THE GEOLOGY OF THE
BELLOWS FALLS QUADRANGLE
New Hampshire and Vermont

by

FREDRICK C. KRUGER

PUBLISHED BY THE NEW HAMPSHIRE PLANNING AND DEVELOPMENT COMMISSION

1946

GREATEST CONCENTRATION OF BERYL IN THE WORLD. BERYL MT., ACWORTH, N. H.

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FOREWORD

This pamphlet is designed to appeal to the layman and is not intended to be an elaborate report for the professional geologist. The text is written in simple language and few scientific names are used. The map accompanying the pamphlet shows the details of the geology of the region, with a key for reading it. All that need concern the layman are the formation names. It is not essential for him to read or understand the detailed mineral and rock descriptions. The fascinating story of the rocks can be understood without these details.

This geological study of the Bellows Falls quadrangle was begun in 1937 under the auspices of the Department of Geology of Dartmouth College, but the bulk of the field work and the laboratory work were completed in 1938-1941 under the direction of the Division of Geological Sciences of Harvard University.

The publication of the geological map in the pocket at the end of the pamphlet was financed by the New Hampshire State Planning and Development Commission and the New Hampshire State Highway Department.

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By Fredrick C. Kruger

THE SCENERY

The tourist, traveling up the valley of the Connecticut River, will often question himself as to the origin of the flat, fertile meadows on either bank, or the why and wherefore of the precipitous cliffs of Fall Mountain across from Bellows Falls. He will, like many others before him, be charmed by the rolling, verdant scene, accentuated here and there by a beautiful brook, a placid pond, or an intriguing cliff. He may become interested in the many little mines whose white waste dumps dot the hillsides in the eastern part of the area. But the recurrent question in the mind of the inquiring individual will probably be, "How did it get that way?" It is hoped that the answer to his question will be found in this pamphlet as it relates the story of the rocks and the landscape.

Like other areas in western New Hampshire, the story has been preserved in the rocks from long ago when this region was a shallow sea receiving sediments from highlands to the east; or an unstable portion of the earth's crust crumpling under mountain-forming pressures; or a land of active volcanic eruptions; or even later, when it was being scoured by an ice sheet. Each of these fascinating phenomena contributed its share to our New Hampshire landscape of today.

THE STORY OF THE ROCKS
The First Invasion by the Sea

Long ago, in the Ordovician period, which the geologist calculates to be about 400 million years ago, this region and much of New England was submerged beneath an extensive sea. Highlands far to the east were being eroded to feed westward-flowing streams with sediments which they deposited in the shallow sea over western New Hampshire. In the Bellows Falls area the first strata laid down were impure limy oozes, which have been changed or metamorphosed to the schists and marbles that constitute the Waits River formation (Fig. 1). These rocks, now exposed in the northwest corner of the Bellows Falls quadrangle, are labelled *Ow* on the geological map.

On the top of these calcareous deposits the streams brought to the sea the great thickness of muds and sands, which, now converted to slate and schist, constitute the main part of the Orfordville formation, labelled *Oo* on the geological map. There was some volcanic activity during this long period of marine sedimentation, for on Hogan and Coburn Hills in Rockingham the strata contain green, altered remnants of volcanic ash and lava flows, some of which may have been submarine eruptions. These volcanic rocks are labelled *Oov* on the geological map. Upon occasions the streams, swollen in flood, carried much larger material than their customary mud and sand, and brought to the sea coarse pebbles and boulders, chiefly of durable quartz. This material, now hardened to a resistant bed of conglomerate, has been named the Hardy Hill quartzite and is labelled *Ooh* on the geological map. This white adamantine formation is most interesting to trace in the well exposed outcrops northeast of Trapshire on Oak Ridge and east of Charlestown on Breakneck Hill.

Still later in the Ordovician period, volcanoes, probably lying to the east, spewed forth both fragmental rocks and lavas, now known as the Ammonoosuc volcanics and labelled *Oam* on the geological map. These rocks are exposed in the valley of the Cold River, between Alstead and South Acworth. Another outstanding place to see them is on the east side of Gilboa Mountain in Westmoreland, where the characteristic interbanding of light and dark beds is especially noticeable.

To close the sedimentation during the Ordovician period, beds of mud were deposited. These muds, now hardened and metamorphosed to schists, constitute the Partridge formation, which is labelled *Op* on the geological map. This formation is best exposed where the Ashuelot River cuts through Surry Mountain in the southeast part of the quadrangle.

By the end of Ordovician time a whole series of formations, many thousands of feet thick, had been deposited on top of one another, as shown in Fig. 1. The sea was never very deep throughout this long period of time during which the formations accumulated. It was always shallow, but the bottom sank at about the same rate as that at which the sediments were deposited.

The First Uplift and the First Erosion

Then, after long submergence, the varied strata which had accumulated on the sea floor were gently folded, as shown in Fig. 2. The sediments and volcanics were exposed to active erosion as the sea retreated and this portion of western New Hampshire was elevated. The attack of weather and running water upon the newly emerged land reduced it irregularly, removing in places almost all of the Partridge formation.

The Second Invasion by the Sea

The sea advanced again over western New Hampshire in Silurian time, some 350,000,000 years ago (Fig. 3). Pure quartz sands and gravels accumulated as a sheet many scores of feet thick. These deposits, later hardened to quartzite and quartz conglomerate, now constitute the Clough formation, which is labelled *Sc* on the geological map. This formation, very similar to the Hardy Hill quartzite, is an easily recognized bed, white and resistant, forming prominent outcrops that aid the geologist to determine the nature of the folds in the east-central part of the Bellows Falls quadrangle.

This invasion of the sea continued into the Devonian period, and the history is recorded in this area by the extensive deposits of the Littleton formation. The deposits were chiefly fine mud and sandy mud, which are now schists and are labelled *Dl* on the geological map. There were two periods of sporadic volcanism during which ash and lava were extruded; these rocks, now greatly altered, are labelled *Dlv* on the geological map. During the Devonian period the sea level was unstable,

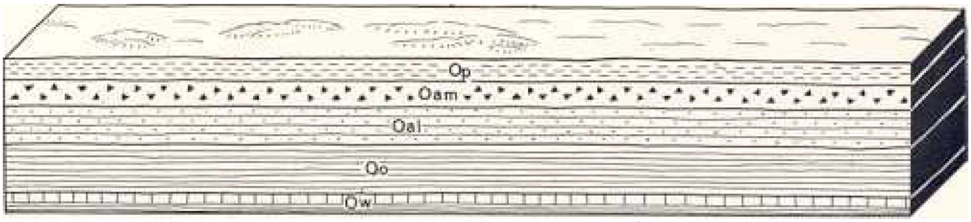

FIGURE 1 — Sand (dots), mud (lines), limy oozes (blocks), and volcanics (triangles) are deposited in middle and upper Ordovician time.

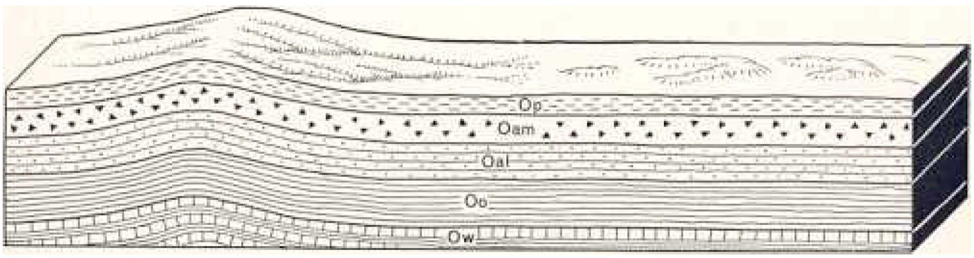

FIGURE 2 — Gentle folding in late Ordovician time.

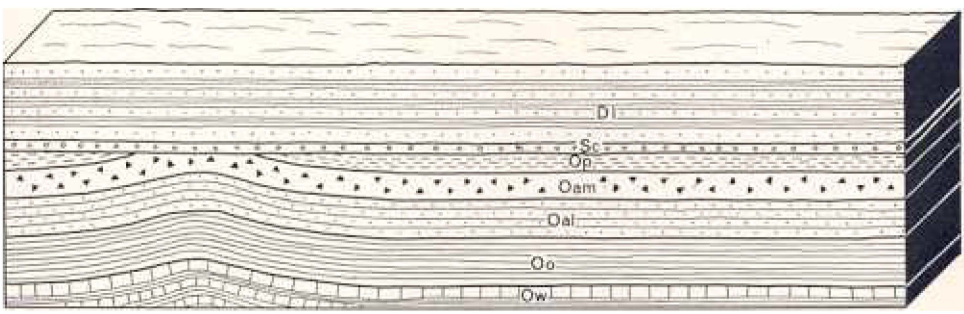

FIGURE 3 — After slight erosion, sand and gravel (circles), sand (dots), and mud (lines) are deposited in Silurian and early Devonian time.

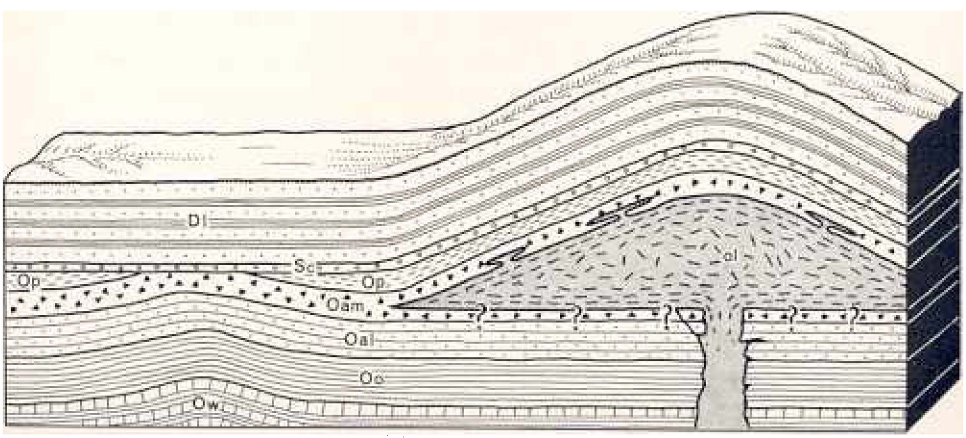

FIGURE 4 — Molten rock (magma) invades region and freezes to form Oliverian magma series, probably in middle Devonian time.

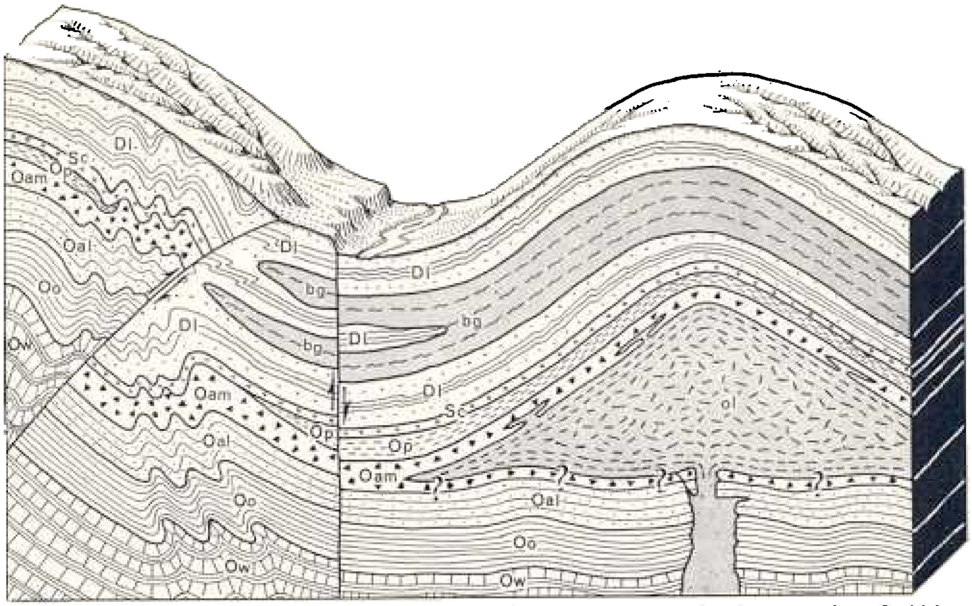

FIGURE 5 — Folding, faulting, and invasion by molten rock (magma) that freezes to form Bethlehem gneiss.

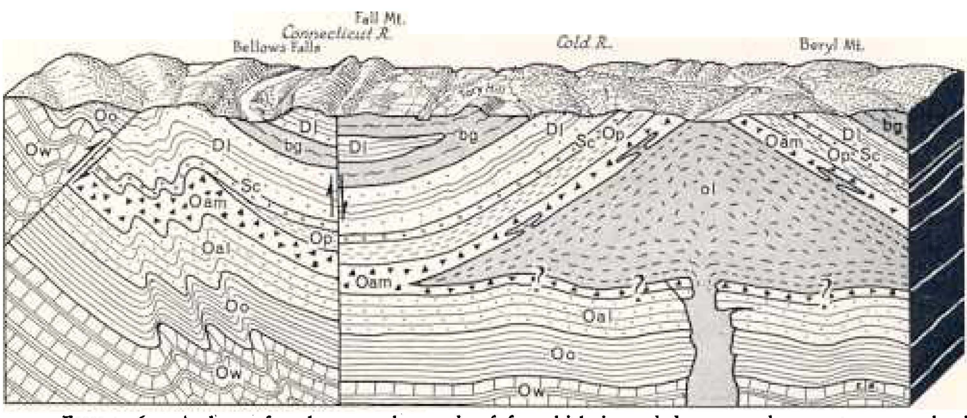

FIGURE 6 — A sheet of rock many thousands of feet thick is eroded away and present topography is the result.

FIGURES 1-6 — Series of diagrams to illustrate the story of the rocks described in the text. The cross sections are imaginary trenches a mile or so deep cut across the Bellows Falls quadrangle at successive stages in its development. ***Ow***=Waits River formation; ***Oo***=Orfordville formation; ***Oal***=Albee formation; ***Oam***=Ammonoosuc volcanics; ***Op***=Partridge formation; ***Sc***=Clough formation; ***Dl***=Littleton formation; ***ol***=Oliverian magma series; ***bg***=Bethlehem gneiss.

and each fluctuation of the sea is marked by a change in the type of strata deposited. One part of the Littleton formation marks a time when the seas were clear enough for the accumulation of limy sediments, but these conditions were interrupted twice by times during which coarse sands and gravels were carried far out to sea to be interlayered with the limy beds. The limy beds have been converted to schists and sugary-looking rocks called granulites; they are labelled *Dll* on the geological map and are extensively exposed in Walpole. The sands and gravels, now quartzite and quartz conglomerate, are labelled *Dlq* on the geological map; these rocks are exposed on Sams Hill in Charlestown and on other lesser prominences. The quartzites and quartz conglomerates in the Littleton formation are very similar to the Hardy Hill quartzite and the Clough formation.

By the time deposition had ceased, seven successive major formations, partly sedimentary and partly volcanic, had accumulated in western New Hampshire, as shown diagrammatically (Fig. 3).

The Great Folding and the Rise of Molten Magma

Then, some 300,000,000 years ago, the seas retreated forever from this part of New Hampshire and the vast accumulation of sediments and volcanics was folded and invaded by molten rock known as magma. Even before the folding a great mass of molten rock rose from the depths of the earth and was injected as a great mushroom-shaped body into the Ammonoosuc volcanics, doming up the overlying rocks (Fig. 4). The molten rock consolidated to form the granite and related rocks belonging to the Oliverian magma series, shown on the geological map in green and labelled *ol*.

The folding followed. The strata, which up to this time were essentially horizontal except near the Oliverian magma series, were squeezed to form a series of folds of the type shown in Structure Section AA′. Locally, where the rocks were too brittle to fold, a major fracture developed, and great masses of rock slid past each other. The Northey Hill fault, near the Connecticut River north of Bellows Falls, is such a fracture, and is shown in Structure Section AA′ and Fig. 5.

During a late stage of the folding, molten rock belonging to the New Hampshire magma series invaded the region. The Bethlehem gneiss, labelled *bg,* was forced into the Littleton formation, as shown in Figure 5. Rising sheet-like from the east, it passed over the domes occupied by the Oliverian magma series and extended as far west as Bellows Falls. The body of Bethlehem gneiss around Bellows Falls was originally continuous with the body in the northeast corner of the quadrangle but the connecting portion has been removed by erosion.

Later still, a few small intrusions of granite took place in Westmoreland, Westminster, and Rockingham; camptonite was intruded at Prospect Hill, Charlestown, but these bodies are of minor importance.

As the molten rock of the Bethlehem gneiss slowly cooled and crystallized, the residual juices, chiefly water bearing some dissolved mineral matter, filled fractures in the country rock, especially in the eastern part of the quadrangle. The resultant small rock-bodies, called pegmatites, are very coarse-grained and contain quartz, feldspar, mica, and many other unusual minerals like beryl and spodumene.

Simultaneously with the great folding and the great invasion by molten rock, changes took places in the Ordovician, Silurian, and Devonian sedimentary and volcanic rocks. Sandstones became strongly cemented glassy quartzites; muds were heated and squeezed so that micaceous minerals formed and the resulting rock is called schist; limy sediments were recrystallized to become marbles and granulites. All of these changes, due to a process called metamorphism, were brought about by the pressure that caused the folding and the heat that accompanied the invading molten rock.

After all, or at least after most of the rocks had formed, more faulting occurred. One of these faults extends from Mine Ledge, at the extreme south end of the quadrangle, to Alstead Center. A second lies 0.5 mile west of Mine Ledge. Along these north-trending vertical fractures (section DD′) large masses of rock slid past each other. The letter *D* is on the down-dropped block. Solutions moving up along the broken rock near the fault deposited considerable silica, form-

Geologic Time-scale with Sequence of Events in the Bellows Falls Quadrangle

OLDEST EVENT IS AT BOTTOM OF CHART; YOU

Era		*Period*	*Time-Scale*	*Sequence of Geologic Events*
Cenozoic		Recent	30,000 years ago to present	Slight erosion
		Pleistocene	2 million to 30,000 years ago	Ice Sheets covered the region
		Tertiary	Began 60 million years ago	Uplift and erosion
Mesozoic		Cretaceous	Began 120 million years ago	Erosion
		Jurassic	Began 150 million years ago	Erosion
		Triassic	Began 175 million years ago	Erosion
		Permian	Began 210 million years ago	Erosion
	Carboniferous	Pennsylvanian	Began 255 million years ago	Erosion
	Carboniferous	Mississippian	Began 290 million years ago	Camptonite at Prospect Hill
Paleozoic		Devonian	Began 330 million years ago	6. End of folding and beginning of erosion 5. Small granite bodies intruded 4. Bethlehem gneiss and pegmatites formed 3. Beginning of folding 2. Oliverian magma series intruded 1. Littleton formation deposited
		Silurian	Began 355 million years ago	Clough formation deposited
		Ordovician	Began 415 million years ago	5. Uplift and erosion 4. Partridge formation deposited 3. Ammonoosuc volcanics deposited 2. Orfordville formation deposited 1. Waits River formation deposited
		Cambrian	Began 515 million years ago	No record
Pre-Cambrian			Began 1600 million years ago	No record

ing the silicified zones shown on the geological map by a special color pattern.

Second Period of Erosion

From the Mississippian period, 290 million years ago, to the present, erosion has relentlessly attacked and modified the complex group of rocks in the Bellows Falls region. Layers of rock thousands of feet thick have been carried away by the streams to the oceans (Fig. 6). It does not follow, however, that the hills were ever much higher than at present. It is probable that a slow rise of the land kept pace with erosion, so that the surface always stood about the same altitude above sea level.

Great Ice Age

One remarkable event in this siege of erosion happened not so long ago, geologically speaking. At the beginning of this event the topography was similar to that found in the region now, but it was somewhat more rugged. The Connecticut River was the master stream and its valley, as well as the valleys of its tributaries, were well established. Then a great ice sheet, which had formed in Canada and was more than a mile thick, invaded New England. We know that the ice came from the north because the glacial striae or scratches on ledges trend north-south. These scratches were made by rocks that had been picked up and were embedded in the moving ice. Moreover, the ice plucked boulders from the parent ledges and carried them to the south. Blocks of syenite derived from Mt. Ascutney, 20 miles to the north, are found in the Bellows Falls quadrangle. A huge glacial erratic of this type lies between the highway and Thompson Brook near Shaws Corner, Surry.

The Great Ice Age began two million years ago, and from evidence in the central United States we know that there were four stages of glaciation separated by long interglacial stages during which the climate was as warm as or warmer than the present climate. Undoubtedly the Bellows Falls quadrangle, as well as the rest of New England, was invaded by Ice Sheets at four different times, but corroboratory evidence has not been discovered.

The ice dropped much of its debris while it was advancing southward and especially while it was melting. Debris dropped directly from the ice is known as till, which consists of an unstratified heterogeneous assemblage of boulders in clay or sand. Most of the surface of the quadrangle is covered by till that is several to many feet thick and conceals the bed rock. Much of the debris dropped while the ice was melting was transported by running water and deposited as stratified glacial outwash consisting of sand, gravel, and mud. The Connecticut Valley was occupied by a long deep lake, on the bottom of which clay many scores of feet thick accumulated.

The torrents that came from the melting glacier cut channel-ways and giant potholes into bed rock in many out-of-the-way places, now high and dry. The most spectacular of these glacial potholes are south of Cock Hat Hill just on the outskirts of Alstead. Others may be seen on Bingham Hill, Gilsum, and on Surry Mountain below Lily Pond.

Eventually the ice had completely melted and the lake in the Connecticut Valley had disappeared. The Connecticut River then began to cut into the weak clays deposited on the old lake bottom. As the river cut down it also meandered sideways, leaving a series of terraces rising above the present flood plain of the river. This erosion continues today and eventually most of the glacial deposits will be removed.

INTERESTING LOCALITIES

If your interests are aroused by physiographic features, such as stream-carved terraces, include the Connecticut River Valley and its tributaries, especially the Saxton, Williams, and Cold Rivers in your trip. The terraces were left as the rivers cut down through the soft, unconsolidated glacial deposits. For a splendid view of the countryside you could climb the easy trail from North Walpole up Fall Mountain, or on another day you could visit the fire tower on top of Sams Hill. Either of these climbs will satisfy the nature lover and geologist. A short but rewarding hike may be made east from Alstead around the south side of Cock Hat Hill. Here glacial drainage ground out numerous huge potholes in the Bethlehem gneiss. This ancient gorge contains little more than a trickle of water now.

Mineral collectors will find interesting specimens at the many pegmatite quarries scattered over the map.* These deposits, as well as others, are described more fully in the section on *Economic Resources.* Well-bladed sillimanite crystals are abundant in the highly metamorphosed schists south of the bridge over the gorge at Bellows Falls. Unusually large crystals of staurolite, both single and twinned, occur on the lower northern slopes of Sams Hill.

Prospect Hill, Charlestown, is capped by camptonite, a variety of trap. This rock was once molten and when it cooled, interlocking cracks divided the mass into polygonal blocks. This is called columnar jointing because of its similarity to the columns in a building. A worthwhile display of igneous rocks of several ages may be seen just below the dam at Bellows Falls, extending for a half-mile downstream to the power house. An excellent proof that the rocks were highly plastic at one time may be observed west of Slades Cemetery on Eaton Hill, Walpole, or on Hemlock Hill, Charlestown, where the quartz pebbles of the Littleton formation have been squeezed into cigar-shaped forms.

ECONOMIC RESOURCES

Minerals of economic or possible economic value in the Bellows Falls quadrangle include feldspar, mica, beryl, quartz, graphite, trap-rock, granite, sand, and gravel. In a short pamphlet such as this attention can be called to only the more important economic minerals and references given to more detailed descriptions.

Feldspar, mica, beryl. Feldspar and mica are obtained from pegmatites, which are shown on the geological map by a special red symbol. On a scale of an inch to a mile it is obviously impossible to show the shape and size of each peg-

*Because the base map upon which the geology has been overprinted was surveyed in 1927, many of the quarries, especially those opened up during World War II, are not shown on the accompanying geological map.

matite. A red plus sign indicates that a pegmatite occurs at the locality. In the summer of 1944 Mr. Glenn W. Stewart, working under the auspices of the U. S. Geological Survey, determined the attitude of some of the pegmatites. On the basis of his work, a long red bar with a short bar on one side indicates the attitude of the pegmatite. The long bar indicates the trend, the short bar indicates the direction in which pegmatite vein is inclined.

Pegmatite is a very coarse-grained granite. It was injected as very watery fluid into fractures in the rocks, pushing the walls apart and eventually consolidating. Because of its very watery character unusually large crystals were able to develop. Feldspar crystals one to three feet across are common, and on Beryl mountain there is an amazing display of beryl crystals four feet long and feldspar crystals fourteen feet across.

The geological map shows very clearly that the pegmatites become progressively more abundant toward the east; whereas there are none in the western third of the map, they are very common in the eastern part. The various minerals are not evenly distributed through the pegmatite. The valuable books of white mica occur near the margins of the body, whereas the feldspar occurs near the center. Quartz and beryl, if present, are near the center. For further details on the pegmatites of the Bellows Falls quadrangle the reader is referred to two recent publications by geologists of the United States Geological Survey (References 4 and 6 at end of this pamphlet). Detailed maps of many of the mines are on file at the State Planning and Development Commission, Concord, New Hampshire. Moreover, in a forthcoming publication of the United States Geological Survey, New England pegmatites will be discussed in greater detail than previously.

Quartz. Quartz of low iron content, less than 0.05 per cent, is in demand for the manufacture of optical glass. In general, the quartz associated with the silicified zones shown on the geological map is not pure enough. At a number of localities, however, quartz veins of probable purity and size occur. The two most promising localities are 0.6 mile southeast of South Hemlock (Charlestown township) and at Beryl Mtn. (Acworth township).

Graphite. Nice specimens of graphite may be found among the abandoned mine workings on the hill ¾ mile northeast of school No. 5, which lies 2 miles south-southeast of Bellows Falls.

Trap rock and crushed stone. The camptonite on Prospect Hill, Charlestown township, is a potential source of trap rock. The body does not extend downward indefinitely, but is a dike or sheet-like mass that dips gently to the south. Although other trap dikes occur in the quadrangle, they are too small to be of value. The Bethlehem gneiss has been used for road ballast; one quarry is one mile west of Drewsville, a second is two miles north of North Walpole.

Sand and gravel. The sand and gravel deposits left along the main valleys by the melting Ice Sheet are potential sources of road material. They have been mapped by the geologists of the New Hampshire State Highway Department.

HOW TO READ THE MAP

The map folded in the pocket in the back of the pamphlet is a topographic map, made by the U. S. Geological Survey in cooperation with the State of New Hampshire, with an overprint of geological information, plus cross sections at the bottom and a legend at the side. The map area is one-quarter of a degree or fifteen minutes of latitude and longitude on a side, so it is called a quadrangle. The exact latitude and longitude are shown by the numbers just off the margin at the corners. The approximate scale is one mile on the ground to one inch on the map, so the quadrangle is about twelve miles by eighteen miles.

The topography or configuration of the land surface is shown by brown contour lines or lines of equal elevation. Every fifth line is somewhat thicker and bears a figure giving the elevation above sea level. The culture or works of man are shown in black. Roads are parallel lines, buildings are black squares, railroads and transmission lines are shown by appropriate symbols. Political boundaries and names are shown prominently in black. All water is shown in blue. Smaller streams appear as a single blue line, and larger bodies of water such as Lake Warren are shown with a blue pattern and a figure giving the elevation of the water's surface.

For example, the area around Alstead village in the center of the map can well illustrate the foregoing. Several roads from the north, east, south, and two from the west meet in the village. The houses of the village, the schoolhouse with the flag, and the churches with the crosses atop are easily distinguishable. The Cold River runs through the settlement from east to west. If you should follow the road from Alstead to Drewsville you would find it fairly level, and on the map you may see that it scarely crosses any contour lines; therefore it does not change much in elevation. The BM or bench mark (a brass surveying plug in concrete) at Alstead is 478 feet above sea level and that at Drewsville is 475. If, however, you should go north from Alstead the road would be very steep, and the map shows that the road crosses many contour lines. Each line crossed is a change in elevation of twenty feet, as indicated at the very bottom of the map. The more closely the contour lines are spaced the steeper the gradient; the fewer the contour lines the more nearly level the surface.

The various colors with the letter symbols shown in the boxes of the legend of the map represent different rocks whose description also appears in the legend. These colors have been overprinted on the topographic map to show the distribution of the rock formations. On the map Alstead may be seen to lie in the area of *bg,* colored orange, representing the Bethlehem gneiss. A short distance east of Alstead the contact between *bg* and *Dl,* the Littleton formation, is shown. Further east the road to South Acworth passes over a succession of different types of rocks, each indicated by a different color or pattern.

Several cross sections of this quadrangle appear at the bottom of the sheet. Section B-B′ depicts the geologist's interpretation of an idealized section of the earth from Bellows Falls to South Acworth. The short T-shaped symbols on top of Fall Mountain, near the line of section, are measurements by the geologist which show that the rock structure there was inclined to the east. This is also shown in the cross section B-B′ below. As the line of section crosses the purple area marking the *Sc* or Clough formation northeast of Alstead, the T-shaped symbol indicates that the beds of rock dip to the west. Near Beryl Mountain the formations dip eastward on the map and the section. This data on the map, plus much more in the geologist's notebook, aided in the construction of these cross sections.

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