THE GEOLOGY OF THE
OSSIPEE LAKE QUADRANGLE
New Hampshire

BULLETIN NO. 3

By James Robert Wilson

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DEPARTMENT OF RESOURCES AND ECONOMIC DEVELOPMENT

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ABSTRACT

The Ossipee Lake Area lies in east-central New Hampshire, including some of the southeast margin of the White Mountains. In general it is an area of wide valleys, 400 to 500 feet above sea level, and rolling hills that rise as much as 1000 feet above the lowlands. The northeastern part of the Ossipee Mountains, a classic example of cauldron subsidence, lies in the southwest corner of the area, here reaching a maximum altitude of 2005 feet. Green Mountain in the southeast corner reaches 1907 feet above sea level. The eastern end of the Sandwich Range, here reaching an altitude of 2330 feet, lies in the northwest corner of the quadrangle.

The bedrock belongs to three groups. The oldest rocks belong to the Early Devonian Littleton Formation, which here consists chiefly of mica schist, with lesser amounts of granofels ("feldspathic quartzite"), lime-silicate granofels, and migmatite gneiss. These rocks were originally shales and siltstones, with very minor amounts of dolomitic shale. A second group of rocks, assigned to the New Hampshire Plutonic Series and considered Middle Devonian, here consists of five mapped units: Winnipesaukee Quartz Diorite, trondhjemite, quartz monzonite at Chase Hill, Concord Granite, and pegmatite. The pegmatite generally forms small dikes and sills that are so abundant in places that they constitute most of the bedrock. The trondhjemite and Concord Granite occur in both large bodies and small dikes and sills. The third group of rocks belongs to the White Mountain Plutonic-Volcanic Series of Early Jurassic age. The extrusive phase of this series consists of the Moat Volcanics, chiefly rhyolite and basalt. The intrusive phases consist of the Albany Porphyritic Quartz Syenite, Mt. Osceola Granite, Conway Granite, and small dikes of felsite, spessartite, and camptonite.

The schistosity of the Littleton Formation is generally parallel to the bedding. In general this bedding and schistosity strikes northeast and dips steeply northwest. Minor folds, an inch to a foot across, and crinkles, less than an inch across, are ubiquitous. Lack of key beds makes it impossible to deduce larger folds hundreds of feet across. But most of the minor folds are left-handed in plan and plunge southwest. This suggests that the Littleton Formation in this area is on the southeast limb of a synclinorium. Slip cleavage evolved from crinkles. A north-trending fault is indicated by aligned silicified zones.

The structure of the Ossipee Mountains is a classic example of cauldron subsidence. In the Ossipee Lake Quadrangle the ring-dike, composed of Albany Porphyritic Quartz Syenite, is convex toward the northeast. It is seven miles long, 3/8 mile wide, and dips steeply outward. The subsided block inside the ring dike is composed of Winnipesaukee Quartz Diorite, Littleton Formation, and Moat Volcanics. A stock of Conway Granite occupies the center of the subsidence.

Regional metamorphism is considered in some detail. In the mica schists the plagioclase ranges from An_{15} to An_{35}, and averages An_{26}; in biotite the $\frac{\mathrm{Fe0}}{\mathrm{Fe0 + Mg0}}$ ratio equals 0.60; and garnet is largely almandine. Fibrolite formed from a reaction involving muscovite and garnet. The local presence of migmatite, in which granitic layers consist of K-feldspar, sodic plagioclase, and quartz, indicates that some of the rocks underwent partial melting. It is concluded that regional metamorphism took place under a load not less than 4 kb nor more than 7 kb, that is, at depths ranging from 9 to 16 miles, and temperatures ranging from 680° to 750°C. This great depth of burial probably resulted from thick sediments, recumbent folding, and igneous intrusion.

Experimental data has been especially useful in studying the petrology of the White Mountain Plutonic-Volcanic series. The Mt. Osceola and Conway Granites were emplaced under a superincumbent load of 1.5 to 2.0 kb., equivalent to 5.7 to 7.6 kilometers or 3.4 to 4.5 miles; the temperature of crystallization was 680° to 750°C.

Between Middle Devonian and Late Triassic time nine miles of rock were eroded from central New Hampshire, at a rate of 250 feet per million years. Between Jurassic time and the present, 4 miles of rock have been eroded, at a rate of 120 feet per million years.

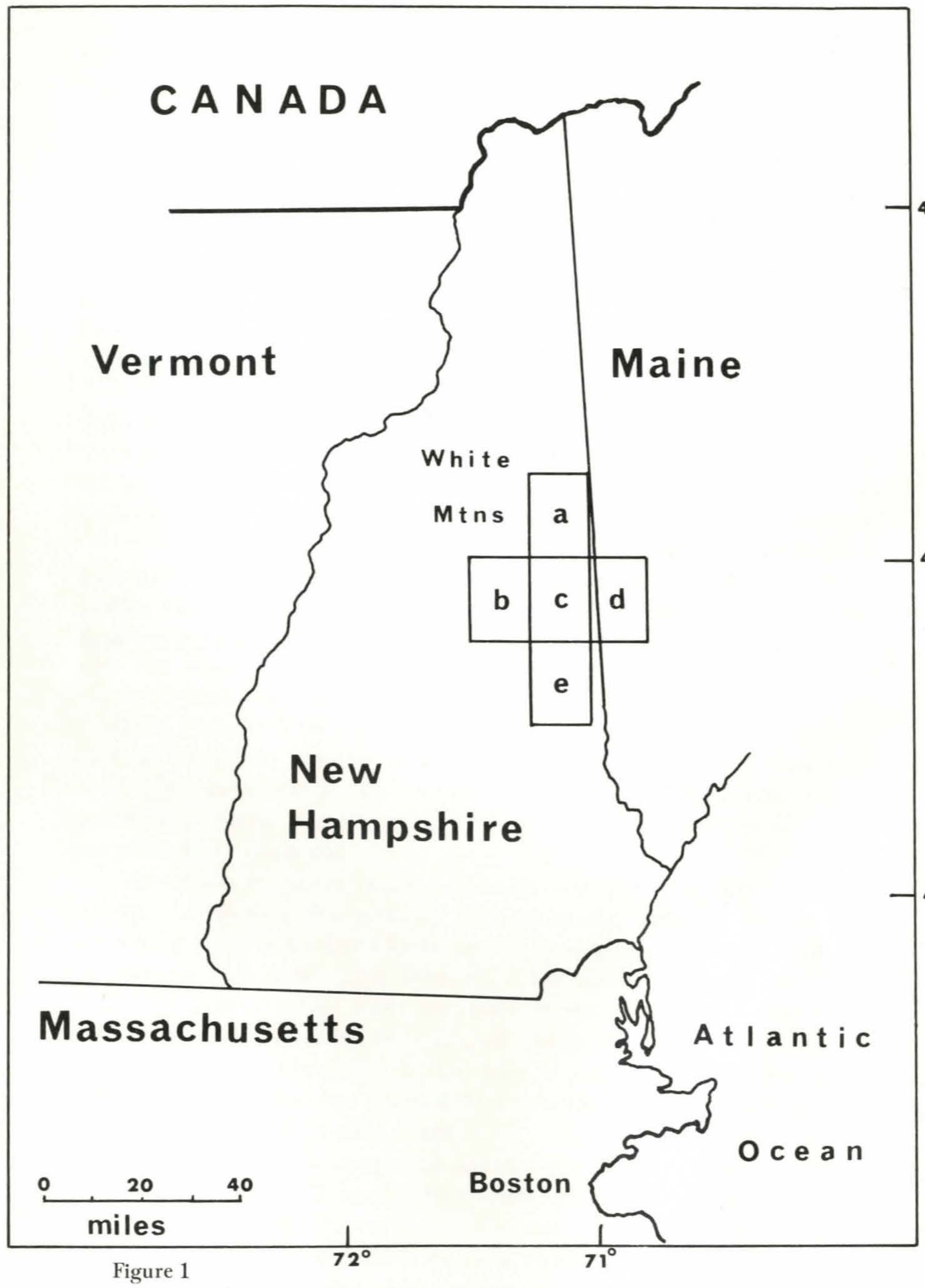


Figure 1
Index Map Showing Location of Ossipee Lake Quadrangle. Adjacent quadrangles are North Conway (a), Mt. Chocorua (b), Kezar Falls (d) and Wolfeboro (e).

CHAPTER 1
INTRODUCTION

LOCATION

The Ossipee Lake Area, New Hampshire, occupies 232 square miles, bordered by north latitudes 43°45' and 44°00', west longitude 71°15' and the Maine State Line a quarter of a mile to one mile east of longitude 71°00'. It lies within Carroll County, and includes all of the townships of Madison, Eaton and Freedom, as well as parts of the townships of Conway, Albany, Tamworth, Ossipee, Tuftonboro, Moultonboro and Effingham. The central part of the area is 108 miles north of Boston, Massachusetts.

The strip of land in New Hampshire lying between the State Line and the 71°longitude (Figure 1) has been mapped by the writer and is included in this report. It lies along the western edge of the Kezar Falls quadrangle.

TOPOGRAPHY

The area lies in the New England physiographic province of North America. It is hilly to mountainous and contains eight prominent topographic subdivisions (see Plate 1). These are: 1. The east end of the Sandwich Range, which forms the southeast edge of the White Mountains; 2. The northeast corner of the Ossipee Mountains (maximum elevation 2,005 feet in this area), 3. Green Mountain (maximum elevation 1,907 feet), 4. The Eaton Hills (maximum elevation 1,830 feet), 5. The Madison Hills (maximum elevation 1,505 feet), 6. The Chocorua Hills (maximum elevation 1,250 feet), 7. The Ossipee Sand Plain (average elevation 450 feet) and 8. The Saco Valley in the northeast (average elevation 450 feet). The highest point, elevation 2,330 feet, is 1.5 miles west northwest of White Ledge. The lowest point, elevation 400 feet, is at the east end of the Ossipee Sand Plain.

DRAINAGE

The network of streams in the area forms a complicated pattern that is typical of many areas of moderate relief in New Hampshire and Maine. The north portion of the area is drained by the Saco River. It meanders south and turns east at the village of Conway. Its major tributary, the Swift River, drains the northwest corner of the quadrangle.

The Saco and Swift Rivers make an interesting contrast. The Saco River channel is about 300 feet wide and carries sand and gravel with some cobbles. It flows through a broad valley before entering the area.

The Swift River, of steeper gradient, rarely reaches a channel width of more than 150 feet. Its bed load consists of coarse sand, gravel, cobbles and boulders. It flows through a canyon before joining the Saco River at Conway.

The south portion of the area is drained by small valleys containing lakes, ponds and bogs; the brooks empty into Ossipee Lake or the bays area east of Ossipee Lake. The Ossipee River flows east, drains these lakes and joins the Saco River near Cornish, Maine. The Bearcamp River, emptying into Ossipee Lake from the west, has a classical meander pattern and has left two small oxbow lakes adjacent to the channel near White Lake State Park.

The larger lakes, in order of decreasing size, are Ossipee Lake, Conway Lake and Silver Lake. The Pequawket and Purity Valleys are narrow, linear and extend N.10°E. for ten miles through the center of the area.

CULTURE

There is an extensive network of blacktop and dirt roads in the area. The most remote point is 2.3 miles from the nearest road. State Routes 16 and 25 and U. S. Route 302 are two-lane paved highways. State Routes 113 and 153, Bald Hill Road, East Madison Road, Freedom Village Road, Potter Road, Stark Road and Bramplains Field Road are all secondary asphalt-covered roads.

The residents number about 7,000. Conway is the only large settlement. Other villages, in approximate order of decreasing size, are Center Ossipee, West Ossipee, Center Conway, Silver Lake, Chocorua, Freedom, Eaton Center, Effingham Falls, Madison and East Madison.

The local industries include lumber mills, construction firms, asphalt producers, real estate, restaurants, motels and hotels, skiing, summer camps and farming.

GLACIAL GEOLOGY

The glacial history of the surficial deposits in the Ossipee Lake quadrangle has not been investigated systematically. In the early 1930's some of the most accessible and most significant glacial deposits were mapped by the late James Walter Goldthwait for the New Hampshire Department of Public Works. These maps are on open file in Concord, Durham and Hanover.

In 1968, "The Surficial Geology of the Wolfeboro-Winnipesaukee Area" by Richard P. Goldthwait was published by the New Hampshire Department of Resources and Economic Development. Colored geological maps that accompany the report show the distribution and types of glacial deposits; the text discusses their origin.

In pre-glacial time the gross features of the topography were similar to the present topography. On the average between 40 and 50 feet of rock has probably been eroded from the higher hills by glaciation, whereas a similar amount has been deposited in the valleys. Evidence elsewhere in North America indicates the continental ice sheets may have invaded New Hampshire more than once in the last million years, melting away completely during the interglacial stages. The glacial deposits in the Ossipee Lake quadrangle represent only the last (Wisconsin) glaciation.

During the maximum glaciation in the Wisconsin stage the ice sheet buried even the highest hills, both here and elsewhere in New Hampshire. In many places in the Ossipee Lake quadrangle the rocks have been smoothed, polished, and striated (scratched) by sand and gravel embedded in the moving ice. The trend of the striae show that the ice moved southeasterly. Lunoid furrows, another type of glacial marking, are present on White Ledge in Albany. Shaped like a new moon, these lunoid furrows are 6 to 12 inches from tip to tip and are convex toward the southeast. The southeast slope is steep, the northwest slope is gentle. The rock was chipped out by the pressure exerted by a pebble or boulder embedded in the ice.

Some of the bedrock hills are elongated in a southeasterly direction due to the flow of the ice. White Ledge has a steep slope that faces southeasterly and a gentle slope facing northwesterly. The smooth gentle slope was produced as the ice rode up over the northwest slope, whereas the steep slope is due to plucking of fractured blocks as it moved across the southeastern slope.

Blocks so plucked out of the bedrock may be carried many thousands of feet or miles by the ice. When dropped from the melting ice they form "erratics." (Figure 2) The Madison boulder is an exceptionally large erratic. The entrance to this geologic site is on Route 113 approximately 2 miles north of the village of Madison. This boulder is one of the largest glacial erratics in the world and is believed to have come from Whitton Ledge 1 1/2 miles to the northwest. Composed of Conway Granite, the boulder measures 83 by 37 by 23 feet and weighs about 4662 tons.

The glacial deposits are generally classified into unstratified (unsorted) material known as till and stratified (sorted) material known as outwash. Till consists of angular to subangular boulders, a few inches to many feet in diameter, set in a matrix. In this area the matrix is rather sandy, but contains some clay and silt. It is generally yellow due to near-surface weathering. Till is deposited beneath the ice as it is advancing, but may also be deposited directly from the melting ice. Till is present throughout the quadrangle. It is thickest on the valley slope, but is thin and discontinuous on the upper parts of hills and mountains. It is seldom observed in the valleys because of the veneer of younger outwash.

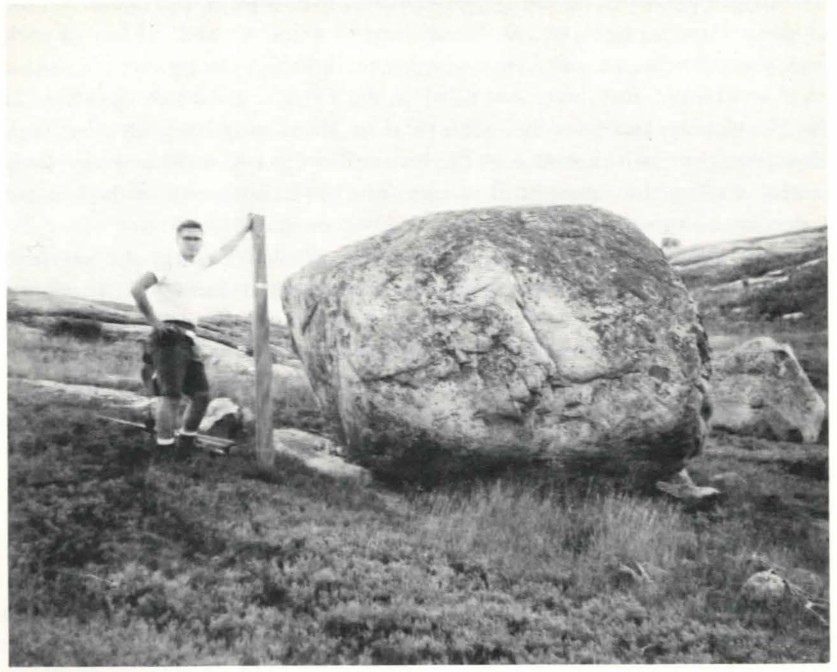


Figure 2

Boulder Transported by Glacial Ice. Foss Mountain. Boulder is composed of granite of the White Mountain batholith, 10 miles to the northwest; view toward the northwest.

As the ice was melting, large amounts of glacial outwash — gravel, sand, silt and clay — were deposited in temporary streams and lakes. Eskers (long gravel ridges) were deposited by streams, either in open fractures in the ice or in subglacial tunnels. Examples may be seen in the Pequawket Pond area in Conway and along Pequawket Brook and the Boston and Maine Railroad in the northern part of Madison. Kame terraces (hummocky masses of sand and gravel) were deposited in temporary lakes between the hillsides and ice in the valleys. These features may also be seen along Pequawket Brook. Small kame terraces and eskers are abundant in the valley extending from Crystal Lake in Eaton to Danforth Ponds in Freedom. Some of the small ponds and depressions, particularly north of Silver Lake, are "kettle holes" that formed by the melting of blocks of ice that were buried in outwash. "Kettles" that extend below the water table contain "kettle ponds".

Today the northern one-third of the quadrangle drains into the Saco River and the southern two-thirds into the Ossipee River. However, the conspicuous and discontinuous series of gravel ridges suggest that during

the wastage of the ice that occupied the Saco and Bearcamp-Ossipee River Valleys, the drainage was southward through a series of tunnels or open fractures. The drainage was along (1) the Pequawket Brook — Silver Lake — Ossipee Lake system and (2) the Conway Lake — Crystal Lake — Danforth Ponds — Broad Bay system. These drainage systems were part of the major system that produced the famous gravel ridges of the Pine River esker complex in the Wolfeboro quadrangle to the south.

Goldthwait (1968) adds two more drainage systems that contributed to the Pine River complex: one from the Tamworth region and the other from Dorrs Corner west of Center Ossipee. He believes that the sand and gravel were derived from the lower dirty 20 to 120 feet of the melting ice that covered the Ossipee, Freedom, Madison and Conway lowlands.

When the ice had completely melted from the southern part of the Ossipee Lake quadrangle, the streams draining southeasterly were overloaded, and gradually began to fill the valleys with sand. The widespread sand deposits below Silver Lake and Ossipee Lake are part of a large valley train. Valley trains are deposits, largely sand, that accumulate in a valley. On the sand plains in the village of West Ossipee a gravel-packed well was drilled recently to a depth of 195 feet. The upper 18 feet of the hole is in an old abandoned well. Of the 177 feet that was drilled, 122 feet is sand, 37 feet is clay, and 18 feet is gravel. Thirteen of the 18 feet of gravel are found in the lower 40 feet of the hole. The clay implies that a temporary glacial lake occupied the Ossipee River Valley.

Another valley train was deposited in the Saco River Valley, but only a small part of these deposits are in the Ossipee Lake quadrangle. The surface of the valley train slopes downstream, standing at 470 feet one mile north of Conway and 450 feet two miles east of Center Conway. More recent erosion by the meandering Saco River has cut some striking terraces in this valley train in the North Conway region.

Borings made to investigate the subsurface conditions for an addition to the Kennett High School in Conway indicate that more than 95 feet of fine-to medium-grained sands are present. In the upper 25 feet of one boring traces of gravel were present and in the lower 50 feet some thin clay layers were noted. Small amounts of clay were found in other nearby borings. The clays suggests the former presence of a lake.

The ice sheet melted off the Ossipee Lake quadrangle about 12,500 years ago.

The origin of the depressions occupied by the lakes and ponds has not been specifically studied. The level of some ponds and lakes has been controlled by dams. Some ponds are clearly kettle ponds — such as those north of Silver Lake — occupying depressions left by the melting of a block of ice that was trapped in the sand and gravel. Other ponds occupying depressions formed by the irregular deposition of glacial till.

Some basins may have been overdeepened by glacial erosion of the bedrock, but evidence for this erosion has not been observed.

PURPOSE OF THIS STUDY

This investigation had several objectives: 1. To study the bedrock geology, construct a geologic map and deduce the geologic history of the area, 2. To study the structure and metamorphism of the metasedimentary rocks, 3. To study the petrology of some rocks in the White Mountain Plutonic-Volcanic series and in the New Hampshire Plutonic Series, 4. To study the lithology and structure of the Ossipee Mountains.

METHOD OF STUDY

Field work was carried out for 45 weeks during the summers of 1962, 1963 and 1964. Traverses were made chiefly up streams and along ridge tops, as exposures in road cuts and outcrops on low slopes were few. Some extensive exposures of bedrock were studied in detail by plane table or by pace and compass. Field data were plotted either on U. S. Geol. Survey fifteen minute topographic sheets (scale 1:62,500) and their enlargements (scale 1:18,300), or on U. S. Dept. of Agriculture aerial photos (scale about 1:22,000). The air photos were useful in locating outcrops. A hand altimeter was useful for plotting outcrops in dense brush.

More than 400 hand specimens and about 200 thin sections were studied. A macro-point counting device was constructed for use on coarse-grained rocks (Fitch, 1959). It consisted of 420 holes 1/32 inch in diameter and 1/4 inch apart drilled as a grating in a thin plastic sheet. Rock slices less than an inch thick were sawed and the surfaces ground smooth. Some of these were treated with the HF acid-cobaltinitrite technique to aid in distinguishing K-feldspar from Na-feldspar.

Mineral separations were carried out with tetrabromoethane, methylene iodide, acetone and a Franz magnetic separator. Optical properties were determined by immersion methods and in thin section. X-ray powder patterns were made of many garnets to determine the size of the unit cell.

ACKNOWLEDGEMENTS

The funds necessary to cover the expenses of field work were derived from my employment with the New Hampshire Division of Economic Development. I am grateful for the help and cooperation rendered by Miss Mary Louise Hancock and Mr. Jonathan B. Pollard, Jr. of that office.

Special thanks go to Richard Gilman and to Arthur M. Hussey II for making available their unpublished maps of parts of Maine. William W. Vernon kindly permitted me to quote two Pb-alpha ages on the Concord granite from his unpublished work. Special thanks are also due to Mr. Paul Hess for his nine weeks of assistance in the field during the summer of 1964.

The thin sections, the aerial photos, most of the field instruments and computer time were kindly supplied by the Department of Geological Sciences, Harvard University, to whom I am greatly indebted.

Sincere thanks go to the many residents of the area who permitted me access to their property. Particular thanks are due to Mr. and Mrs. Everett Grames and family of Silver Lake, who provided me with a residence during the summers of 1962 and 1963. Sincere thanks also go to the late Mrs. Ingersoll Bowditch of Chocorua and Jamaica Plain, who graciously provided my wife and me with a residence during the summer of 1964.

Many helpful discussions were had with David Waldbaum, David Harwood, James Hayes, Takashi Fujii, Patrick Butler, Steven Norton and Douglas Rumble, now or formerly at the Department of Geological Sciences, Harvard University.

Great appreciation is expressed to Professor Marland P. Billings and to Professor James B. Thompson, Jr. Professor Billings mentioned the opportunity for employment with the State of New Hampshire, greatly helped me in the field in 1962 and 1964, and was a continual source of constructive criticism, guidance and inspiration regarding the various structural and stratigraphic problems that arose. Professor Thompson first mentioned the area as a possible thesis project and gave unhesitatingly of his time, and made many pertinent criticisms and useful suggestions for the improvement of this report.

My warmest gratitude is extended to my wife, Mrs. Nancy G. Wilson, whose encouragement and help made this study more rewarding than it otherwise would have been.

PREVIOUS WORK

The geology of the area was first mapped on a scale of 1:158,000 by C. H. Hitchcock, whose published results appeared in 1878 in his Atlas of the Geology of New Hampshire and in a three volume text. The geology of the state has been published on a scale of 1:250,000 (Billings, 1955) from many field studies made in the past 35 years on a scale of 1:62,500. Although several investigators worked in districts near here in the late 19th century, the first relatively modern work arose from Billings' study (1928) of the North Conway quadrangle to the north. A portion of the Ossipee Lake area was first mapped in detail by Louise Kingsley (1931) in her study of the Ossipee Mountains. Althea Page Smith (1940) has studied the petrogenesis of the Mt. Chocorua area to the west (see also Smith et al., 1939). Alonzo Quinn (1941, 1953) has published the geology of the Winnipesaukee and Wolfeboro areas to the south and Richard

Gilman has recently mapped the geology of the Kezar Falls area to the east.

GENERAL GEOLOGIC SETTING

The rocks here can be classed into three groups according to age (Plate 1). The oldest rocks are chiefly sillimanite-mica schists of the Littleton Formation, probably Early Devonian in age in this area. These rocks are everywhere intruded by gray, medium-grained, two-mica two-feldspar granitic rocks of the New Hampshire plutonic series, probably of Early or Middle Devonian age, and by pegmatite, which is the most common rock in the area. The pegmatite is somewhat younger than, but closely associated with, the granitic rocks of the New Hampshire series. Lastly, there are volcanic rocks and coarse-grained to porphyritic, pink and green granites and quartz syenite of the White Mountain Plutonic-Volcanic series, probably Early Jurassic in age. Quaternary glacial deposits, chiefly sands and alluvium, cover most low lying parts of the area.

With the exception of the northeast corner, the rocks of the White Mountain series occupy the corners and sides of the area, as a batholith to the northwest, a ring dike complex to the southwest and as stocks to the southeast and east. The other rocks occupy the central lowlands in the Chocorua Hills, Madison Hills and Eaton Hills.

CHAPTER 2
LITTLETON FORMATION

GENERAL STATEMENT

The Littleton Formation crops out in a broad belt across the center of the area.

The metamorphic rocks all belong to this formation and consist of three rock types, mica schist, granofels and migmatite gneiss. This is a textural classification based on the descriptions the rock names themselves imply: schistose, granoblastic and mixed rock (schist or other metamorphic rock with lenses of granitic rock), respectively. It happens that most mica schist in this area contains more than 40 percent mica, whereas most of the granofels contain more than 40 percent quartz + feldspar. Intermediate types of rock consisting of 50 percent mica and 50 percent quartz + feldspar (±5 percent) are less common. Such rocks, having a texture between schistose and granular, are named schist or granofels according to the dominant mineral group: mica or (quartz + feldspar). Some of the granofels have a foliation due to mica.

The granofels rocks are subdivided into two types. In this report, the word granofels will refer to quartz-feldspar-mica granofels and the word calc-silicate granofels will refer to the assemblage quartz-andesine-actinolite-biotite-sphene.

MICA SCHIST

Mica schist is most common in the Madison Hills and Eaton Hills. Extensive outcrops can be seen on Bald Ledge and on Foss Mountain. The rock is slightly pyritic and has weathered to dark rust-brown or maroon-red. Some mica schist is gray-weathering. Brown schist is most common in the Eaton Hills, whereas gray-weathering schist is most common in the Madison Hills.

The rock is strongly schistose and crenulations have imparted a local lineation at several locations. Tourmaline, however, is randomly oriented.

The average mica schist (Figure 3) consists of 33 percent quartz, 29 percent biotite, 26 percent muscovite, 9 percent oligoclase and one percent each of sillimanite, almandite and tourmaline. Modes of individual specimens are given in Table 1.

Quartz grains are 0.5 to 2.0 mm. in diameter. Some larger quartz grains are an interlocking network of smaller jagged grains. Biotite plates are 3.0 to 5.0 mm. in diameter and have locally altered to chlorite and magnetite around the edges. Pleochroic haloes are common and biotite is

Figure 3
Photomicrograph of Mica Schist from Littleton Formation. Altitude of 1030 feet on east side of hill 1.4 miles north-northwest of B. M. 448 at East Madison. Specimen 176, see table 1 for mode. Magnification x 10.

Table 1
Littleton Formation, modes of mica schist and granofels

	Mica schist						
	173	113	112	335	168	326	226b
Quartz	36	31	------	19	37	34	38
Muscovite	13	22	46	22	27	22	27
Biotite	33	29	41	32	25	31	25
Plagioclase	------	4	------	26	8	10	6
Almandite	9	5	------	tr	1	1	tr
Sillimanite	7	7	8	1	2	2	4
Tourmaline	------	------	5	------	------	------	------
An in plagioclase		20		32	30	15	22

	Mica schist		Granofels			
	235	176	166	285	92	89
Quartz	32	33	46	42	57	35
Muscovite	35	29	18	14	20	1
Biotite	29	22	19	27	23	20
Plagioclase	3	------	11	15	----	44
Almandite	tr	9	6	2	----	----
Sillimanite	1	tr	------	tr	----	----
Tourmaline	------	8	------	------	----	----
An in plagioclase	20	35	25	30		33

Locations and descriptions of specimens.

173 Sillimanite-mica schist, summit of Hill 790, 0.5 mile east northeast of Durgin Pond.
113 Sillimanite-mica schist, north summit of Jackman Ridge.
112 Sillimanite-mica schist, summit of Hill 650, 0.3 mile south of village of Madison.
335 Mica schist, summit of Knoll 1530 on Manson Hill, 2.4 miles southeast of Eaton Center.
168 Mica schist, summit of Blazo Mountain.
326 Mica schist, Knoll 1250 on Prospect Mountain, 2.4 miles east northeast of village of Freedom.
226b Mica schist, summit of western knoll on Crown Hill, 3.5 miles east northeast of Eaton Center.
235 Mica schist, central knoll (elevation 1110 feet) on the ridge southeast of Snowville.
176 Mica schist, east side of the Hill, 1.4 miles north northwest of BM 488 at East Madison at elevation 1030 feet.
166 Quartz granofels, elevation 950 feet, 0.4 mile west southwest of BM at East Madison.
285 Quartz granofels, summit of Hill 1210 on east side of Long Pond.
92 Quartz-mica granofels, summit of Hill 1270, 0.4 mile northwest of Loud Pond. Despite 43 percent mica the name granofels is retained because the thin section included a micaceous layer.
89 Oligoclase granofels, southwest side of the southern summit of Foss Mountain.

locally intergrown with muscovite. Muscovite is consistently coarser-grained than biotite. The diameter of the plates is commonly 4.0 to 7.0 mm. Some mica schist is spangled with large, elongate muscovite plates that are as long as 20 mm. Oligoclase is present as small equant grains generally 1.0 mm. in diameter. Twinning is common. The average composition is An_{25}.

Sillimanite occurs as fibrolite in thin, delicate needles that are commonly closely intergrown with biotite and muscovite. Much fibrolite occurs in only a biotite host. Sillimanite is locally so thoroughly mixed with mica that the minute prisms and hairs of the fibrolite give the mica an indistinct matted or felted appearance (Figure 5).

Almandite occurs as lavender-pink to violet-red euhedral, equant grains 0.5 to 1.0 mm. in diameter. The garnet commonly contains microscopic inclusions of what is presumably quartz and black specks of magnetite. The inclusions are invariably concentrated in the centers of the grains. The garnets are commonly thoroughly fractured and yellow-red iron oxides are present in the crevices.

Four samples of tourmaline from mica schist were studied. The mineral appears black in hand specimens but small chips viewed in sunlight are dark brown. The tourmaline is pleochroic in immersion: olive green (Ne) to brown (No). The indices are No=1.653-1.657 and Ne=1.632-1.635. It is likely a variety of schorl or dravite.

Apatite occurs in small grains but a few prisms are as long as 1.0 mm. Minute zircon crystals are also present.

GRANOFELS

Granofels occurs in beds an inch to a few inches thick interbedded throughout the area with mica schist. Locally, as on Hill 1270 southeast of Mason School and on Blazo Mountain, granofels beds reach 10 to 20 feet in thickness. A granofels is generally gray where fresh, but weathers to a brownish-gray where it is interbedded with brown schist. Granofels is equigranular but locally may have a weak foliation due to the planar alignment of biotite and muscovite. The diameter of these mica plates is 2.0 to 4.0 mm. The quartz and oligoclase grains are 1.0 to 3.0 mm. in diameter.

Modes of some typical granofels are given in table 1. The rock commonly consists of 50 percent quartz, 15 percent muscovite, 20 percent biotite and 15 percent oligoclase with traces of almandite, apatite and zircon. These percentages are not averages of the specimens in Table 1, but are estimates of the most common composition of outcrops. Specimen 166 is typical.

Except for sillimanite, the same minerals occur in granofels as in mica schist. Biotite and oligoclase appear fresher in granofels than in mica schist. The oligoclase in granofels is slightly more calcic than that in mica schist.

CALC-SILICATE GRANOFELS

Calc-silicate granofels occur in many scattered places throughout the area (Plate I). These rocks weather to a light gray, almost white color. Fresh rock is gray, darker in proportion to the content of biotite and actinolite.

The calc-silicate granofels have a fine-grained equigranular texture but locally these rocks have a foliation imparted by the preferred orientation of biotite. Specimen 31 (Figure 4) has an especially high content of biotite (39.5 percent) and could be as well called a calc-silicate biotite schist. The long axes of actinolite are roughly parallel to the biotite plates but are randomly oriented within the plane of foliation.

Modes of nine typical calc-silicate granofels are given in Table 2. The average mode is andesine-labradorite 31 percent, biotite 26 percent, actinolite 21 percent, quartz 20 percent, sphene 2 percent plus traces of apatite, zircon, clinozoisite and monazite.

Quartz occurs as equant grains 0.3 to 0.7 mm. in diameter. Biotite plates are 0.5 to 2.5 mm. in diameter. Actinolite (locally tremolite, see chapter 5) is pale green to colorless in thin section, but in hand specimens the prisms, 0.3 to 1.5 mm. in length, are dark green. Twinned plagioclase, andesine or labradorite, is more calcic than the oligoclase in mica schist and granofels. Sphene is very common in calc-silicate granofels and locally causes radiation damage in adjacent biotite plates. Clinozoisite is rare, but occurs as tiny grains of high relief and moderately low birefringence. Zircon and apatite are also rare and occur as minute scattered grains and as the usual stubby prisms. Monazite is present as small dark yellow grains of high relief that also cause radiation damage in adjacent biotite plates.

CALC-SILICATE CONCRETION

At an elevation of 720 feet, 0.2 mile west of East Madison, a calc-silicate concretion six inches in diameter was found in a bed of granofels one foot thick. This concretion has a granular texture and a fresh surface is glassy in appearance. It is specimen 88 and contains 54 percent quartz, 29 percent calcic labradorite (An_{65}), 8 percent actinolite, 2 percent diopside, 8 percent grossularite (N=1.769), 1 percent sphene and a trace of apatite.

MIGMATITE GNEISS

Migmatite gneiss occurs in many places, but it is especially common on the north slope of Page Hill, an easily accessible locality. The descriptions below pertain to the migmatite gneisses on Page Hill, but are generally applicable to small outcrops elsewhere in the area.

Figure 4

Photomicrograph of Lime-Silicate Granofels from Littleton Formation. Deer Hill, specimen 31. White grains are quartz and andesine. Gray elongate flakes of biotite reveal a pronounced foliation. Dark grains of actinolite occur in the lower center and on left margin. Magnification x 15.

Table 2

Littleton Formation, modes of calc-silicate granofels

	22	29	31	110	114
Plagioclase	29.1	39.6	22.9	38.7	22.6
Biotite	27.3	14.9	39.5	14.0	34.7
Quartz	15.9	16.5	26.9	23.4	14.4
Actinolite	25.2	25.5	8.9	21.2	24.7
Sphene	2.5	2.4	1.1	2.7	3.0
Zircon	-------	0.3	-------	tr	0.2
Clinozoisite	tr	0.8	-------	tr	0.1
An in plagioclase	65	45	40	63	70

	215	238	239	301
Plagioclase	28.8	36.4	33.7	25.0
Biotite	17.2	22.4	20.6	42.9
Quartz	16.5	17.0	28.3	23.0
Actinolite	35.6	22.2	16.4	7.9
Sphene	1.7	1.6	0.8	1.2
Apatite	tr	0.1	tr	-------
Clinozoisite	0.2	tr	tr	-------
Monazite	-------	0.3	0.2	tr
An in plagioclase	60	45	40	60

** includes a trace of K-feldspar.

Locations of calc-silicate granofels in table 2.

22	Elevation 700 feet on east side of knoll 890, 2.0 miles north of Silver Lake village.
29	Summit of Deer Hill, one mile west of Silver Lake.
31	Summit of Deer Hill one mile west of Silver Lake.
110	Elevation 760 feet on the north side of Hedgehog Hill.
114	North summit of Jackman Ridge.
215	Elevation 600 feet on west side of Atkinson Mountain, 2.3 miles north of BM 529 in Eaton Center.
238	Elevation 580 feet on southeast side of the knoll, 1.1 miles north of BM 488 in East Madison. Specimen taken from exposures on King Pine ski lift line.
239	Elevation 700 feet on east side of Hill 770, 0.5 mile north of BM 488 in East Madison.
301	Elevation 770 feet, 0.9 mile west of Four Corners, south side of the dirt road, across from farmhouse.

The migmatite gneiss on Page Hill has weathered to a rusty red-brown. These rocks are pyritic, although the small grains of pyrite are rather rare and are generally seen only in reflected light in thin section. This rock is coarse-grained and layered in alternating thin bands of quartz-feldspar and biotite-muscovite-quartz. The rock locally lacks schistosity due to the abundant granitic rock present. The micas, instead of lying in layers of consistent attitude, occur in wispy stringers that are locally discontinuous.

The migmatite gneisses have essentially the same bulk mineralogy as the mica schists, with the important difference that K-feldspar occurs in the migmatite gneisses but is absent in the mica schists. This is true, however, only of rocks on Page Hill. A mode is given in Table 3 for typical migmatite gneiss on Page Hill. It is an average mode estimated from hand lens examination and thin section study of five typical specimens. This average mode is broken down into granular layers and schistose layers that account for about one-third and two-thirds of the rock respectively. The micaceous layers commonly contain one or two percent sillimanite.

Table 3
Average Mode of Migmatite Gneiss

	entire rock	granitic layers	micaceous layers
Muscovite	20	11	27
Biotite	25	8	31
Quartz	25	29	20
Oligoclase	20	27	16
K-feldspar	10	25	6
	100	100	100

Muscovite is present as small, uncrinkled laths that tend to develop a poikiolitic texture enclosing small quartz grains near small quartz-feldspar lenses. In some specimens muscovite plates are as long as 20 to 25 mm. and give the rock a spangled appearance. Biotite is commonly free of pleochroic haloes. Some plates appear ragged around the edges as though they had suffered a splitting parallel to the basal cleavage. On the margins and in the interior of such grains extremely fine, fibrous sillimanite needles and hairs give the mica a matted appearance (Figure 5). Orthoclase is locally perthitic. The oligoclase is twinned and partially altered.

Figure 5

Photomicrograph of Sillimanite Gneiss from Littleton Formation. Page Hill, specimen 52. White grains are mostly quartz, some are oligoclase and potassic feldspar. Biotite is matted with fibrolitic acicular sillimanite. Magnification x 15.

BEDDING IN THE LITTLETON FORMATION

The Littleton Formation here is commonly well-bedded. A typical outcrop consists of beds of mica schist several inches thick interbedded with layers of granofels an inch or more thick (Figure 6). Individual layers of granofels locally attain a thickness of a few tens of feet. The beds of calc-silicate granofels are consistently a few feet thick. In migmatite gneiss, as on Page Hill, bedding can be seen but it is generally obscured by the granitic rock present.

DIVISION OF THE LITTLETON FORMATION

It is possible to divide the Littleton Formation of this area into two sequences of mica schist, the Foss sequence and the Blazo sequence. These terms are intended to carry no stratigraphic implications. They are names of two sequences of mica schist that can be distinguished from each other by mineralogy and weathered color. Rocks typical of the Blazo sequence are non-pyritic.

The Blazo sequence crops out in the central portion of the Madison Hills. It weathers gray and contains a few layers of granofels 10 to 20 feet thick. The Foss sequence crops out in the eastern portion of the Chocorua Hills, the western and eastern borders of the Madison Hills and in the Eaton Hills. It weathers maroon brown and contains calc-silicate beds. The mica schist of the Foss sequence is more commonly spangled and contains more tourmaline than the mica schist in the Blazo sequence.

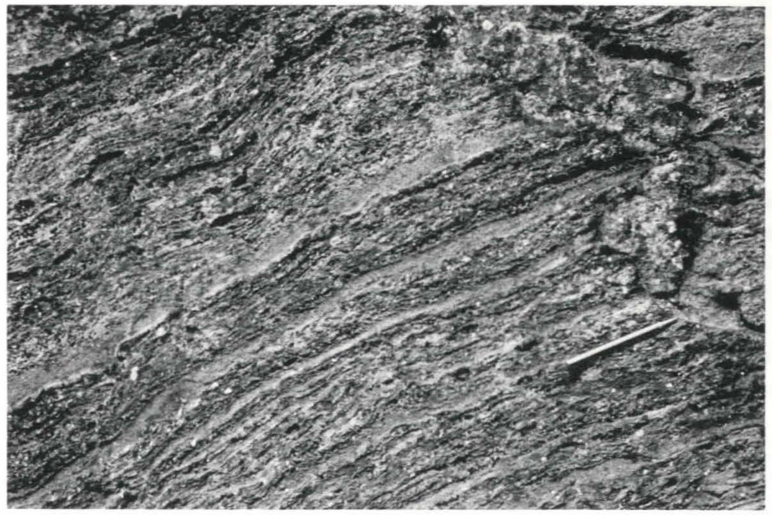
AGE OF THE LITTLETON FORMATION

The Littleton Formation can be continuously traced from the Littleton-Moosilauke district into this area (Billings, 1955, 1956). The fossil localities in that district, including Dalton Mountain in the nearby Whitefield area, have been recently redescribed by Boucot and Arndt (1960). The earlier work was done by Billings and Cleaves (1934). Both of these studies confirm the age of the Littleton Formation to be Lower Devonian in the type locality.

The earlier authors were careful to point out that the fossil horizons in the formation in the Littleton area lie 2,500 feet above the base of that formation. The base of the Littleton Formation in the type area, therefore, is older than Upper Lower Devonian (Schoharie) but how much older is not known. But until fossiliferous evidence is available, the entire Littleton Formation should be considered Lower Devonian in the type area.

The Silurian rocks in Southwestern Maine, the Eliot and Berwick Formations (Doyle et al., 1968), have been correlated with the fossil bearing slates of the Waterville, Maine district (Osberg, 1968) lying 90 miles

Figure 6



Littleton Formation. A. Northeast of Loud Pond. Typical thin-bedded mica schist and granofels. Discordant patch of pegmatite in upper right-hand corner. Pencil is six inches long.

B. Page Hill. Concordant irregular aplite in gneiss. Pencil is six inches long.

to the northeast (Billings, 1956). Hussey (written comm. 1965) has mapped the structure in these Silurian rocks and shows the stratigraphy to proceed up section to the northwest from a southerly plunging anticline at the south edge of the Sebago batholith. The Kezar Falls and Newfield areas form a link between the Silurian rocks to the southeast and this area.

The schist in the Kezar Falls and Newfield areas overlies the rocks of the Berwick Formation of Silurian age (Gilman, written comm. 1965). This schist is considered part of the Littleton Formation by New Hampshire geologists, although these rocks can also be referred to under the old name Rindgemere Formation, sometimes used by Maine geologists (Hussey, 1962). The rocks in this area are structurally continuous with those in the Kezar Falls area in the vicinity of Prospect and Cragged Mountains. Hussey (1962) regards the Rindgemere Formation as Lower Devonian.

In summary, the rocks assigned to the Littleton Formation in the Ossipee Lake Quadrangle can be traced both to the northwest and the east into strata that overlie Silurian formations and are considered to be Lower Devonian.

CHAPTER 3
IGNEOUS ROCKS

GENERAL STATEMENT

The igneous rocks in the area are chiefly granitic. Their classification here will be three-fold, listed below in order of the oldest rocks discussed first: A. Plutonic rocks of the New Hampshire series, B. Pegmatites associated with the New Hampshire series, C. Rocks of the White Mountain Plutonic-Volcanic series.

NEW HAMPSHIRE PLUTONIC SERIES

General statement

Four kinds of granitic rocks have been mapped as units of the New Hampshire series: 1) Winnipesaukee Quartz Diorite, 2) Trondhjemite, 3) Quartz monzonite at Chase Hill and 4) Concord Granite. The Winnipesaukee Quartz Diorite is restricted to three small areas within the Ossipee Mountains. The trondhjemite is most commonly found in the Eaton Hills. The quartz monzonite occurs only as a small body northwest of Pequawket Pond on Chase Hill. Concord Granite crops out around the Ossipee Mountains and Green Mountain, as well as in the western and central parts of the area.

Winnipesaukee Quartz Diorite

The Winnipesaukee Quartz Diorite (Quinn, 1944) crops out in the Ossipee Mountains on top of East Grant Peak, on Rattlesnake Mountain and on the northeast slope of Mt. Whittier. This rock is gray, medium-grained, equigranular and is composed of quartz, sodic andesine, orthoclase, biotite and muscovite. These mineral grains average 3.0 mm. in diameter. Modes of some typical specimens appear in Table 4. The rock is commonly a granodiorite, but the name quartz diorite will be retained here. This rock locally contains many small, thin, sub-parallel shear planes. Other hand specimens are mylonitic, suggestive of faulting and crushing of the rock. These features are especially clear on the summit of East Grant Peak.

Quartz has irregular extinctions due to strained grains and composite fragments consisting of smaller pieces of quartz closely interlocked. The plagioclase is sodic andesine and is twinned by the albite and Carlsbad laws. Weakly zoned crystals are present and some exhibit oscillatory zoning. Small fractures commonly offset the albite twin lamellae. There

Table 4
Modes of Winnipesaukee quartz diorite and trondhjemite

	Winnipesaukee quartz diorite			Trondhjemite			
	142	143	144	20	32	170	178
Quartz	35	43	32	29	31	42	34
Orthoclase	5	12	11	6	9	4	5
Plagioclase	40	31	40	53	46	40	48
Biotite	12	9	11	11	13	12	13
Muscovite	8	6	6	1	1	1	------
An content of plagioclase	35	34	40	23	26	32	31

	Trondhjemite							
	188	190	210	222	249	270	279	281
Quartz	36	29	24	35	27	29	32	32
Orthoclase	5	4	3	5	3	3	3	5
Plagioclase	38	48	53	47	46	47	44	47
Biotite	20	18	18	10	23	20	20	15
Muscovite	1	1	2	2	------	1	1	1
An content of plagioclase	27	28	30	26	32	30	35	27

Locations and names of specimens in table 4.

142 Winnipesaukee quartz diorite, elevation 1200 feet on north slope of Mt. Whittier, 1.7 miles west northwest of Grant Peak.
143 Winnipesaukee quartz diorite, elevation 1300 feet on north slope of Mt. Whittier, 1.8 miles west northwest of Grant Peak.
144 Winnipesaukee quartz diorite, elevation 1450 feet on north slope of Mt. Whittier, 1.8 miles west northwest of Grant Peak.
20 Trondhjemite, elevation 640 feet, 0.8 mile N.80°W. of the village of Madison.
32 Trondhjemite, elevation 750 feet, northeast slope of Deer Hill.
170 Trondhjemite, summit of Hill 930, 0.9 mile east of Durgin Pond.
178 Trondhjemite, elevation 1100 feet, 1.0 mile west southwest of Loud Pond.
188 Trondhjemite, summit of Hill 730, west side of the village of Freedom.
190 Trondhjemite, elevation 750 feet, south slope of Hill 790, 1.8 miles east southeast of the village of Freedom.
210 Trondhjemite, elevation 800 feet, south slope of Atkinson Mountain.
222 Trondhjemite, summit of Birch Hill.
249 Trondhjemite, elevation 1550 feet, west slope of Kent Hill, 3.0 miles southeast of Eaton Center.
270 Trondhjemite, summit of East Grant Peak.
279 Trondhjemite, elevation 970 feet, 1.3 miles east northeast of BM 488 at East Madison village.
281 Trondhjemite, summit of Hill 1190, 1.6 miles east northeast of BM 488 at East Madison village.

is locally a thin layer of much smaller biotite laths around the rims of larger biotite plates. The larger biotite plates are bent in some specimens. Orthoclase occurs as small non-perthitic grains.

Trondhjemite

The largest area of trondhjemite covers 14 square miles southeast of Conway Lake. A small area on Foss Mountain has also been separately mapped (Plates I, III, IV). But trondhjemite crops out in small bodies throughout the eastern and central portions of the area.

There is not complete agreement among petrographers as to what the name trondhjemite means. Tyrell (1926) considered it an oligoclase granite. Turner and Verhoogen (1958) considered trondhjemite a type of granodiorite especially rich in Na_20 and $Si0_2$. Williams, et al. (1958) considered it an oligoclase-biotite-quartz diorite. Johannsen (1932, II) is probably the most authoritative reference short of the original descriptions of the Norwegian trondhjemites by Goldschmidt: trondhjemite is a light-colored plutonic rock essentially composed of sodic plagioclase and quartz in which 1) biotite is the principal ferromagnesian mineral and 2) K-feldspar is rare.

The trondhjemite of this area is fine-grained, equigranular and is composed of quartz, oligoclase with an average composition of An_{29}, biotite, orthoclase, muscovite, apatite, monazite and sphene. The average grain is 1.0 to 2.0 mm. in diameter. The calcic oligoclase is commonly zoned. Myremekite is locally present. The small yellow grains of monazite in this rock are characteristic of many rocks in the New Hampshire plutonic series (Jaffe, Lyons, personal comm. 1965). Of the twelve modes given in Table 4, only one is from the large body southeast of Conway Lake (No. 222); all the rest are from small bodies within the Littleton Formation.

The average mode of the trondhjemite in this area is similar to the average mode of five Norwegian trondhjemites cited by Goldschmidt (Johannsen, II, 1932). These average modes are contained in Table 6.

Quartz Monzonite at Chase Hill

A small body of quartz monzonite is exposed on Chase Hill three miles west of the village of Conway. This rock is light-gray, medium-to coarse-grained and is typically subporphyritic with grains of quartz and feldspar 6.0 to 10.0 mm. in diameter (Figure 7). Fresh rock crops out on both sides of Bald Hill Road where it passes over a rise 0.7 mile west of the standpipe.

Rectangular crystals of microcline are commonly twinned by the Carlsbad law. In the grains of K-feldspar there are, locally, short thin stringers of albite. The plagioclase is about An_{23}, calcic oligoclase, and is slightly altered to a cloudy or speckled appearance. Some of the biotite is altered to chlorite. Pleochroic haloes are common in fresh biotite. Muscovite is in small plates and is associated with biotite and long, euhedral needles of sillimanite. Apatite is present. Modes of two specimens of the quartz monzonite are given in Table 5. An average mode is listed in Table 6 with a calculated chemical composition.

Table 5
Modes of quartz monzonite at Chase Hill and of Concord granite

	80	86	197	24	30	36	85
Quartz	34	27	35	35	40	42	32
Microcline	34	34	40	33	37	34	46
Plagioclase	25	32	15	25	17	15	12
Biotite	4	4	8	4	4	8	8
Muscovite	2	3	2	3	2	1	2
Sillimanite	1	----	------	----	----	----	tr
An content of plagioclase	24	21	27	17	21	22	23

Locations and names of specimens:

80 Quartz monzonite, elevation 780 feet on Bald Hill road, 0.5 mile west of the standpipe.
86 Quartz monzonite, elevation 900 feet on south slope of Chase Hill.
197 Concord granite, large roadcut on Route 25 in village of East Freedom.
24 Concord granite, elevation 680 feet, 0.5 mile east of Crothers Hill.
30 Concord granite, elevation 800 feet, south slope of Deer Hill.
36 Concord granite, elevation 700 feet, south slope of Hedgehog Hill.
85 Concord granite, elevation 640 feet, west slope of the hill 1.6 miles north northeast of the village of Conway.

Concord Granite

The Concord granite was first named by Hitchcock (1878, II). The rock discussed here is equivalent to binary granite and Bickford granite on the geologic map of New Hampshire (Billings, 1955). Concord granite is the preferred overall name (Billings, 1956), but, unlike the more general term binary granite, it implies the youngest granite of the New Hampshire plutonic series.

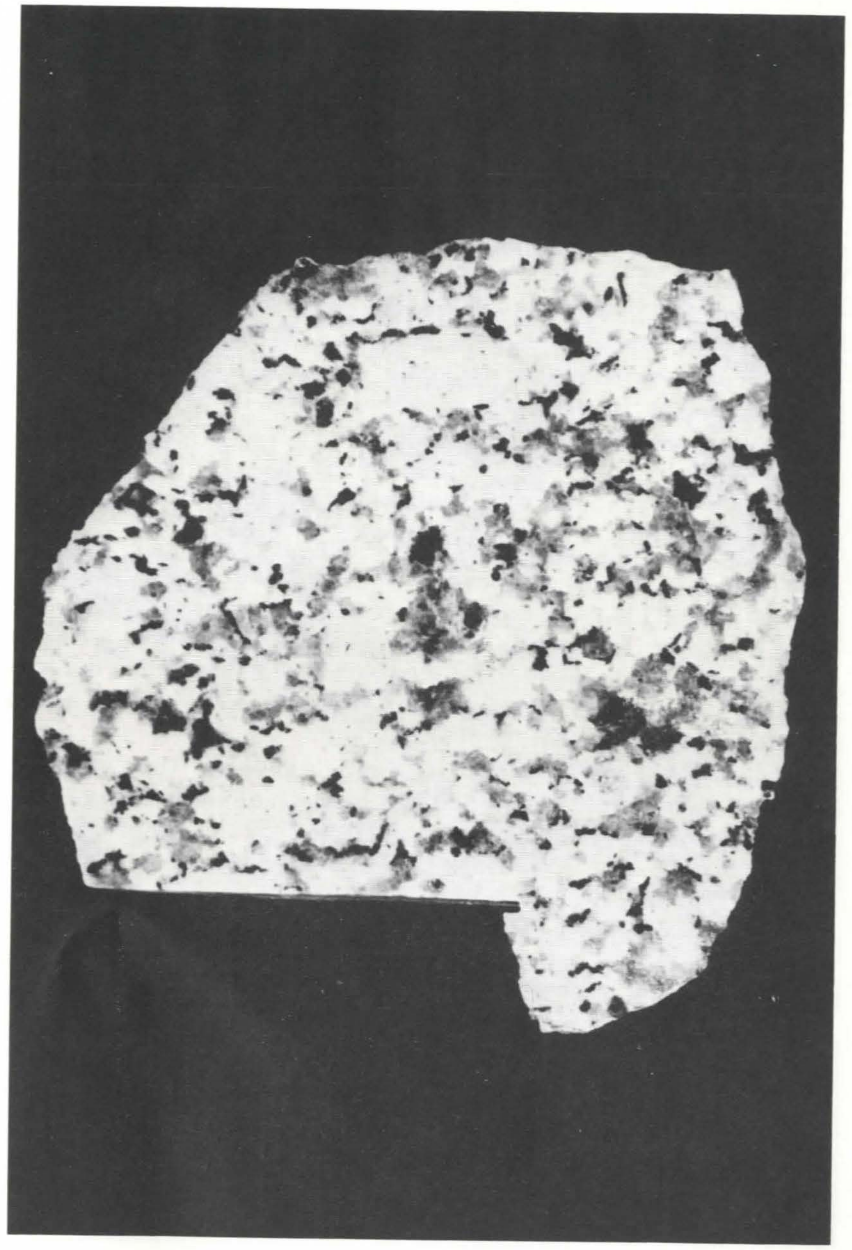


Figure 7
Quartz Monzonite of Chase Hill. Feldspars are white, quartz is gray, biotite is black. Muscovite is indistinguishable from feldspar. Large rectangular crystal in upper center is faintly zoned microperthite. Magnification x 1.1.

This rock (Figure 8) is light-colored, medium-grained, equigranular and contains plagioclase with a composition of about An_{20}, microcline, quartz, biotite and muscovite. The biotite is generally fresh. Sillimanite is present in this rock on the hill 1.6 miles north northeast of the village of Conway (specimen 85). Rarely the Concord granite in the Ossipee Lake area contains a few tiny, euhedral crystals of almandite 1.0 to 2.0 mm. in diameter. One such garnet in a small body of Concord granite on Dundee Hill was red, transparent with an index of 1.818 and a specific gravity of 4.16.

Modes of five typical specimens are given in Table 5, two of them from small bodies in the Littleton Formation. A chemical analysis of a specimen from western New Hampshire is given in Table 6. Locally the Concord granite is actually a quartz monzonite, but the name granite is traditional and generally appropriate.

PEGMATITE

Previous work

There is a voluminous literature on pegmatites in New Hampshire and the minerals in them. One of the most useful publications concerning New Hampshire pegmatites is Cameron, et al. (1954) with a lengthy bibliography. Bannerman (1943) did detailed structural studies of many pegmatites in New Hampshire, his techniques having served as a model for other geologists.

Nothing has been written on pegmatites in this area. There are probably two reasons for this. First, much of the literature concerns pegmatites of economic interest. None here have been mined, nor do any offer serious economic prospect now. Second, much of the literature concerns rare or gem quality minerals taken from pegmatites. The writer knows of no such minerals in pegmatites from this area.

Historically, the greatest interest in New Hampshire pegmatites centered around/the Keene and Grafton districts where pegmatites were mined in the early 19th century. There are only two that have been worked near this area. One is in Fryeburg township, Maine, two miles north of the northeast corner of this area. The other is in Wakefield township, N. H., about one mile south of Pleasant Lake in the Wolfeboro area to the south.

General Statement

The various kinds of pegmatite have not been separately distinguished on the geologic map because they commonly grade into one another over short distances. However, areas where the bedrock is at least 95 percent pegmatite and no more than 5 percent granite or trondhjemite are indicated on the map (Plate I). Sharp contacts between two kinds of

Figure 8

Photomicrograph of Concord Granite. Microcline shows typical grid-structure. Quartz is white to light gray. Other minerals are oligoclase, biotite and muscovite. Magnification x 15.

Table 6

Chemical analyses and modes of trondhjemite, quartz monzonite and Concord granite

	A.	B.	C.	D.
$Si0_2$	69.26	69.88	73.60	70.20
$Ti0_2$	0.20	0.22	tr	0.44
Al_20_3	15.23	15.92	14.47	16.00
Fe_20_3	0.10	0.89	tr	1.10
Fe0	3.51	1.34	1.13	1.00
Mn0	tr	0.02	tr	0.02
Mg0	2.40	1.38	0.41	0.66
Ca0	2.38	2.95	1.22	1.60
Na_20	4.03	5.21	3.74	4.00
K_20	2.02	1.53	5.03	4.60
H_20+	0.77	0.53	0.25	0.43
P_20_5	0.10	0.07	0.05	0.23
	100.00	100.00	100.00	100.28
quartz	32.0	28.7	30.5	30.2
oligoclase	46.5	59.8	28.5	31.8
K-feldspar	4.5	tr	34.0	26.7
biotite	16.0	7.4	4.0	6.7
muscovite	1.0	2.2	2.5*	3.3**

* includes 0.5 sillimanite

** includes 0.3 apatite, 0.2 magnetite and 0.1 ilmenite

A. Trondhjemite, average from Ossipee Lake area, calc.

B. Trondhjemite, average of 5 from Norway (given in Johanssen, II, 1932).

C. Quartz monzonite at Chase Hill, calc.

D. Concord granite, near Newfound Lake, 25 miles west of Ossipee Lake area (Lyons, 1964).

The writer knows of no reliable analysis of Winnipesaukee quartz diorite. Specimen cited by Pirsson and Washington (1907) is actually a dike cutting the Winnipesaukee. Modell's 1936 analysis lists 3.13 K_20 and is peraluminous, but his mode gives only 70 andesine, 15 quartz and 15 biotite.

pegmatite are common. Cross cutting relationships indicate there were several generations of pegmatite.

Localities

Well exposed outcrops of pegmatite occur at these places: Washington Hill, Oak Hill, Stewart Hill, Watson Hill, Dundee Hill, Chamberlain Ledge, Rockhouse Mountain, Knoll 1550 east of Foss Mountain (directly across the dirt road), Hill 910 lying 1.2 miles south of Blazo Mountain, Hill 1500 lying north northwest of Cragged Mountain and Hill 1350 lying south southeast of Cragged Mountain.

Texture and Mineralogy

Throughout the area the average outcrop in areas shown as pegmatite consists of about 70 percent pegmatite, 20 percent granitic rock and 10 percent migmatite gneiss or schist. The pegmatite is generally massive (non-zoned) and consists of perthitic orthoclase and albite 70 percent, quartz 25 percent, muscovite 5 percent and minor amounts of biotite, garnet and beryl. Tourmaline is extremely rare. The perthite is generally white, but is locally pink. In several places pink perthite and white albite occur together. In many places the feldspar is essentially all albite.

Three garnets from typical massive, coarse-grained pegmatite were studied. The localities below are followed by the index of refraction, unit cell edge in angstroms and the specific gravity of the garnet:

1) Dundee Hill	N_d=1.823	A_o=11.568	S.G.=4.07
2) Foss Mountain	N_d=1.818	A_o=11.575	S.G.=4.25
3) Hedgehog Hill	N_d=1.821	A_o=11.563	S.G.=4.23

Garnets 3) and 2) are about 50 percent $Fe_3Al_2(Si0_4)_3$ and 50 percent $Mn_3Al_2(Si0_4)_3$. Garnet 1) is about 40 percent $Fe_3Al_2(Si0_4)_3$, 50 percent $Mn_3Al_2(Si0_4)_3$ and 10 percent $Mg_3Al_2(Si0_4)_3$ (Winchell, 1958).

Several varities of pegmatite are present and are summarized below: **A**) *Granite type* – fine-grained microcline-perthite, albite and quartz, diameter of the grains is 1.0 to 3.0 mm., mica is absent. **B**) *Garnet type* – same as A, but with pyralspite garnets 5.0 to 10.0 mm. in diameter uniformly dispersed, common on Dundee Hill. **C**) *Coarse pegmatite* – most common type, large microcline-perthite crystals 3.0 to 5.0 inches long with albite, quartz, muscovite, minor garnet and biotite. **D**) *Medium-grained pegmatite* – feldspar, quartz, with or without muscovite, massive garnet-bearing kind locally, grains average 5.0 to 10.0 mm. in diameter. **E**) *Graphic granite* – patterned intergrowth of quartz in feldspar, common on south side of Watson Hill. **F**) *Porphyritic pegmatite* – crystals of K-feldspar 1.0 to 2.0 inches long set in a fine-grained groundmass of granite-type pegmatite A. **G**) *Banded pegmatite* – alternating bands of A, B and D, most commonly an inch or so thick, common on Cragged Mountain. **H**) *Quartz-muscovite rock* – a local intergrowth of quartz and randomly oriented muscovite plates, the mica plates are 5.0 to 20.0 mm. in diameter, sugar appearance prominent where proportions are 30 percent fine-grained quartz, 40 percent fine-grained feldspar and 30 percent medium-grained muscovite.

Some of these types of pegmatite are illustrated in Figures 9, 10 and 11.

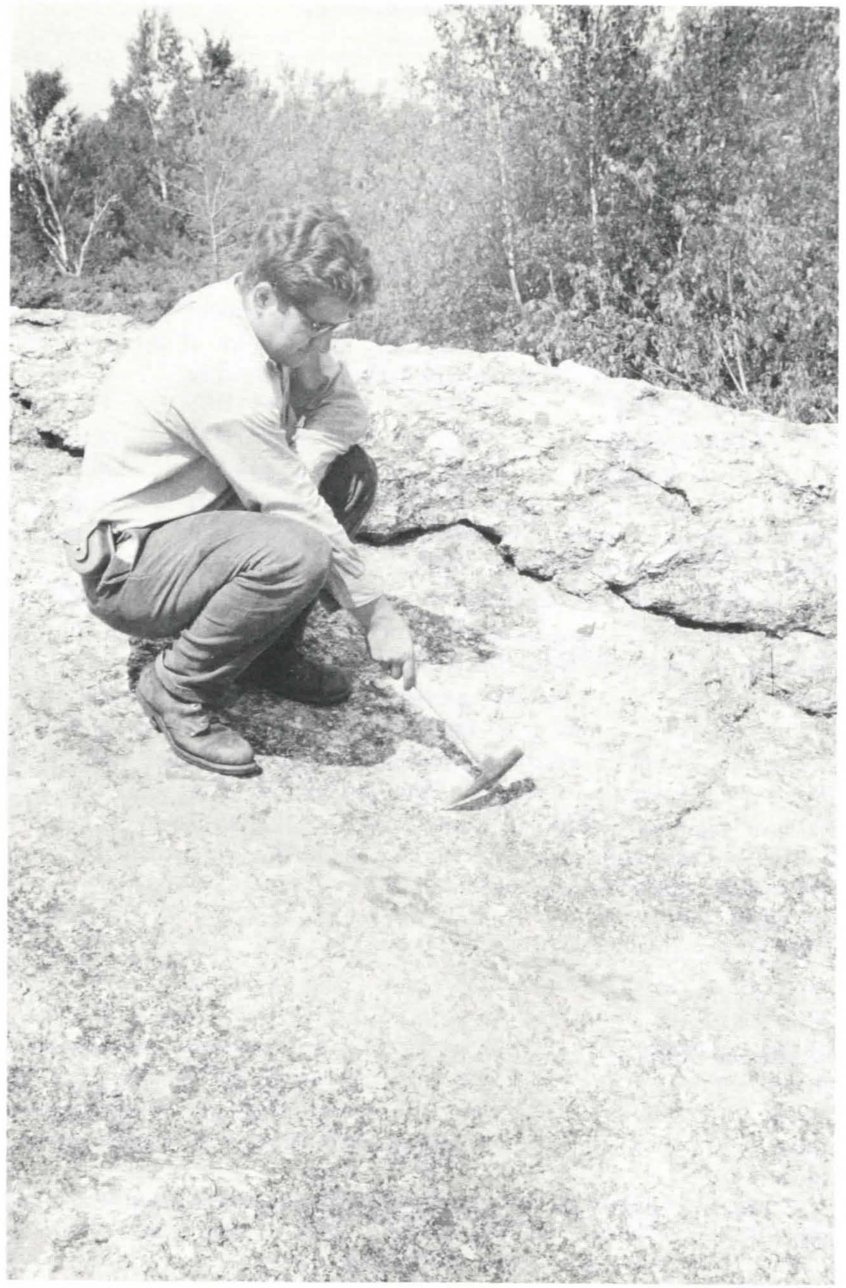


Figure 9

Pegmatite. Summit of hill 1350, north of Durgin Hill. Contact between typical coarse-grained pegmatite (background) and medium-grained subporphyritic pegmatite.

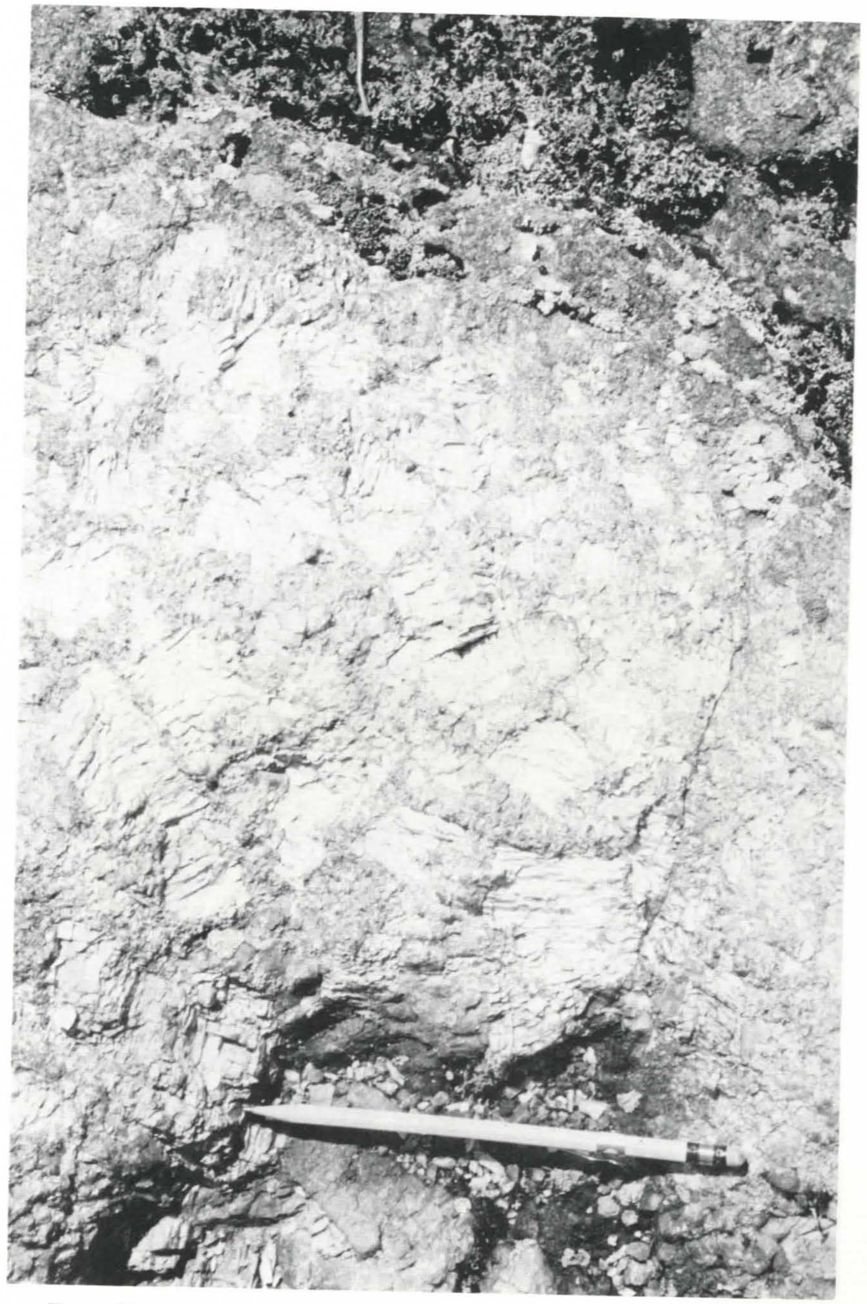


Figure 10

Porphyritic Pegmatite. Summit of hill 1320, 2.2 miles east-northeast of Freedom. White crystals of perthite are in a groundmass of granular pegmatite rich in muscovite. Pencil is six inches long.

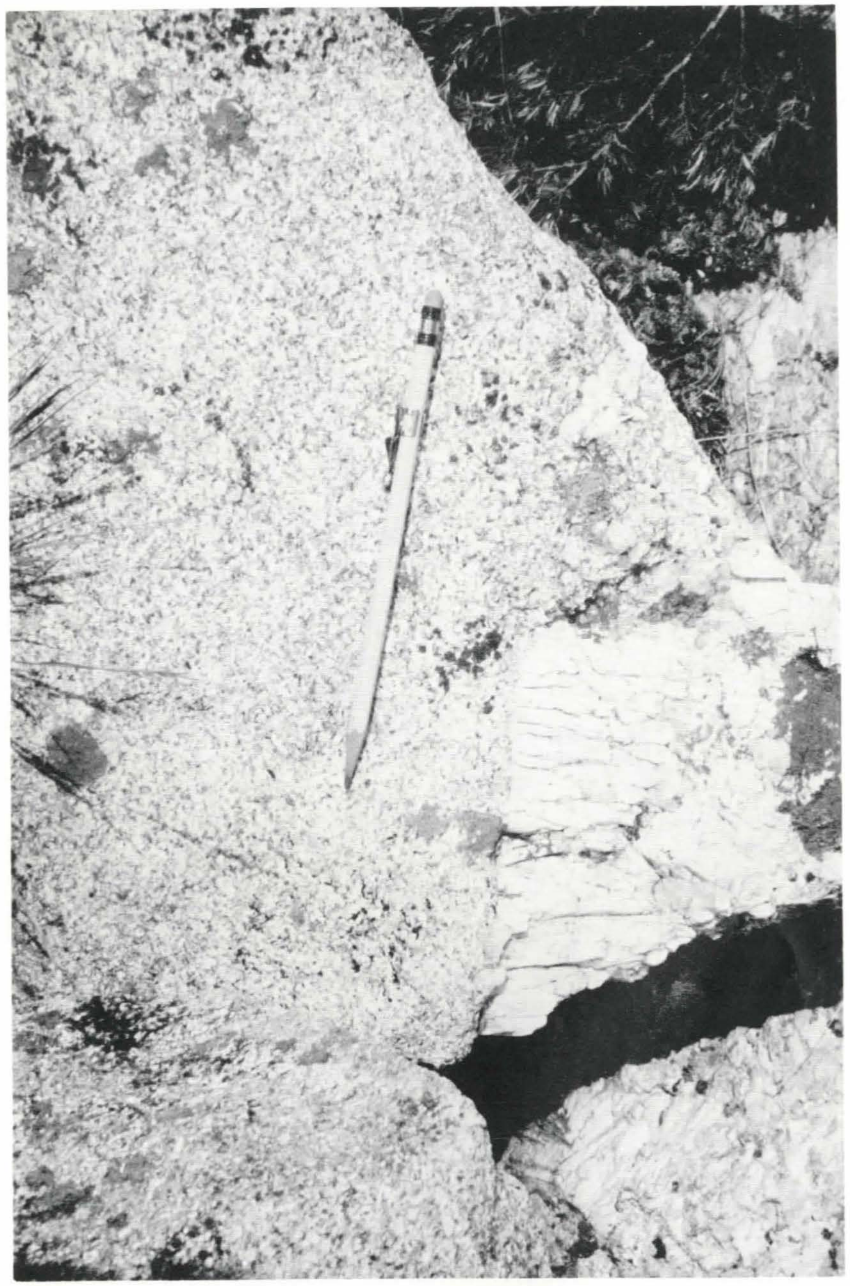


Figure 11

Pegmatite. Watson Hill. White crystals of perthite in medium-grained granite associated with pegmatite. Pencil is six inches long.

WHITE MOUNTAIN PLUTONIC-VOLCANIC SERIES

General statement

Four units of the White Mountain series have been mapped in this area. In order of probable decreasing age they are: Moat Volcanics, Albany Porphyritic Quartz Syenite, Mt. Osceola Granite and Conway Granite. These map-units crop out in the southeast portion of the White Mountains batholith exposed in the Sandwich Range, in the northeast portion of the Ossipee Mountains, in the Green Mountain stock in the southeast corner and in the Whalesback stock on the central-eastern edge of the area.

Moat Volcanics

The Moat volcanics were first named by Billings for the extensive exposures in the North Conway area (1928). They have been described by Billings (1928), Kingsley (1931) and by Williams and Billings (1938). These rocks crop out one mile east of Eagle Ledge and in the Ossipee Mountains.

These volcanics consist chiefly of porphyritic rhyolite, porphyritic basalt and basalt. There are several areas that contain basaltic breccia. Andesitic tuff is also present.

Porphyritic Rhyolite

This rock (Figure 12) is common in the Nickerson Mountains and is poorly exposed one mile east of Eagle Ledge. Porphyritic rhyolites are blue gray to light gray. The phenocrysts are 2.0 to 4.0 mm. long and consist of quartz and microperthite with a few albite laths. The microperthite is commonly a cream to pale copper-pink. The exsolved stringers of sodic plagioclase are relatively thick and comprise about one-third by volume of the microperthite. Quartz grains are free of strain shadows and have rounded as well as sharp, jagged edges. In the rhyolite around the Nickerson Mountains the quartz grains are highly rounded and embayed.

The groundmass of the rock is fine-grained to microgranular and rarely shows flow banding (Figure 13). The microgranular groundmass is chiefly feldspar and quartz. Accessory amounts of brown biotite, green-brown hastingsite, colorless augite, chlorite, opaques and fayalite are also present. The modes in Table 7 give separate volume percentages of the groundmass and of the phenocrysts.

Table 7
Moat Volcanics, modes of porphyritic rhyolites

	58	124	132	268	362	404
Quartz	12	13	10	16	10	9
Microperthite	27	24	29	24	27	24
Albite	2	tr	tr	tr	3	1
Quartz+feldspar in groundmass	59	63	61	60	60	66
Others present:						
biotite			tr			
augite						tr
hastingsite			tr			
fayalite	tr	tr				
opaques+chlorite	tr	tr	tr	tr	tr	tr

Locations of the specimens:

58 Elevation 1200 feet, 0.5 mile east of Eagle Ledge.

124 Elevation 1550 feet on north slope of Thurley Mountain.

132 Elevation 900 feet on east slope of middle knoll on Rattlesnake Mountain.

268 Elevation 880 feet on the northwest slope of Nickerson Mountains.

362 Elevation 1550 feet on the east slope of Grant Peak.

404 Elevation 1000 feet on the south slope of Little Mt. Whittier.

Table 8
Moat Volcanics, modes of porphyritic basalt and basalt

	123	136	274	270
Quartz	tr	tr	tr	------
Orthoclase	tr	tr	tr	------
Plagioclase	20	50	35	49
Titanaugite	------	------	------	20
Kaersutite	------	------	------	10
Opaques	tr	tr	tr	10
Chlorite and epidote	tr	tr	tr	10
Calcite	------	------	------	1
Groundmass	80	50	65	
An in plagioclase	55	63	58	67

Locations of the specimens:

123 Porphyritic basalt, elevation 1660 feet on the northwest slope of Thurley Mountain.

136 Porphyritic basalt, saddle between middle and south knoll on Rattlesnake Mountain.

274 Porphyritic basalt, saddle between Grant Peak and East Grant Peak.

270 Basalt, elevation 1100 feet on northwest slope of Nickerson Mountains.

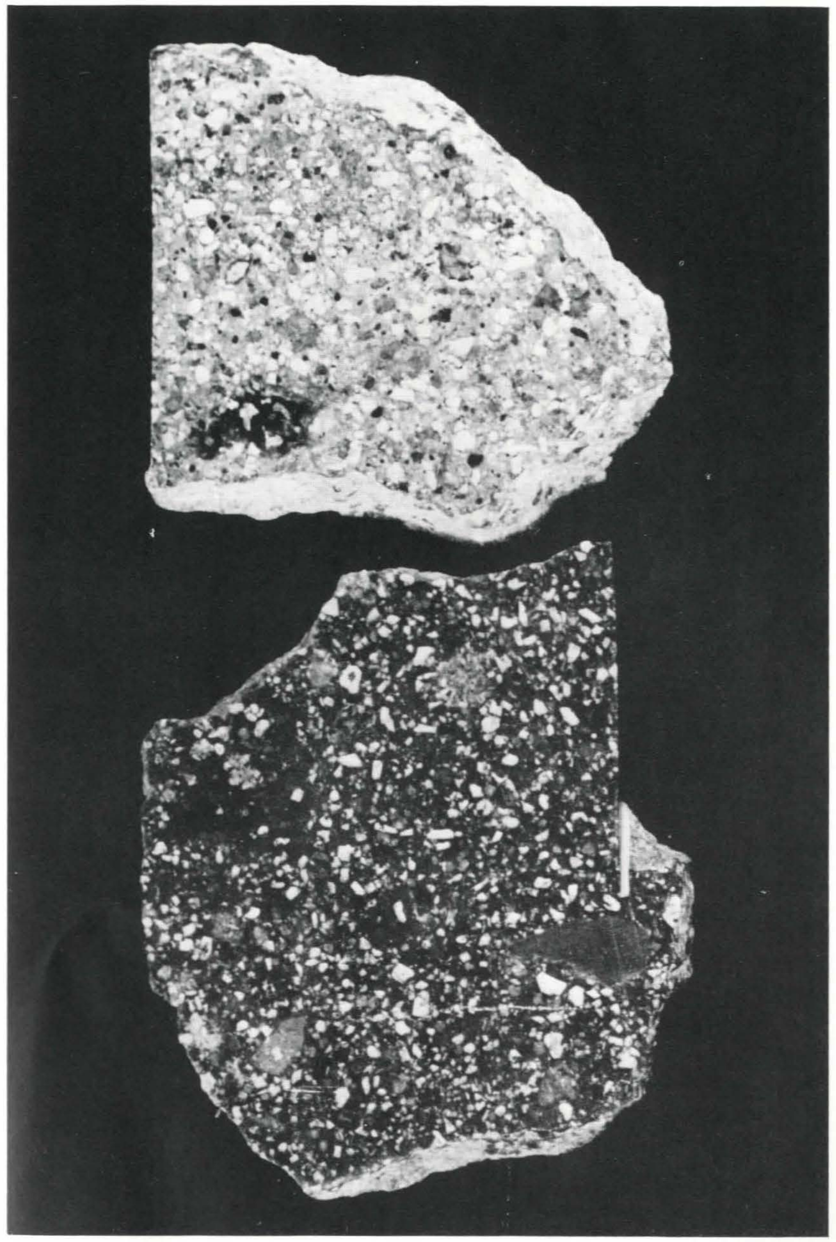


Figure 12

Porphyritic Rhyolites from Moat Volcanics. A. North summit of Nickerson Mountain, altitude of 1670 feet. Magnification x 1.1. B. Altitude of 1200 feet, one-half mile east of Eagle Ledge. Mode 58, Table 8, Magnification x 1.1.

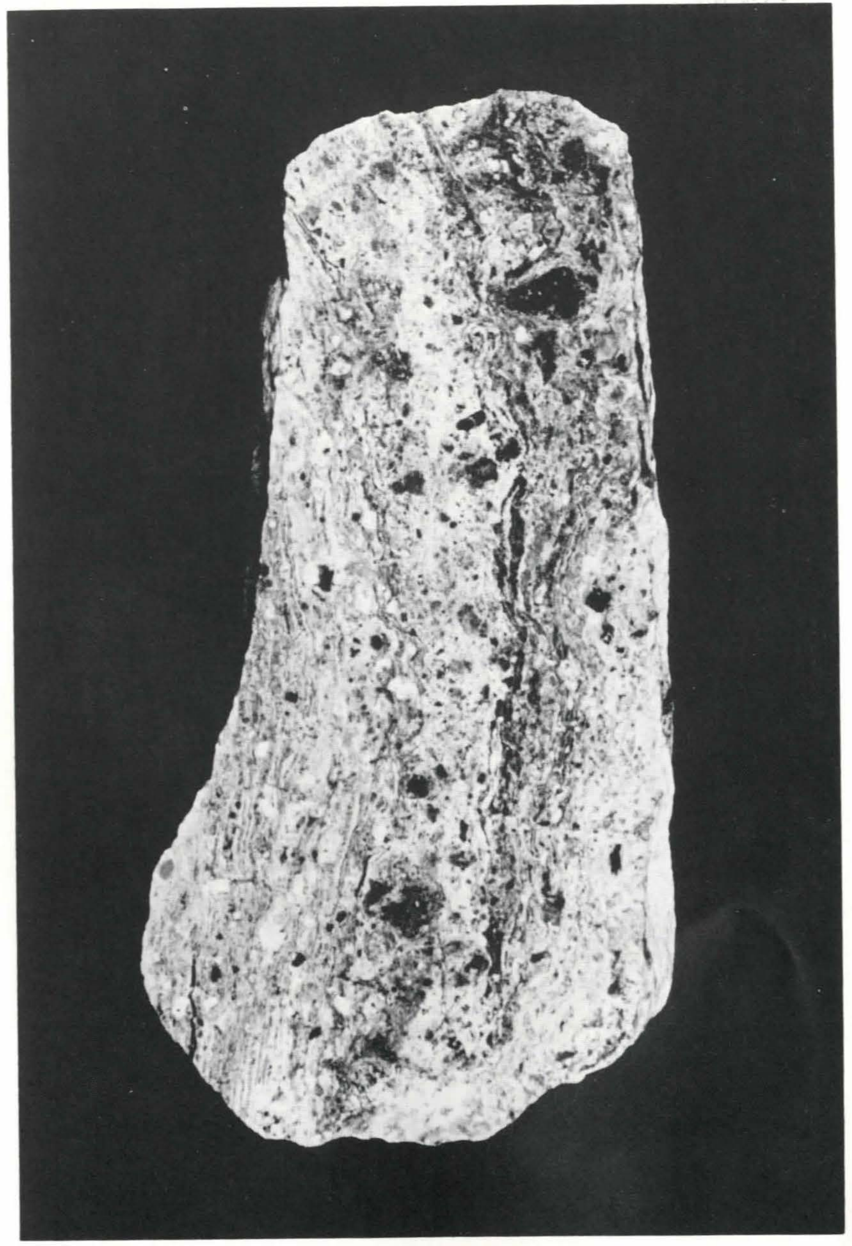


Figure 13

Rhyolite Flow from Moat Volcanics. Altitude of 1550 feet on east slope of Grant Peak. Note flow-banding; phenocrysts of quartz and microperthite. Mode is No. 362 in Table 7. Magnification x 1.6.

Porphyritic Basalt

This rock is only found in the Ossipee Mountains and is fairly common between Rattlesnake Mountain and Grant Peak. It is also found on Little Mt. Whittier. The rock is generally dark gray. Phenocrysts are labradorite (An_{55-63}) with rare small grains of orthoclase or quartz. The groundmass is fine-grained and altered so as to obscure the minute ferromagnesian minerals. Chlorite, epidote and opaques are common accessories. Modes of porphyritic basalts are given in Table 8.

Basalt

This rock is common throughout the Nickerson Mountains (Figure 15). It is dense, black, brittle and fine-grained to microgranular, locally porphyritic. The phenocrysts are generally calcic andesine to sodic labradorite, weakly zoned and 3.0 to 10.0 mm. long, but include smaller grains of titanaugite and kaersutite, the titaniferous oxy-hornblende. The titanaugite is fresh and has a colorless to violet-pink pleochroism. In sections viewed normal to the c-axis an hourglass structure of inclusions can be seen. Smaller crystals of kaersutite and titanaugite also occur in the groundmass where chlorite, epidote and opaque grains are common. The mode of a typical basalt is included in Table 8.

Breccia

Breccia is fairly common locally throughout the Nickerson Mountains but is best observed in the saddle south of Little Mt. Whittier and on the northwest slopes of the Nickerson Mountains (Figure 14). Breccia consists of angular blocks of basalt and tuff set in a groundmass of porphyritic andesite or rhyolite. There are also breccias that consist of angular blocks of porphyritic rhyolite set in porphyritic andesite and others that consist of the reverse arrangement. Blocks of thinly layered tuff occur with large blocks of basaltic breccia in the saddle southeast of Little Mt. Whittier and on the small knoll at elevation 1150 feet lying 3,500 feet east of Grant Peak. The blocks of tuff and basalt are set in a matrix of porphyritic rock.

Welded Tuff

A piece of welded tuff was found as a cobble in the saddle southeast of Little Mt. Whittier, but none was seen in outcrop. Prof. William F. Jenks of the University of Cincinnati (written comm. 1965) states that welded tuffs of dacitic or rhyolitic composition occur to the north on the west side of Moat Mountain near the summit (North Conway area). Jenks has also found boulders of welded tuff in the Ossipee Mountains.

Noble and Billings (1967) have also recognized welded tuffs on Moat Mountain. Observations of a sawed section and a thin section of the rock found by this writer shows it to closely resemble welded tuffs mapped by Rankin (1961) in the Traveller - Katahdin area in Maine.

In the hand specimen there are elongate collapsed vesicules 3.0 to 7.0 mm. long and 1.0 to 2.0 mm. thick. These cavities are filled with chalcedony, epidote and chlorite. The groundmass is microgranular.

Table 9
Chemical Analyses of Minerals

	1	2	3	4	5
SiO_2	37.40	47.58	35.37	49.0	37.8
TiO_2	3.20	0.37	3.20	n.d.	4.5
Al_2O_3	12.34	1.16	13.43	13.7	12.9
Fe_2O_3	4.16	2.60	4.32	n.d.	6.1
FeO	25.84	24.21	27.26	9.8	12.6
MnO	1.24	0.59	0.26	n.d.	n.d.
MgO	2.20	3.34	4.03	12.0	4.1
CaO	9.72	18.80	0.69	11.2	13.6
Na_2O	1.80	0.47	0.88	2.4	5.3
K_2O	1.36	0.21	7.86	n.d.	3.2
H_2O+	tr	0.34	2.03	n.d.	n.d.
H_2O-	0.60	n.d.	n.d.	n.d.	n.d.
BaO	0.00	n.d.	n.d.	n.d.	n.d.
Cr_2O_3	0.00	n.d.	n.d.	n.d.	n.d.
Total	99.86	99.67	99.33	98.1	100.01

1. Hastingsite, Albany Porphyritic Quartz Syenite, Jackson Falls (Billings, 1928).
2. Hedenbergite, syenite, Percy Quadrangle (Chapman and Williams, 1935).
3. Biotite (annite), Conway Granite, Redstone Quarries, Conway (Henderson, 1924).
4. Hornblende, mafic dike, Littleton, N. H. (Hawes, 1876).
5. Barkevikite, Camptonite, Livermore Falls, N. H. (Lord, 1898).

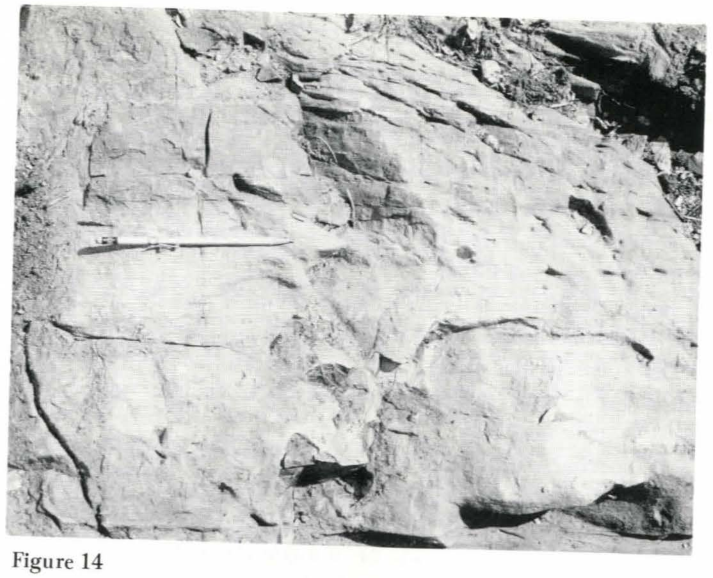


Figure 14

Moat Volcanics. Saddle southeast of Little Mt. Whittier. This block of basalt and several like it form a breccia of which porphyritic andesite is the groundmass. Pencil is six inches long.

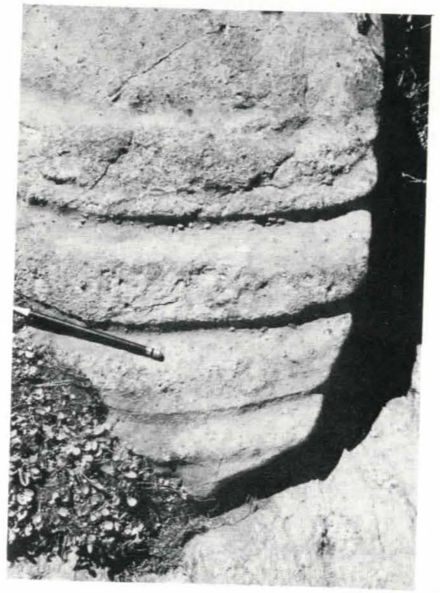


Figure 15

Moat Volcanics. Altitude of 700 feet, one mile northwest of Grant Peak. Basalt resting on rhyolite porphyry. Differential weathering has brought out layering in the basalt flow.

Albany Porphyritic Quartz Syenite

Hitchcock (1878) called this rock the Albany Granite. Later Billings (1928) adopted the name Albany Porphyritic Nordmarkite. Since then this has been replaced by the present name. The Albany crops out in the northwest and southwest corners. In the northwest it forms a broad arc that trends east-west around the south end of South Moat Mountain (North Conway area). In the southwest it forms the ring dike that surrounds the Ossipee Mountains.

In large roadcuts that have been recently blasted along the Kancamagus Highway in the northwest the rock is a dark blue-gray (Figure 16). Pastel olive-green to light green-gray phenocrysts of microperthite have imparted a faint green tint to the rock. In the Ossipee Mountains the Albany is gray and pink.

Hand specimens commonly contain a few scattered phenocrysts of anorthoclase mantled by a thin rim of K-feldspar. The non-mantled phenocrysts of microperthite are abundant and average 7.0 to 9.0 mm. long. The rimmed phenocrysts of anorthoclase have a different color than the non-rimmed phenocrysts of microperthite. Where microperthites are pale olive-green, pink or light gray, the mantled phenocrysts of anorthoclase are, respectively, gray with cream rims, gray with white to pink rims and dark gray with cream-colored to light-pink rims. The rims of K-feldspar are about one-tenth as thick as the mantled grains of anorthoclase which are commonly 5.0 mm. long. Quartz also is present as small equant phenocrysts that average 4.0 mm. in diameter. These grains show sharp extinction and are free of strain shadows.

There are many minerals present as small grains in the groundmass of the Albany. The light-colored minerals are microscopic quartz (equant, 0.2 mm. in diameter) and apatite. Several dark-colored minerals occur in the groundmass: hastingsite, biotite (rare), augite, fayalite and magnetite.

The hastingsite shows well-developed prismatic cleavage and occurs as stubby prisms 1.0 to 2.0 mm. long. Commonly it appears spongy in poikilitic intergrowth with minute granules of quartz (Figure 17). The pleochroism is brown-yellow (X), olive-green (Y) and dark green (Z). The indices of refraction from specimen No. 1 are Nx=1.695, Nz=1.720 and suggest that the mineral is similiar to the hastingsite from Jackson Falls in the North Conway area (Table 9).

Biotite is rare. Augite, colorless in thin section and commonly surrounded by a reaction rim of hastingsite, occurs as grains 0.3 to 1.0 mm. in diameter. Fayalite is rare but occurs as small grains about 0.1 mm. long. Rock fragments of diorite and diabase also occur in the Albany. Modes of typical specimens are given in Table 10.

A small body of a variety of the Albany crops out on the southwest slopes of Cragged Mountain. The rock is green-gray and porphyritic with cream-colored phenocrysts of microperthite that average 4.0 mm. in length. The groundmass consists of microscopic quartz, feldspar and hastingsite. The hastingsite is pleochroic in green (X), blue-green (Y) and dark olive-green (Z), with indices of Nx=1.692, Nz=1.716. Biotite, chlorite, zircon, apatite and magnetite are also present.

While examining the Harvard collection the writer came across a quartz porphyry contact phase of the Albany collected by Kingsley (1931, No. 19213) who gave the location as altitude of 570 feet on brook east of South Tamworth. This village is three miles west of BM 436 on Route 25. In the groundmass quartz, Na-feldspar, fayalite, magnetite and chlorite are present. These minerals account for about one half of the groundmass. The remainder consists of light and dark areas, partially occupied by spherules 0.1 mm. in diameter. Phenocrysts of quartz are euhedral but rounded at the edges and corners. The phenocrysts of orthoclase are a rusty-pink color in hand specimen and appear dusty and clouded in thin section. The indices are Nx=1.522, Nz=1.528. This feldspar has a faint microperthitic texture.

Similiar rocks can be observed adjacent to both sides of the ring dike in the stream cut 0.5 mile north of Rattlesnake Mountain. Kingsley (1931) recognized that the Albany crops out as more than one variety in the Ossipee Mountains. She stated (p. 157), "The name porphyritic nordmarkite was used by Billings for a group of closely related porphyritic quartz amphibole syenites . . . . In the Ossipee district these nordmarkites form a distinct group of rocks."

Table 10
Modes of Albany Porphyritic Quartz Syenite

	1	4	7	133	145
Quartz	18	15	16	19	17
Microperthite	61	59	63	63	66
Anorthoclase	10	14	9	7	6
Hastingsite	10	10	8	10	7
Augite	1	tr	1	------	1
Biotite	tr	------	1	tr	1
Magnetite, zircon apatite and fayalite	tr	2	2	1	1

Locations of the specimens:

1 Elevation 900 feet, 0.4 mile west of spot check elevation mark 824 west of Woodchuck Ledge. Large outcrop from road blasting.
4 South bank of Swift River, 100 yards southeast of spot check elevation mark 800.
7 North side of Swift River Valley, elevation 900 feet at base of Woodchuck Ledge.
133 Elevation 700 feet on east side of Rattlesnake Mountain.
145 Elevation 1500 feet on ridge crest leading east from Mt. Whittier, 1.7 miles west northwest of Grant Peak.

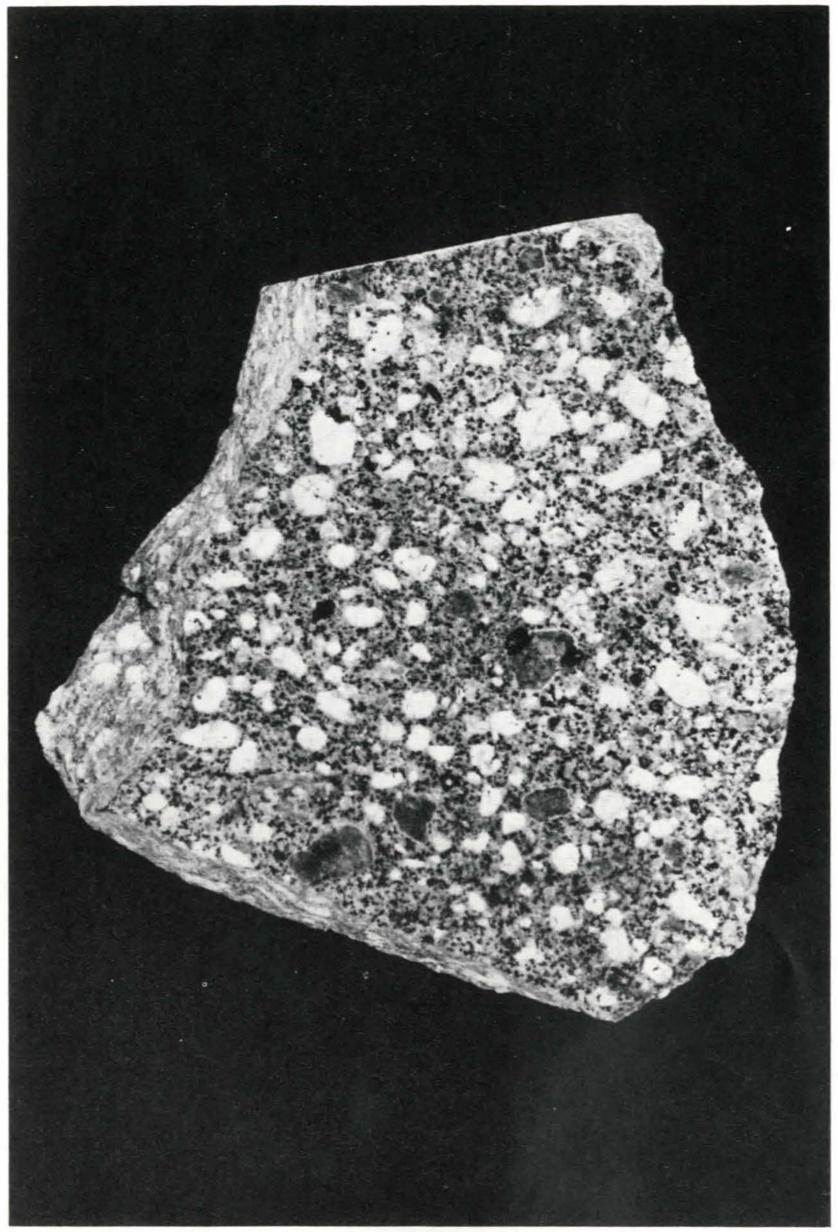


Figure 16

Albany Porphyritic Quartz Syenite. One mile N. 30°W. of Bald Hill. White phenocrysts are microperthite; dark phenocrysts are anorthoclase mantled by a thin pale rim of K-feldspar. Groundmass is flecked with small dark grains of hastingsite. Magnification x 1.2.

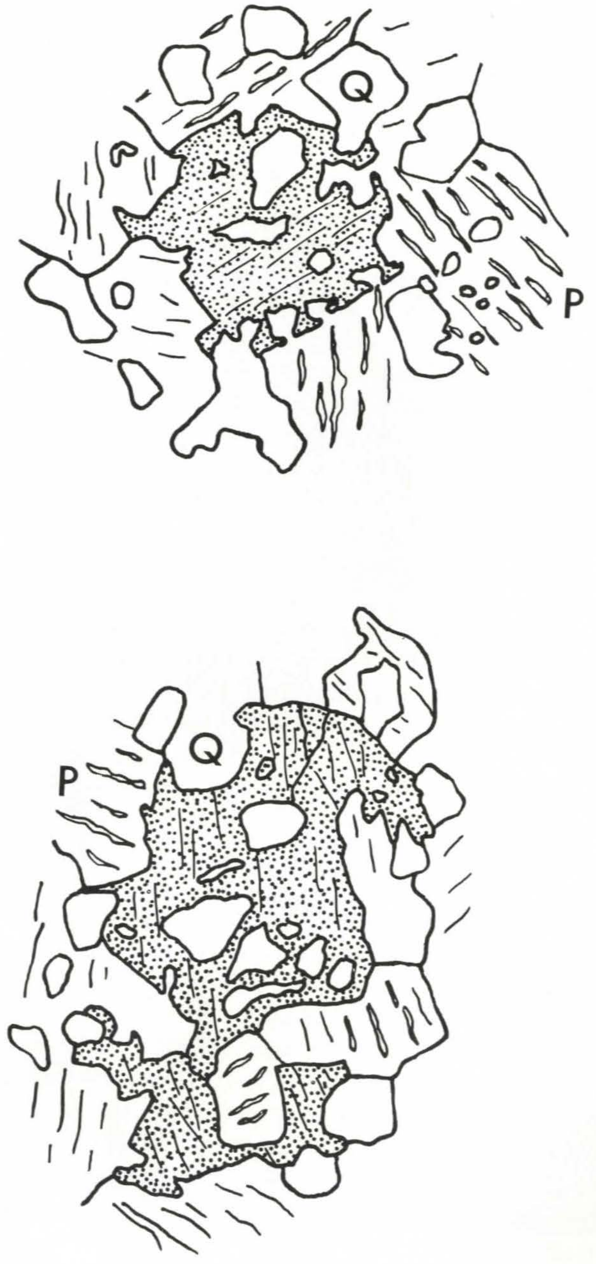


Figure 17

Albany Porphyritic Quartz Syenite. Poikilitic texture of hastingsite. P = microperthite, Q = quartz, Shaded area = hastingsite. Camera lucida x 60.

Mt. Osceola Granite

The name of this rock derives from the type locality on Mt. Osceola in the Franconia area (Williams and Billings, 1938). The rock crops out in the vicinity of Bragdon Ledge and around Hill 2330 in the northwest.

The Mt. Osceola is a coarse-grained, equigranular, olive-green to gray granite. Felsic minerals are microperthite, which constitutes about three-fourths of the rock, and quartz, which is about one-fourth of the rock. The average diameter of these grains is 5.0 mm. Some of the microperthite contains relatively thick stringers of polysynthetically twinned albite. The perthitic texture so common throughout the rock is generally delicate and distinct in thin section (Figure 18). Quartz is free of strain shadows. Fluorite, apatite and zircon are present.

The dark minerals locally present are hastingsite, ferroaugite, aegirine-augite, fayalite, magnetite and yellow-red iron oxides of secondary origin. Representative modes of the Mt. Osceola are given in Table 11. The hastingsite is pleochroic in light brown (X), green-brown (Y) and dark olive-green (Z) with indices of Nx=1.698 and Nz=1.723. This is similar to an analysed hastingsite from the Albany near Jackson Falls in the North Conway area Table 9.

Smith (1940) discussed a pyroxene in this rock where it crops out around Mt. Chocorua. Her sample was considered hedenbergite because the optics (Nx=1.732, Ny=1.738, Nz=1.756) compared favorably with those of an analysed hedenbergite from syenite in the Percy area, N. H. (Table 9).

When the chemical analysis of this pyroxene is recalculated to ionic fractions per 6 oxygen atoms, it becomes:
$\text{Na}_{.037}\ \text{K}_{.011}\ \text{Ca}_{.82}\ \text{Fe}_{.826}\ \text{Mg}_{.203}\ \text{Mn}_{.02}\ \text{Fe}_{.080}\ \text{Al}_{.056}\ \text{Ti}_{.011}\ \text{Si}_{1.94}0_6$. Neglecting K, Ti and Mn, this can be rewritten as the sum of 80 percent $\text{Ca}(\text{Fe}_8\ \text{Mg}_2\ )\text{Si}_2 0_6$ + 20 percent $\text{Na}_2\ (\text{Fe}_{.9}\text{Mg}_{.2})\ (\text{Fe}^{'''}_{.4}\text{Al}_{.3}\ )\text{Si}_{1.5}\ 0_6$, that is, 80 percent hedenbergite and 20 percent aegerine-augite.

Of the two places where the Mt. Osceola Granite crops out in this area, the pyroxene from Hill 2330 is not the same as that from the rock on Bragdon Ledge. The pyroxene from Hill 2330 has an extinction angle of Z/c=40°, an optic angle of 2V=45° (+). These data suggest a member of the augite-ferroaugite series. The pyroxene from Bragdon Ledge has an extinction angle of X/c=5°, a large optic angle of about 80° and is optically (-). The birefringence is high, at least 0.040. These data suggest a member of the aegirine-augite series.

Deer, et al. (1962) show that the optic sign of the aegirine-augite series changes from (+) to (-) at about 40 mole percent aegirine: more sodic members are (-). Despite the small amounts of Ti and Al present, the pyroxene from Bragdon Ledge probably has a composition inter-

Figure 18

Photomicrograph of Mt. Osceola Granite. Three-tenths mile S. 70°W. of hill 2330. Microperthite. Quartz grain is in upper center. Note microtexture of quartz and feldspar surrounding grain of microperthite in lower right-hand corner. Crossed micols, magnified x 15.

Table 11
Modes of Mt. Osceola Granite

	5	102	103	360	400
Quartz	22	20	13	23	20
Microperthite	77	77	80	71	65
Albite	1	------	------	0.5	3
Hastingsite	1	2	6	3.5	8
Augite	----	tr	1	1.5	3
Fayalite	----	1	tr	0.5	1

Locations of the specimens:

5	South bank of Swift River, 2/3 mile southeast of spot check elevation mark 800.
102	Summit of Bragdon Ledge, two miles north of Chocorua Lake.
103	Elevation 1250 feet on small ridge, 0.4 mile southeast of Bragdon Ledge.
360	Elevation 1200 feet on Weetamoo Trail, 0.3 mile north northeast of Bragdon Ledge.
400	Elevation 1900 feet on Bald Mountain, 0.4 mile west of Bragdon Ledge.

Table 12
Modes of Conway Granite

	BM-1	BM-2	73	68	330
Quartz	33	31	32	39	26
Microperthite	51	43	42	38	64
Albite	13	20	21	19	4
Biotite	2	6	4	5	5
Accessories	1	tr	tr	tr	1

Locations and details of the specimens:

BM-1	Average of two thin section modes, B & M Ledge quarry.
BM-2	Average of six macro-point counts on six sawed slices of granite from the B & M Ledge quarry. Four slices were treated with HF acid and cobaltinitrite to aid in distinguishing K-from Na-feldspar.
73	Summit of Birch Hill, one mile N.35°W. of the B & M Ledge quarry.
68	Summit of Albany Ledge, one mile N.40°E. of the B & M Ledge quarry.
330	Elevation 1700 feet, 0.3 mile southwest of Hanson Top on Green Mountain.

mediate between aegirine and augite. The available data suggest that there are two pyroxenes in the Mt. Osceola, an augite-ferroaugite from Hill 2330 and an aegirine-augite from Bragdon Ledge.

Conway Granite

The name Conway Granite was used by Hitchcock (1877) to designate the massive, coarse-grained granite that forms prominent cliffs and ridges on the east and west sides of the Saco River Valley in the vicinity of what is now North Conway. The rock is well exposed in the Redstone quarries, 2.8 miles north-northeast of Conway. Inasmuch as a formal type locality for the Conway Granite has never been proposed, the writer suggests that the Redstone quarries be so considered. Many chemical analyses and nuclear age dates have come from specimens taken at this locality. Large quantities of fresh Conway granite are also available from the B and M quarry, 4.5 miles north of Silver Lake (Figure 19).

Conway Granite, including its varities, crops out in four places. It occupies most of the northwest corner, forming the southeast edge of the White Mountains batholith. It occupies the extreme southwest corner, forming the central stock in the Ossipee Mountains. A medium-grained type of Conway Granite crops out on Green Mountain and the Whales Back stock in the center of the N. H.-Maine state line contains two kinds of Conway Granite.

This rock is typically a medium-to coarse-grained, light pinkish to buff colored, equigranular biotite granite. The biotite is annite (Table 9, column 3). The grains of quartz and feldspar are 7.0 to 12.0 mm. in diameter. Accessory minerals are hastingsite and fayalite (both near the contact with the Mt. Osceola), apatite, zircon, rutile, fluorite, allanite and molybdenite.

One-half to three-fourths of the alkali feldspar is microcline-perthite, but the perthite contains coarse stringers and irregular patches of the sodic phase, instead of the delicate or finely interlaced microperthite so common to the Mt. Osceola Granite. About 5 percent to 20 percent of the feldspar is albite, present in individual laths twinned by the albite law. Some grains are faintly zoned. The quartz is generally a dark smoky color and occupies one-fourth to one-third of the rock. Modes of some specimens of Conway Granite are given in Table 12.

On and around Green Mountain the Conway Granite is medium-grained. It is nearly two-thirds microperthite and about one-fourth quartz. The ratio of total feldspar to quartz is high (2.6) compared to the coarse-grained and porphyritic varieties (2.0 to 1.5). Biotite altered to chlorite, magnetite, fayalite, allanite, zircon and apatite are also present.

In the vicinity of Birch Hill the Conway Granite is subporphyritic (Table 12, No. 73). The largest phenocrysts are pink to cream perthitic

Figure 19

Conway Granite. B and M Ledge Quarry. Feldspar is white, quartz is dark-gray, small biotite flakes are black. Magnification x 1.1. Slices like this were used for the micro-point modes, BM-2, Table 11.

microcline about 1.0 cm. long. Medium-grained white oligoclase and biotite make up the remainder of the rock. Allanite is present.

In the vicinity of Albany Ledge, one mile N 40°E of B and M Ledge quarry the Conway granite is distinctly prophyritic. Phenocrysts are quartz, perthitic microcline and sodic plagioclase set in a groundmass of fine-grained, equigranular alkali feldspar and quartz. Biotite is present in aggregates of several small books, each book 0.2 to 0.4 mm. long. The biotite is pleochroic from pale tan (X) to very dark brown-black (Z). Fluorite is present in both the Birch Hill and Albany Ledge types of Conway Granite. Allanite is also present in the Conway Granite at Albany Ledge.

The Whales Back stock is located 2.5 miles east of Foss Mountain. The northern half of this stock consists of a medium-grained type of Conway Granite of the same mineralogy as the coarse-grained type described above. The southern half of the stock is much different, but is still regarded here as a kind of Conway Granite. The best exposures are on the cliff face of the extreme northeast edge of a ridge that extends from Cragged Mountain towards Whales Back. Exposures are also good on and below the cliffs that face south on Whales Back.

This variety of Conway Granite is a medium-grained to fine-grained, light-brown to pink porphyritic granite. The phenocrysts are quartz, microperthite and sodic plagioclase averaging 2.0 to 3.0 mm. in length. The fine-grained groundmass is about half quartz and half alkali feldspar. Biotite is abundant and is altered to chlorite in places. Dark-green hastingsite with indices of $Nx=1.695$ and $Nz=1.719$ is also present. Accessories are zircon, magnetite, apatite and rutile. A few grains are present that are biaxial (-), yellow-brown and weakly pleochroic. They resemble Winchell's (1951, p. 452) description of the nagatelite variety of allanite.

One very small isolated area lying one mile west northwest of White Ledge consists of an unusual kind of Conway Granite. The rock consists almost entirely of a fine-grained, delicate micrographic intergrowth of quartz and alkali feldspar. Biotite is the principal dark mineral, but some hastingsite is present.

Dike Rocks

General statement

The rocks described here occur in thin, discordant, unmetamorphosed, steeply dipping dikes. Their thickness averages one to three feet and ranges from two inches (dike swarms on Foss Mountain) to fifty feet (Hedgehog Hill and Cragged Mountain). Fifty hand specimens of dike rocks were collected. Twenty-three are camptonites, thirteen are spessartites and four are felsites. The others are ordinary dark, dense, brittle diabase. Of the twenty thin sections studied, three are felsites, five are spessartites and twelve are camptonites.

In the following discussion the dikes are classed into two broad groups, felsites and lamprophyres. The lamprophyres are further classed into spessartites and camptonites.

Felsites

Felsite dikes are uncommon. On the southern half of Washington Hill a felsite dike two feet wide cuts pegmatite about 100 yards northwest of the high point on the road at elevation 890 feet. A felsite dike several feet wide cuts the Green Mountain type of Conway Granite about 400 yards west of Davis Top at an elevation 1200 feet.

All the felsite dikes are pink to light orange. The groundmass consists of microcrystalline quartz and feldspar and amounts to about half of the rock. The rest is composed of euhedral laths of sodic plagioclase 2.0 to 4.0 mm. long, biotite flakes 2.0 mm. long, green hornblende in minute granules and zircon. An estimated mode of a typical dike is groundmass 60 percent, sodic plagioclase 25 percent, biotite 10 percent with hornblende and others 5 percent.

Lamprophyres

A convenient summary of the lamprophyres is given in Williams, Turner and Gilbert (1958, p. 85). In this area only lamprophyres in which plagioclase is the dominant feldspar are encountered. This leads to a three-fold classification that depends upon the dominant mafic mineral or minerals present: kersantite contains biotite, spessartite contains augite or hornblende and camptonite contains pyroxene or alkali amphibole. Johannsen (1937, vol. III) states that biotite-bearing hornblende spessartites are transitional to kersantites. The dike rocks discussed here under the name spessartite are largely such transitional types.

As for camptonite, the original description of the rocks from the type locality at Livermore Falls, N. H. (Hawes, 1879) was "porphyritic basic diorite" (also Hitchcock, 1878, III, part 4, p. 160). Rosenbusch (1887, p. 328, 333) proposed the name camptonite because the locality was then known as Campton Falls. Moke (1945) showed the location of the five dikes at Livermore Falls in a sketch map, used by the writer in a visit to the locality in 1964. Moke's map points out that the two dikes (Hawes' No. 2 and 5) called camptonite are different: one contains augite and the other does not, as Hawes originally noted. Both consist otherwise of barkevikite in a groundmass of calcic plagioclase, neglecting accessory minerals. Johannsen (1937, IV) points out that Rosenbusch intended camptonites to mean "lamprophyres of the alkali series". A field example consistent with this is the intrusive alkali syenite on Mt. Monadnock, Vt., cut by camptonite dikes described by Wolff (1922).

A lamprophyre containing plagioclase and mafic minerals, as phenocrysts of amphibole or pyroxene, can be called spessartite or camptonite depending on the chemistry of the principal dark minerals. Consider the partial analyses in columns 4 and 5, Table 9. The barkevikite has a higher soda content and a much higher FeO/MgO ratio than the hornblende.

Spessartites are reasonably common. There are several thin spessartite dikes offset by fractures on the eastern slope of the hill west of the Madison Boulder. These dikes also occur, with diabase, on Lyman Mountain and many other places. The spessartites here consist generally of small phenocrysts, 1.0 to 2.0 mm. long, of green hornblende set in a groundmass of fine-grained plagioclase. Small flakes of biotite constitute about 10 percent of the rock. The hornblende is generally altered to chlorite except in the centers of grains. Magnetite is common. Augite was the only ferromagnesian mineral in one of the spessartites.

Camptonite dikes are the most common lamprophyre in the area. The two localities that have the thickest dikes, up to fifty feet, are on the south slopes of Hedgehog Hill and on the knoll at 1800 feet just west of the summit of Cragged Mountain.

The camptonite dikes contain abundant brown prisms of barkevikite 0.5 to 1.0 mm. long. Some augite is generally present, but it is commonly altered to chlorite. It is likely that the fresh rock, prior to deuteric alteration, locally had as much augite as barkevikite for there are many larger patches of chlorite that suggest pseudomorphic replacement of former pyroxene.

Barkevikite is invariably fresh (Figure 20). It is recognized by the light brown (X) to dark rusty-brown (Z) pleochroism and by the small extinction angle of about 8°=Z/c. Small extinction angles are characteristic of barkevikite, kaersutite and oxy-hornblende. Barkevikites are commonly titaniferous. Wilkinson (1961) and Deer, et al. (1962) consider barkevikite as a calciferous amphibole similar to oxy-hornblende and kaersutite. The indices of refraction of the barkevikite on Hedgehog Hill are Nx=1.685, Nz=1.705.

Kemp and Marsters (1889) emphasized the deuteric alteration so common in camptonites and advocated that the name camptonite be restricted to dike rocks consisting of "brown basaltic hornblende" (barkevikite), plagioclase and magnetite with or without augite.

A mode of specimen No. 34 shown in Figure 20 is: calcic plagioclase 39 percent (altered), barkevikite 35 percent, chlorite 12 percent, epidote 6 percent, magnetite 4 percent, augite 1 percent, calcite 1 percent and iron oxides 1 percent.

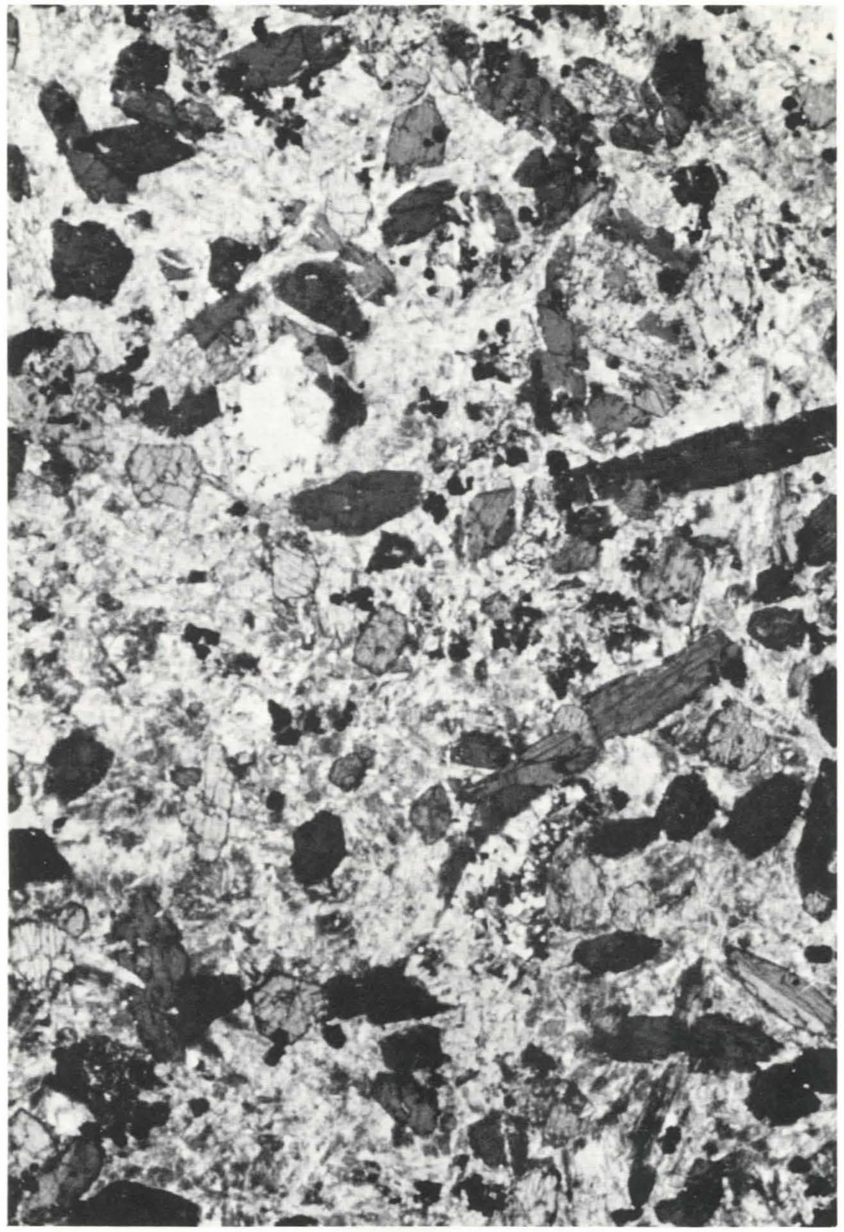


Figure 20

Photomicrograph of Camptonite. Hedgehog Hill. Specimen 34. Barkevikite appears as dark elongate grains where cut parallel to c-axis, and as gray equidimensional grains where perpendicular to c-axis. Groundmass is chiefly altered calcic plagioclase, chloritized pyroxene, and magnetite. Crossed nicols, magnification x 15.

AGES OF THE PLUTONIC ROCKS

New Hampshire plutonic series

Lyons, et al. (1957) dated some rocks in the New Hampshire Plutonic Series by the lead-alpha method (Larsen, 1952) using zircon, monazite and xenotime. The average ages in millions of years were: Bethlehem Gneiss 297, Kinsman Quartz Monzonite 298, Winnipesaukee Quartz Diorite 277 and Concord Granite 325.

Faul, et al. (1963) published four ages for two rocks of this series from west-central New Hampshire with these results: Bethlehem Gneiss 246 m.y. (K-Ar, biotite and muscovite) and 310 m.y. (Pb-alpha), Kinsman Quartz Monzonite 248 m.y. (K-Ar) and 410 m.y. (Pb-alpha).

Hurley and others at M.I.T. have published several ages of Paleozoic granites in New England, including some of rocks in the New Hampshire Plutonic Series. Biotite and muscovite were dated by the K-Ar and Rb-Sr methods. However, Hurley (written comm. 1965) considers those results unreliable because the micas appear to reflect a tectonic pattern in which the rocks of a given district yield the same age whether they are host rocks or intrusive rocks.

William Vernon (written comm. 1965) has two ages for the Concord granite of 350 m.y. and 370 m.y. determined by the Pb-alpha method on samples from quarry rock at Concord, N. H. The work was done in 1961 with great care and these might be more reliable than any previously published dates for the Concord Granite.

White Mountain Plutonic-Volcanic Series

The Conway Granite has been dated by various writers using several methods. Table 13 summarizes the data. The locality in all this work was the Redstone quarry, Redstone, N. H. in the North Conway area.

In general, the Pb-Pb, Pb-alpha, U-Pb (both) and Th-Pb methods were used on zircon or thorite, whereas the K-Ar and Rb-Sr methods were applied to biotite in the above studies. Neglecting the two low ages of 137 and 140 m.y., the results above give an average age for the Conway granite, youngest member of the White Mountain series, of 185 m.y.

Summary of the Ages of the Plutonic Rocks

At this writing the most reliable data appear to be the ages of 350 and 370 m.y. for the Concord Granite (Vernon, written comm. 1965), and an average age of 185 m.y. for the Conway granite. The rocks of the New Hampshire series are generally believed to be contemporaneous with the Acadian Orogeny which Boucot (1958) has considered as Early Devonian or Early Middle Devonian, based on regional stratigraphic studies. The date of 185 m.y. for the Conway granite is Early Jurassic according to the symposium on the Phanerozoic Time-scale recently held in Great Britain (1964).

Table 13
Age of Conway Granite

Reference	Method	Ages*
Lyons, et al. (1957)	Pb-Pb	186
Tilton, et al. (1957)	Pb-Pb	140
	K-Ar	182
	U_{235}-Pb_{207}	184
	Rb-Sr	185
	U_{238}-Pb_{206}	187
	Th_{232}-Pb_{208}	190
Aldrich, et al. (1958)	K-Ar	168
	Rb-Sr	190
	K-Ar	137
	Rb-Sr	183
Hurley, et al. (1960)	Rb-Sr	170
	K-Ar	180

*In millions of years.

CHAPTER 4
STRUCTURE

FOLDING

Observations

The schistosity in the Ossipee Lake area is nearly everywhere paralled to the bedding, as displayed by alternating layers of schist and granofels. The term bedding-schistosity is used here as a basis for deducing folds.

Small-scale folds with amplitudes and wave lengths of approximately one inch to one foot are ubiquitous. The axial planes of these folds strike northeasterly and are vertical or dip steeply to the northwest or southeast. The axes of these folds plunge commonly to the southwest 30°-80°, but some plunge to the northwest 40°-75°. The pattern of these folds in plan is more commonly left-handed, less commonly right-handed. Figure 21 shows minor folds and associated crinkles.

Crenulations, also called crinkles, are a fraction of an inch in size. These are especially well developed on Foss Mountain, Watson Hill and on the knolls on the west side of Purity Lake. The axial planes are vertical and the axes commonly plunge southwesterly 40°-70°.

Broad open folds, two to twenty feet across and with an amplitude of six inches to two feet, are shown by repetitious alternations in strike or dip or both.

Possible larger folds hundreds or thousands of feet in wave-length can not be observed because of the small size of exposures here.

Slip cleavage is not common and will be discussed later. Axial plane cleavage is very rare, but can be seen on the southwest end of Jackman Ridge. There the small-scale folds are in tight chevron patterns and some axial plane cleavage cuts across the pelitic beds.

Some of the structural features described above are shown in the sketch map of the structure on the hill northeast of Loud Pond (Figure 22). Bedding-schistosity is shown with the usual symbol accompanied by the angle of dip. The strikes and dips of two axial planes are shown by bars with a small tick mark giving the direction and angle of dip. The plunges of the two larger folds are given by the numbers next to the arrows, which are the traces of the axes of the folds in a horizontal plane. The axial planes trend northeasterly. The plunge of one of the two large folds must be inverted with respect to the other. This map illustrates a feature that has been observed occasionally; adjacent folds plunge in opposite directions. Although they may have resulted from two stages of folding, it is more likely that the rocks were very plastic in one stage of folding.

Figure 21

Folds in Mica Schist. 1.2 miles north of B. M. 488 at East Madison. Surface of outcrop is essentially horizontal. Pencil points in direction of plunge of axis of folds and crinkles.

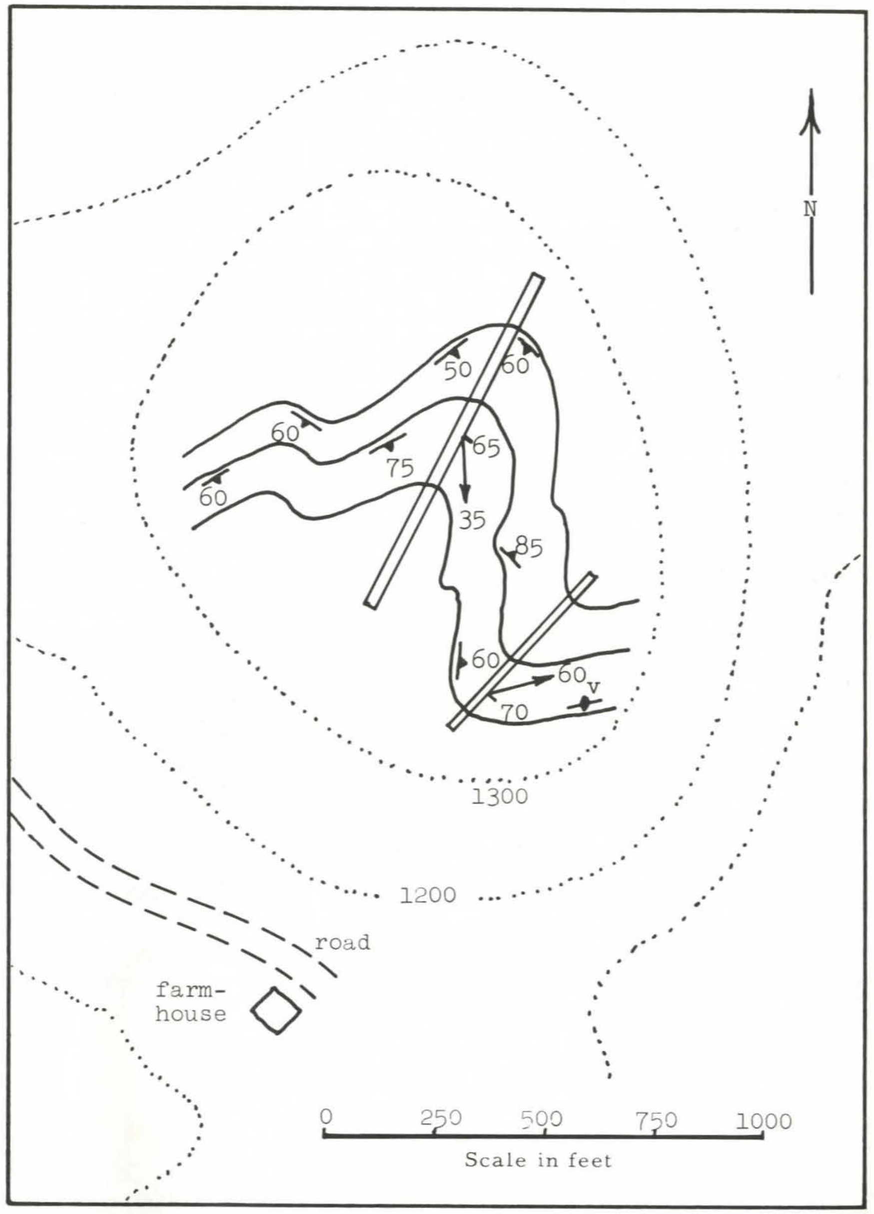


Figure 22

Structure on Hill Northeast of Loud Pond. Dotted lines are topographic contours. Heavy lines are bedding. Strike-dip symbols are bedding-schistosity. Bars are traces of axial planes; arrows are plunge of fold axes.

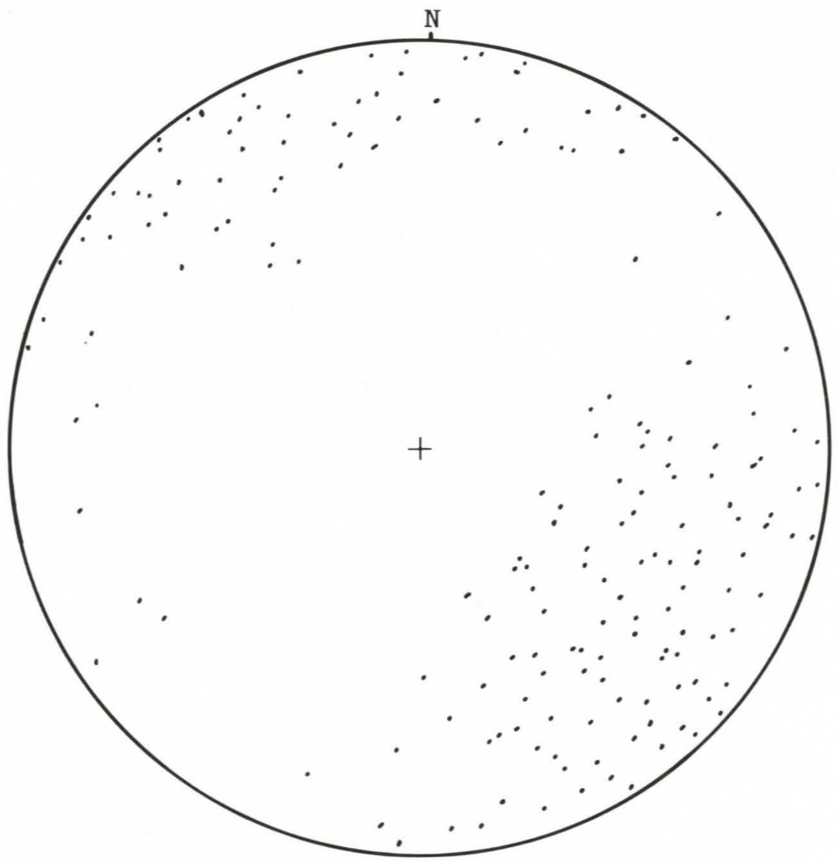


Figure 23
Attitude of Bedding-Schistosity. Equal-area projection, lower hemisphere, attitude of bedding-schistosity at 177 localities.

Plate III is a tectonic map of the area. Each symbol represents a closely spaced group of outcrops within which the structural pattern is reasonably consistent. In Figure 23 are plotted 177 of the representative attitudes of bedding-schistosity in the area. The density of poles in the northwest and southeast quadrants shows that the general strike of the bedding-schistosity is northeast-southwest and that most beds dip steeply northwest.

Structure on Foss Mountain

Foss Mountain was mapped by plane table (Figure 24) in order to 1) show the relative abundance of schist, pegmatite and other granitic rocks in a representative, although larger than usual, outcrop; 2) illustrate the pattern of some of the folding and 3) show the age relationships between the schist and the granitic rocks. Two maps of Foss Mountain are given in Plates 3 and 4.

Plate 3 shows that most of Foss Mountain is trondhjemite and pegmatite, but there are large areas of schist at the northwest end of the exposures. Plate 4 is a large-scale map of this northwest portion. For structural analysis the area has been divided into six domains. Inspections of Plate 4 shows that the bedding and schistosity in general strike NNE, N, and NW and dip steeply WNW, W, and SW. This is also shown by the pi diagrams in Figure 25.

Symbols for 28 minor folds are shown on the map. Since the folds are only a few inches across, many of them do not affect the trend of the bedding-schistosity on the scale employed. But 120 feet N.25°W. of station G one of these folds is 10 feet across. The pattern of most of these folds is left-handed in plan. Most of the axial planes strike northeast and are vertical. On the average these minor folds plunge 60° in a direction S.54°W.

The attitude of the crinkles (crenulations) is also recorded on Plate 4 by an arrow giving the bearing and plunge of the crinkle axis. The axes consistently plunge 40° to 70° SW, and on the average plunge 58° in a direction S.62°W.

The similarity in the attitude of the minor folds and the crinkles suggests that they are contemporaneous. More significant is the fact that in the field the distinction between minor folds and crinkles is entirely a matter of size.

Assuming congruous drag folds, this area is on the southeast limb of a syncline plunging 60° toward the southwest.

Separate beta diagrams have been constructed for each of the six domains (Fig. 26). Each diagram is based on about 13 dip-strike symbols that give 78 intersections. Four of these diagrams (E, Gb, Ge, and D) indicate fold axes that bear N.20°E. and have horizontal plunges. In a fifth diagram (Gg) a minor concentration suggests fold axes plunging N. at a low angle. Two diagrams (Gg and Gr) indicate fold axes plunging 45° and 70° in a direction N.80°W. The attitudes of the axes shown by these diagrams differ greatly from those shown by the minor folds and crinkles. But the beta diagrams are based on a very different kind of data. The symbols on which they are based are 30 feet apart, whereas the minor folds and crinkles are measured in inches or fractions of an inch. The beta diagrams represent larger folds 5 to 20 feet across. These

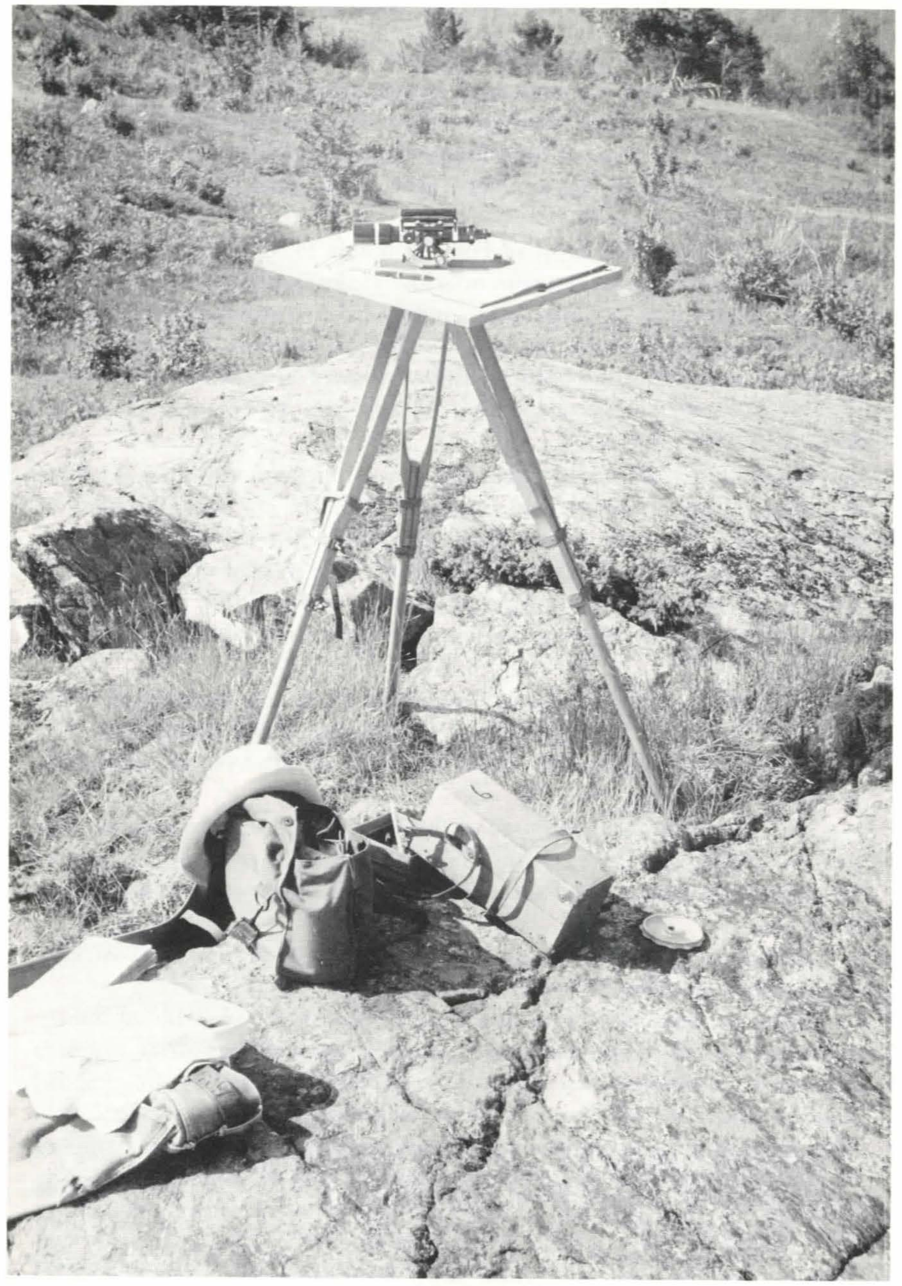


Figure 24
Plane Table Station G on Foss Mountain. Glacially scoured hillock, viewed looking southwest.

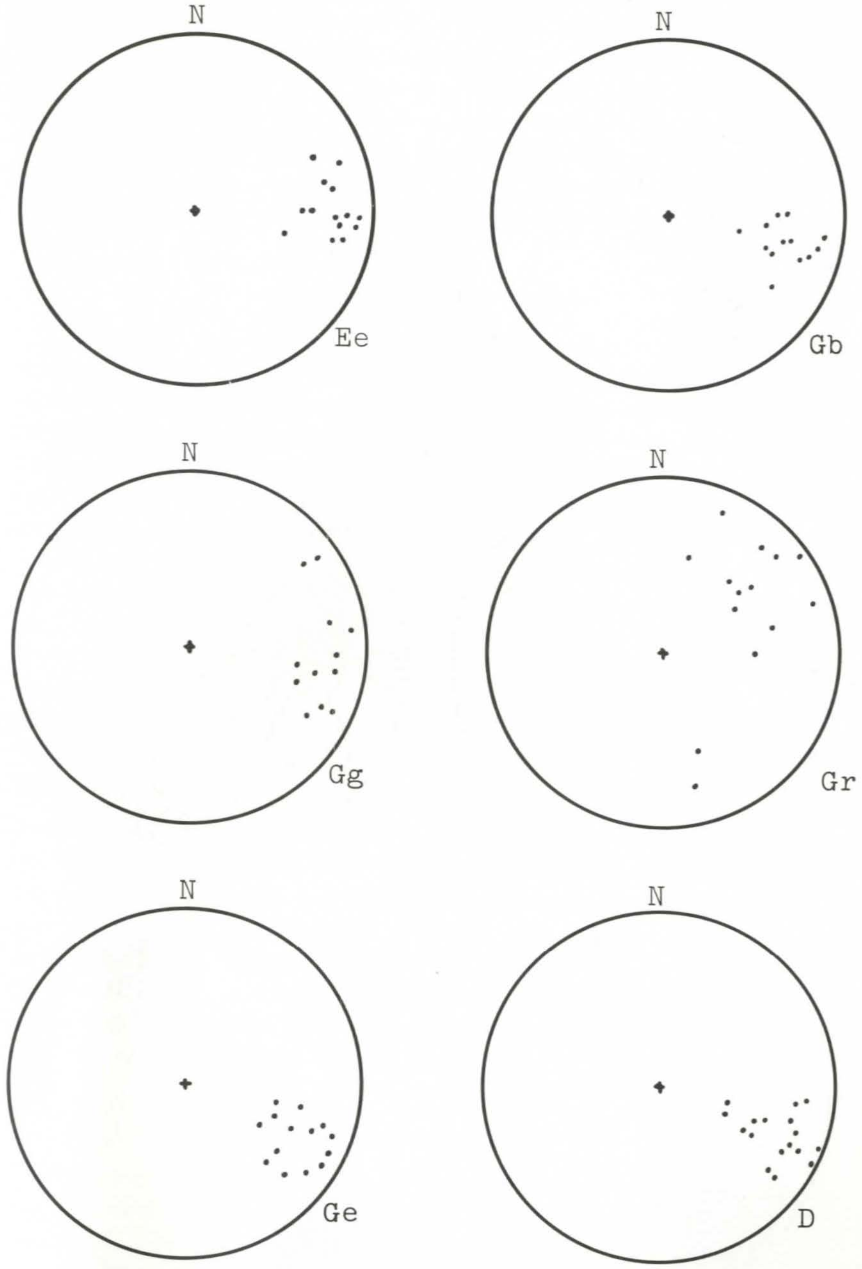


Figure 25
Pi Diagrams of Rocks on Foss Mountain. Letters refer to six domains shown on Plate 4. Points plotted are bedding - schistosity. N = north.

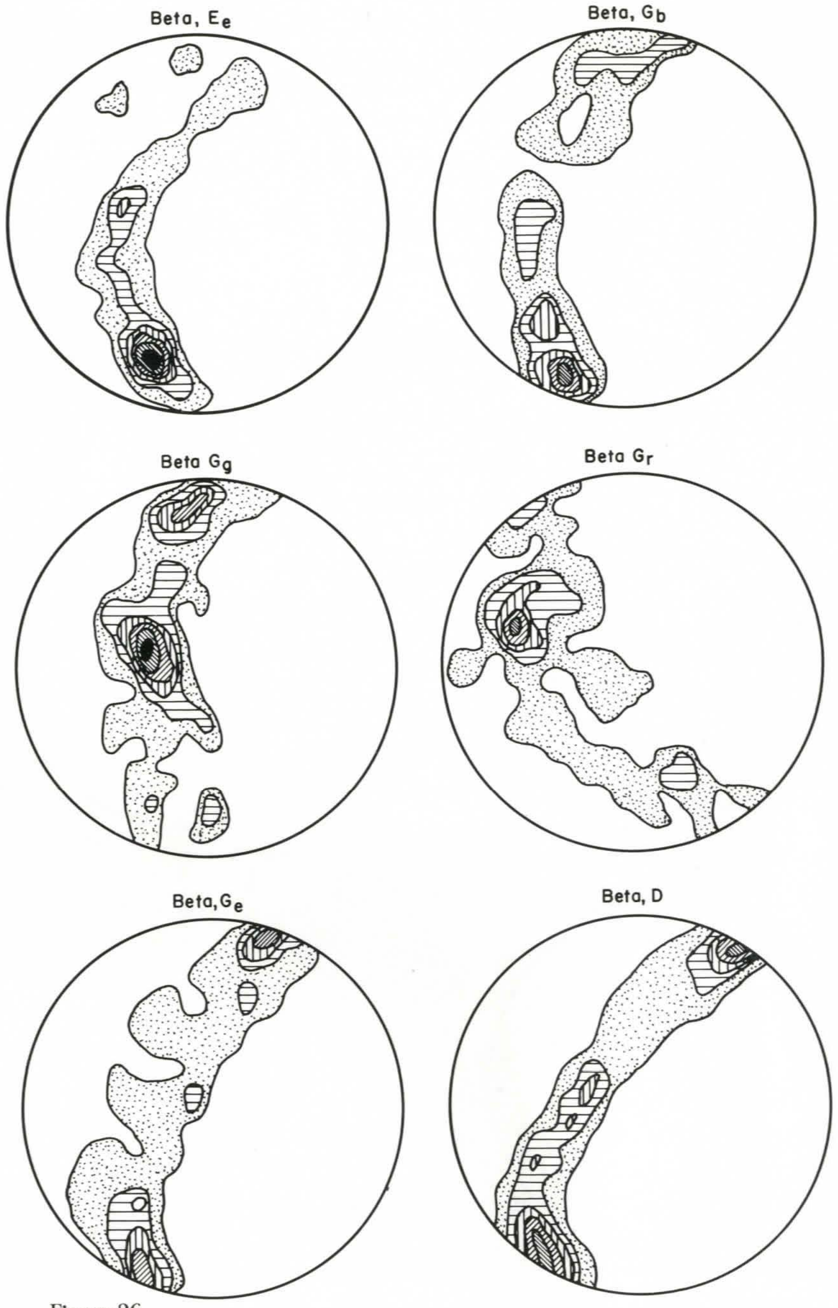


Figure 26
Beta Diagrams of Rocks on Foss Mountain. Letters refer to six domains shown on Plate 4. Contours are 1, 2, 3, 4, 5, and 6 percent.

are later folds. The data from Foss Mountain could be interpreted to indicate two later stages of folding, one about horizontal axes bearing N.20°E., and another about steeply plunging axes bearing N.80°W. But it is equally possible that there was only one stage of later folding, but around variously oriented axes. Beta diagrams of other parts of the quadrangle indicate that the set with horizontal plunges is rather common, but the more steeply plunging folds differ in altitude from place to place.

Structure of the Littleton Formation

The strike of most bedding-schistosity and the plunge of most fold axes is fairly consistently southwesterly. There has probably been some repetition of beds by folding, and it is not possible to precisely calculate the thickness of the Littleton Formation in this area. The representation of folding on the cross sections (Plate I) is diagrammatic and is intended only to show that the rocks have been highly folded and that they are everywhere intruded by granitic rocks and pegmatite.

Without better stratigraphic control, it is inappropriate to draw specific anticlinal or synclinal axes on the tectonic map. The predominance of left-handed drag folds suggests, however, that most of the area is on the southeast limb of a southwesterly plunging synclinorium, assuming that most beds are right side up.

Top/Bottom Criteria

In general, the primary sedimentary features, such as cross bedding, ripple marks or graded bedding, have been obscured by the metamorphism and deformation. However, an example of graded bedding occurs at the 700 foot elevation on the east slope of the knoll just east of Blazo Mountain. Thin layers of feldspathic granofels, one to two inches thick, are interbedded with thin layers of mica schist. The sandy layers in the granofels change character in an upslope direction (west) as larger grains grade into smaller ones. The finest sandy layers grade into mica schist. The beds are apparently right side up, top to the west, as the beds dip west.

Slip Cleavage

The localized slip cleavage is probably related to the crenulations and the evolution of the slip cleavage "s. c." of Plate 4 and shown in Figure 27. The cleavage begins as a well developed set of crinkles that may be right- or left-handed or neutral. If they are neutral, a slip cleavage can develop between each crinkle crest, permitting some slip paralled to the axial planes of the crinkles. If the crinkles have a clear drag sense, then the slip cleavage tends to develop only on one flank of a crinkle.

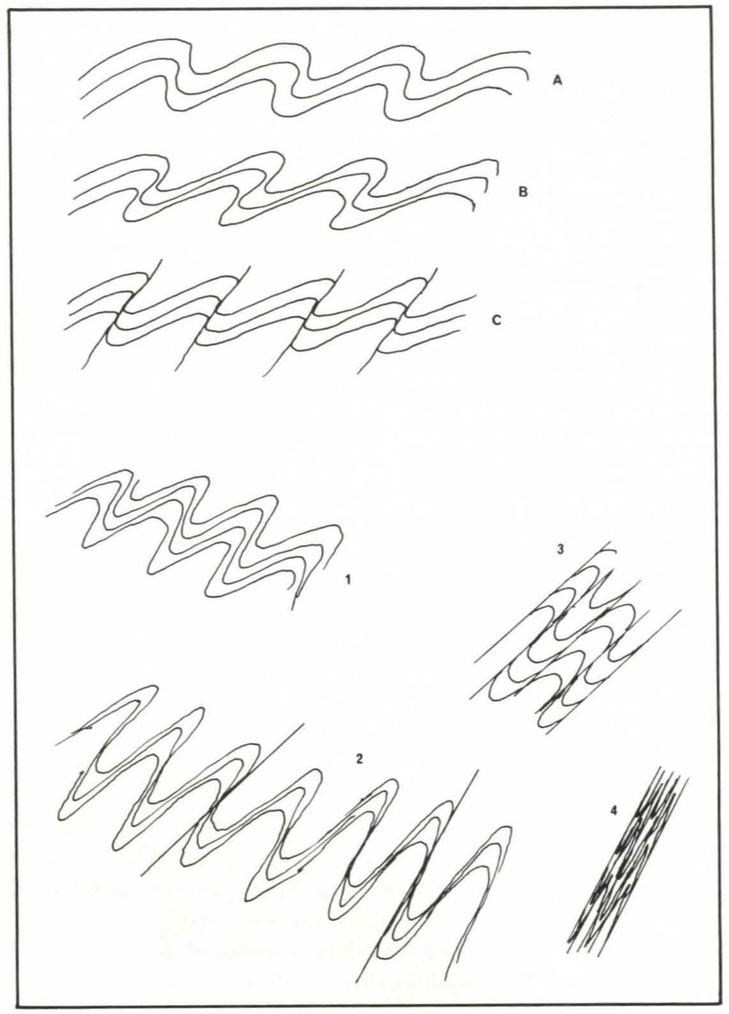


Figure 27

Evolution of Slip-Cleavage. Curved lines are schistosity, straight lines are slip-cleavage. A, B, C = development of slip-cleavage by progressive deformation of crinkles. Magnification x 5.

PEQUAWKET FAULT

Faulting approximately parallel to the trend of the Pequawket Valley was mapped on a basis of the alignment of two linear zones of crushed and silicified rock. One zone is located about half way between the villages of Madison and Silver Lake, 100 yards south of Route 113, northeast of a gravel pit. The other zone occupies the position of the old Madison Lead Mine at spot check elevation mark 530 on the Lead Mine Road east of the south end of Silver Lake. Both zones contain crushed rock.

The north zone is about 15 feet wide and 300 feet long. It consists largely of quartz with some cavities and vugs lined with quartz crystals. The south zone is about 100 feet wide and 1,000 feet long. It contains galena, sphalerite and some pyrite as well as quartz.

Elsewhere in New Hampshire many silicified zones have been mapped and interpreted as lying along normal faults and thrusts. Faults have been mapped on a basis of the occurrence of silicified zones, the long axes of which are coincident (Billings, 1941). The dip of the zones in this area is unknown but assumed to be steep, as is the case in western New Hampshire (Moore, 1949).

Brecciated granite in the dump area of the old mining operation suggests movement has occurred along the fault prior to as well as later than the mineralization. A few miles west, in the Mt. Chocorua area, several silicified zones form arcs that are perhaps related to the formation of the rink dike and stock of White Mountain age in the Ossipee Mountains, but none of the zones in this area fit that pattern. There is no doubt that the silicified zones are younger than the granite-schist complex they cut. Moreover, no zone has ever been observed to cut any White Mountain series rock. The faulting is, therefore, probably older than Late Triassic but younger than Devonian.

Most faults in western New Hampshire are thought to have developed in Triassic time. A large fault has been found to cut Triassic conglomerate of the Newark series in northern-central Massachusetts (Keeler and Brainard, 1940). It created a silicified breccia. Faulting in the Triassic basin of New England was contemporaneous with deposition in several areas, as shown by faults bordering mountains at Mt. Toby, Massachusetts (Longwell, 1937). Moore (1949) concluded that the fluorite mineralization along the Mine Ledge fault in the Keene, N. H. area took place in Triassic time.

IGNEOUS ROCKS

Joints

In the northwest corner of the area jointing is well exposed by the Swift River in its channel traversing the Albany. One of the most prominent fracture zones extends for 100 yards half way between the 800 foot spot check elevation mark on the Passaconaway Road and the Dugway Camping Area. A stereonet plot of the joint data failed to reveal a systematic pattern. Most of the joints there dip 50°-80° in several directions.

In the Ossipee Mountains the most prominent joints occur in the ring dike and tend to strike tangent to it and dip toward the center. Secondary joint sets strike northeast and dip steeply north and south. The best exposures of joint sets in the ring dike are on Raccoon Mountain, on the east slopes of Rattlesnake Mountain and in the stream cuts north of Rattlesnake Mountain.

Contacts

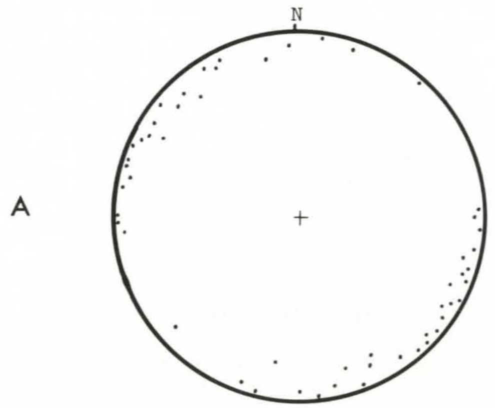
No generalizations are appropriate. There is a sharp contact 0.4 mile up Hobbs Brook between Conway granite and the Albany. However, the contact between the Conway granite and the Mt. Osceola granite is gradational, the only difference between the two being one of mineralogy. Control on this contact is aided by the many trails leading to Mt. Chocorua.

Contacts between pegmatite and granitic rocks of the New Hampshire series are sharp, but there are many outcrops that show a gradual transition from schist to migmatite to various kinds of pegmatite. One such place is the west side of Atkinson Mountain. In other places contacts between pegmatite and schist are very sharp (Figure 28).

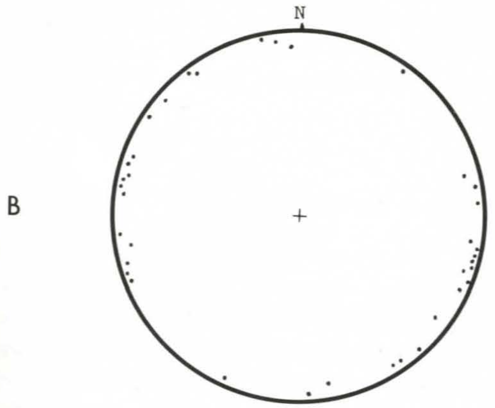
Figure 28
Dike of Aplite and Granite Cutting Mica Schist. Behind farmhouse, 0.8 mile northeast of Cooks Pond. Vertical face 1.5 feet high.

Dikes

Figure 29A shows the altitude of 53 dikes throughout the entire area, they are felsite, camptonite, spessarite and diabase. The altitude of 37 dikes on Foss Mountain are shown in Figure 29B. Most dikes in the Ossipee Lake area strike approximately tangent to the White Mountains batholith.



53 dikes, entire area.



37 dikes, Foss Mountain.

Figure 29
Attitude of Dikes. Poles to dikes, equal area projection, lower hemisphere.

OSSIPEE MOUNTAINS

Location and previous work

The Ossipee Mountains occupy a circular area roughly centered on the intersection of longitude 72°15' west and latitude 43°45' north. As a result, they occur on four U. S. Geological Survey 15' topographic sheets. The Ossipee Lake sheet contains the northeastern corner of these mountains.

They were studied several years before detailed mapping had begun in any of the surrounding areas (Kingsley, 1931). Billings discussed the Ossipee Mountains with regard to earthquakes in this area (1942), the origin of rink dikes (1943) and the mechanics of igneous intrusion in New Hampshire (1945). Many valuable discussions have resulted from the writer's field work with Dr. Lincoln Page and Prof. Billings in the Ossipee Mountains. Alonzo Quinn (1944, 1953) and Althea P. Smith (1941) have also mapped in the surrounding areas, but all published geologic maps that include parts of the Ossipee Mountains refer to Kingsley (1931) as the source for the geology of those mountains.

General Statement

The Ossipee Mountains consist of three broad structural units: 1) the Moat volcanics, 2) the ring dike and 3) the central stock. The outcrop pattern of these rocks is reasonably well known. There are several new observations in this report that concern the dip of the rink dike, the dip of the Moat volcanics, the unconformity at the base of the volcanics and faulting in the Ossipee Mountains. These observations will be discussed, followed by a brief discussion of the structural role of the volcanics and the evolution of the Ossipee Mountains.

Dip of the Ring Dike

Kingsley observed five places, three of them outside this area, where the dip of the ring dike was vertical or "at a high angle". That author noted that the ring dike dips steeply on the north side of Little Mt. Whittier and on the east side of Rattlesnake Mountain. The latter location is still a good one at which to observe the dip of the ring dike. On the east side of Hill 1000, just north of Rattlesnake Mountain, the ring dike dips 80° east, away from the center of the mountains. The exposure is 20 feet high and is depicted in Figure 30. The ring dike is in contact with basalt of the Moat volcanics. It has intruded this basalt and pieces of the dike can be seen stuck to the steep basalt face.

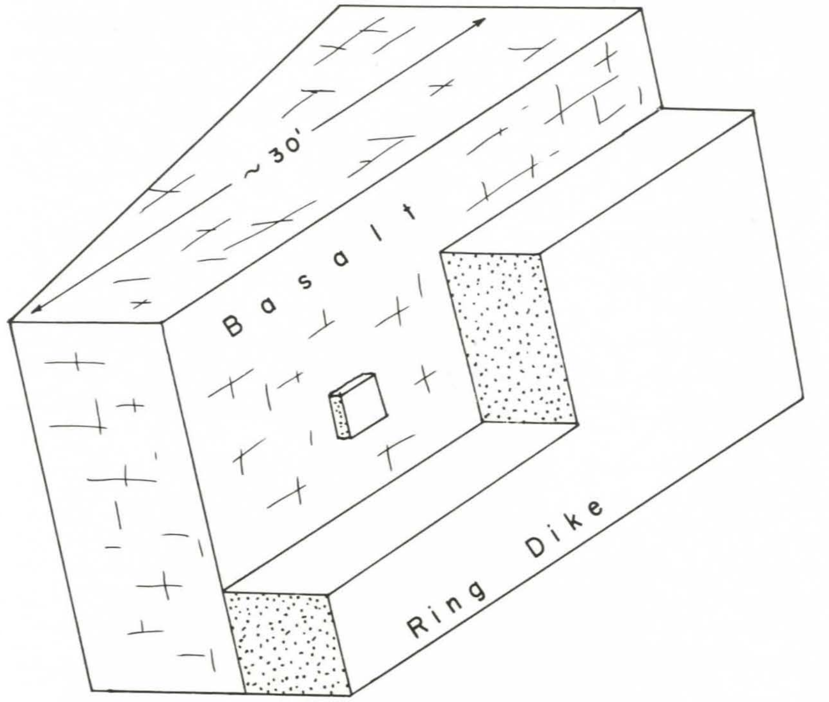


Figure 30

Contact of Ring-Dike. Contact (diagrammatic) between Moat volcanics (basalt) and Albany Porphyritic Quartz Syenite (ring-dike). East side of Rattlesnake Mountain, looking northwest. Note chunk of dike on basalt face.

Dip of the Moat Volcanics

Kingsley noted five localities where the volcanics dipped from 25° to 90° toward the center of the mountains. Two of these localities are in the area: Little Mt. Whittier and Grant Peak. The writer has also observed the inward dip of the volcanics on the northeast side of Mt. Whittier, where they dip 60° south, and on the east side of the Nickerson Mountains where the volcanics dip 50° west. The stratification is commonly seen in thin bedded andesitic tuffs.

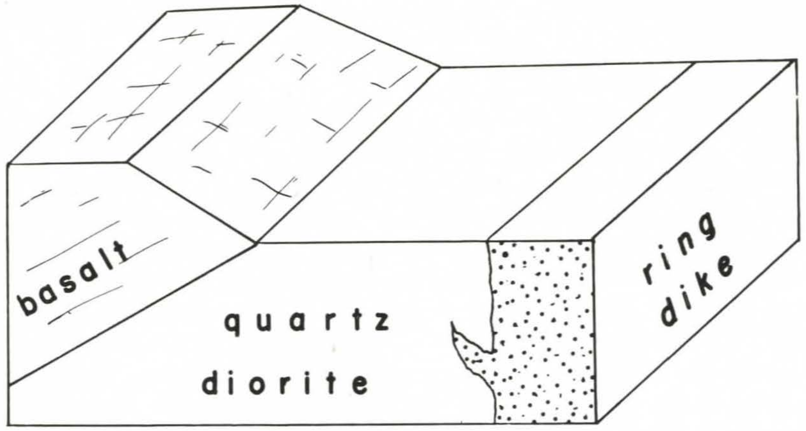


Figure 31

Unconformity at Base of Moat Volcanics. Rattlesnake Mountain, 300 yards south of Figure 30. Diagrammatic. Moat Volcanics (basalt), Winnipesaukee Quartz Diorite, and Albany Porphyritic Quartz Syenite (ring-dike). View looks northeast, front of block about 60 feet across.

Unconformity at the Base of the Volcanics

An unconformity can be observed in the saddle between Rattlesnake Mountain and Hill 1000 just to the north. There massive basalt of the Moat volcanics rests on an erosional surface of Winnipesaukee Quartz Diorite. This is the only place in the Ossipee Mountains where the base of the volcanics is exposed and can be shown to rest unconformably on older granitic rocks of the New Hampshire plutonic series. Several tens of square feet of the erosional surface is exposed and it dips about 35° west, as shown schematically in the block diagram of Figure 31. About 100 yards east is the contact between the ring dike and the Winnipesaukee quartz diorite.

Faulting

Faults have played an important role in the evolution of the Ossipee Mountains. Kingsley discussed this in connection with the theory of cauldron subsidence. One of the best locations to observe the effects of faulting is on East Grant Peak. Granitic rocks of the New Hampshire series, chiefly quartz diorites, have been thoroughly crushed to form mylonites. In the adjacent volcanic rocks, chiefly porphyritic rhyolite and basalt, there are fragments and angular boulders of Concord Granite, Winnipesaukee Quartz Diorite, pegmatite, gneiss and mica schist. The fault in Stony Brook to the northwest of Grant Peak is inferred. One outcrop of volcanics was found 1.1 miles northwest of Grant Peak at elevation 850 feet. This was the only volcanic rock found on the west side of Stony Brook.

There is evidence that the faulting involved the plutonic rocks of the New Hampshire series and metasedimentary rocks. On the northeast side of East Grant Peak there are some outcrops of schist, gneiss and breccia. The gneiss contains some garnet. These rocks might have been originally situated at a much different structural position than they now occupy, but there is no way to know whether these rocks have been downdropped with the volcanics or whether they are a remnant of country rock approximately in place.

There has probably been some post-Triassic faulting as well. The ring dike appears displaced by a fault that strikes east-northeast, 0.7 mile north of Rattlesnake Mountain. The relative movement has caused the north side of the dike to move about 200 feet east relative to the south side. Although there is no surficial expression of faulting in recent times, Billings (1942) has suggested a possible causal relationship between the earthquakes near Whittier, N. H. and faults in the Ossipee Mountains.

Structural Role of the Moat Volcanics

First, textural, mineralogical and/or chemical similarity between some Moat volcanics and some of the plutonic rocks of the White Mountain series has been long known. Second, it has been equally well known for some time that the Moat volcanics exhibit a definite structural association with the Albany Porphyritic Quartz Syenite. Namely, the Albany seems to have been intruded chiefly as ring dikes and other arcuate bodies along faults which permitted the Moat volcanics to be downdropped on the concave side of the ring dikes. Third, many field observations over the years show that the Moat volcanics consist of shallow intrusive porphyries as well as extrusive flows and tuffs. For example, Henderson (1949) noted that the Moat volcanics in the Crawford Notch quadrangle, N. H. are much coarser-grained than most volcanic rocks and stated (p. 50) that, "They (Moat volcanics) are most probably shallow intrusive rocks associated with volcanic rocks" and (p. 54), "Some of the granite porphyry resembles the comendite of the Moat volcanics . . ."

Evolution of the Ossipee Mountains

First, several thousand feet of volcanic flows and tuffs were extruded and deposited on an erosion surface consisting of mica schist, pegmatite and granitic rocks of the New Hampshire series. Volcanic necks and fault zones were probably developed, similar to those at many modern volcanoes. Kingsley mapped a volcanic neck just outside the ring dike in Cold Brook four miles west of the north summit of the Nickerson Mountains. She described it as a dike-like mass about 16 feet thick composed of basaltic breccia and quartz porphyry. Eruptions probably took place along rifts as well. The volcanic breccia on Rattlesnake Mountain was interpreted by Kingsley as a fault intruded by quartz porphyry, basalt and breccia, and was apparently used as a volcanic vent. The faults broke the volcanics up into large blocks that weakened the crust over the area. The volcanics began to drop down at a faster rate when the arcuate fracture zone surrounding the mountains developed. This arcuate fracture zone, produced by the intrusion of Albany Porphyritic Quartz Syenite and Conway Granite from below, served as a path for further shallow volcanic intrusions and surface eruptions. Later, the Albany was intruded along this arcuate fracture zone to form the ring dike. This was followed by the emplacement of the central stock of Conway Granite by stoping.

The inward dip of the volcanic rocks could have been partly due to differential movement along faults. This is a mechanism that is known to commonly result in tilting wherever stratified rocks are faulted at high angles.

CHAPTER 5
METAMORPHISM

General statement

The metasedimentary rocks in the area have been subjected to high-grade regional metamorphism. There are two contrasting types of mineral assemblages in these rocks: 1) pelitic schist and 2) calc-silicate granofels. Among the purposes of this discussion are to discuss the origin of fibrolite (sillimanite) in the schist, to explain the absence of diopside in the calc-silicate granofels and to estimate the conditions of temperature and pressure under which these rocks were metamorphosed.

PELITIC SCHIST
Compositions of the minerals

The compositions of the plagioclase in ten specimens of pelitic schist were given in Table 1. The range was An_{35} to An_{15} and the average composition was An_{26}. These compositions were determined in thin section by optical methods. The biotite, based on immersion measurement of three samples (112, 235, 326), has a gamma index of 1.642 to 1.648. This corresponds to a composition of approximately $K(Fe_{.60-.65}Mg_{.40-.35})_3AlSi_30_{10}(OH)_2$, ignoring Ti, Fe^{+++}, Mn and other cations (Wones and Eugster, 1958). This also ignores the probable small amount of Al present in octahedral coordination.

Modell (1936) reported an almandite from the sillimanite zone of the Littleton Formation just south of the Belknap Mountains, 20 miles to the south southwest, as containing 81 percent $Fe_3Al_2(Si0_4)_3$, 12 percent $Mn_3Al_2(Si0_4)_3$, 6 percent $Mg_3Al_2(Si0_4)_3$ and 1 percent $Ca_3Al_2(Si0_4)_3$, with N_d=1.815 and S. G.=4.23. Table 14 summarizes the physical properties determined by the writer on garnets from this area. Based on composition-physical property diagrams of Winchell (1958) and Sriramadas (1957), the composition of the average garnet from mica schist in this area is 80 percent $Fe_3Al_2(Si0_4)_3$, 10 percent $Mn_3Al_2(Si0_4)_3$, 8 percent $Mg_3Al_2(Si0_4)_3$ and 2 percent $Ca_3Al_2(Si0_4)_3$, with N_d=1.812 and S.G.-=4.13.

The Origin of Fibrolite

The presence of sillimanite in fibrous clots closely associated with biotite and muscovite has been described above. In the migmatite gneisses on Page Hill, K-feldspar, muscovite, sillimanite and quartz are all present,

Table 14

Physical properties of some garnets from mica schist

Specimen	Index of refraction	Unit cell in angstroms	Specific gravity
163	1.811	11.552	4.20
168	1.813	11.545	4.10
169	1.813	11.544	
173	1.812	11.555	4.09
176	1.810	11.557	
192	1.812	11.553	
345	1.811	11.553	

Locations of specimens:

163 Elevation 850 feet, 3/4 mile west northwest of BM 488 at East Madison.
168 Summit of Blazo Mountain.
169 Elevation 1000 feet, one mile east of Durgin Pond.
173 Elevation 790 feet, 1/2 mile northeast of Durgin Pond.
176 Elevation 1030 feet, east side of the hill 1.4 miles north northwest of BM 488 at East Madison.
192 Elevation 1400 feet, east side of Prospect Mountain.
345 Elevation 1600 feet, south side of summit of Foss Mountain.

suggesting the familiar reaction muscovite + quartz = sillimanite + K-feldspar + H_20. The "second sillimanite" isograd is mapped on the basis of this reaction (Plate I).

K-feldspar was undetected in pelitic schist outside the vicinity of Page Hill, necessitating another origin for the fibrolite in the rest of the area. The absence of porphyroblasts of sillimanite and of pseudomorphs of sillimanite or muscovite after kyanite or andalusite suggests that fibrolite was the first Al_2Si0_5 polymorph to form in the progressive metamorphism of these rocks. Staurolite might have been present in the schist at a lower grade. If so, some sillimanite could have formed by the reaction staurolite + quartz = sillimanite + almandite + H_20. The nearest staurolite is in mica schist in the southeast corner of the Kezar Falls area (Gilman, written comm. 1965).

The Thompson (1957) AFM diagram is useful here because its purpose is to aid in graphically analyzing the mineral assemblages in pelitic schists. It considers all the major minerals present in the schist of this area. Figure 32 is a diagram appropriate to the fibrolite schists in this area, except for Page Hill where fibrolite occurs with K-feldspar. "X" in the solid-line triangle represents the assemblage of a sillimanite schist containing garnet, biotite, quartz and muscovite.

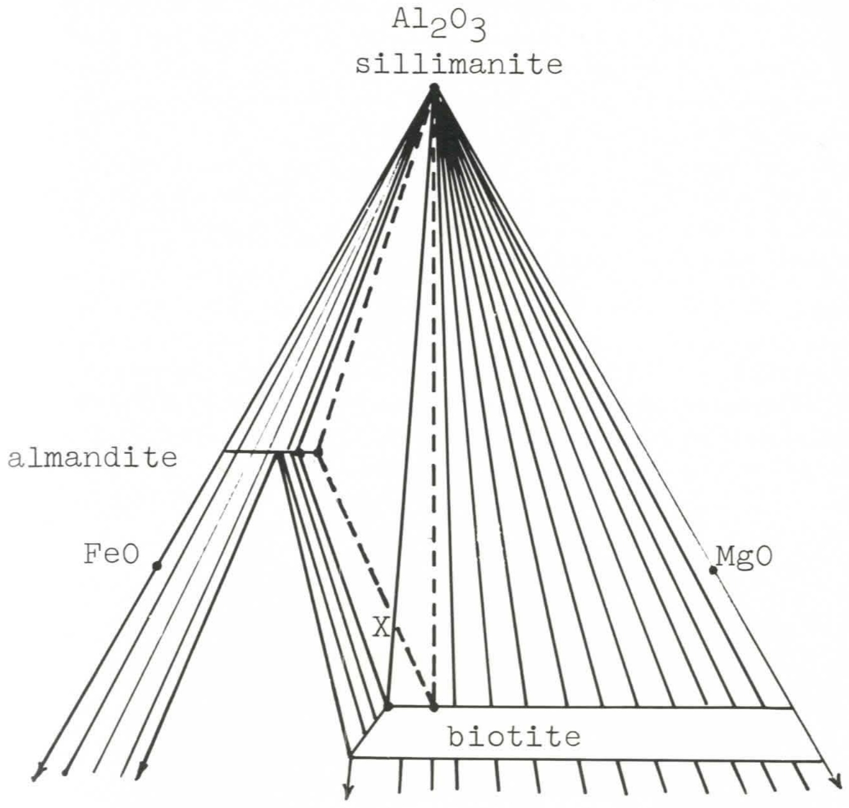


Figure 32

Genesis of Febrolite. Thompson's AFM projection for mica schist of this area; quartz and muscovite are present in all assemblages. X = bulk composition of pelitic schist.

The suggested reaction to form sillimanite is: $KAl_2(AlSi_30_{10})(OH)_2 + (Fe, Mg)_3Al_2(Si0_4)_3 = 2Al_2Si0_5 + K(Fe, Mg)_3(AlSi_30_{10})(OH)_2 + Si0_2$. This may also be written as muscovite + garnet = sillimanite (fibrolite) + biotite + quartz.

The reaction envolves no loss or gain of H_20. Figure 32 represents the reaction graphically. Suppose a pelitic schist initially contains biotite

+ almandite (+ quartz + muscovite). This assemblage can be represented by the "X", where it lies between almandite and biotite under conditions of pressure and temperature in which the dashed-line triangle is a stable three-phase assemblage. Now let the conditions of pressure and temperature change so that the stable almandite and biotite are those joined by the solid-line triangle. "X" now falls within the three-phase assemblage almandite + biotite + sillimanite, the sillimanite having been formed by the reaction written above. As almandite is used up its composition and that of the biotite become more ferrous.

CALC-SILICATE ROCKS

Assemblages

The following principal assemblages occur in calc-silicate granofels and in the concretion described earlier:

Table 15

Mineral Assemblages in Calc-Silicate Granofels

Granofels

qtz-actinolite
qtz-biotite
biotite-plag
actinolite-plag
qtz-plag

qtz-plag-Kspar
qtz-plag-actinolite
qtz-biotite-actinolite
plag-actinolite-biotite

qtz-plag-biotite-actinolite

Concretion

qtz-plag
qtz-actinolite
qtz-grossular
qtz-diopside
plag-actinolite
plag-diopside
plag-grossular
actinolite-grossular
diopside-grossular
actinolite-diopside

qtz-plag-grossular
qtz-plag-actinolite
qtz-actinolite-grossular
qtz-plag-diopside
qtz-diopside-grossular
plag-diopside-grossular

qtz-plag-actinolite-grossular

Compositions of the Minerals

The composition of plagioclase from nine specimens of calc-silicate granofels were given in Table 2. The range was An_{70} to An_{57} and the average composition was An_{64}. Actually, four specimens in Table 2 are andesines and five are labradorites. Two of these compositions (31, 110) were determined by measuring indices in immersion and using the determinative chart of Chayes (1954). The other compositions were inferred from optical properties determined in thin section.

Biotite is probably about $K(Mg_{.6}Fe_{.4})_3AlSi_3 0_{10}(OH)_2$, judging by the relatively low gamma refractive indices of 1.600 and 1.625, the range of Nz in three biotites from Table 16. This table also lists the optics and specific gravities determined by the writer for actinolite and tremolite in six specimens. The data indicate that the actinolites and tremolites vary in composition over the range of about $Ca_2(Fe_{.5}Mg_{.5})$ - $Ca_2(Mg_{.9}Fe_{.1})_5 Si_8 0_{22}(OH)_2$. The grossularite in the concretion was so identified on the basis of a refractive index of 1.769.

Table 16

Properties of some minerals from calc-silicate granofels

Specimen	Mineral	Nx	Nz	Z/c°	Other
106	tremolite	1.619	1.642	18	S.G.=3.03
	biotite		1.600		
114	tremolite	1.624	1.653		
31	actinolite	1.637	1.663	17	
	andesine	1.549	1.557		An_{40}
	biotite		1.610		
29	actinolite	1.651	1.671	16	
22	actinolite	1.653	1.678	15	
	biotite		1.625		
110	actinolite	1.652	1.676	17	S.G.=3.20
	labradorite	1.562	1.569		An_{63}

Comparison of Calc-Silicate Granofels and a Concretion

Most calc-silicate rocks in Maine and New Hampshire that have been metamorphosed under medium to high-grade conditions contain diopside. Many geologists would regard the absense of diopside from a calc-silicate rock in rocks of this metamorphic grade as unusual. The lack of diopside here simply means that the original sediment was so low in carbonate that all of it was used up in the formation of actinolite. Table 17, listing calculated chemical compositions of five calc-silicate granofels, shows that the average content of Ca0 in these rocks is less than 7 weight percent. A concretion had enough carbonate to form diopside and grossularite as well as actinolite. The presence of diopside in the concretion proves that its absence in the calc-silicate granofels is due to bulk composition and not to metamorphic grade. Based on the abundance of biotite in the calc-silicate granofels and its total absence in the concretion, a similar argument holds for the potassium content of the two rocks.

Table 17
Calculated chemical compositions of some lime-silicate of rocks in the Littleton Formation

	114 a	31 a'	29 a	22 a	110 a	88 a	SAL
$Si0_2$	57.03	61.70	59.45	57.12	61.75	76.00	61.66
$Ti0_2$	1.06	0.39	0.85	0.91	0.96	0.50	0.99
Al_20_3	10.32	10.67	13.26	11.63	13.40	9.50	19.85
Fe_20_3	tr	tr	tr	tr	tr	0.50	1.49
Fe0	5.32	5.98	7.53	8.96	6.09	1.62	5.38
Mg0	12.65	9.61	5.63	8.03	5.16	2.15	2.05
Ca0	6.50	3.77	8.52	7.35	8.47	8.50	0.38
Na_20	1.42	1.58	2.02	1.53	1.67	1.21	1.17
K_20	3.80	4.24	1.59	2.92	1.49	-------	3.74
H_20+	1.94	1.80	1.11	1.58	0.98	-------	3.22
	100.04	100.02 b	99.96	100.03	99.97	99.98	99.93
$\frac{Ca0}{Fe0+Mg0+Ca0}$	.27	.20	.39	.30	.43	.69	.05

a)=Calculated analysis, based on mode in table 2-2 and, for 88, based on mode in text.
b)=includes 0.28 P_20_5.

The figures in this table are in weight percent. Nos. 114 through 110 are calc-silicate granofels, No. 88 is the concretion described elsewhere in the text and SAL is Shaw's (1956) average Littleton schist.

CONDITIONS OF METAMORPHISM

General statement

In estimating conditions of metamorphism, the mineralogy and texture of the rocks can be considered in light of pertinent experimental studies. First, however, some attention will be given to the field observations described previously, namely that 1) the pelitic schists and migmatite gneisses commonly contain muscovite, biotite, quartz and oligoclase, with lesser amounts of almandite, sillimanite, tourmaline and K-feldspar, and 2) these rocks are thoroughly intruded by pegmatites and by two-mica two-feldspar granitic rocks. Moreover, migmatite is common, locally isolated from any intrusive granitic rocks.

The migmatites give the impression of partial melting in layers containing K-feldspar, sodic plagioclase and quartz. The original rock might have been an interbedded series of shales and graywackes. With increasing grades of metamorphism these rocks yielded increasingly less hydrated mineral assemblages. Finally conditions were obtained at which partial melting of layers with feldspar and quartz could occur. The fraction of liquid produced would depend on the bulk composition of the rock and on how high the temperature was raised.

Figure 33 shows quartz-bearing mineral assemblages produced in the migmatites of this area during the metamorphism. The composition plane for the diagrams **a** and **b** in Figure 33 is a section through the tetrahedron $Si0_2$ - Al_20_3 - $KAl0_2$ - $NaAl0_2$. Diagram **a** shows assemblages prior to the partial melting of layers with quartz and alkali feldspar. Diagram **b** shows assemblages with a liquid phase(L) produced by partial melting. The modal bulk composition of the pegmatite, of the quartz-feldspar-muscovite layers in the migmatite and of the Concord Granite plot approximately at the liquid (L). The presence of muscovite in all those rock types indicates that the liquid (L) was slightly peraluminous as shown.

Experimental Studies

Winkler (1961) and Winkler and von Platten (1958, 1960) have conducted some pertinent experiments on the melting of shales and graywackes. These authors were concerned with the way the chemistry of shales and graywackes affected 1) the temperature of the beginning of melting, 2) the quantity of melt formed at given temperatures and 3) the chemistry of the melt. A summary of some of their findings is relevant here:

1. At 2 kilobars, in the presence of an aqueous phase, a "highest grade" metamorphic facies is developed at about 630°C. and extends to 700± 40°C. at which point the first melt appears. The mineralogy of this artificial facies is quartz, plagioclase, alkali feldspar, biotite, sillimanite

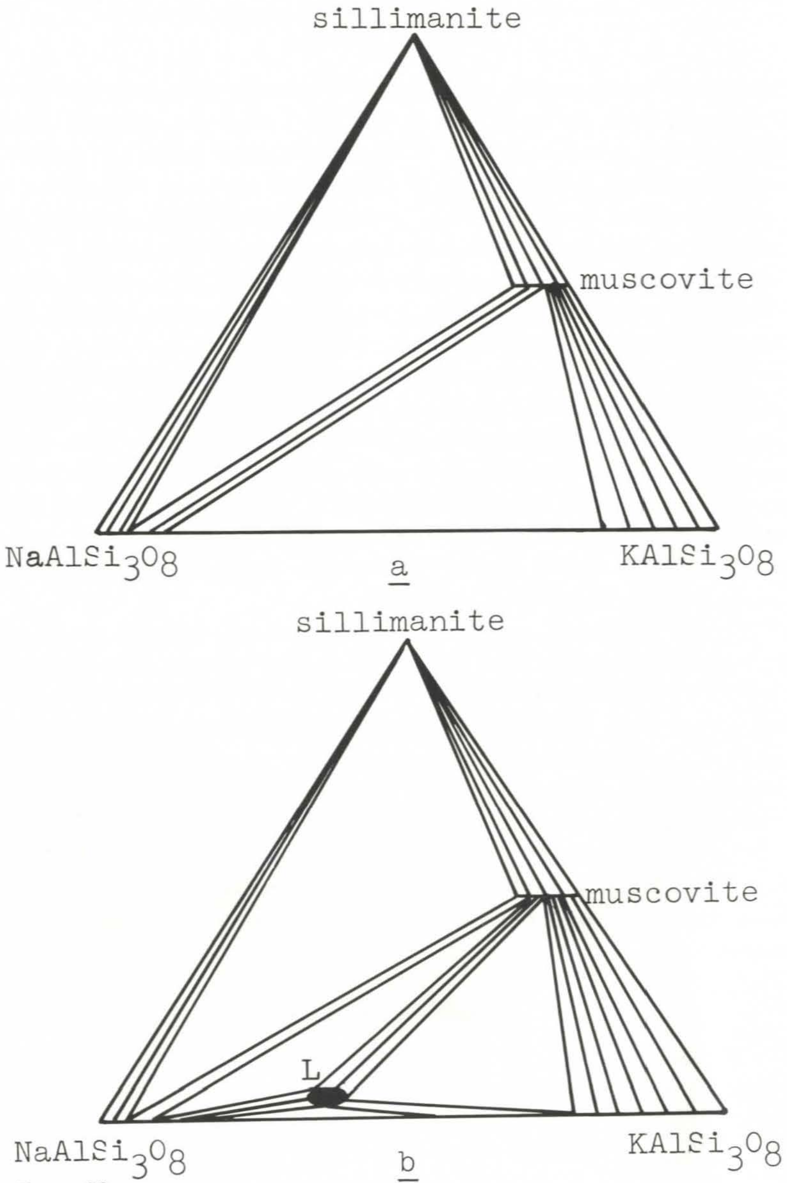


Figure 33

Genesis of Migmatite. Phase relations in the system Al_2O_3-$KAlO_2$-$NaAlO_2$-SiO_2 related to the high-grade regional metamorphism of pelitic schist developing into migmatite. All assemblages contain quartz.

a. Temperature too low to develop a liquid phase.

b. Temperature sufficiently high to develop a liquid.

L = liquid phase, slightly peraluminous, the composition of which is inferred from the average mode of granitic lenses in the migmatites.

and cordierite. Above 625°C. no more muscovite was present.

2. These temperatures are affected chiefly by the modal ratios of Na-plagioclase/K-feldspar (a result of fractional fusion in the granite system).

3. Initial melts are aplitic for rocks low in lime. (By aplitic, Winkler means chiefly quartz + K-feldspar).

4. On a highly metamorphosed basement complex one must consider the formation of melts and the possibility of their more or less extensive separation from their host rock, leading to "granitoid" magmatic rocks and the formation of migmatites. Such melts, according to Winkler, on tectonic separation from their host rocks, might be emplaced as individual intrusions.

In a similar vein, Wyllie and Tuttle (1957) worked on the hydrothermal melting of shales low in soda compared to potash and they concluded that sediments with a wide range of composition will be partially melted in the presence of water vapor at temperatures that could be reached "at no great depth in orogenic belts of the earth's crust".

Figure 34 shows three pressure-temperature plots that are useful in studying the pelitic schist and migmatite gneiss of the Ossipee Lake area. One plot shows the most recent information on the univariant equilibria in the system Al_2SiO_5 (kyanite-andalusite-sillimanite) (Richardson et al., 1969). A record plot is the granite melting curve (Tuttle and Bowen, 1958); however, an important restriction is that this curve assumes the rock is saturated with water at all pressures. The third plot is the muscovite stability curve of Segnit and Kennedy (1961).

Evidence from Ossipee Lake Area

Apparently the rocks in the Ossipee Lake area were not aluminous enough to produce either andalusite or kyanite prior to sillimanite. This is based on the observation that the only sillimanite here is fibrolite. No pseudomorphs of sillimanite or muscovite after andalusite or kyanite occur. In southwestern New Hampshire, by contrast, there are large porphyroblasts of sillimanite in the Littleton Formation and on Mt. Washington the formation contains large porphyroblasts of andalusite.

Referring to Figure 34, the conditions of regional metamorphism in the Ossipee Lake Quadrangle took place under conditions lying to the left of the muscovite curve (except in the Page Hill area) but within the sillimanite zone. Moreover, conditions were close to those represented by the granite curve, as partial melting of the rocks took place. As a first approximation, and fully cognizant of the limitations of Figure 34, regional metamorphism took place at a pressure somewhere between 4 and 7 kilobars and at a temperature around 700°C. But if the granite melting curve should lie further to the right, pressures might have been as low as 3 kb

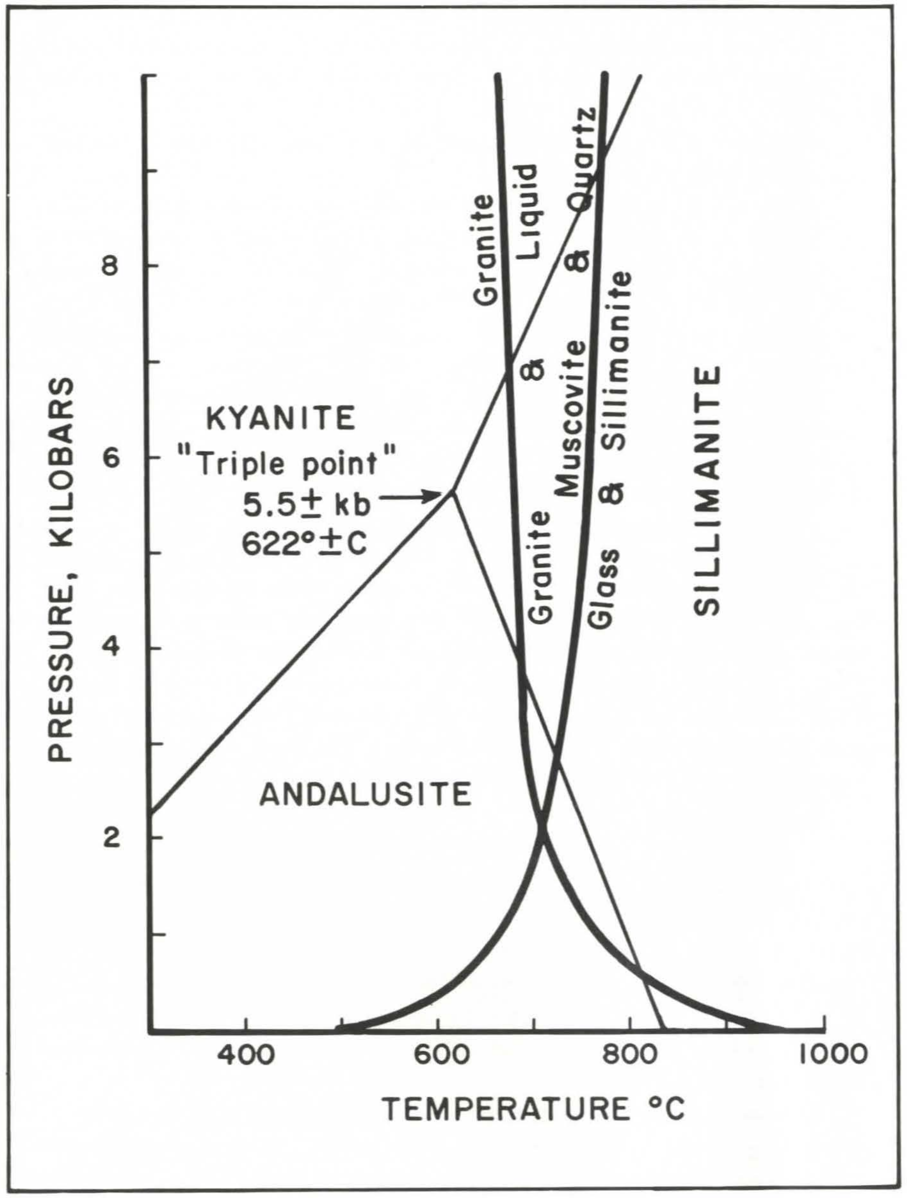


Figure 34

Some Experimentally Determined Stability Relations. Data for kyanite, andalusite, and sillimanite system from Richardson et al (1969); granite melting curve from Tuttle and Bowen (1958); muscovite stability curve from Segnit and Kennedy (1961).

or as high as 9kb. The conversion factor 3.8 converts pressure in kilobars, assuming the average density of rock to be 2.75 g/cc to rock load in kilometers. Thus the cover of overlying rock, in round numbers, was between 11 and 34 km (7 and 20 miles). This subject is discussed again in a later section.

Regional Observations

Regional observations also offer some evidence on the pressure and temperature during regional metamorphism. The most easily interpretable relations are the regional distributions of the Al_2SiO_5 polymorphs. The particular polymorphs present should place definite restrictions on the conditions of pressure and temperature that could have existed while the rock was metamorphosed. Sillimanite has been produced by high temperatures superimposed on kyanite- and andalusite-bearing rocks in many parts of New England. In some places, as in northeastern Vermont, the sillimanite occurs in contact zones around plutonic rocks of the New Hampshire series (Albee, 1968). In other areas, as on Mt. Washington, the sillimanite is a product of regional metamorphism. However, the regional distribution of andalusite and kyanite, shown on Figure 35, is especially helpful in estimating ranges of pressure that probably existed prior to the superimposed higher temperatures that, in many places, produced sillimanite. Prof. James B. Thompson, Jr., first suggested this to the writer (See also Thompson and Norton, 1968).

Andalusite-bearing rocks and some scattered kyanite-bearing rocks occur in the eastern two-thirds of New Hampshire and western Maine. Kyanite without andalusite occurs further to the west and southwest in New England. In Figure 35 a dashed line has been drawn at the western limit of the andalusite-bearing rocks. Sillimanite occurs on both sides of this line. Thus temperature-pressure conditions along this line must have been essentially those of the triple point, that is, 5.5 ± kb and 622° ± C. This is equivalent to a depth of 21 kilometers or 13 miles.

Mechanics of Deep Burial

How rocks deposited originally at the surface of the earth could attain such depths is a problem. Burial under later sediments is one factor. Much of the kyanite is in pre-Silurian rocks that were covered by at least several miles of Devonian rocks. Moreover, an unknown amount of Devonian strata has been eroded away. Tectonic thickening by recumbent folding and overthrusting may also be a factor. This is especially true in western New Hampshire (Thompson et al., 1968). Great sheet-like intrusions may also depress the strata on which they lie. The overlying load in the Ossipee Lake area may have been less than that in western New Hampshire.

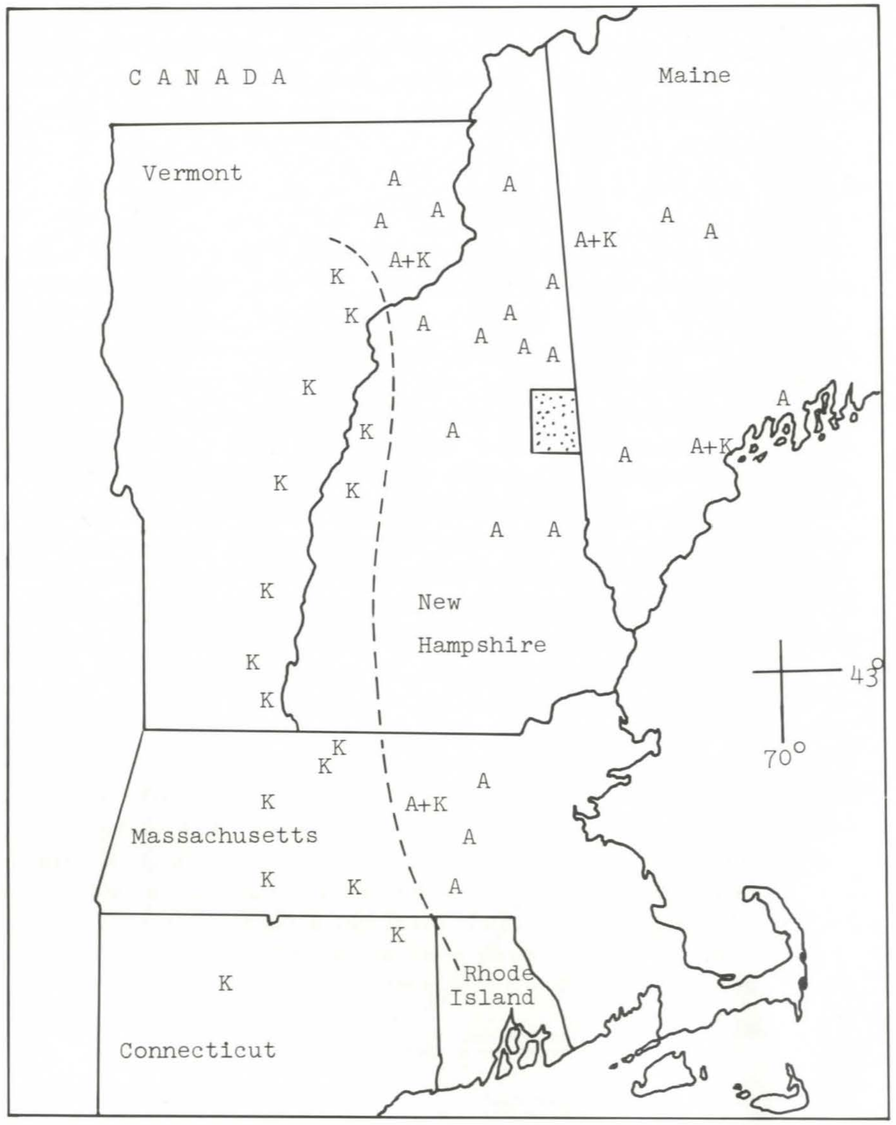


Figure 35

Distribution of Kyanite and Andalusite in New England. A = Andalusite. K = Kyanite. Compiled from data in Billings (1928, 1937, 1942), Doll (1961), Chapman (1939), Emerson (1917), Hussey (1965), Green (1963), Hadley and Chapman (1939), Hatch (1963), Henderson (1949), Milton (1961), Modell (1936), Moke (1949), Pankiwskyj (1964), Pendexter (1949), Robinson (1963), Stanley (1964), Stewart (1961), and Woodland (1963). Also personal communications from Roberta Dixon, J. B. Thompson, Jr., and Jeffrey Warner. See also Thompson and Norton (1968).

The best estimate we can make is that regional metamorphism in the Ossipee Lake area took place under a pressure of not less than 4 kb or more than 7 kb at temperatures from 650°C. to 700°C. These pressures imply a cover of 15 to 27 kilometers, that is 9 to 16 miles.

PROBLEM OF TOURMALINE

Tourmaline is common in the high-grade schists of this area. Curiously, the pegmatite here, unlike that in the adjacent Kezar Falls area, is practically devoid of tourmaline. This discussion is concerned with the genesis of tourmaline in the schist.

Frondel and Collette (1957) synthesized tourmaline and remarked that, "With increasing temperature the boron may become available to interstitial solutions . . . and these solutions may then react with the aluminosilicates to form tourmaline . . .". They quoted several authors who have studied the geochemistry of boron and found it to be present in argillaceous marine sediments to the extent of about 0.03 to 0.15 weight percent B_2O_3. Tourmalines commonly contain about 10 weight percent B_2O_3. In this area tourmaline accounts for probably about 0.1 percent of all the schist in the Foss sequence, where it is especially common. This gives a figure of 0.01 weight percent B_2O_3 in the schist, at least three times lower than the lowest common range for B_2O_3 in marine shales. This might be explained by the relatively sandy nature of much of the schist in this area, even in the Foss sequence. Apparently, authigenic boron resides chiefly in the clay minerals present in shale.

It is concluded here that the tourmaline in schist of this area is authigenic. Its distribution might be stratigraphically controlled.

CHAPTER 6
IGNEOUS PETROLOGY

General statement

Several studies have been made of the mineralogy and evolution of the White Mountain plutonic series (Billings, 1928; Chapman and Williams, 1935; Smith, 1940; Henderson, 1949). The following discusses several aspects of igneous petrology related to plutonic rocks of the White Mountain series. This includes 1) the genesis of some textures in the Albany Porphyritic Quartz Syenite, in the Mt. Osceola Granite and in the Conway Granite, and 2) a discussion of the conditions under which plutonic rocks of this area crystallized. The abbreviations An = $CaAl_2Si_2O_8$, Ab = $NaAlSi_3O_8$, Or = $KAl\,Si_3O_8$ and "kb" = kilobars will be used. It will be necessary to first summarize pertinent experimental studies.

Approximately 80 percent of the outcrop area in the White Mountains batholith, including the Baldface Mountain, Cannon Mountain and Mad River stocks, consists of Conway Granite or of Mt. Osceola Granite. The normative and modal compositions of these granites (Table 18) consist mainly of quartz and alkali feldspar. Therefore, most of the White Mountains batholith consists of granites with compositions that can be closely represented in the system SiO_2-Ab-Or. Equilibria involving An and H_2O, however, are pertinent to many aspects of the discussion.

EXPERIMENTAL STUDIES IN THE SYSTEM SiO_2-An-Ab-Or-H_2O

Alkali feldspar solvus in the subsystem Ab-Or-H_2O

Orville (1963) found the critical feldspar, i.e. the critical point or maximum on the Ab-Or miscibility gap, to have a composition of Ab_{67}-Or_{33} (mole percent) at 2 kb and about 680°C. Bowen and Tuttle (1950) found the critical feldspar to be $Ab_{55}Or_{45}$ at one kilobar and 660°C. Yoder, et al. (1957) found the critical feldspar to be $Ab_{55}Or_{45}$ at 5 kb and 715°C. The minimum on the liquidus in this system is $Ab_{70}Or_{30}$ at pressures between 1 and 3 kb (Tuttle and Bowen, 1958); at 5 kb it is $Ab_{71}Or_{29}$ according to Yoder, et al. (1957) or $Ab_{73}Or_{27}$ according to Luth, et al. (1964). The above critical points and minimum compositions in this system are plotted on the base edge Ab-Or of Figure 37.

Two-feldspar field boundary in the system An-Ab-Or-H_2O

Figure 36 summarizes the available information on the two-feldspar field boundary, i.e. the line that shows how a liquid in the feldspar system saturated with respect to two feldspars, a plagioclase and a K-feldspar, and with respect to an aqueous phase, changes composition as the two feldspars crystallize under conditions of falling temperature.

Table 18
Comparison of chemical composition of some New England granites

	CG	HG	QG	MOG
SiO_2	71.73	69.85	72.26	72.94
TiO_2	0.50	0.74	0.36	0.18
Al_2O_3	14.30	14.44	13.18	12.46
Fe_2O_3	1.25	0.94	0.24	0.62
FeO	1.51	2.37	2.77	2.23
MnO	0.05	tr	0.10	0.06
MgO	0.18	0.24	0.20	0.17
CaO	1.11	1.25	1.10	2.15
Na_2O	3.89	3.93	3.99	3.63
K_2O	4.89	5.04	5.01	5.02
H_2O+	0.42	0.66	0.20	0.38
H_2O	0.10	0.35	0.08	0.16
P_2O_5	0.02	0.03	0.07	0.05
	99.95	99.84	99.56	100.05
Norms				
Qtz.	29.8	26.4	26.1	31.0
Or.	27.7	28.9	29.5	28.4
Ab.	33.4	34.2	34.1	31.3
An.	6.8	6.3	3.1	2.8
Wo+En+Fs	0.8	3.2	5.0	5.7
Mt. + Ilm.	1.5	1.7	1.0	0.7
Apat.	0.1	0.1	0.2	0.1

CG: Conway Granite, average of two analyses from the Redstone quarry, N. H. (Perry, 1903; Billings, 1928).
HG: Hastingsite Granite, Redstone quarry, "green phase" of Conway granite (Billings, 1928).
QG: Quincy Granite, Mass. (Tuttle and Bowen, 1958).
MOG: Mt. Osceola Granite, Franconia quadrangle, N. H. (Williams and Billings, 1938).

Granite system Ab-Or-SiO_2-H_2O

As an aid in explaining further the genesis of the mineralogy and texture of some of the igneous rocks in this area, it is useful to consider the phase relations in the granite system. The liquidus for this system, in the presence of an aqueous phase, has been investigated at low to moderate pressures by Tuttle and Bowen (1958) and at higher pressures by Luth, et al. (1964).

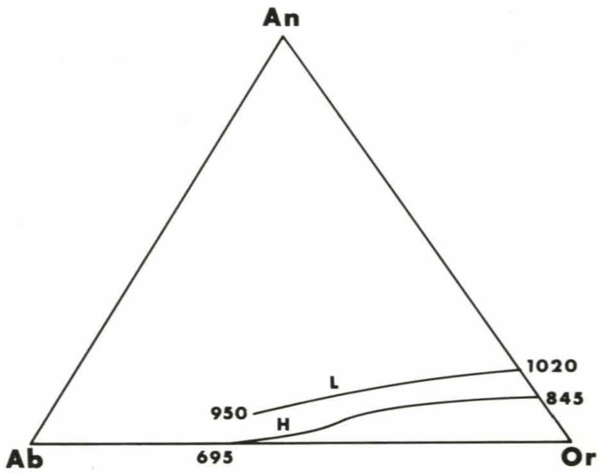


Figure 36

Two-feldspar Field Boundary. In system An-Ab-Or. Boundary L is a low-pressure case for trachytic lavas at high temperature. Boundary H is a high-pressure case (5kb) at lower temperatures. See text for source of data.

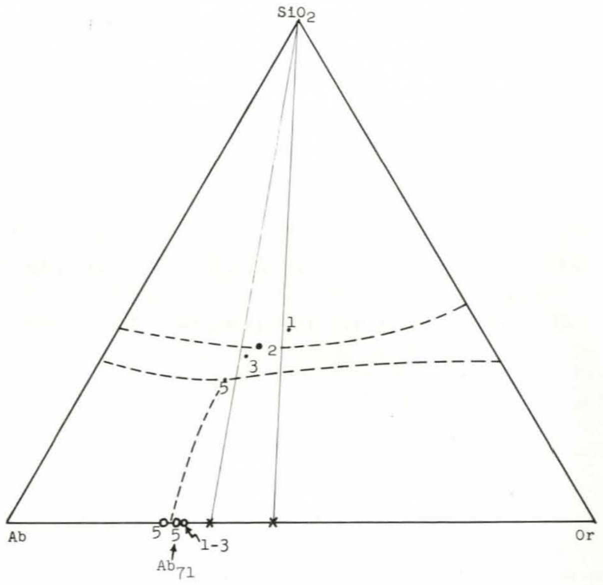


Figure 37

Phase Relations in Granite System (Ab-Or-SiO_2-H_2O). Dark circles are ternary minima at pressures of 1, 2, 3, and 5 kb. Open circles are binary minima in subsystems Ab-Or-H_2O plotted on the edge Ab-Or at pressures of 1-3 kb, and 5 kb (for which different investigators give slightly different figures). Sources: Tuttle and Bowen, 1958; Yoder et al (1957); Luth et al (1964).

In Figure 37 dark circles are ternary minima at pressures of 1, 2, 3 and 5 kb, and open circles are binary minima in the subsystem Ab-Or-H_2O plotted on the edge Ab-Or in weight percent at pressures of 1-3 kb (Tuttle and Bowen, 1958) and at 5 kb (Yoder, et al. 1957, and Luth, et al. 1964).

Figure 38 is a pressure-temperature diagram for the granite system. All of the univariant curves except two, B3 and H6, have been experimentally determined. The locations of curves B3 and H6 are inferred. All equilibria are with an aqueous phase present that is essentially pure H_2O. The compositions of the other phases can thus be represented in terms of SiO_2, Ab and Or only.

The line 23456 in Figure 38 is the critical curve for the miscibility gap in the system Ab-Or (Orville, 1963; Yoder, et al. 1957). The curve AB2C shows the temperature of the minimum on the liquidus surface of Figure 37 as a function of pressure (Tuttle and Bowen, 1958; Luth, et al., 1964). Curve D4EF is the corresponding curve for the subsystem SiO_2-Ab-H_2O (Luth, et al. 1964), curve LJEM is the corresponding curve for the subsystems SiO_2-Or-H_2O (Luth, et al. 1964) and curve GH5JK is the corresponding curve for the subsystem Ab-Or-H_2O (Luth, et al. 1964).

The four-phase equilibrium on B3 and the three-phase equilibrium on H6 have not been determined experimentally, but their existence can be inferred on theoretical grounds. The precise location of either B3 or H6 has not yet been determined.

The curve AB3 represents the pressure-temperature curve for the coexistence of a liquid, two feldspars, a silica mineral and (as in all the above equilibria) an aqueous phase. Points on AB are ternary eutectics in the projected system and points on B3 are ternary peritectics in the projected system. The curve GH6 plays a similar role in the binary subsystem Ab-Or-H_2O. GH represents the binary eutectic in the projected subsystem and H6 represents the binary peritectic in the projected subsystem. It is of interest to know in what sense the equilibria on B3 and H6 are peritectic, i.e. "rapakivi" or "antirapakivi".

From Figure 37 it can be seen that the minimum on the liquidus along the edge Ab-Or plots to the Ab-side of the critical feldspar at any pressure. At pressures and temperatures on curve H6 in Figure 38, where the feldspar solvus has intersected the solidus, the three-phase equilibrium Liquid - Na feldspar - K feldspar is therefore "rapakivi" in the sense that the peritectic reaction Liquid + K-feldspar = Na-feldspar produces mantles of potassic feldspar around sodic feldspar.

The nature of the reaction that takes place on crossing curve B3 in Figure 38 is ambiguous. On crossing curve AB with increasing temperature there is only one possibility. A eutectic liquid first forms inside the three-phase triangle SiO_2-Na feldspar-K feldspar. On crossing curve B2 with

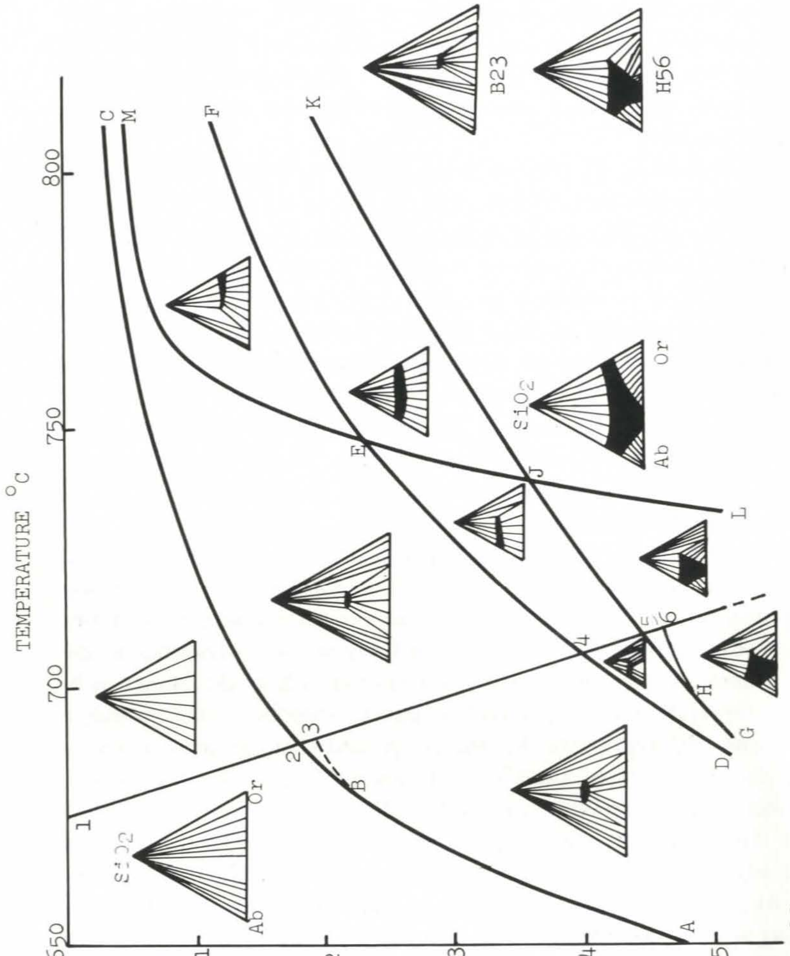


Figure 38

Pressure-Temperature Phase Relations in the Granite System. Each triangle represents different equilibrium conditions. Solid black areas are liquids, two phase tie-lines are faint straight lines. Curve 1 is miscibility gap in system Or-Ab. Other curves are temperature of minimum or liquidus surface as a function of pressure: AC for system Ab-Or-SiO - H_2O; DF for system Ab-SiO_2-H_2O; GK for system Ab-Or-H_2O; LM for system Or-SiO_2-H_2O. Sources: Orville (1963), Tuttle and Bowen (1958), Luth et al (1964). See text for discussion.

increasing temperature or pressure, there are two possibilities. Either the first liquid appears in the field SiO_2-Na feldspar or it appears in the field SiO_2-K feldspar. Which of these two-phase fields the first liquid appears in is determined by the composition of the ternary minimum relative to the composition of the critical feldspar. Point 2 in Figure 38, where a liquid at the ternary minimum is in equilibrium with a critical feldspar, is at a pressure of about 2 kb.

From Figure 37 there are two versions of the composition of the critical feldspar (at any pressure between 1 and 5 kb). Orville gives it as Ab_{66} (calculated to weight percent). Yoder, et al., and Bowen and Tuttle give it as Ab_{55}.

If Ab_{66} is used for the critical feldspar, then the first liquid forms in the field SiO_2-K feldspar, as shown in Figure 38. If Ab_{55} is used for the critical feldspar, then the first liquid forms in the field SiO_2-Na feldspar (across curve B3).

Thus, the phase relations in field B23 will either be those shown or the mirror image of those relations, with the corners of the composition triangle fixed, depending on the true composition of the critical feldspar. As drawn in Figure 38, the equilibrium along curve B3 is a ternary peritectic in the sense that K-feldspar mantles Na-feldspar by the reaction Liquid + Na-Feldspar = K-feldspar + SiO_2. This is based on Orville's critical feldspar. The sense of the reaction across B3 would be reversed if the critical feldspar is more Or-rich than the liquid at the ternary minimum at about 2 kb, as the data of Yoder, et al. and of Bowen and Tuttle suggest.

Tuttle and Bowen (1958) have determined the amount of H_2O dissolved in melts at the ternary minimum for four pressures, as follows: 0.5 kb - 2.9 percent H_2O, 1.0 kb - 4.5 percent H_2O, 2.0 kb - 6.6 percent H_2O and 3 kb - 9.7 percent H_2O. Luth, et al. (1964) found that the H_2O content in the ternary eutectic liquid at 5 kb was 11 percent and at 10 kb it was 17 percent.

System An-Ab-Or-SiO_2-H_2O

Figure 39 shows three partly hypothetical liquidus diagrams at one atmosphere, at 2 kb and at 5 kb. Figure 39a is based on data for the anhydrous system SiO_2-Ab (Schairer and Bowen, 1947), and for the systems SiO_2-An-Or (Schairer and Bowen, 1947a) and SiO_2-Ab-Or (Schairer, 1950). Temperatures on the liquidus of Figure 39a are those along the SiO_2-feldspar field boundary projected through SiO_2. The internal form of the diagram is inferred. The experimental data are for purely anhydrous systems listed above, but had the experiments been conducted in the presence of an aqueous phase, the temperatures would not be appreciably different because so little H_2O is soluble in silicate melts at one atmosphere. In diagram 6-4a a two-feldspar field boundary must originate at the eutectic on the An-Or edge, in the vicinity of which crystallization is clearly cotectic because the composition of both feldspars lies on opposite sides of the point of intersection of the tangent to the field boundary and the line joining An and Or. However, under conditions of fractional crystallization, the liquid-feldspar equilibrium becomes peritectic, for reasons discussed below.

Figure 39b is based on data at 2 kb for the systems $Si0_2$-Ab-H_20 (Tuttle and Bowen, 1958), $Si0_2$-Ab-Or-H_20 (Tuttle and Bowen, 1958) and $Si0_2$-Or-H_20 (Luth, et al. 1964). The internal form of the diagram is inferred to differ from Figure 39a only in that the critical end point at 2 kb is further displaced towards the Ab-Or edge.

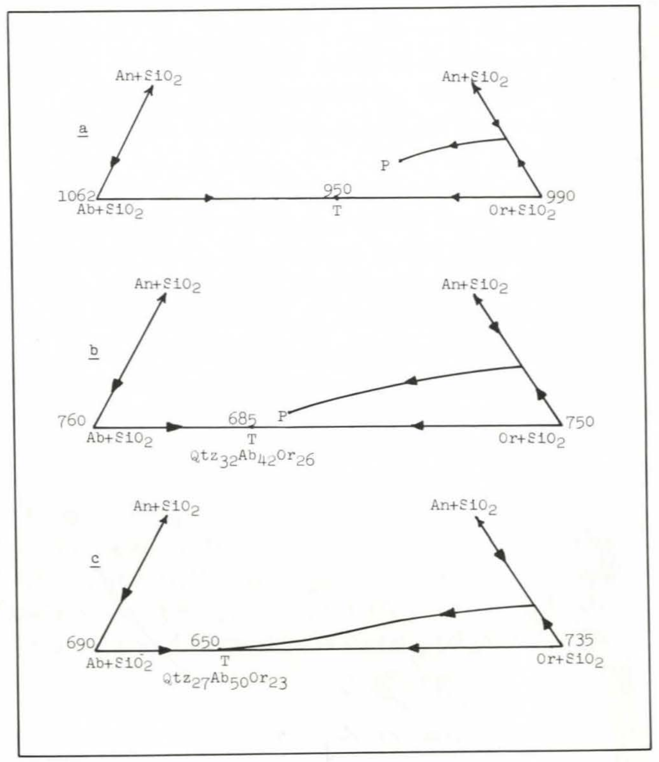


Figure 39

Liquidus Diagrams in the System $Si0_2$-An-Ab-Or-H_20. Projected to base An-Ab-Or. In part hypothetical. Numbers are temperature in degrees centigrade. T = ternary minimum in the granite system, projected to the edge Ab-Or. Black wedges point to falling temperature. Arrows point to the apex (An + $Si0_2$).

P = critical point

a. At atmospheric pressure
b. At pressure of 2 kb
c. At pressure of 3 kb

Temperature data from Tuttle and Bowen (1958) and Luth et al (1964).

Figure 39c is based on data at 5 kb for the systems $Si0_2$-Ab-H_20, $Si0_2$-Or-H_20 and $Si0_2$-Ab-Or-H 0 (Luth, et al. 1964). The internal form of the diagram is assumed to resemble that of the 5 kb field boundary in figure 6-1. As in Figure 39b, the presence of an aqueous phase is assumed. In this diagram the field boundary extends to the Ab-Or edge and meets the projected binary eutectic there at approximately Ab_{72} (Luth, et al. 1964, Yoder et al. 1957). At pressures somewhat less than 5 kb the crystallization in the vicinity of point Ab_{72} is peritectic in the "rapakivi" sense, as has been shown above (Figure 38), but it is not known where on the field boundary of diagram 6-4c the crystallization ceases to be cotectic.

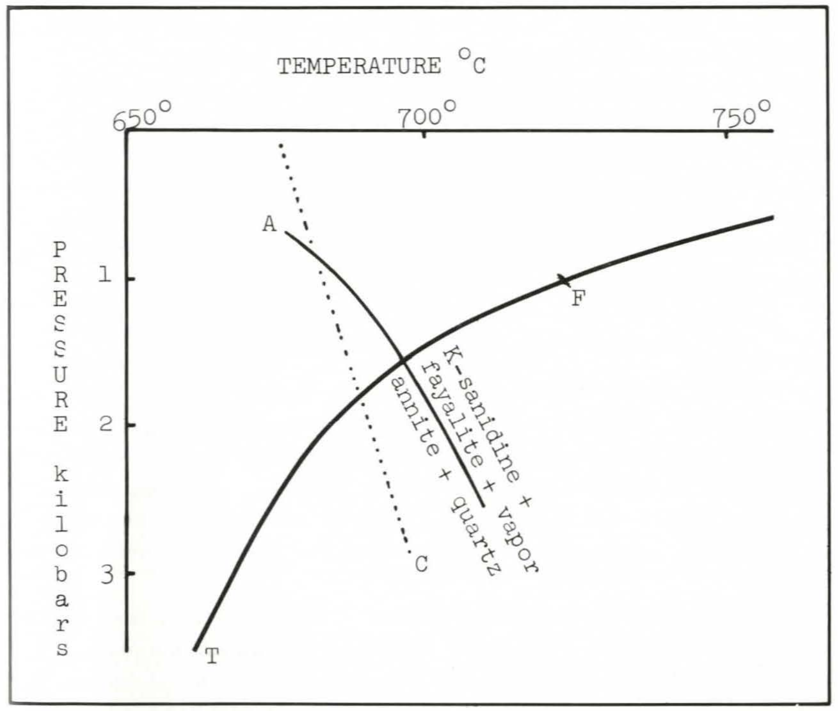


Figure 40

Data Bearing on Crystallization of Mt. Osceola and Conway Granites. Along curve A the assemblage annite + quartz is in equilibrium with K-sanidine + fayalite + vapor. T is granite melting curve. C is the critical feldspar curve. Data from curve A is from Eugster and Wones (1962). F is pressure on granite melting curve below which ferrohornblende from the Quincy Granite is not stable.

Note that silica saturation on the liquidus in the feldspar system lowers the temperatures greatly (compare Figure 39c with the 5 kb field boundary in Figure 36), in much the same way that liquidus temperatures are much lowered by saturation with an aqueous phase. This is because the extra SiO_2 and the H_2O are soluble in the melt but not in the feldspar crystals. The general form of the liquidus surface in each diagram is assumed to be similar to that in the system An-Ab-Or (Figure 36).

Stability of Annite and Ferrohastingsite

The biotite in the Conway Granite is essentially annite (Table 9). Eugster and Wones (1962) have investigated the stability of annite. In Figure 40 are shown the granite melting curve, AB2C of Figure 38, and a curve, labled A, for the breakdown of annite + quartz to K-sanidine, fayalite and vapor (after Figure 12 in Eugster and Wones, 1962). These two curves intersect at 1.6 kb. Fayalite was earlier noted as an accessory mineral in the Conway granite. At a pressure less than 1.6 kb, therefore, annite is not stable in a granitic melt at the ternary minimum.

Tuttle and Bowen (1958) have found that the amphibole in the Peabody stock of the Quincy granite of eastern Massachusetts decomposed at 650°C at one kilobar in the presence of an aqueous phase. This amphibole is a ferrohornblende (Toulmin, 1964), but is nearly identical to the hastingsite in the Albany Porphyritic Quartz Syenite. The amphibole from the Peabody stock of the Quincy Granite has been erroneously called riebeckite in the past.

Cotectic-Peritectic Crystallization in Ternary Systems

Detailed treatments of crystallization in ternary systems have been given by Bowen (1928) and by Turner and Verhoogen (1960) and others. However, these discussions do not include the situation where the crystalline phases, as in the feldspars, are ternary solutions. For a full discussion see Ricci (1951) and Bowen (1941). Figure 41 illustrates two kinds of crystallization appropriate to liquid-crystal equilibria between ternary solutions.

The diagrams are modified from Ricci (1951, p. 224; see also Stewart and Roseboom, 1962). The heavy black line L-L' is the boundary along which the liquids are saturated with two crystalline phases A and O. The arrow points towards lower temperatures. The narrow solid and dashed lines are tie-lines. Each sketch represents a partial isothermal section at two temperatures. The dashed tie-lines join compatible phases A-O-L at a higher temperature and the solid tie-lines join compatible phases A'-O'-L' at a lower temperature. The dotted line shows how the crystals coexisting with liquid along L-L' change composition.

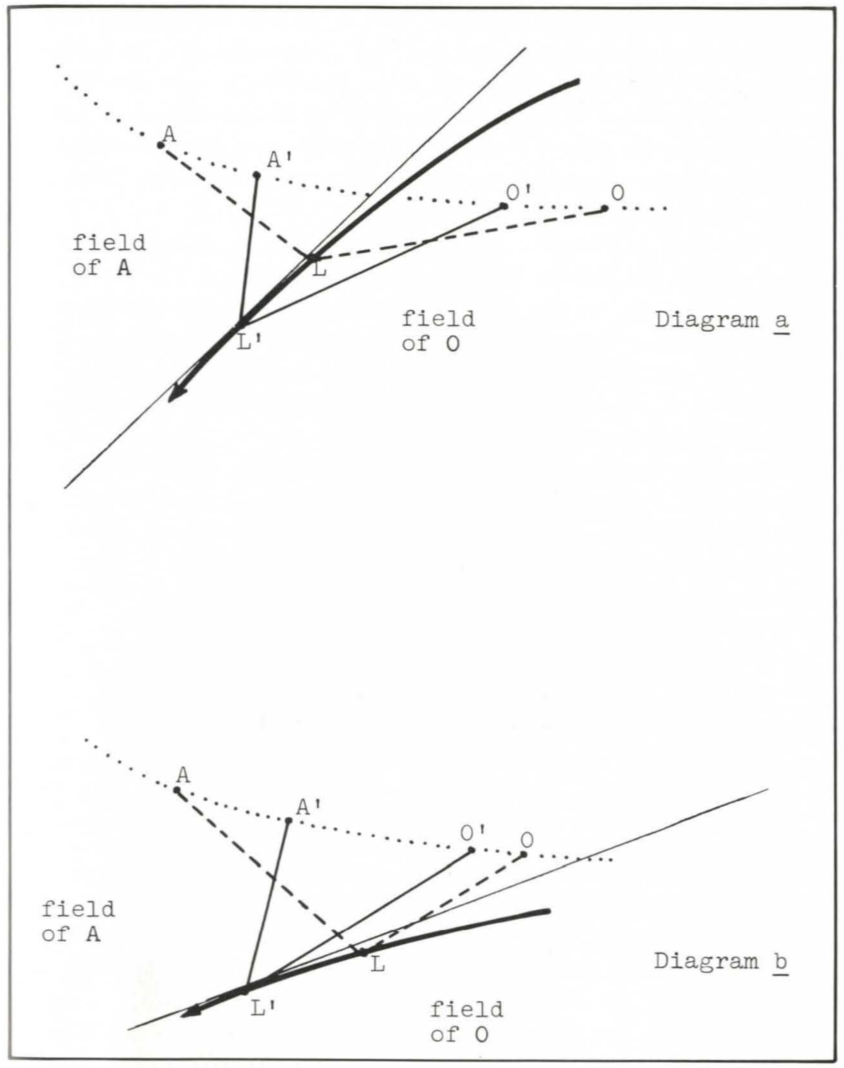


Figure 41

Cotectic and Peritectic Crystallization in a Ternary System. L-L' is boundary along which the liquids L, L'are saturated with two crystalline phases A and O. The arrows point to falling temperature. In a the crystalline phases A and O crystallize together from liquids L, L'. In b phase A is mantled by phase O with falling temperature.

Cotectic literally means "built together", i.e. crystallized together. Peritectic literally means "built around", i.e. one phase mantles another. In Figure 41, diagram **a** is the configuration for cotectic crystallization and diagram **b** is the configuration for peritectic crystallization.

To determine whether crystallization is cotectic or peritectic (Ricci, 1951, p. 224), draw a tangent to the path of crystallization of the liquid at the point where the liquid composition plots. Draw a tie-line through the two compositions of the two crystals. If the tangent intersects this tie-line between the two crystal compositions, then the crystallization is cotectic, i.e. both crystals separate from the liquid with falling temperature, and the liquid remains on the boundary curve L-L'.

If, however, the tangent and the tie-line joining the two crystals intersect at a point not between the two crystal compositions, then the crystallization is peritectic. In this case, that phase will be mantled (by the other) which lies further from the point of intersection of the tangent and the tie-line. In peritectic crystallization the liquid does not remain on the boundary L-L', but leaves it to enter the liquidus field of the mantling phase, 0 in diagram **b,** Figure 41.

Note that in diagram **a** there is an increasingly greater chance that crystallization will eventually become peritectic as A' and O' approach the same composition with falling temperature. This is the reason why crystallization along the field boundary in diagrams **a** and **b,** Figure 39, becomes peritectic near the point P, the critical end point. In the vicinity of P, the two feldspars approach the same composition.

CRYSTALLIZATION OF ROCKS OF THE WHITE MOUNTAIN PLUTONIC-VOLCANIC SERIES

General statement

In Figure 42 five chemical analyses of granitic rocks in the White Mountain series are plotted in weight percent. Each analysis was recalculated to the normative components qtz($Si0_2$), or($KAlSi_30_8$), ab($NaAlSi_30_8$), an($CaAl_2Si_20_8$), wo($CaSi0_3$), en($MgSi0_3$), fs($FeSi0_3$), mt($Fe\text{-}_30_4$), il($FeTi0_3$) and ap($(Ca_5P_4)_{12}Cl$), then the sum of qtz+ab+or was recalculated to 100 percent. The points are Mt. Osceola Granite (+) from Williams and Billings (1938), riebeckite granite (x) from Henderson (1949), amphibole granite (o) from Sandell and Goldich (1943) and the two small dots are Conway Granite from the Redstone quarries (Billings, 1928).

Figure 42 also shows the liquidus surface in the granite system at 2 kb, because this is the pressure most applicable to the crystallization of plutonic rocks in the White Mountain series. First, the Mt. Osceola Granite, the riebeckite granite and the amphibole granite plotted in Figure 42 are all one-feldspar perthite granites in which normative qtz+ab+or averages 94.7 percent (standard deviation = 3.5 percent). These perthite granites are too low in normative **an** to have contained any plagioclase (average **an** = 1.0 percent). With reference to Figure 38, these perthite granites must have crystallized at pressures less than 2 kb, else the melts would have

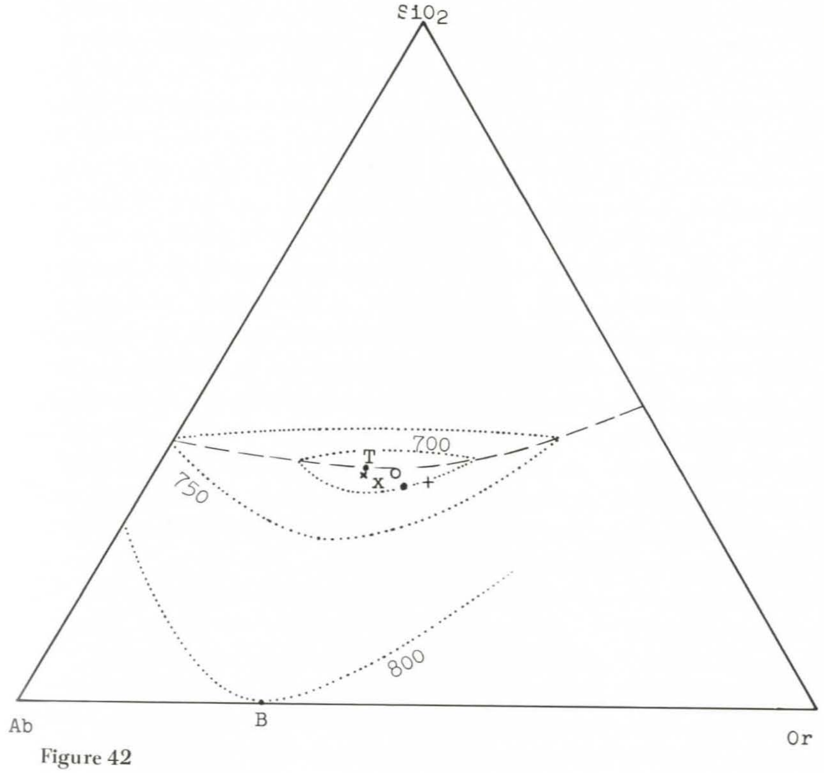


Figure 42

Chemical Analyses of Some Rocks of White Mountain Series Plotted in System $Si0_2$-Ab-Or. Dotted lines are isotherms for liquidus surface at 2 kilobars. Dashed line is $Si0_2$-feldspar field boundary; T is ternary minimum; B is the binary minimum. Plot in weight percent, as explained in text. + = Mt. Osceola Granite from Franconia Quadrangle; o = Conway Granite, green phase, Redstone Quarry; x = amphibolite granite from Pilot Range in the Percey Quadrangle; X = riebeckite granite from Crawford Notch Quadrangle; O = Conway Granite, red phase, Redstone Quarry References to chemical analyses are in text.

crossed the critical curve (23456 in Figure 38) and would therefore have crystallized two alkali feldspars prior to complete crystallization on the granite melting curve (AB2C in Figure 38).

Moreover, Figure 40 suggests that the Conway Granite must have crystallized at pressures greater than about 1.5 kb, otherwise the annite could not have remained stable in the granitic melt. The "red phase" of the Conway Granite (Billings, 1928) plotted in Figure 42 is the one nearest the ternary minimum (T) and this rock contains annite. The other analysis of Conway Granite plotted in Figure 42 is the "green phase", and that rock contains hastingsite. The green phase of the Conway Granite, therefore, must have crystallized at pressures above one kilobar. Otherwise, the hastingsite would have decomposed at magmatic temperatures of the minimum in the granite system that are well above 650°C at which Bowen and Tuttle (1958) noted the decomposition of ferrohastingsite from the Quincy Granite at one kilobar. Most of the granitic rocks in the White Mountains batholith were therefore emplaced between about 1.5 and 2.0 kb lithostatic pressure. Projecting from the pressure axis of Figure 38, this gives a temperature range during final crystallization of magma in the batholith of about 680 - 700°C. These melts were probably hotter during the initial stages of emplacement. An upper limit on the temperature of the Conway Granite at emplacement is about 750°C, as will be shown later.

Many granitic rocks in the White Mountain Plutonic - Volcanic Series contain Na - rich ferromagnesian minerals. A sample of a contact phase of the Conway Granite cut by a small pegmatite dike that contains arfvedsonite crystals as long as 3 cm. is in the Harvard petrology collection (No. 18348, North Conway area, Billings, 1928). Astrophyllite and riebeckite have also been found in granites in the White Mountains batholith (Henderson, 1949).

The presence of such minerals suggests that the liquids from which these granitic rocks crystallized contained sodium in excess of an amount that could be contained in feldspar, i.e. the liquids were peralkaline. Bailey and Schairer (1964) have suggested that the projection of the low temperature portion of the liquidus in the granite system (area between T and B in Figure 42) should shift towards Or as the liquidus is increasingly saturated with normative Ac.Ns (=acmite.sodium silicate), but the magnitude of this shift is not yet known.

Mt. Osceola Granite

The chemistry, mineralogy and normative composition of the Mt. Osceola Granite has already been discussed. The abundance of microperthite, absence of mantled feldspars and virtual absence of plagioclase suggests that the Mt. Osceola liquid was probably in equilibrium with only a single alkali feldspar throughout its history of crystallization. The liquid probably first crystallized a sanidine of intermediate Ab - Or composition while the liquid was in the K - feldspar liquidus field. The general geometry of the appropriate liquidus surface at 2 kb is shown in Figure 42. The Mt. Osceola liquid eventually reached the SiO_2 - feldspar field boundary at or near the ternary minimum where quartz began to crystallize as well. Thereafter the entire mass crystallized.

The delicate or finely interwoven texture of the microperthite in this rock (Figure 18) suggests that the rock cooled relatively rapidly so as to prevent extensive exsolution of Ab - and Or - rich feldspar in the microperthite. The nearer to the surface of the crust the rock was emplaced, the sooner it would have cooled. Had it been annealed (permitted to cool slowly at depth) at a high temperature below the miscibility gap in the system Ab - Or, then a more extensive or coarse - textured exsolution should have taken place in the alkali feldspar. Finely interwoven microperthite is common in the riebeckite and amphibole granites plotted in Figure 42.

Conway Granite

The Conway Granite contains some sodic plagioclase (approximately $Ab_{85}\,An_{15}$) as well as microperthite, quartz and Fe - rich biotite. The preponderance of microperthite suggests that a K - feldspar was the first to crystallize from the liquid. The normative **an** content of this rock, however, is almost three times that in the Mt. Osceola granite. This larger **an** content explains why two feldspars are present. Figure 39, diagram **b,** shows that a small amount of normative **an** requires a granitic liquid at 2 kb to eventually meet the two - feldspar field boundary and crystallize two feldspars. The presence of two feldspars in the Conway Granite can be attributed to the **an** content and is not due to the liquid crossing the alkali feldspar critical curve (23456 in Figure 38) prior to complete crystallization.

Some of the perthite in the Conway Granite is replacement perthite. This probably formed after the rock was emplaced to permit 1) somewhat coarse exsolution of the perthite and 2) a replacement reaction whereby residual liquid and aqueous vapor rich in silica and alkalies replaced some of the microperthite. It might have been during this post - intrusion stage that miarolitic cavities containing quartz - albite - microcline were formed at the Redstone quarries, South Baldface (North Conway area) and elsewhere.

An upper limit on the temperatures of White Mountain rock melts during actual emplacement is about 750°C. The reason for this is that when the andalusite - sillimanite curve from Figure 34 is extrapolated to 1.5 kb, the temperature above which sillimanite is the stable phase at that pressure is 750°C. Moke (1949) found a zone of andalusite surrounding the southwestern edge of the Mad River stock of Conway Granite in the Plymouth quadrangle. He interpreted this as a contact metamorphism produced by the Conway magma because there were only two other sporadic occurrences of andalusite in pelitic rocks otherwise containing sillimanite produced by the Devonian metamorphism. Therefore, the maximum temperature of the country rock adjacent to the Conway Granite magma at a minimum depth of 1.5 kb (5.7 km.) was probably less than 750°C. This estimate, however, depends upon the slope of the andalusite-sillimanite equilibrium curve on Figure 34.

Any explanation of the crystallization of this rock must account for the thin mantles of K-feldspar around anorthoclase, the small and much less abundant phenocrysts of quartz, which are locally rounded euhedral crystals, and the fine-grained groundmass of quartz and alkali feldspar.

The Albany melt probably first crystallized a sanidine and then, because of the insufficient **an** content, the liquid became saturated with anorthoclase. The crystallization of anorthoclase instead of sodic plagioclase might have been partly due to relatively higher temperatures which afforded a greater tolerance for potassium in solid solution in the sodic feldspar.

Mantling in the Albany is of the "antirapakivi" type and is explained by Figure 43. In this figure is drawn the two-feldspar field boundary at 2 kb from Figure 39, diagram **b,** although the condition of silica saturation on the liquidus may not be appropriate because the rock has only a few percent quartz as phenocrysts. That is, when the mantling reaction took place there is no way to know whether the liquid was saturated with $Si0_2$ or not. In figure 6-9 the tangent to the field boundary at liquid L'' cuts the A''-O'' tie-line furthest from A'', indicating that A'', a sodic feldspar (anorthoclase in the Albany) is the resorbed or mantled phase. The configuration and various lines of Figure 43 are analogous to Figure 41.

The fact that the rims of K-feldspar are very thin suggests that the peritectic reaction did not last long. The mantling reaction might have been terminated when the melt was intruded into ring dikes below New Hampshire. At intrusion, the liquid must have been silica-saturated because 1) the groundmass contains considerable quartz, and, as expected, 2) although there are only a few modal percent quartz as phenocrysts, the two chemical analyses of the Albany average about 15 percent normative qtz.

In several places the small phenocrysts of quartz are well rounded, even though euhedral outlines are preserved. This is common in contact varieties of the Albany in the ring dike around the Ossipee Mountains. Specimen No. 19213 in the Harvard petrology collection (Kingsley, 1931) shows this characteristic extremely clearly. This specimen has been described earlier in this report.

The explanation for the dissolution of quartz crystals lies in the way pressure changes displace the $Si0_2$-feldspar field boundary. Consider a granitic liquid on the $Si0_2$-feldspar field boundary at some moderate pressure. The liquid is crystallizing quartz. If this liquid is intruded higher into the crust so that the lithostatic pressure is reduced, the reduction in pressure displaces the $Si0_2$-feldspar field boundary towards $Si0_2$ in the granite system (see Figure 37). The liquid now plots entirely in the feldspar field and is no longer saturated with silica at the new lower pressure.

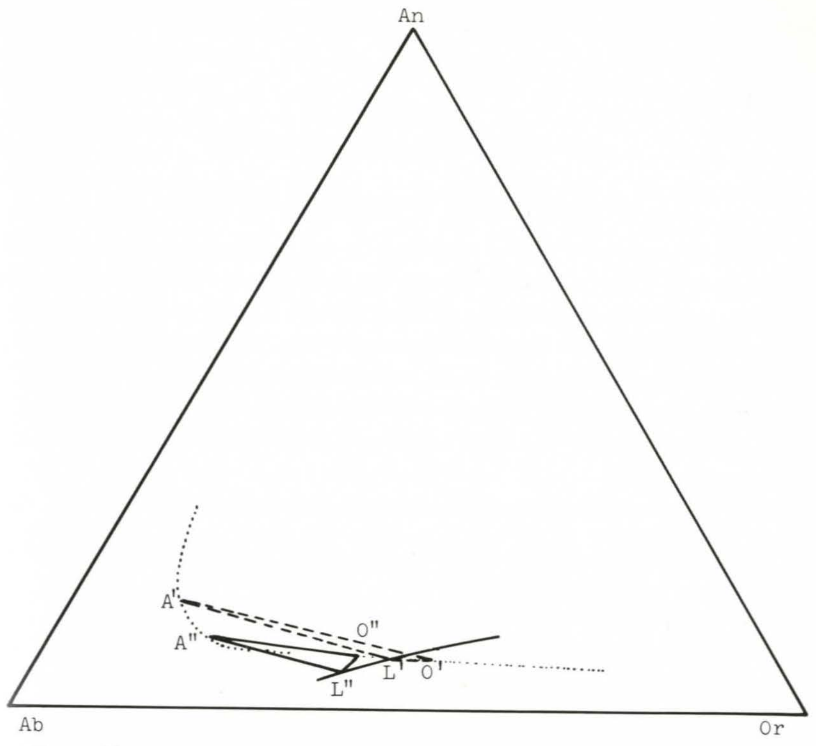


Figure 43

Genesis of Mantles of K-feldspar about Anorthoclase in Albany Porphyritic Quartz Syenite. A = Anorthoclase in Albany Porphyritic Quartz Syenite; O = mantles of K-feldspar, L = liquids.

The previously formed quartz crystals are then metastable and will dissolve, enriching the liquid in silica until its composition once again reaches the $Si0_2$-feldspar field boundary at the lower pressure.

CHAPTER 7
CONCLUSIONS AND SUMMARY

STRATIGRAPHIC AND STRUCTURAL CONCLUSIONS

The metamorphic rocks in this area are correlated with the Littleton Formation of Early Devonian age. These rocks are highly folded. The bedding schistosity commonly strikes northeast with moderate to steep northwesterly or southeasterly dips; most minor folds plunge moderately to the southwest; most drag folds are left-handed. The area perhaps lies on the southeast limb of a southwesterly plunging synclinorium. Later folds are open, 5 to 20 feet across and with an aplitude of a few feet.

SIGNIFICANCE OF THE PETROLOGIC STUDIES

The genesis of fibrolite in the sillimanite schists can be explained by the reaction muscovite + almandite = sillimanite + biotite + quartz and can be graphically represented in the Thompson AFM projection. The metamorphism took place at a preasure of 4 to 7 kb. The partial melting of layers in the schist of appropriate composition indicates the temperatures during final stages in the metamorphism reached 650°C. The initial genesis of fibrolite took place at somewhat lower temperatures. The preservation of muscovite throughout much of the area indicates the temperature during metamorphism only locally exceeded 700-750°C.

The conversion factor 3.80 converts pressures in kilobars to equivalent kilometers of rock of density 2.75 g/cc. Taking 5.5 kb as the average pressure during metamorphism, the thickness of the overlying rocks in this area during Middle Devonian time was 21 km., or 13 miles. This means that 9 miles of rock was eroded from Central New Hampshire between Middle Devonian and Late Triassic time. This is an average erosion rate of about 250 feet per million years. The Acadian Orogeny probably produced an Alpine- or Himalayan-style mountain range over much of New Hampshire in Middle Devonian time.

The plutonic rocks of the White Mountain series were emplaced under a lithostatic pressure in the range of 1.5 to 2.0 kb, at temperatures in the range 680-750°C. Using 1.75 kb as the average pressure at emplacement, the rocks of the White Mountain batholith crystallized at about 6.5 km. in the crust beneath Central New Hampshire in Late Triassic time. This is equivalent to a depth of about 20,000 feet, a minimum figure for the amount of rock that was eroded from this region between Early Jurassic time and the present. This is an average rate of erosion of 120 feet of rock per million years.

The above has significant implications for the cauldron subsidence in the Ossipee Mountains. The unconformity at the base of the Moat volcanics described in chapter 4 means that the volcanic rock and the Early Jurassic erosion surface upon which it was extruded must have dropped down a distance of 20,000 feet into the Ossipee Cauldera. This minimum distance the volcanics have been dropped (about four miles) is structurally reasonable when it is remembered that the diameter of the Ossipee Mountains ring dike is 9.0 miles, on the average. In 1928 Billings estimated that the volcanics on the northeast side of Moat Mountain (North Conway area) are 17,000 feet below their original level.

In the White Mountains batholith there is relief of approximately 4,500 feet. Inasmuch as this is a sizeable fraction of the total estimated lithostatic pressure on the White Mountain batholith during emplacement (0.4 kb), textural and mineralogical differences between granitic rocks in the batholith might be a function of elevation. It is perhaps noteworthy that the highest elevations in the batholith, on the western edge (Mt. Lafayette 5250, Twin Mountain 4925 and 4770 and Mt. Bond 4715), are all areas of granite porphyry, which "are similar both in mineralogy, texture and composition to many of the rhyolites in the Moat volcanics" (Billings, 1956). Another unknown is the attitude of the Early Jurassic erosion surface with respect to the shape of the top of the batholith.

The figure of 20,000 feet, the minimum distance the volcanics were dropped, does not include the difference in the elevation of the unconformity in the Ossipee Mountains (920 feet) and the highest point in the batholith (Mt. Lafayette, 5250 feet).

SUMMARY OF THE GEOLOGIC HISTORY

In Early Devonian time, interbedded sandstones and shales of the Littleton Formation were deposited in a shallow sea that covered this entire region. Perhaps 10,000 to 20,000 feet of these rocks accumulated when this portion of the Appalachian geosyncline subsided. As these rocks were buried deeper in the crust, they were highly folded, eventually metamorphosed to the sillimanite grade and finally partially melted at a depth of about 21 km. and a temperature of about 650°C.

In Middle Devonian time, granitic rocks of the New Hampshire series intruded this schist and migmatite during the Acadian Orogeny. This event created a large mountain range over much of New England. Later in Devonian time vast quantities of pegmatites were intruded from the root zone of these mountains into the Acadian orogenic belt of granite and schist. This area was never again covered by the seas. The rocks were rapidly eroded throughout the rest of the Paleozoic.

In Early Jurassic time a vast thickness of volcanic rocks was extruded over Central New Hampshire, fed by many vents and volcanic necks that were tapping granitic and syenitic magmas a few miles beneath the surface. These magmas were then emplaced in the White Mountain batholith and in many surrounding stocks at a depth of about 6.5 km. and at a temperature of about 700°C. During the early process of emplacement, extensive faults developed in the crust beneath this area.

Many of these faults were high-angle and arcuate, centered on large bodies of magma below. Over what are now the Ossipee Mountains, the Moat volcanic complex began to drop along these faults. Finally, a large ring dike of Albany porphyritic quartz syenite was formed when the Albany magma intruded one of the large arcuate fractures. Batholithic masses of Mt. Osceola Granite and of Conway Granite were then emplaced by magmatic stopping to form the batholith, many surrounding stocks and the central stock in the Ossipee Mountains. By the end of Early Jurassic time the Moat volcanics had dropped a distance of at least 20,000 feet below their original level.

Erosion continued to the present time, culminating in an extensive glaciation that produced continental ice sheets over all of New England in Pleistocene time. The last of these sheets retreated 10,000 to 12,000 years ago, exposing the present topography.

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MICA-BEARING PEGMATITES OF NEW HAMPSHIRE. U. S. Geological Survey Bulletin. 931-P. Preliminary Report. J. C. Olson. 1941. 41 p. Maps. Free.

ROCK-WELL SURVEY IN NEW HAMPSHIRE. Progress Report. Glenn W. Stewart. 1964. 10 p. $.30.

The following reports should be purchased directly from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402:

PEGMATITE INVESTIGATIONS, 1942-45, NEW ENGLAND. U. S. Geological Survey Professional Paper. 255. Eugene N. Cameron, and others. 1954.

BERYL RESOURCES OF NEW HAMPSHIRE. U. S. Geological Survey Professional Paper. 353 p. James J. Page and David M. Larrabee. 1962. $4.00.

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The following report may be purchased from the Geological Society of America, Colorado Building, P. O. Box 1719, Boulder, Colorado 80302.

STRATIGRAPHY AND STRUCTURE OF THE BOUNDARY MOUNTAIN ANTICLINORIUM IN THE ERROL QUADRANGLE, NEW HAMPSHIRE-MAINE. Geological Society of America Special Paper 77. John G. Greene. 1964. $3.50.

The following publications are available in limited supply from the N. H. Water Resources Board, State House Annex, Concord, New Hampshire.

NEW HAMPSHIRE BASIC-DATA REPORT NO. 2, GROUND-WATER SERIES, LOWER MERRIMACK RIVER VALLEY. James M. Weigle and Richard Kranes. Prepared by the U. S. Geological Survey in cooperation with the New Hampshire Water Resources Board. 1966. 44 p. Map.

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The following maps are on open file for public use and may be referred to at (1) Graphic Arts Division, Department of Resources and Economic Development, Forestry Warehouse, 5 Langdon Street, Concord, New Hampshire; (2) Department of Geology, James Hall, University of New Hampshire, Durham; and (3) Department of Geology, Dartmouth College, Hanover.

SAND AND GRAVEL DEPOSITS OF NEW HAMPSHIRE. A set of 62 U. S. G. S. quadrangle maps. Prepared by James W. Goldthwait in the 1920's and 1930's. Revised by Glenn W. Stewart, 1962.

SURFICIAL GEOLOGIC MAP OF THE MILFORD QUADRANGLE. Prepared by Carl Koteff, U. S. Geological Survey. 1967 (at D.R.E.D., Concord, N. H. and University of New Hampshire, Durham.)

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