Geology of the CRAWFORD NOTCH QUADRANGLE NEW HAMPSHIRE

by

Donald M. Henderson, Marland P. Billings, John Creasy, and Sally Anne Wood

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Frontispiece. Presidential Range.
View northeast over the northwest half of the Crawford Notch Quadrangle. Snow-capped Presidential Range on the center skyline. Mt. Webster and Crawford Notch below and to the right of the Presidential Range. Whitewall Mountain and Zealand Notch left side of photo. Mt. Hancock in lower right-hand corner. Photo Dick Smith.

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Photographs by Dick Smith, North Conway, N. H.

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FOREWORD

The geological map accompanying this brochure (Plate 1) is based largely on field work by Henderson. His doctoral thesis on the eastern half of the quadrangle was prepared at Harvard University (Henderson, 1949). He mapped the western half of the quadrangle in 1950. No report was prepared, but his map was available to Billings (1956) in the compilation of the geological map of New Hampshire. Creasy (1974), remapping parts of the quadrangle, especially the Willey Range and the Mt. Carrigain region, confirmed Henderson's mapping. Wood (1975) made a detailed study of the mineralogy and chemistry of the rocks in the Hart Ledge Complex as an A.B. thesis at Middlebury College; columns 11 to 18 of Table 3 are based on her work. The map of the Hart Ledge Complex in Plate 1 has been compiled by Billings, utilizing the work of Henderson, Wood, and himself. Billings, who is very familiar with the quadrangle, has compiled the geological map (Plate 1), and has prepared the text and illustrations.

The first draft of this paper was read by Professors John B. Lyons and Richard P. Goldthwait, both of whom gave many valuable suggestions.

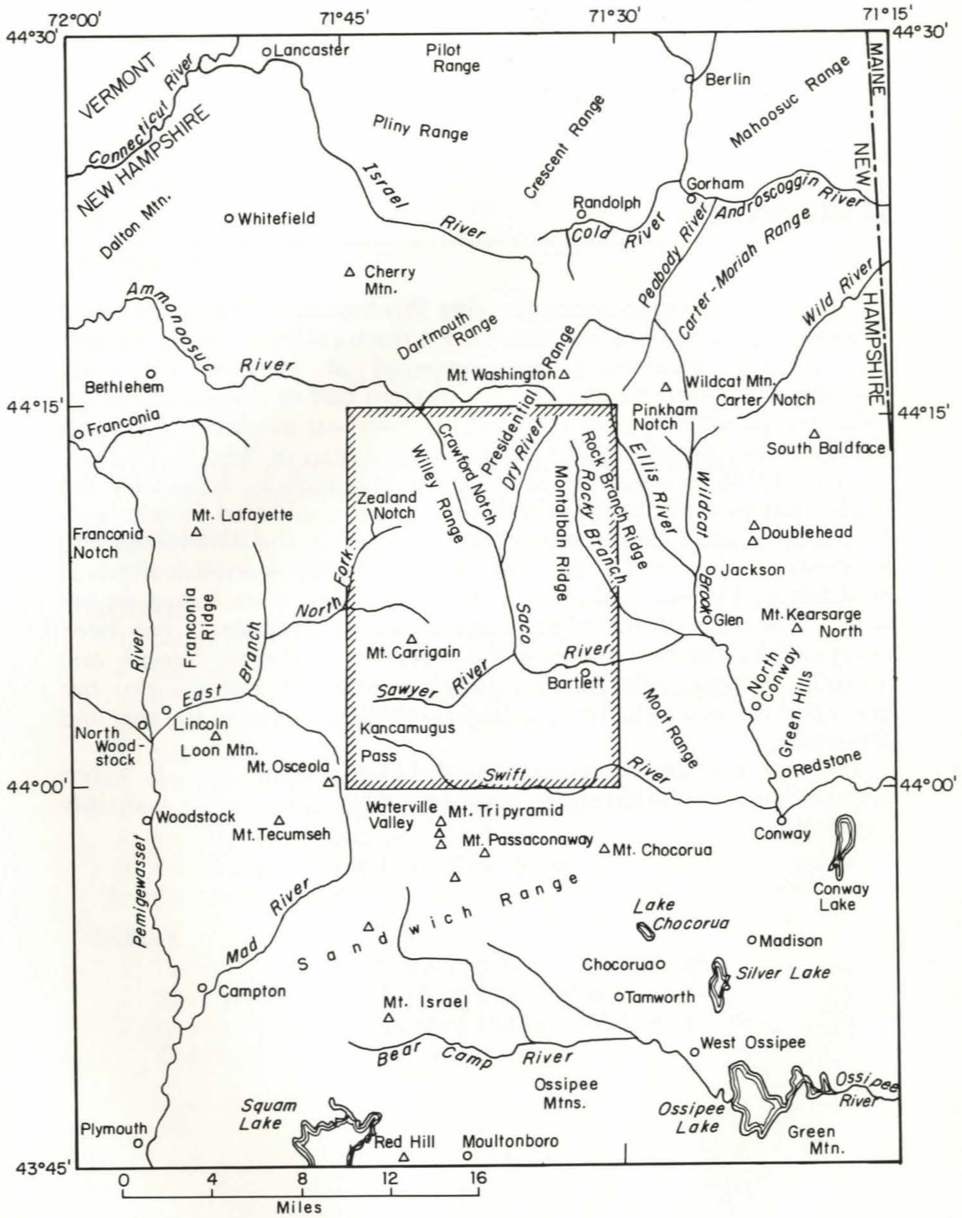

Figure 1. Index Map.
Crawford Notch Quadrangle is rectangle enclosed by diagonal lines.

LOCATION

The Crawford Notch Quadrangle, covering 214 square miles, is located in central New Hampshire in the heart of the White Mountains (Fig. 1). Lying just southwest of Mt. Washington, the highest peak in the northern Appalachian Mountains (altitude 6288 feet), the northeastern part of the quadrangle contains the Southern Peaks of the Presidential Range. Three major passes (notches) through the crest of the White Mountains are in the northern part of the quadrangle; they are Pinkham, Crawford, and Zealand Notches. A history of human occupation is described by Hancock (1967) and Morse (1966).

THE LANDSCAPE

Drainage

Figure 1 shows the relation of the principal drainage and topographic features of the Crawford Notch Quadrangle to the surrounding area. Most of the quadrangle is drained by the Saco River and its tributaries. The Saco River rises in Saco Lake, altitude of 1900 feet, in the northwest part of the quadrangle (Pl. 1), flows southerly for 10 miles, then turns east for 5 miles, leaving the quadrangle at an altitude of 615 feet two miles east of the village of Bartlett. The average gradient is thus about 86 feet per mile. The principal tributaries of the Saco in the northeast quarter of the quadrangle are Dry River, Rocky Branch, and Ellis River. The southwest corner is drained by the Sawyer and Swift Rivers, which are also tributaries of the Saco. The northwest corner is in the drainage basin of the Ammonoosuc River, which eventually joins the Connecticut River. The west-central part of the quadrangle is in the Pemigewasset drainage basin; 40 miles to the south this river joins the Winnipesaukee River to form the Merrimack River.

Mountains

Because of the complexity of the bedrock geology, the mountains show no systematic trend (Fig. 2). The highest point is Mt. Franklin, altitude of 5004 feet, along the northern margin of the quadrangle; it

Figure 2. Carrigain Notch.
Looking northwest. Mt. Carrigain left center. Carrigain Notch right foreground. Ridge on skyline is west of Crawford Notch Quadrangle; from left to right Mt. Garfield, Twin Mountain, and Mt. Hale. Photo Dick Smith.

is one of the Southern Peaks of the Presidential Range. Since the lowest point is 615 feet, the total relief is 4389 feet.

In the northeastern quarter of the quadrangle a series of ridges extends southerly from Mt. Washington (Fig. 1). These are: (1) Southern Peaks and Mt. Webster; (2) Montalban Ridge*, of which Bemis Ridge is a spur; and (3) Rocky Branch Ridge. In the northwest corner of the quadrangle the Rosebrook Mountains (3110 feet) and the Willey Range (Mt. Field, 4326 feet) trend northwesterly, a direction controlled by cauldron subsidence, as discussed below.

The southern half of the quadrangle is dominated by large irregular masses: Mt. Carrigain (4600 feet), Mt. Hancock (4403 feet), Mt. Huntington (3870 feet), Mt. Kancamagus (3728 feet), Mt. Tremont (3384 feet), Bartlett Haystack (3010 feet), Bear Mountain (3217 feet), and Table Mountain (2710 feet).

* Montalban is incorrectly spelled on U.S.G.S. topographic map and on Plate 1.

BEDROCK AND ITS STORY

Introduction

Two major concepts are essential in thinking about the evolution of the present mountains. One must think in terms of vast lengths of time — hundreds of millions of years, as shown in Table 1. Secondly, one must realize that since the last bedrock formed, many thousands of cubic miles of rock have been eroded, much of it to be deposited on the continental shelf off the coast of New England. The mountains may never have been higher than at present; erosion was accompanied by regional uplift.

In general, bedrock is the hard rock, such as granite, that can be broken only with a hammer. But locally the bedrock may be weathered to "rottenstone," as discussed below. The surficial rocks are the sand, gravel, till and alluvium that normally can be readily penetrated by a shovel. They seldom exceed 100 feet in thickness and in many places are absent so that bedrock is exposed.

The evolution of the area (Figs. 3 and 4) was accomplished in five stages: (1) Devonian Period, 400-350 million years ago (Fig. 3, 4A, B, C); (2) a long period of erosion, 350-190 million years ago (Fig. 4D); (3) part of the Mesozoic Era, 190-100 million years ago (Fig. 4E and F); (4) a long period of erosion, from 100 million years ago to two million years ago (Fig. 4G); and (5) the Quaternary (including the Great Ice Age), covering the last two million years (Fig. 4H & I).

Devonian Period

General statement. The rocks that formed in the Crawford Notch Quadrangle during the Devonian Period, 400-350 million years ago, belong to three major rock units: (1) Littleton Formation, (2) Kinsman Quartz Monzonite, and (3) Concord Quartz Monzonite. Older rocks of Cambrian, Ordovician, and Silurian ages are found in western New Hampshire, and Precambrian rocks crop out in the Green Mountains of Vermont.

Littleton Formation. These rocks occupy most of the northeasterly fifth of the quadrangle. Another belt, much cut up by younger intrusives, extends southwesterly for nine miles from the east-central edge of the quadrangle to near Mt. Carrigain. Another small band 5 miles long extends northwesterly from Mt. Willey to the west edge of the quadrangle.

The Littleton Formation is composed of metamorphosed

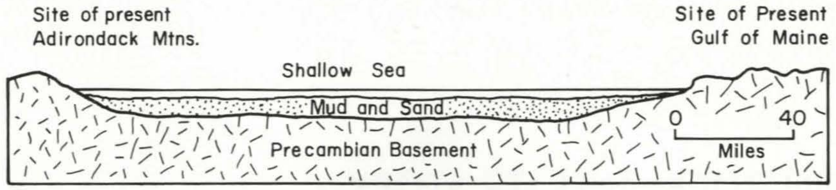

Figure 3. Sedimentation During Early and Middle Paleozoic.
Site of Crawford Notch Quadrangle is between Gulf of Maine and Adirondack Mountains.

sedimentary rocks; that is, it was deposited as mud, silt, and sand in a shallow sea (Fig. 3), but later, because of heat and pressure, it was recrystallized into metamorphic rocks.

Four principal varieties of rocks are present: (1) gneiss, (2) interbedded mica schist and quartzite, (3) lime-silicate rocks, and (4) interbedded andalusite schist and quartzite.

Gneiss is the most common rock in the Littleton Formation (**Dllg** on Pl. 1). It is a gray rock composed of two components, one that is dark gray and is composed primarily of mica (muscovite and biotite), with a little feldspar and quartz, and a second that is white and composed primarily of feldspar and quartz. In many places these two components form alternating irregular layers an inch thick. In other areas the quartz-feldspar component forms irregular ellipsoidal pods one to three inches in maximum dimension. Prior to metamorphism these gneisses were siltstones (Billings and Fowler-Billings, 1975, p. 20-21).

Interbedded mica schist and micaceous quartzite (**Dlu** and **Dlli** on Pl. 1) is common in the Presidential and Mahoosuc Ranges (Billings and Fowler-Billings, 1975). But in the Crawford Notch Quadrangle such rocks are confined to a few small areas in the northeast part of the quadrangle. Some of these areas (**Dlu**) are enclosed by the Boott Member (Pl. 1). Other areas (**Dlli**) are in the midst of gneisses. Contacts with the gneisses are generally not sharp; moreover, transitional types between gneiss and interbedded mica schist and micaceous quartzite are common. The interbedded mica schist and micaceous quartzite were deposited as mud and sand (Fig. 3).

A very different variety of the Littleton Formation is found in the Willey Range (**Dlu**). These rocks are superbly exposed along the Maine Central Railroad both north and south of the trestle over Willey Brook. Beds of gray micaceous quartzite, 2 to 10 inches thick, are interbedded with beds of andalusite schist 2 inches thick. The andalusite crystals, which should more correctly be called pseudo-andalusite, because they have been converted to sericite (small grains of white mica), range in length from 1 to 4, even 6,

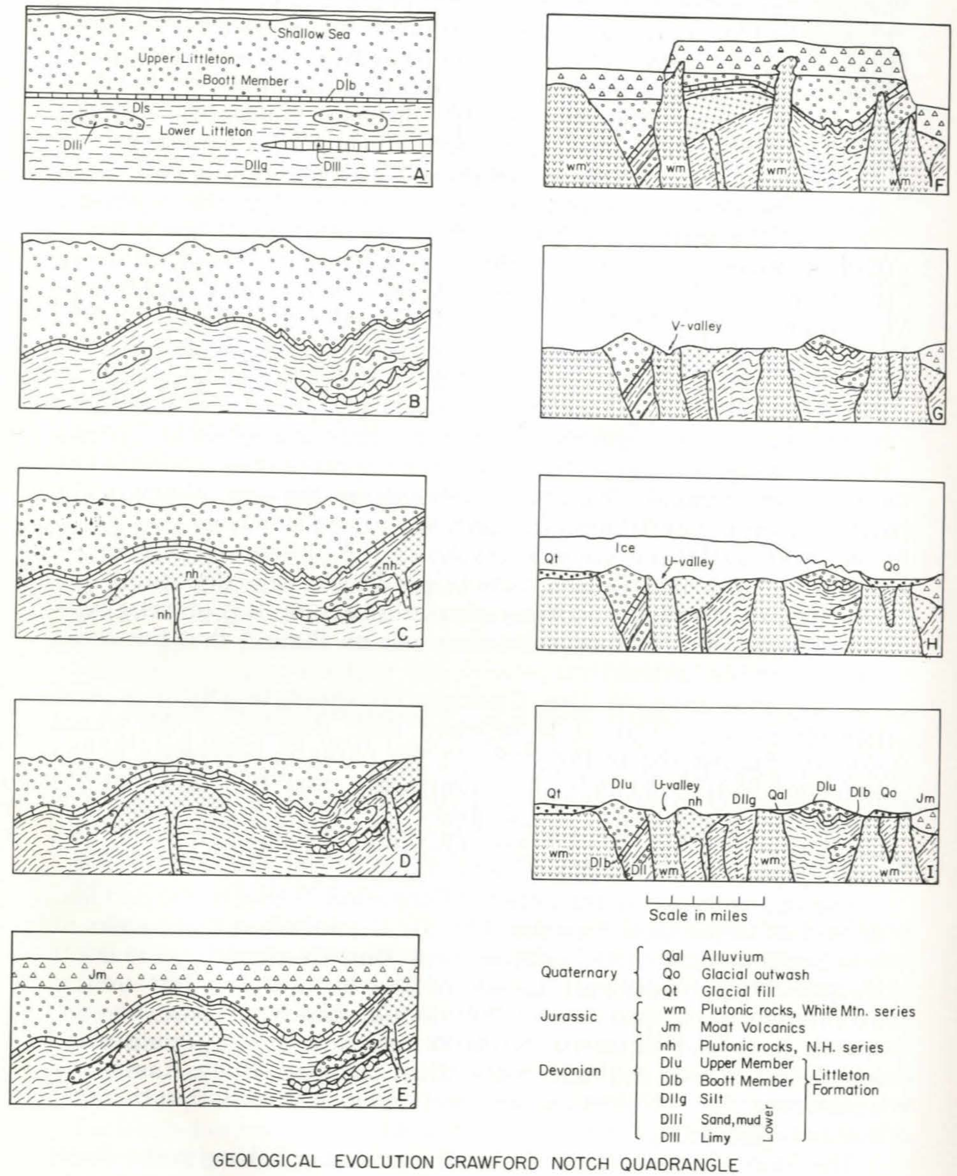

Figure 4. Evolution of Crawford Notch Area.
A. Early Devonian, 400 million years ago, sedimentation. B. Middle Devonian, 380 million years ago, Acadian Revolution, folding. C. Middle Devonian, 375 million years ago, Acadian Revolution, intrusion of New Hampshire Plutonic Series. D. Middle Devonian to Late Triassic, 375 to 190 million years ago, erosion. E. Late Triassic, 190 million years ago, eruption of Moat Volcanics. F. Early Jurassic, 185 million years ago, Cauldron subsidence of Willey Range and intrusion of plutonic members of White Mountain Volcanic-Plutonic Series. G. Jurassic through Tertiary, 185 to 2 million years ago, erosion. H. Pleistocene, beginning 2 million years ago, Great Ice Age. Evidence for only last part of epoch is recognized in Crawford Notch Quadrangle. Figure shows stage when ice front had melted back from Long Island to Crawford Notch Quadrangle. I. Recent. Stream erosion began about 12,000 years ago, after continental ice sheet had melted away.

inches. The width is about one-quarter of the length. The andalusite crystals lie parallel to the bedding, but are diversely oriented in these planes; the groundmass is composed of quartz, feldspar, and mica. These rocks were deposited as mud and sand (Fig. 3), but the sequence of metamorphic events differed from that in the interbedded quartzites and mica schists elsewhere.

Lime-silicate rocks (**Dlb** and **Dlll**) on Plate 1 comprise a very small part of the Littleton Formation. Some are found in the northeast corner of the quadrangle (**Dlb**); others are north of Meserve Brook (**Dlll**) and west of Notchland (**Dlll**). Many are greenish gray to white granular rocks called granofels. Some have green amphibole (actinolite) needles 0.1 to 0.3 inch long set in a matrix of quartz, feldspar, and biotite. Others are white granular rocks composed of quartz and feldspar, with grains of light-green pyroxene (diopside). A dark-brown biotite granofels composed of quartz, feldspar, and biotite is commonly associated with these lime-silicate rocks. Locally these rocks are schistose, hence are more appropriately called schist rather than granofels. Prior to metamorphism the lime-silicate rocks were calcareous and dolomitic sandy shales and siltstones.

In order to deduce the stratigraphy of the Littleton Formation — that is, the sequence in which the original rocks were deposited — it is necessary to understand the geological structure. It is obvious from the bedding and foliation symbols given on Plate 1 that the rocks must be highly folded.

From evidence in the Gorham Quadrangle (Billings and Fowler-Billings, 1975), it is believed that, despite all the minor folding, the net dip of the strata of the Littleton Formation in the Crawford Notch Quadrangle is northwest; that is, the strata are progressively younger to the northwest. This is also consistent with data from the Mt. Washington Quadrangle (Billings, 1941). The stratigraphic data are summarized in Table 2.

The youngest part of the Littleton Formation — that is, the part laid down last in the Devonian sea (Fig. 3) — is found in three areas of interbedded mica schists and quartzites (**Dlu**) enveloped by the Boott Member in the northeast corner of the quadrangle. This unit is extensively developed in the Presidential and Mahoosuc Ranges, where it is estimated to be 4000 feet thick. The interbedded andalusite schist and quartzites (**Dlu**) in the Willey Range are considered to be the same unit, but somewhat differently metamorphosed.

The lime-silicate rocks in the northeast corner belong to the Boott Member (**Dlb**) of the Littleton Formation; it averages about 50 feet in thickness (Billings, 1941).

The gneisses (**Dllg**) so extensively developed in the northeast corner of the quadrangle underlie the Boott Member. They were originally siltstones. The interbedded mica schists and quartzites (**Dlli**) in this part of the quadrangle are considered to have been lenses of mud and sand in the original silts. This unit is believed to be about 10,000 feet thick and the net dip to be about 25° NW, as in the Gorham Quadrangle (Billings and Fowler-Billings, 1975).

The lime-silicate beds (**Dlll**) around Meserve Brook and Notchland are considered to be the same series of beds. They continue northeasterly across the North Conway Quadrangle into the Gorham Quadrangle, where it is called unit 4, and estimated to be 0-500 feet thick (Billings and Fowler-Billings, 1975, p. 108).

The gneisses north of the hamlet of Livermore apparently underlie this "unit 4" and are about 1500 feet thick. The gneisses east of the Albany Quartz Syenite along the east-central margin of the quadrangle are presumably involved in a cauldron subsidence and their correlation is uncertain.

No fossils are known from the Crawford Notch Quadrangle. But the uppermost unit may be correlated with unmetamorphosed rocks in the Littleton area (Billings 1937) that contain Lower Devonian fossils. All the underlying units are believed to be younger than rocks containing Middle Silurian fossils, hence to be Lower Devonian, possibly Upper or Middle Silurian (Billings and Fowler-Billings, 1975, p. 28).

Kinsman Quartz Monzonite. This unit (**kqm**) underlies an oval-shaped area 4 by 2 miles, that trends south-southwest south of Mt. Carrigain. In popular parlance this rock is a granite. The Kinsman is a very distinctive rock because of large crystals (phenocrysts) of potash feldspar one-half to two inches long; these may constitute as much as 10 percent of the rock. The matrix is a coarse-grained mixture of quartz, feldspar, muscovite, and biotite.

Concord Quartz Monzonite. This rock (**cqm**) is found in three areas: (1) north of Saco Lake a large body, which is the southerly extension of a big area in the Mt. Washington Quadrangle; (2) south of Mt. Parker; and (3) in the southeast corner of the quadrangle. This rock is a white to gray medium-grained rock composed of feldspar, quartz, biotite, and muscovite. The Kinsman and Concord are believed to be Middle Devonian.

Acadian Revolution. This event occurred in the Middle and Late Devonian, 380 to 350 million years ago. The horizontal strata of the Littleton Formation (Fig. 4A) were compressed into folds (Fig. 4B). Steep dips of the bedding and foliation are common, and minor folds are ubiquitous. The major structure is not obvious, but the map pattern of stratigraphic units and analogy with the Gorham Quadrangle (Billings and Fowler-Billings, 1975) indicate that the Littleton Formation of the Crawford Notch Quadrangle is on the southeast limb of a major synclinorium.

The magma that consolidated to form the Kinsman Quartz Monzonite was injected in the late stages of the folding (Fig. 4C), whereas the magma that formed the Concord Quartz Monzonite was injected after the folding. Professor John B. Lyons of Dartmouth College has determined by radiometric methods that the Concord is 383±22 million years old (personal communication, May 5, 1976).

The shales, siltstones, sandstones, and calcareous shales of the Littleton Formation were metamorphosed to gneiss, schist, quartzite, and lime-silicate rocks in the late stages of the folding and shortly thereafter. Experimental studies of the system kyanite-andalusite-sillimanite indicate that the metamorphism took place at depths of nine miles and temperatures of 620° C. This does not mean that the mountains were 9 miles high at that time; during subsequent periods of erosion the crust of the earth slowly rose.

Late Paleozoic and Early Mesozoic Erosion

Following the Acadian Revolution the area was subjected to erosion, presumably by streams. This event lasted from the Middle Devonian to the Late Triassic, that is, from about 370 to 190 million years ago, an interval of 180 million years (Fig. 4D).

Mesozoic

White Mountain Plutonic-Volcanic Series, General Statement. Initially this series was considered Mississippian (?) (Billings, 1956), but later radiometric ages indicated that the Conway Granite is about 185 million years old, that is Late Triassic, as shown in Table 1 (Wilson, 1969, p. 54). Radiometric studies by Foland et al. (1971) suggested that the age of the White Mountain Series may range from Late Triassic into Cretaceous. Although the radiometric methods on which this conclusion is based are of dubious value, they may nevertheless be correct.

Beginning in Late Triassic time vast quantities of magma rose into the crust. Some of this erupted onto the surface to form the Moat Volcanics (Fig. 4E). But much of it consolidated beneath the surface to form gabbro, syenite, quartz syenite, and granite. The Hart Ledge complex is described after the other units of the White Mountain Series, partly for convenience, but also because it may be younger.

Table 3 has been prepared for those interested in precise information on the percentages of the various minerals in the plutonic rocks of the White Mountain Series.

Moat Volcanics. These rocks are extensively exposed in Moat Mountain, just east of the southeast ninth of the Crawford Notch Quadrangle (Billings, 1928). Here this formation is about 10,000 feet thick and consists chiefly of rhyolite, rhyolite tuff, breccia, and a little trachyte. Noble and Billings (1967) concluded that some of these rhyolites are ash-flows. A small part of the volcanics on Moat

Mountain extends into the Crawford Notch Quadrangle 2¼ miles southeast of the village of Bartlett. The Moat Volcanics in the Willey Range and on the southeast flanks of Mt. Carrigain consist of porphyritic trachyte and coarse rhyolite.

Gabbro. This rock, in a body about ¾ mile long, crops out on Dry River between altitudes of 2000 and 2200 feet. It is a dark-green, medium-grained rock with an ophitic (diabasic) texture; diversely oriented feldspar (plagioclase) laths are 0.02 to 0.2 inch long; the dark minerals are irregularly shaped grains between the feldspar laths. The most common variety is composed of feldspar, olivine, and augite. In places dark layers, that are 0.5 to 6 inches thick, are composed of olivine, augite, and hornblende. A less abundant variety of the gabbro is composed of plagioclase, biotite, and hornblende.

Carrigain Syenite Porphyry. This is a medium-grained gray rock forming an oval-shaped area 3 miles in maximum dimension on Mt. Carrigain. White to pink phenocrysts of feldspar (microperthite), 0.3 inch long are set in a groundmass of microperthite and subordinate amphibole, the grain size of which is 0.025 to 0.05 inch.

Quartz Syenite Porphyry. A small body of this rock, 1500 feet in diameter, lies on the south side of the summit of Mt. Hope. Phenocrysts of quartz and pink feldspar (microperthite and anorthoclase), 0.4 inch long, are set in a gray fine-grained matrix of feldspar (microperthite, orthoclase), quartz, and ferrohastingsite.

Mt. Lafayette Granite Porphyry. This porphyry, which varies somewhat in texture and mineralogy, is found in four places in the quadrangle: (1) a narrow body 3 miles long on the east flanks of Mts. Bemis and Saunders; (2) an oval-shaped body nearly one mile long around Mt. Hope; and (3) two small bodies 4 miles north of Mt. Carrigain.

Phenocrysts of quartz and feldspar (microperthite), 0.08 to 0.15 inch in diameter, are set in a fine-grained groundmass. The grains of this groundmass are 0.004 to 0.02 inch across, and are chiefly quartz and feldspar (microperthite), with a few percent of dark minerals (fayalite, hedenbergite, ferrohastingsite, and biotite). These rocks are similar in mineralogy and chemistry to the rhyolites of the Moat Volcanics, but the groundmass is coarser.

Albany Porphyritic Quartz Syenite. This rock forms arcuate bodies (ring-dikes) in four localities: (1) Rosebrook Mtns. and Willey Range, a body 5 miles long and averaging ½ mile in width; (2) southeast flank of Mt. Carrigain, a body 2 miles long and 0.2 mile wide; (3) east-central edge of the quadrangle, a body 3 miles long and 0.25 mile wide; and (4) the southeast edge of the quadrangle, a body 4 miles long and 0.5 mile wide. In the Franconia Quadrangle (Williams and Billings, 1938, p. 1030) this rock was called the Mt. Garfield Porphyritic Quartz Syenite because the phenocrysts are somewhat larger than in the typical Albany. Fresh specimens are dark-green but weathered rocks are gray or pink speckled by the dark minerals. Feldspar (microperthite) phenocrysts average about 40% of the rock; in the body in the Willey Range they range in length from 0.2 to 0.6 inch, but in the other bodies they average 0.2 inch in length. Angular and irregular smoky quartz phenocrysts, averaging 0.08 to 0.16 inch in maximum dimension, constitute 5% of the rock. The granular groundmass, the grains of which range from 0.01 to 0.03 inch in diameter, is composed chiefly of feldspar (microperthite) and quartz, with a few percent each of fayalite, hedenbergite, and ferrohastingsite.

Mt. Osceola Granite. This granite occurs throughout the quadrangle. It is an amphibole granite, in contrast to the Conway, which is a biotite granite. There are five principal areas: (1) subcircular area 3 miles in diameter around Mt. Hancock; (2) large oval area, 10 miles long and 3 miles wide, extending from Shoal Pond Brook to Rocky Branch; (3) irregular area, shaped like a horseshoe opening north, 10 by 2 miles, extending from Sawyer River to east edge of quadrangle; (4) small circular area, 1½ miles in diameter, at headwaters of Swift River; and (5) a small body, ¾ mile in diameter, 2 miles north of the village of Bartlett.

The Mt. Osceola Granite is a medium-grained to coarse-grained rock, dark-green where fresh, brown to dull-white where weathered. The average grain is 0.1 to 0.3 inch in diameter. The principal minerals are feldspar (microperthite), composing 65% of the rock, and quartz, making up 30%. The dark minerals, average about 5%. The most abundant dark mineral is ferrohastingsite; less common are hedenbergite, ferrorichterite, biotite, and fayalite.

Conway Granite. This unit is extensively developed in the Crawford Notch Quadrangle. One very irregular mass underlies much of the northwest part of the quadrangle, except for the Rosebrook and Willey Ranges. It is the bedrock in the headwaters of the East Branch of the Pemigewasset River. Another large body lies in the southwest and southern parts of the quadrangle. Yet another area centers around the village of Bartlett.

The Conway Granite is a biotite granite, which is typically pink or light tan; the grains range in size from 0.1 to 0.2 inch, up to 0.4 inch. Pink feldspar (mostly microperthite, a little plagioclase) constitutes 65% of the rock, smoky quartz 30%, and biotite 5%. Locally, especially near contacts, the rock may be porphyritic, with feldspar (microperthite) phenocrysts 0.3 inch long set in a finer-grained groundmass; in places fine-grained phases are associated with this porphyritic phase. Pegmatitic lenses are rare; pegmatites are merely exceptionally coarse-grained phases of the rock, in which the minerals may be an inch or more across. Miarolitic cavities are locally present; they are open spaces, one to three inches in diameter, into which well-formed crystals of quartz, feldspar and other minerals grew. They are significant because they show that the Conway Granite consolidated near enough the surface for gases to

evolve from the magma — just as gas does not escape from a gingerale bottle until the pressure is released.

Black Cap Granite. This rock occupies an oval-shaped area, 2 x 1 miles, in the center of the quadrangle. It is a fine-grained rock composed of feldspar (microperthite and oligoclase), quartz, and biotite. The grains average 0.05 inch in diameter. Some dikes of this rock cut the Conway Granite, and hence are considered to be younger than the Conway.

Six dikes of Black Cap Granite are shown on the geological map: (1) two near Hancock Notch; (2) 2½ miles east of the summit of Mt. Huntington; (3) one mile northeast of the summit of Mt. Carrigain; (4) lower part of Davis Brook; and (5) two miles southeast of the village of Bartlett.

These dikes are 20 to 30 feet thick; some are vertical, others nearly horizontal. They consist of 25% quartz, 30% microperthite, 35% oligoclase, 9% biotite, and 1% accessories. They are darker than the typical Conway because of the relatively high percentage of biotite. The average grain is 0.05 inch across.

Hart Ledge Complex, General Statement. This complex (Fig. 5) is described separately from the rest of the White Mountain Plutonic-Volcanic Series for several reasons. For one thing, the mineralogy is somewhat different from the rest of the series. The shape of the body and the internal distribution of its various members suggest that it may be younger than the surrounding Mt. Osceola granite. Finally, in a quarry 1.75 miles southwest of the village of Bartlett, dikes of syenite cut the Mt. Osceola granite.

On Plate 1 four map-units are shown in the Hart Ledge Complex: syenite, quartz syenite, ferrorichterite granite, and riebeckite granite. Aegerine-augite granite occurs in bodies too small to show separately.

Syenite. This rock forms a circular body, 2 miles in diameter, that is bisected by the Saco River 2 miles west of the village of Bartlett. The syenite is a coarse-grained rock, dark-green where fresh, buff to white where weathered, composed primarily of feldspar (microperthite), but containing 10% to 15% dark minerals and a few percent quartz (Table 3, columns 11 and 12). On Hart Ledge the dark mineral is mostly ferrohastingsite. In the southern part of the body hedenbergite and ferrohastingsite are present in about equal amounts.

Quartz Syenite. This rock occupies two arcuate bodies, one that extends for four miles from Bartlett Haystack to Sawyer River, a second that lies a mile south of the Saco River and is two miles long. The quartz syenite is a coarse-grained rock that is green where fresh, buff to tan where weathered. This rock is composed mainly of feldspar (microperthite), but contains 10% dark minerals and 5 to 15% quartz (Table 3, columns 13 and 14). The dark mineral is mostly ferrorichterite, but in places there is some hedenbergite.

Figure 5. Saco Valley.
View west. Bartlett Village in center foreground. Snow-covered outcrops in center are Hart Ledge. On left side of photograph are north slopes of Bartlett Haystack (with snow-covered ledges) and Mt. Tremont. Mt. Carrigain is high summit in center background. Photo Dick Smith.

In places a rock containing aegerine-augite has been found (Table 3, column 15). Since much more field and laboratory work would be necessary to determine the distribution of such rocks, they have not been separately distinguished from the quartz syenite. They are white, medium-grained rocks composed primarily of feldspar (microperthite), but also containing 17% quartz and 6% aegerine-augite.

Ferrorichterite Granite. This rock forms a small body on the east end of Hart Ledge. It is a white to buff rock with feldspar (microperthite) crystals up to 0.1 inch long and somewhat smaller quartz grains (Table 3, column 16). The principal dark mineral, ferrorichterite, constitutes 7% of the rock. Biotite, hedenbergite, and fayalite are present in small amounts.

Riebeckite Granite. This granite forms an arcuate body convex toward the south, extending for five miles from the Saco River 1½ miles west of the village of Bartlett across the northern flanks of Bartlett Haystack and Mt. Tremont, thence northward to the Saco River. The dark mineral is riebeckite, which is an amphibole containing soda; quartz is about 30% of the rock (Table 3, columns 17 and 18).

Emplacement of the White Mountain Series. This was a long complicated process. It will be assumed here that the Hart Ledge Complex is younger than the rest of the series.

The Moat Volcanics were deposited as lava flows, ash flows, and ash showers on the eroded surface of the Devonian rocks (Fig. 4E). On Moat Mountain these volcanic rocks accumulated to a thickness of at least 10,000 feet. They were undoubtedly present over the whole Crawford Notch Quadrangle.

The western third of the quadrangle is part of a huge cauldron subsidence that extends westward to Franconia Ridge. A ring-dike of Albany Porphyritic Quartz Syenite extends northwesterly from the west slopes of Mt. Willard for 5 miles to the west edge of the quadrangle. From here it trends westerly and southwesterly to Franconia Ridge, where it trends south. Eight miles to the south of Mt. Willard, a fragment of this ring-dike is found on the southeast slopes of Mt. Carrigain. The ring-dike may originally have made a complete circle 12 miles in diameter, but throughout much of its former extent it has been cut out by younger intrusions of granite.

Significant relations are shown in the Mt. Willey Range. Inside the ring-dike are steeply dipping interbedded quartzites and andalusite schists correlated with the upper part of the Littleton Formation, that is, the part above the Boott Member. These in turn are overlain by Moat Volcanics. On the top and west slopes of Mt. Hale, which lies just west of the northwest corner of the Crawford Notch Quadrangle, the Littleton Formation is unconformably overlain by Moat Volcanics (Billings and Williams, 1938, p. 12). Outside the Albany ring-dike a ring-dike of Conway Granite 2000 feet wide and 3½ miles long, extending from Mt. Echo to Mt. Willard, connects a stock around Mt. Rosebrook with the main mass of Conway Granite south and west of the Willey Range. The outer contact of the ring-dike of Conway Granite is superbly exposed at the head of Crawford Notch. It trends northwest. At an altitude of 1500 feet along the highway the contact is readily observed and climbs to 2700 feet on Mt. Willard and to 3600 feet on Mt. Webster. It must be very steep. The inner contact of the Conway Granite, which is the same as the outer contact of the Albany Porphyritic Quartz Syenite, likewise trends northwest and dips steeply.

On Mt. Carrigain the structure dips northwest (Fig. 6).

In Figure 4F, Moat Volcanics are shown inside the ring-dike of Albany Porphyritic Quartz Syenite. The block inside the ring-dike has subsided. Whereas the Boott Member would have an altitude of 9000 feet just outside the ring-dike if it had not been eroded (Fig. 7), inside the ring-dike it might be as low as 1000 feet above sea level. Hence the rocks inside the ring-dike have subsided about 8000 feet. Two other ring-dikes of Albany Porphyritic Quartz Syenite are present. One lies southeast of the village of Bartlett; to the east of this ring-dike is the large area of volcanics on Moat Mtn. No volcanics are preserved inside the ring-dike northeast of Mt. Parker.

The plutonic rocks in the ring-dikes consolidated from magma beneath the surface of the earth. The magma rose into fault zones along which the subsidence took place.

The manner of emplacement of large masses of granite, such as the Conway and Mt. Osceola Granites, has always been a problem in geology. The best explanation is that large blocks of the older rocks sank into an underlying magma reservoir. As these blocks sank, the magma rose to fill the potential cavity.

The granitic rocks formed at least four miles beneath the surface when they were emplaced (Wilson, 1969, p. 102).

The mechanics of emplacement of the rocks of the Hart Ledge Complex must await further study.

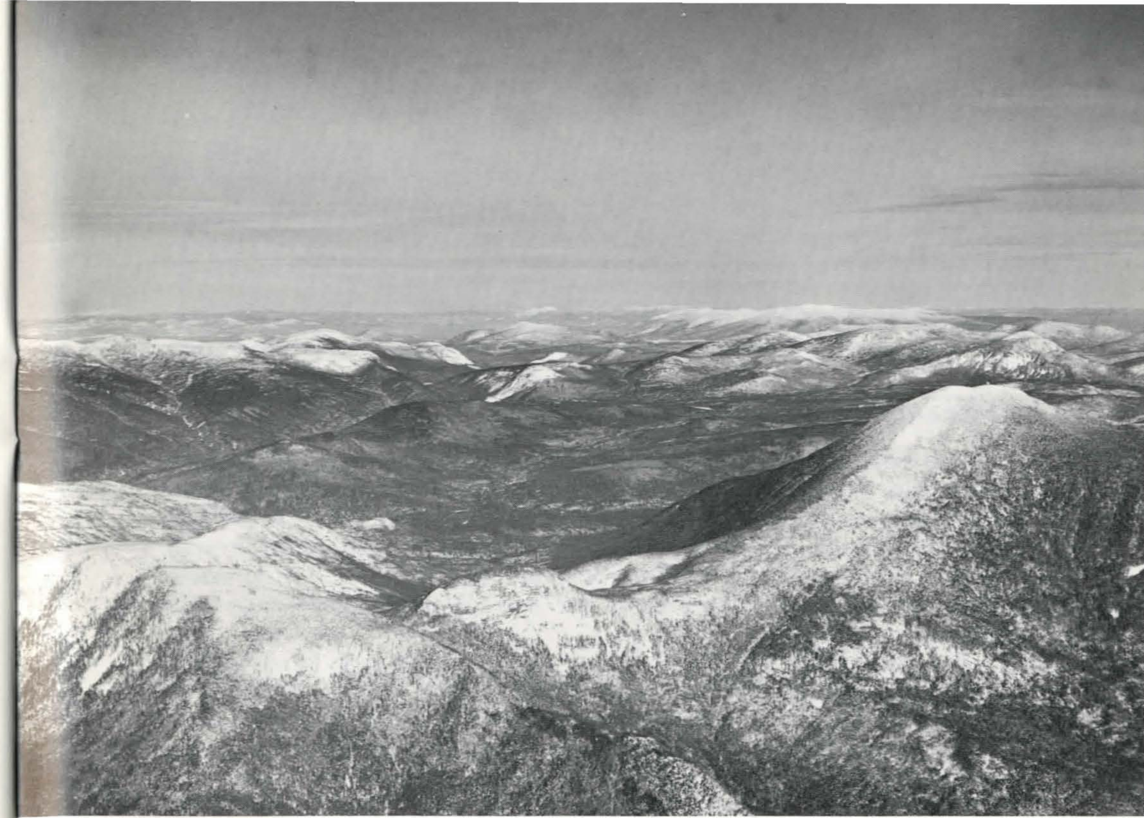

Figure 6. Mt. Carrigain from the southwest.
Thick light-colored sill of Carrigain Syenite Porphyry dips 45° NW, consistent with the cauldron subsidence of the western part of the quadrangle. Photo Dick Smith.

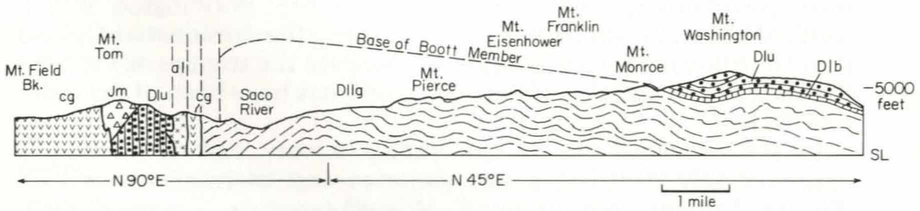

Figure 7. Cauldron Subsidence of Willey Range.
See Plate 1 for letter symbols. Upper Member of Littleton Formation in Willey Range (Mt. Tom) has subsided about 8000 feet.

CARVING OF THE LANDSCAPE

Stream Erosion

The youngest bedrock in the quadrangle is at least 100 million years old. Presumably stream erosion has been going on since then, but there may well have been other events, the record of which has been destroyed. The land forms did not begin to obtain their present aspect until perhaps a few million years ago. As erosion progresses, the land slowly rises, so that on the average uplift keeps pace with erosion.

The mountains and hills are not the result of individual uplifts. They are residuals left by stream erosion of the valleys. Differential hardness of the rocks determines whether a valley or a mountain forms. Many factors are involved: the firmness with which the grains are held together; susceptibility to chemical weathering and frost action; closeness of bedding planes and cleavage; and the closeness of joints. Rocks like the Conway Granite seem to be most capricious, forming great exfoliation domes, such as the Percy Peaks (Chapman, 1942, 1949) or eroded into deep valleys, such as the Saco Valley at North Conway. The difference is probably controlled by the abundance of joints (smooth fracture planes) in the rocks. Valleys develop where the granite is heavily jointed, exfoliation domes where the joints are rare.

If the crust does not rise for a sufficiently long time, the streams may erode the area to a surface of low relief that stands not far above sea level. Such a surface is a peneplain. But uplift may take place before the peneplain is completed, and residual hills and mountains may rise above the partial peneplain.

The Alpine Garden on Mt. Washington has long been considered a remnant of such a surface, now standing 5000 to 5500 feet above sea level (Goldthwait, 1970). The "cone" of Mt. Washington was a residual hill rising above this surface, called the Presidential Upland (Fig. 9). Allowing for a moderate gradient for the streams at the time the surface was cut, the subsequent uplift may have been of the order of 4500 feet.

In the Crawford Notch Quadrangle a very striking surface is approximately 2600 feet above sea level west of Frankenstein Cliff (Fig. 8). Looking south from Mt. Willard one may observe the Mt. Bemis Range rising as a residual above this surface. The area has been uplifted 2000 feet since the Frankenstein surface formed. The age of the Presidential and Frankenstein surfaces is hard to deduce; they are probably not over a few million years old.

Other similar surfaces may be present in the area. But they may be hard to distinguish from surfaces that developed for other reasons.

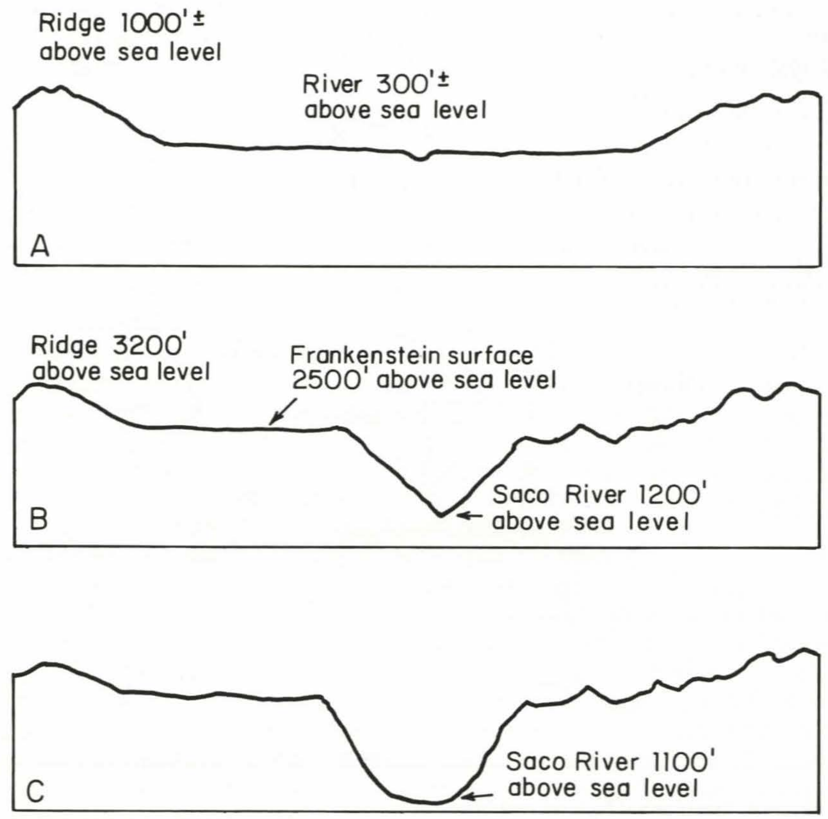

Figure 8. Frankenstein Surface.
A. Erosion of a surface of low relief, above which hills rise 1000 or more feet. B. Uplift of over 2000 feet, cutting of V-shaped valley. C. Glaciation, V-shaped valley is converted to U-shaped valley.

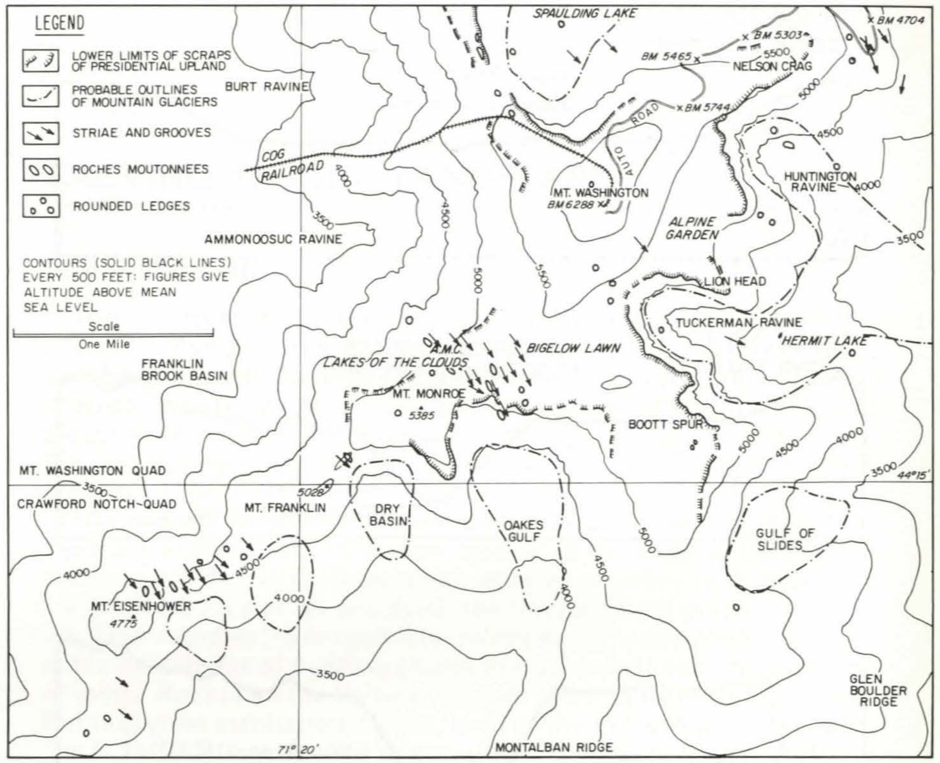

Figure 9. Presidential Upland and Glaciation.
Southern part of the Presidential Range. By R. P. Goldthwait (1970). Modified from a map in Arctic and Alpine Research, Vol. 2, pp. 85-102, 1970.

Pleistocene (Great Ice Age)

At the beginning of the Great Ice Age the major topographic features were similar to those existing today. The length of the Great Ice Age is conjectural, depending in part on the criteria one uses to define its beginning and end. Two million years may be taken as a good approximation. In the Middle West it is known that there were at least five or six glacial stages separated by interglacial stages, some of which were warmer than at present. But in the Crawford Notch Quadrangle no indisputable evidence of the older glaciations is present. We have a record of only the Wisconsin Stage, which began about 70,000 to 50,000 years ago and ended about 12,000 years ago (Goldthwait, 1970, p. 96).

Mountain glaciers formed at higher elevations. The most spectacular cirques cut by these glaciers are the ravines and gulfs of the Presidential Range (Fig. 9). Their fresh form suggests that the last excavation was no older than early Wisconsin time. But the whole

area was overwhelmed by a continental ice sheet (Fig. 4H), which was at least one mile thick, and had its center east of Hudson Bay.

The evidence of glaciation is both erosional and depositional (Goldthwait *et al.*, 1951).

The most spectacular results of *glacial erosion* are the cirques and notches. Cirques, cut by mountain glaciers, are found along the northeast margin of the quadrangle: Gulf of the Slides and Oakes Gulf (Fig. 9). Deep ravines east of Mt. Franklin and Eisenhower are probably cirques. The floor of the cirques is about 3800 to 4100 feet above sea level. Other cirque-like valley heads are found 1000 feet lower on the ridge between Mts. Carrigain and Hancock. Evidence in Tuckerman Ravine shows that the cirques were cut prior to the last invasion by continental ice (Goldthwait, 1970, p. 92).

Notches are another spectacular result of glacial erosion. Crawford Notch, trending south-southeast for 3 miles, is a superb U-shaped valley with a flat floor and smooth walls (Fig. 10). Zealand Notch, also trending south-southeast, is smaller but equally spectacular. The continental ice sheet, moving south-southeast, modified pre-existing V-shaped stream valley into U-shaped valleys. Converging striae northwest of these notches suggest that much more ice poured through these notches than came over the ridges.

Roches Moutonnées ("sheep rocks") are rounded ledges elongated in the direction of ice movement; they are smooth on the northwest (stoss) side, jagged on the southeast (lee) side. A typical roche moutonnée is 10 to 30 feet long, 3 to 8 feet high. Superb examples are found on the Southern Peaks of the Presidential Range from Mt. Franklin to a mile southwest of Mt. Eisenhower (Fig. 9). The continental ice sheet in crossing over the Southern Peaks ground down the original jagged ledges.

Ice-shaped hills are, in a sense, large roches mountonnées, with a gentle northwest side and a steep southeast side. Examples are Mt. Willard, Greens Cliff, Hart Ledge, and Mt. Huntington.

Minor features resulting from glacial erosion are polished ledges, glacial striae, lunoid furrows, and crescentic fractures. *Glacial striae* (scratches) trend southeast in this quadrangle. Many are found on the Southern Peaks (Fig. 9). *Lunoid furrows* are arcuate depressions, shaped like the new moon, 6 to 12 inches from tip to tip. They are about an inch deep, with a gentle slope on the concave side, a steep slope on the convex side; lunoid furrows are convex in the direction in which the ice was moving. *Crescentic fractures* are convex steeply dipping fractures, 3 to 12 inches across; they are concave in the direction of ice movement. Lunoid furrows and crescentic fractures are abundant on granites, but are rarely found on metamorphic rocks.

Glacial deposits are laid down not only when the ice is advancing but mostly when it is melting. They are absent at outcrops, but can reach a maximum thickness of about 100 feet.

Glacial *till* is ubiquitous. It is poorly sorted with a great range in the size of the component particles. The matrix is generally a tan sandy

Figure 10. Crawford Notch.
View northwest toward Mt. Willard. Mt. Webster on right, Willey Range on left. Route 302 in bottom of valley, Maine Central Railroad on flanks of the Willey Range. Photo Dick Smith.

till; the clasts are angular to subangular pebbles, cobbles, and boulders ranging from a fraction of an inch to many feet in diameter. Some of the till was deposited underneath the ice as compact dirt while it was slowly plodding southeastward. Much of the till was deposited from the melting ice surface, but did not travel far. In many places the upper few feet of the till has been disturbed by uprooted trees and frost action.

Erratics are large boulders, generally one foot to 20 feet in diameter, that rest on ledge or till. The most obvious erratics are those that differ in lithology from that of the bedrock on which they rest. The source of erratics is to the northwest; they may have been moved many thousands of feet or miles. Some have been raised 1000 to 2000 feet, as, for example, blocks of Conway granite on Mt. Eisenhower.

Glacial outwash is sand and gravel deposited when the ice was melting (Cotton, 1975). Much of the sand in the Saco Valley in the North Conway Quadrangle was deposited in a temporary lake when the ice was melting. The Saco Valley in the Crawford Notch Quadrangle was above the level of this lake, so that sand and gravel were laid down by streams flowing into this lake. The top of these sand and gravel deposits was about 20 feet above present normal river level.

Recent

After the ice had melted away and the climate became warmer, streams began to erode the glacial deposits. In places small streams on the mountain sides cut valleys tens of feet deep into these deposits. Many did not cease their downward cutting until they reached bedrock. Larger rivers, such as the Saco River began to erode the sands and gravels. Downward erosion stops when the river hits a ledge of hard rock; thus temporarily prevented from down-cutting, the stream slowly meanders back and forth, developing a broad flood plain. Eventually it works its way around the ledge, cuts downward very rapidly until somewhere it hits another ledge. In the North Conway Quadrangle a succession of terraces was left as the river cut down. The 10-year flood rises about 10 feet above normal river level, the 100-year flood rises about 12 feet (Anonymous, 1975).

Gravel in the stream bed of the Saco River is partially reworked glacial gravel and till, partially new gravel brought in from tributaries.

Although most of the glacial deposits are removed slowly from the mountain slopes by stream erosion, occasionally they move catastrophicly as landslides. The most famous landslide in this quadrangle was at the site of the Willey House in Crawford Notch (Morse, 1966). On the night of August 18, 1826 a landslide came down the slopes of Mt. Willey toward the Willey home. The family apparently fled the house, but all were killed — 4 adults and 5 children. Paradoxically, the slide split just above the house and left it intact.

The slides in Zealand Notch are worthy of detailed study. The Conway Granite on Whitewall Mtn., forming the east wall of the notch, is riven by countless fractures; it is very unstable. Numerous landslides have occurred. A lumber railroad abandoned many years ago is now followed by the Ethan Pond Trail. Some of the slides are older than the railroad. But many of them cross the railroad. Trees have grown on the slides. By studying the tree rings it may be possible to get approximate dates of the slides.

Table 1. EVENTS IN AND NEAR CRAWFORD NOTCH QUADRANGLE

Era	Periods and Epochs		Time-Millions of years Duration	Time-Millions of years Beginning		
Cenozoic	Quaternary	Recent	*	*	Erosion	
		Pleistocene	2	2	Glaciation - mountain glaciers and continental ice sheets. Last ice disappeared about 12,000 years ago.	
	Tertiary	Pliocene	9	11	No record except for erosion	
		Miocene	14	25		
		Oligocene	15	40		
		Eocene	20	60		
		Paleocene	10	70		
Mesozoic	Cretaceous		65	135	White Mountain Volcanic-Plutonic Series	
	Jurassic		45	180		
	Triassic		45	225		
Paleozoic	Permian		45	270	No record except for erosion	
	Pennsylvanian		40	310		
	Mississippian		40	350		
	Devonian		50	400	Acadian Revolution - folding, intrusion of New Hampshire plutonic series (Kinsman and Concord). Deposition of silts, muds, and sands of Littleton Formation in shallow sea.	
	Silurian		40	440	Deposition of muds and calcareous of Fitch Formation.	Preserved in areas to west, northwest, and north
	Ordovician		60	500	Deposition of Ammonoosuc Volcanics and Partridge Formation. Deposition of silts, muds, and sands of Albee Formation.	
	Cambrian		100	600	Deposition of silts, sands, and limestones	Preserved in southeastern Vermont
Precambrian					Deposition of silts, muds, and sands and intrusions of granite.	Preserved in Green Mts. and southeastern Vermont.

* Recent began about 12,000 years ago.

Table 2.

Stratigraphy of the Littleton Formation

		Thickness (feet)
"Upper Littleton"	e. Interbedded mica schist and quartzite (Unit 9*)	4000
Boott Member	d. Lime-silicate rocks (Unit 8)	50
"Lower Littleton"	c. Gneiss, with some lenses of interbedded mica schist and quartzite (Units 7, 6, 5)	10,000±
	b. Lime-silicate rocks (Unit 4)	0-500
	a. Gneiss (Unit 3)	1500±

*Numbered units based on correlation with Gorham Quadrangle.

Table 3. MODES OF WHITE MOUNTAIN PLUTONIC-VOLCANIC SERIES, CRAWFORD NOTCH QUADRANGLE.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Quartz		8	10	30	20	18	15	29	30	25	4	2	10	10	17	18	31	6
Microperthite		70	34	36	25	41	15	61	45	30	86	82	80	80	76	74	64	91
K-feldspar	tr		30	25	50	25	33	3	19	35								
Plagioclase	68		5	4	2	4	15	2			tr							
Olivine	10																	
Fayalite								tr			tr	tr	tr	tr	tr	tr		
Augite	20																	
Hedenbergite			tr			1	tr	1			tr	7		1		tr		
Aegerine-augite															6			
Ferrohastingsite		20	20		1	8	20	2			9	9						
Ferrorichterite								1					10	9	tr	7		
Riebeckite								tr									5	3
Biotite	tr	1	1	3	2	1	tr	1	4	9	1			tr	tr	1	tr	1
Opaques	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr								
Accessories	2	1	17	2	tr	2	2	tr	2	1	tr	tr	tr	tr	1	tr	tr	tr
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Anorthite in plagioclase	55	-	20	12	15	15	16	12	19	15								

1. Gabbro, 2060 feet altitude, Dry River, Henderson
2. Carrigain syenite porphyry, Creasy, average 2 specimens
3. Quartz syenite porphyry, south slope of Mt. Hope, Henderson
4. Mt. Lafayette Granite Porphyry, altitude 1850 ft., Mt. Bemis trail, Henderson
5. Mt. Lafayette Granite Porphyry, subporphyritic phase, altitude 2050 ft. north fork of Nancy Brook, Henderson
6. Albany porphyritic quartz syenite, road along Swift River, one mile east of quadrangle boundary, Henderson
7. Albany porphyritic quartz syenite, 1.7 miles east of summit of Mt. Parker, Henderson
8. Mt. Osceola Granite, average of 6 modes, Henderson
9. Conway Granite, average of 4 modes, Henderson
10. Black Cap granite in dike, ½ mile N 10° W of intersection of Swift River and east border of quadrangle, Henderson
11. Syenite, Hart Ledge Complex, Hart Ledge, average of 13 modes, Wood
12. Syenite, Hart Ledge Complex, southern part of body, average of 4 modes, Wood
13. Quartz syenite, Hart Ledge Complex, north of riebeckite granite, average of 3 modes, Wood
14. Quartz syenite, Hart Ledge Complex, south of riebeckite granite, average of 11 modes, Wood
15. Quartz syenite, aegerine-augite granite phase, Hart Ledge Complex, average of 5 modes, Wood
16. Ferrorichterite granite, Hart Ledge Complex, average of 3 modes, Wood
17. Riebeckite granite, Hart Ledge Complex, average of 5 modes, Wood
18. Quartz syenite phase of riebeckite granite, average of 2 modes, Wood.

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Glossary

Accessories. Minerals present in small amounts.

Actinolite. Member of the amphibole group. Light-green to dark-green stubs and needles. Composed of lime, magnesia, iron, silica, and water.

Aegerine-augite. Member of the pyroxene group. An augite with some soda. Intermediate between augite and aegerine, which consists of soda, ferric iron, and silica.

Alluvium. Clay, silt, sand, and gravel deposited by rivers in recent time.

Amphibole. A group of closely related minerals, characterized by cleavage planes that intersect at angles of 56° and 124°. Composed chiefly of lime, iron, magnesia, alumina, silica, and water. See actinolite, ferrohastingsite, ferrorichterite, hornblende, tremolite.

Andalusite. A red or red-brown glassy mineral occurring as square prisms. An aluminum silicate. Most of the andalusite in the White Mountains has been altered to other minerals, notably muscovite, sericite, sillimanite, and quartz.

Anorthoclase. A homogeneous potash-soda feldspar that appears to be orthoclase, but contains much soda.

Ash-flow. Volcanic ash consists of very fine particles. Such ash, buoyed up by gases, may flow like lava to form an ash-flow.

Ash-shower. Volcanic ash that has been blown into the air and then deposited.

Augite. Member of the pyroxene group. Black, composed of lime, magnesia, iron, alumina and silica.

Bed. Sedimentary rocks are deposited in horizontal layers, which may differ in color, grain size, and mineralogy. Beds may differ in thickness from a fraction of an inch to many feet.

Bedrock. In New England the hard rock, such as granite, that can be broken only with a hammer. Locally maybe weathered to "rottenstone."

Biotite. Member of the mica group. Black, composed of potash, magnesia, iron, alumina, silica, and water.

Calcareous. Rocks containing calcite, which is composed of lime and carbon dioxide.

Cambrian. A geologic period and system, see Table 1.

Cauldron subsidence. Sinking of a large block of rock, miles in diameter, into an underlying magma chamber (the "cauldron").

Cirque. Amphitheatre carved by a mountain glacier.

Clay. Unconsolidated rock composed primarily of particles less than 0.0002 inch in diameter and more or less plastic.

Continental ice sheet. Large ice sheet covering part of a continent. In North America the centers were around Hudson Bay, the southern margin at Long Island, the Ohio River, and the Missouri River. The surface of the ice was above the top of Mt. Washington.

Crescentic fractures. Steeply dipping arcuate fractures, 3-12 inches across, that are concave in the direction of ice movement.

Crust. The outermost rocky shell of the earth that extends to depths of 6 to 30 miles.

Devonian. A geologic period. See Table 1.

Diabasic. See ophitic

Diopside. Member of the pyroxene group. In this quadrangle occurs as irregular light-green to dark-green grains; composed of lime, iron, magnesia, and silica.

Dip. Angle of inclination of any planar feature, such as bedding, foliation, joints; defined by direction in which it is inclined and angle of inclination measured from a horizontal plane.

Dolomitic. Containing dolomite, a member of the carbonate group; composed of lime, magnesia, and carbon dioxide.

Era. A major subdivision of geologic time, consisting of several periods. See Table 1.

Erosion. The removal of rocks from an area. In this region mostly by streams, to a minor extent by ice and wind.

Erosion Surface. The surface produced by erosion. May vary from plateau with deep canyons ("youth"), to rugged mountains, as in present White Mountains ("mature"), or to gently rolling hills with low relief ("old age" = peneplain).

Erratics. Large boulders transported by glaciers.

Exfoliation dome. A large domical mountain initially devoid of joints; as erosion progressed, residual stresses caused large fractures (exfoliation surfaces) to form.

Fayalite. A black mineral. The iron end of the olivine group; composed of iron and silica.

Feldspar. A group of minerals composed of silica, alumina, and variable amounts of lime, soda, and potash. See anorthoclase, orthoclase, microperthite, and plagioclase.

Ferrohastingsite. Hastingsite is a member of the amphibole group and is composed of lime, magnesia, iron, alumina, silica and water. Ferrohastingsite is the iron-rich end of the series.

Ferrorichterite. Richterite is a member of the amphibole group and is composed of lime, magnesia, iron, alumina, silica and water. Ferrorichterite is the iron end of the series. It has more soda and less lime than ferrohastingsite.

Folding. After their deposition the horizontal beds may be compressed into folds.

Foliation. A general term used to describe the property whereby rocks split into slabs. Roofing slate has a good foliation. Foliation in many cases is not paralled to bedding.

Formation. An assemblage of rocks that have some common characteristic. A formation may consist of more than one kind of rock. Formations are the basic units used in geological mapping.

Fossils. Remains or traces of animals and plants entombed in rocks when they were deposited.

Gabbro. A plutonic rock composed primarily of plagioclase feldspar and augite, olivine and hornblende may also be present.

Gneiss. A medium-grained to coarse-grained rock in which layers rich in granular minerals (generally feldspar and quartz) alternate with layers rich in mica.

Granite. A medium-grained to coarse-grained rock composed mainly of feldspar and quartz. As used here, plagioclase in less than one-third of the total feldspar. If plagioclase is one-third to two-thirds of the total feldspar, the rock is quartz monzonite. In a new classification both these rocks are called granite.

Granofels. A metamorphosed sedimentary rock in which the grains are irregular spheres or diversely oriented platy minerals.

Gravel. Sand containing pebbles and boulders.

Groundmass. The finer grained material surrounding phenocrysts.

Hedenbergite. Member of the pyroxene group. Black. The iron-rich end of the diopside-hedenbergite series.

Hornblende. Member of the amphibole group. Black. Chiefly lime, magnesia, iron, alumina, silica and water.

Ice-shaped hills. Essentially large **roches moutonnées.** Oval shaped hills, with gentler slope on the side from which the ice came, and a steeper plucked slope on the opposite side.

Igneous rocks. Rocks formed by crystallization from magma.

Joints. Smooth planar fractures in rock.

Kyanite. One of three aluminium silicates (andalusite and sillimanite are the others). Occurs as long blue tabular blades and aggregates. Does not occur in Crawford Notch Quadrangle, but absence helps determine pressure and temperature at which metamorphism occurs.

Lime-silicate rock. A rock containing one or more minerals rich in lime. In Crawford Notch Quadrangle these minerals are actinolite and diopside.

Lunoid furrows. Arcuate depressions shaped like the new moon; 6 to 12 inches from tip to tip. One inch deep, with gentle slope on concave side, small scarp on convex side. Convex in direction in which ice was moving.

Magma. Molten rock. Lava issuing from a volcano is magma.

Member. A subdivision of a formation

Mesozoic. One of the geologic eras. See Table 1.

Metamorphism. The process whereby the mineral composition and physical character of the rock is altered due to changes in heat, pressure, moving solutions, and stresses.

Miarolitic cavities. Irregular holes, one to several inches in diameter, in plutonic and volcanic rocks due to gas bubbles in the cooling rock.
Mississippian. A geologic period. See Table 1.
Mica. A group of minerals characterized by good cleavage so they break into sheets. See muscovite and biotite.
Mica schist. A metamorphic rock rich in mica flakes that are more or less parallel to one another, causing the rock to split into sheets.
Microperthite. A feldspar that is typical of the White Mountain Series. Under the microscope a single grain consists of orthoclase with thin plates of plagioclase (albite).
Mountain glacier. A glacier that is confined to a valley in a mountain range.
Muscovite. White mica. Composed of potash, alumina, silica, and water.
Olivine. A green mineral composed of magnesia, iron and silica.
Ophitic. A texture of some igneous rocks; diversely oriented tabular feldspar crystals, between which are irregular grains of dark minerals. Same as diabasic.
Ordovician. A geologic period. See Table 1.
Orthoclase. A homogeneous feldspar composed primarily of potash, alumina, and silica.
Outwash. Sand and gravel deposited in streams and lakes when ice was melting.
Pegmatite. A very coarse-grained plutonic rock. In this area chiefly quartz and feldspar, with considerable mica.
Peneplain. The surface of low relief that develops as the result of prolonged erosion of a stable crust.
Period. A division of geologic time, shorter than an era, but longer than an epoch.
Phenocryct. A larger crystal set in a finer-grained groundmass of a volcanic or plutonic rock.
Plagioclase. A soda-lime feldspar.
Pleistocene. A portion of geologic time. The "great ice age". See table 1.
Plutonic. Medium-grained to coarse-grained igneous rocks that crystallized beneath the surface of the earth.
Porphyritic. An igneous rock containing phenocrysts.
Precambrian. That eon of geologic time that ended 600 million years ago. See table 1.
Pyroxene. A group of minerals characterized by prismatic cleavage planes intersecting at 87°; composed of iron, magnesia, and silica; some have lime, soda, and alumina; no water. See augite, diopside, aegerine-augite.
Quartz. A glassy mineral composed of silica. Where free to grow it forms hexagonal prisms. In most rocks it is present as round or irregular grains.
Quartzite. A rock composed chiefly of quartz grains that are cemented by quartz to form a hard compact rock.
Quartz Monzonite. A plutonic rock composed chiefly of quartz and feldspar. The feldspar consists of potash feldspar and plagioclase in about equal proportions. In a recent classification such rocks are included in the granites.
Quartz Syenite. A rock composed primarily of feldspar, but with 5% to 15% quartz.
Quaternary. The youngest geologic period. See table 1.
Radiometric Methods. Rocks may be dated by methods based on radioactivity. For example, Uranium (atomic weight 238) breaks down into lead (atomic weight 206) and eight heliums (atomic weight 4). The rate of breakdown is known; the greater the age the higher the ratio of lead (206) to uranium (238). There are many radioactive methods. Because of many complications great discretion is necessary in applying the methods.
Recent. The youngest geologic epoch. Also called Holocene. See Table 1.
Recrystallize. The process whereby the minerals of rock are converted in whole or in part to new minerals.
Relief. Difference in altitude of two points, usually a mountain top and a valley bottom.
Revolution. A time of great disturbance of the rocks, involving folding and often the intrusion of plutonic rocks and metamorphism.
Rhyolite. A lava that has the composition of granite and thus has a high percentage of silica.
Riebeckite. Member of the amphibole group. Black, dark blue under the microscope. Rich in soda and ferric iron.

Ring-dike. A body of igneous rock, arcurate in plan and steeply dipping. Generally a few hundred to a few thousand feet wide on a map. Radius of curvature of arc is several miles. Magma intruded a fracture involved in cauldron subsidence.
Roches Moutonnées. Rounded ledges elongated in direction of ice movement. Smooth on side from which ice came, jagged ("Plucked") on the opposite side.
Sand. Unconsolidated sediment composed chiefly of grains between 0.002 and 0.08 inch in diameter.
Sandstone. Sedimentary rock in which most of the grains are sand size.
Schist. A rock characterized by schistosity, that is, the property of breaking into sheets due to the parallelism of recognizable platy and ellipsoidal mineral grains.
Sedimentary Rock. A rock formed by the accumulation of clay, silt, sand, and larger material on the bottom of streams, lakes, seas, or the atmosphere. A layered structure known as bedding or stratification is typical.
Sericite. Fine-grained white mica.
Shale. A sedimentary rock in which the grains are dominantly of clay and silt size. The paralled arrangement of platy and ellipsoidal grains, produced while the sediments were accumulating, causes a fissility along which the rocks break.
Sill. A tabular body of igneous rock injected parallel to the bedding.
Sillimanite. An aluminium silicate. Long, slender crystals where well formed, but very small in this quadrangle.
Silt. Unconsolidated composed of grains 0.0002 to 0.002 inch in diameter.
Siltstone. A compact sedimentary rock in which most of the grains are silt size. Lacks the bedding fissility characteristic of shales.
Silurian. A geologic period. See Table 1.
Strata. Synonymous with "beds", which see.
Stratigraphy. The study of the sequence in which sedimentary and volcanic rocks were deposited.
Striae. Scratches on rock. Glacial striae are made by sand and rocks embedded in the moving ice.
Surface. See "erosion surface"
Surficial rocks. Loose, unconsolidated material that can be penetrated by a shovel. Rests on bedrock, which see.
Syenite. A plutonic rock composed primarily of potash feldspar (microperthite here), some dark minerals, and less than 5% quartz.
Symbols. On geological maps special symbols are used to show some features. On Plate 1 symbols show the dip (inclination) of bedding and foliation.
Synclinorium. A syncline is a fold that is convex downward. A synclinorium is a large syncline on which many minor folds are superimposed.
Till. A heterogeneous mixture of clay, sand, and boulders deposited by a glacier.
Trachyte. A volcanic rock of the same composition as syenite, mostly feldspar.
Tremolite. Member of the amphibole group. Chiefly lime, magnesia, silica, and water.
Triassic. A geologic period. See table 1.
Unconformable. If strata are folded, and then partially eroded, horizontal strata may later be deposited on the erosion surface. The younger rocks are unconformable on the older rocks.
Wisconsin. The last glacial stage of the Pleistocene epoch.