THE GEOLOGY OF THE SUNAPEE QUADRANGLE NEW HAMPSHIRE

by

CARLETON A. CHAPMAN

Published by
NEW HAMPSHIRE DEPARTMENT of RESOURCES and ECONOMIC DEVELOPMENT

Lake Sunapee from North Peak, Mt. Sunapee. *Don Sieburg*

GEOLOGY
of the
SUNAPEE QUADRANGLE

by

CARLETON A. CHAPMAN

Originally published by the
State Planning and Development Commission
1953

Reprinted by
Division of Forests and Lands
Department of Resources and Economic Development
Concord, New Hampshire
1980

**NEW HAMPSHIRE DEPARTMENT OF
RESOURCES & ECONOMIC DEVELOPMENT**

George Gilman
Commissioner

Theodore Natti, Director
Division of Forests and Lands

Robert I. Davis
State Geologist

CONCORD, N.H.
1953
Reprinted 1980

Foreword

This pamphlet is an attempt to present in non-technical language the story of the rocks of the Sunapee quadrangle. The scientific names and terms are held to a minimum, but where used each term is defined or explained in simple language. A number of mineral names have been used, and in order to make these more meaningful, the composition of each is given in one of the tables. The other tables in the text will prove helpful to the average reader. In the pocket at the back of the pamphlet is a colored map which explains the geology of the area in a pictorial fashion. It should be consulted frequently during the reading of the pamphlet.

The cost of field work involved in this study was financed largely by generous grants from the Research Board, University of Illinois and the Shaler Memorial Fund of Harvard University. The colored geological maps are the contribution of the New Hampshire State Planning and Development Commission, the New Hampshire State Highway Department, and the Geological Society of America.

Geology of the Sunapee Quadrangle New Hampshire

By Carleton A. Chapman

THE SCENERY

The Sunapee area, with its low wooded hills and numerous lakes and ponds, lies within the Dartmouth - Lake Sunapee Region of west-central New Hampshire, one of the six recreational regions of the state. Its appeal to the summer tourist and vacationist lies in its scenic beauty. The area has an equally strong attraction, however, for those interested in the natural sciences, and particularly geology. To the geologist who deals with a continually changing earth, the present scenery is but a single frame from a long motion picture. It is the result of a great number of factors operating over a long period of time. So slow are these changes that they may commonly escape detection by man.

The reader should now spread before him the colored map at the back of this pamphlet. If he is unfamiliar with topographic maps, he should first read the section of this pamphlet entitled *How to Read the Map,* Page 29.

From the colored map one sees that the northern half of the area is drained by southerly flowing streams, whereas in the southern half the streams flow northward. These small streams are confluent with Sugar River which is the largest drainage line in the area and flows westward from Sunapee Lake. Stream valleys are highly irregular and frequently interrupted by small ponds, lakes, and swamps. These small water bodies are most numerous in the northwestern section of the quadrangle. The hills are generally rounded, a few hundred feet high, and many are slightly elongate in a north-south direction. The two most conspicuous elevations are Sunapee Mountain (elevation 2743 feet) in the southeast part of the area and Croydon Mountain (elevation 2781 feet) in the northwest corner of the quadrangle. Numerous high hills are found, however, throughout the area. Most of the quadrangle is covered with forest, and the best pasture and cultivated land is confined to the lower elevations and flatter sections.

THE GEOLOGIST AND HOW HE WORKS

Geology is the science of the earth and has as its principal objective the deciphering of earth history. This history of the earth's evolution is unveiled by a study of records preserved in the rocks of all ages. These records, many of which will be explained later, take on various forms. It is not always a simple matter, however, to interpret correctly what one sees in the rocks, and one must be extremely careful to observe correctly, for our conclusions can be no sounder than our observations. One must be constantly alert to observe even the minutest details of these records, for in them often lies the secret to a large and perplexing problem. An attempt should be made to observe completely and to guard against a common human weakness of seeing only what one wishes to see. This brings us to another important point. The geologist should work in large part without preconceived ideas and always be willing to record the facts without prejudice, regardless to what conclusions they may eventually lead him. He must always be open-minded, keenly alert, and observing, for in that way alone will he find the truth concerning the science of the earth.

The geologist, in dealing with problems of the earth, is concerned largely with material things and processes. The materials are represented by the great variety of minerals and rocks; the processes are the means by which changes on or within the earth are brought about. As he pieces together the many bits of evidence which indicate the succession of changes undergone by the different masses of rocks and minerals, he builds up an orderly sequence of events which leads to a more complete understanding of the geology of a region. Not only is he interested in the chronological order of events, but he is also concerned as to how and why these many transformations have taken place.

It would be interesting for the layman to follow the geologist in the field to see how he gathers his data and, particularly, to have demonstrated and explained the numerous features in rock exposures which, undoubtedly, one would otherwise overlook. With the aid of a good map, the geologist will normally lay out a course over the ground he wishes to cover. This traverse must be planned with the idea in mind of covering the ground efficiently, encountering a large number of rock exposures, and conserving time and energy. Parts of the course may lie along the road, others along a stream bed or mountain ridge. In some heavily wooded areas, particularly where there are no conspicuous topographic features to follow, straight line traverses are followed by aid of a compass. Distances along these traverses may be determined by recording the number of steps or paces taken from the starting point. In this manner the observer can pinpoint his position at any instant on his map. Such a practice is essential when it is desired to locate on the map the true position of an outcrop or the location at which any other observation was made. By judiciously planning his traverses, the geologist is able to get a very complete and detailed picture of a region.

At each outcrop studied, a great variety of observation is made. Included may be such things as the kind of rock, mineral composition, rock textures, and structures. All field data are recorded in a note book, and each outcrop may be indicated by a small symbol at its correct position on the map. As the field data begin to accumulate, it becomes possible to delineate on the map the various kinds of rock. A glance at the geologic map of the Sunapee quadrangle will show that this has been done by a series of colored patterns. Each pattern indicates a different type of rock as explained in the legend of the map.

In the Sunapee quadrangle many of the rocks appear to be made up of numerous layers or beds. In places these layers are horizontal but most commonly they incline at various angles. At each outcrop a record is made of the direction and degree of slope of these rock layers. On the geologic map the attitude of the beds is indicated by small T-shaped symbols. The short line of the symbol gives the direction of inclination or *dip* of the beds and the angle of inclination is shown by a number. The long line of the symbol indicates what the trend or *strike* of the layers would be on a horizontal surface. Special symbols are used to indicate horizontal and vertical beds. (See legend on map.)

Most of the rocks in the quadrangle show alternating sheets or film-like layers of dark and light minerals. This type of layering is known as schistosity or foliation and may or may not be parallel to bedding layers in the rock. Planes of schistosity and foliation are shown much as are the bedding planes but by a special set of symbols.

By projecting the layered structures of the outcrops upward into the air and downward into the earth, one may get an idea of the architecture or conformation of the rock layers and rock bodies. This has been done for the Sunapee quadrangle and two cross-sections are shown on the sheet below the colored map. The sections, labelled A-A′ and B-B′, give a picture of the rock structures as they might appear on the walls of a deep trench extending along the heavy lines shown on the geologic map. From these cross-sections it is obvious that the rocks have been deformed into a series of gigantic folds. In the outcrops it is very common to observe the rock layers folded and contorted on a much smaller scale, and there are apparently all gradations between these small folds and the huge structures revealed in the cross sections.

In the laboratory the geologist studies the rocks and minerals collected in the field. From his samples, thin slices are cut, with a diamond saw, and mounted on small glass plates. When finished, these thin sections are approximately one hundredth of an inch thick and highly transparent. Each section is examined with a special instrument called a polarizing or petrographic microscope. With the aid of this microscope bountiful information regarding the composition and history of the rocks may be obtained.

THE STORY OF THE ROCKS

The Land and the Sea

Before relating the story of the rocks, it seems well to outline a few major geological processes. It has long been recognized that our continents and deep oceans are very ancient surface features. But the continents are not stable, and certain portions of them may be elevated while other portions become depressed. Where depression is sufficient, the land becomes submerged and relatively shallow seas extend inland over great areas of the continents. Such changes in shoreline have been numerous, and there is no part of any continent which has not at some time or other been submerged beneath the sea. Indeed, many parts of our continents have submerged and re-emerged many times.

Whenever an area becomes raised above sea level, this new land is subjected to erosion, and the rock masses are broken up and decomposed by the many agents of weathering, such as frost action and chemical changes. The disintegrated material is thus easily washed away by rain. It creeps down slope under the force of gravity and is carried away by the streams only to be deposited finally in the sea. This eternal process is important to bear in mind. High land tends to be torn down, and the material of which it was composed is carried away to build up low areas.

A study of a great many different areas throughout New England has shown that for many millions of years most of New Hampshire has been covered from time to time by a great inland sea. Into this shallow body of water was poured vast quantities of rock debris, which had formed in part by disintegration of a land mass somewhere to the east. This debris was composed largely of clay and sand particles which were readily transported to the sea by the westerly-flowing streams. Another major source of rock debris was from the numerous volcanoes which were active during part of the period of deposition. Great quantities of volcanic ash and dust descended, some falling directly into the shallow sea and some being washed in by streams after falling upon the land to the east. These beds of volcanic material became interlayered and mixed with the more normal disintegrated rock material. Locally, true lava flows have been found within the great thicknesses of sand and mud deposited in this sea.

Studies in many parts of the world indicate that seas, like the one which covered New Hampshire, never reach depths greater than a few hundred feet. Remains of animals which lived in these seas are preserved as fossils in the fine sediments deposited over the sea floor. Such animals bear close resemblance to present day forms, which are known to inhabit relatively shallow waters. If the depth of water never exceeded a few hundred feet, how then can we account for the many thousands of feet of sediment which have been deposited layer upon layer in these inland water bodies? The simplest answer must be that the sea floor continued to sink as rapidly as it was built up by incoming sediments. Thus, the depth of water could remain essentially constant.

Formation of the Sedimentary Rocks

The earlier part of the geologic history of the Sunapee quadrangle is not recorded in the rocks exposed, and our story begins about 375 million years ago in the late part of what is known as the Ordovician period. (See Table 1.) This was a period of great volcanic activity in which a blanket of volcanic material several thousand feet thick was deposited over most of New Hampshire. The volcanoes are believed to have lain to the east, although no trace of them remains today. This thick deposit of rock material, known as the Ammonoosuc volcanics, was composed largely of volcanic ash and fine rock fragments, which were formed by shattering of solid rock during volcanic explosions. These small angular particles may still be seen in the rocks in many places. A much smaller portion of this volcanic formation is made up of lava flows which may have come from volcanoes relatively close by. In the Sunapee quadrangle only the upper few hundred feet of the Ammonoosuc volcanics are exposed, and the formation is shown on the geologic map principally as a long belt of rocks extending along the east slope of Croydon Mountain in the northwest part of the quadrangle.

During the latter part of the Ordovician period, perhaps while the upper layers of the volcanics were still being deposited, the land began to rise and the sea temporarily withdrew from New Hampshire. The volcanics were thus left exposed to the elements of weathering and erosion. Within a relatively short time, the land again subsided and the sea returned. Volcanism had ceased and the Silurian Period had begun. At first layers of sand and gravel with small amounts of mud were laid down in this shallow sea to form the Clough formation. Along the ridge and western slope of Croydon Mountain, the thickness of the formation ranges up to about 800 feet. Here much of the formation appears to have been derived from rather pure quartz sand. Large pebbles and cobbles are visible in some layers which originally were beds of gravel.

Conditions gradually changed; the sea spread farther over the land making the Sunapee area more remote from the supply of sediment carried by streams. Wave action and sea currents were now able to bring only the finer sediments and so muds accumulated. During short intervals when the sea was clear, shell

Table 1

Geologic Time-Scale with Sequence of Events in the Sunapee Mountain Quadrangle

OLDEST EVENT IS AT BOTTOM OF CHART; YOUNGEST IS AT TOP

Era	*Period*	*Time-scale (age of beginning of period)*	*Sequence of geological events*
Cenozoic	Recent	30 thousand years ago	Slight erosion
	Pleistocene	2 million years ago	Glaciation
	Tertiary	60 million years ago	Uplift and erosion
Mesozoic	Cretaceous	120 m'llion years ago	Erosion
	Jurassic	150 million years ago	Erosion
	Triassic	175 million years ago	Erosion and faulting
Paleozoic	Permian	210 million years ago	Erosion
	Pennsylvanian	255 million years ago	Erosion
	Mississippian	290 million years ago	Erosion
	Devonian	330 million years ago	6. Erosion 5. End of folding. Spaulding quartz diorite and Concord granite formed. 4. Metamorphism of the rocks. Bethlehem gneiss and Kinsman quartz monzonite formed. 3. Folding begins. 2. Doming of rocks by the Croydon group. 1. Littleton formation deposited. At least 11,000 feet of mud and sand.
	Silurian	355 million years ago	2. Fitch formation. 0-800 feet of mud, limestone, and sand. 1. Clough formation. 800 feet mostly of sand.
	Ordovician	415 million years ago	Ammonoosuc volcancis. Only 300 feet exposed.
	Cambrian	515 million years ago	No record.
Pre-Cambrian		More than 1,000 million years ago	No record.

fish flourished, and thin layers of sea shells accumulated on the shallow sea floor. In time these shells became broken and the finely divided material was consolidated into layers of limestone. These interbedded muds and limestone layers constituted the Fitch formation. On Croydon Mountain the thickness of this formation ranges up to a few hundred feet. Locally beds of rather pure quartz sand were deposited.

In the Devonian period which followed, the sea still covered most of New Hampshire, and many thousands of feet of sand and mud were deposited. This thick sequence of rocks, known as the Littleton formation, was composed of well defined layers or beds.

Folding and the Rise of Molten Rock

Near the end of the Devonian period, about 300 million years ago, the great inland sea withdrew permanently from New Hampshire in response to a general uplift of the land. This uplift was accompanied by horizontal movements in the earth's crust. The thick sequence of sedimentary and volcanic rocks, which had been deposited on the slowly sinking floor of the sea, became squeezed and crumpled as if caught between two rigid blocks of the earth's crust. It might be inferred from the shape and trend of the folds produced that one of these blocks of the crust lay to the east and the other to the west of New Hampshire. As powerful forces tended to draw these blocks closer together, the intervening and nearly flat layers of sediment were buckled and folded into upwarps and downwarps of various sizes all trending roughly north-south. The true cause of such compressive forces is still one of the great mysteries in geology.

In the beginning stages of folding great masses of molten rock, known as magma, rose up from deeper parts of the earth. This magma penetrated upward to within a few hundred feet of the top of the Ammonoosuc volcanics. Here it spread outward laterally and bulged up the overlying rock layers forming a huge dome. Upon cooling, the rock melt crystallized to form a kind of granite composed of quartz, feldspar, and biotite (black mica). This rock is shown on the geologic map as the Croydon group in the northwest part of the quadrangle. Only the western part of the large dome is now to be observed and the nature of its architecture is shown in cross section A-A'.

Metamorphism of the Rocks

Folding and crushing of the rocks continued over a long period of time, and accompanied by great heat and pres-

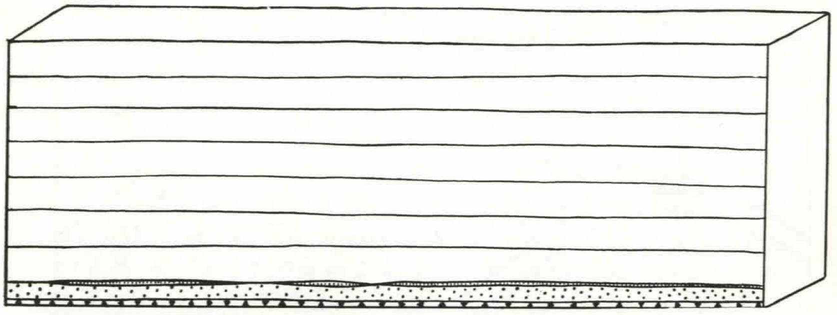

Figure 1—End of lower Devonian. The Ammonoosuc volcanics, Clough formation, Fitch formation, and Littleton formation have accumulated.

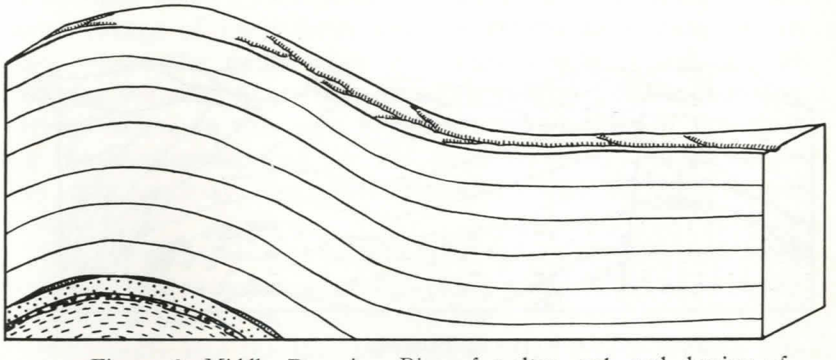

Figure 2—Middle Devonian. Rise of molten rock and doming of sedimentary layers.

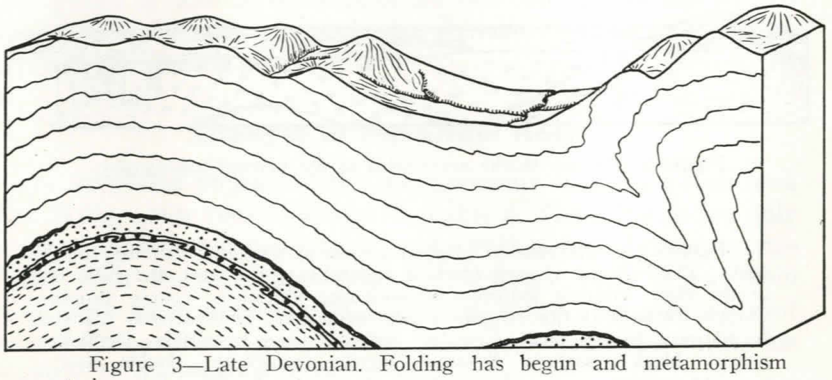

Figure 3—Late Devonian. Folding has begun and metamorphism sets in.

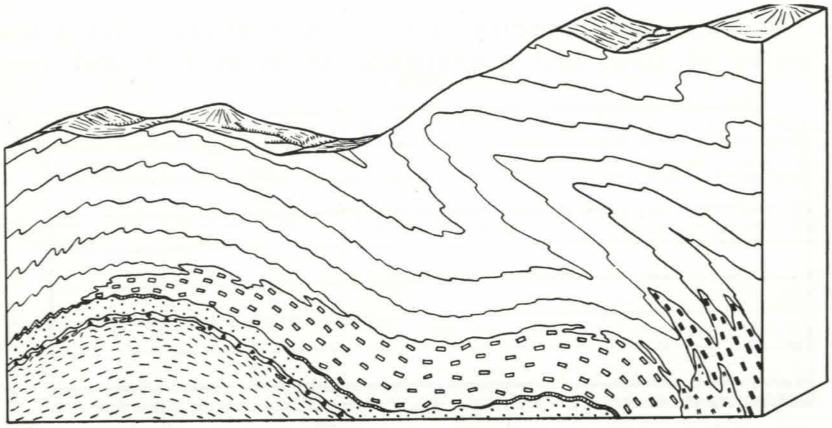

Figure 4—Late Devonian. Folding about completed, metamorphism very intense. The feldspathic gneisses and Concord granite are formed.

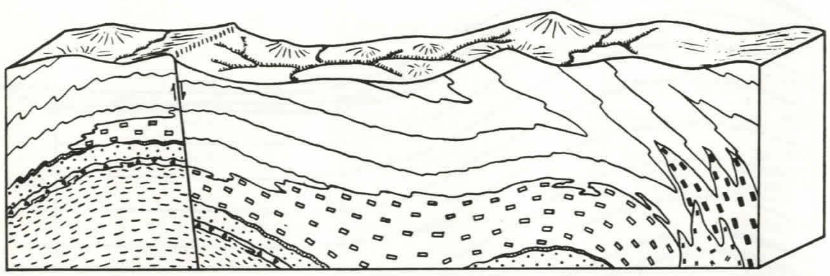

Figure 5—Triassic period. Faulting.

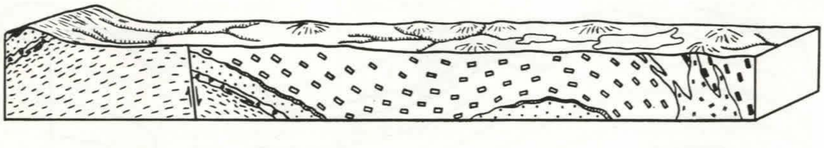

Figure 6—Recent. Rocks are eroded to the present topography.

Figures 1-6—A series of block diagrams to illustrate the story of the rocks. The left end of each block is generally to the west, the right end to the east. Triangle pattern—Ammonoosuc volcanics; coarse stipple—Clough formation; fine stipple—Fitch formation; line pattern—Littleton formation; single dash—Croydon group; open rectangle—Bethlehem gneiss; black rectangle—Kinsman quartz monzonite; double dash—Concord granite.

sure, the sedimentary rocks became changed or metamorphosed. In general, all rocks were forced to recrystallize as the original mineral constituents reorganized themselves and many old minerals gave place to new ones. The clay-like minerals in the muds, for example, were unstable at these higher temperatures and pressures, and they recrystallized to form mica. At still higher temperatures other new minerals formed, only to change again whenever temperature and pressure exceeded certain intensities.

Most of the rocks were composed of thin layers or beds which were quite uniform and well developed throughout the area. As recrystallization progressed, thin mica flakes grew most readily along bedding planes, because these planes constituted a weak direction in the rock. Consequently numerous parallel and continuous layers of mica formed which gave the new metamorphic rock the property to split or cleave readily into thin smooth slabs. Such a rock is called a schist, and the parallel continuous layers of mica form what is known as schistosity. In places, where the rocks were very tightly compressed, it was easiest for the mica flakes to grow at right angles to the direction of compression. In this case the bedding had little or no effect upon the arrangement of the flat mica crystals, and the schistosity may or may not have formed parallel to the original bedding.

Where temperature was higher, recrystallization was more intense. Small mineral grains became integrated into larger crystals and coarser-grained rocks were formed. With an increase in grain size the thin continuous mica layers became disrupted, and large discrete masses or flakes of mica formed. The rock began to lose it schistosity as the continuous layers disintegrated and it took on its place a structure known as foliation. Such a rock is called a gneiss.

Changes in the Older Rock

A simplified picture of the metamorphic changes which took place in the older rock is shown in Table 2. The table shows only the most abundant metamorphic rocks within each formation, together with the corresponding sedimentary rock types from which they were derived. The principal mineral components of each metamorphic type is also included with the minerals arranged in decreasing order of abundance.

Table 2

Formation	*Sedimentary Material*	*Metamorphic Rock*	*Mineral Composition*
Kinsman quartz monzonite	Mud and sand	Feldspar-mica gneiss	Plagioclase, quartz, potash feldspar, biotite
		Feldspar-mica-garnet gneiss	Plagioclase, quartz, potash feldspar, biotite, garnet
Bethlehem gneiss	Mud and sand	Feldspar-mica gneiss	Plagioclase, quartz, potash feldspar, biotite, (muscovite)
Littleton formation	Mud and fine sand	Mica schist and gneiss	Quartz, muscovite, biotite
		Staurolite schist	Quartz, muscovite, staurolite biotite
		Mica-garnet schist and gneiss	Quartz, muscovite, garnet, biotite
		Mica sillimanite schist and gneiss	Quartz, muscovite, sillmanite, biotite
		Feldspar gneiss	Quartz, potash feldspar, biotite
	Sand	Quartzite	Quartz, (feldspar, mica)
Fitch formation	Sand	Quartzite	Quartz, (feldspar, mica)
	Mud	Mica schist	Quartz, muscovite, biotite, plagioclase, potash feldspar, (calcite, actinolite)
	Impure limestone	Amphibolite	Hornblende, plagioclase, (biotite)
		Lime-silicate granulite	Plagioclase, potash feldspar, diopside, actinolite
Clough formation	Sand and gravel	Quartzite and quartz conglomerate	Quartz, (feldspar, mica)
	Muddy sand	Mica schist	Quartz, muscocite, biotite, (garnet, sillimanite)
Ammonoosuc volcanics	Dark volcanic rock	Hornblende schist	Plagioclase, hornblende
		Amphibolite	Hornblende, plagioclase
	Light volcanic rock	Biotite gneiss	Plagioclase, quartz, biotite

Table 3

Mineral	*Chemical composition*	*Formula*
Quartz	Silicon oxide	SiO_2
Potash feldspar	Potassium alumino-silicate	$KAlSi_3O_8$
Plagioclase	Sodium-calcium alumino-silicate	$(Na, Ca)\ Al\ (Al, Si)\ _3O_8$
Muscovite	Hydrous potassium alumino-silicate	$KAl_2AlSi_3O_{10}(OH)_2$
Biotite	Hydrous potassium iron-magnesium alumino-silicate	$K(Mg, Fe)_3\ AlSi_3O_{10}\ (OH)_2$
Hornblende	Hydrous sodium-calcium iron-magnesium alumino-silicate	$(Ca, Na)_3\ (Mg, Fe, Al)_5\ (Al, Si)_8O_{22}(OH)_2$
Actinolite	Hydrous calcium magnesium-iron silicate	$Ca_2(Mg, Fe)_5\ Si_8O_{22}(OH)_2$
Diopside	Calcium magnesium-iron silicate	$Ca(Mg, Fe)Si_2O_6$
Garnet	Iron-magnesium alumino-silicate	$(Fe, Mg)_3Al_2Si_3O_{12}$
Staurolite	Hydrous iron alumino-silicate	$Fe(OH)_2.2(Al_2SiO_5)$
Sillimanite	Alumino-silicate	Al_2SiO_5
Tourmaline	Hydrous sodium-calcium iron-magnesium boron alumino-silicate	$(Na, Ca)\ (Mg, Fe)_3B_3Al_3(AlSi_2O_9)_3\ (O, OH, F)_4$
Beryl	Beryllium alumino-silicate	$Be_3Al_2Si_6O_{18}$
Apatite	Calcium fluorine-chlorine phosphate	$Ca_5(F, Cl)\ (PO_4)_3$
Calcite	Calcium carbonate	$CaCO_3$

In the Ammonoosuc volcanics, for example, the light-colored rocks were metamorphosed to light-colored biotite gneiss. The dark volcanics recrystallized into feldspar and a dark mineral called hornblende which usually forms in long slender crystals. Where the long crystals grew in closely spaced parallel planes, like the mica flakes in many other rocks, a hornblende schist was formed. Other rocks in which hornblende is abundant, but not in parallel layers, are known as amphibolites.

In the other formations sand, composed almost wholly of quartz, recrystallized to tough, hard quartzite whereas gravel formed quartz conglomerate. Both rock types are massive or may show a faint foliation. Mud formed mica schist upon metamorphism, and rocks composed of various mixtures of mud and sand recrystallized to rocks intermediate between schist and quartzite. The impure limestone of the Fitch formation was changed to various kinds of schist and sugary looking rock called granulite. Some rocks of special composition formed amphibolite which resembles the amphibolite in the Ammonoosuc volcanics.

Changes in the Littleton Formation

The Littleton formation was originally the most extensive formation in the Sunapee quadrangle and, therefore, warrants somewhat detailed consideration. The rocks were composed of mud, sand, and various mixtures of the two. The total thickness of the formation was perhaps many thousands of feet, but the composition throughout was remarkably uniform. Originally deposited as essentially flat beds, the layers were folded slightly in places and more intensely in others. The general nature of the folding is shown in cross sections A-A′ and B-B′. Largely as a result of this folding and subsequent erosion of the up-arched portions, the Littleton formation now appears confined to several belts trending roughly north-south.

The mineralogical and textural changes suffered by the rocks of the formation in different parts of the quadrangle indicate that the severity of metamorphism increased from west to east across the area. In some of the schists, particularly in the extreme northwest corner of the quadrangle, staurolite crystals formed. In essentially equivalent rocks further east, staurolite gave rise to sillimanite, and further east where metamorphism was still more intense, muscovite mica was destroyed and potash feldspar formed.

In addition to these mineral changes one notes an increase in grain size of the rocks in going from west to east. This coarsening of grain is accompanied, furthermore, by the development of a foliation at the expense of schistosity. In brief, finer rocks gave place to coarser ones and gneisses were developed more abundantly than schists.

A conspicuous and very interesting feature of recrystallization is the presence of numerous large but widely separated crystals. These large crystals, or porphyroblasts as they are called, range up to several inches and may be many times larger than the average grains of the rock. This power to form huge crystals is most frequently expressed in such minerals as garnet, staurolite, stillimanite, and potash feldspar. Reddish garnet porphyroblasts occur sporadically throughout the Littleton formation, but staurolite, as red-brown crystals up to several inches long, is found in the formation only near the west border of the area. Small sillimanite porphyroblasts are common in the belt of the Littleton formation extending from the northeast corner of the quadrangle to the central part of the southern border. Porphyroblasts of potash feldspar occur in the Littleton formation on the east slope of Sunapee Mountain.

Formation of the Feldspar Gneiss

A thorough acquaintance with the rocks of the area will impress one with the similarity between the intensely metamorphosed rocks of the Littleton formation and the two large bodies of feldspar gneiss shown on the map as Kinsman quartz monzonite and Bethlehem gneiss. In some respects, however, these gneisses differ from the rocks of the Littleton formation. They contain more potash feldspar, less quartz and biotite, and little or no muscovite mica. Furthermore, they universally carry large amounts of another feldspar called plagioclase which is essentially absent from the Littleton formation. The rocks show, generally, a coarsening of grain and a more irregular arrangement of mica flakes as one goes from west to east across the area. In fact much of the Kinsman quartz monzonite (in the eastern part) is very massive. These feldspar gneisses on the whole are coarser grained and show a more poorly developed foliation than the gneisses of the Littleton formation. They are believed to represent portions of the Littleton formation which have suffered intense metamorphism. In their development muscovite mica changed to potash feldspar which segregated into large porphyroblasts up to several inches long. More intense metamorphism, in the eastern part of the area, caused biotite as well as muscovite to be made over into potash feldspar.

During the metamorphism some material migrated upward through the rocks from deeper parts of the earth. Perhaps the most abundant element to seep into the rocks of the Sunapee quadrangle was sodium, although there is good reason to believe that small amounts of calcium and potassium were also introduced. As the sodium and perhaps calcium moved upward and toward the west, they reacted with certain minerals to form plagioclase feldspar in the feldspar gneisses. The more local introduction of potassium, in the eastern part of the quadrangle, helped to form additional potash feldspar. This introduction of material was not uniform throughout the area, because all of the Littleton formation did not develop new feldspar. Migration was confined to certain zones or layers in the rocks which were more effective "channel ways" for the nomadic material. The selective movement is indicated by the way tongues of Kinsman quartz monzonite project far into the Littleton formation on the west side of Sunapee Mountain.

Second Invasion of Molten Rock

Sometime after the compressive forces had subsided, small masses of magma were injected into fracture-like openings in the rocks west of Sunapee Lake. The magma congealed to form a rather massive, granular rock known as the Spaulding quartz diorite. This rock is dark and composed of plagioclase feldspar, biotite, hornblende, quartz, and a little potash feldspar. Slightly later the Concord granite formed. It is a light-colored, granular massive rock composed of quartz, potash feldspar, muscovite, and biotite. Perhaps most of the granite formed from a magma injected into fractures and openings in much the same manner as the Spaulding quartz diorite. More or less contemporaneous with the Concord granite are the great number of tabular masses of quartz and feldspar known as pegmatites which cut through nearly all rocks of the area. These light-colored masses appear as veins or pods of varying sizes. In addition to quartz and feldspar they carry numerous other minerals in minor quantities such as mica, tourmaline, garnet, and beryl. Pegmatites in this general region are one of the chief sources of feldspar and mica in New England.

Erosion and Faulting

While the thick sequence of sedimentary layers was being folded and metamorphosed, larger and larger areas were raised above sea level. Erosion by the newly formed streams attempted to reduce the land to sea level again, but gradually the rate of uplift exceeded that of erosion and a high land mass, deeply carved with valleys, was formed. The mountains thus formed were the young Appalachians.

Gradually the landscape changed as the streams continued to carry away the disintegrated and decomposed rock material formed by weathering on mountain slopes. As the mountains grew older, the higher elevations were reduced, and the topography took on a form not too different from that of today. Examination of cross sections A-A′ and B-B′ will show the reader how the present land surface cuts across the folded rock formations. If we project these truncated layers up into the air and attempt to reconstruct the large folds, we will get a much better idea of the tremendous amount of rock materials which was removed during the prolonged period of erosion.

During the Triassic period, about 160 million years ago, minor adjustments took place in the earth's crust. Certain areas tended to settle relative to other areas, and the adjustment was accomplished by the formation of large fractures or breaks in the crust. Slipping took place along these fractures, and the rocks on one side moved downward relative to the rocks on the other. Such a fracture is called a fault. One fault, extending roughly northeast-southwest is shown on the map by a heavy line in the northwest part of the quadrangle. The rocks on the southeast side of this fault have moved down relative to those on the opposite side. Cross section A-A′ shows a different view of this same fault. Locally the walls of the fracture pulled apart, and the huge cavities formed were quickly filled with quartz which probably migrated upward from depth. On the geologic map. several of these quartz masses are shown by the symbol "s." One of the largest and best exposed is on Dunbar Hill at the north border of the map.

The Great Ice Age

Many conspicuous remnants of the Great Ice Age are to be seen in the Sunapee quadrangle. During the Pleistocene, which began about two million years ago, climatic temperatures were much lower than at present and great ice fields began to form in northern Canada. Over many thousands of years, snow accumulated in great thicknesses in these areas, and the load of the overlying layers of snow caused compaction and recrystallization of the bottom layers to form a thick mass of ice. Gradually the ice sheet got thicker, and the pressure of the overlying material became so great on the bottom layers that the ice was forced to "flow" or spread out in all directions along the earth's surface. Year by year the ice cap grew and finally it advanced into the Sunapee area. At first it filled the valleys and covered the low hills, and then later even Croydon Mountain and Sunapee Mountain were buried by the glacier. As the ice pushed along, it moved the loose soil from the hill tops to the low areas. In places it tended to form great ridges and mounds of soil more or less mixed with angular blocks and boulders torn loose from the rocky ledges. Blocks of hard rock, frozen into the bottom of the advancing glacier, scraped and grooved the solid ledges where the soil cover had been removed. In many places one may find smoothed or even polished rock surfaces, the result of abrasion by fine rock material under the ice. The loose material moved by the ice was strewn over the surface as a veneer of varying thickness. In some localities this material, called till, is fine-grained, but throughout much of the quadrangle, boulders and blocks up to many feet across were scattered over the surface or mixed with the finer constituents. Boulders may be so abundant locally that the land is useless for cultivation.

While the ice was melting, great volumes of water escaped in swift-flowing streams which carried silt, sand, and gravel to scattered areas of deposition. Lakes formed and in them thick deposits of sand and silt accumulated. Many of these lakes were completely filled; others drained away.

At one time the outlet of Sunapee Lake into Sugar River was dammed, probably by a small mass of ice, and the lake overflowed at Newbury and drained southeast into the Merrimack River. A conspicuous gorge was cut in the rocks just south of Newbury village, and the whirlpool action of the swift water caused pebbles and boulders to swirl in circular motion, grinding away at the rocky stream bottom and forming pits several feet deep. Remnants of these pits or pot holes as they are called may still be seen here. Later when the ice dam melted, the lake water again drained westward into Sugar River at Sunapee village. The lake level was lowered from an elevation (1140 feet) slightly above the spillway in Newbury gorge to its present position of 1091 feet above sea level.

INTERESTING LOCALITIES

Sunapee Mountain extends southward from the south end of Sunapee Lake for about five miles. This long wooded ridge ranges from 2300 to 2700 feet in elevation. The highest point (2743 feet) is at the north end, within Mount Sunapee State Park, and is accessible by foot trails and by a gondola lift which leaves from the park's main visitation center located about a mile off the Mount Sunapee traffic circle on Route 103.

A trail leads from the Mount Sunapee summit to Lake Solitude. This small, shallow pond is at 2400 feet elevation and lies at the base of a 300-foot cliff on its west side. From the top of the cliff, one may obtain a splendid view of the pond and of the countryside to the east. The cliff is composed of Kinsman quartz monzonite and from here a large, well-exposed dike of Concord granite can be traced southward for a mile. Lake Solitude, which lies entirely within the state park, can also be reached from the east via a foot trail which follows Andrew Brook from its junction with the "Between-the-Mountains" road.

Croydon Mountain, or *Blue Mountain* as it is also called, is another long wooded ridge in the northwest corner of the quadrangle. Its highest elevation, Croydon Peak, is 2781 feet or slightly greater than that of Sunapee Mountain. The marked elevation of this long ridge is attributed to the durable quartzite of the Clough formation which outcrops extensively all along its extent. From State Route Number 10 just north of the village of Grantham, great cliffs and ledges of light-colored quartzite on Croydon Mountain stand out against the blue-green color of the forested slopes. A hike across the mountain will take one over the complete sequence of formations from Ammonoosuc volcanics to Littleton formation, and beautiful examples of folded beds may be seen here in the Clough formation.

About 15 square miles of the northwest corner of the quadrangle, as well as several times this area in adjacent quadrangles, is included in a large private game reserve. Formerly known as Corbin Park but now going by the name of the Blue Mountain Forest Association, this area serves as a private hunting ground and is well stocked with European wild boar and elk as well as game common to most other parts of the state.

Sunapee Lake is the center of attraction to summer tourists and vacationists in this part of New Hampshire. Its shoreline is dotted with cottages, and numerous resort hotels are located on the lakeward slopes. Sunapee Lake is the highest large lake in New Hampshire, and it is perched close to the divide between the Connecticut River and Merrimack River drainage basins. If a 50-foot cut were made in the narrow valley half a mile south of the village of Newbury, Sunapee Lake would have a new outlet and would drain southeast into the Merrimack River. The great number of large boulders along the lake shore have been exposed as their finer matrix of the glacial till has been washed away by waves and currents.

Lake Sunapee is of special interest to fishery biologists and fishermen because it is one of the few lakes in which are found the *aureolus* or *eastern golden trout,* a close relative of the *Arctic charr.* Many ichthyologists believe the aureolus is a survival from post-glacial times. The popular theory is that because of its large area of deep cold water, its excellent spawning reefs, and absence of predatory deep-water fish, Sunapee enabled the *aureolus* to survive long after it had disappeared from other New England waters.

Writers have called this interesting specie a "living relic from glacial times."

Little Sunapee Lake is a small but beautiful body of water. It is 126 feet higher than Sunapee Lake and drains into it by way of Otter Pond. A glance at the map will show the lake to be nearly divided by a narrow strip of land projecting southward from the north shore. This peninsula is actually a long ridge of sand and fine gravel. It is known as an esker and was formed by a stream of glacial water which deposited the fine sediment in a channel or crevasse in the glacier. After the glacier disappeared, a long serpentine-like ridge was left separating Little Sunapee Lake into two basins. Eventually the soft sediments were in part worn away and the two lakes were integrated.

ROCK AND MINERAL COLLECTING LOCALITIES

Some of the more accessible localities for examining and collecting rock and mineral specimens will now be given. The best locations to collect specimens of the Ammonoosuc volcanics are on Croydon Peak or in the same belt of volcanics about five miles to the south. The best exposures of the Clough formation are along Croydon Mountain, but the quartzite may be more readily obtained along the road on the south side of Sugar River near the west border of the map. On Mount Tug, just south of Sugar River near the west border of the quadrangle, several rock types of the Fitch formation may be collected. Here is quartzite, amphibolite, and mica schist in order from east to west. Lime-silicate granulites so typical of the Fitch formation are exposed only in the narrow belt on Croydon Mountain. Just west of this belt is mica-staurolite schist to the Littleton formation in which staurolite crystals attain the length of 3 to 4 inches. Quartzite, mica schist, mica-sillimanite schist, and mica-garnet schist may be readily obtained from the numerous outcrops along roads which traverse the belt of the Littleton formation between Georges Mills, at the north end of Lake Sunapee, and the central part of the south border of the quadrangle. In the western part of this belt and in the belt extending south from the village of Newbury, specimens of quartzite, mica gneiss, mica-sillimanite gneiss and mica-garnet gneiss may be obtained. Fresh exposures of Bethlehem gneiss may be found east of Newport, along State Route Number 103, about one and a half miles south of Wendell. Other good places to collect are along State Route Number 11 between Newport and Kelleyville and State Route Number 10 between Croydon Flat and the village of Croydon. Many of these outcrops show the abundant large crystals of potash feldspar. The freshest specimens of Kinsman quartz monzonite will be found in new road cuts along State Route Number 103 between

Edgemont and South Newbury. Large crystals of potash feldspar several inches long are abundant. Here also may be found small masses of garnet-rich gneiss of the Littleton formation. Along State Route Number 103B, half a mile west of Fisher Bay, are several outcrops of Spaulding quartz diorite. The Concord granite outcrops on Burpee Hill, just south of Little Sunapee Lake, and good exposures are found at the road junction a mile southeast of the hill. Fine-grained Concord granite and Spaulding quartz diorite may be obtained from the old quarry on Keyser Hill just east of the village of Sunapee.

Many of the large pegmatities in the Sunapee quadrangle have been prospected or worked for feldspar. These deposits will furnish the mineral collector with a great variety of specimens such as quartz, potash feldspar, plagioclase, biotite, muscovite, tourmaline, garnet, beryl, and apatite. A few of the most accessible pegmatities where collecting is good include: (1) Smith mine at the west end of cross section B-B′; (2) west knoll of Youngs Hill, three miles east of Newport village; (3) knoll south of Ledge Pond, Sunapee township; (4) knoll east of Kolelemook Lake, Springfield township; and (5) off road 1¼ miles south of West Springfield village.

A remarkable exposure of vein quartz, which constitutes a zone of silicification along a fault, occurs on Dunbar Hill northwest of Grantham village. Here small but well-formed quartz crystals have been found in small cavities or vugs. Less commonly hematite occurs in small masses.

HOW TO READ THE MAP

The colored map in the pocket at the back of the pamphlet is a topographic map upon which has been printed the distribution and structure of the various kinds of bedrock. Many features of the geology have already been referred to; further explanation may be found in the legend at the side of the map. An explanation of the cultural and topographic features not explained in the map legend will be covered briefly here. Roads are shown by double lines, solid if good and dashed if poor or private. Trails are shown by single dashed lines and railroads by cross-ruled lines. Small black squares represent houses. A square with a cross represents a church and a square with a flag represents a school. County and town boundaries are shown by heavy dashed lines. Streams and lakes are shown in blue and swamps are indicated by blue tufted symbols.

The configuration of the ground is conveyed by brown lines called contour lines. All points on any particular line have the same elevation above sea level. In passing from one contour line to the next, the elevation changes 20 feet. This vertical distance between adjacent contours is known as the contour interval of the map. To facilitate reading every fifth contour line is made somewhat heavier than the others, and its elevation is indicated by a number. Since contour lines represent lines on the ground, steep slopes are indicated by closely crowded contours and gentle slopes by widely spaced lines. Bald Sunapee, in the southeast corner of the quadrangle, is an elongate hill trending about northeast-southwest as shown by the elliptical contour lines. The steep slope is on the east side and the highest point has an elevation of 1951 feet above sea level.

REFERENCES

General Geological Books

1. Croneis, C. and W. C. Krumbein. **Down to Earth.** University of Chicago Press, 1936.
2. Fenton, C. L. **Our Amazing Earth.** Doubleday-Doran, New York, 1938.
3. Fenton, C. L. and M. A. Fenton. **The Rock Book.** Doubleday-Doran, New York, 1940.
4. Loomis, F. B. **Field Book of Common Rocks and Minerals.** G. P. Putnam's Sons, New York, 1923.
5. Shand, S. J. **Earth Lore or Geology Without Jargon.** T. Murby & Co., London, 1937.

SUNAPEE QUADRANGLE AND ADJACENT AREAS

1. Chapman, C. A. **Intrusive Domes of the Claremont-Newport Area, New Hampshire.** Geol. Soc. Amer., Bull. 53, p. 889-916, 1942.
2. Chapman, R. W. and C. A. Chapman, **Cauldron Subsidence at Ascutney Mountain, Vermont**. Geol. Soc. Amer., Bull. 51, p. 191-212, 1940.
3. Daly, R. A. **Geology of Ascutney Mountain, Vermont.** U. S. Geol. Sur., Bull. 209, p. 1-122, 1903.
4. Fowler-Billings, K. and L. R. Page, **Geology of the Cardigan and Rumney Quadrangles, New Hampshire.** Concord. N. H. State Planning and Development Commission, 1942. 31 p.
5. Goldthwait, J. W. **The Geology of New Hampshire.** Concord. New Hampshire Academy of Science, Handbook No. 1, 1925.
6. Hadley, J. B. and C. A. Chapman. **The Geology of the Mt. Cube and Mascoma Quadrangles, New Hampshire.** Concord. N. H. State Planning and Development Commission, 1939. 28 p.
7. Heald, M. T. **Structure and Petrology of the Lovewell Mountain Quadrangle, New Hampshire.** Geol. Soc. Amer., Bull. 61 p. 43-89, 1950.
8. Hitchcock, C. H. **Geology of New Hampshire,** 3 vols. and atlas. Concord, 1874, 1877, and 1878.
9. Hitchcock, C. H. **Geology of the Hanover, New Hampshire Quadrangles.** Vermont State Geol., 6th Bienn. Rept., p. 139-186. 1907-1908.
10. Kruger, F. C. **Geology of the Bellows Falls Quadrangle, New Hampshire.** Concord. N. H. State Planning and Development Commission, 1946. 19 p.