses and schists are pre-Silurian. The evidence as a whole is admittedly inconclusive, but it favors an early Paleozoic or pre-Cambrian age for the Montalban schists.

Intervale Clay-Slates.

One small area of clay-slate has been found in the quadrangle. It may be either the less intensely metamorphosed equivalent of the Montalban schists or it may be a fragment of a westward extension of the great Silurian slate belt of central Maine. The present writer favors the latter interpretation, but more field work in the adjacent quadrangles is necessary before the problem can be considered settled. It is proposed to call this group the Intervale clay-slates because the known occurrence in the North Conway quadrangle is found on the southern slope of Mt. Pequawket. The outcrop is just east of the

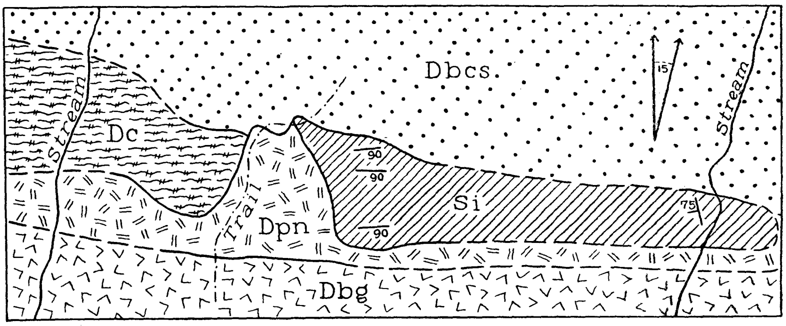


Figure 2. Geological map of the slate belt at an elevation of 1500 feet on the Kearsarge Village trail up Mt. Pequawket. Scale: one inch equals about 750 feet. *Si*, Intervale clay-slate; *Dc*, comendite; *Dbcs*, some comendite, but mainly breccia with many fragments of clay-slate; *Dpn*, porphyritic nordmarkite; *Dbg*, biotite granite. The comendites and breccias were deposited uncomformably on the clay-slate; this group then settled as a great block into the batholith and was intruded by the porphyritic nordmarkite and the biotite granite.

Kearsarge Village trail at an elevation of 1500 feet (see figure 2). Two miles NE of Intervale, in the vicinity of the trail, the slate strikes N 75° E and dips vertically. The cleavage and original bedding are essentially parallel, a fact that may be determined from the occasional quartzite layers interbedded with the slate. This slate is the basement upon which the Moat volcanics, exposed to the north on the mountain slope, rest unconformably; to the south and west the Albany porphyritic nordmarkite is intrusive into the slate and in places shows a quartz-porphyry contact-phase. Most of the fragments in the Pequawket breccia, which is exposed higher up on the mountain, are composed of this clay slate. Fragments of an andalusite-bearing phyllite, which are found in the breccia at the very summit of North Moat Mountain, may represent a contact-metamorphosed phase of this slate.

The clay-slates are black or very dark gray, with a more or less conspicuous silky luster. They show in addition to the regular cleavage, which is parallel to the original bedding, a cross-cutting fracture-cleavage. The slates are composed essentially of somewhat flattened quartz grains and flakes of sericite lying parallel to the slaty cleavage. Important accessories include chlorite, pyrite, and ilmenite.

REFERENCES.

1. C. H. Hitchcock. Geology of New Hampshire.
2. Pirsson and Schuchert. Textbook of Geology, vol. II, 1924; geologic map of North America.
3. E. B. Knopf. Some results of recent work in the southern Taconic area. Am. Jour. Sci., vol. 14, 5th series, pp. 430–458, 1927.
4. E. H. Perkins, and E. S. C. Smith. A geological section from the Kennebec River to Penobscot Bay. American Journal of Science, 5th series, vol. 9, pp. 204–228, 1925.

CHAPTER III.

Older Granites and Regional Metamorphism.

Introduction. In addition to the granites, quartz syenites, syenites, and diorites of the Devonian (?) alkaline batholith, the White Mountains contain large areas of earlier granites, usually characterized by muscovite and biotite. At least three major groups may be recognized. (1) The Bethlehem granite of Hitchcock (1) is a coarse, red, biotite granite; it is not exposed in the North Conway quadrangle and is therefore not discussed in this paper. (2) The Meredith granite (the porphyritic gneiss of Hitchcock) is a coarse muscovite-biotite granite with large orthoclase phenocrysts. (3) I have named a coarse two-mica granite which often intrudes the Montalban group in lit-par-lit fashion the Chatham granite. For a fine-grained and somewhat younger phase of the Chatham granite, which intrudes the injection gneisses, I propose the term Randolph granite. That this phase is actually younger than the granites forming the injection gneisses may be observed in the Ravine of the Castles, Mt. Washington quadrangle. In the areal mapping the Randolph granite has not been separated from the Chatham granite. In some places it was mapped as "Winnepesaukee Gneiss" by Hitchcock, but, inasmuch as this name covers a number of very different gneisses and granites, a new term is proposed. The Randolph granite is considered to be a late manifestation of the Chatham igneous activity.

Chatham granite. The Chatham granite, including the Randolph phase, has a wide distribution throughout the White Mountains region. Hitchcock (1) did not satisfactorily separate it, for in some places he mapped it as part of the Montalban group, but in others, as for example in the eastern part of the North Conway quadrangle and in western Maine, he mapped it separately as "granites." The name Chatham granite is proposed for the non-porphyritic, two-mica granite which is intrusive into the Montalban schists but older than the White Mountains alkaline batholith.

We may list three general types of occurrence. (1) Large areas, covering many square miles, such as the mass in Chatham township. (2) Small isolated patches in the granites of the White Mountains group which vary from blocks a few feet in diameter to others covering several acres. Typical exposures of this type may be seen in the smaller reservoir at Kearsarge Village, at Swift River Falls (Crawford Notch quadrangle), and at the upper end of Jackson Falls; in the last locality the granite is associated with the Montalban group as a xenolith in the porphyritic nordmarkite. (3) In the third type of occurrence the Chatham granite is intimately associated with the schists of the Montalban group, either intruding them in lit-par-lit fashion or containing streaky patches of schist which have been strewn about through the granite. Exposures of this type may be seen along the upper part of the Ellis River, above the uppermost highway bridge.

The Chatham granite is a group of white or yellow medium to fine-grained granites with conspicuous black specks of mica. The essential minerals are white feldspar, quartz, biotite, and often muscovite. Locally black tourmaline and red garnet are present.

Under the microscope the hypidiomorphic-granular rock is composed essentially of quartz, orthoclase, oligoclase, biotite, and often muscovite. The orthoclase is completely lacking in some varieties, but in others it is the dominant feldspar. It occasionally shows intergrown albite lamellae. Carlsbad twinning is noted in both the orthoclase and the plagioclase. The oligoclase usually shows polysynthetic twinning and varies from albite (Ab_{88}) to andesine (Ab_{70}). Undulatory extinction is common in the quartz. The biotite contains pleochroic haloes, is in places partially altered to chlorite, and is always in irregular flakes, either as individuals or as aggregates.

Zones of magnetite dust around the biotite are found in some specimens. The muscovite may occur in irregular flakes or, less commonly, in aggregates of small flakes, clearly working along cleavages in the feldspar; a fact that demonstrates a secondary origin for at least some of the mica. Among the accessory minerals the most noteworthy are andalusite and sillimanite. The former often shows a strong euhedral tendency; the latter occurs in bundles of needles. These minerals are considered to have been derived from the schists which have been shredded and strewn about through the granite. A little epidote is rarely associated with the andalusite. Among the accessories we find apatite, zircon (very rare), titanite (very rare), magnetite, ilmenite, pyrite, and leucoxene. Small needles, probably apatite, are sometimes common in the quartz.

According to the micas present, the Chatham rocks may be classified as two-mica granite, biotite granite, and muscovite granite.

One of the most striking differences between the Chatham granite and the younger White Mountains batholith is the large amount of pegmatite associated with the former. In addition to feldspar and quartz, the pegmatites contain considerable muscovite and biotite and smaller amounts of black tourmaline and red garnet. The pegmatites may be seen almost everywhere in the Chatham granite, but particularly large areas are seen on Little Deer Hill (northeast corner of the quadrangle) and on the east slopes of North Baldface, especially on the ridge north of Charles Brook.

Meredith granite. One of the most striking rocks in the whole state is the porphyritic granite, a formation studied in detail by Daly (2) thirty years ago. Hitchcock (1) termed it the porphyritic gneiss and Daly called it the porphyritic granite. Inasmuch as other porphyritic granites are present in the state, it is proposed that this particular type be designated the Meredith granite, for typical exposures may be seen in the township of Meredith. Only one large area of this formation is found in the North Conway quadrangle. It covers the whole summit of North Baldface, the hills to the west, the lower portion of the west slope of South Baldface, and a bench south of this mountain. The position of the western and southern boundaries are unknown, due to the heavy covering of drift and forest.

The Meredith granite of the North Conway quadrangle is a coarse-grained rock composed of white tabular orthoclase phenocrysts, which are frequently an inch long and show Carlsbad twinning. In places the phenocrysts have a distinctly parallel orientation which gives a trachytoid structure. The attitude of this structure is not regional, however, for the strike and dip may greatly vary within short distances. More commonly such a structure is lacking and the individual feldspar phenocrysts show a great diversity of orientation.

Under the microscope the orthoclase phenocrysts are found to enclose small poikilitic patches of oligoclase. The groundmass is composed of irregular and interlocking quartz, orthoclase, microcline, and oligoclase with numerous flakes of biotite and muscovite. In some varieties the groundmass oligoclase is distinctly dominant over the groundmass orthoclase. The muscovite is clearly secondary in many cases, for it is in flakes parallel to the feldspar cleavages. Minor accessories include apatite, andalusite, titanite, magnetite, and zircon.

Relationship of the Chatham and Meredith granites. Unfortunately the contacts of the Chatham granite and the Meredith granite are everywhere deeply buried by drift. Several lines of evidence indicate, however, that the two granites are closely related. (1) The mineralogy is strikingly similar, both for the major constituents, such as orthoclase, oligoclase, muscovite, biotite, and the accessories, apatite, zircon, and andalusite. (2) On the west slopes of North Baldface, where exposures are excellent, the number of phenocrysts in the Meredith granite in places approaches zero and the resulting rock is thus similar to the Chatham granite. (3) Both granites are shattered by the same type of pegmatite, characterized by black tourmaline and red garnet. (4) Both are intrusive into the Montalban schists, but are in turn intruded by the White Mountains alkaline batholith. These facts are clearly shown in the Baldface region, where blocks of the Montalban schist are found in the Chatham and Meredith intrusives; moreover, the Conway granite of South Baldface shows a typical porphyritic marginal facies against both of the earlier granites. These facts indicate that the Chatham and Meredith granites are closely related in chronology and mineralogy.

Regional Metamorphism. In the Montalban group there are no conglomeratic rocks to demonstrate rock flowage, but the differential effects of flowage on the tough lime-silicate rocks and the readily yielding mica schists is well illustrated by an outcrop in the Ellis River west of Eagle Mountain. The accompanying diagram (figure 3) shows a line of blocks of the highly siliceous lime-silicate type, each block being about a foot wide. The most reasonable interpretation is that a one-foot stratum of siliceous rock was interbedded with mica schists. During the metamorphism the micaceous rocks readily yielded by flowage, but the more brittle siliceous layer was broken into blocks. With the continuation of rock flowage the siliceous blocks would be strewn about through the mica schists. Numerous blocks of lime-silicate rocks in the mica schists and injection gneisses are to be explained in this same way.

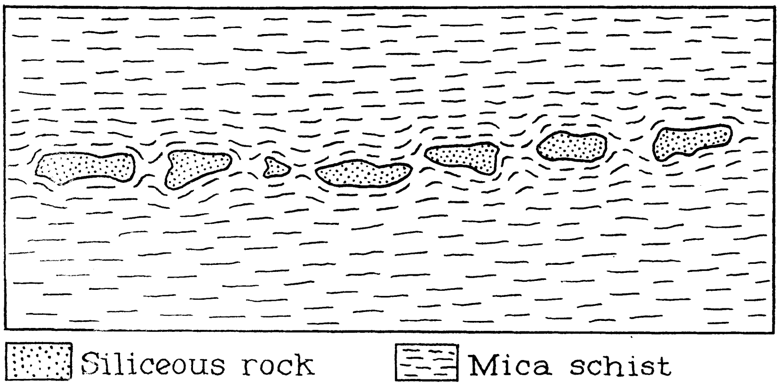


FIGURE 3. Diagram of blocks of siliceous rock in mica schist, Ellis River, west of Eagle Mountain. Scale: one inch equals about four feet. This group of siliceous blocks is considered to represent a brittle zone which was broken up during general flowage and metamorphism of the rocks.

The manner in which the Chatham granite has intruded the Montalban schists is very clearly shown in the White Mountains. Between true schist and true granite we find all intermediate stages. The first step in the injection shows narrow stringers of granite intruded parallel to the schistosity of the mica schists. With an increase in the relative amount of granite the layers of schist begin to break up into individual plates surrounded by granite. A still further stage shows a rock that is mainly granite with small shreds of schists strewn about through it. The final stage shows what is ostensibly a normal two-mica granite, but which under the microscope shows andalusite and sillimanite. The most reasonable way to explain the andalusite and sillimanite, so persistent in the Chatham granite, is to consider them as originally metamorphic minerals that have been strewn about in the granite by the shredding up of schists.

The process of lit-par-lit injection and the shredding and strewing-about of the Montalban schists through the Chatham granite may be well studied along the Ellis River above the uppermost highway bridge. On the west slope of Wildcat Mountain the granite contains shreds of sillimanite-mica schist. Beyond the limits of the North Conway quadrangle a large area of injection gneiss is exposed on the Southern Peaks of the Presidential Range and particularly good exposures may be seen between Mt. Clinton and Mt. Webster. In the bed of Meserve Brook injection gneisses are interbedded with lime-silicate rocks.

The problem of regional metamorphism is too involved to discuss in this place. The facts in the White Mountains indicate, however, that the Montalban schists are closely associated with the Chatham granite. The known evidence in the White Mountains is admittedly inadequate to prove any theory of metamorphism. But the interpretation that best fits the known facts is Barrell's (3) conception that metamorphism, orogenic movements, and granitic intrusions are essentially contemporaneous. Juices from the invading Chatham granite soaked through the folding sediments, greatly augmented the tendency to rock flowage, and caused recrystallization. As the granite moved up into a given horizon of the metamorphosed zone, it first intruded the schists in lit-par-lit fashion and then gradually ripped them to pieces, strewing the shreds throughout the granite.

In contrast with the main phases of the Chatham granite, the medium-grained Randolph phase intruded the schists with sharp contacts and shows no tendency to intrude lit-par-lit. It apparently represents the closing stages of the batholithic intrusion, after the orogenic movements had ceased (3).

REFERENCES.

1. C. H. Hitchcock. Geology of New Hampshire.
2. R. A. Daly. Studies on the so-called porphyritic gneiss of New Hampshire. Jour. Geol., vol. 5, pp. 694–722, 776–794, 1897.
3. J. Barrell. Relations of subjacent igneous invasion to regional metamorphism. Am. Jour. Sci., 5th series, vol. I, pp. 1–19, 174–186, 255–267, 1921.

CHAPTER IV.

The White Mountains Alkaline Batholith.

General Relations.

The White Mountains alkaline batholith is located just south of the main axis of the White Mountains (see figure 4). The main batholith covers approximately 680 square miles, and if we include the two satellitic stocks of Red Hill and the Ossipee Mountains, the

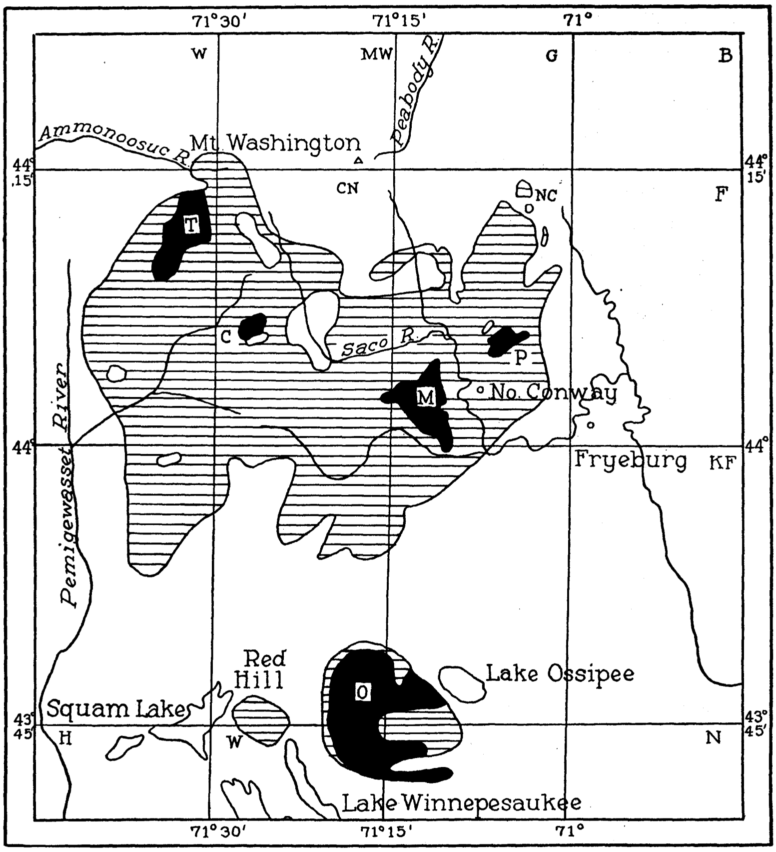


FIGURE 4. Geological map of the White Mountains alkaline batholith. Scale, about one inch to twelve miles. White areas represent mainly the older gneisses, schists, and granites. Horizontal lining indicates the plutonic phases of the batholith (diorite, nordmarkites, hastingsite granite, riebeckite granite, biotite granite, and nepheline syenite). Solid black represents extrusive phases (tuffs, breccias, trachyte, and comendites): O = Ossipee Mountains, M = Moat Mountain, P = Mt. Pequawket, C = Mt. Carrigain, T = Twin Mountain. U.S.G.S. topographic maps indicated thus: B = Bethel, G = Gorham, MW = Mt. Washington, W = Whitefield, F = Fryeburg, NC = North Conway, CN = Crawford Notch, KF = Kezar Falls, N = Newfield, W = Winnepesaukee, H = Holderness. The other sheets have not yet been published. The data for the lithology of the North Conway quadrangle are original; the rest of the map has been compiled from other authors, mainly C. H. Hitchcock. A number of stocks, possibly satellitic to the alkaline batholith, have been omitted; these include Pleasant Mountain, Burnt Meadow Mountains, and Tripyramid Mountain.

area is augmented to 740 square miles. The Burnt Meadow Mountains and Pleasant Mountain in Maine are also probably satellitic stocks. The main batholith extends from near the Maine boundary on the east to Franconia Notch on the west, a distance of thirty-six miles. The maximum north-south dimension is twenty-six miles; the northern limits are Fabyans on the west and Baldface Mountain on the east; Mt. Chocorua is somewhat north of the southern boundary. Within the confines of the batholith is a number of areas of the older formations. The Ossipee stock, covering approximately fifty-eight square miles, is four miles south of the main batholith; and the Red Hill satellitic stock, which covers nearly five square miles, is ten miles south of the main batholith and four miles west of the Ossipee Mountains.

Both extrusive and intrusive phases are well exposed, the former being preserved as great blocks, from a few feet to eight miles in diameter, that have settled into the batholith. The various phases may be classified chronologically as follows, but it should be noted that within the plutonic group many transitional types are found, and the named types can be considered only as members of a more or less continuous series of rocks. The groups are arranged in the order of increasing age.

TABLE III.

Chronology of the White Mountains Alkaline Batholith.

Intrusive phases	[Nepheline syenite] Conway biotite granite (Conway granite) Riebeckite granite Hastingsite granite (Chocorua granite) Nordmarkite (Chocorua syenite) Porphyritic nordmarkite (Albany granite) Nordmarkite porphyry Diorite
Extrusive phases Moat volcanics	Comendites, riebeckite comendite, trachyte, microgranite, feldspathic tuffs, clay-slate breccia, polygenous breccia, and quartz porphyry breccia. Total thickness at least ten thousand feet.

The following qualifications of the table should be made:

1. The position of the nepheline syenite is not known from field evidence; it is considered to be the youngest intrusive, from evidence in other similar batholiths.

2. The diorite may be older than the extrusive phases.

3. The existence of a biotite granite older than the Albany porphyritic nordmarkite is discussed on a latter page.

The names in parentheses are those used by C. H. Hitchcock (1).

Geological Age.

No fossiliferous horizons are associated with the White Mountains batholith, and its geological age is therefore difficult to determine. All that we definitely know is that the alkaline rocks are younger than the Pre-Cambrian (?) Montalban schists and Chatham granites and antedate the long period of subaerial erosion which has carved the White Mountains. The separation of some of the allanite from the Conway biotite granite to determine the lead-uranium ratio might solve the problem. At present the only method available is to correlate the White Mountains group with similar alkaline rocks of eastern North America and western Europe. As far as they can be dated, all the alkaline rocks of the Appalachian belt of eastern North America are Devonian, with two possible exceptions. One exception is in southeastern Maine, where the alkaline rocks are intrusive into metamorphic rocks which are considered to be Carboniferous by the United States Geological Survey (2). They are correlated with the Carboniferous phyllites at Worcester, Massachusetts, but Wandke (3) states that this conclusion is by no means certain. An occurrence of alkaline rocks that are clearly not of Devonian age is found at Litchfield, Maine, where the litchfieldite and associated soda-syenites are probably Pre-Cambrian (4).

Moat Volcanics.

General Relations.

In the North Conway quadrangle two large areas of volcanics are exposed, the type locality on Moat Mountain and a second large area on Mt. Kearsarge (Mt. Pequawket). These volcanics are composed of siliceous flow rocks and interbedded tuffs and breccias, I propose the name Moat volcanics to include the Pequawket breccia and "quartz porphyry" of Hitchcock (1). Most of the comendites (quartz porphyries) are considered to be lava flows, but some occurrences may represent shallow intrusives.

The type locality for the Moat volcanics is on South Moat Mountain where an excellent section is exposed from an elevation of 1100 feet upwards on the South Moat trail to the Red Ridge (see figure 5). The lowest exposures are composed of Pequawket breccia, which continues up to an elevation of 1250 feet. From this point to 1410

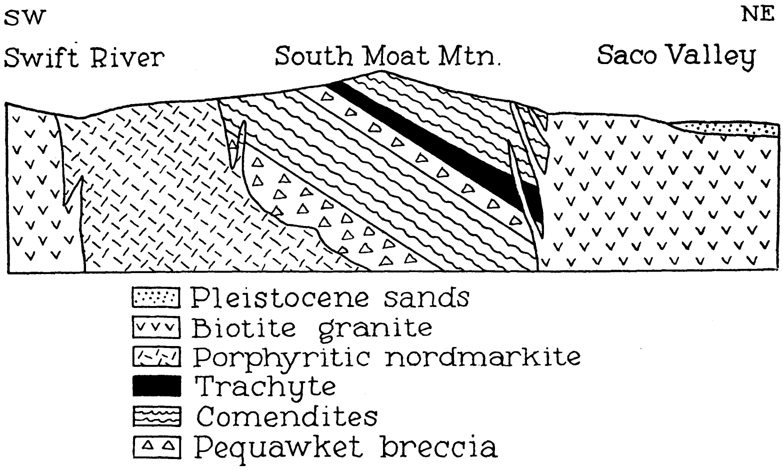


FIGURE 5. Structure section across South Moat Mountain. Scale about one inch to one mile and a half.

feet is a quartz porphyry (comendite) flow, above which comes a breccia that gradually passes upwards into a feldspathic tuff. The stratification becomes more pronounced and may be readily viewed in the cliffs east of the trail between 1670 and 1760 feet. The strata strike northwest and dip about 32° NE. Immediately above a dense tuff is a red trachyte which extends up the trail to 2400 feet. The upper fifty feet of this flow is strongly brecciated. Above the breccia zone comes the great series of gray quartz-porphyry flows which comprise the South Moat Ridge. The structure of these flows may be readily seen on a large scale as one looks north from South Moat Mountain; the dip of thirty two degrees to the northeast is clear. Looking south toward South Moat, the same structure is observed, and in the winter the alignment of the spruces, as seen from Conway station, shows that this structure is characteristic of South Moat. In details the same attitude is found, not only in the tuffs and breccias already mentioned, but also in the flow structure and the contacts of individual flows seen on South Moat Mountain and the ridge to the north. The whole aspect of the group indicates clearly that the Moat volcanics form a series of interbedded flows and breccias. The same structure is shown on the spur leading from the South Moat Ridge to the Albany Haystack, where tuffs, breccias, a trachyte flow, and comendite flows are conspicuously interbedded. The accompanying structure section (figure 5) shows the relations of the various groups. The area of breccia west of the Moat Range, exposed along Little Deer Brook, shows frequent bedding and a structure similar to that of the South Moat area. Summing up, all the evidence indicates that the Moat Mountain block of volcanics forms a monocline striking N 45° W and dipping 32° NE. The attitude of the volcanics of North Moat and Big Attitash is not clearly shown, but the general distribution of rock types indicates an attitude similar to that on South Moat. The structure of Mt. Pequawket is very poorly shown, but the detailed mapping and an occasional stratified layer indicate in general an east-west strike and a vertical dip (see figure 6).

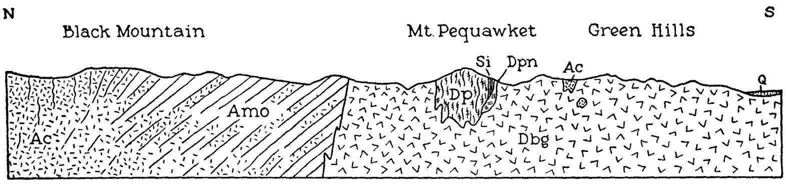


FIGURE 6. Semi-diagrammatic cross-section through the North Conway quadrangle along a north-south line. Scale one inch equals about four and a half miles. *Amo* = Montalban schists, *Ac* = Chatham granite, *Si* = Intervale clay slates, *Dp* = comendites, tuffs, and breccias, *Dpn* = porphyritic nordmarkite, *Dbg* = biotite granite, *Q* = Quaternary deposits. This section illustrates the difference in the mechanics of intrusion of the Chatham granite and the Devonian (?) granites and syenites. The former intruded the schists lit-par-lit, and was essentially contemporaneous with a period of folding; it belongs to a *synchronous* batholith. The Devonian plutonics were intruded with sharp contacts after a period of orogeny; they belong to a *subsequent* batholith. Mt. Pequawket is an isolated block of volcanics immersed in the granites and syenites of the Devonian batholith; a small part of the floor upon which these volcanics were deposited (*Si*) is preserved.

The relative age of the Moat volcanics and the other formations in the White Mountains is readily determined. The volcanics are younger than the Montalban schists, Intervale clay-slates, Chatham granites, and Meredith porphyritic granite, for fragments of these formations are found in the breccias. On the other hand, the plutonic phases of the White Mountains batholith, with the possible exception of the diorite, are younger; not only are fragments of them completely lacking in the tuffs and breccias, but the Albany porphyritic nordmarkite and Conway biotite granites are clearly intrusive into the Moat group. On the east slopes of Moat, where the biotite granite and volcanics are in contact for five miles, the biotite granite is distinctly finer-grained, and apophyses from it cut the volcanics. The striking manner in which the biotite granite cuts off the structures southeast of South Moat Mountain is seen on the geological map (Plate I). That the porphyritic nordmarkite (Albany granite of Hitchcock) is intrusive is shown by its general distribution, by a detailed map on the south slopes of Mt. Pequawket (figure 2), by the manner in which the Albany type cuts off the structures of the volcanics on the southeast slopes of Mt. Pequawket, and by the fact that the porphyritic nordmarkite shows contact modifications against the volcanics. On the south slopes of Mt. Pequawket a hastingsite sölvsbergite (nordmarkite) dike cuts the Pequawket breccia.

The exact contact of the Moat volcanics with the basement upon which they were extruded is everywhere lacking in the North Conway quadrangle, except at the small slate patch on the south slopes of Mt. Pequawket, which is exposed at an elevation of 1500 feet on the Kearsarge Village trail (Figure 2). That a mountain-making movement followed the deposition of the slates and preceded the formation of the Moat volcanics is demonstrated by several facts: (1) slate fragments which show fracture cleavage and slaty cleavage, the latter being essentially parallel to the original bedding, are abundant in the volcanics; (2) the detailed map (figure 2) suggests that a distinct angular unconformity exists between the slate and the volcanics at the east end of the slate belt.

Since the Moat volcanics on Moat Mountain form a simple monocline striking northwest and dipping 32° NE, the thickness of the formation may be readily determined, assuming no faulting parallel to the strike. A section in the vicinity of the Red Ridge gives a thickness of 8,300 feet; a section from the northwestern slopes of Big Attitash toward Humphrey Ledge gives a value of 9,700 feet; and a measurement on the Moat mass as a whole gives a value of 11,800 feet. These are minimum figures for the thickness of the formation, because both the top and the bottom have been stoped away. Assuming Mt. Pequawket to be a vertically-dipping monocline, the volcanics are found to be 9,200 feet thick. Again this is a minimum figure, for although the basement is exposed in the south, the top of the series has been carried away by intrusions along the northern border.

South Moat Flows.

Comendites. (*Quartz porphyries*). The comendites are typically exposed on South Moat Mountain, but they also occur in large areas on the north slopes of Big Attitash Mountain, on the north and east slopes of North Moat Mountain, on the Red Ridge (the Red Ridge is a mile southeast of North Moat), and also on the spur extending southwest from the Red Ridge. On Mt. Pequawket the comendites are found well exposed on the southwest slopes of Bartlett Mountain; the exposures on the west and northwest slopes of Bartlett Mountain and on the north and east slopes of Mt. Pequawket are poor.

The comendite outcrops vary in color. On the South Moat trail they are typically gray, but on the Red Ridge a red color is pronounced. On the east slopes of South Moat a yellow tinge is present; certain phases with a coarse groundmass are white; in varieties with a dense groundmass a black color is prominent. On the west slopes of South Moat the upper ten feet of one of the porphyry flows is much redder than the main portion of the flow. Flow structure is not common. On South Moat Mountain and the ridge to the north, broad flow bands, one or two inches thick, conform with the monoclinal structure, and on the west slopes of peak 2750 (South Moat Ridge) a zone fifteen feet thick shows typical rhyolitic flow texture.

The comendites greatly vary in detail, but they are all similar in showing quartz and feldspar phenocrysts, set in a relatively dense groundmass. The quartz phenocrysts are smoky or less commonly milky white, vary in size from one to three millimeters, and in many cases show the bipyramidal termination characteristic of high-temperature quartz. In any one hand specimen the feldspar phenocrysts are uniform, but throughout the area the color may be milky white, pink, or occasionally a light greenish-gray. They are usually from one to three millimeters in length. The groundmass is dense or fine-grained and may be bluish-gray, greenish-gray, yellowish-gray, or white.

Under the microscope we note in addition to the characteristic phenocrysts of quartz and microperthite an occasional phenocryst of biotite or hastingsite. The feldspar phenocrysts are microperthite, antiperthite, or, much less commonly, a homogeneous feldspar, probably soda orthoclase. Although the quartz phenocrysts are occasionally euhedral in outline, they are more commonly irregular and in many cases are corroded and embayed. The ferrous amphibole, hastingsite, is not abundant and is smaller than the quartz and feldspar phenocrysts but larger than the groundmass. It is very irregular in outline and frequently shows sieve structure; its detailed description would merely duplicate that of the hastingsite of the porphyritic nordmarkite (see below). Fayalite was observed in one of the thin sections, the largest grain being more than a millimeter in its greatest dimension. Fluorite is frequently associated with the fayalite and hastingsite. Biotite flakes locally constitute as much as four per cent of the rock. The hornblende and biotite may occur together in the same hand specimen, or only one may be present, or both may be lacking.

The mineralogy of the groundmass seems to be fairly constant, but the textural pattern and grain-size are very variable. Within a given specimen, however, the groundmass is usually uniform. It is composed of quartz and alkali feldspar, and is generally panallotriomorphic or microfelsitic (cryptocrystalline), in the former case showing frequent micropoikilitic or microgranitic tendencies. In general the feldspar is homogeneous, with indices considerably lower than those of quartz and balsam, and is therefore considered to be orthoclase, probably with more or less albite in solid solution. Some twinned albite and oligoclase, however, are present in small grains. Minor accessories include zircon, magnetite, and fluorite. The latter is relatively widespread and occurs in irregular isolated patches in the groundmass, but occasionally it is clearly associated with the corroded hastingsite. Small needles of apatite occur. Secondary minerals include kaolin, sericite, titanite, clinozoisite, biotite, magnetite, chlorite, and calcite.

A variety which contains very few phenocrysts may be termed a *microgranite*. It has been noted on the northwest slopes of Bartlett Mountain and on the southeast slopes of Mt. Pequawket. In the latter area we find flow structure. A *riebeckite comendite* was found on Dry Brook (Albany) at an elevation of 1480 feet. The riebeckite occurs as microlites in both the groundmass and the phenocrysts. An *aegerine-augite comendite* found on the ridge between Big and Little Attitash Mountains contains abundant grains of what Washington and Merwin (5) would term acmitic diopsidic hedenbergite. The pyroxene occurs as small irregular blebs, a habit that suggests a deuteric origin. The optical data follows: Biaxial positive, $\alpha = 1.718$, $\beta = 1.728$, $\gamma = 1.742$; $2V = 70° \pm 5°$; $Y = b$; $X \wedge c =$ high, about 35°. $X =$ yellowish green, $Y =$ yellowish green, and $Z =$ light yellowish green; $X = Y > Z$. These optical data correspond rather closely to the data given by Washington and Merwin (5) for the aegerine-augite from Salem Neck, Massachusetts.

Perry (6) has made four analyses of the Moat volcanics, but, inasmuch as he did not recognize the true origin of the group, one of his analyses seems to have been made from the tuffs and is therefore omitted. An analysis of the riebeckite comendite has been made for this paper by W. H. Herdsman of Glasgow, Scotland. A paisanite dike from Mt. Ascutney is very similar and is therefore quoted.

The similarity between the Mt. Ascutney rocks and those from the White Mountains batholith is very striking and analyses of rocks from the former locality will be frequently quoted.

	1	2	3	a	b	4	c
SiO_2	75.38	73.33	72.25	73.65	74.44	72.05	73.03
Al_2O_3	11.85	12.95	13.40	12.73	11.27	14.72	13.43
Fe_2O_3	1.78	0.98	1.10	1.29	2.78	1.02	0.40
FeO	0.88	1.66	1.53	1.36	0.94	1.46	1.49
MgO	0.00	0.00	0.00	0.00	0.35	0.15	0.14
CaO	0.33	0.98	0.74	0.68	0.21	0.79	0.79
Na_2O	3.68	3.46	4.27	3.80	4.18	4.42	4.91
K_2O	5.37	5.61	5.56	5.51	4.95	4.00	4.54
H_2O+	0.50	0.30	0.31	0.37	0.59	0.55	0.35
H_2O-	0.15	0.11	0.10	0.12		0.55	0.18
MnO	0.10	0.13	0.11	0.11	0.08	tr	0.15
TiO_2	nd	nd	nd	nd	0.19	0.23	0.30
P_2O_5	nd	nd	nd	nd	0.02	nd	0.06
Total	100.02	99.51	99.37	99.62	100.00	99.94	99.77

1. Bluish-gray comendite with fine groundmass. From 1550 feet elevation, south slope of Mt. Pequawket, just above the clay-slate. Sp. Gr., 2.62. J. H. Perry, analyst.

2. Dark gray comendite. East slope of Mt. Pequawket, about 2000 feet elevation. Sp. Gr., 2.64. J. H. Perry, analyst.

3. Dark gray comendite, summit of Mt. Pequawket. Sp. Gr., 2.643. J. H. Perry, analyst.

a. Average of the three analyses above. (Average sp. gr., 2.63.)

b. Average comendite. (Daly, Igneous Rocks and Their Origin.)

4. Riebeckite comendite, Dry Brook, Albany, 1480 feet elevation. W. H. Herdsman analyst. Sp. Gr., 2.61.

c. Paisanite dike, Mt. Ascutney, Vermont. (R. A. Daly, Bull. 209, U. S. G. S., p. 75, 1903.) Sp. Gr., 2.63. Additional data on analysis: $ZrO_2 = 0.06$, $Cl = 0.03$, $F = 0.08$, $FeS_2 = 0.09$; total $= 100.03$.

Norms. In the Norm classification these specimens are liparose and give the following normative composition:

Specimen	1.	2.	3.	4.
Symbol	I.″4.1.3	I.4.1″.3	I.4.1.3	I.4.1″.3
Quartz	32.76	28.62	23.94	28.44
Orthoclase	31.69	33.34	33.34	23.91
Albite	31.44	29.34	36.15	37.20

Specimen	1.	2.	3.	4.
Anorthite		3.06	0.56	3.89
Corundum				1.63
Diopside	0.49	1.73	2.97	
Hypersthene	0.53	1.72	0.40	1.85
Magnetite	2.15	1.39	1.62	1.39
Ilmenite				0.46

Trachyte. The trachyte is found as a distinct flow only on the south slopes of South Moat Mountain, but fragments of it are persistent, though rare, throughout the tuffs and breccias of Moat Mountain and Mt. Pequawket. On the South Moat trail and even better in the small cliffs to the east of the trail, at an elevation of about 1760 feet, one may see the base of the trachyte overlying a dense, water-laid tuff. The top of the flow is found at 2400 feet; it is brecciated and overlain by a well stratified tuff. The dark color of the rock differentiates it from the other volcanics, and, looking west from the Saco Valley, the dark cliffs of trachyte stand out in sharp contrast with the white, red, and gray comendite ledges. The rapid thickening of the flow to the southeast is well shown on the geological map. The base of the flow, usually underlain by a water-laid tuff, is conformable to the general structure, but the top is not. The writer is not prepared to state whether the rapid thinning is due to the fact that the flow originally came from the southeast, thinning toward the northwest, or is the result of erosion after the trachyte was extruded but before the quartz-porphyry flows of South Moat Mountain were extruded. A northeast section taken across the South Moat trail at 1750 feet elevation indicates that this flow is about 1100 feet thick at maximum. The manner in which the trachyte is cut off by the younger biotite granite southeast of South Moat Mountain is striking.

The trachyte of South Moat Mountain is composed of pinkish-white phenocrysts of feldspar, set in a dense, red or purplish groundmass. The phenocrysts are somewhat larger than the feldspar phenocrysts of the quartz porphyries and often reach half a centimeter in their maximum dimension. A few smoky quartz phenocrysts are present.

The microscope shows two generations of feldspar phenocrysts—a larger group averaging about 2.5 millimeters in length, and a smaller group about 0.2 millimeters long. The feldspar crystals of the groundmass are approximately 0.04 millimeters in length. The trachytes have suffered considerable alteration and for this reason the feldspars are clouded by clinozoisite, sericite, and kaolin. The feldspar phenocrysts, irregular in outline, are composed of a patchy mixture of twinned albite and orthoclase. The quantity of albite greatly varies, comprising from 25 to 95 percent of the crystal. Quartz phenocrysts are very rare and have suffered considerable corrosion.

The groundmass is strikingly different from that of the quartz porphyries and microgranites, as it is composed chiefly of tabular feldspar crystals, usually parallel to one another. It is homogeneous and probably a soda-orthoclase; microperthite and albite are also present. Much dust of hematite clouds the slide. Minor accessories are zircon and rather abundant, ragged grains of magnetite. Epidote and clinozoisite in large irregular masses are not uncommon, and chlorite is also present.

The following analysis of the South Moat trachyte has been made by W. H. Herdsman.

	5.	6.	m.	d.
SiO_0	65.05	64.40	62.63	60.68
Al_2O_3	16.80	16.75	17.06	17.74
Fe_2O_3	4.97	1.31	3.01	2.64
FeO	1.12	3.44	1.98	2.62
MgO	0.20	0.62	0.63	1.12
CaO	1.68	1.85	1.51	3.09
Na_2O	3.94	4.44	6.26	4.43
K_2O	5.22	4.96	5.37	5.74
H_2O+	0.30	1.05	0.71	1.26
H_2O-	0.45	0.22		
TiO_2	0.25	0.88	0.62	0.38
P_2O_5	Tr	0.11	0.09	0.24
MnO	Tr	0.05	0.13	0.06
Total	99.98	100.08	100.00	100.00

5. Trachyte from the South Moat trail, 2040 feet elevation. W. H. Herdsman, analyst. Sp. Gr. 2.65.

6. Albany porphyritic nordmarkite, Jackson Falls. W. H. Herdsman analyst. Sp. Gr. 2.68.

m. Average alkaline trachyte (Daly, Igneous Rocks and Their Origin).

d. Average trachyte. (Daly, Igneous Rocks and Their Origin.)

Comparing our trachyte with average trachyte, the most striking features are the high silica and ferric-iron content, and the low lime and magnesia. The high silica is due to the presence of more quartz than is usual in the average trachyte; the high ferric iron is due to the unusual amount of hematite. The low lime and magnesia indicate a trachyte with alkaline affinities. The close chemical similarity of the trachyte to the Albany porphyritic nordmarkite, hereafter described, is noteworthy. The chief difference is in the state of oxidation of the iron.

From analysis No. 5 the following norm has been calculated.

Name	Toscanose
Symbol	I''.4.(1)2.''3.
Quartz	18.30
Orthoclase	30.58
Albite	33.54
Anorthite	8.34
Corundum	1.63
Hypersthene	0.50
Ilmenite	0.61
Magnetite	2.55
Hematite	3.20

The percentage of quartz is much higher than one would expect from a microscopical examination of the rock, but the high hematite content checks well.

Pequawket breccia.

Interbedded with the quartz porphyry and trachyte flows of the Moat volcanics is a group of clastic rocks varying greatly in composition and appearance. On Moat Mountain three relatively large areas are found in addition to a number of smaller lenses. The structural relations are best shown on the south and southwest slopes of South Moat Mountain, where a great group of tuffs, breccias, and quartz porphyry flows underlie the trachyte. A second large area of breccias is found on North Moat Mountain, and, although the exposures are good, the structural relations are by no means clear. A third area is well exposed along that branch of Little Deer Brook that drains the southwestern slopes of Big Attitash Mountain. Smaller areas have been found on the ridge between Little Attitash Mountain and Humphrey Ledge, on the east slope of South Moat, and in that branch of Little Deer Brook flowing west from the Red Ridge. On Mt. Pequawket the whole southern slope and the two main peaks are zones of clastic rocks. A second area is found on the northern slopes, but it is very poorly exposed. A third area is found at the extreme eastern end of the Pequawket mass; this area is likewise poorly exposed.

In describing the various tuffs and breccias I will first discuss in some detail the fragments occuring in the clastic rocks and then describe the matrix; finally, I will group them into lithologic types. A fragment may be described rather arbitrarily as a rock or mineral of macroscopic size; anything smaller is classed as matrix. In maximum the fragments may reach three, four, or even five feet in diameter. Blocks reaching these dimensions are rare; but bowlders of two-mica granite of this size occur on the southwest slopes of South Moat, and on the summit of Mt. Pequawket a diabase bowlder ten feet across is found in the feldspathic tuffs. Blocks a foot or two in diameter are very common in all the areas of breccia. As a general rule these clastic fragments are angular to subangular, the feldspar, quartz, slate, and schist being particularly angular; the quartz-porphyry and granite bowlders as a rule show considerably more rounding than the other rocks.

In certain respects the lithology of the fragments occurring in the clastics of Moat Mountain and Mt. Pequawket are similar, but there are certain striking differences. On Mt. Pequawket the most common fragment is clay-slate with important quantities of quartzite and quartz porphyry; on the upper slopes quartz and feldspar become very abundant. The clearness of the quartz and the frequent magmatic corrosion imply that most of it is of volcanic origin; some of it may be detrital, the product of the decay of older granites. The feldspar, usually orthoclase with irregular albitic patches, is apparently all of volcanic origin. Pebbles of trachyte have also been found, but diabase bowlders are rare. Fragments composed of fine-grained tuffs are not uncommon. Relatively rare minerals that are found embedded in the groundmass include rounded zircon (probably originally from the quartzites which occur so commonly as pebbles) and sericite (probably chipped off from the clay-slate fragments).

On Moat Mountain these types are found, and in addition, andalusite clay-slate (on the summit of North Moat), quartz-mica schist, quartz-chlorite-muscovite schist, two-mica granites, muscovite granites, Meredith porphyritic granite, rhyolite showing flow-structure, and detrital feldspar. That some of the feldspar is of detrital origin rather than volcanic, is implied by the fact that it is a cross-hatched microcline, similar in every respect to the microcline found in the Chatham and Meredith granites and quite unlike any of the feldspar of the quartz-porphyry group. Most of the quartz and feldspar, however, is apparently volcanic. Rounded apatite stubs, titanite, and muscovite are found.

From this survey of the fragments it is obvious that those from Mt. Pequawket, being essentially clay-slates and quartzites, represent less deep-seated rocks than the andalusite clay-slate, two-mica granite, muscovite granites, Meredith porphyritic granite, and schists of Moat Mountain.

The matrix is macroscopically black, greenish-black, or light gray; it is very dense, occasionally sprinkled with a few recognizable muscovite flakes. The mosaic is often impossible to resolve under the microscope; where sufficiently coarse, it is seen to be composed essentially of quartz and orthoclase, often with important quantities of chlorite, sericite, and biotite in small flakes. Although some of the biotite and chlorite is probably detrital, much of it occurs in aggregates of many flakes and is apparently secondary. Irregular patches of magnetite are frequently present, and hematite dust sometimes clouds the slide.

The proportion of matrix to fragments greatly varies. In some of the slate-bearing feldspathic tuffs of Mt. Pequawket, there is practically no matrix; any original cavities have been filled by squeezing and crushing of the clay-slate fragments. In many of the feldspathic tuffs of South Moat the matrix makes up half the rock. In still other specimens the fragments may be completely absent, resulting in dense red or black tuffs, the groundmass of which can not be resolved under the microscope.

Because of the variation in the lithology and in the relative proportion of matrix and fragments, numerous rock-types may be differentiated. On the southern slopes of Mt. Pequawket there is exposed a breccia, composed essentially of clay-slate, with small amounts of quartzite, quartz porphyry, quartz, and feldspar; it may be classed as a *clay-slate breccia.* Lithologically similar rocks are found on the South Moat trail between 1100 and 1250 feet. On the summit of North Moat, covering an area of ninety feet by forty-five feet, is a breccia composed essentially of andalusite clay-slate. On the west slope of South Moat, at an elevation of about 2300 feet, are exposures of a *coarse polygenous breccia* which shows a great variety of bowlders, including muscovite granite, two-mica granite, pegmatite, quartz porphyry, quartzites, quartz-mica schist, and sillimanite-mica schist. One of the granite blocks is five feet long. Similar types are found in two small patches east of Little Attitash Mountain. In these occurrences many of the bowlders are composed of the Meredith porphyritic granite, the orthoclase phenocrysts show the typical Carlsbad twinning, but they are seldom over half an inch long. In the bed of Dry Brook, at an elevation of 950 feet, on the southern border of the North Conway quadrangle, is a similar rock, composed largely of a white muscovite graphic-granite. The widespread breccia on the northern slopes of North Moat may be assigned to the polygenous type, but in this case the most abundant fragments are red and black tuffs; other fragments are quartz-biotite schist, micaceous quartzites, quartz porphyries, porphyritic granite, two-mica granite, and pegmatite.

Still a third type of clastic rock, a *feldspathic tuff*, is exposed on the southern slopes of Mt. Pequawket between 2100 feet and the summit. The most common fragments are composed of microperthite or orthoclase with irregular albite patches, and clear, unstrained quartz, sometimes showing evidence of magmatic corrosion. Clay-slate fragments are relatively abundant, and occasional pieces of quartzite, sericitic quartzite, volcanic tuff, trachyte, diabase, and zircon are observed. The feldspathic tuff of Mt. Pequawket grades downwards into the clay-slate breccia on the lower slopes of the mountain. Feldspathic tuffs have also been observed below the trachyte of South Moat Mountain, on the north slopes of North Moat at about 2300 to 2400 feet, and on the Rocky Branch of the Saco River, about a mile below Jericho, where a xenolith of Pequawket tuff is found in the biotite granite. A *quartz-porphyry breccia*, composed essentially of fragments of quartz porphyry, is found on the summit of North Moat, extending down to about 2750 feet on the northern slope and to 3160 feet on the southern slope. A *dense, black tuff* is found typically developed on the west slopes of South Moat at 2330 feet, immediately underlying the trachyte. Somewhat similar, but *gray tuffs* are found east of the South Moat trail at 1760 feet. In the Little Deer Brook locality black, dense tuffs and *dense, red tuffs* are interbedded with polygenous breccias. Dense, red tuffs are also found in Dry Brook (southwest of South Moat) at about 2050 feet; this lithological type is rather commonly present as fragments throughout the clastic phases of the Pequawket volcanics.

Plutonic Phases.

The plutonic phases of the White Mountains batholith form a nearly continuous series of closely allied rocks. Although the end members of the series are very different chemically, mineralogically, and texturally, almost complete gradation may be seen between many of the phases. For example, the nordmarkite porphyry, although locally in sharp contact with the porphyritic nordmarkite, elsewhere seems to grade into it. In the nordmarkite group there are all gradations from pulaskites through nordmarkites to hastingsite granites. The hastingsite granite of Doublehead grades southward into the biotite granite; some phases of the biotite granite are richer in hastingsite than biotite and are thus closely allied to the hastingsite granites. Yet, in spite of the close association and frequent gradations, the following chronological sequence may be determined: diorite, nordmarkite porphyry, porphyritic nordmarkite (Albany granite of Hitchcock), nordmarkites (Chocorua syenites), hastingsite granite (Chocorua granite), riebeckite granite, and biotite granite (Conway granite).

Diorite. A diorite, which is an early phase of the White Mountains batholith, is found in numerous small dikes, two to five feet wide, in a stream bed east of Hurricane Mountain, and also in a small stock-like mass east of Mt. Pequawket along that branch of Weeks Brook north of Mirror Lake. In the latter occurrence actual outcrops are found along the stream-bed between an elevation of 1560 feet and 1450 feet, and the distribution of stream bowlders indicates that the formation extends up to at least 1740 feet. The total area underlain by this stock-like mass of diorite is thus about half a mile long, measured parallel to the stream; the other dimensions are unknown due to the heavy covering of glacial drift.

The normal diorite, as exposed in the dikes and parts of the stock, is a medium to fine grained black to gray granular rock with the typical "salt and pepper" appearance of diorite. With the hand lens the rock is resolved into white plagioclase of tabular habit, hornblende, and small amounts of biotite. An occasional striated plagioclase phenocryst dots the specimen and irregular patches of pyrite are observed in the dike variety.

In the stock-like mass the diorite has been remarkably shattered and impregnated by the biotite granite. Small dikes of medium-textured biotite granite, from a fraction of an inch to half a foot in diameter, cut the diorite. Large crystals of pink microperthite, some half an inch across, are irregularly distributed through the diorite. Somewhat smaller quartz crystals are present. In other parts of the diorite irregular hornblende crystals, as much as a quarter of an inch long, are abundantly distributed; and honey-yellow patches of titanite are visible to the naked eye. The microperthite, the quartz, the hornblende, and the titanite have clearly soaked in from the biotite granite.

Under the microscope the diorite is seen to be composed of frequently zoned, tabular plagioclase, abundant anhedral hornblende, and ragged biotite flakes. Minor accessories include quartz, apatite, magnetite, and pyrite. Alteration minerals are sericite and chlorite. The unzoned plagioclase is andesine (about Ab_{55}) and shows both polysynthetic and Carlsbad twinning. The zoned feldspar is similarly twinned; the core is labradorite (about Ab_{40}) and the periphery is usually oligoclase (about Ab_{80}). The amphibole is in irregular grains and has the following optical properties. Biaxial, negative; dispersion medium, $\rho > \nu$; optic angle medium; $Y = b$, $Z \wedge c = 17°$. Pleochroism: $Y > Z > X$; X = light yellow, Y = olive green, and Z = deep green. Indices $\alpha = 1.670$, $\gamma = 1.698$. These indices are about 0.025 lower than those for hastingsite, and indicate that the amphibole in the diorite is a normal hornblende, relatively rich in magnesia compared to hastingsite.

In the less metamorphosed types the chief change has been the introduction of microperthite, either interstitial to the plagioclase or in aggregates of half a dozen grains; quartz, allanite, and titanite are also introduced. In the more completely soaked varieties the number and size of the introduced amphibole crystals greatly increases, the microperthite is much more abundant, large, irregular patches of titanite are noted (one is seven millimeters long), and apatite appears. A little epidote was found in the titanite. The significance of these observations and their bearing on the origin of essexite is discussed on a later page.

The diorite is obviously older than the biotite granite, as the former is intensely shattered by the latter. On the other hand, it cuts the Montalban schists and the Chatham granites. Since no igneous cycles other than the Chatham and White Mountains periods of activity have been recognized in this quadrangle, and because the law of decreasing basicity seems to be fairly general, we may consider the diorite as an early phase of the White Mountains batholith.

It is obvious that much of the diorite mass was stoped away by the magma of the younger Conway granite, for we have seen this very process "caught in the act" in the shatter-zone along Weeks Brook. We may reconstruct the geological history as follows. A diorite stock, with associated satellitic dikes, was intruded into the Chatham granite occupying the area east of Mirror Lake; the stock may have extended as far south as Hurricane Mountain. The diorite crystallized, and, after a long period of magmatic differentiation, the great mass of Conway granite rose by stoping away most of the diorite stock and the Chatham granite. In the vicinity of Weeks Brook a small part of the stock, intensely shattered, was still preserved, and at South Chatham the Chatham granite and the satellitic diorite dikes were untouched.

Nordmarkite porphyry. The nordmarkite porphyry has been observed in five small areas. Two represent small stocks satellitic to the main batholith. Two others are border phases of the nordmarkite of the main batholith. The fifth body is completely surrounded by the Albany porphyritic nordmarkite. The satellitic stock on Mt. Eastman is about half a mile in diameter, although the exact boundary on the northeast slope could not be established. The Sloop Mountain stock is a long, dike-like body striking north; it is a mile and a half long and a quarter of a mile wide. On the northeast slope of Sable Mountain a belt at least half a mile long and perhaps a quarter of a mile wide is found between the nordmarkites and the older Meredith granite. Still a fourth area is found on the west slopes of Chandler Mountain. This region, although densely wooded and characterized by poor exposures, is important because the nordmarkite porphyry is here intensely shattered by the nordmarkites of Chandler Mountain. The fifth area is well exposed on the northeast slopes of Little Attitash Mountain, between the elevations of 2300 feet and 1750 feet; a few isolated exposures between 1000 and 1200 feet along Stony Brook indicate that the area extends at least that far west. As a rule the contact between the nordmarkite porphyry and the Albany porphyritic nordmarkite is sharp, but locally the two grade into each other.

Dikes of the nordmarkite porphyry cut the Montalban schists at an elevation of 1450 feet, in the brook west of Sloop Mountain; and the Chatham granite, at an elevation of 1040 feet in the "flume" of Chandler Brook. It is thus clearly younger than the Pre-Cambrian (?) formations. On the other hand, it is older than the nordmarkites of Chandler Mountain, as already stated. Thus the nordmarkite porphyry is to be considered an early phase of the White Mountains batholith. The age relative to the diorite is not known from field evidence, but presumably the diorite is the older.

In the hand specimen the nordmarkite porphyry is composed of rather scattered greenish-gray or white, tabular feldspars, set in a greasy greenish-gray or dense, black groundmass. The feldspar phenocrysts vary in length from several millimeters to over a centimeter.

Under the microscope the nordmarkite porphyry is seen to consist essentially of ragged feldspar phenocrysts set in a micropegmatitic or panallotriomorphic groundmass. The feldspar phenocrysts vary from orthoclase with small areas of twinned albite to crystals of untwinned albite containing small shreds of orthoclase. The groundmass consists essentially of orthoclase (which may contain albitic patches), quartz, hastingsite, and hedenbergite. The hastingsite is exceedingly ragged and is frequently peppered by round grains of quartz and orthoclase. The hedenbergite is colorless, has a high extinction angle, and possesses closely-spaced cleavage, along which some magnetite dust is observed. It is often enclosed in the hastingsite. That the pyroxene actually is hedenbergite is demonstrated below, in the description of the nordmarkites. In one slide a number of rather ragged grains of fayalite, some phenocrystic, are present. Another slide showed euhedral phenocrysts of titaniferous augite. Another rare mineral is yellow in thin section and has a low birefringence. Apparently a chlorite, pseudomorphic after fayalite, it is enclosed either in hedenbergite or hastingsite, the former being in turn enclosed by the latter. Minor accessories include large grains of zircon and apatite, biotite, and small irregular magnetites. Secondary minerals include matted sericite, leucoxene, and a little zoisite.

Porphyritic nordmarkite. A porphyritic hastingsite granite or nordmarkite was termed the Albany granite by Hitchcock from its good exposures in the town of Albany. Two areas are found in the North Conway quadrangle, one of which lies to the north and west of the volcanics of Moat Mountain. The second fringes the volcanics of Mt. Pequawket on the southeast, south, west, and northwest, whence it extends to Spruce Mountain as a dike-like mass, varying from a quarter of a mile to a mile wide; at Spruce Mountain the outcrop belt takes a right angle turn and strikes southwest, finally ending in the Crawford Notch quadrangle.

The porphyritic nordmarkite is very close to the boundary between granite and nordmarkite. In the particular specimen analysed the percentage of silica is 64.40; Brögger (7) considered 66 per cent of silica as marking the boundary-line between nordmarkite and granite. It is very possible that some of the porphyritic nordmarkite has more than the maximum allowed; the contact phases, described below, certainly have more than 66 per cent of silica. Hawes's analyses (8) of the so-called Albany granite of Mt. Willard show 72 per cent of silica, thus placing the rock definitely in the granite group; but the rock classified by Hawes is not the same as the original rock from Albany. The present writer would classify the rock described by Hawes as a hornblendic, porphyritic contact-phase of the Conway biotite granite and similar in many respects to the green type described on a later page.

One of the most striking features of the porphyritic nordmarkite is the existence of a chilled contact-phase, which has the chemical and mineralogical composition of a quartz porphyry. Usually this contact zone is twenty feet or less in width; it is often entirely absent. Progressing from the typical porphyritic nordmarkite to the contact with an older rock the groundmass becomes fine-grained and lighter in color, due to the decrease in the amount of hastingsite. The feldspar phenocrysts are of the same size as those in the typical porphyritic nordmarkite. Euhedral quartz crystals bounded by the hexagonal pyramid become very abundant, and, although as a rule smaller than the feldspar phenocrysts, they are more numerous; quartz phenocrysts a quarter of an inch across have been noted. This contact phase has usually been seen against the Moat volcanics, but it has also been seen where the porphyritic nordmarkite is intrusive into the Intervale clay-slates. Unfortunately the relations are best exposed in rather inaccessible localities: one example is a large ledge three quarters of a mile north of Mirror Lake and a mile east of the summit of Mt. Pequawket, where the porphyritic nordmarkite intrudes a tuffaceous phase of the Moat volcanics (2220 feet elevation). The same phenomena were noted north of the Albany Haystack and at an elevation of 2650 feet on the southeast slopes of Big Attitash, peak 2884. In both places the intruded rock is quartz porphyry. The same relation was noted southeast of the slate belt on the south slopes of Mt. Pequawket and on the southwest side of the clay-slate exposed in the East Branch of the Saco River.

The occurrence of such a chilled phase rich in quartz violates the common rule that the marginal phase of a plutonic mass is less siliceous than the main intrusive. Other exceptions have, however, been noted in a number of the alkaline batholiths. Daly (9) records a quartz-porphyry, marginal phase of a nordmarkite at Mt. Ascutney. Ussing (10) found the same relation at Julianehaab, and Brögger (7) observed in the Christiania (Oslo) region quartz-porphyry, marginal phases for the äkerites and nordmarkites. At Red Hill, one of the satellitic stocks of the White Mountains alkaline batholith, Pirsson and Washington (11) noted that the main nepheline syenite intrusion has a nordmarkite marginal facies. I have no explanation of the phenomenon. Ussing's suggestion that it is the result of the assimilation of sandstone is unsatisfactory. It is true that the example cited by Ussing might be explained in this manner, for the intruded rock was sandstone; likewise in the North Conway quadrangle where the country-rock is quartz porphyry a similar explanation might hold. But it does not account for the cases where clay-slate is the intruded rock.

The relative age of the porphyritic nordmarkite is fairly well established. It is younger than the Montalban schists and Chatham granites, for a large xenolith of these two formations has been observed in the porphyritic nordmarkite at Jackson Falls. Dikes of the latter cut the Montalban group at Thorn Mountain. The quartz-porphyry, marginal facies against the Intervale clay-slates has already been noted. The general distribution of the porphyritic nordmarkite as a shell around the Moat volcanics implies that the former is the younger rock; the chilled, marginal phase of the Albany against the volcanics confirms this impression; and on the southeast slopes of Mt. Pequawket blocks of tuff are found in the Albany formation..

The porphyritic nordmarkite is very probably older than the hastingsite granites, because on the south slopes of South Doublehead, between 1980 and 2220 feet, a porphyritic nordmarkite is intensely shattered by a hastingsite granite. Southwest of South Moat Mountain a medium-textured hastingsite granite cuts the porphyritic nordmarkite. Not only does the general distribution of the porphyritic nordmarkite imply that it is older than the biotite granite, but also two small dikes of biotite granite cutting the porphyritic nordmarkite were noted at an elevation of 1730 feet on the northwest slopes of Attitash Mountain, Crawford Notch quadrangle. A number of dikes of biotite granite, described on a later page, cut the porphyritic nordmarkite near Jackson. The mineralogical and chemical relations indicate that the porphyritic nordmarkite is to be correlated as essentially the same as the nordmarkites. The position of the porphyritic nordmarkite is thus determined younger than the Montalban schists, Chatham granites, Intervale clay-slates, and the Moat volcanics; it is older than the hastingsite and biotite granites, but nearly contemporaneous with the nordmarkites.

The porphyritic nordmarkite often contains many inclusions, such as hornfels and schist. This feature may be noted either on the south slopes of Mt. Pequawket or on the ledges in the Swift River at the mouth of Little Deer Brook. A large amount of biotite granite has been found associated with the porphyritic nordmarkite southwest of the volcanics of Moat Mountain. In the hand specimen it is a fine-grained, pink granite speckled with black flakes of biotite. In the field it frequently shows horizontal sheeting, a feature which is excellently displayed near the mouth of Little Deer Brook on the south side of the new road up the Swift River Valley. Under the microscope the textural pattern is conspicuously hypidiomorphic-granular, the albite and microperthite crystals forming a striking network which contains the interstitial, anhedral grains of quartz. The biotite contains abundant poikilitic quartz and feldspar; it is often altered to chlorite, and a muscovite-like mica has occasionally resulted from the "bleaching" of biotite. Minor accessories include fluorite, zircon, and iron ore. Hematite is noted as a secondary mineral.

This biotite granite is assigned to the White Mountains batholith rather than to the earlier granites, because of the nature of its feldspars, the presence of fluorite, and the absence of true muscovite. On the other hand, it is definitely older than the Conway biotite granite, which encloses blocks of this granite. I have not succeeded in conclusively demonstrating that the fine biotite granite is present as inclusions in the porphyritic nordmarkite, but the manner in which they are associated in the field makes the conclusion almost inevitable. The existence of inclusions of biotite granite in the porphyritic nordmarkite is important for a theory of the magmatic differentiation, for it demonstrates that a more siliceous rock (granite) may be older than the less siliceous (nordmarkite), contrary to the general rule in composite batholiths.

In the hand specimen the porphyritic nordmarkite consists of irregular or tabular feldspar phenocrysts, averaging about five millimeters in length, set in a relatively fine groundmass, speckled with black hastingsite. Both the groundmass and the phenocrysts may be pink, white, bluish-gray, or greenish-gray. Twinning in accordance with the Carlsbad law is common. The percentage of phenocrysts is variable, in places forming more than half the specimen, in others only twenty-five per cent of the rock. Quartz phenocrysts, irregularly spheroidal in habit, are as a rule rather scarce; in fact, the typical porphyritic nordmarkite shows on the average only three or four quartz phenocrysts in a standard hand specimen. The groundmass varies in grain-size, but micrometer measurements show that in the typical type the feldspar and quartz of the groundmass are from 0.1 to 0.2 millimeters in diameter; in the contact phase, described on a previous page, the groundmass grains are from

0.01 to 0.02 millimeters across, being actually smaller than the groundmass of some of the comendites.

Under the microscope the porphyritic nordmarkite is a holocrystalline rock with phenocrysts of microperthite and quartz, the former greatly predominating. The feldspar phenocrysts are as a rule irregular, tending to be tabular in shape. Aggregates of feldspar crystals are sometimes found. The quartz, on the other hand, is rounded and invariably shows more or less corrosion. The groundmass is composed essentially of a hypidiomorphic intergrowth of orthoclase, microperthite, albite, quartz, and hastingsite. Micropegmatitic intergrowths are present. The hastingsite occurs in the typical subhedral crystals elongated parallel to the c-axis and is somewhat larger than the typical groundmass quartz and feldspar. Minor accessories include zircon, allanite, apatite, fluorite, magnetite, and biotite (both primary and secondary). Secondary minerals include sericite (poikilitic in the albitic feldspars), chlorite, and very rarely clinozoisite.

Of widespread distribution throughout the White Mountains batholith is an amphibole belonging to the soda-iron series. It forms the essential dark mineral in the nordmarkite porphyry, porphyritic nordmarkite, nordmarkite, and hastingsite granite, and it is present in small quantity in the biotite granite and the comendites. The habits of this amphibole are very variable. In the comendites it is very spongy, enclosing poikilitically quartz and feldspar. In the porphyritic nordmarkite it is more compact with euhedral tendencies; in the nordmarkites it is frequently zoned about hedenbergite.

The optical properties are as follows. Biaxial negative. Indices (determined to within three in the third decimal place): $\alpha = 1.698$, $\beta = 1.719$, $\gamma = 1.722$. $2V = 47° \pm 3°$. Dispersion is medium-strong. Optical orientation, $Y = b$, $Z \wedge c = 20°$. Pleochroic formula $Y > Z > X$, but Y and Z are almost equal: X = light yellowish brown, Y = olive green, Z = deep green. The specific gravity, determined by pycnometer, is 3.375 at 4° C.

The high indices and high specific gravity imply richness in iron and inasmuch as an analysis of the widespread amphibole in the alkaline syenites and granites of the White Mountains has not been made, it seemed advisable to separate some for chemical analysis. The material was taken from the porphyritic nordmarkite at Jackson Falls, for an analysis of this rock had already been made. The rock was ground up so as to pass through a screen with 60 mesh to the inch; all the material passing through a 200-mesh screen was discarded. A magnetic concentration was first made; this concentrate consisted essentially of hastingsite and some magnetite, but some quartz, feldspar, and biotite were present as impurities. The powder was then run through methylene iodide (specific gravity about 3.3); the feldspar, quartz, and biotite floated but the hastingsite and magnetite (of which there was very little) sank in the liquid. After drying the powder, it was run under a hand magnet and the electro-magnet to eliminate any magnetite that might be present. A careful check was kept by microscopic methods during the course of the separation. The final product was more than 99 per cent pure. The analysis of this amphibole and the porphyritic nordmarkite from which it comes are given below, along with the analysis of the original hastingsite (12) and similar analyses by Quensel (13), Shannon (14), and Nelson (15).

	6.	C.	g.	h.	i.	j.
SiO_2	64.40	37.40	34.18	37.49	38.50	36.86
Al_2O_3	16.75	12.34	11.52	10.81	10.88	12.10
Fe_2O_3	1.31	4.16	12.62	7.52	6.70	7.41
FeO	3.44	25.84	21.98	25.14	27.28	23.35
MgO	0.62	2.20	1.35	1.34	1.40	1.90
CaO	1.85	9.72	9.87	9.77	11.30	10.59
Na_2O	4.44	1.80	3.29	2.06	1.22	3.20
K_2O	4.96	1.36	2.29	1.91	1.66	1.20
H_2O+	1.05	Tr	0.35	2.01	1.27	0.60
H_2O-	0.22	0.60			0.00	0.70
TiO_2	0.88	3.20	1.53	0.86	tr	1.04
P_2O_5	0.11	nd	nd	nd	nd	nd
MnO	0.05	1.24	0.63	0.95	tr	0.77
BaO	nd	0.00	nd	nd	nd	nd
Cr_2O_3	nd	0.00	nd	nd	nd	nd
Totals	100.08	99.86	99.61	99.86	100.16	99.72

6. Porphyritic nordmarkite, Jackson Falls. W. H. Herdsman, analyst.

C. Hastingsite from porphyritic nordmarkite, Jackson Falls. W. H. Herdsman, analyst.

g. Hastingsite, Dungannon, Ontario.

h. Hastingsite, Seglinge, Almunge.

i. Metamorphic amphibole from Custer County, Idaho.

j. Hudsonite, Cornwall, Orange County, New York.

The Rosiwal method has been employed to determine the proportions of the various minerals in the analyzed porphyritic nordmarkite.

The result is here stated, along with the norm. The percentage of allanite is probably a little high for the average porphyritic nordmarkite.

Mode		Norm	
Quartz	12.6	Quartz	13.08
Feldspar	74.1	Orthoclase	29.47
Hastingsite	12.3	Albite	37.73
Allanite	0.4	Anorthite	8.34
Biotite	0.5	Corundum	0.92
Apatite	tr	Hypersthene	5.43
Magnetite	0.1	Apatite	0.34
Zircon	tr		
Total	100.0		

The following chemical analysis has been made by W. H. Herdsman. Along with it are given the analyses of average nordmarkite and also a nordmarkite from Mt. Ascutney.

	6.	e.	f.
SiO_2	64.40	64.36	64.88
Al_2O_3	16.75	16.81	16.24
Fe_2O_3	1.31	1.08	1.37
FeO	3.44	2.71	2.70
MgO	0.62	0.72	0.89
CaO	1.85	1.55	1.92
Na_2O	4.44	5.76	5.00
K_2O	4.96	5.62	5.61
H_2O+	1.05	0.70	0.46
H_2O-	0.22		0.19
TiO_2	0.88	0.45	0.69
P_2O_5	0.11	0.09	0.13
MnO	0.05	0.15	0.14
Total	100.08	100.00	100.22

6. Porphyritic, nordmarkite, Jackson Falls. W. H. Herdsman, analyst. Sp. Gr. 2.68.

e. Average nordmarkite (Daly, Igneous Rocks and Their Origin).

f. Nordmarkite from Mt. Ascutney. Sp. Gr. 2.68. Contains in addition $ZrO_2 = 0.13$, $Cl = 0.04$, $F = 0.08$, $BaO = 0.06$; total 100.53.

Comparing this analysis with the average nordmarkite, we note that the ferrous iron is somewhat higher and the alkalies lower than the average. The alkalies are lower than in the average, because the analyses used in Daly's computations come mainly from the unique Oslo region. Similarity in the proportions of the other oxides and with the Mt. Ascutney analysis as a whole is noteworthy.

According to the Norm classification, analysis No. 6 is a toscanose with the symbol I(II).4(5).''2.3.

Nordmarkites. The nordmarkites are a group of medium-textured quartz-hastingsite syenites. Hitchcock applied the name Chocorua Group to the hastingsite-quartz syenites and granites of the White Mountains group; these granites are well exposed on Mt. Chocorua, just south of the North Conway quadrangle. The proportion of quartz is very variable; in some places it is almost lacking, giving a pulaskite, but in others it is so high that the rock must be classed as a hastingsite granite. In fact, any division between nordmarkites and hastingsite granites is purely arbitrary and an exact separation has not been possible in the areal mapping. In the Christiania (Oslo) region Brögger (6) similarly observed all gradations between quartz-poor and quartz-rich rocks. He wrote: "The less siliceous rocks of the nordmarkite series appear to be transitional into the äkerite series; the more acid are transitional into the later soda granites."

The only large area of nordmarkites and associated hastingsite granites is found in the north-central part of the quadrangle, on Sable and Chandler Mountains, and on the hills around Mountain Pond. The nordmarkite types are much the more numerous, but the granitic phases are common. Good exposures may be seen on the northeast, south, and southwest slopes of Sable Mountain and on the north slope of Chandler Mountain. Although heavily wooded, the south slope of Chandler Mountain and the hills north and south of Mountain Pond show outcrops of similar rocks. Unfortunately the northern part of the quadrangle is at present very inaccessible, for the mountains are far back from the roads, trails are lacking, and a heavy underbrush makes traveling extremely difficult. South of Mountain Pond the heavy forest-cover and the paucity of outcrops makes mapping difficult. A small patch of syenite has been noted on Tin Mountain near the Tin Mines, apparently as an inclusion in the Albany porphyritic nordmarkite. On the west slopes of Mt. Bartlett a small syenite area is associated with the Albany type.

The isolation of the nordmarkites from the other phases of the batholith makes it difficult to determine the exact age relations. They are slightly younger than the nordmarkite porphyry, for they shatter it on the west slopes of Chandler Mountain, and also the marginal distribution of the nordmarkite porphyry implies its greater age. The pulaskite phase of the nordmarkites exposed on the southwest slopes of Chandler Mountain is intruded by dikes of hastingsite granite. These facts indicate that the nordmarkites are younger than the nordmarkite porphyry but older than the hastingsite granites. Moreover, the similarity in mineralogical and chemical composition of the nordmarkite and porphyritic nordmarkite implies that they are essentially contemporaneous; since the latter is older than the biotite granites, the nordmarkites are likewise considered to be pre-Conway.

In the hand specimen the hastingsite-quartz syenite is a medium-textured rock composed essentially of greenish feldspar and black hastingsite in the proportion of about seven to one. The feldspar crystals tend to be tabular, average three to five millimeters in length, and occasionally show Carlsbad twinning. In some varieties the feldspar is pink, and in the more weathered specimens white. The hastingsite is usually irregular in habit, but tends to be either circular or oval in cross-section. The amount of quartz varies from five to fifteen per cent.

Under the microscope the nordmarkites are found to be holocrystalline hypidiomorphic-granular rocks composed essentially of microperthite and hastingsite. Quartz is sparingly present as small grains interstitial among the feldspars. Hedenbergite, constituting as much as ten per cent of the rock in the pulaskitic phases, is commonly zoned in an extremely patchy manner by the hastingsite, but it has also been noted without any associated amphibole. Minor accessories include albite, apatite, magnetite, zircon, biotite, allanite, fluorite, and chlorite.

Pyroxene is very rare in the granitic phases of the White Mountains batholith, but it may be relatively abundant in the syenitic phases; in the pulaskite it is the dominant ferromagnesian mineral. It usually occurs as a core surrounded by hastingsite. From the analysis, No. 7, stated below, the core pyroxene is inferred to be hedenbergite rather than augite. The low magnesia implies only a small content of that oxide in the pyroxene, which makes up 3.6 per cent of the rock. Knowing the relative proportions of all the minerals in the rock analysed and the chemical composition of all the minerals except the pyroxene, it has been possible to determine that the pyroxene is composed essentially of lime, ferrous iron, and silica; rather abundant ferric iron and titanium accompany small quantities of soda, potash, and magnesia.

The modes of two specimens, one from a type without pyroxene (A), a second with considerable pyroxene (7), are given below. These two specimens are lower in quartz than the average nordmarkite of the quadrangle.

	7.	A.
Quartz	6.3	4.0
Feldspar	75.9	86.0
Hastingsite	12.6	9.5
Hedenbergite	3.6	
Biotite	0.4	
Apatite	0.1	0.2
Magnetite	1.0	0.3
Zircon	0.1	
Totals	100.00	100.00

7. Nordmarkite from an elevation of 2410 feet on the ridge extending south from Chandler Mountain.

A. Nordmarkite from the northwest slope of Bartlett Haystack, elevation of 1980 feet. (Crawford Notch Quadrangle.)

The following chemical analysis has been made for this paper by Mrs. S. Parker of Zürich, Switzerland. The specimen is the same as that for which the mode is given above.

	7.	e.	k.
SiO_2	62.24	64.36	62.99
Al_2O_3	15.82	16.81	14.25
Fe_2O_3	1.94	1.08	2.78
FeO	4.69	2.71	5.15
MgO	0.07	0.72	1.30
CaO	2.65	1.55	2.72
Na_2O	4.80	5.76	4.86
K_2O	6.26	5.62	6.35
H_2O+	0.56	0.70	0.18
H_2O-	0.07		n.d.
TiO_2	0.87	0.45	0.16
P_2O_5	0.14	0.09	n.d.
MnO	0.24	0.15	0.18
Total	100.35	100.00	100.92

7. Nordmarkite from an elevation of 2410 feet on the ridge extending south from Chandler Mountain. Sp. Gr. 2.67.

e. Average nordmarkite. (Daly, Igneous Rocks and Their Origin.)

k. Umptekite, Beverly, Massachusetts (16). Sp. Gr. 2.73.

The White Mountains nordmarkite is richer in iron and lime than the average nordmarkite, due to the greater percentage of dark minerals in the former. Some specimens, such as *A* in the modal determinations, would have a proportion of dark minerals more like that of the average nordmarkite. The umptekite from Beverly, Massachusetts, is similar in many respects, but is richer in dark minerals.

From analysis No. 7 the following norm has been calculated:

Name	Ilmenose
Symbol	(I)II.5.1.″3
Quartz	4.44
Orthoclase	37.25
Albite	40.35
Anorthite	3.06
Magnetite	2.78
Diopside	8.15
Hypersthene	1.82
Ilmenite	1.67
Apatite	0.34
Total	99.86

Hastingsite Granite. A few miles southwest of the North Conway quadrangle, the typical hastingsite granite is exposed on Mt. Chocorua. The upper seven hundred feet of Mt. Chocorua has very little vegetation and the bare ledges give superb exposures. The granite weathers white, but it is often stained a dirty yellow by limonite. The rock is relatively uniform in composition, but on the Champney Falls trail a number of other rock types are exposed. In the North Conway quadrangle the area of hastingsite granite centers about South Doublehead, although a few patches of riebeckite granite have also been observed. The exposures on the great white ledges on the southern slopes of the mountain are excellent. Working toward the south we find that the hastingsite granite is transitional into the biotite granite south of Doublehead; transitional types containing equal amounts of biotite and hastingsite may be observed in the field. The Robbins Ridge region shows some areas of a hastingsite granite, which is finer-textured than usual.

The hand specimens of the hastingsite granites are somewhat variable in color and texture. The most common variety is a medium-textured, granular rock composed essentially of white feldspar, colorless to smoky quartz, and black amphibole. The individual crystals vary from two to five millimeters in diameter. It is very probable that the white color of the feldspar is not primary, but rather the result of profound chemical alteration of this rock. Carlsbad twins are readily recognized. Apparent transitions into the nordmarkites have already been mentioned.

These granites are holocrystalline hypidiomorphic-granular rocks composed of microperthite, albite, quartz, and hastingsite. Minor accessories are zircon, allanite, apatite, fluorite, magnetite, biotite, and hedenbergite. Much of the biotite is in veins composed of small flakes, a habit that indicates a secondary origin for part of the mica. Occasionally the potash feldspar shows microcline cross-hatching. The pyroxene, noted in specimens low in quartz, is free or else zoned by hastingsite. Occasionally the hastingsite shows small blue patches, suggesting a riebeckitic tendency. Micropegmatite is rare. Alteration products include kaolin from the potash feldspar, chlorite associated with the hastingsite, and some sericite in the albite.

A modal determination on a specimen from Mt. Chocorua, Champney Falls trail, 2940 feet elevation, shows that the percentage of quartz is too high to place the rock among the nordmarkites.

Quartz	17.4
Feldspar	72.6
Hastingsite	8.3
Magnetite	0.7
Chlorite	0.3
Biotite	0.6
Zircon	0.1
Total	100.00

In other specimens the quartz runs higher, reaching thirty per cent as a maximum.

Riebeckite Granite. The riebeckite granites occur only in small, widely separated patches, closely associated with nordmarkites and hastingsite granites. What may be considered the type locality is found on the summit of North Doublehead. On the southwest slopes of South Doublehead, at 1680 feet elevation, a biotite-bearing riebeckite granite has been observed. A third area was noted on the eastern end of the range of hills southeast of Mountain Pond, at an elevation of 1970 feet. The exact size of each area is not well known, partly due to the scarcity of outcrops and partly due to the failure to separate the riebeckite granites and hastingsite granites during the field work. The riebeckite granite has also been noted on Stony Brook, Hart Location, in the Crawford Notch Quadrangle.

The age relations of the riebeckite granites are not known from any field observations. They are closely allied, both in distribution and in composition, to the nordmarkites and hastingsite granites. They are therefore considered as essentially contemporaneous with the hastingsite granites.

In the hand specimen the riebeckite granites are snowy white, black riebeckite being set in a granular or micropegmatitic somewhat drusy intergrowth of quartz and feldspar. The grain-size averages about two millimeters and is thus distinctly smaller than that of the normal hastingsite granite. The quartz, in contrast to the smoky quartz of the hastingsite granites, is clear and vitreous. The riebeckite usually has a distinct stub-like habit and is somewhat less abundant than the amphibole of the hastingsite granites. Prominent accessories, which are readily seen with the hand lens, are astrophyllite, zircon, and titanite. The astrophyllite occurs as elongated, light brown, micaceous sheaves, frequently with a radiating habit. A single crystal may be two millimeters long and in exceptional cases five millimeters. Zircon is reddish-brown in color; the largest crystal observed was about a millimeter across. One showed its habit so well that it was set up on the two-circle goniometer. The unit pyramid (111) was the only form present, the prisms being completely suppressed. Titanite, in dirty yellow patches, is interstitial among the feldspars.

Under the microscope the riebeckite granites are seen to be hypidiomorphic-granular to micropegmatitic, and composed essentially of microperthite, quartz, and riebeckite. Accessories include astrophyllite, often in radiating groups, zircon, magnetite, ilmenite, titanite, apatite, fluorite, and biotite.

The complex titanium silicate, astrophyllite, is very persistent and may constitute one per cent of the rock. Microscopically it is readily recognizable by its radiating habit and distinctly yellow pleochroism. Optical data obtained from the astrophyllite in the granite of North Doublehead are as follows: Biaxial positive, $\beta = 1.711$, and $\gamma = 1.738$. $2V$ = large; dispersion strong; $\rho < \nu$. The plane of the optic axes is parallel to the base, the acute bisectrix Z emerges on the front pinacoid, and the obtuse bisectrix X on the side pinacoid; that is, $X = b$, $Y = c$, and $Z = a$. The pleochroic formula is X = deep orange, Y = yellowish orange, Z = lemon yellow; $X > Y > Z$.

A following modal determination on a specimen from North Doublehead shows the abundance of quartz and the importance of astrophyllite. This specimen is richer in quartz than the average riebeckite granite of the White Mountains batholith.

Quartz	39.4
Feldspar	54.0
Riebeckite	5.5
Astrophyllite	1.1
Total	100.0

Conway Biotite Granite. The Conway group is primarily composed of a biotite granite with occasional phases of hastingsite granite. It is widespread in the central part of the quadrangle, and a satellitic stock is found on Baldface Mountain. At least six distinct phases may be recognized, some of which are segregation phases and others distinct intrusives: (1) the Red phase, a coarse biotite granite; (2) the Green phase, a relatively coarse, hastingsite granite; (3) the Baldface phase, a medium-textured biotite granite low in dark minerals; (4) the Diana phase, a porphyritic biotite granite; (5) the Black Cap phase, a fine-grained biotite granite; and (6) contact phases.

The Red phase shatters the diorite in Weeks Brook, as has been described on a previous page. The general distribution of the rock types indicates that the biotite granite is younger than the porphyritic nordmarkite; also two small dikes of the former cut the latter on the northwest slopes of Big Attitash (Crawford Notch Sheet). On the east slopes of Moat Mountain and on the north slopes of Mt. Pequawket the biotite granite clearly dikes the Moat volcanics, against which the biotite granite shows contact modifications, more fully described below. South of South Doublehead, however, the biotite granite grades into the hastingsite granite. These facts indicate that the biotite granite is the youngest of all the phases of the alkaline batholith, though perhaps contemporaneous with the hastingsite granites; the relation with the nepheline syenites of Red Hill is, however, unknown.

That the biotite granite is younger than the Montalban schists and the Meredith granite is eloquently demonstrated on South Baldface Mountain. The fine exposures on the west slope show that toward the contact with the Meredith granite the biotite granite becomes distinctly porphyritic, quartz and microperthite phenocrysts being set in a relatively fine-grained groundmass. Similar phenomena have been observed near Charles Brook, where the country rock is Montalban schist.

The exact relations of the various phases of the Conway itself are not clear. That the Red and Baldface phases actually represent two distinct intrusions is shown near the Hurricane gold mine and also on

Redstone Ledge. In both of these localities a sharp contact exists between the two phases, but it has not been possible to determine the age relations. The Diana phase is merely a variety of the Red phase that takes on a porphyritic habit, due to the assimilation of inclusions. The Green hastingsite phase is considered a segregation from the main biotite granite.

The *Red phase* of the biotite granite is a coarse-grained holocrystalline rock composed of pink feldspar, gray smoky quartz, and biotite. Occasionally the quartz is milky white. The minerals occur very distinctly in aggregates. The average grain-size of the feldspar is seven millimeters, quartz five millimeters, and biotite two millimeters; some of the feldspars, however, attain a length of two centimeters. They tend to be tabular, frequently show Carlsbad twinning, and sometimes show patches of white, striated albite. In the more weathered specimens the feldspar may be entirely white and the rock spattered by specks of limonite. In a medium-grained type from Thompson's Falls on Moat Brook, white albite is as abundant in macroscopic grains as the pink microperthite.

Under the microscope the Red phase is found to be coarse and hypidiomorphic-granular, the essential minerals being microperthite, quartz, and biotite. The accessories include albite, allanite, fluorite, apatite, zircon, magnetite, and hastingsite. The tendency for the three dominant minerals to gather together into aggregates has been noted above. The potassic member of the microperthite shows microcline cross-hatching in some cases. Some slides show the development of a thin shell of fine-grained quartz and albite along the contacts of microperthite crystals. The biotite occurs as large, ragged, primary grains, and as small, secondary flakes, showing simultaneous extinction. Secondary minerals include sericite poikilitic in the albite, chlorite developed from the biotite, and kaolin in the potash feldspar.

A striking feature is the intense, post-glacial weathering undergone by the coarse Red phase. This may be observed in the glacial drift, where bowlders a foot in diameter have completely disintegrated; bowlders larger than this usually show a relatively solid core. Large glacial erratics, some of them five feet across, that have been exposed to weathering since the close of the Wisconsin stage have completely broken down. The weathering may also be observed in the bed-rock. At Goodrich Falls, for example, weathering has affected horizons thirty feet below the surface. (See Plate II B.) Exactly how much of this weathering has progressed from above and how much from the sides one can not say. Certain layers, controlled by horizontal sheeting, have yielded much more readily than others, producing a distinctly stratified appearance in the rock. The unweathered portions of certain horizons remain as ellipsoids. This weathering may also be seen on the brook leading up to the Hurricane gold mine, in exposures on the east slopes of Moat Mountain, on Peaked Mountain, and on the west slopes of Mt. Stanton.

That the weathering is post-glacial is demonstrated by a number of facts. (1) The decay of the boulders of biotite granite in the glacial till has been mentioned. The only logical explanation is that the granite was carried as blocks of fresh rock by the ice, was then deposited in the till, and was finally disintegrated. It might be thought that after pre-glacial weathering the resulting arkosic sand was frozen to form a compact gravel that was ripped up and carried as frozen blocks to be deposited in the till. The textural appearance of the weathered boulders and the fact that the larger boulders may show unweathered cores disprove this suggestion. (2) Heaps of arkosic sand, obviously of the Conway type, have been found on the east slopes of Black Cap at an elevation of 2100 feet. The only explanation is that glacial erratics have there disintegrated. (3) Slopes, such as that on the south side of Peaked Mountain, whose general outline indicates glacial plucking, are covered by a large amount of arkosic sand.

In the hand specimen the *Green phase* is a coarse hastingsite-biotite granite, composed essentially of green feldspar, smoky quartz, hastingsite, and biotite. The average sizes of the grains are respectively seven, four, three, and two millimeters. The feldspars tend to be tabular, but as a rule they are irregular in habit; Carlsbad twinning is seen occasionally.

Under the microscope the Green variety does not differ from the red phase except that hastingsite is more abundant than biotite. This phase is considered to be a segregation from the coarse biotite granite. A problem that arises is how to separate the type under consideration from the normal hastingsite granite. The green phase is coarser, is more deficient in hastingsite, has a less granular texture, and is closely associated areally with the coarse biotite granite.

The *Diana phase* is a porphyritic biotite granite composed essentially of large pink feldspar phenocrysts and smaller light, gray quartz phenocrysts set in a fine-textured granular groundmass made up essentially of feldspar, quartz, and biotite. The respective sizes of the various components are: feldspar phenocrysts, ten to twenty millimeters; quartz phenocrysts, three to five millimeters; groundmass material, one to two millimeters. Due to weathering the feldspars are often pure white. In the field the Diana phase is associated with large, slightly darker patches, which vary in diameter from one to ten feet. These patches are ghosts of xenoliths and the Diana phase has resulted from the wholesale replacement of inclusions by the Conway granite. Various stages in the replacement of inclusions have been noted in different parts of the quadrangle.

The best exposed *contact-phase* of the Conway biotite granite is to be seen on the west slopes of South Baldface Mountain, where the country rock is the Meredith granite. The contact as a whole has a relatively regular trend, somewhat west of north (N 25° W), but in detail it is extremely jagged. No blocks of the older granite in the younger were observed, but numerous dikes of the biotite granite cut the Meredith granite. The contact zone is rather variable in width, varying from one to ten feet. As is typical in the contact facies of the Conway, the porphyritic contact type does not form a definite zone, but rather occurs as irregular patches in the normal granite along the contact belt. The type developed is a white porphyry in which smoky quartz and white feldspar phenocrysts, about two millimeters in diameter, are set in a white granular groundmass, speckled with black biotites. An occasional small pegmatite druse is present, similar to those described below on the east slope of Moat Mountain.

Although the lower eastern slopes of Moat Mountain are heavily wooded, a detailed study of the chilling effects is readily made. The porphyritic tendency is not so pronounced as on South Baldface; a fine-grained granite is the common contact type. Small druses of pegmatite, with crystals of clear quartz and white feldspar, are abundant in this fine contact phase. As on South Baldface, the contact facies does not occur as a definite zone, but is very erratic in its distribution, as irregular patches in the more normal granite. At the immediate contact the granite is so fine-grained that in places it is at first difficult to separate it from the Moat porphyries. For a distance of half a mile west of the contact the comendites are injected by dikes of a fine biotite granite, biotite granite porphyry, and biotite pegmatites.

Contact phases of the biotite granite have also been noted (1) on Cedar Brook about half a mile east of the point where the North Moat trail leaves the valley to climb the mountain; (2) on the northeast slopes of Mt. Pequawket; (3) in the bed of the East Branch of the Saco River just north of the xenolith of Montalban schist; and (4) between North and South Twin Mountains. Where the Conway is in contact with the Albany porphyritic nordmarkite no contact modifications are observable, implying that the Albany was still warm at the time of the Conway intrusion.

Black Cap Biotite Granite. The Black Cap granite is a fine-grained, pink biotite granite, typically exposed on the southeast slopes of Black Cap. A second area is on Thorn Mountain. Occasionally the rock is white instead of pink and thus superficially resembles certain phases of the Chatham granite. With the microscope the Black Cap granite is seen to be very similar to the biotite granite found as inclusions in the Albany porphyritic nordmarkite southwest of Moat Mountain. It is a fine-grained, hypidiomorphic-granular rock, composed essentially of albite, microperthite, quartz, and chloritized biotite. Accessories include fluorite, zircon, magnetite, and apatite.

This granite belongs to the White Mountains alkaline batholith, a fact that is demonstrated by its mineral composition and its chemical analysis (see below). Is it to be correlated with the pre-nordmarkite biotite granite of the Swift River Valley or with the Conway biotite granite? The evidence seems to be somewhat contradictory; but at present the writer is inclined to consider the Black Cap granite as an early phase of the Conway biotite granite.

Two facts seem to show that the Black Cap granite is post-nordmarkite, but pre-Conway (or early Conway):

(1) The Black Cap granite is shattered by the Conway granite on the southeast slopes of Black Cap.

(2) On the west slopes of Middle Mountain a dike of fine-grained biotite granite, apparently an apophysis from the mass of Black Cap granite on Thorn Mountain, cuts the porphyritic nordmarkite.

Apparently contradicting evidences are:

(1) The general distribution of outcrops around Thorn Mountain suggests that the Black Cap granite is older than the porphyritic nordmarkite.

(2) Lithologically the Black Cap granite is similar to the biotite granite found as inclusions in the porphyritic nordmarkite southwest of Moat Mountain.

From these two facts the Black Cap granite appears to be pre-nordmarkite. However, the first two evidences seem the stronger and the writer considers the Black Cap granite as an early phase of the Conway biotite granite, though shown on the areal map as a distinct lithological unit.

The following modal determinations have been made of the various phases of the Conway biotite granite.

	8.	9.	10.
Quartz	26.7	18.5	30.0
Feldspar	69.4	77.8	68.4
Biotite	3.0	0.2	1.6
Hastingsite	0.2	3.5	
Allanite	0.6		
Magnetite	0.1		
Apatite	tr		
Total	100.00	100.00	100.00

8. Conway granite, Red phase, Redstone granite quarries.
9. Conway granite, Green phase, Redstone granite quarries.
10. Conway granite, Baldface phase, east slopes of South Baldface Mountain.

These modes emphasize the paucity of dark minerals in the Conway granite.

Five analyses of the Conway granite are available and are listed below. One is quoted from Perry (6). The other four are new analyses made for this paper. An analysis of the biotite granite from Mt. Ascutney is entered for comparison.

	8.	9.	10.	11.	12.	1.
SiO_2	70.45	69.85	73.65	73.01	72.35	71.90
Al_2O_3	14.87	14.44	13.73	13.73	12.48	14.12
Fe_2O_3	1.07	0.94	0.23	0.44	1.22	1.20
FeO	1.54	2.37	0.95	1.48	1.25	0.86
MgO	0.35	0.24	0.11	0.01	0.42	0.33
CaO	1.28	1.25	0.90	0.94	1.19	1.13
Na_2O	4.28	3.93	4.47	3.50	3.76	4.52
K_2O	4.16	5.04	4.27	5.62	5.98	4.81
H_2O+	0.65	0.66	0.77	0.18	0.60	0.42
H_2O-	0.50	0.35	0.56	0.05	0.17	0.18
TiO_2	0.69	0.74	0.22	n.d.	0.39	0.35
P_2O_5	0.04	0.03	tr	n.d.	0.27	0.11
MnO	0.00	tr	tr	0.09	0.03	0.05
Total	99.88	99.84	99.86	99.05	100.11	99.98

8. Conway granite, Red phase, Redstone quarries. W. H. Herdsman, analyst. Sp. Gr. 2.63.

9. Conway granite, Green phase, Redstone quarries, W. H. Herdsman, analyst. Sp. Gr. 2.65.

10. Conway granite, Baldface phase, east slopes of South Baldface Mountain. W. H. Herdsman, analyst. Sp. Gr. 2.60.

11. Conway granite, Red phase, south slope of Mt. Pequawket. J. H. Perry, analyst. Sp. Gr. 2.62.

12. Black Cap granite, east slope of Black Cap. Mrs. S. Parker, analyst.

l. Biotite granite from Mt. Ascutney, Vermont. Sp. Gr. 2.62. Contains in addition $CO_2 = 0.21$, $ZrO_2 = 0.04$, $Cl = 0.02$, $F = 0.06$, $FeS_2 = tr$, $BaO = 0.04$, $SrO = tr$, $LiO_2 = tr$; total 100.35.

Norms. The norms of these rocks have been determined as follows:

Specimen	8	9	10	11	12
Name	Toscanose	Liparose	Liparose	Toscanose	Liparose
Symbol	I.4.(1)2.3	I.4.1(2).3	I.4.1''.3	I.4.(1)2.3	I''.4.1.3
Quartz	25.80	23.64	28.50	28.08	25.80
Orthoclase	25.02	29.47	25.58	33.36	35.58
Albite	36.15	33.54	37.73	29.34	30.92
Anorthite	6.39	6.12	4.45	4.73	.....
Corundum	1.63	0.20	.....	0.20	.....
Acmite	.....	.....	.....	.....	0.92
Hypersthene	1.56	2.98	1.49	2.51	0.23
Diopside	.....	.....	.....	.....	3.19
Magnetite	1.62	1.39	0.23	0.70	1.39
Ilmenite	1.37	1.37	0.46	.....	0.76
Apatite	.....	.....	.....	.....	0.67

Pegmatites associated with the Conway granite are rare. The pegmatites in the Red phase at Redstone have been described by J. L. Gillson (17). My crystallographic study on topaz and phenacite from the pegmatites associated with the Baldface phase on South Baldface has been presented in another paper (18).

Dike Rocks.

A great variety of dike rocks occur in the North Conway quadrangle and to describe them in detail would demand far more space than is here available. All of the dikes described below are phases of the alkaline batholith. The granite and pegmatite dikes associated with the Chatham granite are not considered. For convenience the dikes may be divided into three major groups: (1) granitic, (2) syenitic, and (3) lamprophyric.

Granitic Types. The granitic types are composed essentially of quartz, alkali feldspar, and such ferromagnesian minerals as biotite, riebeckite, and hastingsite. Minor accessories include fluorite, allanite, zircon, magnetite, and chlorite. Dikes of *biotite granite*, often porphyritic, were observed cutting the Albany porphyritic nordmarkite near Jackson. *Paisanite* types carrying riebeckite are associated with the hastingsite and riebeckite granites. Some varieties are porphyries, the phenocrysts being microperthite. Wide *quartz porphyry* dikes, up to eighteen feet in width, were noted on Black Mountain, cutting the amphibolites of the Montalban schists. A medium-textured *hastingsite granite* dike cuts the Albany porphyritic nordmarkite southwest of South Moat Mountain. *Aplite* dikes are often associated with the Conway granite. Apophyses of the Conway granite include *biotite pegmatites,* and *biotite granites;* they intrude the Moat volcanics, Meredith granite, and diorite.

Syenitic Types. The syenitic types are composed essentially of alkali feldspar with such major accessories as augite and hastingsite. The typical *augite syenite porphyry* shows three generations of minerals, an earliest stage of microperthite phenocrysts, an intermediate stage of alkali feldspar, augite, and biotite phenocrysts, and a groundmass stage of quartz and alkali feldspar. The type specimen occurs near the Tin Mines in Jackson. At Champney Falls (Mt. Chocorua) a similar dike has been eroded to a depth of twenty feet to form the basin into which the falls plunge. A medium-textured *hastingsite sölvsbergite* cutting the Moat volcanics of Mt. Pequawket is composed of a net of euhedral alkali feldspar with interstitial hastingsite. The *bostonite* is a dense, red rock, which under the microscope is found to be composed essentially of tabular crystals of microperthite showing a typical trachytic arrangement. Dikes of the *nordmarkite porphyry* which cut the Montalban schists and Chatham granites have been described on a previous page. Dikes of the Albany *porphyritic nordmarkite* have also been mentioned.

Lamprophyric Types. The lamprophyric dikes are composed essentially of soda-lime feldspar with such major accessories as hornblende, augite, biotite, and barkevikite. The *diorite* dikes of Weeks Brook have already been described. The *kersantites* are composed of tabular labradorite and biotite or its alteration products, particularly chlorite. The phenocrysts, which are very variable in amount, are andesine or labradorite or augite. The rocks are usually badly altered, a fact indicated by the large amount of chlorite, calcite, and epidote. These kersantite dikes intrude the Conway biotite granite, the Moat volcanics, and the Albany porphyritic nordmarkite. The *camptonites* are composed essentially of labradorite and an amphibole, which under the microscope is pleochroic brown. The optical properties of this amphibole suggest either barkevikite, or basaltic hornblende. Some of the camptonites are porphyritic with phenocrysts of either augite or barkevikite. Such dikes cut the schists of the Montalban group.

Economic Products of the White Mountains Batholith.

The only product of the Conway granite that is of economic importance at present comes from the Redstone Quarries, about three miles south of North Conway. Two of the three pits are located in the coarse Red phase, but the third is in the Green phase. Operations began in the fall of 1886 and the quarries are still being actively worked. When they were first opened, paving stones for New York City were among the chief products. Many fine buildings have been constructed in part of Conway granite. The masonic temple at Alexandria, Virginia, is being built of the Red and Green phases of the Conway granite. In the past as many as three hundred men have been employed; during the summer of 1926 about one hundred and fifty men were working in the quarries and sheds.

Two miles southwest of North Conway is the defunct White Mountains Quarry. The drydock at the Charlestown Navy Yard, Boston, is reputed to have been built of granite from this quarry.

On the south slopes of Iron Mountain, between an elevation of 2000 and 2150 feet, there are three openings that have been excavated for hematite ore. Two of the openings are open pits and one is a tunnel thirty-five feet long. The ore occurs as irregular bodies in the Conway granite and is composed of hematite and quartz with small amounts of galena and other sulphides. Field and microscopic evidence indicate that the ores are a replacement of the Conway biotite granite: (1) the ore bodies are very irregular in shape and difficult to delimit; (2) although the contact of the granite and ore is often relatively sharp, a small transition zone may be found showing blebs of hematite in the granite; (3) specimens in the dump show granite in all stages of replacement. Under the microscope radiating needles of hematite may be seen cutting across the hypidiomorphic granular texture of the granite. The writer has no data concerning the operation of the mines.

The "gold mine" at 1620 feet elevation on the west slopes of Hurricane Mountain is apparently more famous for its hopes than for its products. The shaft is located in the bed of a brook and is reported to have been originally eight feet deep and five feet wide. The bait is a siliceous rock zoned into white, red, and brown wavy belts a few inches wide. The country rock in Conway granite, Baldface phase. The siliceous rock is apparently an irregular replacement of the granite, for it is possible in the field and under the microscope to observe siliceous rocks which still preserve a granitic texture.

A number of small pits and tunnels on the west slopes of Tin Mountain, near Jackson, mark the site of the Tin Mines, which are no longer operated. The present writer has been unable to find any ore, but there is no doubt that it exists, for in 1843 C. T. Jackson (19) gave a complete description of the tin veins of this locality.

REFERENCES.

1. C. H. Hitchcock. Geology of New Hampshire.
2. F. J. Katz. Stratigraphy in southwestern Maine and southeastern New Hampshire. P.P. 108, U.S.G.S., pp. 165–177, 1917.
3. A. Wandke. Intrusive rocks of the Portsmouth basin, Maine and New Hampshire. Am. Jour. Sci., 5th series, vol. 4, pp. 139–158, 1922.
4. R. A. Daly. Field relations of litchfieldite and soda-syenites of Litchfield, Maine. Bull. G.S.A., vol. 29, pp. 463–470, 1918.
5. H. S. Washington and H. E. Merwin. The acmitic pyroxenes. Am. Min., vol. 12, pp. 233–252, 1927.
6. J. H. Perry. Notes on the geology of Mt. Kearsarge. Jour. Geol., vol. 11, pp. 403–412, 1903.
7. W. C. Brögger. Mineralien der Syenitpegmatitgänge der südnorwegischen Augit-und Nephelinsyenite, allgemeiner Theil, 1890.
8. G. W. Hawes. The Albany granite and its contact phenomena. Am. Jour. Sci., vol. 21, 3rd series, pp. 21–32, 1881.
9. R. A. Daly. Geology of Ascutney Mountain. Bull. 209, U.S.G.S., 1903.
10. N. V. Ussing. Geology of the country around Julianehaab, Greenland, 1911.
11. L. V. Pirsson and H. S. Washington. Contributions to the geology of New Hampshire, no. III, On Red Hill, Moultonboro. Am. Jour. Sci., 4th series, vol. 23, pp. 257–276 and 433–447, 1907.
12. F. D. Adams and B. J. Harrington. On a new alkali hornblende and a titaniferous andradite from the nepheline syenite of Dungannon, Hastings County, Ontario. Am. Jour. Sci., 4th series, vol. 1, pp. 210–218, 1896.
13. Percy Quensel. The alkaline rocks of Almunge. Bull. 12, Geol. Instit. of Upsala, pp. 129–200, 1914.
14. E. V. Shannon. An iron amphibole similar to hudsonite from Custer County, Idaho. Am. Jour. Sci., 5th series, vol. 8, pp. 323–324, 1924.
15. S. Weidman. Note on the amphibole hudsonite previously called a pyroxene. Am. Jour. Sci., 4th series, vol. 15, pp. 227–232, 1903.
16. F. E. Wright. Der alkalisyenit von Beverly, Mass., U.S.A. Tschermak's Min. und Petrog. Mittheilungen, neue folge, vol. 19, pp. 308–320, 1900.
17. J. L. Gillson. The granite of Conway, New Hampshire, and its druse minerals. Am. Min., vol. 12, pp. 307–319, 1927.
18. M. P. Billings. Topaz and phenacite from Baldface Mountain, Chatham, N. H. Am. Min., vol. 12, pp. 173–180, 1927.
19. C. T. Jackson. Description of the tin veins of Jackson, N. H. Report of the Association of American Geologists, pp. 316–321, 1843.

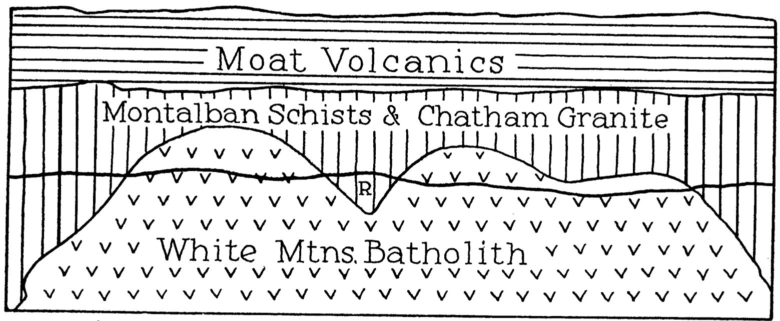
CHAPTER V.

Conclusions.

A. Roof-Collapse in the Late-Paleozoic Alkaline Batholiths.

Evidence from the White Mountains. The area of the White Mountains batholith incloses five major volcanic masses, which vary from two to eight miles in diameter—Mt. Pequawket, Moat Mountain, the Ossipee Mountains, Mt. Carrigain, and Twin Mountain (Figure 4). Are the volcanics merely roof-pendants projecting down into the batholith or are they blocks that have settled from above? I believe that they are great blocks that have settled from above. The basis of the argument is the fact that the volcanics occur only within the limits of the batholith and its satellitic stocks; nowhere are they found beyond the limits of the batholith.

The volcanics were extruded upon a surface composed of slates, schists, and muscovite-biotite granites, for fragments of these rocks are found in the breccias. These relations are illustrated in the accompanying diagram (Figure 7A). If we assume the batholith to have stoped up into its roof, any roof-pendants that are left, as for example "R" in the diagram, would be composed of the same formation as the walls of the batholith, Montalban schists in the case illustrated. If stoping continued into the volcanics the same rule would hold; the walls and any roof-pendants would be composed of volcanics (figure 7B). But in the case of the White Mountains neither of these relations holds. We have great blocks of Moat volcanics within the limits of the batholith and its satellitic stocks, but nowhere outside of these areas do we find these volcanics; we find only the rocks of the basement on which these volcanics were deposited. This observation in itself might be explained as due to the fact that the volcanics were extruded only directly above the batholith. Although this is possible, some observations remain unexplained. If a batholith were to stop into a volcanic pile which existed only directly above the intrusion, we might now have volcanic rocks exposed only within the area of the batholith. But if this were so, the exposures of volcanics would occupy only the highlands and the older basement rocks would be in the lowlands (see figure 8). However, in the White Mountains the relations are just the reverse, for the schists and gneissic mountains are higher than the volcanic mountains. The most logical explanation is that the volcanics have settled into the batholith from above. The down-sunken blocks may represent isolated xenoliths which were



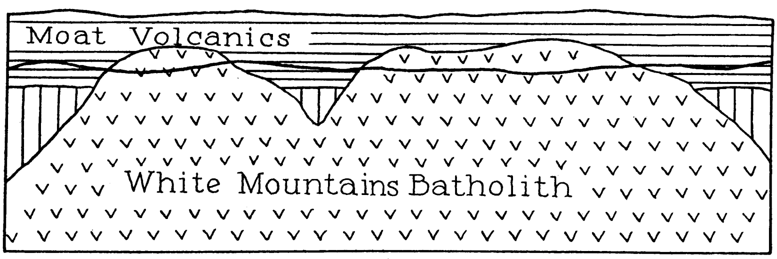


FIGURE 7. Diagrammatic cross-section of a subsequent batholith, showing the lithological similarity of the walls and roof-pendants. In 7 A the batholith is assumed to have stoped into the schists; the roof-pendant (R) and the walls are both composed of schists. In 7 B the batholith is assumed to have stoped into the volcanics; in this case both the walls and the roof-pendant would be composed of volcanics. For simplicity the diagrams indicate (1) that the lavas were extruded before roof-collapse began, and (2) that the lavas covered an area extending beyond the limits of the batholith.

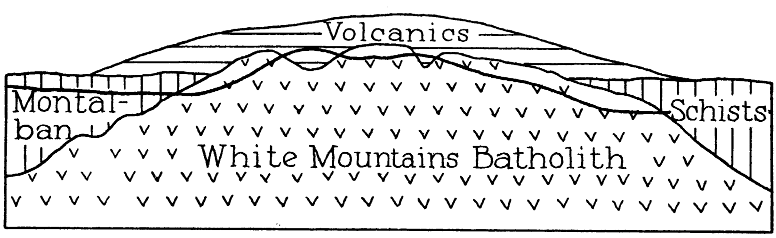


FIGURE 8. Diagrammatic cross-section of a batholith stoping into a volcanic pile, which is confined to an area immediately above the batholith.

completely immersed in the magma (figure 9), or they may be blocks that were attached to the roof along fault-planes (figure 10). The difference in strike and the steep dips of the Moat and Pequawket masses suggest that they are isolated xenoliths.

We may determine in a general way a minimum value for the amount of settling. Outside the batholithic area, in those places where there was no collapse, the base of the volcanics must have been higher than the present summits of the highest schist mountains fringing the batholith. That is, the base of the volcanics was higher than a level which now stands at 6,000 feet. In Moat Mountain the lowest exposed horizon of the volcanic group is at 900 feet. In other words, the elevation of the base of the volcanics is less than 900 feet within the batholith; how much lower, we have no way of telling. The western part of the Moat mass has settled therefore at least 5,000 feet below its original level. By simple trigonometry it may be demonstrated that in the northeastern portion of Moat Mountain the lowest known horizons are at least 17,000 feet below their original level, if we assume that piecemeal stoping has not shattered the large block at depth (see figure 5). All these figures are clearly only a minimum, for the actual basement on which the volcanics of Moat Mountain were extruded is lower within the batholith, and higher beyond its limits, than the horizons from which we have made our measurements. Thus the volcanics of Moat Mountain seem to have settled at least 5,000 feet into the batholith, and probably at least 17,000 feet on the northeastern end of the block. That this down-sinking took place during the intrusion of the batholith and not later is shown by the intrusive nature of the contacts between the Moat volcanics and the biotite granites.

It is frankly admitted that the exact value of the minimum amount of collapse can not be determined for a number of reasons. Late-Paleozoic or post-Paleozoic crustal warping has undoubtedly introduced complications. But the most difficult problem is to find a plane of reference from which to make measurements. In the discussion we have constantly referred to the floor upon which the volcanics were extruded as the reference plane. That floor may have had considerable relief. What we have actually used as a plane of reference is the *plane formed by the lowest points in that floor*. We find no volcanics beyond the limits of the batholith, so that we assume even the lowest points in the floor to have been above what are now the schist mountains surrounding the batholith. I wish to emphasize this point, lest it be thought that the surface upon which the volcanics

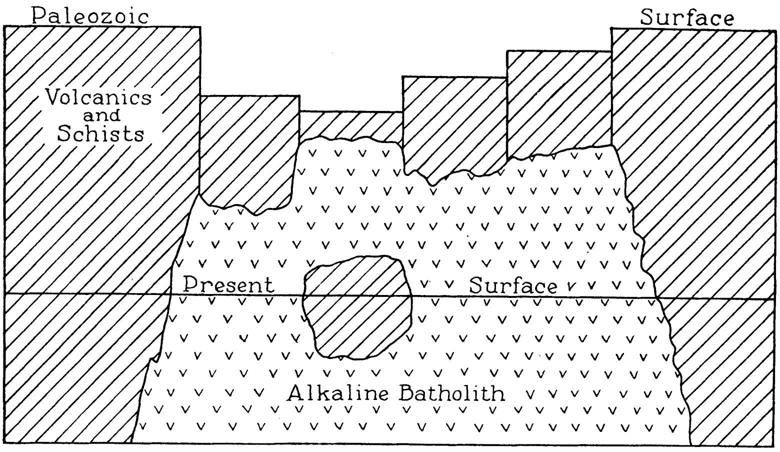


FIGURE 9. Diagrammatic cross-section showing the masses of Moat volcanics as isolated xenoliths in the plutonic phases of the batholith.

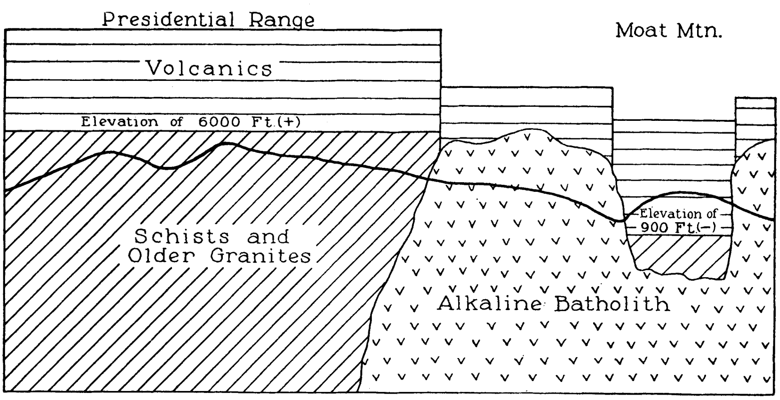


FIGURE 10. Diagrammatic cross-section showing the masses of Moat volcanics as down-faulted blocks attached to the roof of the batholith along fault-planes. The heavy black line represents the present surface. In the Presidential Range the floor upon which the volcanics were deposited would lie more than 6000 feet above sea level if it had not been eroded away. Within the confines of the batholith this same floor lies less than 900 feet above sea level. The Moat Mountain block has therefore settled at least 5000 feet below its original level.

were extruded is assumed to have been either a peneplane or a region of moderate relief. On the contrary, I have taken the plane formed by the lowest points in the floor as the reference plane and have made no assumptions as to the topography.

Having established the facts, we may briefly speculate as to the details of the process. We may assume that after a long period during which the magma was working upward, presumably by stoping, a stage was reached in which the roof was too thin for full support and began to break up into large blocks that would sink into the magma below. By this collapse of the roof over the batholith great differences in relief would result and great quantities of coarse sediment would pour into the collapsing area. Presumably the whole roof would settle, but it would undoubtedly break up into subsidiary blocks sinking at different rates. Accompanying collapse, great quantities of magma would well up along the fracture-planes to form surface flows, accompanied by considerable explosive activity. As collapse continued, great flows would flood the region, and vast quantities of detrital matter, mingled with explosive ejecta, would be swept in from the highlands to the lowlands. Probably at no time would the uncongealed magma in the upper portions of the batholith be exposed directly to the air; instead it would well up around the collapsing blocks to pour forth as lava flows. That all of the flows were extruded before roof collapse began does not seem probable. The high relief essential for the production of the coarse breccias is best explained by the contemporaneous collapse; moreover, collapse without accompanying volcanic activity seems improbable.

Evidence from other Late-Paleozoic Alkaline Batholiths. If the White Mountains are compared with other of the Late-Paleozoic alkaline batholiths of eastern North America, Greenland, and Norway, the conception of roof-collapse is clearly substantiated. The extrusion of flows and the contemporaneous collapse of the roof is illustrated by the following batholiths: Oslo (Christiania) batholith in Norway (1); Julianehaab batholiths in Greenland (2); East Greenwich batholith in Rhode Island (3); and the Quincy batholith in Massachusetts (4, 5). In the first two cases the field workers, Brögger (1) and Ussing (2) respectively, fully recognized the phenomenon of roof-collapse.

At Julianehaab in Greenland a series of Devonian (?) red sandstones, 1200 meters thick, underlie diabases, porphyrites, quartz porphyries, and subordinate volcanic tuffs that are 1000 meters thick (2*a*) (see figure 11). Just as in the White Mountains the sandstone and volcanics are found only within the limits of the alkaline plutonics (2*b*). Ussing has conclusively shown that their preservation in this region is due to the down-sinking of the roof of the batholith (2*c*); moreover, he shows that the portion of the volcanic series now preserved is older than the plutonic phases of the batholith and also that *subsidence accompanied batholithic intrusion* (2*d*). The subsidence amounts to at least 2000 meters and probably at least three kilometers (2*e*).

In the Oslo (Christiania) region of Norway, the classical works of Brögger have adequately demonstrated the collapse of the crust over the batholith (1*a*). In this down-faulted tract we find preserved Cambrian, Ordovician, Silurian, and Devonian (?) shales, limestones, and sandstones, overlain by a great series of extrusive augite porphyry, melaphyr, labradorite porphyry, and rhombenporphyries. To quote Brögger (1*b*): "The whole Christiania region forms, as I have already demonstrated, a long down-sunken graben about 230 kilometers long and within this great graben the collapsed portion of the earth's crust has broken up into numerous blocks shoved against one another.

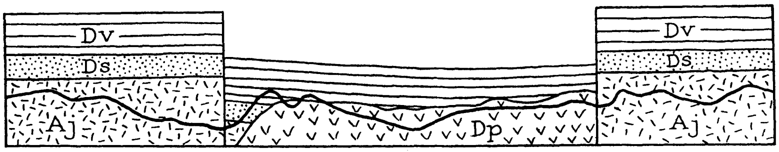


FIGURE 11. Diagrammatic cross-section of the batholith at Julianehaab, Greenland, to show roof-collapse. (After Ussing.) *Aj*, Julianehaab granite (Pre-Cambrian); *Ds*, red sandstone (Devonian ?); *Dv*, volcanic phases of the alkaline batholith; *Dp*, plutonic phases of the alkaline batholith. The heavy line represents the present surface. The collapse amounts to at least three kilometers.

The blocks have subsided varying amounts, and some blocks are twisted or even pushed up." Brögger estimates that the collapse amounts to at least 1300 meters (1*a*). The fact that the graben has broken up into many subsidiary blocks should be emphasized.

There are certain great contrasts between the White Mountains batholith on the one hand and the Julianehaab and Oslo batholiths on the other. In the White Mountains the down-faulted volcanics form only a very small proportion of the whole igneous area; in Oslo and Julianehaab the volcanics and associated sediments form more than half the batholithic belt. Moreover, the down-sunken blocks of New Hampshire have suffered much more rotation than in the Greenland example.

In the Shetland Islands volcanics and plutonic phases of the same alkaline batholith are known (6, 7). The Old Red Sandstone, with associated sandstone, conglomerate, tuff, agglomerate, porphyrite, diabase, and rhyolite, has been dropped down into a late-Devonian batholith composed essentially of a biotite granite with associated riebeckite-bearing dike rocks.

In the East Greenwich batholith of Rhode Island (3) approximately a square mile is represented by a microgranite breccia, which locally shows a rude stratification and contains fragments of rhyolite, quartzite, and granite. The strike is east-west, at right angles to the normal trend-lines of the region, and the dip is about twenty-five degrees to the north. I suggest that the microgranite and associated breccias are to be interpreted as a series of interbedded flows and fanglomerates which have settled into the biotite granites due to roof-collapse.

In the Quincy-Blue Hill batholith of eastern Massachusetts there are associated with the riebeckite granites a series of rhyolites, quartz porphyries, tuffs, and breccias, which Crosby (4) and Warren (5) have interpreted as a large, chilled, marginal phase of the batholith. The physiography, lithology, and other field evidence indicate that the rhyolite, porphyries, tuffs, and breccias represent a volcanic pile which has collapsed into the alkaline batholith.

One of the best examples of roof-collapse is found in the cauldron-subsidence of Glen Coe, so ably described by Clough, Maufe, and Bailey (8). A great ellipsoidal tract of volcanic rocks, nine miles by five miles, has settled into a tonalite magma of Late-Devonian age. This is a subalkaline batholith and is therefore not described further.

In summary, roof-collapse seems to have taken place in a number of the Late-Paleozoic alkaline batholiths, not only in the White Mountains of New Hampshire, but also in Norway, Greenland, Rhode Island, and eastern Massachusetts.

B. Synchronous Versus Subsequent Batholiths.

The Chatham batholith and the White Mountains batholith were intruded under very different conditions and by very different mechanisms (see figure 6). The Chatham batholith was intruded during an orogenic period under such conditions of pressure and temperature that it regionally metamorphosed the surrounding sediments, then intruded them in lit-par-lit fashion, and finally ripped them up and strewed them about through the granite. Folding was going on at the same time and the batholithic roof was always intact, greatly hindering the escape of magmatic gases; as a result great quantities of pegmatite were formed. Some large-scale stoping took place, but much of the space occupied by the granite originated through the folding, squeezing, and flowage of the schists. It is a *synchronous* batholith, for it accompanied a period of folding.

The White Mountains batholith on the other hand was not intruded during a period of orogeny and produced no regional metamorphism. It formed its chamber, at least in the closing stages, by stoping off small and large blocks of the older rocks, blocks which in some cases reached miles in diameter. The roof of the batholith was broken, and as a result the gases were not confined. Their escape caused extensive vulcanism at the surface and their loss prevented the formation of pegmatites in any great quantities. This batholith was intruded shortly after the compressive forces of the Acadian disturbance (9) had ceased, and the intrusion is therefore *subsequent* to a period of orogeny.

C. Assimilation of Inclusions in the White Mountains Batholith.

Small inclusions immersed in the granites and nordmarkites of the White Mountains batholith were not melted or corroded, but they were converted into granite by a process of impregnation. Each inclusion preserved its form and solutions soaking through the granite gradually caused microperthite, hastingsite, quartz, biotite, fluorite, allanite, and other minerals to replace the original minerals of the inclusion. At the same time the elements displaced must have diffused outward into the granite. The process has been described in detail for the impregnation of the diorite of Weeks Brook and in a general way for the re-making of inclusions to form the Diana phase of the Conway granite. The writer has observed the process elsewhere in the North Conway quadrangle.

The same phenomenon has been described by Warren (5) in the Quincy batholith, where the rhombenporphyry has been made over after being immersed in the riebeckite granite. Clapp (10) has maintained that the original essexite of Salem Neck is a hybrid rock resulting from the impregnation of diorites by exhalations from a nepheline-syenite magma. With this conclusion the present writer is in full accord. The Salem Neck and Weeks Brook occurrences are very similar, except that in the former case the diorite was stewing in a nepheline-syenite magma and in the latter case a biotite-granite magma. In the Salem occurrence alkali feldspar, nepheline, and ferromagnesian minerals have soaked into the older rock; in the White Mountains locality alkali feldspar, quartz, and ferromagnesian minerals have been added to the diorite.

D. Summary of the Geological History.

During a long period of time, presumably in the Pre-Cambrian, the site of the present White Mountains was inundated by an epicontinental sea in which thousands of feet of shale, sandstone, limestone, and dolomite were deposited. During a latter period, also probably Pre-Cambrian, the rocks were folded. With the folding, highly aqueous granitic magmas were intruded, to aid the mountain-building forces in metamorphosing the shales, sandstones, limestones, and dolomites into mica schists, micaceous quartzites, and lime-silicate rocks. Following the metamorphism, the granite intruded the schists, lit-par-lit, and gradually strewed them about through the granite.

The later Pre-Cambrian and early Paleozoic history is shrouded in mystery. It is probable that during the Silurian the region was submerged by an epicontinental sea, in which muds and sands were deposited; a mountain-making movement followed this deposition.

In the Devonian a great batholith, ranging in composition from diorite to granite, was intruded into the older rocks. The magma stoped upwards, ripping off great blocks of the older rocks, which sank to abyssal depths, to be assimilated. Eventually the roof of the batholith became so thin that collapse began. Along the great fractures molten magma moved upwards and issued at the surface as great flows and pyroclastic deposits. Coarse breccias accumulated in the lower basins. Eventually the magma spent its energy, and the great molten mass congealed to form syenites and granites.

The bed-rock structure of the White Mountains was now essentially complete; all further processes were confined to carving the present mountains from the schists, granites, syenites, and volcanics. For a long period the rivers have been striving to reduce the surface to a plain, but without complete success. Large areas were frequently reduced to the base-level of erosion, but each time, long before the process was complete, a continental uplift of a few hundred feet forced the rivers to begin anew their work of destruction. The repetition of this process formed many terraces. There were complications; at times the uplift was slow and gradual rather than swift and periodic; at other times the region subsided. The net effect was to produce many benches rising above one another, like a series of steps.

Then came the Great Ice Age. In the first stages of refrigeration mountain glaciers formed on the higher summits, carving out cirques. Eventually the ice-sheet from the north overwhelmed the mountains, scouring, striating, and fracturing the rocks. Projecting spurs and summits were rounded off, and hill sides were planed away. Glacial till was dumped to block the valleys. In the waning stages of the Ice Age a glacial lake filled the Saco Valley around North Conway. Since that time the meandering Saco River has been engaged in cutting away the sand plain, but little has been accomplished.

REFERENCES.

1. W. C. Brögger.
   a. Mineralien der Syenitpegmatitgänge der südnorwegischen Augit- und Nephelinsyenite, Allgemeiner Theil, ss. 16 & 17.
   b. Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol, s. 133.
2. N. V. Ussing. Geology of the country around Julianehaab, Greenland. a = p. 13–14. b = p. 289. c = pp. 287–292. d = p. 290–291. e = pp. 289–290.
3. B. K. Emerson, and J. H. Perry. The green schists and associated granites and porphyries of Rhode Island. Bull. 311, U.S.G.S., 1907.
4. W. O. Crosby. Geology of the Boston Basin, vol. 1, part 3: the Blue Hills complex. Boston Society of Nat. Hist., Occasional Paper IV, pp. 289–563, 1900.
5. C. H. Warren. Petrology of the alkaline granites and porphyries of Quincy and the Blue Hills, Mass., U.S.A. Am. Acad. Arts and Sci., Pr. 49, pp. 203–331, 1913.
6. B. N. Peach, and J. Horne. The old red volcanic rocks of Shetland. Trans. Royal Soc. Edinburgh, vol. 32, part 2, pp. 359–388, 1884.
7. F. C. Phillips. Notes on a riebeckite-bearing rock from the Shetlands. Geol. Mag., vol. 63, pp. 72–77, 1926.
8. C. T. Clough, H. B. Maufe, and E. B. Bailey. The cauldron subsidence of Glen Coe, and the associated igneous phenomena. Quart. Jour. Geol. Soc., London, vol. 65, pp. 611–678, 1909.
9. L. V. Pirsson, and C. Schuchert. Textbook of Geology, Part II, p. 316, second edition, 1924.
10. C. H. Clapp. Igneous rocks of Essex County, Mass. Bull. 704, U.S.G.S., p. 124–126.

PLATE II A.

Aerial photograph of the Saco Valley at North Conway. In the foreground may be seen the meandering Saco River; in the middle distance, White Horse and Cathedral Ledges; and in the background, Moat Mountain.

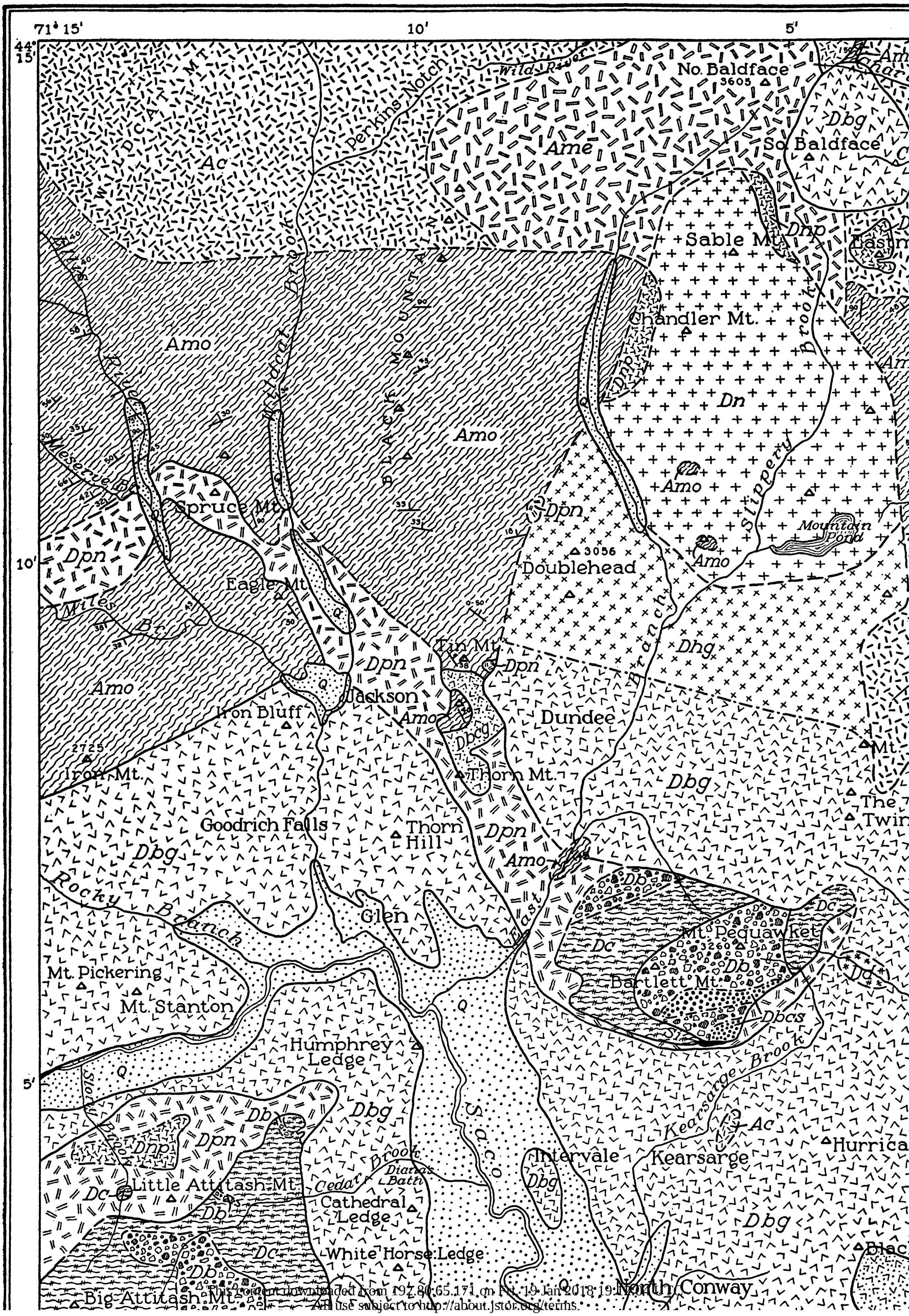
PLATE II B.

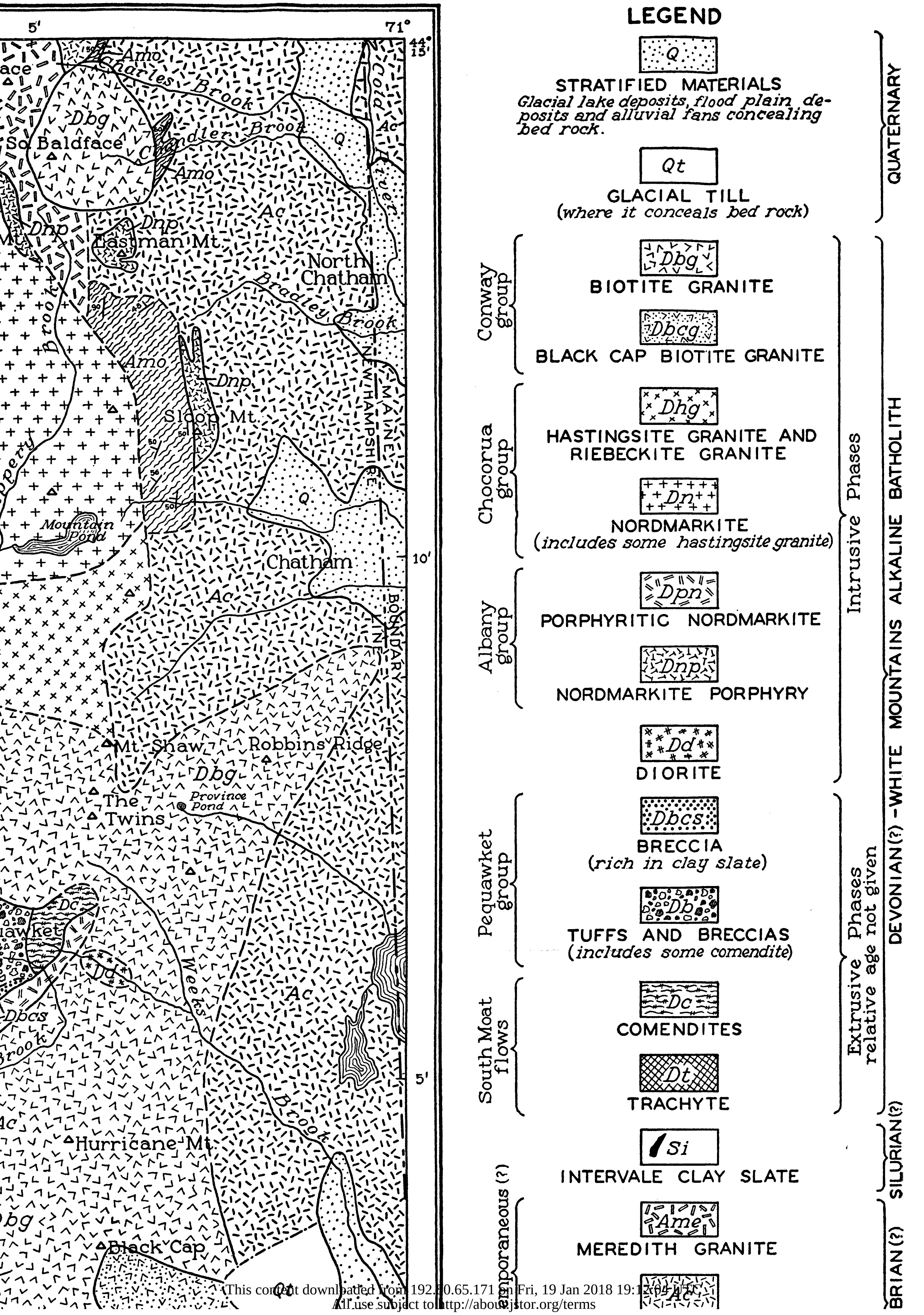
Weathering of the Conway biotite granite at Goodrich Falls.

Photograph from Hunting's Studio, North Conway.

A

B


71° 15'
10'
5'
44° 15'
10'
5'
Wild River
No. Baldface
3605
So. Baldface
Perkins Notch
WILDCAT MT.
Ac
Ame
Dbg
Sable Mt.
Dnp
Eastm
Amo
Wildcat Brook
BLACK MOUNTAIN
Chandler Mt.
Slippery Brook
Dn
Dnp
Rocky Branch
Meserve Br.
Spruce Mt.
Dpn
Mountain Pond
Doublehead
3056
Miles Br.
Eagle Mt.
Q
Tin Mt.
Dhg
Branch
Jackson
Iron Bluff
Dundee
2725
Iron Mt.
Dbcg
Thorn Mt.
Goodrich Falls
Thorn Hill
The Twin
East
Db
Glen
Dc
Mt. Pequawket
3260
Bartlett Mt.
Mt. Pickering
Mt. Stanton
Dbcs
Humphrey Ledge
Kearsarge Brook
Saco
Dbg
Intervale
Kearsarge
Hurrica
Little Attitash Mt.
Cedar Brook
Diana's Bath
Cathedral Ledge
White Horse Ledge
Big Attitash Mt.
North Conway
Blac


5'
71°
44°
15'
10'
5'
Amo
Charles Brook
Chandler Brook
Cold River
Ac
Q
Dbg
So. Baldface
Dnp
Eastman Mt.
North Chatham
Bradley Brook
Brook
Sloop Mt.
NEW HAMPSHIRE
MAINE
Mountain Pond
Chatham
BOUNDARY
Mt. Shaw
Robbins Ridge
The Twins
Province Pond
Dc
Dd
Dbcs
Weeks
Brook
Hurricane Mt.
Black Cap
Qt
LEGEND
Q
STRATIFIED MATERIALS
Glacial lake deposits, flood plain deposits and alluvial fans concealing bed rock.
Qt
GLACIAL TILL
(where it conceals bed rock)
QUATERNARY
Conway group
Dbg
BIOTITE GRANITE
Dbcg
BLACK CAP BIOTITE GRANITE
Chocorua group
Dhg
HASTINGSITE GRANITE AND RIEBECKITE GRANITE
Dn
NORDMARKITE
(includes some hastingsite granite)
Albany group
Dpn
PORPHYRITIC NORDMARKITE
Dnp
NORDMARKITE PORPHYRY
Dd
DIORITE
Intrusive Phases
Pequawket group
Dbcs
BRECCIA
(rich in clay slate)
Db
TUFFS AND BRECCIAS
(includes some comendite)
South Moat flows
Dc
COMENDITES
Dt
TRACHYTE
Extrusive Phases
relative age not given
DEVONIAN(?) - WHITE MOUNTAINS ALKALINE BATHOLITH
Si
INTERVALE CLAY SLATE
SILURIAN(?)
Contemporaneous (?)
Ame
MEREDITH GRANITE
Ac
BRIAN(?)

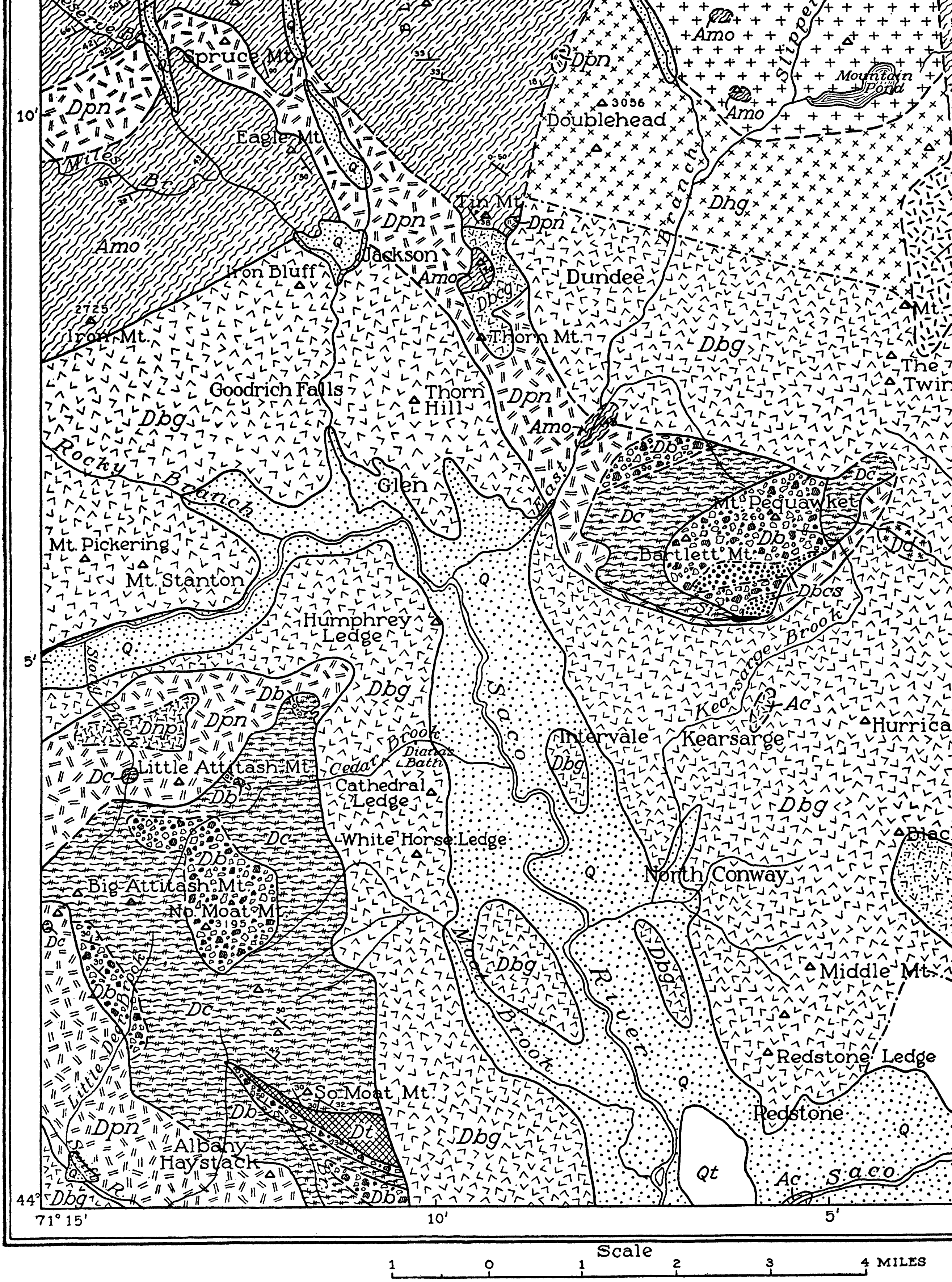
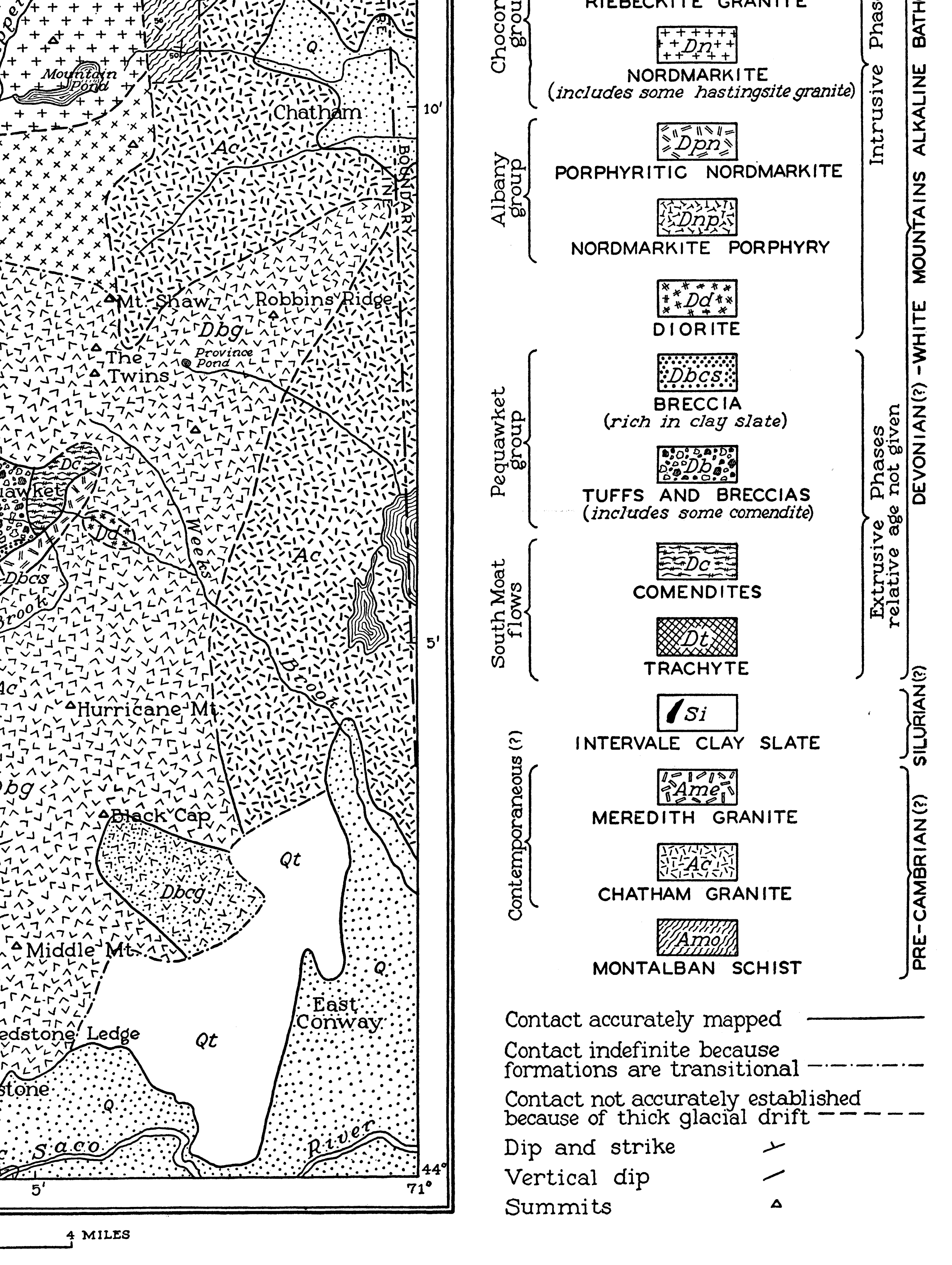


PLATE I. GEOLOGICAL MAP OF THE NORTH CONWAY QUADRANGLE, NEW H

The following additional notes may be made to the legend: (1) the diorite of the White Mountains alkaline batholith may be ol vicinity of Robbins Ridge small areas of hastingsite granite have not been separated from the biotite



RANGLE, NEW HAMPSHIRE.

e batholith may be older than the extrusive phases; (2) in the arated from the biotite granite.