Geology of the Old Speck Mountain Quadrangle, Maine

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ABSTRACT

The Old Speck Mountain quadrangle, Maine (44° 33' - 44° 45' N. lat., 70° 45' - 71° 00' W. long.), is underlain by Paleozoic metamorphic and intrusive rocks. The metamorphic rocks comprise the Albee formation, and the Ammonoosuc volcanics, and the Partridge formation, Ordovician (?) age, and, unconformably above them, the Littleton formation of ~~Silurian (?) and~~ Devonian age. The Albee consists of feldspathic quartz-mica schist and some quartzite, both commonly pin-striped, cut by amphibolite dikes and sills. The Ammonoosuc is composed largely of metamorphosed tuffaceous sediments, now mostly biotite schist, chlorite schist, and amphibolite. A stratum of kyanite schist is probably a metamorphosed bentonitic sediment. The Partridge formation consists of schist, micaceous quartzite, and black phyllite, all commonly containing sulfide minerals and graphite. The Littleton formation has been divided into seven lithologic types, which, although interbedded, tend to succeed one another in order. From bottom to top these are: amphibolite with some pillow lava ~~(Whitecap Brook member)~~, gneiss, biotite schist, calc-silicate granulite, conglomerate and quartzite, interbedded schist and quartzite, and two mica schist. About 4000 feet of the Albee, Ammonoosuc, and Partridge formation and 10,000 feet of the Littleton formation are exposed.

Granitic gneiss of the Oliverian plutonic series forms concordant sheets within the Ammonoosuc volcanics at the northeast end of the

Jefferson dome in the west-central part of the quadrangle. Mafic granodiorite of the Umbagog pluton (early New Hampshire plutonic series ?) occupies the northwest corner of the quadrangle. The Andover pluton in the central and eastern parts of the quadrangle is a complex of many small intrusions of granodiorite, quartz monzonite, granite, and related rock types belonging to the New Hampshire plutonic series. In this pluton is the first American locality for sphene-flecked diorite, a rock characterized by white flecks in which mafic minerals are absent, with a single highly poikilitic grain of sphene in the center of each fleck. Experimental data on the albite-anorthite-sphene system are applied to this rock and indicate that it formed by magmatic processes. All of these intrusive rocks are approximately syntectonic and of probable Devonian age. Narrow basalt and lamprophyre dikes and a volcanic breccia pipe are correlated with the White Mountain plutonic-volcanic series of ~~Triassic (?)~~ Permian age.

The northwestern part of the quadrangle lies on the extension of the Bronson Hill anticline. This is a complex structure, with two stages of folding. The earlier folds have northwest-southeast axes and are inverted. These folds may have developed as recumbent digitations off the Jefferson dome. They have been refolded by rather tight folds with northeast-southwest axes. In the southern and eastern parts of the quadrangle is a broad open syncline (the Mahoosuc syncline) plunging to the northeast. The center of the syncline is largely occupied by the Andover pluton. A series of minor open folds with horizontal northwest-southeast axes and some isoclinal folds suggest that the Mahoosuc syncline, like the Bronson Hill anticline, may have a complex internal structure. Folding presumably took place during the Middle and Late Devonian Acadian orogeny. Subsequently only minor faulting occurred.

The stratified rocks have been metamorphosed to the staurolite and sillimanite grades. Kyanite, andalusite, and sillimanite all occur, indicating that the temperature-pressure curve during metamorphism passed close to the triple point for Al_2SiO_5. The assemblages of the pelitic schists can be arranged in a normal sequence of progressive metamorphism. There is some evidence, however, that potassium was added to and removed from pelitic schists at various times during the metamorphism. In the metavolcanic rocks cummingtonite and gedrite, as well as hornblende occur. Chemical analyses and optical data for three hornblendes and a complete mineralogical description, including chemical analysis and x-ray data, for a gedrite are given. Retrograde metamorphism was minor; an unusual process was replacement of biotite by prehnite.

The area was covered by the Pleistocene continental ice sheet, which flowed toward the southeast. Mountain glaciation probably occurred on Old Speck Mountain.

INTRODUCTION

Location, Culture, and Accessibility

The Old Speck Mountain quadrangle comprises slightly more than two hundred square miles in west-central Maine between 44° 30' and 44° 45' north latitudes and 70° 45' and 71° 00' west longitudes. It includes large parts of the organized towns of Upton, Andover, and Newry, of the unorganized townships of Riley, Grafton, Andover West Surplus, Andover North Surplus, Township C, C Surplus, and corners of Byron, Hanover, and Township D, all in Oxford County except the last, which is in Franklin County.

The largest concentration of population is in the village of Andover, just on the east edge of the quadrangle. One or two families of the smaller village of Upton live within the quadrangle and a dozen or so homes are scattered along the highway in Newry. From the first settlement of this area (Andover in 1804, Grafton in 1834) the population rose for one or two generations and then declined. Fobes (1951) gives an account of the rise and fall of a mountain community in Grafton which from a population of 115 in 1880 has dwindled to extinction. The "Surplus Settlement" along the West Branch of the Ellis River was a similar, though smaller, community, now marked only by a cemetery, an abandoned house, and some apple trees.

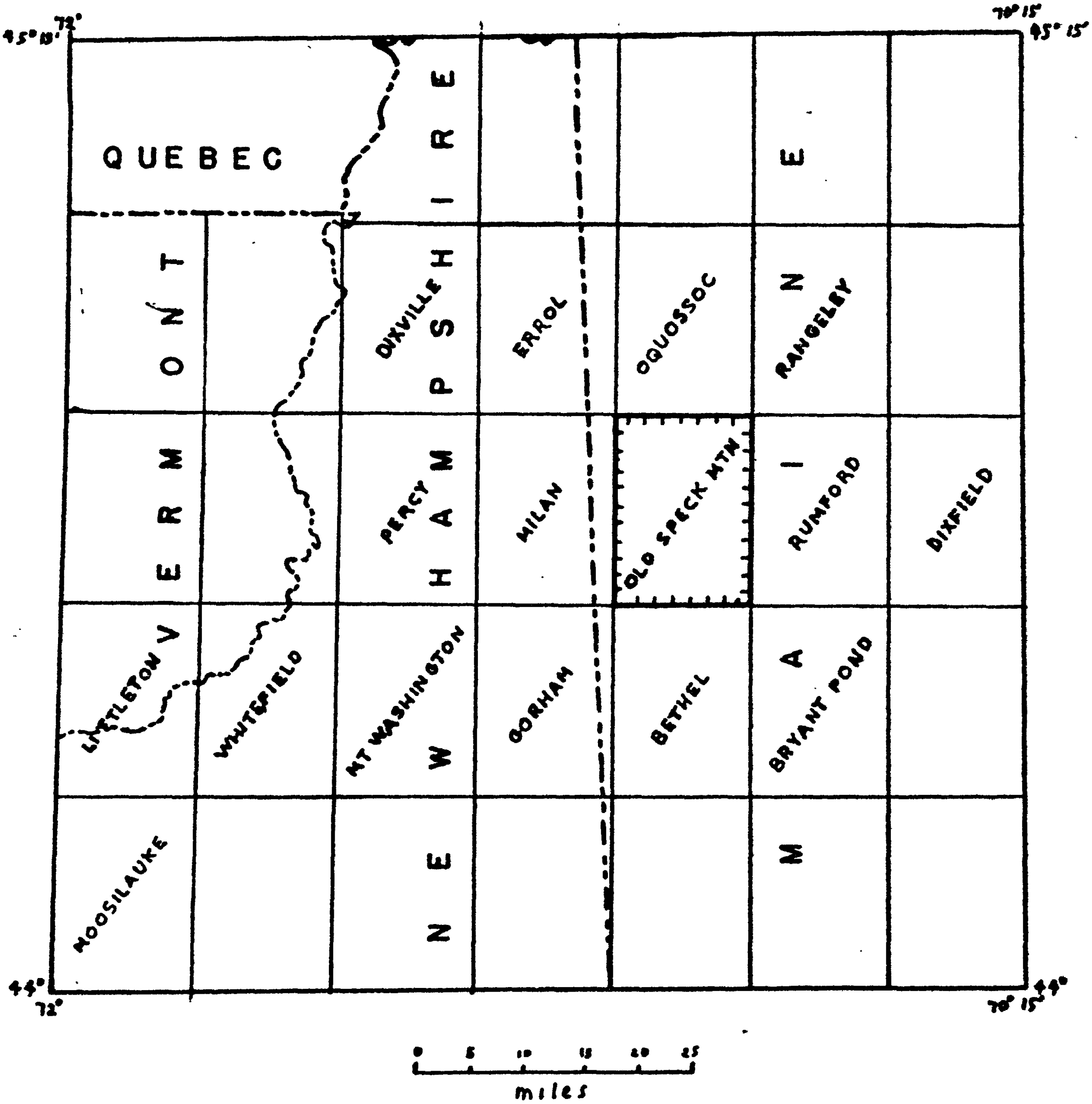

FIGURE I. Index Map.

The economy of the area has always been based on forest products. Only two or three percent of the land is now kept cleared for hay fields and pasture and about as much was once cleared but has reverted to woodland. The forest that covers the quadrangle, except the fields and barren zones atop the higher mountains has been entirely cut over, much of it many times. One encounters all stages of reforestation from the nearly impassable slash piles and raspberry thickets of freshly cutover land to forests of tall trees with a clear understory. The present forest is about half soft wood, mostly spruce and balsam fir, and half hard wood, mostly yellow birch and red maple. It is cut mainly for pulp wood, both hard and soft, for the paper mills in Berlin, New Hampshire, and Rumford, Maine.

State Highway 26 from Upton to Newry, the East B Hill Road from Upton to Andover, State Highway 5 from Andover to South Arm of Richardson Lake, the Sunday River Road up to Ketchum, and a few local roads are maintained. In addition, wood roads are always being built into cutting jobs and usually remain passable, at least to four wheel-drive vehicles, for a few years. The Appalachian Trail traverses the quadrangle from corner to corner, approximately at right angles to the general course of the roads. It was extremely useful during field work, especially in the Mahoosuc Range, which was mapped in great part by traverses based on camps at the Trail shelters.

Topography and Drainage

An axis of high mountains extends from the southwest to the northeast corner of the quadrangle, culminating in Old Speck Mountain itself, which at 4180 feet elevation is the third highest mountain in Maine. Those mountains southeast of Grafton Notch belong to the Mahoosuc Range; no group name covers the rest. To the northwest of the mountain axis is a low area of subdued relief drained mostly by the Swift and Dead Cambridge Rivers into Umbagog Lake, which lies at 1245 feet elevation just outside the quadrangle, and from which the Androscoggin River arises. The area southeast of the mountain axis is more rugged with several peaks over 3000 feet elevation and low points of below 660 feet elevation on the Ellis and Bear Rivers, which both drain into the Androscoggin.

Present Investigation

Purpose. Our present knowledge of the geology of New England relies to a considerable extent on stratigraphic relationships discovered in widely separate fossil localities. As studies are made farther from these localities the reliability of the stratigraphy and consequently the structure becomes less and less. Correlation between fossil localities is particularly important. The present study carries northeastward the stratigraphy that ultimately depends on the work of M. P. Billings and his coworkers in the Littleton-Moosilauke area of New Hampshire. The Old Speck Mountain quadrangle should become a link in a chain of correlations that should in a few years connect the Littleton-Moosilauke

PHOTO 1. View south and southeast from north of Mollidgewock Pond, Upton (Milan quadrangle). Mountains on the skyline are (left to right) Surplus Mountain, Baldpate Mountain, Sunday River Whitecap, Old Speck Mountain and the Mahoosuc Range, and Red Ridge.

PHOTO 2. Sheeted gneiss of the Littleton formation. North Peak, Riley. Such continuous exposure is typical of brooks on the steeper slopes.

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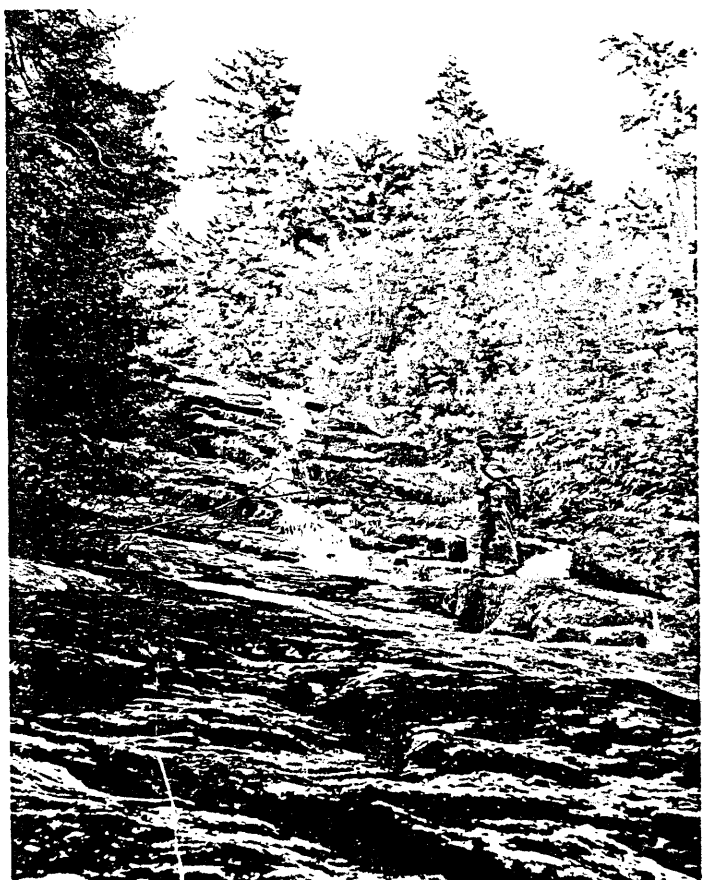


area with fossiliferous areas in Maine such as Moosehead Lake and Waterville, placing the geology of the entire area on a much sounder basis.

The Old Speck Mountain quadrangle lies on the projection of a structural belt that has proved of great complexity and interest farther southwest. It was found that this structure not only extends into the quadrangle but exhibits special features that make it particularly amenable to elucidation.

Several problems of metamorphic and igneous petrology were encountered and investigated, some common to terranes such as this, and some of a rather unusual nature.

Finally, this quadrangle was chosen for a study of the relationships of geology and geomagnetism in a metamorphic terrane. This phase of the study will be reported separately.

Methods. Field work occupied about forty-two weeks in the summers of 1957, 1958, and 1959. Mapping was done on the excellent topographic quadrangle map enlarged to a scale of two inches to the mile. Aerial photographs at this scale were available, but the dense forest cover reduced their usefulness. Traverses were preferentially made along brooks, where the outcrop is good and locations can be determined with an aneroid barometer.

An aeromagnetic map made by the U. S. Geological Survey was available during field checking and compilation in 1960. Some contacts have been carried through areas of surficial cover on the basis of the aeromagnetic pattern.

Over five hundred and fifty specimens were collected, most of which were studied in thin section. X-ray diffraction charts were made on many, particularly as a check on the estimate of the quartz-plagioclase ratio. Most modes were estimated; point counts of a few thin sections were made as a check on the accuracy of estimation. Compositions of plagioclases were mostly determined by relief and twinning relations in thin section; some were determined by the immersion method. When precise optical determinations of minerals were made, sodium light was used and immersion oils were mixed and their refractive index determined at the time of use with a Leitz microrefractometer. A spindle stage (Wilcox 1959) was found very useful in precise index determination of amphiboles.

Acknowledgments. The first field season was supported financially by the Carlton Thayer Broderick Scholarship of Harvard University. The second season was supported by the Maine Geological Survey. Work in the third season was carried out as part of the U. S. Geological Survey's program for correlated geological and geophysical studies.

Field assistance was provided in 1958 by Lincoln S. Hollister and in 1959 by E. David Roderick. Mr. Hollister is to be particularly thanked for working without financial recompense.

Professor M. P. Billings followed the work with interest, spending considerable time in the field with the writer and furnishing much valuable advice. Professor J. B. Thompson, Jr. also gave helpful advice.

Both critically read drafts of this thesis.

Discussion and visits in the field with geologists mapping nearby or similar areas were of great value. The writer's colleagues John C. Green, Norman L. Hatch, Jr., Charles V. Guidotti, and Peter Robinson are to be particularly thanked. Jun Ito has chemically analyzed several minerals for the writer.

The friendliness of the people of Upton, Maine, contributed greatly to the enjoyment of the field seasons. In particular, Mrs. Mabel Durkee of the Lake House provided an excellent base of operations for the writer and his assistants.

Previous Publications

In 1838 C. T. Jackson travelled over the East B Hill Road while engaged on the first Geological Survey of Maine. His report (1839) is illustrated by drawings of Frye Falls, Speckled (Old Speck) Mountain, and Saddleback (Baldpate) Mountain.

The area of the Old Speck Mountain quadrangle is included in the geologic map of New Hampshire by C. H. Hitchcock, (1878) who probably visited the area while engaged in the second Geological Survey of Maine during the early 1860's. The units of his map correspond to some extent to those recognized in the present investigation, although contacts were apparently not walked out. The Lyman group corresponds to the Ordovician (?) formations and the Whitecap Brook amphibolite. The Montalban group corresponds to the metasedimentary members of the Littleton formation, with a band of "mica schist and limestone" apparently having been based on beds containing lime silicate concretions that crop out along Bear River and the West Branch of Ellis River. The granite near the center of the quadrangle was mapped as "granite"; the Umbagog granodiorite, the granite near Andover and some near North Newry as "granitic gneiss".

Keith's (1933) Geologic Map of Maine gives essentially a simplification of Hitchcock's map, with the incorrect addition of another granite body in the southern part of the quadrangle.

The only other publications presenting new information on the geology of the quadrangle are by Leavitt and Perkins (1935) who made a reconnaissance of the glacial deposits, by Crosby and Crosby (1925) on "keystone faults", and popular articles on mineral occurrences by Shaub (1959) and Jorgensen (1960). Joyner (1958) measured gravity at several stations in the quadrangle.

An outline of preliminary results of the present study and a road log (Milton 1960a) and an abstract on sphene-flecked diorite (Milton 1960b) from the quadrangle have been published.

In contiguous areas, the Rumford quadrangle has been mapped by Forsythe (1955) and the Newry Hill pegmatite area on the east end of Plumbago Mountain by Shainin and Dellwig (1955). The Bryant Pond quadrangle is being mapped by C. V. Guidotti, the Bethel quadrangle has been mapped by I. S. Fisher (1955), and the Gorham quadrangle by M. P. Billings and K. Fowler-Billings (Billings 1955). The Milan quadrangle has been mapped in reconnaissance by M. P. Billings (1955) and the northern third has been mapped in detail by the writer (unpublished). The Errol quadrangle has been mapped by J. C. Green (1960).

STRATIGRAPHY AND LITHOLOGY

General Statement

About 12,000 to 15,000 feet of stratified rocks are exposed in the Old Speck Mountain quadrangle. These have been intruded by igneous rocks that now underlie about half the quadrangle. The stratified rocks have been divided into four formations: Albee, Ammonoosuc, Partridge, and Littleton. The first ~~three form a group~~ two are of Ordovician age, and the third is of Ordovician (?) age. The Littleton formation, of Early Devonian ~~(?)~~ age is a more complex formation in which seven lithologic types have been mapped.

All of the stratified rocks have been regionally metamorphosed. In general, the Ordovician and Ordovician (?) formations lie in the staurolite zone and the Littleton formation in the sillimanite zone.

The stratigraphy is summarized in a columnar section in figure 2.

Albee Formation

General Statement. The Albee formation of Ordovician age consists mostly of quartz-mica schists. It crops out in a belt less than a mile wide and about five miles long extending from southwest of Whitecap Brook, Grafton, northeastward across East B Hill, where it splits into two prongs, one continuing northeastward over Spruce Mountain and the other extending eastward into Andover North Surplus. Continuity of the outcrop area is interrupted only by the alluvial fill in Grafton Intervale. The tip of the northern prong is concealed by ground moraine, but its approximate location was determined from the aeromagnetic pattern.

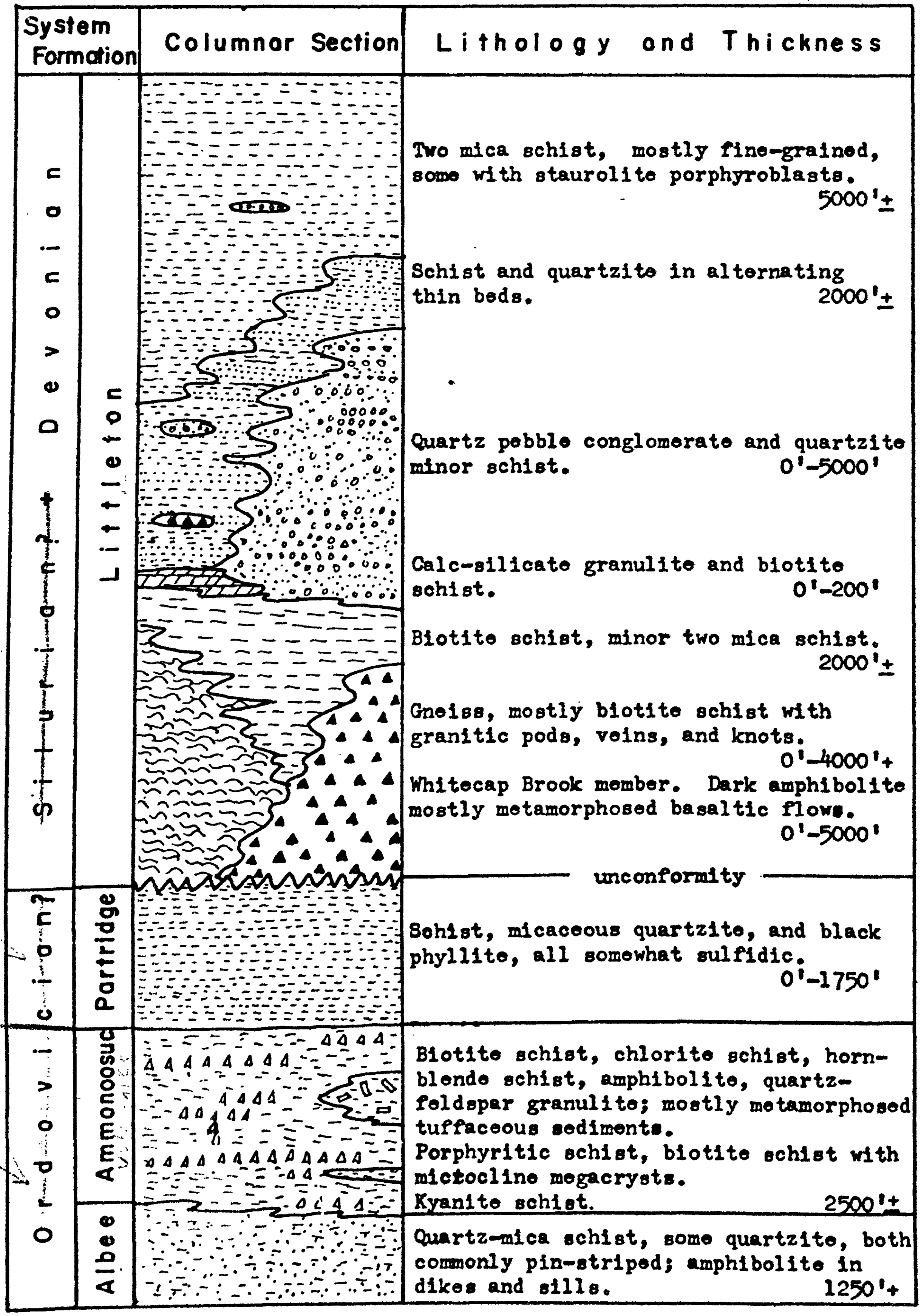


FIGURE 2. Columnar section for the Old Speck Mountain quadrangle.

There is no sharp distinction between Albee and Ammonoosuc metasedimentary rocks. Moreover, rocks of typical Albee lithology are found interbedded with Ammonoosuc volcanics. In general the presence of any amphibole-bearing rock, except intrusive dikes or sills, or of a dominant amount of highly feldspathic rocks, was considered diagnostic of the Ammonoosuc volcanics. As a result, a considerable proportion of Albee-like rock may be found within the area mapped as Ammonoosuc, particularly on the lower west slope of East B Hill.

Although some of the rocks of the Partridge formation are similar in gross composition to the ordinary Albee type, the characteristic pin-striping of the Albee and the accessory sulfide minerals and graphite of the Partridge are sufficiently diagnostic to prevent confusion.

Lithology. The Albee formation has been metamorphosed to an intermediate (staurolite and low sillimanite) grade. The bulk of the formation is quartz-plagioclase-muscovite-biotite schist. (Representative modes are given in table 1.) Quartz and plagioclase make up about seventy or eighty percent of the rock. In the most distinctive Albee type the quartz to plagioclase ratio is high, on the order of ten to one or more. Rocks with a lower quartz to plagioclase ratio, and commonly with more biotite than usual, also occur, particularly where the Albee grades toward the Ammonoosuc (OSM 13). Biotite and muscovite each usually make up five to fifteen percent of the rock. Neither potassic feldspar nor staurolite or sillimanite are more than occasional minor phases, indicating

Table 1. Estimated modes of the Albee formation.

	13	17	90	294	446	453	456	458
Quartz	40	77	59	65	75	60	53	74
Plagioclase	37	2	5	7	10	7	17	2
Potassic feldspar						3	3	
Muscovite		13	20	15	4	15	15	8
Biotite	22	4	10	12	10	15	10	12
Chlorite		1	3					
Garnet		T					1	
Staurolite		1	T					
Sillimanite								3
Apatite	T	T	T		T			
Zircon		T						
Opaques	1	2	3	1	1		1	1
An content of plag.	15				30		30	

OSM 13 Irregularly laminated biotite schist.
1500' elev. on road north of Dunn Notch, North Surplus.

OSM 17 Pin-striped micaceous quartzite.
1700' elev. on road east of East B Hill, C Surplus.

OSM 90 Highly contorted pin-striped schist.
Summit of East B Hill, C Surplus.

OSM 294 Straight pin-striped gray micaceous quartzite.
1520' elev. east of trail fork west of Deer Hill, Grafton.

OSM 446 Gray micaceous quartzite.
1700' elev. on north ridge of hill SW of Whitecap Bk., Grafton.

OSM 453 Pin-striped micaceous quartzite.
1900' elev. on west ridge of hill SW of Whitecap Bk., Grafton.

OSM 456 Interbedded pin-striped quartzite and schist.
1970' elev. on north ridge of hill SW of Whitecap Bk., Grafton.

OSM 458 Pin-striped gray quartzite.
1880' elev. on west ridge of hill SW of Whitecap Bk., Grafton.

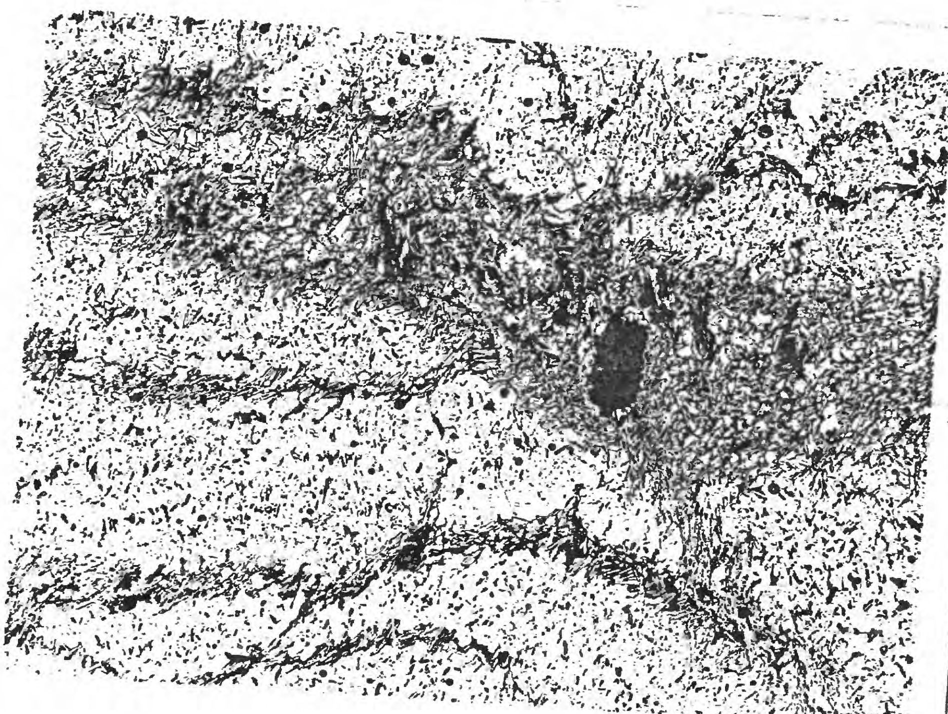
that the contents of K_2O and Al_2O_3 are in close balance. Garnet and chlorite, except as a product of retrograde alteration of biotite, are minor phases or absent.

Quartz and plagioclase occur in rather simply shaped equant grains 0.1 or 0.2 mm in diameter. Large disparities of grain size characteristically do not occur. In OSM 446, however, some quartz grains are two or three times the diameter of the average in the specimen and apparently represent original clasts.

A striking feature of the Albee formation in the Old Speck Mountain quadrangle, as well as elsewhere in New England, is "pin-striping", an alternation of quartzo-feldspathic laminae about 2 mm thick with dark micaceous lamellae about 0.3 mm thick. Micas also occur in the light laminae, but much less abundantly and usually in smaller flakes than in the dark partings. Pin-striping, although not invariably present, can be found in a greater or lesser degree of perfection in most outcrops of Albee. In some areas, particularly south of Whitecap Brook, the pin-striping is straight and parallel. More commonly, however, it is highly contorted. Most of the pin-striping is assumed to be parallel to bedding. This is confirmed by the fact that where thicker beds of differing composition occur, the pin-striping is parallel to them. In a few outcrops, however, pin-striping definitely transects bedding. The most obvious foliation in one outcrop is a rather straight pinstripe-like lamination. A closer examination indicates that this is a shear cleavage transecting a fainter, highly contorted pin-striping, which

PHOTO 3. Pin-striped micaceous quartzite of the Albee formation, OSM 453. x5.

PHOTO 4. Pin-striped micaceous quartzite of the Albee formation, OSM 17. The flakes of mica are oriented parallel to a shear cleavage transverse to the pin-stripes. x10.



presumably follows bedding, at a high angle. Under the microscope, many of the mica flakes of this specimen are seen to be oriented transversely to the bedding pin-stripes in which they lie, but to be parallel to the shear cleavage (Photo 4). Other mica flakes lie in the cleavage planes rather than in the older lamellae. It is not difficult to imagine that with further deformation and recrystallization the original pin-striping could be completely erased and be replaced by a pin-striping parallel to the shear cleavage.

Veins and pods of glassy quartz are common in the Albee, particularly in the more contorted portions. The coarseness of the grain size contrasts sharply with that in the adjacent rock.

The Albee formation contains, besides the metasedimentary rocks, ten or twenty percent of amphibolite. This occurs in tabular bodies several feet or yards across, usually but not always parallel to the general trend of bedding or pin-striping. These amphibolites show no bedding and usually only a weakly developed foliation, although a strong lineation is commonly present. Many bodies have fine-grained margins and coarse-grained interiors. The amphibolites are sills and dikes of basalt that were intruded into the Albee sediments before metamorphism. Preservation of chilled borders as a relict texture through metamorphic recrystallization is a well known phenomenon. Presumably these amphibolites are comagmatic with extrusive metavolcanics in one of the overlying formations. In the Old Speck Mountain quadrangle metabasalt flows of similar appearance characterize the ~~Devonian~~ (?) Whitecap Brook amphibolite, but are rare in the Ammonoosuc volcanics. Massive amphibolite, probably of extensive origin is, however, abundant in the Ammonoosuc volcanics of the Milan quadrangle. The rarity or absence of dikes in the Partridge formation, which lies between the two volcanic strata, suggests that the dikes in the Albee are comagmatic with the Ammonoosuc volcanics.

Origin. Chemical composition is one of the few characteristics of finer-grained sediments that remains unchanged through metamorphism. Unfortunately, it is not directly considered in any of the standard classifications of sedimentary rocks. In order to properly characterize the protolith of highly metamorphosed sediments it is necessary to make perhaps dubious assumptions about the original distribution of the components of the rock.

By the simplest assumption the quartz and plagioclase of the Albee formation is derived from original sand. The peraluminous nature of the rock, shown by the presence of muscovite, suggests an original clay content. Presumably the sediment originally contained detrital potassic feldspar, which has reacted with kaolinitic clay minerals to form mica. In short, the protolith could well have been a "dirty sandstone". The Albee contains much less potassic feldspar than would be expected in a metamorphosed arkose, so the protolith would belong to the graywacke class of sandstone. The close association of the Albee with the Ammonoosuc volcanics suggests that much of the material may be of ultimate volcanic derivation. If so, the composition, particularly the low content of potassic feldspar, may reflect the nature of the source material rather than the maturity of the sediment.

The pin-striping which characterizes the Albée suggests another, less obvious protolith. A lamination on such a fine scale as the pin-striping is unusual, although not impossible, in a sediment of sand-size particles. It is more typical of shales and siltstones. Compositionally the Albée could belong to the group of siliceous shales and porcellanites represented, for example, by the Monterrey and Mowry formations of the Western United States, which contain much opaline or cryptocrystalline silica of ultimate volcanic origin. The protolith of the pin-striped phases of the Albée may have been a nearly uniform siliceous shale with a well developed bedding fissility. During recrystallization the soluble silica would have been reprecipitated in the parting planes, leaving the residues to form the dark lamellae. In the more feldspathic specimens the plagioclase is concentrated in and near the dark partings, which is to be expected if the quartzose laminae are secretions. This mode of origin certainly does not hold for the entire Albee formation. Detrital grains in the lower grade zones in New Hampshire demonstrate the clastic nature of at least part of the Albee. Probably more than one protolith, perhaps of overlapping compositions, was present in the Albee.

Correlation. The principal argument for the equivalence of this map unit with the Albee formation of New Hampshire is its lithologic similarity, in particular to the Albee of approximately the same metamorphic grade in the Errol quadrangle, which on the basis of available mapping is continuously traceable to the type locality in the Littleton-Moosilauke area.

Moreover, the entire sequence of formations matches that of New Hampshire. This unit is conformably underneath the Ammonoosuc, hence it is Albee.

An alternative possibility is that this unit is a lens of Albee-like lithology within the Ammonoosuc volcanics. This hypothesis has little to recommend it. The general structural pattern of this part of the quadrangle can be deduced on the basis of the relations of the other units, particularly the Ammonoosuc and Partridge. The relations of the Albee add details that enter into a consistent picture of the whole structure. If this unit were actually a lens in the Ammonoosuc, these details would be lost and the structure would be more vaguely defined but not really simplified.

Thickness. The belt of Albee formation is over 4000 feet wide. The structural interpretation indicates, however, that all exposed contacts of the Albee represent the top of the formation, and that the section across the widest part of the outcrop belt crosses an isoclinal fold axis twice. Therefore, only about 1000 or 1500 feet of the top part of the Albee formation are exposed in the Old Speck Mountain quadrangle.

Ammonoosuc Volcanics

General Statement. Ammonoosuc volcanics of Middle Ordovician age crop out in a zone that narrows northeastward from the middle half of the western boundary of the quadrangle toward Sawyer Notch. Continuity of the zone is interrupted by infolds of Albee and Partridge formations, by granite gneiss of the Oliverian plutonic series, by discordant intrusives, and by surficial deposits.

The Ammonoosuc is a formation of varied lithology, but most types are bedded rocks with a considerable content of volcanic detritus. Feldspathic biotite and amphibole schists predominate; chlorite schists, leucocratic quartzo-feldspathic rocks, amphibolites and kyanite schists are also present. Several more or less distinct varieties have restricted geographical ranges. Only two, however, are sufficiently clearly delimited both petrographically and areally to have been mapped as distinct units, kyanite schist and porphyritic schist. With more detailed mapping other local units could be distinguished. They are so lenticular, however, that it is unlikely that a stratigraphic column for the Ammonoosuc could be developed that would be valid over even the single quadrangle.

The exact delineation of the contact of the Ammonoosuc with other formations is in many places difficult. The criteria used for the distinction from the Albee, discussed in the previous section leaves few rocks of Ammonoosuc type in the Albee map area, but consequently considerable Albee-like rock in the Ammonoosuc area. The Ammonoosuc-Partridge contact is usually sharp, but it is gradational in a few places where the Ammonoosuc does not contain hornblende and the Partridge is feldspathic. The massive dark amphibolites ~~of the~~ Whitecap Brook ~~member of~~ the Littleton formation contrast on the whole with the Ammonoosuc volcanics, but the exact contact is often difficult to place. Some of the biotite schist in the northwestern part of the Littleton outcrop area is similar to Ammonoosuc types, but it is assumed that no Ammonoosuc can be present

Table 2. Estimated modes of Ammonoosuc volcanics.

61-105

	20	70*	72	73	77	79	89	101	226	296	299	301	303	306	309	311	320	321	323	378	466	467	471	473	512	542	546	547	551	553p	553g	558
Quartz	50		60	35	40	50	41	52	30			35	25	50		50	30	17	35	25	12	30	46	45	45	64	40	40	25	35		
Plagioclase	32	75	16	36	45	30	41	20	40	87	65	30	22	25	52	30	1		44	31	50	40	46	25	30	15	40	46	25	} 60	60	33
Potassic feldspar													35	10			45	55	T	25					20				37			
Muscovite								12		1		10	T				3	12	1				3	12	5							
Biotite*	15	T	5	8	1	1	8	8	5		2	25	15	10	1				20	15	5		5	3		1	15		10			
Chlorite*		15	7	5	1	15		1	20	8	10				10	1	17	12				1		10				10			20	
Hornblende		2					10								2	T					7	2				20				1		33
Cummingtonite											20				4	18					7	20										
Gedrite				9	7	1			5						25							4										
Augite																																33
Epidote		T				T				1			5				2	3		T									3	4	15	
Allanite													T							T									T			
Garnet	1				5			2		1		1					1			1	18						5	3				
Staurolite			1					2																								
Sillimanite			T																													
Cordierite**			10	8																												
Prehnite		5																													T	
Tourmaline												T														T						
Sphene		T								1			1	1				1		T									T		3	T
			-	-								T							T		T					T						

Table 2 cont'd.

OSM 20	Thinly bedded, almost pin-striped gray schist. 1800' elev. on East B Hill Road, C Surplus.
OSM 70	Medium-grained dark greenish lineated schist. 1870' elev. in bk. along trail S of upper Swift Camb. R., Grafton.
OSM 72	Medium-grained strongly lineated gray schist. 1750' elev. in highest trib. on left of Black Bk., Grafton.
OSM 77	Medium-grained light colored anthophyllite-garnet granulite. 1730' elev. in trib. entering Black Bk. at 1650', Grafton.
OSM 79	Fine-grained light colored schist with chlorite laminae. 1510' elev. in outlet of York Pond, Grafton.
OSM 89	Strongly lineated gray schist with hornblende needles. 2130' elev. on middle knob of East B Hill, Upton.
OSM 101	Contorted two mica schist. Narrows of Swift Cambridge River just in Upton.
OSM 226	Coarse-grained chlorite-anthophyllite schist. 1730' elev. in trib. entering Black Bk. on left at 1590',Grafton.
OSM 296	Fine-grained greenish porcellaneous rock. 1510' elev. on NE slope of Deer Hill, North Surplus.
OSM 299	Hard greenish-gray massive cummingtonite-chlorite schist. 1530' elev. in bk. crossing trail S of Dunn Notch, N. Surplus.
OSM 301	Fine-grained dark colored schist. 2110' elev. on smaller knob West of Surplus Pond, N. Surplus.
OSM 303	Porphyroblastic schist. 2400' elev. on ridge NW of Surplus Pond, N. Surplus.
OSM 306	Light-colored granofels with elongated granule-size clasts. Swift Camb. R. at bend just N of due E of North Pond, Grafton.
OSM 309	Medium-grained anthophyllite schist. Top of knob SE of York Pond, Grafton.
OSM 311	Light colored cummingtonite schist. 1700' elev. SE of York Pond, Grafton.
OSM 320	Hard fine-grained greenish schist. 2000' elev. south of notch on Spruce Mtn., North Surplus.

Table 2 cont'd.

OSM 321	Soft medium-grained greenish schist. Near OSM 320.
OSM 323	Hard finely laminated dark schist. 1900' elev. due south of where Appalachian Trail crosses the town line, North Surplus.
OSM 378	Hard greenish schist. Route 26, just at quadrangle boundary, Upton.
OSM 466	Medium-grained greenish schist with garnet megacrysts. 1920' elev. south of summit of Hemenway Ridge, Grafton.
OSM 467	Fine-grained light colored porcellaneous rock with cummingtonite needles. 1550' elev. north of narrows of York Pond outlet, Grafton.
OSM 471	Medium-grained gray granulite with small feldspar megacrysts. 1900' elev. on main ridge north of Cedar Bk., Grafton.
OSM 473	Friable white granulite. In brook west of houses on Back St., at quad. bdry., Upton.
OSM 512	Massive fine-grained white granulite. 1980' elev. on Back Street, Upton.
OSM 542	Hard quartzose rock with hornblende. 2200' elev. on ridge west of rte. 26, just in Upton.
OSM 546	Medium-grained gray schist. 1840' elev. in trib. entering Black Bk. at 1650', Grafton.
OSM 551	Porphyroblastic schist. 1860' elev. in Mountain Brook, North Surplus.
OSM 553	Interbedded fine-grained pink porcellaneous rock (p) and green chlorite schist (g). 1660' elev. in Mountain Brook, C Surplus.
OSM 558	Dark amphibolite. 1550' elev. in Sawyer Brook, C Surplus.

southeast of the Whitecap Brook amphibolite, wherever this is present. The Ammonoosuc-Oliverian contact presents special problems, discussed in the section on the latter unit. In the northwesternmost parts of the quadrangle (Mountain Brook area, Greenwood Brook outlier, Upper Sawyer Brook area) the rocks have been transformed into gneisses so that determination of the original nature and stratigraphic assignment is difficult.

Lithology and origin. Biotite schist is the most abundant rock in the Ammonoosuc. This is typically a rather fine-grained dark rock, usually with thin irregular bedding, occasionally approaching the pin-striping of the Albee. The average biotite schist consists of thirty to fifty percent each of quartz and oligoclase or andesine, fifteen to twenty percent brownish biotite, and minor garnet and accessory minerals (OSM 20, 301, 323, etc. table 2). Commonly some muscovite is present. The biotite may be particularly or even completely replaced by retrograde chlorite.

The protolith of the biotite schist was probably waterlain dacitic tuff. In most specimens quartz and plagioclase are in simple subequant grains, with the biotite mostly interstitial. Some specimens, however, show a complexly intergrown texture of quartz and feldspar grains of highly irregular shape with biotite flakes included in the grains or cutting across boundaries indiscriminately. While all gradations occur, the contrast between the extremes is striking. The grain size of the ordinary granoblastic rocks corresponds to sand size. While every grain certainly does not represent an original clast, it seems likely that the texture of these rocks reflects that of the original sediment. The highly complex texture on the other hand, is what might be expected from the crystallization of an original vitric tuff.

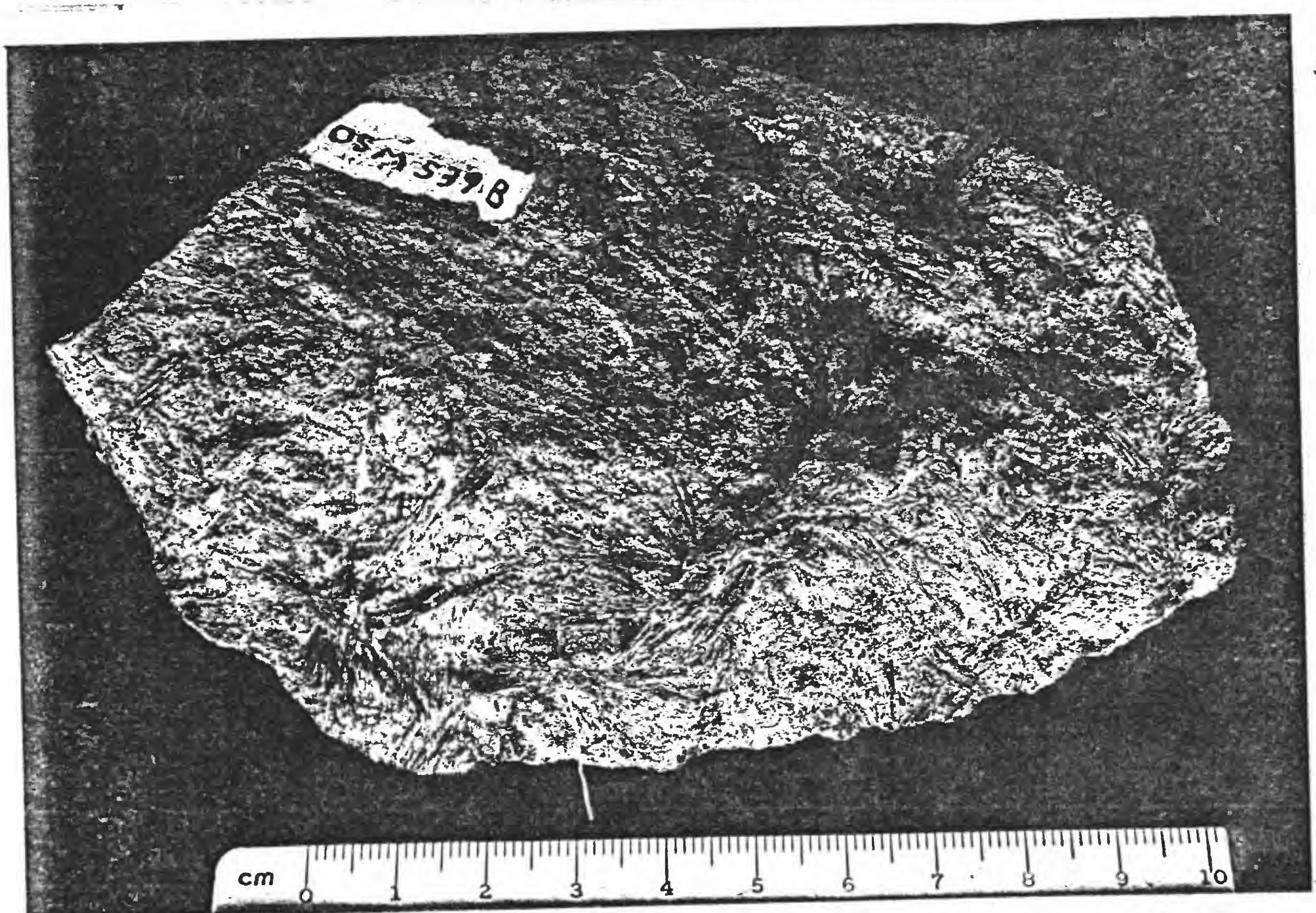
Several other rock types are from variations from the dacitic composition. Quartz-poor or quartz-free chlorite schists are of andesitic composition (OSM 296). Rocks containing potassic feldspar and a more sodic plagioclase are of rhyodacitic or quartz latitic composition (OSM 306, 378). Rocks of rhyolitic composition are less common, but do occur (OSM 320, 321, 551).

Most of these rocks are foliated. There is usually sufficient variation between layers to indicate that the protoliths were bedded sediments, presumably waterlain tuffs. One outcrop is composed of several feet of alternating pink quartzo-feldspathic beds and green feldspar-chlorite-epidote beds each a few inches thick, presumably reflecting rapid changes in the available sediment (OSM 553). The textures suggest that the tuffs were composed of sand size and smaller particles. Occasional larger grains may be clasts of granule size. Rocks of rhyolitic composition occasionally are foliated on an exceedingly fine scale, suggesting that their protolith was a flow-banded lava or ash flow, rather than a waterlain sediment.

The area of Ammonoosuc on the north end of the hill west of the highway in Upton is occupied by a massive friable rock of dacitic and quartz latitic composition (OSM 473, 512). The little iron present in this rock is mostly in pyrite rather than in silicates, so the rock is white where fresh and rusty where weathered. Compositional banding

PHOTO 5. Epidote veinlet in metamorphosed rhyolite of the Ammonoosuc volcanics, OSM 553. Clear grains are quartz; cloudy grains are potassic feldspar. x60.

PHOTO 6. Gedrite schist of the Ammonoosuc volcanics.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is absent and the foliation is generally poor or lacking. The protolith may have been lava or an ash bed slightly, if at all, reworked by sedimentary processes, but with iron removed and sulfur introduced by hydrothermal action.

The more quartzose and staurolite-bearing varieties of the Ammonoosuc (OSM 101) probably originated from the admixture of nonvolcanic sediment or by the maturing of volcanic detritus during the process of sedimentation. Indeed the rocks considered as metadacites may themselves be derived at least in part from andesitic pyroclastics diluted by quartz-rich sand. The kyanite schist member, discussed below, was probably a pyroclastic sediment considerably altered by diagenetic processes.

Amphibolites of several types are common in the Ammonoosuc, although they do not total a large proportion of the formation. Very mafic types, resembling those of the Whitecap Brook amphibolite, are present but not abundant (OSM 558). More commonly, smaller amounts of hornblende occur in amphibolitic schists (OSM 89). Gedrite-bearing rocks characterize a belt extending from Cedar Brook to Hemenway Ridge and the area near the head of Black Brook in Grafton (photo 6). An unusually quartz-rich amphibole-bearing rock was found at one locality in Upton (OSM 542). Bedding is usually present in the amphibole-bearing rocks to indicate the sedimentary nature of the protolith. Intrusive amphibolites are found, but are either less abundant or less well exposed than those cutting the Albee formation.

Porphyritic schist. A variety of the Ammonoosuc volcanics occurring near Sable Mountain, Andover North Surplus, is sufficiently distinctive and areally delimited to be mapped as a member. This is a biotite schist of quartz latitic or rhyolitic composition (OSM 303, 501, table 2) that resembles the normal biotite schist of the Ammonoosuc volcanics except that it contains megacrysts of microcline about 2 cm long, that compose from a few percent to a third of the total rock (photo 7). Most megacrysts lie in the plane of the foliation, but some are transverse. Septa in the foliation are partly bowed around and partly cut off by the megacrysts.

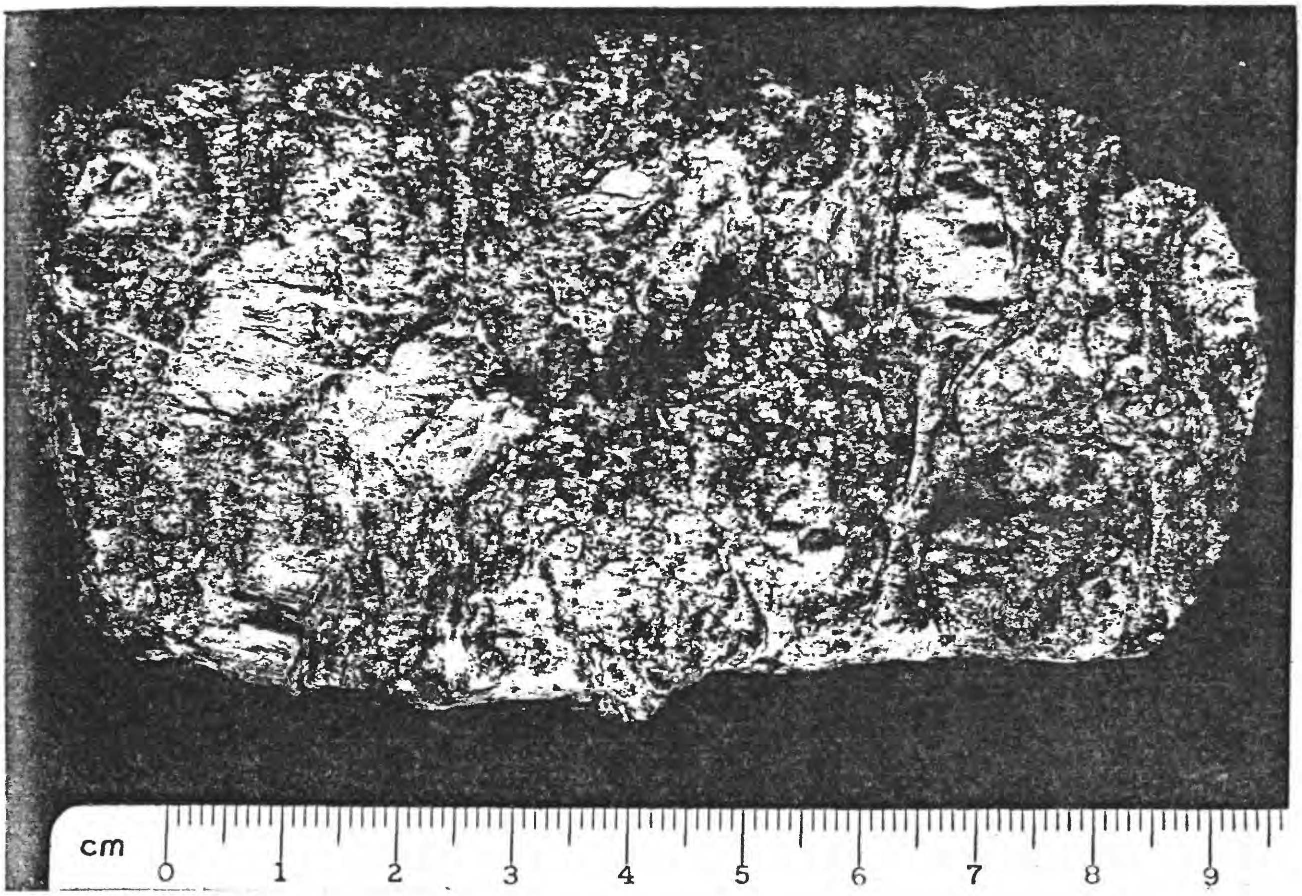
The porphyritic schist forms a lenticular body parallel to the regional strike and not obviously related to any intrusive body, which suggests that it represents an original stratigraphic lens within the Ammonoosuc volcanics. Why this particular lens developed such a texture, while rocks of similar composition elsewhere did not, and whether the microcline represents material originally present or somehow added, are not known.

Kyanite schist. The kyanite schist is a unit of small extent in the Ammonoosuc volcanics, but its distinct and unusual character justifies mapping as a member. It can be traced as a band several hundred feet thick from the farmhouse at the south end of Back Street (the road near the quadrangle boundary in southern Upton) eastward to the Upton-Grafton town line near the crest of the hill.

The kyanite schist consists mainly of bedded, weakly schistose, granular, light colored rock. It generally shows an original clastic

PHOTO 7. Porphyritic schist of the Ammonoosuc volcanics.

PHOTO 8. Kyanite schist of the Ammonoosuc volcanics, OSM 155. High relief grains with cleavage are kyanite; high relief grains without cleavage are andalusite (above center); other gray minerals are biotite and chlorite; light-colored minerals are quartz and plagioclase. x35.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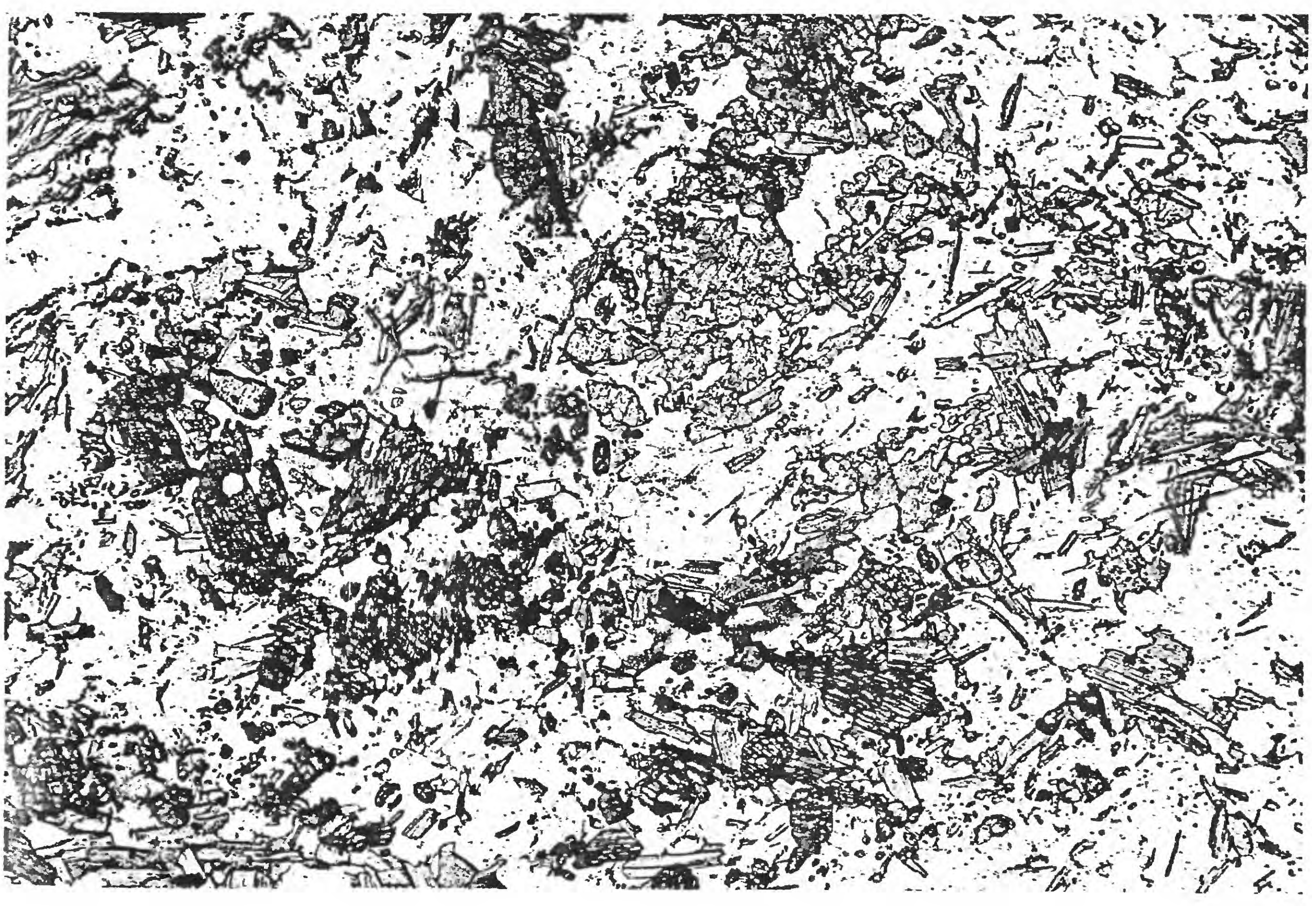
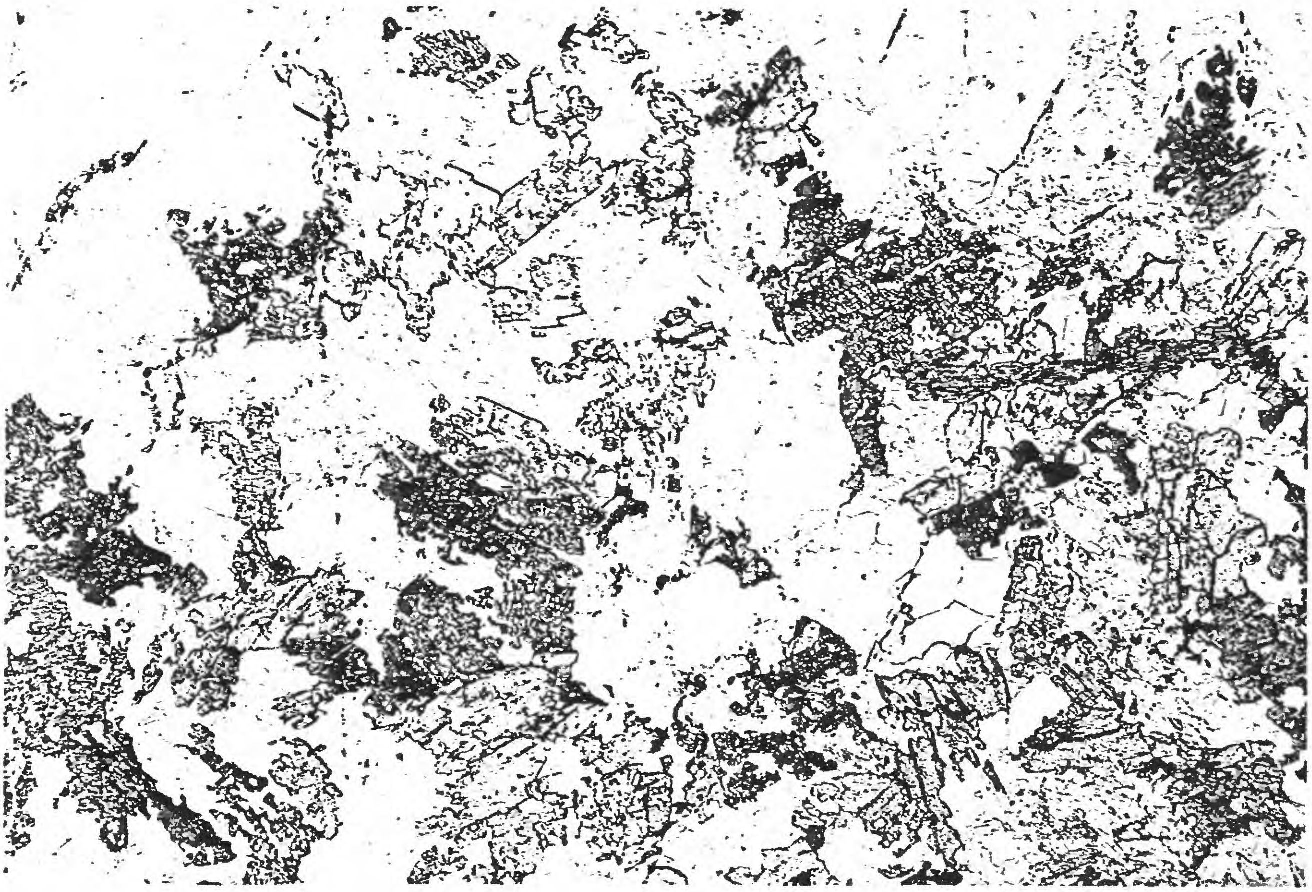
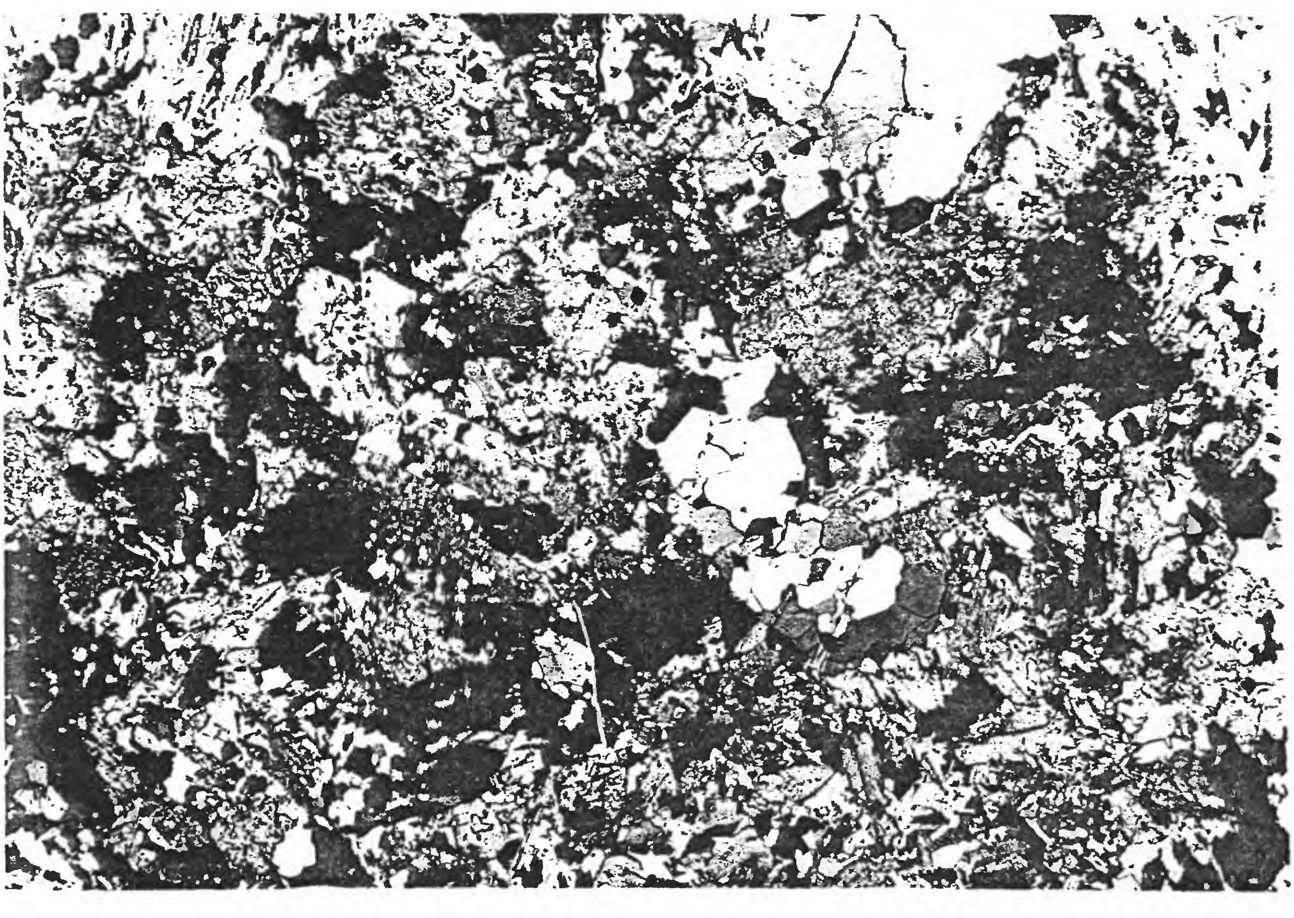


PHOTOS 9 and 10. Kyanite schist of the Ammonoosuc volcanics, OSM 64, in plane-polarized light and between crossed nicols. Kyanite is dark in plane-polarized light. Very pale brown biotite is barely distinguishable from quartz and plagioclase in plane-polarized light but shows its platy habit between crossed nicols (a large patch of biotite is marked on upper edge). Patches of coarse quartz grains (right center, upper right) are original clasts. x12.





texture. Some outcrops contain quartz granules up to 5 mm in diameter and a few contain subangular clasts as large as 2 cm, which differ slightly in appearance and composition from the matrix. In some specimens the clastic texture is evident only in thin section, where it is shown by large disparities in the sizes of grain of quartz and plagioclase.

The predominant minerals are quartz and plagioclase (oligoclase or andesine). Many of the plagioclase megacrysts are poikilitic, with inclusions of quartz, which may be a relict texture inherited from the original clasts. Biotite and primary chlorite, both of unusually magnesian composition, are present in almost all specimens. Muscovite is generally a minor or even trace constituent. Kyanite occurs in colorless poikilitic blades a few millimeters long. As kyanite was found in most, although not all, specimens from this member and in only a very few from other map units, the member is called the kyanite schist. Andulusite occurs less commonly. Garnet and staurolite were found in a few specimens.

Chemical and spectrographic analyses of two specimens of kyanite schist are given in table 4. The major factors that control the rather unusual mineral assemblages are high ratios of MgO to FeO and of Al_2O_3 to K_2O. The MgO/FeO ratio is reflected in the exceptionally magnesian compositions of biotite and chlorite and the rarity of garnet and staurolite. The high ratio of Al_2O_3 to K_2O causes the relative abundance of kyanite (and andalusite) and scarcity of muscovite.

Table 3. Estimated modes of the kyanite schist member of the Ammonoosuc formation.

	25	64	155	156	157	161	165	166	167	543
Quartz	93	38	47	63	50	30	41	45	45	35
Plagioclase		15	20	20	35	38	25	32	25	40
Potassic feldspar								10		
Muscovite	7	5	T	T	3	5	2	3	15	4
Biotite		20	15	7	11	15	6	10	5	11
Chlorite		7	8	3	1	T	15		10	
Kyanite		15	6	6		12	4			
Andalusite		T	4	T						
Staurolite										5
Garnet							5			4
Sphene			T	T					T	
Apatite			T							T
Opaques	T	T	T	T			2			1
An content of plag.		45		35	5	40				

Table 3 cont'd.

OSM 25	Sugary white quartzite. 1980' elev. SE of Back Street, just in Upton.
OSM 64	Medium-grained kyanite schist with quartz granules. 50 yards north of OSM 25.
OSM 155	Medium-grained dark kyanite schist. 2100' elev. on Upton-Grafton line east side of hill.
OSM 156	Greenish schist with biotite flakes. 2160' elev. on ridge NW of OSM 155.
OSM 157	Light colored schist with feldspar megacrysts. Near OSM 156.
OSM 161	Medium-grained light colored kyanite schist. Near OSM 64
OSM 165	Medium-grained darker schist. 2100' elev. on Grafton-Upton line on west side of hill.
OSM 167	Fine-grained greenish schist. 2200' elev. north of OSM 165.
OSM 543	Coarse-grained garnet-staurolite schist. Behind house at end of Back Street, Upton.

Table 4. Composition of kyanite schist, Upton, Maine.

	OSM 64	OSM 155	Montmorillonite
SiO_2	67.94	69.05	52.43
TiO_2	.19	.51	.08
Al_2O_3	18.16	16.21	15.95
Fe_2O_3	1.22	.72	1.42
FeO	.07	3.13	.10
MnO	.06	.04	-
MgO	4.67	3.73	5.02
CaO	1.37	1.57	2.97
Na_2O	1.11	1.56	
K_2O	2.71	1.44	
H_2O+	1.76	1.58	7.60
H_2O-	.16	.06	13.96
P_2O_5	.09	.14	.08
CO_2	.01	.01	
Cl	.00	.00	
F	.19	.07	
	99.71	99.82	
Less O	.08	.03	
TOTAL	99.63	99.79	100.13
Ba	.15	.07	
Be	.0	.00015	
Co	0	.0003	
Cr	.0003	d	
Cu	.00015	.0003	
Ga	.0015	.0015	
La	.003	.003	
Nb	0	d	
Ni	.0003	0	
Pb	.003	.003	
Sc	0	.0015	
Sr	.015	.015	
V	.0015	.0015	
Y	.0015	.003	
Yb	.00015	.0003	
Zr	.015	.015	

d = barely detected.
Looked for and not found: Ag, As, Au, B, Bi, Cd, Ce, Ge, Hf, Hg, In, Ir, Li, Mo, Nd, Os, Pd, Pt, Re, Rh, Ru, Sb, Sm, Sn, Ta, Te, Th, Tl, U, W, Zn.

Kyanite schist analyzed by E. L. Munson, with semiquantitative spectrographic determination of trace elements by P. R. Barnett, U. S. Geological Survey.

Montmorillonite ("smectite"), Cilly, Styria, analyzed by A. M. Smoot (Kerr 1932).

Such chemical compositions do not occur in ordinary sediments, in which the fine materials are mostly illitic clays. There is, however, a rock, bentonite, composed essentially of montmorillonite. Bentonite is a product of the alteration of volcanic material, most commonly ash beds deposited in sea water. The composition of montmorillonite, and so of bentonite, is variable, but typically the MgO/FeO ratio is high and the contents of CaO, Na_2O, and Fe_2O_3 are low. An analysis of montmorillonite ("smectite") from Styria is given in table 4. According to Kerr (1932), abundant relict structures of volcanic glass indicate that this specimen is an altered volcanic ash. The kyanite schist was obviously never pure clay, but it is reasonable to suppose that it was a clastic sediment containing, besides coarse detrital quartz and feldspar, a considerable amount of volcanic glass which was diagenetically altered to montmorillonite.

C. A. Chapman (1939), described kyanite schist as a metasedimentary rock within the Post Pond volcanic member of the Orfordville formation in the Mascoma quadrangle, New Hampshire. This is similar to the more muscovitic variety of the kyanite schist in the Old Speck Mountain quadrangle.

The kyanite schist member contains some rocks of a more normal composition, like the ordinary Ammonoosuc biotite schist (OSM 167), but still with a markedly clastic texture. Within the kyanite schist is also a bed several yards thick of pure quartzite, with muscovite and a trace of an opaque mineral as the only impurities (OSM 25).

Thickness. The thickness of the Ammonoosuc volcanics in this quadrangle is exceedingly difficult to estimate. In places the Partridge formation rests directly on the Albee, but this is believed to be the result of tectonic thinning rather than of the original absence of the Ammonoosuc. At several places where there is no reason to suppose particular structural complexities, about 2500 feet of Ammonoosuc lies between the Albee or the Oliverian and the Partridge. This may be taken as the thickness of the Ammonoosuc in this quadrangle.

Partridge Formation

General Statement. The Partridge formation of late Ordovician (?) age is composed mostly of schist with a lesser amount of micaceous quartzite. Sulfidic black phyllite composes probably less than ten percent of the Partridge, but it occurs in no other formation in this quadrangle.

The main area of Partridge occupies several square miles on both sides of route 26 in Upton. An area south of Cedar Brook in Grafton and one east of the river in Upton are underlain by Partridge whose connection with the main body is concealed by surficial deposits. A band of Partridge crossing Hemenway Ridge and the hill southwest of Whitecap Brook is less certainly connected under surficial deposits with the area at Cedar Brook. Deer Hill in Grafton is underlain by an isolated body of Partridge.

Lithology. The typical hand specimen of schist is a rather dark, silvery, fine-grained rock. Biotite flakes are usually just visible to the naked eye. Garnet is usually present as scattered dodecahedra of pinhead size.

PHOTO 11. Glacially polished outcrop of schist of the Partridge formation, hill southwest of Whitecap Brook.

Table 5. Estimated modes of the Partridge formation.

	21	29	31	32	33	69	96	104	105	153	181	281	282	284	286	396	398	448	451	477	478	510
Quartz	62	70	58	50	50	75	38	53	52	55	33	40	45	64	79	45	50	68	34	4	50	85
Plagioclase	3	10				5	5	10	3	T		5	38	T		35	7	3	3	4	8	
Muscovite	15		20	20	20	15	25	15	15	20	45	28	7	20	10		15	12	33			8
Biotite	15	10	15	10	15		25	15	20	14	15	20	6	10	5		18	10	20	9	17	
Chlorite				7	2					3	1			2							4	
Kyanite																					7	
Sillimanite									2								3	T	8		2	
Staurolite				2	10							3		1							12	
Garnet	4	5	5	5	1		1	5	5	5		3	2	T		10	5	4				
Hornblende		T														7				78		
Epidote																T				T		
Sphene		1												1		2						
Tourmaline				T	T			T		T			T	T				1	T		T	
Zircon																			T			
Talc																				3		
Apatite					T				T	T			T								T	
Opaques	1	4	1	3	1	5	5	1	3	2	5	1	2	1	1	1	2	2	2	2		
Graphite			1	3	1		1	1		1	1			1	5							7
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Table 5 cont'd.

OSM 451	Rusty weathering coarse-grained schist. 1700' elev. SW of summit of hill SW of Whitecap Bk.,,Grafton.
OSM 477	Medium-grained dark hornblendite from a three inch bed. 1650' elev. in gulch west of major bend in rte. 26, Upton.
OSM 478	Coarse-grained staurolite-kyanite schist. 1960' elev. on ridge west of major bend in rte. 26, Upton.
OSM 510	Sulfidic black phyllite. 2110' elev. east of group of houses on Back Street, Upton.

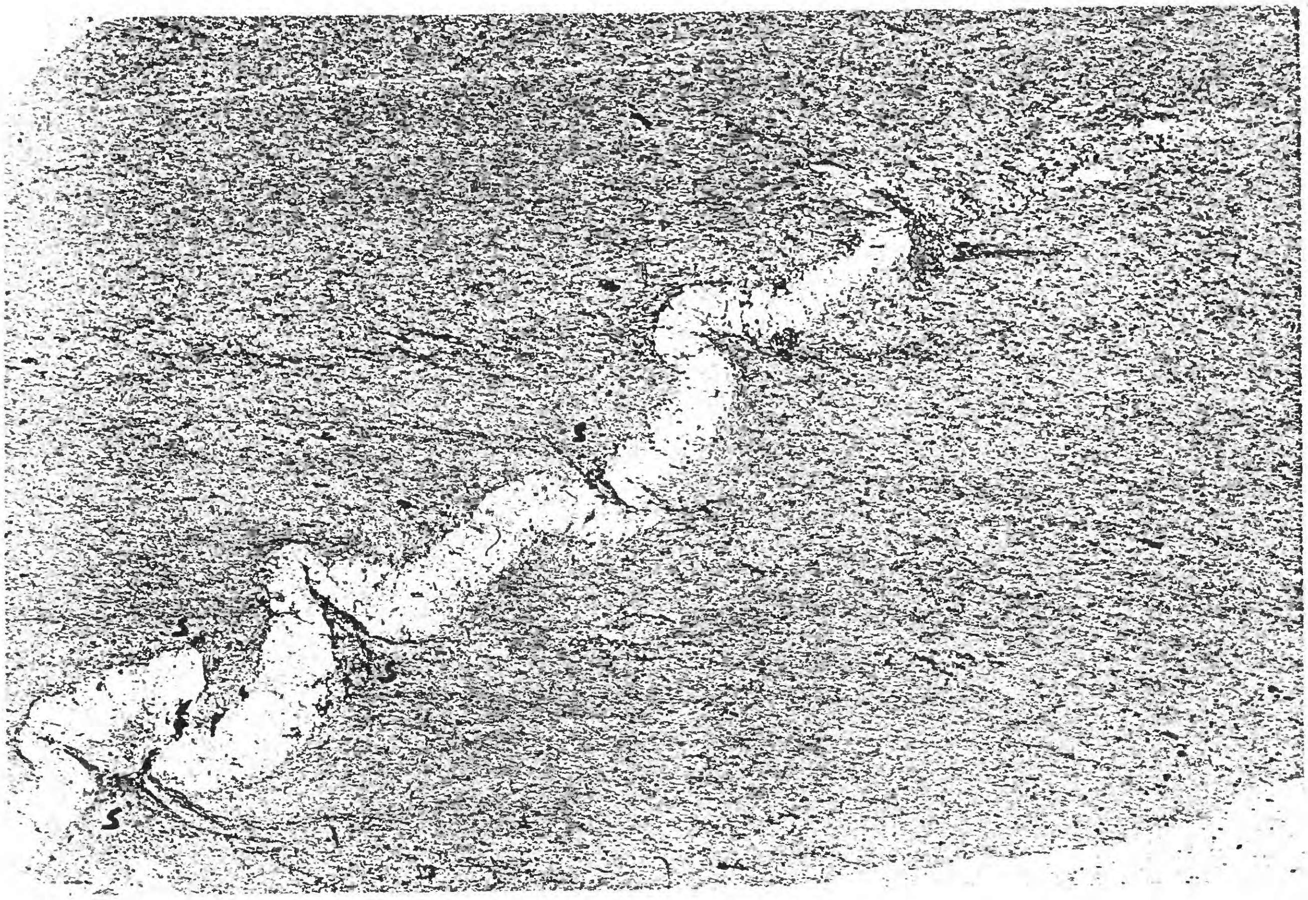
Staurolite is commonly present, in grains a few millimeters or even centimeters long. Iron sulfide characterizes the Partridge; its weathering gives rise to rusty outcrops. Bedding is detectable, though usually not prominent, in most outcrops. Individual beds are generally an inch or several inches thick. The bedding is chiefly marked by a variation in the quartz-mica ratio, but also by variations in accessory features, such as the abundance or even the grain size of garnets or the amount of pigmenting iron sulfide or graphite. Finer-scaled laminations are commonly found, but never with such sharp distinction of laminae as in the pin-striping of the Albee formation.

Under the microscope, quartz appears as the dominant mineral. Plagioclase (oligoclase or andesine) is present in very minor proportion or is absent. Muscovite and biotite are, with rare exceptions, both present, each generally composing from fifteen to twenty percent of the rock. Garnet is present as a minor constituent in nearly all specimens; chlorite and staurolite are common. Some fibrolitic sillimanite occurs in the higher-grade zone. Coarse-grained opaque minerals, usually pyrite, are almost universally present and commonly finely divided dusty-appearing graphite also. Tourmaline is present in many specimens as microscopic grains.

Micaceous quartzite is less abundant than the schist, to which it is very similar, except for a greater content of quartz. The quartzite and the schist are gradational into one another, even where they are interbedded, so that outcrops of the Partridge formation rarely show such sharply

PHOTO 12. Two mica schist of the Partridge formation, OSM 284. Staurolite grains (s) are all located at kinks along a quartz vein. x3.

PHOTO 13. Sulfidic black phyllite of the Partridge formation, OSM 286. Dark bands are fine grained quartz, muscovite, iron sulfide, and graphite. Light bands are beds (?) of quartz. x40.



differentiated beds as the interbedded schist and quartzite map unit of the Littleton formation.

Black phyllite is particularly abundant near the base of the formation on top of the hill east of Back Street, Upton, and just south of Cedar Brook, Grafton. This is a very fine-grained, black or dark-gray, fissile rock. It appears to be richer in quartz and poorer in mica than the ordinary schist (OSM 286, 510). The whole rock is dusted with finely divided graphite. Pyrite and, less commonly, pyrrhotite occur as discrete grains and interstitial to the quartz grains.

Other rock types are rather uncommon in the Partridge formation. Some feldspathic schists, resembling those of the Ammonoosuc, are found (OSM 282, 396). An outcrop of muscovite-free biotite-staurolite-kyanite schist (OSM 478) resembles the kyanite schist of the Ammonoosuc. Calc-silicate rocks are very rare in the Partridge, but layers of small nodules or strongly boudined beds are infrequently encountered (OSM 396). A bed of hornblendite three inches thick was found in a single outcrop (OSM 477). The protolith may have been an impure dolomite or a mafic ash bed.

The protolith of the Partridge formation as a whole was a somewhat sandy shale. The graphite and sulfides indicate that the environment of deposition was usually reducing, occasionally strongly so.

Correlation. This unit lies on the opposite side of the Ammonoosuc volcanics from the Albee and the Oliverian. Relations in the Hemenway Ridge and Deer Hill areas indicate that it lies unconformably beneath the

Littleton formation. Thus it lies in the proper stratigraphic position to be correlated with the Partridge formation of New Hampshire. The rock types of this unit support the correlation, considering that the type area of the Partridge formation lies in a lower zone of metamorphism.

Thickness. In the northern part of its outcrop area the Partridge is involved in complex folds in which only the base of the formation is exposed. Only a minimum thickness can be obtained in this area, about 1200 feet. The Hemenway Ridge-Deer Hill belt is probably a homoclinal sequence, but the apparent thickness, ranging from 0 to 4000 feet, is probably in large part a function of tectonic flowage. Along part of the post-Taconic unconformity, particularly to the northeast, the Partridge formation is entirely cut out. A range of thickness before deformation of from 0 to 2000 feet seems reasonable for the Partridge.

Relationships and Correlation of the Ordovician (?) Formations

The tripartite division of the Ordovician (?) group in the Old Speck Mountain quadrangle into an upper sedimentary formation with no obvious volcanic affinities, an intermediate formation of clearly volcanic, and a lower sedimentary formation of perhaps more distant volcanic affinities seems natural. It also matches the column set up in the classical Littleton-Moosilauke area by Billings. In the Old Speck Mountain quadrangle the contact of the two lower units is gradational, while the contact of the upper two is generally sharp.

None of the formations in this quadrangle is directly traceable back to the Littleton-Moosilauke area. The nearest area in which the equivalent

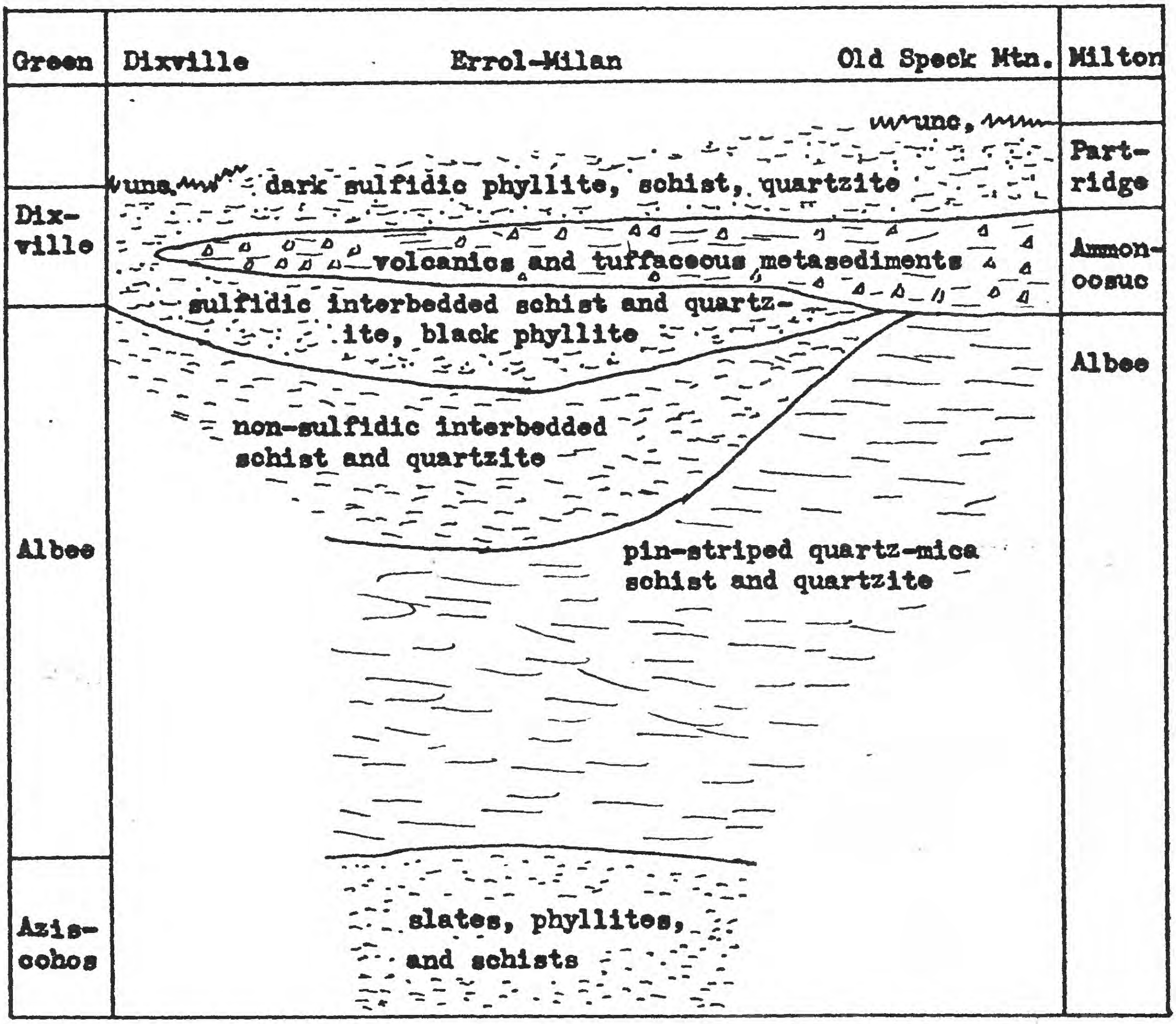


FIGURE 3. Diagrammatic stratigraphic section of the Ordovician and Ordovician (?) strata from the Dixville quadrangle to the Old Speck Mountain quadrangle. Formation names used by Green are given in left column.

section is exposed includes parts of the Errol (Green 1960), Dixville (N. L. Hatch, Jr., in progress) and Milan and Percy (Milton, in progress) quadrangles in New Hampshire. The stratigraphic relations in these areas are diagrammatically represented in figure 3. Green divided the Ordovician strata into three formations. The lowest is a newly established formation, the Aziscohos, consisting mostly of slates, phyllites, and schists. This is lower in the section than any strata exposed in the Old Speck Mountain quadrangle. Above is about 10,000 feet of the Albee formation, mostly micaceous quartzite, with gneiss, schist phyllite, and slate. Finally, Green established another new formation, the Dixville, about 5000 feet thick, that contains a metavolcanic member between upper and lower members composed predominantly of dark-gray to black schists, phyllites, and quartzites. Mapping by the writer in the Milan and Percy quadrangles indicates that the Albee formation of Green can be divided into a lower pin-striped member and an upper non-sulfidic interbedded quartzite and schist member with a very gradational contact between them. The upper member is transitional into the lower member of the Dixville, which is very similar but is sulfidic and contains some black phyllite. In the adjacent northern corners of the Milan and Percy quadrangles the volcanics are amphibolite, with sharp upper and lower contacts. Above this is a uniform sulfidic black phyllite. The volcanics are much thicker in the eastern than the northwestern part of the Milan quadrangle and both the sulfidic and non-sulfidic interbedded schist and quartzite units are much thicker in the northwest than the northeast (and, of course, are absent in the Old Speck Mountain quadrangle).

Further northwest, in the Dixville quadrangle, Hatch finds the volcanic unit thinning into isolated lenses.

Although the Dixville formation probably occurs in an isolated syncline, it seems most reasonable to correlate the volcanic member with the Ammonoosuc. Green and Hatch (personal communications) concur in this interpretation.

In summary, ~~there is~~ a volcanic unit wedging out to the northwest. A surface marking the first appearance upward in the section of black and dark gray color and of accessory sulfide minerals in the metasedimentary rocks indicate a transition from oxidizing to reducing conditions of sedimentation. From northwest to southeast this surface approaches the base of the volcanics. Near the western boundary of the Old Speck Mountain quadrangle it reaches the volcanics and perhaps passes beyond ~~it~~ into the upper sedimentary sequence.

The writer believes that the volcanic unit is a better stratigraphic marker, and its contacts more likely approximate time lines, than the transitions in the metasedimentary units. The writer suggests, therefore, that the Ordovician (?) volcanics in all the area discussed be mapped as Ammonoosuc, the sedimentary strata conformably above as Partridge and below as Albee. The name "Dixville", if retained, should be restricted to the lower sedimentary member of Green's formation and this should be considered a member at the top of the Albee formation with Partridge-like lithology.

Relations in the Old Speck Mountain quadrangle furnishes no new information on the age of these three formations, which elsewhere are considered of Upper Ordovician (?) (Billings 1956) or Middle Ordovician (?) (Cady 1960) age.

Littleton Formation

General Statement. The stratified rocks in over half of the quadrangle, southeast of a line running from the west side of the Mahoosuc Range to near South Arm of Richardson Lake, belong to the Littleton formation. Seven units within the formation were mapped, each characterized by a distinctive lithologic type. These are:

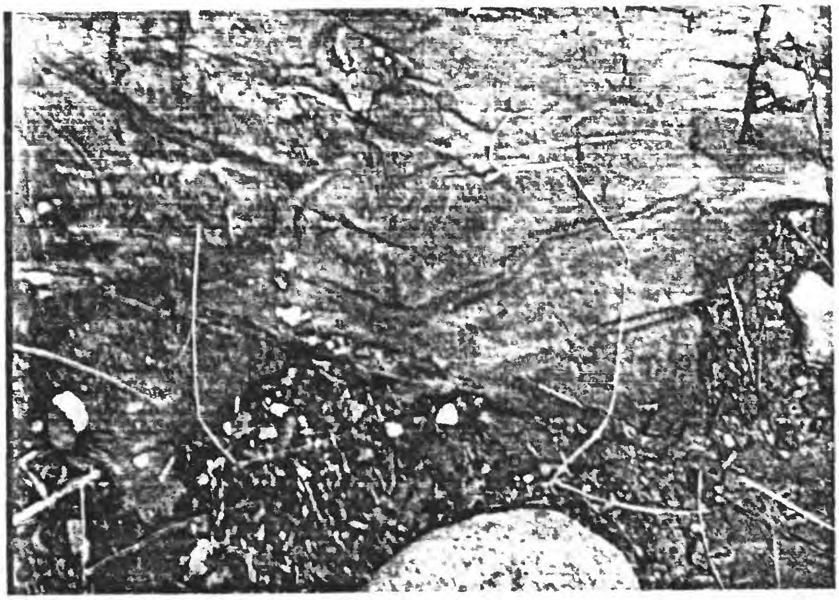
1) amphibolite
2) biotite schist
3) gneiss
4) conglomerate and quartzite
5) calc-silicate granulite
6) interbedded schist and quartzite
7) two mica schist

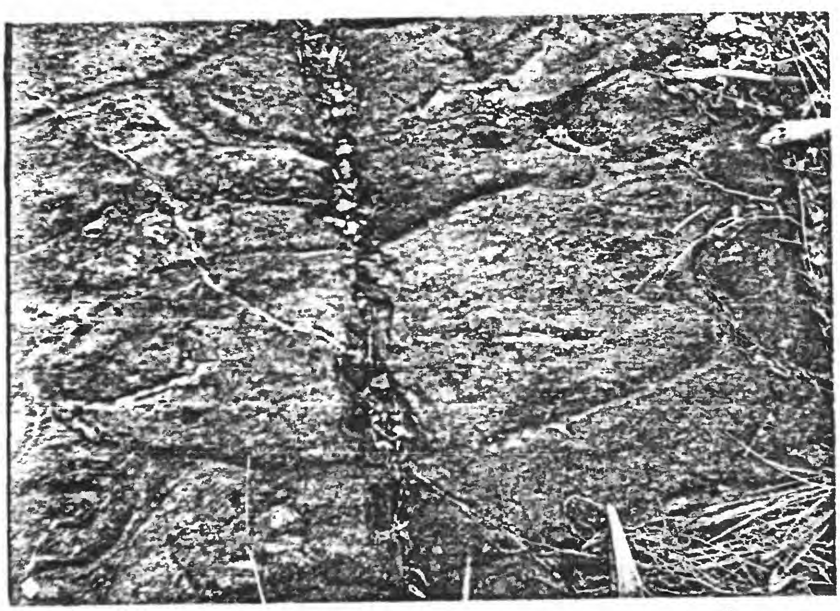
With the probable exception of the gneiss, the distinctive characteristics of each of these map units reflect different protoliths rather than merely different styles of metamorphism.

The amphibolite is distinct enough from the other units [illegible] ify [illegible] The six metasedimentary types are less well defined lithologically and areally as they are interbedded and gradational with one another. The units on the geologic map should be considered as indicating the location of the predominant or more distinctive rock types rather than as formal stratigraphic units. The stratigraphic significance of these map units is discussed below after all are described.

Whitecap Brook Amphibolite. The [illegible] amphibolite [illegible] [illegible] is study. It occurs in a discontinuous zone trending

PHOTOS 14 and 15. Pillow structure in the Whitecap Brook amphibolite. Near summit of hill southwest of Whitecap Brook.





northeast-southwest across the quadrangle. The two largest segments are a belt three and a half miles long extending from Whitecap Brook ~~itself~~ over Hemenway Ridge onto the slopes of Old Speck Mountain and a belt a mile and a half long near Dunn Notch. Farther southwest a small area lies near the quadrangle boundary west of Old Speck Mountain. To the northeast small areas of amphibolite near South Arm and on Moody Mountain are regarded as belonging to the ~~Whitecap Brook~~ unit, although the latter area may belong to the Ammonoosuc volcanics. Three small areas of amphibolite north of Frye Brook, Andover West Surplus, are mapped with the unit ~~as Whitecap Brook~~ for the sake of convenience, although they may lie higher in the section.

The ~~Whitecap Brook member~~ unit consists almost entirely of amphibolite, formed by the metamorphism of basalt. In the Hemenway Ridge-Whitecap Brook area most of the unit originally formed lava flows. This is most clearly indicated by pillow structures, well developed near the top of the hill southwest of Whitecap Brook (photos 14 and 15) and poorly or doubtfully developed elsewhere. The cross sections of the pillows on the face of the outcrops (about at right angles to the plane of bedding) measure about two feet long and six or ten inches high. It was impossible to find any consistent top sense. Most of this belt is composed of massive non-bedded dark amphibolite without pillows. Much of this is amygdoloidal, with the amygdules flattened parallel to the foliation and greatly elongated in the direction of the regional plunge. Under the microscope each amygdule is seen to consist of a number of small grains of plagioclase, and in some, a little quartz (photo 16). Metamorphosed porphyritic basalt,

Table 6. Estimated modes of the Whitecap Brook amphibolite ~~member of~~ in the Littleton formation.

	2	3	4	5	6	11	189	190	193	275	312	449	450	480	483
Quartz		45	35		65	30		5			1			5	18
Plagioclase	50	45	1	47	18	33	58	35	15	65	50	50	47	66	38
Potassic feldspar						T		15	25						
Muscovite			28		5										
Biotite*		10	23		12	10	1	T	8	3	5	1	8	8	12
Hornblende	35	T		47		25	40	28	45	20	40	40	45	6	20
Cummingtonite	T													10	8
Augite	15			5				10		10					
Staurolite			3												
Sillimanite			4											T	
Andalusite			3												
Prehnite**	T					T			1						
Tourmaline								T							
Epidote	T							5	1						
Sphene	T	T		1			1	T	5	T		5	T		
Apatite	T	T	T		T				1	T				T	T
Calcite**	T	T				T		1							
Opaques	T	T	2	T	T	2		1		2	4	T	T	5	4
An content of plag.				35	15				60	17	35				

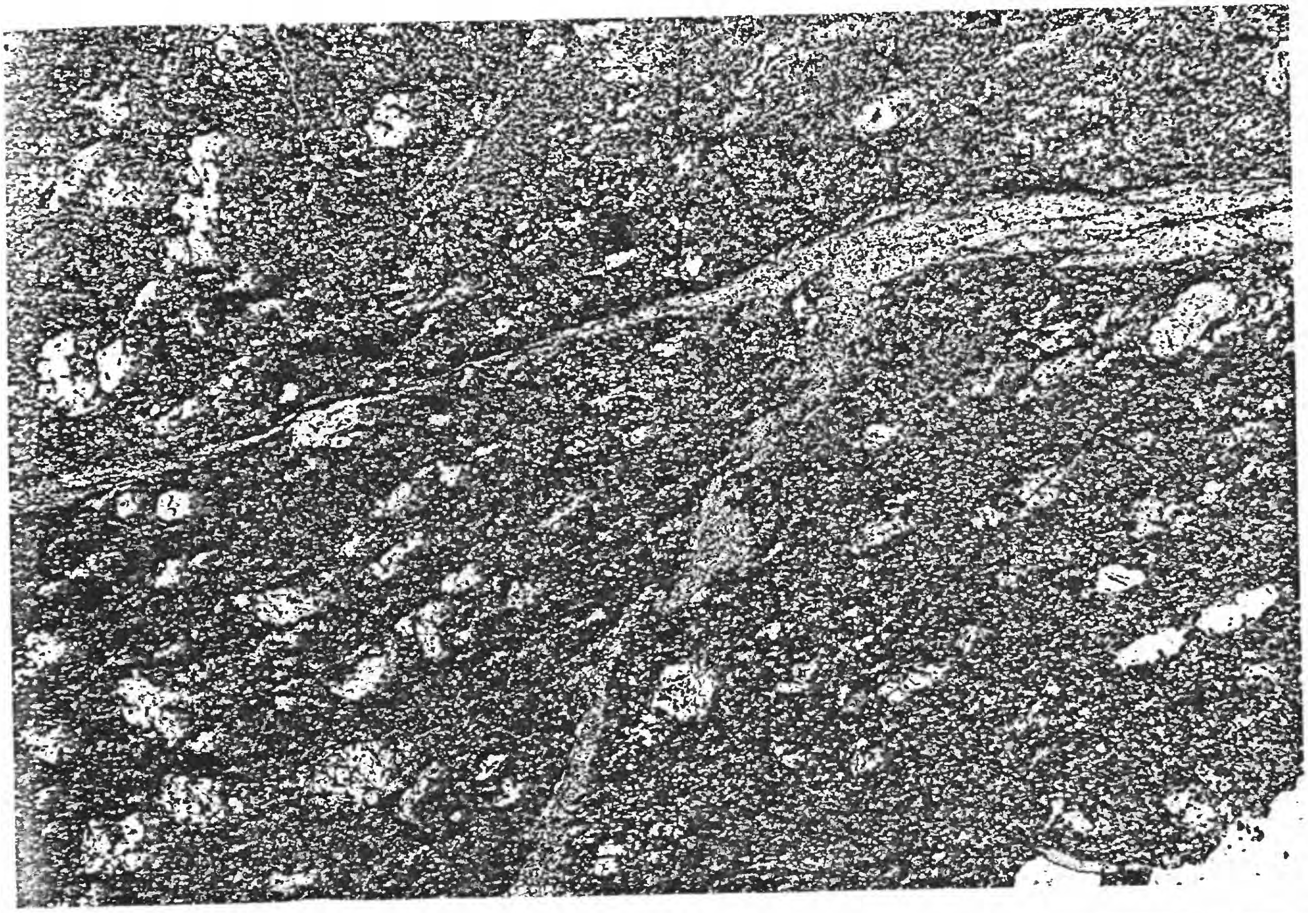
*Some biotite is altered to chlorite.
**Prehnite and calcite are alteration products.

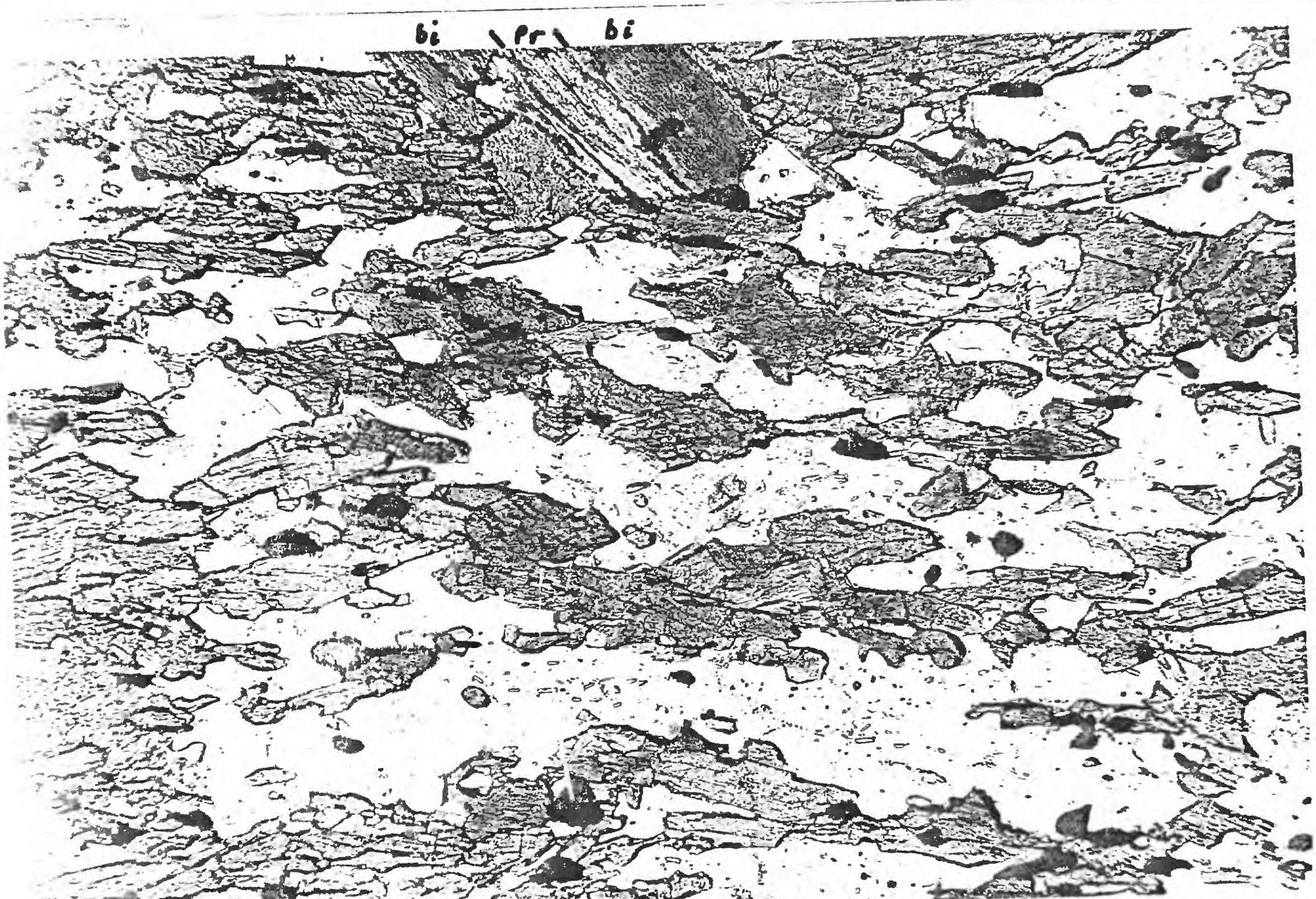
Table 6 cont'd.

OSM 2	Bedded dark amphibolite. 1280' elev. on trail in Dunn Notch, North Surplus.
OSM 3	Hard thinly laminated gray rock. With OSM 2.
OSM 4	Medium-grained light colored schist. 1320' elev. on trail in Dunn Notch, North Surplus.
OSM 5	Bedded dark amphibolite. 1340' elev. on trail in Dunn Notch, North Surplus.
OSM 6	Hard thinly laminated light colored rock. At forks in West Branch, Dunn Notch, North Surplus.
OSM 11	Bedded dark amphibolite. 1415' elev. in bk. west of road north of Dunn Notch.
OSM 189	Massive dark amphibolite with feldspar megacrysts. 1610' elev. in Whitecap Brook, Grafton.
OSM 190	Medium-grained light colored granulite with hornblende. 1660' elev. in Whitecap Brook, Grafton.
OSM 193	Thinly laminated coarse-grained dark amphibolite. 2380' elev. in brook NW of Speck Pond, Grafton.
OSM 275	Massive dark amphibolite. Culvert on rte. 26 0.4 miles south of river crossing, Grafton.
OSM 312	Dark amygdaloidal amphibolite. 2080' elev. on east ridge of hill SW of Whitecap Bk., Grafton.
OSM 449	Bedded dark amphibolite. 2000' elev. on north ridge of hill SW of Whitecap Bk.
OSM 450	Fine-grained massive dark amphibolite from a pillow structure. 2060' elev. on north ridge of hill SW of Whitecap Bk.
OSM 480	Bedded hornblende schist. 2200' elev. on north slope of Moody Mtn. at town line.
OSM 483	Medium-grained dark hornblende schist. 1700' elev. on ridge west of Birch Brook, T C.

PHOTO 16. Pillow lava of the Whitecap Brook amphibolite, OSM 450. Dark mass is hornblende and plagioclase. White spots are amygdules, each showing ten or twenty plagioclase crystals. White bands are fine-grained plagioclase, filling interstices between pillows. x5.

PHOTO 17. Bedded Whitecap Brook amphibolite, OSM 11. Light grains are plagioclase. Dark grains are hornblende except for a large grain of biotite at upper edge, which is partially replaced by prehnite. x60.

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also occurring in this area, is characterized by white spots very similar to those of the amygdaloidal amphibolite, although slightly more angular and less deformed. Each of these consists, however, of a single crystal of plagioclase, presumably phenocrysts that have survived metamorphism.

The amphibolites in Andover West Surplus, near South Arm, and on Moody Mountain are mostly fine-grained massive types, probably also originally lava flows.

Some amphibolite, particularly in the Dunn Notch area, is a well bedded rock, originally basaltic tuff rather than lava.

All the amphibolites, including both the massive and bedded types, are petrographically similar. Hornblende and plagioclase (usually andesine, oligoclase or labradorite) are the dominant minerals. Quartz is absent or minor, although it seems to be somewhat more abundant in the bedded amphibolites. Biotite is usually present in small amounts. Augite also occurs in minor quantities, occasionally as a major constituent in beds 1 cm or less thick. Epidote is absent or present only in small quantities. Cummingtonite is occasionally found in homoaxial intergrowths with hornblende.

The ~~Whitecap Brook member~~ amphibolite unit includes a small proportion of rock types other than amphibolite. Bedded biotite schist (OSM 3, 6) quite like that of the Ammonoosuc, and even some muscovitic schist (OSM 4), occur near Dunn Notch. As these are rather restricted in extent and are in contact with amphibolite on both sides, they are regarded as part of the ~~Whitecap Brook member~~ amphibolite unit.

A gabbro body west of Sable Hill, Grafton, is compositionally like the amphibolite, but is much coarser. It is mapped and described separately, but it may well have been a shallow intrusive comagmatic with the amphibolite. A few outcrops of similar gabbro on the east end of Hemenway Ridge are not distinguished from the amphibolite on the map. Coarse hornblendite cropping out on the hillside southwest of Whitecap Brook may represent a mafic phase of the Whitecap Brook vulcanism or may belong to an intrusive unrelated to the country rock, such as the hornblendite on Sawyer Mountain.

Biotite schist. Biotite schist occurs in the southeastern and the northwestern parts of the area of Littleton formation. In the southeast it occupies a discontinuous zone extending across Newry from the quadrangle boundary to Sargent Mountain. Similar schists occur further west, but as they are associated with major amounts of calc-silicate granulites, they are mapped as a separate unit. In the northwest, biotite schist extends in a nearly continuous belt from the quadrangle boundary west of Mahoosuc Arm to Dunn Notch and occurs farther along the strike near Richardson Lake.

The diagnostic rock of this unit is a dark-colored, rather fine-grained feldspathic biotite schist, crumbly rather than fissile. The three major minerals are quartz, plagioclase (sodic andesine), and biotite. Small crystals of red garnet are almost invariably present, but generally compose only one to three percent of the rock. Muscovite is absent or present to the extent of one or two percent. The muscovite-bearing rocks usually contain fibrolitic sillimanite in small amounts. Staurolite occurs in a few specimens.

Table 7. Estimated modes of the biotite schist map unit of the Littleton formation.

61-105

	1	66	67	246	314	413	428	429	431	432	437	441	465	484	499	500	532	533	549	*
Quartz	20	25	40	40	40	58	52	42	38	40	35	28	23	32	22	45	50	33	31	36.5
Plagioclase	35	45	45	35	33	5	T	30		25	18	35	23	40	43	30	32	42	35	42
Potassic feldspar	22	5											20							
Muscovite			1			10	22		33	1	17		15	2	2	1	1	1	15	2.5
Biotite	15	20	12	15	25	20	22	25	20	28	22	35	15	25	28	19	15	20	15	14
Garnet				2	2	5	2	2	1	1	2			T	1	3	1	3	1	
Staurolite						T			1	4										
Sillimanite						1	2		5	T	5			T	T	T	T	T	2	3
Andalusite						1														
Hornblende				8																
Sphene	T																			
Tourmaline						T	T		1		T		T							
Zircon		T										T		T	T			T	T	
Monazite																		T		
Apatite	T	T	1		T		T	T	T		T	1	T	T	1		T	T	T	0.3
Opaques	8	5	1		T	T	T	T	1		T	1	4	1	1	2	1	1	1	1.5
An content of plag.		and-lab	and		and-lab			olig		and	and	lab	olig	and	and	and	and	and	olig-and	35

*Norm calculated for average graywacke of Pettijohn (1957, table 52A). Opaques are magnetite.

Table 7 cont'd.

OSM 1	Hard fine-grained gray granulite. 1180' elev. on trail in Dunn Notch, North Surplus.
OSM 66	Fine-grained dark biotite schist. 1640' elev. in Swift Cambridge River, Grafton.
OSM 67	Medium-grained light-colored gneissic schist with biotite. Near OSM 67.
OSM 246	Medium-grained hard dark biotite schist. 1700' elev. in trib. entering Stony Bk. at 1300' elev., Newry.
OSM 314	Coarse-grained semigneissic biotite schist. 2500' elev. in highest trib. on right to Swift Camb. R.
OSM 413	Medium-grained two mica schist. 2170' elev. on top of small knob on Surplus Mtn., N. Surplus.
OSM 428	Medium-grained silvery-gray two mica schist. 1430' elev. in Meadow Brook, Newry.
OSM 429	Fine-grained dark granulite. 1510' elev. in Meadow Brook, Newry.
OSM 431	Medium-grained silvery-gray two mica schist. 2350' elev. in Meadow Brook, Newry.
OSM 432	Fine-grained dark granulite. 2450' elev. in Meadow Brook, Newry.
OSM 437	Medium-grained two mica schist. 2150' elev. on NE ridge of Surplus Mtn., North Surplus.
OSM 441	Coarse-grained schist with large biotite flakes. 2550' elev. NE of town corner, Surplus Mtn., N. Surplus.
OSM 465	Fine-grained silvery-gray two mica schist. 1590' elev. in Swift Cambridge River, Grafton.
OSM 484	Coarse-grained gneissic schist. 1700' elev. 0.6 miles east of Richardson Lake, T C.
OSM 499	Coarse-grained schist. 1350' elev. on N ridge of small knob SE of Bald Mtn., Newry.
OSM 500	Medium-grained dark schist. 1300' elev. just north of OSM 499.

Table 7 cont'd.

OSM 532	Fine-grained granular schist with coarse biotite partings. 1700' elev. in hollow on NE slope of Bald Mtn., Newry.
OSM 533	Fine-grained biotitic granulite. 2500' elev. on southeast ridge of Stowe Mtn., Newry.
OSM 549	Coarse-grained semigneissic schist. 1650' elev. in brook west of Sable Hill, Grafton.

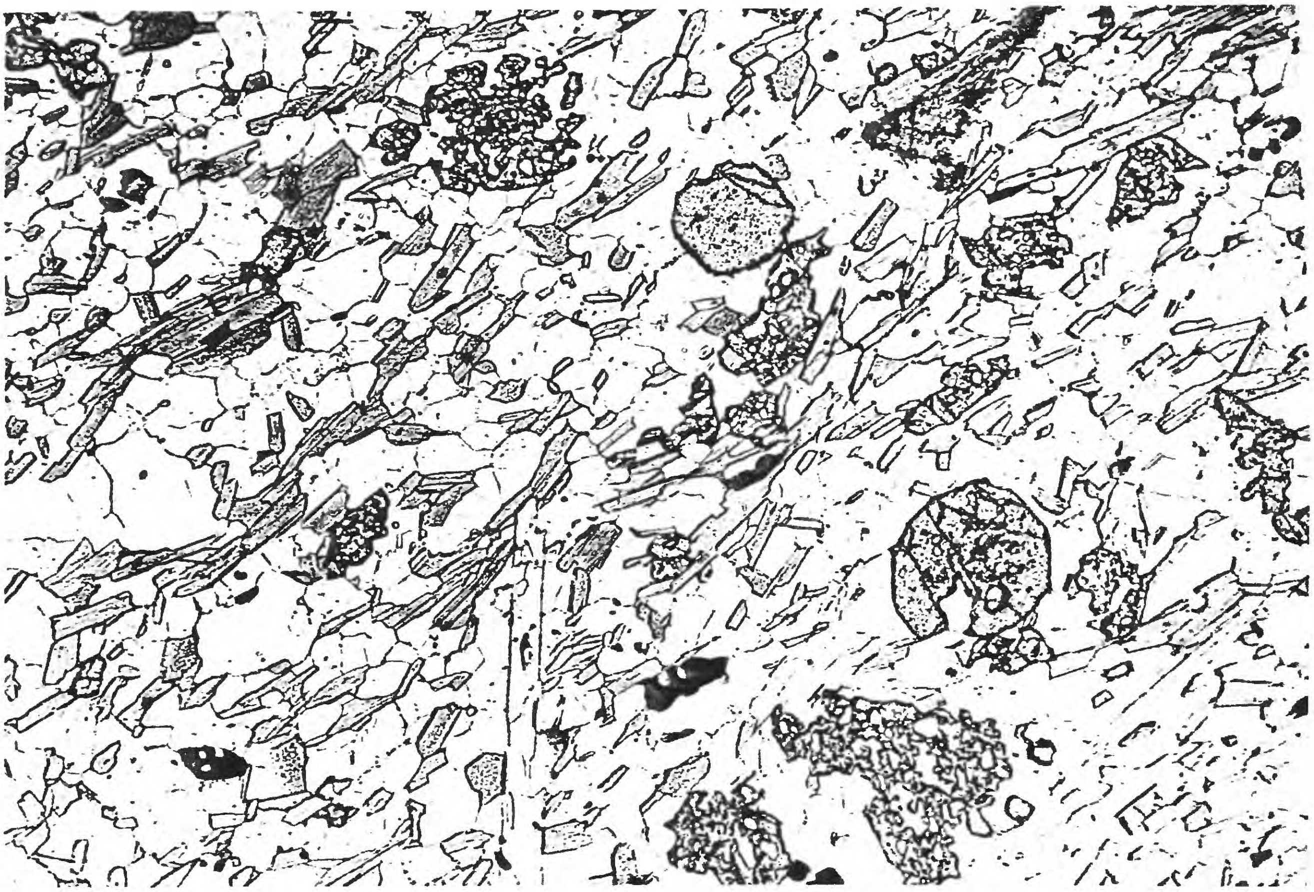
The quartz and feldspar form simple, roughly equant grains. Biotite is in flakes distributed uniformly through the rock rather than concentrated on certain planes, and oriented in such a way that their axes form a girdle normal to the lineation, with a strong maximum normal to the schistosity. This arrangement of the biotite flakes is the cause of the poor fissility which is occasionally so poor that the rock is better called a granulite than a schist. Where present, muscovite is usually in tablets larger than the biotite flakes and oriented transversely to the schistosity.

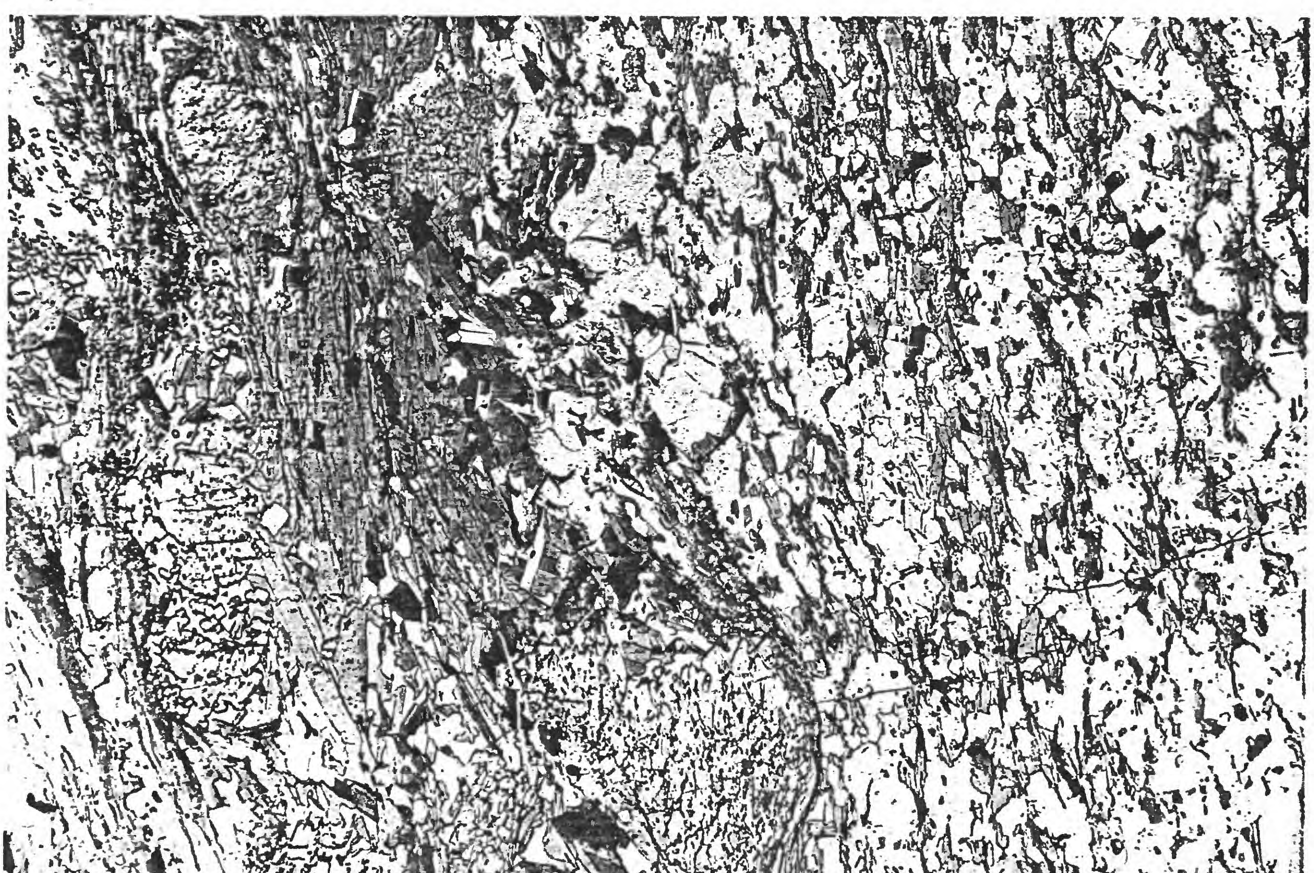
In the northwestern belt some biotite schist is similar to that described above except that it contains a considerable amount of potassic feldspar (OSM 1, 66). Garnet is absent in this type. This rock occasionally contains flattened and elongated quartzo-feldspathic lenses a few inches long. They resemble distorted sedimentary clasts, but their distribution is so erratic that they are more likely podlike segregations.

The second most abundant lithologic type in the biotite schist map unit is two mica schist, identical with that which characterizes the two mica schist map unit (OSM 428, 431, etc.). Interbedding of the two types occurs on all scales from that shown on the map down to that seen in thin section. Although each type grades toward the other compositionally, they tend to remain distinct, so that it is rare that there is doubt as to which to consider an individual bed. The interbedding makes mapping difficult; as it was done there is a considerable amount of two mica schist in the biotite schist unit, but not much biotite schist in the two mica schist unit.

PHOTO 18. Biotite schist of the Littleton formation, OSM 432. Light grains are quartz and plagioclase. The two round grains of high relief are garnet, others are staurolite. A few muscovite grains are present, the long one at bottom center has the typical orientation transverse to the foliation. Ragged area in upper right is biotite largely replaced by fibrolitic sillimanite. x25.

PHOTO 19. Interbedded schist and quartzite from the conglomerate and quartzite unit of the Littleton formation, OSM 496. Sillimanite forms both large porphyroblasts and fibrolitic aggregates in the schist bed. x10.





In the southeastern areas, the biotite schist unit contains some calc-silicate granulite similar to that mapped as a separate unit farther west. The abundance of this rock type is difficult to determine, as it is more susceptible to erosion than the schist and is commonly found only in float. Where rather complete sections are exposed, however, calc-silicate granulite appears to be a very minor component. Calc-silicate concretions like those in the interbedded schist and quartzite map unit occur in the biotite schist also.

The biotite schist is mineralogically very similar to the major paragneiss of the northwestern Adirondacks of Engel and Engel (1953). Their description of the origin of that unit is relevant here. They consider the possibilities that the paragneiss was produced by isochemical metamorphism of graywacke, tuff, or an unusual zeolitic sediment, or by allochemical metamorphism of some protolith of different composition. The biotite schist in the Old Speck Mountain quadrangle is not gneissic and is in a lower zone of metamorphism than the paragneiss of the Adirondacks, so that significant allochemical metamorphism of the biotite schist may be ruled out as very unlikely. Engel and Engel point out that a high ratio of soda to potash is a characteristic feature of graywackes and largely on this basis they favor the hypothesis that the paragneiss is a metagraywacke. A high soda-potash ratio also characterizes the biotite schist unit. A norm calculated for Pettijohn's average graywacke in about this metamorphic grade is quite close to the modes of the biotite schist (table 7).

The more potassic schist of the northwestern belt resembles some of the metamorphosed tuffs of the Ammonoosuc volcanics. The association of these with the Whitecap Brook amphibolite suggests that this biotite schist may contain volcanic detritus, if it was not indeed a pyroclastic rock.

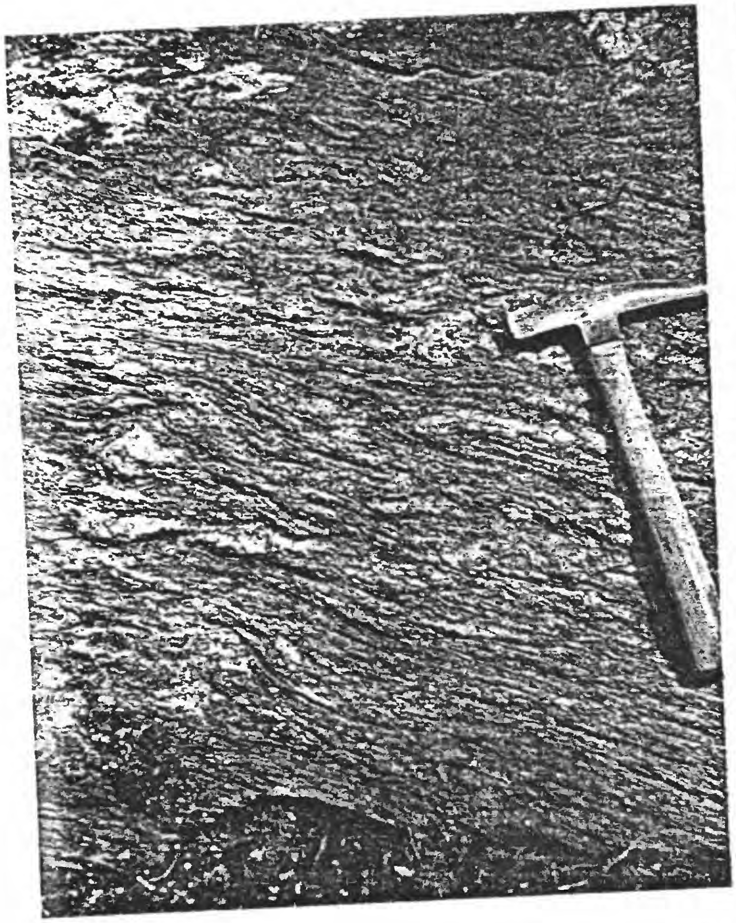
Another protolith that can become biotite schist is dolomitic shale. Dolomitic shale contains more CaO and MgO than the common type of the biotite schist unit. A variety of biotite schist with a more calcic plagioclase and a more phlogopitic biotite may be metamorphosed dolomitic shale. This type is rather minor in the biotite schist map unit, although it is rather abundant in the calc-silicate granulite unit.

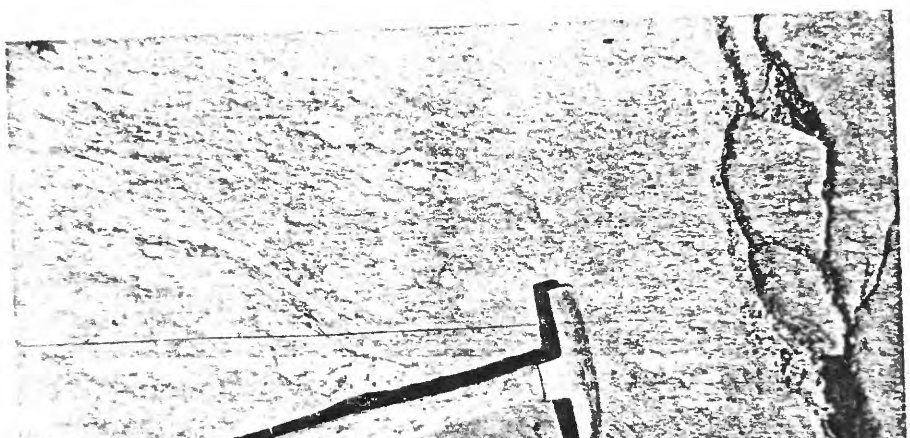
Gneiss. The gneiss map unit extends about a mile into the Old Speck Mountain quadrangle all along its southern boundary. The characteristic feature of the gneiss is that portions the size of a hand specimen or slightly larger can be readily seen to consist of two types of material, schistose and granitic. The schistose component is usually dominant, with the granitic component in veins, pods, or knots. Less commonly the granitic component is more abundant, with the schist forming wisps. In this quandrangle the schistose component usually resembles the biotite schist, less commonly the two mica schist. The granitic component is composed of plagioclase and quartz, usually of coarse, even pegmatitic, grain size.

The contact of the gneiss map unit with the other metamorphic map units is everywhere rather arbitrary. It excludes schist in which

PHOTO 20. Gneiss of the Littleton formation. Gooseeye Mountain.

PHOTO 21. Conglomerate of the Littleton formation. Bear River above North Newry.





granitic material occurs only sporadically, and schist with which granitic material is intermingled on a scale too fine to be readily distinguishable at sight.

The gneiss is believed to have formed from schist. Fisher (1952) has presented evidence that the gneiss of the adjacent Bethel quadrangle (apparently somewhat more muscovitic than that of the Old Speck Mountain quadrangle) formed with at most minor change of bulk composition from original sandstones and shales.

Conglomerate and quartzite. All the Littleton formation which contains pebbles is included in this map unit. A few bodies were mapped with this map unit in which pebbles were not seen, but which are composed of coarse clean quartzite like that associated with pebble beds elsewhere. This map unit forms small bodies through much of the Littleton formation in this quadrangle, but it is most abundant in a belt somewhat above the northwestern base of the formation.

In most localities the largest clasts are small pebbles, but some cobble-size clasts occur. Some of the conglomerate consists of close-packed pebbles (notably the white quartz-pebble conglomerate near the summit of Surplus Mountain), but in most occurrences pebbles are more or less sparsely scattered through a finer-grained matrix. Much of this map unit would be included with the interbedded schist and quartzite map unit were it not for the presence of scattered pebbles in the quartzite and, less commonly, the schist beds. In most such occurrences the quartzite is coarser and cleaner than in the schist and quartzite map unit. The

Table 8. Estimated modes of the conglomerate and quartzite map unit of the Littleton formation.

	192	197	270	364	436	439	442	474	475m	475p	487	495	496s	496q
Quartz	82	87	72	62	82	82	92	50	82	40	62	70	35	65
Plagioclase	5	8	15	5	4	5		31		15	10	15	5	15
Potassic feldspar	3	2	10	2			1		1	35				
Muscovite		1			3	5					5	T	10	
Biotite		2	3		10	5		12	15	8	20	14	25	15
Staurolite					T									
Sillimanite						3					3		24	5
Garnet				2	1	T		3				1		
Hornblende	3			3			2							
Pyroxene	4			1										
Epidote	3			20			5		2	2				
Zoisite				5										
Tourmaline					T		T							
Sphene	T			T			T		T	T				
Zircon	T				T	T						T		
Monazite		T												
Apatite	T	T		T	T			T				T	T	T
Opaques	T	T	T	T	T		T	4				T	1	T

Table 8 cont'd.

OSM 192	Coarse-grained glassy quartzite. 2150' elev. in north fork of Whitecap Brook, Grafton
OSM 197	Coarse-grained quartzite with small quartz pebbles. 3000' elev. in trib. to Pond Bk. SW of Old Speck Mtn., Grafton.
OSM 270	Medium-grained gray quartzite with quartzitic clasts. 1860' elev. in brook south of Deer Hill, Grafton.
OSM 364	Medium-grained light colored granulite. 2500' elev. in north fork of brook west of Notch 2, Grafton.
OSM 436	Schistose conglomerate with small quartz and quartzite pebbles. 3060' elev. on west ridge of Puzzle Mtn., Newry.
OSM 439	Schistose quartzite with small quartz pebbles. 2100' elev. north of easternmost knob, Surplus Mtn., N. Surplus.
OSM 442	White quartz granule conglomerate. 2900' elev. on Surplus Mtn. on West Surplus-Grafton line.
OSM 474	Medium-grained dark biotite schist with clastic texture. 2200' elev. 0.2 miles south of quad. bdry., Old Blue Mtn., T C.
OSM 475	Schistose conglomerate matrix (m) enclosing granite pebble (g). 2200' elev. just inside quad. bdry., Old Blue Mtn., T C.
OSM 487	Medium-grained biotite schist with quartz granules. 2230' elev. on SW slope of Riley Hill, Riley.
OSM 495	Medium-grained gray granulite. Near OSM 487.
OSM 496	Interbedded coarse-grained sillimanite schist (s) and medium-grained biotitic quartzite (q).

(page 70 follows)

conglomerate and quartzite bodies near Pond Brook, south of Old Speck Mountain, consist in large part of uniform, clean, medium-grained, white quartzite. Glassy quartz pebbles are found in these bodies, but are not abundant.

The fragmental character of many finer-grained specimens from this map unit which do not contain clasts visible to the naked eye becomes apparent in thin section. The quartz and feldspar grains in a single section may range in size through several orders of magnitude, which is rarely the case in other units in the quadrangle except the kyanite schist member of the Ammonoosuc volcanics. Feldspar grains poikilitically including quartz, presumably as a relict texture preserved from the original clasts, are common, whereas they are rare in the more even-grained metamorphic rocks.

The majority of the pebbles are quartzite and vein quartz, with a few pebbles of granitic rock. Granules of single feldspar crystals are probably of granitic origin. None of the clasts is definitely referrable to any one of the older formations of the area. In particular no certain fragments of volcanic rocks have been found. The Albee might be the source for much of the quartzite. Quartz veins capable of supplying glassy quartz pebbles are now common in the Albee, but they probably formed during the post-Littleton metamorphism.

The conglomerate body just south of Deer Hill is of an exceptional type. Fifteen or twenty feet of conglomerate are exposed, unconformably overlying the Partridge ~~schist~~. This is the only truly basal conglomerate in the Littleton in this quadrangle. It consists of extremely flattened and elongated lenticles of light-colored feldspathic quartzite set in a dark schistose matrix that resembles the schist of underlying Partridge formation. The lenticles, which are almost certainly sedimentary clasts, attain boulder size at the base of the conglomerate. The lenticles are themselves conglomeratic, as they contain rounded quartz granules. This indicates a two-stage depositional history, with the primary granule-bearing conglomerate broken into boulder size fragments and redeposited. The extreme deformation of the lenticles indicates a low cohesiveness, which suggests that the second stage of transport was only for a short distance.

The calc-silicate minerals diopside, hornblende, and epidote-clinozoisite occur as minor constituents in the conglomerate in several areas (OSM 192). The band of conglomerate crossing Mahoosuc Arm contains a bed of calc-silicate granulite at least five feet thick (OSM 364). The dominant calc-silicate mineral in this bed is clinozoisite, rather than hornblende, as in the calc-silicate granulite map unit. Elsewhere the conglomerate contains calc-silicate concretions, some of which have grown so as to include pebbles.

In all outcrops of conglomerate, pebbles are flattened parallel to the local foliation and elongated parallel to the lineation. Vein quartz pebbles are only slightly deformed, quartzite pebbles more severely. An extreme is reached with the second generation clasts south of Deer Hill, where the ratio of the intermediate to the minor axis may exceed five, and the ratio of the major to the intermediate axis is even greater, too large to be measured.

Calc-silicate granulite. Calc-silicate granulite occurs near Ketchum in the townships of Riley and Newry. About half of the map unit is actually granulite; the other half is biotite schist similar to that of the biotite schist map unit in Newry, although in general with a more calcic plagioclase. The granulites include hornblende, hornblende-biotite, and hornblende-diopside-biotite types. They contain very calcic plagioclase, a considerable amount of quartz and some contain a small amount of potassic feldspar. Carbonate minerals are usually absent, but occasionally a carbonate (presumably calcite) occurs as an accessory mineral. Sphene, apatite, and blue tourmaline are the characteristic accessories.

The various types of granulite characteristically alternate in layers an inch or less in thickness. This layering is not entirely original bedding, but is modified from it by metasomatic processes. For example, in specimen OSM 237 a sequence of types A-B-C-B-A (as in table 9) is encountered in a single thin section (photos 23, 24, 25). Zone B appears to be a reaction zone between A and C. Moreover, these zones cut at a slight angle across what seems to be original bedding.

The protolith of the calc-silicate granulite map unit was probably a sequence of beds in which dolomitic, quartzose, and shaly components were mingled in varied proportions.

Table 9. Estimated modes of the calc-silicate granulite map unit of the Littleton formation.

	237A	237B	237C	335	338	490	493
Quartz	45	33	22	45		25	46
Plagioclase	30	25	45	28	23	15	25
Potassic feldspar					15	25	T
Muscovite				1			
Biotite	25	1		25	25	10	28
Hornblende		38	19		35	15	
Diopside						8	
Epidote			1				
Allanite	T						
Garnet			9				
Tourmaline	T	T	T	T		T	
Sphene	T	3	3	T	1	1	T
Zircon		T			T		
Apatite	T	T	1	T	T	T	T
Calcite				1			
Opaques	T	T		T	1	1	1
An content of plag.	70	77	77	43	30	60	57

OSM 237 Thinly bedded lime silicate granulite. B is a reaction zone between A and C.
On road at notch at Head of Eames Brook, Riley.

OSM 335 Hard fine-grained biotite schist.
Bull Branch 0.2 miles above Ketchum, Riley

OSM 338 Friable dark biotite-hornblende schist.
Bull Branch 0.3 miles above Miles Notch Brook, Riley.

OSM 490 Thinly bedded medium-grained granulite.
2059' elev. just inside quad. bdry. west of Sunday R., Riley.

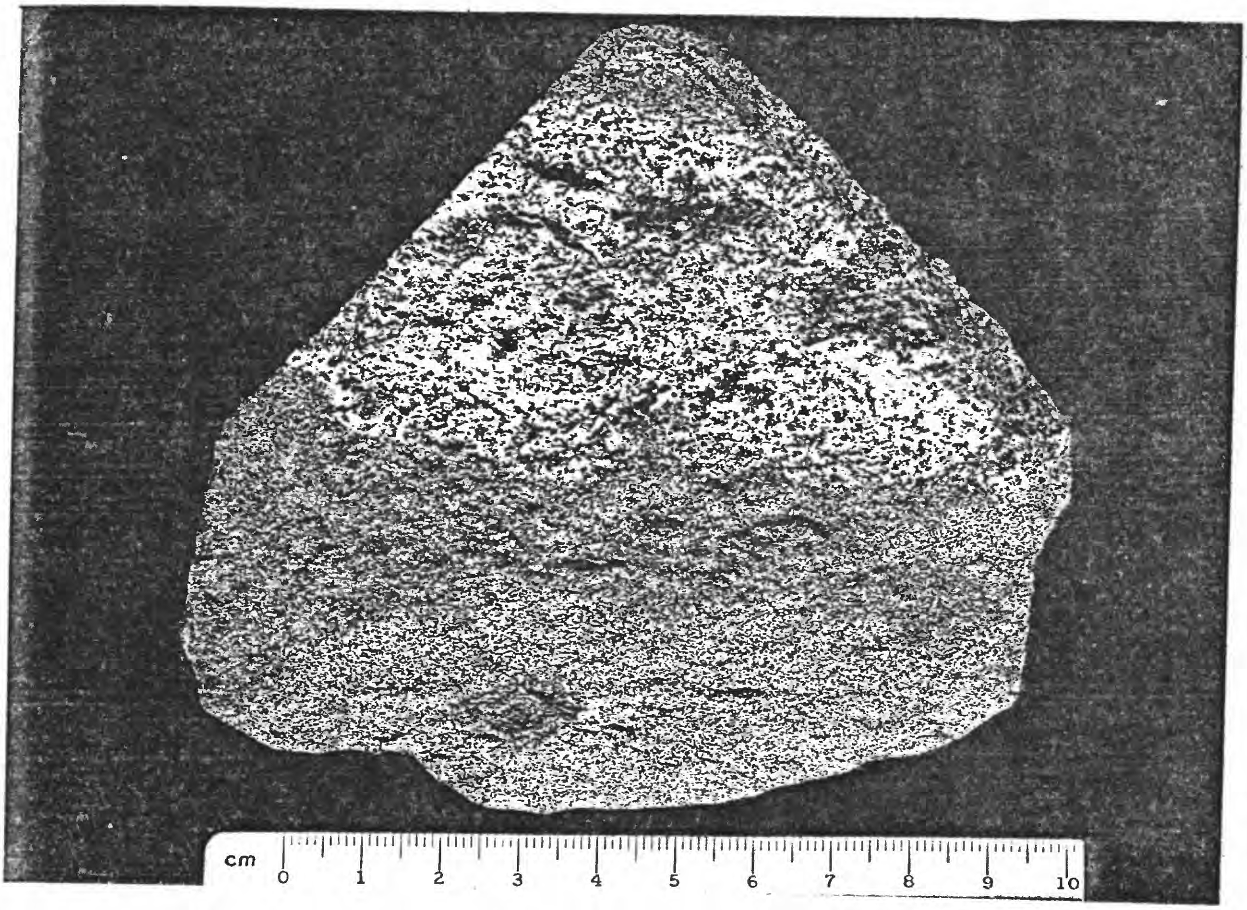
OSM 493 Fine-grained gray biotite granulite.
1350' elev. 1 mile WNW of Ketchum, Riley.

PHOTO 22. Tightly folded calc-silicate granulite of the Littleton formation. The upper light-colored bed has been pulled apart into segments at each fold. Head of Eames Brook, Newry.

PHOTO 23. Calc-silicate granulite of the Littleton formation, OSM 237. A is biotite zone; B is hornblende zone; C is hornblende-garnet zone. Note curved dark bands extending through zones A and B (the upper end of one is at right corner of specimen, the end of another is at center).

PHOTO 24. OSM 237. Lower right half is biotitic zone A; upper left half is hornblendic zone B. Plagioclase appears darker than quartz. x10.

PHOTO 25. OSM 237, zone B. Line of dark grains is sphene lamina seen at left in photo 23. x10.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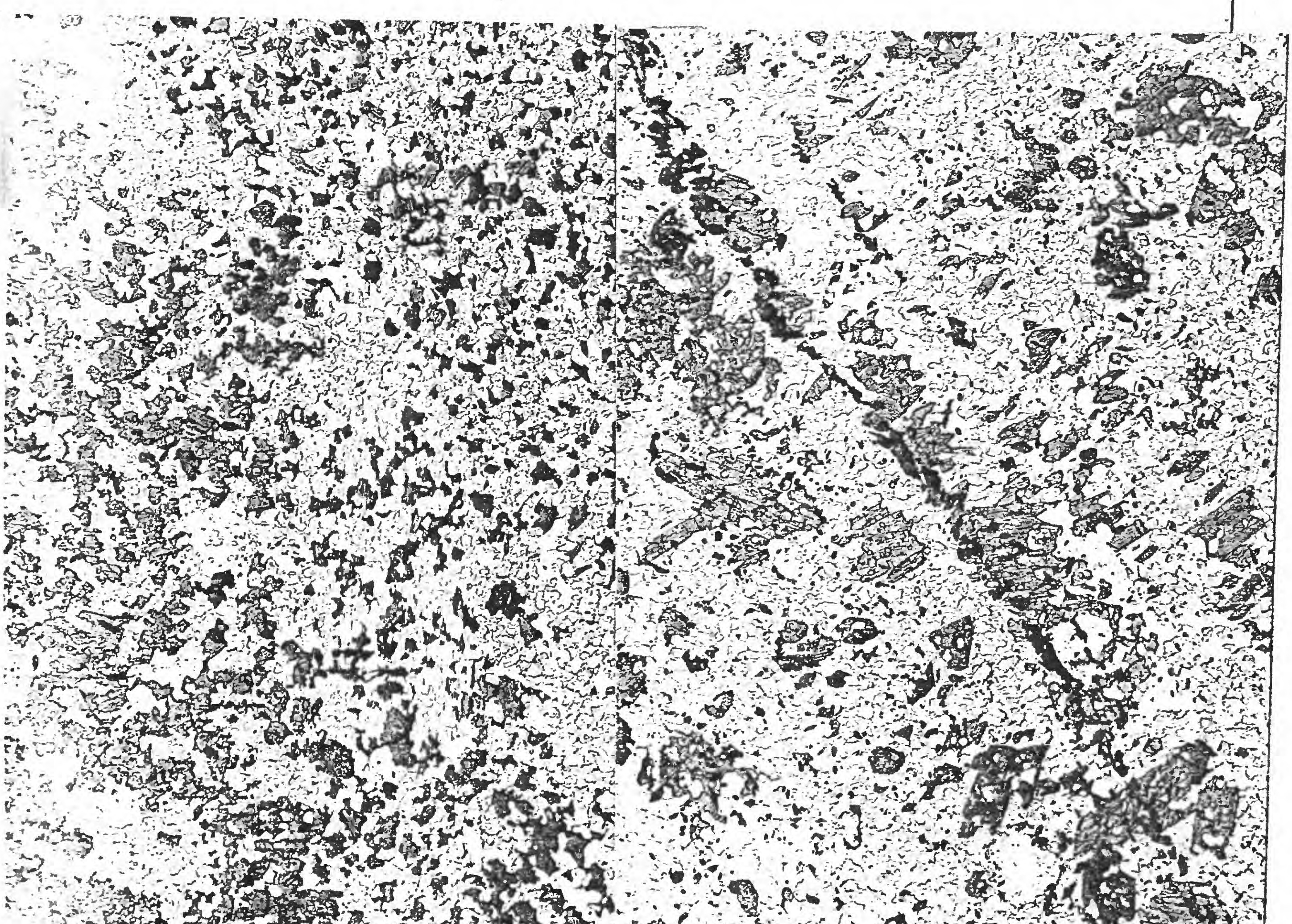


Interbedded schist and quartzite is an important type in the Littleton formation in all areas except the southeasternmost. The characteristic feature of this map unit is the repeated alternation of thin beds of schist and quartzite. This is strikingly exhibited in weathered outcrops, where the quartzite stands in relief (photos 26, 27).

Quartzite and schist are usually approximately equal in amount; one is rarely more than three times as abundant as the other. Individual beds more than 15 cm thick are rather exceptional; 3 cm is a more usual thickness. Close inspection usually reveals thin schistose partings in the quartzite beds and particularly thin quartzite laminae in the schist beds. This unit also contains much "ribbed schist," a schist with quartzite partings, perhaps 1 mm thick every 3mm or so in the schist, with or without thicker quartzite beds. The sequence of thickness of beds in any outcrop is typically highly irregular, with only the crudest approach to any rhythmic pattern. Graded bedding was observed obscurely developed in only a few localities.

Petrographically, the quartzitic beds resemble the quartzites of conglomerate and quartzite unit, but are on the whole less pure and finer grained. The schistose beds correspond to the two mica schist, less commonly to the biotite schist. The greater abundance of sillimanite and garnet in the modes is attributable to the accident that much of this unit lies in the area of highest grade metamorphism, in the Mahoosuc Range.

The protolith of this map unit consisted of interbedded sands and

Table 10. Estimated modes of the interbedded schist and quartzite map unit of the Littleton formation.

	41q	41s	49q	49s	434	481q	481s	482	518	521	529	53
Quartz	75	19	77	35		72	33	30	45	18	2	1
Plagioclase	4	2	3	2	47	7	17	44	33	38	15	46
Muscovite	8	35				1	20					
Biotite	12	25	3	25	20	18	30	25	20	20	12	1
Garnet	1	10	5	5		2			1			
Sillimanite	1	7	10	30			T					
Hornblende					30			T		20	67	35
Epidote												4
Allanite								T		T		
Sphene												4
Zircon						T	T					
Apatite						T	T	T	T	T	T	T
Opaques	1	2	2	3	3	T	T		1	4	4	1
Chlorite*												5
Prehnite*								1	T			
Calcite*												[illegible]
An content of plag.					and-lab		and	and-lab	lab		lab	al

*Alteration products.

Table 10 cont'd.

OSM 41 Interbedded quartzite (q) and coarse-grained schist (s).
Knob on east end of Surplus Mtn. ridge, West Surplus.

OSM 49 Interbedded quartzite (q) and coarse-grained schist (s).
1350' elev. in gulch east of Hall Mtn. summit, North Surplus.

OSM 434 Fine-grained biotite-hornblende granulite.
Branch Brook behind church, North Newry.

OSM 481 Interbedded biotitic quartzite (q) and coarse-grained schist (s).
1590' elev. north of north bend in Black Brook, T C.

OSM 482 Coarse lineated schist with large biotite flakes.
Near OSM 481.

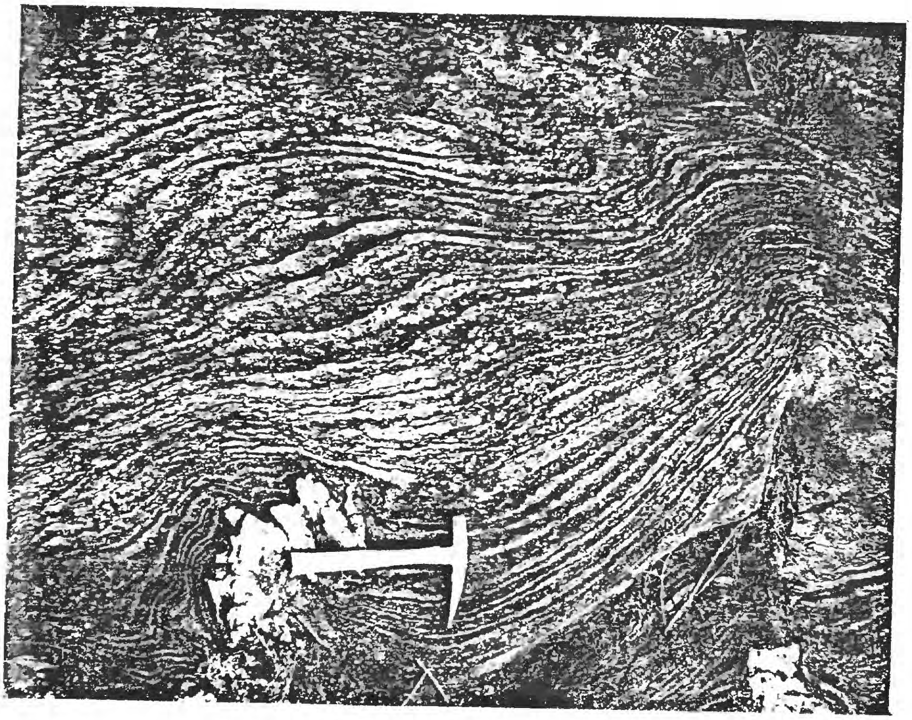
OSM 518 Medium-grained biotite schist.
1250' elev. in hollow south of Sawyer Mtn., North Surplus.

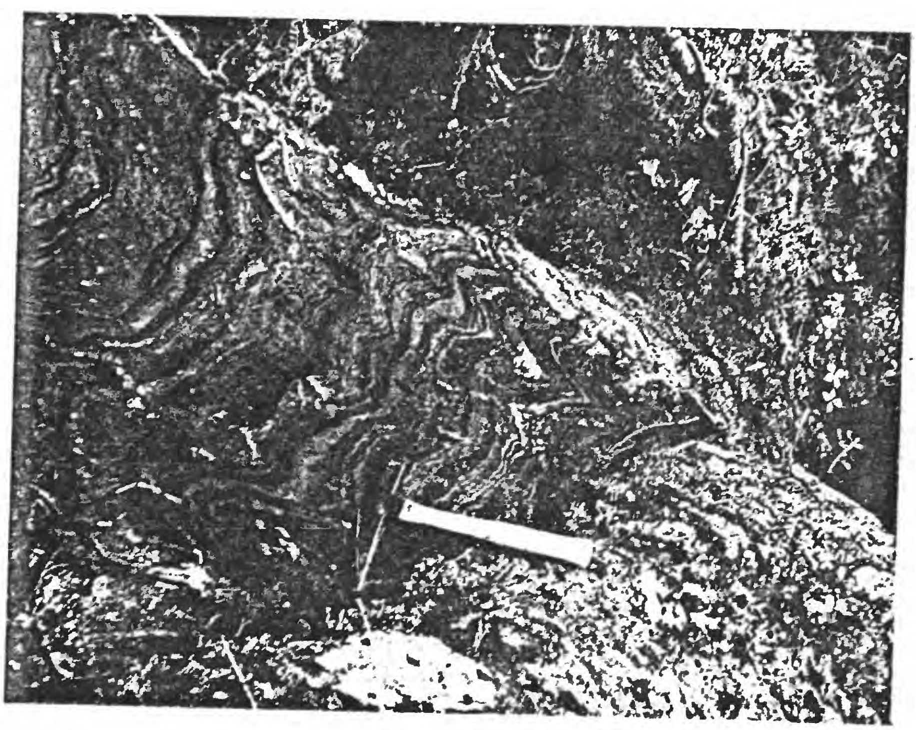
OSM 521 Medium-grained biotite-amphibole granulite.
2490' elev. in south fork of Shelter Brook, Riley.

OSM 529 Massive black amphibolite from large boudin in schist.
860' elev. in West Branch of Ellis River, Andover.

OSM 530 Massive blue-gray matted amphibolite from large loose block.
Near OSM 529.

PHOTOS 26 and 27. Typical interbedded schist and quartzite of the Littleton formation. Pegmatite dike in right foreground of photo 27. Just west of Grafton Notch.





shales. The beds, except some of the thinnest quartzite ribbings, are undoubtedly primary features. Sedimentary formations showing such interbedding are common in geosynclinal sequences, but (unless the literature grossly overemphasizes this feature) are characterized by graded bedding. The problem then arises of deciding whether the sharpness of contacts on both the top and bottom of beds is an original feature or was produced during metamorphism. The same minerals occur in both types of beds, but in different abundances and grain sizes. Any exchange of material between beds would be along gradients determined by the surface energies of the minerals and would tend to increase original differences in composition ("concretion effect") and might sharpen originally gradational contacts. A few observations by the writer of possibly correlative formations occurring in lower metamorphic zones in the quadrangles to the northeast, indicated better developed grading. It might be an interesting study to make detailed comparisons of localities from these formations selected for their general similarity, to see if an eradication of grading with increasing metamorphism can be found.

Some of the thin quartzite ribbings are clearly secondary. In one outcrop intersecting sets were found, one following bedding around a fold and the other parallel to the axial plane. In the great majority of cases, however, the ribbing, whether primary or secondary, follows bedding.

Cleavage banding, formed by the injection of shale into cleavage planes of the quartzite, was noted at several localities. A particularly interesting possible example is found in the Bear River, 0.3 mile above North Newry, near the erosion feature known as the Devil's Horseshoe (actually within the conglomerate map unit). The outcrop exhibits a sequence of bands about six inches wide, each of which is composed of alternating quartzite and schist laminae about half an inch thick that are oriented at about 45^{o} to the broad bands. Alternative interpretations are that the broad structure is the bedding, and the narrow structure cleavage banding, or that the narrow structure is bedding, cut by wider regularly spaced shear zones.

Ellipsoidal bodies of calc-silicate minerals occur in all the metasedimentary map units of the Littleton formation but particularly in the interbedded schist and quartzite. They range in size from a few inches to a yard or more in mean diameter. They are flattened and elongated, usually in the plane of the foliation. In some, but not all, localities they are aligned along certain beds. Petrographically, they are diopside-hornblende-garnet-plagioclase-epidote granulites resembling those of the calc-silicate granulite unit. Very commonly they are zoned, probably as a result of metasomatic exchange of material with the enclosing rock. The protolith was dolomitic, how pure it is difficult to determine because of the possible metasomatic addition of material. Some aligned groups of ellipsoids are transitional into boudined beds, but the majority are believed to have originated as dolomite concretions in the original clastic sediments.

Beds of hornblende-biotite schist a few inches or a few feet thick are common, although quantitatively insignificant, in the interbedded schist and quartzite, and less commonly occur in other map units of the Littleton formation (OSM 434, 521). The plagioclase in these is rather calcic and the biotite, judging from the pale brown color, is more magnesian than the biotite of the ordinary schist. The protolith of these beds was probably dolomitic, although their present composition may in large part be determined by exchange of components with adjacent strata.

In the West Branch of Ellis River, above Stony Brook, mafic amphibolite occurs, in a bed boudined into ellipsoids about three feet thick and six feet long (OSM 529). The cores of the boudins are dominantly hornblendic and the rims are biotitic. Nearby are loose blocks of a similar rock, but with a sodic rather than a calcic plagioclase (OSM 530). These rocks are probably also metadolomites, although they (particularly the latter) might have been basalt dikes or sills. The biotitic rim around the boudins suggests an introduction of potash from the enclosing schist, a process that has apparently extended completely through the thinner beds described in the preceding paragraph.

Two mica schist. Two mica schist is abundant in the eastern part of the quadrangle, with the most extensive bodies in the Puzzle Mountain area of Newry and Andover. The zone in which two mica schist is found seems to narrow westward and little occurs in the Mahoosuc range.

Table 11. Estimated modes of the two mica schist map unit of the Littleton formation

	249	258	261	267	328	353	370	501	505	506	531	*
Quartz	58	30	50	47	33	40	45	40	37	70	65	40.
Plagioclase			1	5	5	23	8	15	3	3	10	23
Muscovite	13	12	23	12	35	12	15	15	35	12	5	21
Biotite	18	18	20	26	22	18	18	20	20	12	15	9
Garnet	3	15	3	2		4	5	4	4	1	2	
Staurolite	7	5		5	T							
Andalusite		16										
Sillimanite	T	2	3	2	3	2	8	5		1	3	2
Tourmaline			T	T	1		T	T	1	T		
Zircon			T	T			T	T		T		
Apatite			T	T	T			T	T	T	T	0.
Opaques	1	2	T	1	1	1	1	1	1		1	4.
An content of plag.						alb	olig-and	and			and	45

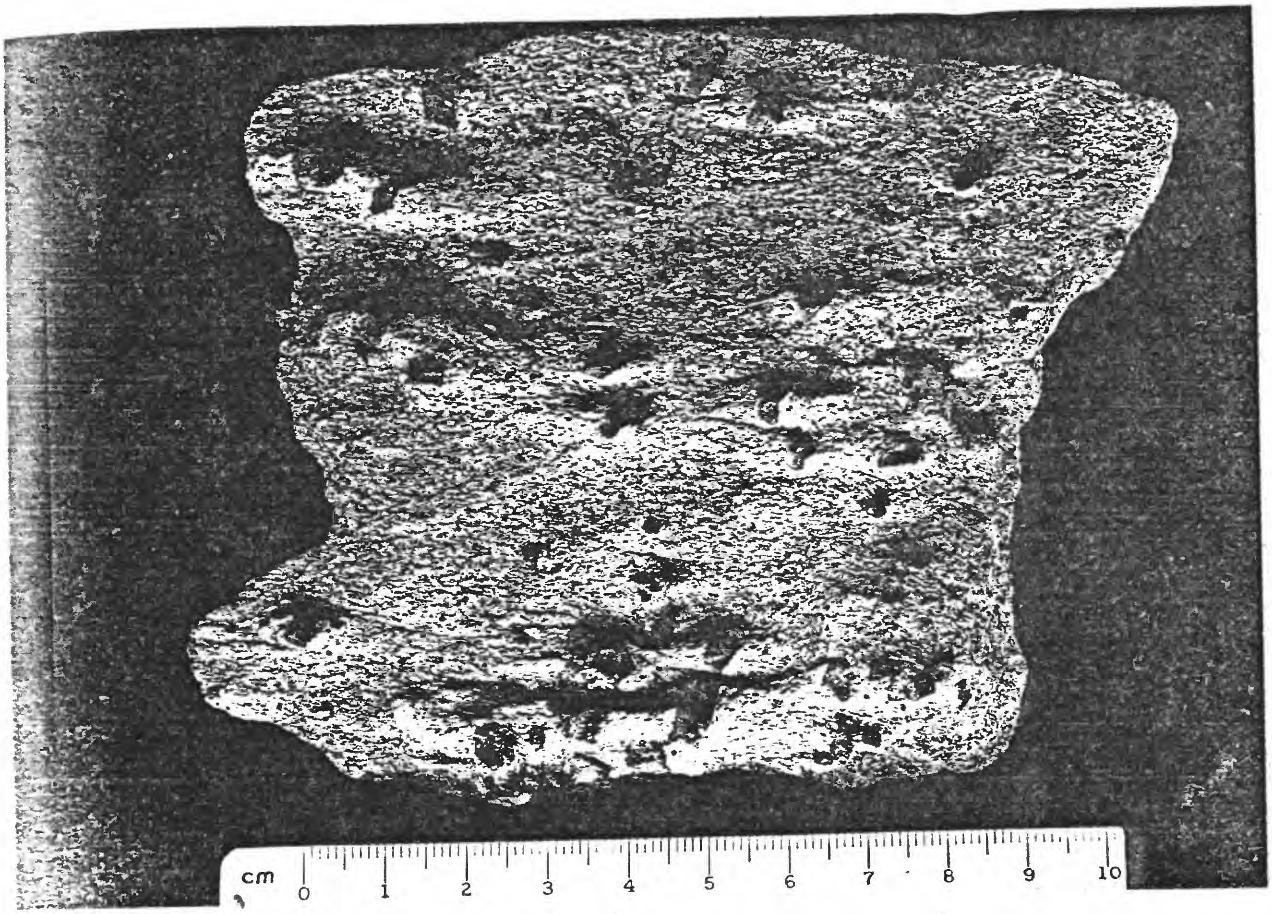
*Norm calculated for Clarke's average shale (Pettijohn 1957, table 61A). Opaques are 3.5% magnetite and 1.0% ilmenite.

Table 11 cont'd.

OSM 249	Fine-grained silvery-gray schist with staurolite porphyroblasts. 2560' elev. on south of ridge between Great and Meadow Bks., Newry.
OSM 258	Fine-grained two mica schist with large staurolite porphyroblasts. 2600' elev. on PuzzleMtn.-Plumbago Mtn. ridge, Newry.
OSM 261	Medium-grained silvery-gray two mica schist. 1500' elev. in tributary entering Great Brook at 1320', Newry.
OSM 267	Medium-grained white schist with biotite flakes. 2880' elev. on ridge SW of town corner, Puzzle Mtn., Newry.
OSM 328	Coarse-grained two mica schist with large mica books. 1050' elev. north of 898' survey point on river, Andover.
OSM 353	Medium-grained two mica schist. 2080' elev. in bk. east of bench mark, Old Blue Mtn., T C.
OSM 370	Two mica schist. 1750' elev. on southwest ridge of Dresser Mtn., Newry.
OSM 501	Coarse-grained two-mica schist. 1550' elev. on southeast ridge of Bald Mtn. , Newry.
OSM 505	Medium-grained light colored schist with biotite grains. 2520' elev. SW of triangulation station on Puzzle Mtn., Newry.
OSM 506	Fine-grained light colored schist with biotite grains. 2720' elev. on ridge SW of town cornet, Puzzle Mtn., Newry.
OSM 531	Medium-grained two mica schist. 1200' elev. 1 mile SSW of North Newry.

PHOTO 28. Staurolite schist of the two mica schist member of the Littleton formation. Puzzle Mountain - Plumbago Mountain ridge.

PHOTO 29. Schist containing sillimanite and orthoclase rather than muscovite. Black areas are biotite; round gray grains are garnet; white areas are mostly sillimanite with some quartz, plagioclase, and orthoclase. Boulder in Bull Branch, Riley.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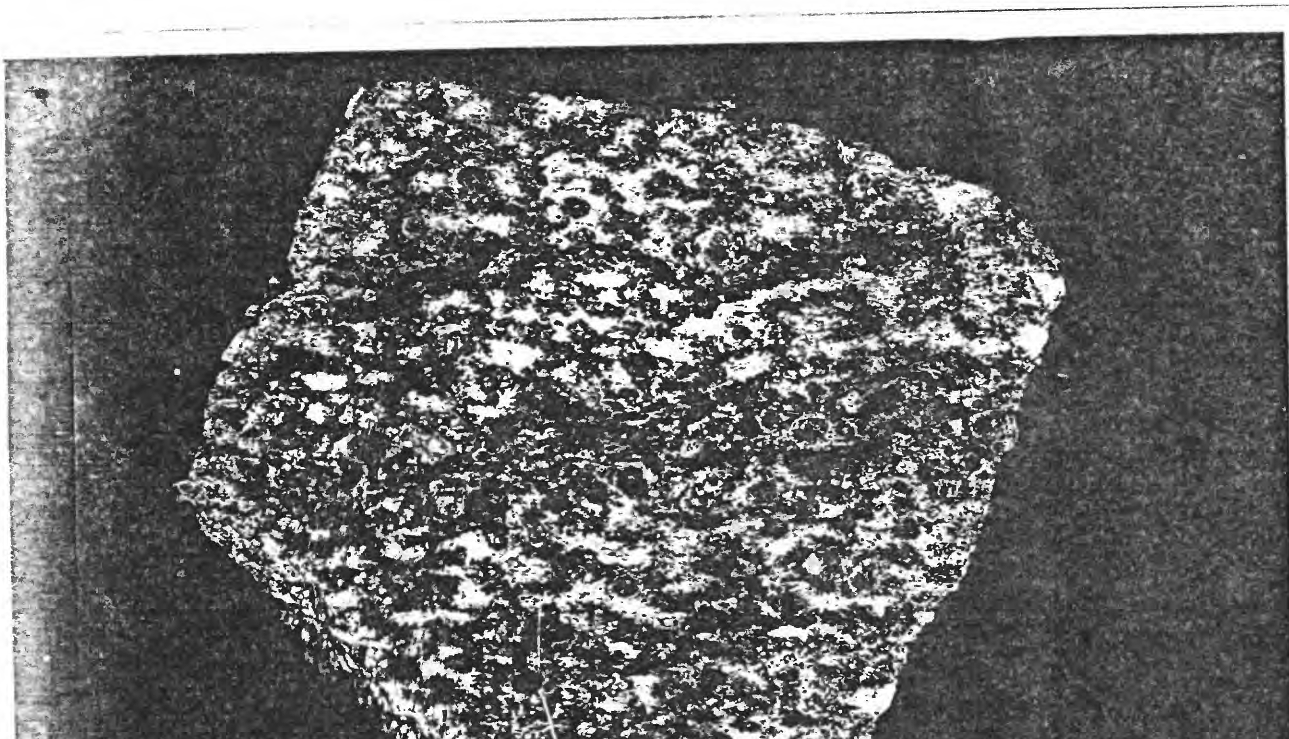
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The two mica schist is fine- to medium-grained (except for staurolite porphyroblasts), gray on fresh surfaces but commonly somewhat rusty in the weathered outcrops.

Outcrops and hand specimens usually appear uniform, but a weakly expressed bedding can generally be detected. This is commonly indicated by an alternation of more and less biotitic beds an inch or two thick. A foliation and a lineation are well developed. The schist is more fissile than the biotite schist, but still rather weakly so, chiefly because the larger muscovite grains are oriented transversely to the foliation.

Microscopically, quartz appears as the dominant mineral. Plagioclase is present in lesser quantity than in the biotite schist and is less calcic (about oligoclase). Muscovite and biotite are present in about equal amounts. In some areas both minerals occur in flakes parallel to the foliation, with the biotite flakes slightly larger, but very commonly much or all of the muscovite is in much larger flakes or composite grains, commonly oriented transversely to the foliation. These may at least in part replace staurolite as distinct pseudomorphs were occasionally found. Staurolite occurs in large poikilitic porphyroblasts up to an inch long (Photo 28). Although these are almost invariably 60° twins, the cross is usually poorly developed, with the smaller individual appearing only as excrescences on the sides of the larger. Red garnet is nearly ubiquitous, but never abundant. Sillimanite usually occurs in fibrolitic aggregates, and andalusite occurs in the low grade zone. Apatite, opaque minerals, zircon, and tourmaline are the usual accessories.

A comparison of the modes with a norm calculated in about this metamorphic grade for Clarke's average shale (table 11), indicates that the protolith of the two mica schist was a shale, perhaps somewhat more quartz-rich than the average shale.

Internal stratigraphic relations. The Littleton formation lies in a syncline with a northeast-southwest axis. Figure 4 is an extremely generalized stratigraphic cross section of the exposed portion of the Littleton formation from northwest to southeast, with the folding removed. The figure shows that the base of the formation is exposed only in the northwest, the top is nowhere preserved, and a somewhat greater thickness is exposed toward the southeast.

The ~~Whitecap Brook~~ amphibolite is the usual unit immediately above the unconformity, but biotite schist, interbedded schist and quartzite, and the unique conglomerate south of Deer Hill also occupy this position. The general sequence toward the southeast, which is also upward in the section, is ~~Whitecap Brook~~ amphibolite, biotite schist, interbedded schist and quartzite, and two mica schist. The major horizon of conglomerate is between the biotite schist and interbedded units, but conglomerate also occurs elsewhere in the section.

In the southeast corner of the quadrangle, the generalized sequence toward the north, which is upward in the section, is gneiss, biotite schist, and two mica schist. Further west calc-silicate granulite takes the place of the biotite schist at about the same horizon.

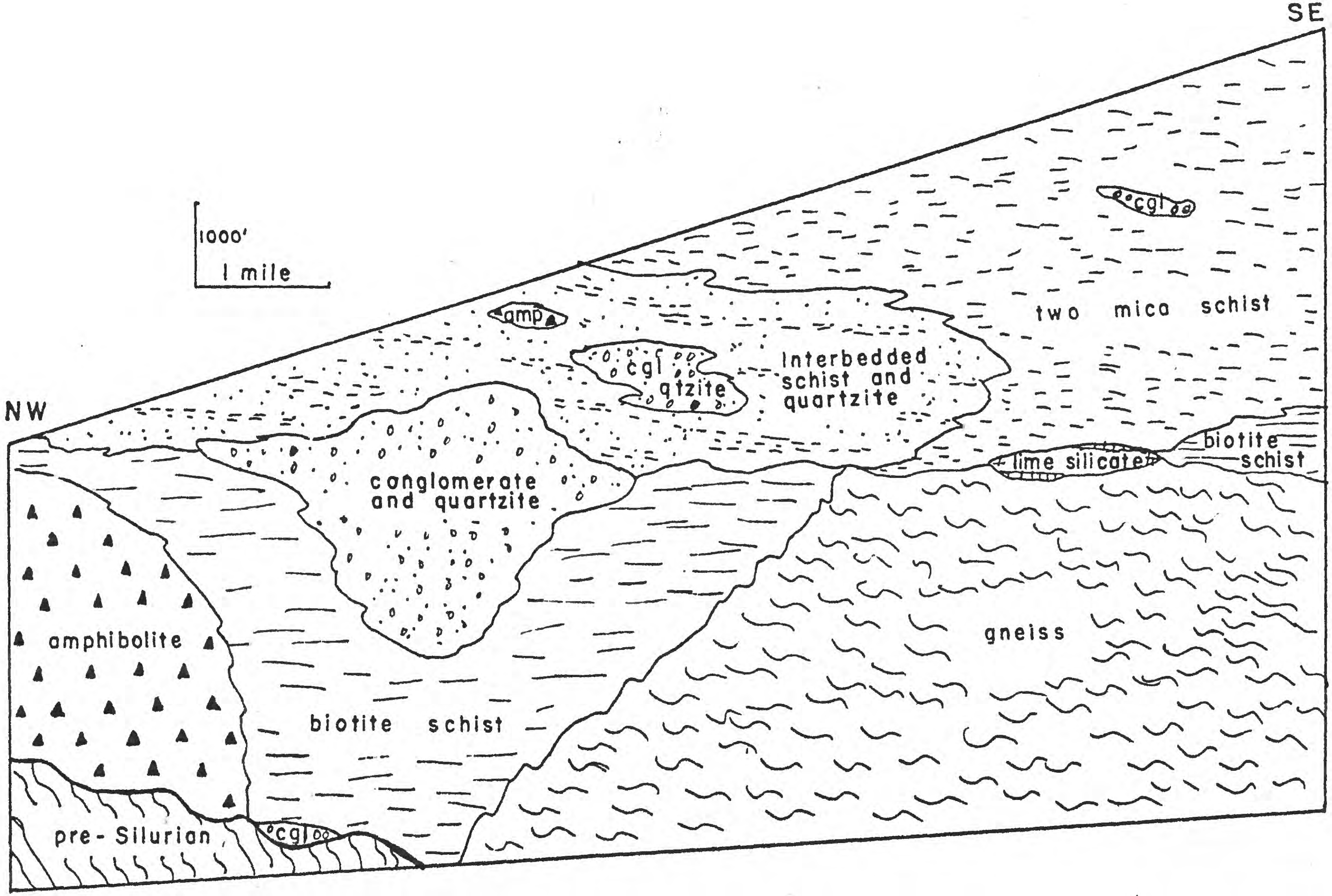


FIGURE 4. Diagrammatic stratigraphic section of the Littleton formation in the Old Speck Mountain quadrangle.

The assignment of the Whitecap Brook amphibolite to the Littleton seems satisfactory. It lies on the opposite side of the Partridge formation from the Ammonoosuc volcanics, so it is in the proper position to be the basal member of the Littleton. The northwest contact of the ~~Whitecap Brook~~ amphibolite cuts across the Partridge in a manner that suggests that it is an unconformity, although other structural complications may interfere. The southeast contact of the ~~Whitecap Brook~~ amphibolite is more regular. The adjacent biotite schist seems to be in part of tuffaceous origin, suggesting that the vulcanism continued after formation of the ~~Whitecap Brook~~ amphibolite. Moreover, some amphibolite occurs higher in the section, in undoubted Littleton formation.

Outcrops of amphibolite in Whitecap Brook itself extend over a distance of about 5,000 feet of vertically dipping strata, with no indication of structural repetition. On the other hand, amphibolite is absent not far distant along strike. All the amphibolite lies immediately on the unconformity except that in West Surplus and at South Arm. The amphibolite thus appears to form a series of lenses at the base of the Littleton formation, with a few small lenses higher in the section.

The biotite schist forms a nearly continuous belt perhaps 2,000 feet thick above the amphibolite in the west and central parts of the quadrangle and also occurs on about the same horizon near South Arm of Richardson Lake. Biotite schist also underlies a belt in the southeastern part of the quadrangle. The correlation of the two belts of biotite schist is not certain; the gneiss may actually be a closer equivalent of the northwestern biotite schist.

The maximum thickness of gneiss exposed in this quadrangle is probably under 4,000 feet. Gneiss continues, however, through much of the Bethel and Bryant Pond quadrangles to the south. The contact of the gneiss may be more a limit of migmatization than an original sedimentary contact. The gneiss within the Old Speck Mountain quadrangle is probably in large part the stratigraphic equivalent of the biotite schist of the northwestern part of the Littleton formation.

When first encountered, it was hoped that the conglomerate would provide a single reliable stratigraphic marker. This hope has not been realized. The distribution of the conglomerate seems too complex to accommodate a single horizon, however complexly folded, even ignoring some of the smaller bodies. Moreover, there is considerable lithologic variation within the conglomerate and quartzite unit. For example, the massive white pebble-bearing quartzites of the Pond Brook area differ considerably from the interbedded pebble beds and schists of the North Peak area and seem to lie higher in the section. Conglomerates apparently form lenses in the Littleton formation from the very base at Deer Hill up to nearly the highest exposed strata on Puzzle Mountain. Nevertheless, there seems to be a fairly persistent conglomerate horizon between the biotite schist in the northwest or the gneiss in the south and the interbedded schist and quartzite. Conglomerate is more abundant toward the west, suggesting that the source area lay in this direction.

At the quadrangle boundary west of North Peak, a thickness of 5,000 feet of conglomerate can be traversed, with no indication of structural repetition. Even this section is cut off by granite. The massive quartzites of the Pond Brook area are apparently at least 1,500 feet thick. Both these bodies are very lenticular, pinching out in a short distance along the strike.

The calc-silicate granulite map unit is much thinner than its mapped breadth would suggest, as it occurs in a region of low dips and gently rolling folds. The thickest section of granulite itself exposed in any one place is about 60 feet, but nowhere are both contacts exposed. There is probably only a single stratum of granulite, with which is associated a somewhat greater thickness of biotite schist. The biotite schist continues to the east (mapped as the biotite schist map unit) with very little granulite associated. Calc-silicate granulite does not occur on the northwestern limb of the syncline, except the thin bed associated with the conglomerate.

Interbedded schist and quartzite occurs mostly above the conglomerate or biotite schist map units. It apparently thickens southeastward and then thins or pinches out, so that it does not occur in the southeast part of the quadrangle. It probably attains a thickness of 2,000 or 3,000 feet.

The two mica schist seems to lie near the top of the stratigraphic column. Its apparent thickening toward the east may be only the effect of a syncline plunging in this direction. Perhaps 5,000 feet are exposed in the Puzzle Mountain area.

The total thickness of the Littleton formation is exceedingly difficult to estimate, because of the lenticular form of units, the folding, and particularly the granite intrusives. However, the total exposed section is estimated to be about 10,000 feet thick.

The subdivision of the Littleton formation into seven lithologic map units was, at least initially, done without stratigraphic implications. It was found, however, that the distribution of the lithologic types is actually quite systematic, as implied in the preceding pages.

The Littleton formation in this quadrangle is rather distinctly divided into an upper and a lower part. The lower part consists of the Whitecap Brook amphibolite (except the small bodies in Andover West Surplus), the northwestern belt of biotite schist, and the gneiss. The upper part consists mostly of conglomerate and quartzite, interbedded schist and quartzite, and two mica schist. On the northwest limb of the syncline the base of the upper part is marked by the thicker, more continuous bodies of conglomerate. On the south limb the contact is less well defined, but the calc-silicate granulite is somewhat arbitrarily considered as at the base of the upper part. Farther east the contact roughly follows the top of the gneiss; the map indicates that rock types characteristic of the lower and upper parts are interstratified.

The abundance of conglomerate at the base of the upper part of the Littleton suggests that the twofold division reflects a significant break in the stratigraphic history, that may eventually lead to the establishment of two formations rather than one in this area. Between Dunn Notch and Richardson Lake the upper part of the Littleton rests directly on the Ordovician (?) formations. This more likely indicates overlap during the deposition of the Littleton than an unconformity within the formation.

Correlation. The Littleton formation of this quadrangle is a direct continuation of the Littleton formation mapped in the Gorham (Billings and Fowler-Billings, unpublished), Mount Washington (Billings, 1941; Billings et al., 1946), and Bethel (Fisher, 1952) quadrangles to the southwest and south.

In the type area, the Littleton-Moosilauke area, three formations lie unconformably above the Ordovician (?) formation; Clough quartzite, Fitch formation (predominantly calcareous), and Littleton formation. Middle Silurian fossils are found in the Fitch; Lower Devonian fossils are found in the Littleton at some distance above the base. The strata in the northeastern White Mountains, including the Old Speck Mountain quadrangle, are cut off from direct correlation with the Littleton-Moosilauke area by intrusives and faults. In this area the Clough and Fitch formations are now believed to be absent. The Littleton is divided into a lower and upper member, respectively characterized by gneiss and interbedded quartzite and mica schist (Billings et al., 1946), separated by a thin calc-silicate granulite, the Boott member, with which rare beds of white quartzite and conglomerate are associated.

Correlation of the upper and lower parts of the Littleton in the Old Speck Mountain with the corresponding members in the Mount Washington and adjacent quadrangles, seems very satisfactory. The calc-silicate granulite map unit probably can be correlated with the Boott member.

In his original study Billings (1941) considered the lower unit to be Partridge, the calc-silicate granulite to be Fitch, and only the upper unit to be Littleton. In a later study (Billings et al., 1946) several reasons were given for adopting the present correlation, in which these are all Littleton formation, resting directly on Ammonoosuc volcanics. The Old Speck Mountain quadrangles presents strong evidence supporting the newer correlation. Here the conglomerate, which on the older hypothesis would be Clough, lies several thousand feet up in a conformable sequence that unconformably overlies Partridge formation.

An unexpected feature of the Littleton formation in the Old Speck Mountain quadrangle is the presence of volcanics, the Whitecap Brook amphibolite, near its base. Volcanics occur in the lower part of the Littleton formation in western New Hampshire, but have not been found previously in the northeastern White Mountains. Volcanics do occur in the ~~Siluro~~ Devonian sequence to the northwest in the Dixville (N. L. Hatch, Jr., personal communication) and Second Lake (J. C. Green, personal communication) quadrangles, and to the northeast in Maine.

When the intervening areas are mapped, correlation with fossiliferous sections to the east and northeast may prove more reliable than correlation with the New Hampshire sequence. In the Rumford quadrangle, immediately to the east, Forsythe (1955) mapped three units. The lower unit is composed of rock types corresponding to the interbedded schist and quartzite, the two mica schist, and the gneiss of the Littleton formation of the Old Speck Mountain quadrangle. The other two units, which occur in synclines, are sulfidic black phyllite and thick calc-silicate granulite, that are apparently younger than any strata in the Old Speck Mountain quadrangle. In the Dixfield quadrangle, the next to the east, rocks resembling the two mica schist of the Littleton of the Old Speck Mountain quadrangle are abundant. The famous Rangely boulder conglomerate locality is only about fifteen miles distant from the Old Speck Mountain quadrangle. This is part of a highly lenticular unit that pinches out before reaching the common corner of the Rangely and Old Speck Mountain quadrangles (C. W. Wolfe, personal communication). The Rangely conglomerate has been thought by some to mark the base of the Siluro-Devonian sequence. The position of the admittedly far less impressive conglomerates of the Old Speck Mountain quadrangle well above this horizon suggests that this should not be assumed until the matter is investigated.

INTRUSIVE ROCKS

The intrusive rocks of the Old Speck Mountain quadrangle belong to three major groups: granitic gneiss of the Oliverian plutonic series; granodiorite, quartz monzonite, and related rock types of the New Hampshire plutonic series; and Umbagog granodiorite, possibly also belonging to the New Hampshire series. Gabbro, hornblendite, and post-metamorphic dike-rocks are quantitatively unimportant.

Granitic gneiss of the Oliverian Plutonic Series

Granitic gneiss of the Oliverian plutonic series occupies two belts in Grafton and several small irregular areas in C Surplus and Andover North Surplus. The two belts are dipping sheets that form the northeast end of the Jefferson dome. The petrology and structure of the central part of this dome have been studied by C. A. Chapman, M. P. Billings, and R. W. Chapman (1944).

The granitic gneiss ranges in composition from true granite through quartz monzonite to granodiorite. The potassic feldspar is mostly, if not entirely, mocrocline, some slightly perthitic. It is commonly pink, whereas that of the New Hampshire plutonic series is usually white. Plagioclase is sodic, commonly albite. Biotite and muscovite are usually present in small amounts, and occasionally also garnet.

Rocks of this series are characteristically gneissic, with a lineation usually even more strongly developed than the foliation. Both the megascopic and microscopic texture are strongly suggestive of

Table 12. Estimated modes of granitic gneiss of the Oliverian plutonic series.

	18	26	325	472	545
Quartz	25	40	20	30	25
Plagioclase	30	40	18	45	40
Potassic feldspar	40	15	55	12	30
Muscovite	1	3	5	7	
Biotite	2	2	2	5	3
Garnet	2				T
Apatite		T	T	T	
Zircon				T	T
Opaques	T	T		1	T
Fluorite					2*
An content of plag.	10	25	5	0-5	0-5

*Fluorite in OSM 545 may be a product of hydrothermal activity related to the volcanic vent.

OSM 18 Coarse-grained white granite gneiss.
On road at notch between East B Hill and Spruce Mtn., C Surplus.

OSM 26 Coarse-grained pink granodiorite gneiss with mica streaks.
1710' elev. NNW of junction of Black and Cedar Bks., Grafton.

OSM 323 Fine-grained pink lineated granite gneiss.
2250' elev. on west ridge of Sable Mtn., C Surplus.

OSM 472 Medium-grained white granodiorite gneiss.
1800' elev. northwest of OSM 26.

OSM 545 Fine-grained lineated white quartz monzonite gneiss.
1900' elev. in tributary entering Black Bk. at 1650', Grafton.

cataclasis and partial recrystallization. In outcrop, bands of fine-grained and coarse-grained rock of the same composition commonly alternate. In thin section, the texture is granoblastic, with large grains set in a mortar of small grains.

Pegmatite is associated with the Oliverian plutonic series, but not as abundantly as with the New Hampshire series. Octahedra of magnetite are found in some of the pegmatite. The pegmatite bodies mapped in Grafton may belong to either plutonic series.

Distinction of rocks of the Oliverian plutonic series from rocks of the New Hampshire series and from Ammonoosuc volcanics presents some difficulties. The contact with Ammonoosuc is commonly gradational. Where a sharp contact can be drawn, it is usually marked by a coarser grain size in the granite gneiss, although some of the nearby volcanics may be of similar composition. Many of the rocks that resemble granitic gneiss, but were eventually mapped as Ammonoosuc volcanics on the basis of appearance in the field, were found to have a composition further removed from the granite minimum, mostly in the direction of excess quartz. It seems likely that volcanics close to the granite eutectic composition were recrystallized by either solid state processes or partial melting into granite. Rocks of such origin, however, do not necessarily constitute a major part of the Oliverian series.

Where rocks of the New Hampshire series are associated with volcanics of the Ammonoosuc and Whitecap Brook, types very similar to those of the Oliverian occur. Particularly in the north-central part of the quadrangle, the assignment of isolated bodies of granitic rocks to the two plutonic series is rather arbitrary. The same uncertainty (as well as poor outcrops) makes the mapping of granitic gneiss of the Oliverian series in contact with Littleton formation on the west slope of the Mahoosuc Range of doubtful significance.

The age relations of the Oliverian plutonic series are indeterminate in this quadrangle. In New Hampshire it has generally been considered as younger than the Littleton formation but older than the final stages of the Acadian orogeny (Billings 1956). It may in part consist of older material remobilized during the orogeny.

Umbagog Granodiorite

The ~~Umbagog~~ granodiorite ~~(Green 1960)~~ occupies an approximately circular topographic basin centered on Umbagog Lake. It underlies about thirty square miles in the Old Speck Mountain quadrangle and comparable areas in each of the contiguous Milan, Errol and Oquossoc quadrangles. Where the granodiorite invades older rocks, the contact is smooth and sharp. To the east, where the ~~Umbagog~~ granodiorite is intruded by rocks of the later New Hampshire Plutonic series, the mapped contact is a rather arbitrary line drawn through an area of intrusive breccias of ~~Umbagog~~ in later granites.

Unaltered Umbagog granodiorite is a massive to weakly foliated medium-grained dark rock. The dark minerals, particularly biotite, have a tendency to form clots. Petrographically, the bulk of the Umbagog

Table 13. Estimated modes of intrusive rocks of the Umbagog pluton.

	52	116	127	219	461
Quartz	20	15	5	10	15
Plagioclase	48	48	60	53	45
Potassic feldspar		15	3	5	15
Biotite	30	15	20	25	15
Hornblende	1		1		10
Augite		5	10	5	
Hypersthene				2	
Epidote	T	2			T
Allanite	T				
Sphene	T	T	1		T
Apatite	T	T		T	T
Opaques	1	T	T	T	T
An content of plag.	38	40	40	40	30

OSM 52 Medium-grained dark quartz diorite, somewhat metamorphosed.
1340' elev. in gulch on NE side of Hall Mtn., North Surplus.

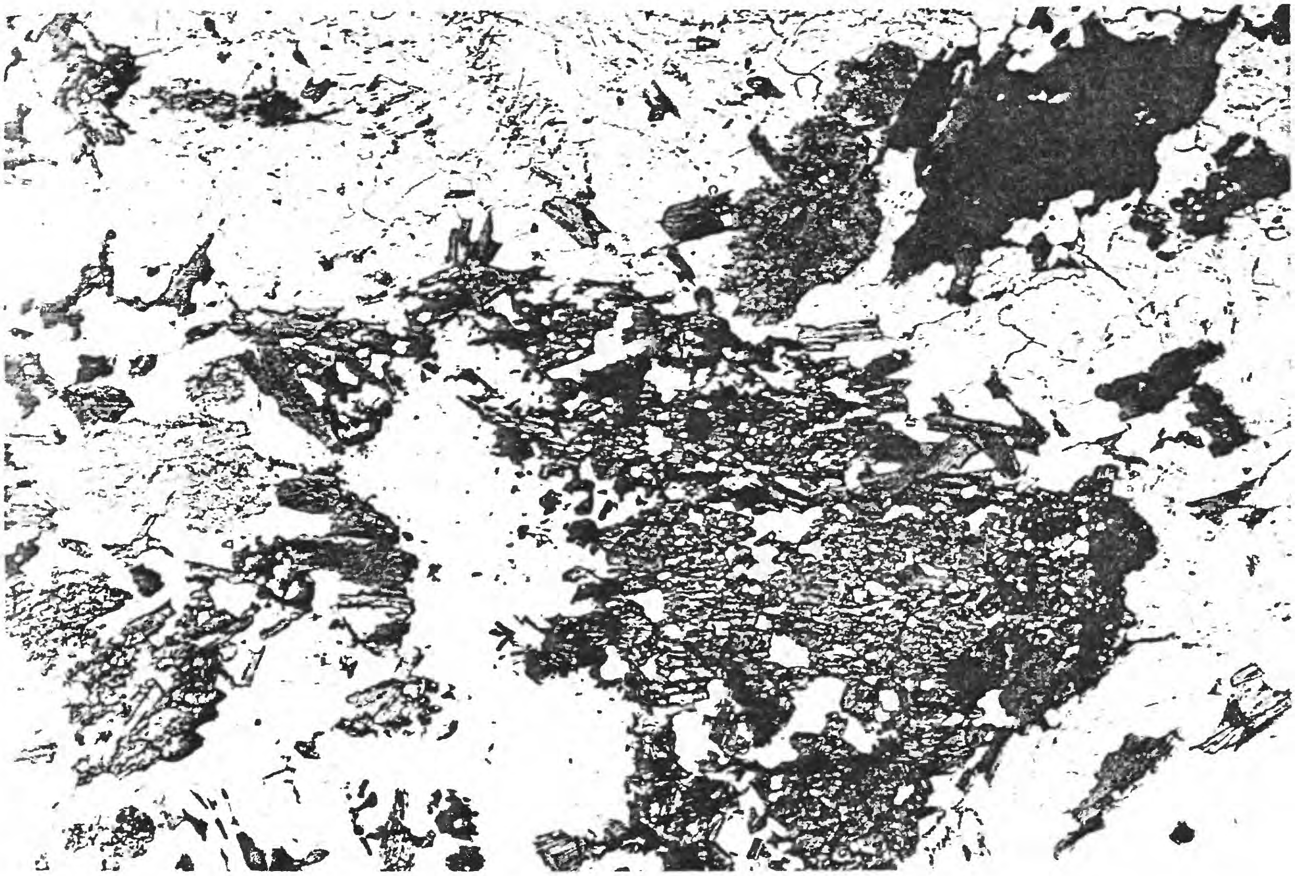
OSM 116 Fine-grained greenish granodiorite, from within a few tens of yards of the pluton.
In LouAnn Bk., SSW of Rabbit Knoll, Upton.

OSM 127 Fine-grained dark diorite, within a hundred yards of contact.
1440' elev. in Mountain Brook, C Surplus.

OSM 219 "Opdalite", medium-grained granodiorite with coarse biotite.
1300' elev. on trail in gulch south of B Brook, Upton.

OSM 461 Coarse-grained granodiorite with biotite clots.
1390' elev. in Lost Brook, C Surplus.

PHOTOS 30 and 31. Umbagog granodiorite, OSM 461, in plane-polarized light and between crossed nicols. Poikilitic dark grains are hornblende, others are biotite. Large light grains are plagioclase, some small interstitial grains are potassic feldspar. Gray patches in left center and upper right center are sericitized feldspar. x15.



pluton is a mafic granodiorite (OSM 461). Plagioclase (calcic andesine), quartz, and potassic feldspar are the light minerals, in decreasing order of abundance. Hornblende and biotite are the major dark minerals; they usually occur together, in a wide range of ratios (hornblende is more abundant than the modes would suggest). Augite is generally a minor constituent, but is abundant near the contact of the pluton with older rocks (OSM 116, 127). One specimen of granodiorite (OSM 219) contains biotite, augite, and hypersthene, but no hornblende, matching the opdalite of Norway (Goldschmidt, 1916). Hypersthene would be expected to react with plagioclase to form hornblende in the middle grades of metamorphism, so this may be a least metamorphosed specimen, indicating that the intrusive was originally noritic.

Feldspar veins with hornblende crystals up to an inch long occur in the Umbagog granodiorite, but no real pegmatites are associated.

Where the Umbagog pluton is intruded by later granite, the ratio of biotite to hornblende increases and the rock develops a strong lineation and foliation, in the extreme becoming a biotite schist. Meager evidence suggests that there is a concomitant decrease in the content of potassic feldspar, indicating that the metamorphism was isochemical, but too few specimens have been examined to state this with any confidence.

It is likely that an undetermined, perhaps major, fraction of the biotite in the apparently unaltered granodiorite is of metamorphic rather than primary origin. The commonly occurring clots of biotite may represent original hornblende or pyroxene phenocrysts. A metamorphic origin for some of the biotite may explain the discrepancy between the age of 360 ± 40 m. y. obtained for zircon by the Pb/alpha method and the age of 323 m. y. obtained for biotite from the same specimen by the K/Ar method (Green 1960). K/Ar dating of hornblende from the same specimen would be of great interest.

Umbagog granodiorite intrudes the Ordovician (?) strata, but its age relative to the Littleton formation is indeterminate. It is older than any rocks definitely assignable to the New Hampshire Plutonic series with which it is in contact. The radioactive dating suggests that the Umbagog granodiorite formed as an early phase of the Devonian (?) New Hampshire plutonic series, but a correlation with the Ordovician (?) Highlandcroft plutonic series, or an intermediate age can not be ruled out.

Granitic Rocks of the New Hampshire Plutonic Series

Nearly half of the Old Speck Mountain quadrangle is underlain by granitic rocks that form part of a pluton of batholithic dimensions extending into the contiguous quadrangles to the east and north. This body is here named the Andover pluton, after the village located in the basin that marks the main part of the pluton. Petrographic similarity and the approximately synkinematic age suggest that this pluton can be correlated with those of the New Hampshire plutonic series of that state. These have been assigned an Upper Devonian (?) age on geologic evidence (Billings 1956), an age that does not conflict with radioactive dating.

The Andover pluton is composed of a considerable variety of granitic rocks. Were sufficient time employed, the pluton could be divided and

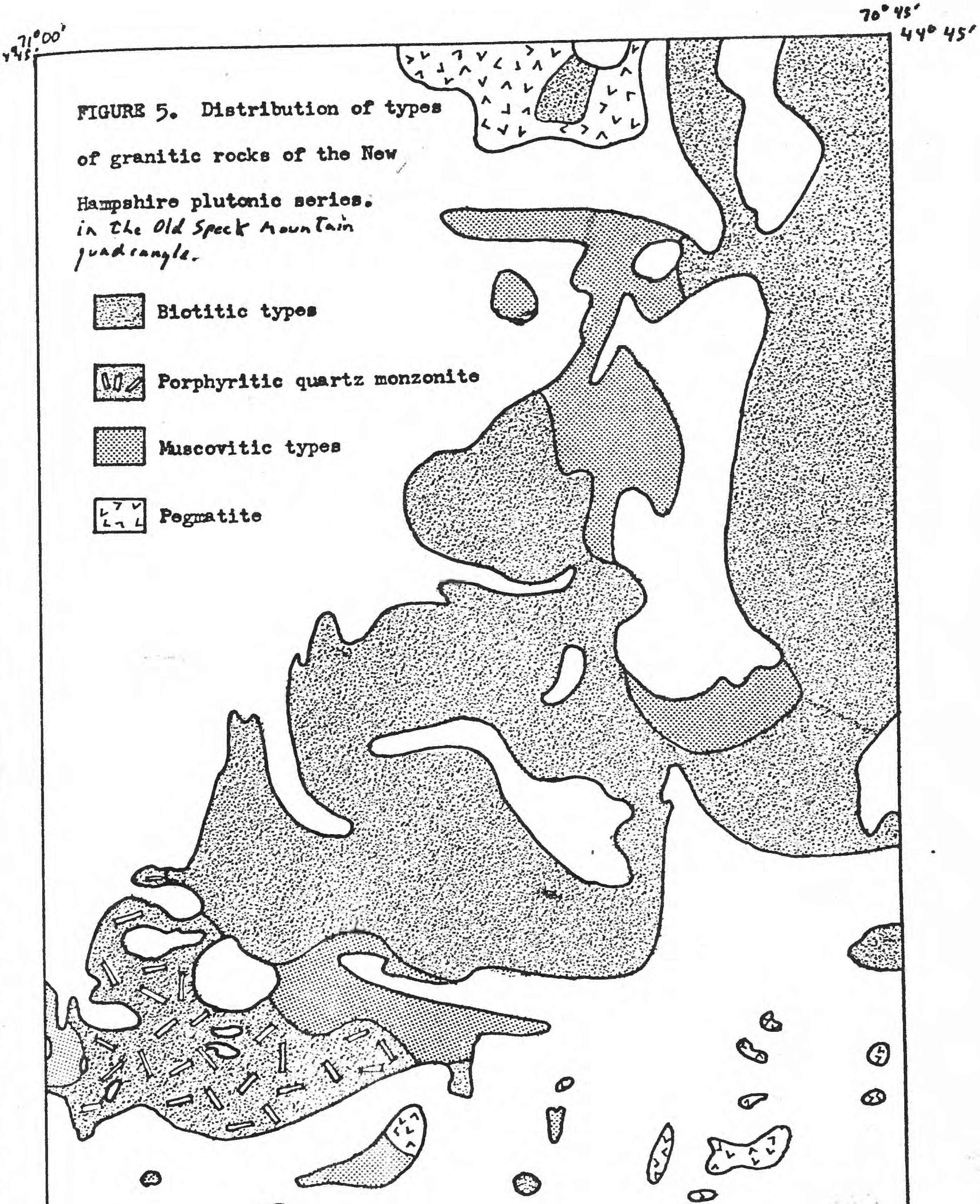


FIGURE 5. Distribution of types of granitic rocks of the New Hampshire plutonic series. in the Old Speck Mountain quadrangle.

Table 14. Estimated modes of : granitic rocks of the New Hampshire . plutonic series.

	42	136	152	202	251	343	344	352	372
Quartz	T	15	30	26	15	5	35	33	20
Plagioclase	62	53	25	26	60	67	25	30	20
Potassic feldspar	3	3	40	40			35	35	40
Muscovite			4	3			2		
Biotite	29	25	1	5	20	25	3	1	20
Hornblende	3	1			4	1			
Augite		1							
Garnet								1	
Epidote	T	1			T	T			
Allanite	T				T	T			
Sphene	2	1			1	2			
Apatite	1	T	T	T	T	T	T		T
Zircon	T					T	T		
Opaques	T	T				T	T		T
An content of plag.	22	35	10	10	36	35	25	5	30

Table 14 cont'd.

OSM 42	Medium-grained sphene-flecked diorite. 2100' elev. in brook west of Appalachian Trail, Little Baldpate Mtn., West Surplus.
OSM 136	Coarse-grained quartz diorite. 2380' elev. in Morse Brook, Grafton.
OSM 152	Fine-grained slightly foliated muscovite granite. 2200' elev. in brook due north of summit of Sunday River Whitecap, Grafton.
OSM 202	Medium-grained granite. 2250' elev. north of northeasternmost peak, Long Mtn., Andover.
OSM 251	Medium-grained inequigranular quartz diorite. Summit of Farrington Hill, Andover.
OSM 343	Medium-grained inequigranular foliated quartz diorite. Black Brook, North Surplus, just in Rumford quadrangle.
OSM 344	Medium-grained slightly foliated quartz monzonite. Several hundred yards upstream from OSM 343.
OSM 352	Fine-grained aplitic quartz monzonite, from a dike cutting biotite granite. 1650' elev. in brook east of bench mark, Old Blue Mtn., T C.
OSM 372	Porphyritic quartz monzonite. Appalachian Trail near Speck Pond shelter, Grafton.

subdivided into as many mineralogic and textural varieties as one might wish. Not uncommonly a half dozen or more varieties can be distinguished by casual inspection of a single outcrop. According to the standard petrographic classifications, granodiorite and quartz monzonite are most abundant, but granite (sensu stricto), quartz diorite, and diorite also occur. A field classification was more easily based on the micas than on the feldspars. In the greater part of the pluton biotite is the dominant mica, with muscovite absent or distinctly less abundant. In a general way the amounts of muscovite and potassic feldspar vary together, so that the biotitic types are quartz diorites and granodiorites, those with some muscovite are quartz monzonites, and those with dominant muscovite are true granites. The generalized distribution of the simplest grouping of rock types is mapped in figure 5.

Biotitic types are most abundant; most are quartz diorite, granodiorite, and quartz monzonite (OSM 136, 251, etc.). These are mostly medium-grained hypidimorphic-granular rocks. Commonly some phenocrysts (particularly of potassic feldspar) are noticeably larger than the other mineral grains, but these are only the largest members in a continuous range of sizes, so that the rock is better described as inequigranular rather than as porphyritic. None of these rocks is really gneissic, but a weak foliation, usually expressed by the orientation of the biotite flakes, is commonly present. This folia tion could well be a flow structure.

More mafic varieties carry some hornblende, and occasionally augite and epidote, in addition to biotite. Most of these are quartz diorites, although the quartz content of some is low enough to make them diorites. These are most abundant in scattered bodies intruded by the more felsic types in the Baldpate Mountain area. Sphene-flecked diorite (OSM 42, described in appendix A) is a typical example of the diorites in composition although the texture is unusual.

The porphyritic quartz monzonite of the Mahoosuc Range is a rock of striking appearance (OSM 372, photo 32). This is a medium-grained rock that contains twenty to forty percent of microcline megacrysts, each about 3 cm long. The megacrysts show some parallel arrangement, particularly near contacts. Foliation in the matrix can be observed only with difficulty. The size and abundance of the megacrysts is the same in dikes and apophyses in the country rock as in the bulk of the body. This strongly suggests that the megacrysts were brought in with the magma in essentially their present form and were aligned in a crude flow texture.

The porphyritic quartz monzonite looks much like the porphyritic schist of the Ammonoosuc, which, of course, is some miles distant. The porphyritic Ammonoosuc has a strongly foliated groundmass, however, while the quartz monzonite does not. The possibility suggests itself that the history of the quartz monzonite involves the metamorphism of some suitable protolith at depth to a rock like the porphyritic Ammonoosuc, and the subsequent melting of at least a great enough fraction of the rock to make it a fluid magma, and the intrusion upward of this magma carrying the

PHOTO 32. Porphyritic quartz monzonite, OSM 372.

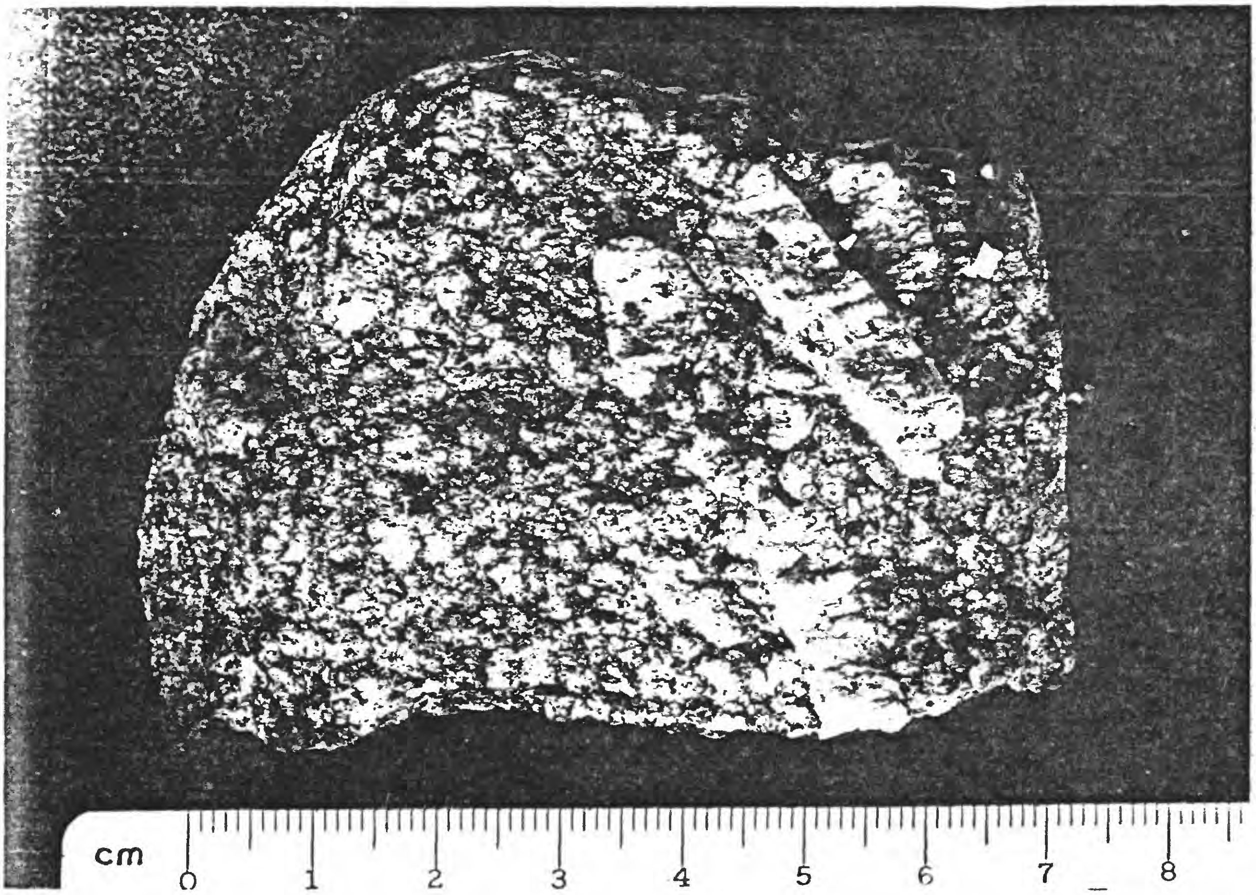

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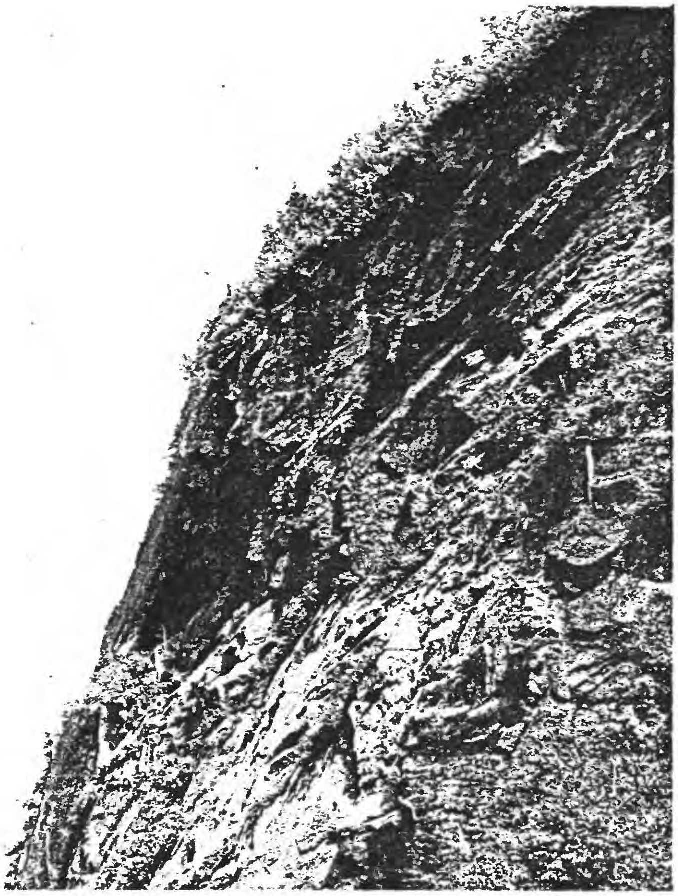
PHOTO 33. Two mica granite on the south wall of Mahoosuc Notch. The wall is nearly a thousand feet high.

PHOTO 34. Waterfall over a pegmatite dike cutting biotite schist and calc-silicate granulite of the Littleton formation. Bull Branch, Riley.



microcline porphyroblasts with it.

Muscovite and two-mica granitic rocks form several large bodies and many more too small to be distinguished on the map. Those in the Andover-Andover North Surplus area are largely medium to coarse grained (OSM 202); in the northern part much is even pegmatitic. The Sunday River Whitecap area consists more of fine to medium grained types (OSM 152). These rocks are richer in potassic feldspar and contain a more sodic plagioclase than most of the biotitic types and are commonly true granites. The muscovite granites grade into leucogranites or aplites with little of either mica but commonly containing small dark red garnets (OSM 352). These are particularly common as small bodies around the margins of the biotite granite part of the pluton. In the Andover North Surplus area, they are somewhat pink and resemble the granitic gneiss of the Oliverian plutonic series in the same area.

In general the more felsic rocks intrude the more mafic. The light-colored granites of Sunday River Whitecap are clearly younger than the porphyritic quartz monzonite. The other main area of light granitic rocks is probably younger than the biotitic granitic rocks but it is difficult to determine whether the small bodies of light-colored rocks that clearly intrude the biotitic rocks are actually part of the main bodies of light granitic rocks.

"Wispy granite" was the field name given to a fine-to medium-grained light-gray granitic rock with a gneissic structure caused by thin wisps of biotite. This occurs in intimate association with the gneiss and gneissic biotite schist in the southernmost part of the quadrangle. Rocks representing all stages of transition from biotite schist to migmatitic gneiss to wispy granite to clean unfoliated granite can be found. The biotite wisps almost certainly represent remnants surviving recrystallization of the salic constituents of original biotite schist. The wispy granite seems to be considerably less mafic than the biotite schist. Whether the compositional transformation was accomplished by introduction of material as a magma or solution or by removal of mafic elements is not determined.

The petrographic characteristics of the great bulk of the Andover pluton are those found in similar plutons over the world and require little special comment. The rocks are subsolvus granite (Bowen and Tuttle 1958), that is, they contain potassic feldspar and plagioclase in distinct grains, with little or no perthite. Both feldspars are characteristically white as in the New Hampshire plutonic series generally. Chayes' (1952, p. 212) statement concerning New England calcalkaline granites in general seems to hold for the Andover pluton: "Potash feldspar seems to be mostly, and is perhaps entirely, microcline. Grains devoid of optical complexity occur in almost every thin section but are, on the whole, uncommon." Sphene-flecked diorite, a rock distinguished by a texture previously described only from Europe, is discussed in appendix A.

The petrographic varieties in the Andover pluton can be matched by rocks occurring in the New Hampshire plutonic series of that state. The porphyritic quartz monzonite resembles certain phases of the Kinsman quartz monzonite. The non-porphyritic biotitic rock types resemble other phases of the Kinsman, the Winnepesaukee quartz diorite, and other varieties. Binary granite (Concord granite), which is the predominant variety in the nearer parts of New Hampshire, is represented in the Sunday River Whitecap body and elsewhere, but is not too abundant.

The Mason granodiorite of the Albany pluton in the Bethel quadrangle (Fisher 1952) is similar to the biotitic granodiorite and quartz monzonite. The "wispy" granite is apparently identical with Fisher's "Evans Notch quartz monzonite".

Pegmatite. Pegmatite bodies are extremely common in the Andover pluton and in the metamorphic rocks in its vicinity. They range from thin veins to bodies covering several square miles. The largest bodies occur in association with granitic rocks in the north central part of the quadrangle (fig. 5). On the geologic map only the larger bodies entirely surrounded by metamorphic rocks are distinguished.

Although the world famous mines of Newry Hill are only a mile away on the east end of Plumbago Mountain, the pegmatites of the Old Speck Mountain quadrangle with very few exceptions are simple in structure and mineralogy. They are composed of feldspar, quartz, muscovite, and commonly biotite; dark red garnet is an accessory in many. Most of the feldspar is white, but some is light pink. The pegmatites usually have a higher ratio of muscovite to biotite than the wall rock. Thus pegmatites associated with biotite granite usually have two micas and those associated with two mica granite have only muscovite. This rule does not hold everywhere, however, and some biotite-rich pegmatites are associated with muscovitic granites. The pegmatite bodies rarely show any internal structure. Some of the narrower veins have quartz cores.

The only mineralogically interesting pegmatite is exposed in prospect pits between 1900' and 2000' elevation on the ridge between Great Brook and Stony Brook, Newry. This pegmatite is structurally complex, with massive quartz zones, but the pattern is not clear. Minerals noted were rose quartz, triphylite, several as yet unidentified secondary phosphate minerals, tourmaline, beryl, apatite, and unidentified uranium minerals. A heavy wad stain pervades much of this pegmatite.

Black tourmaline is fairly common in pegmatites of the Plumbago Mountain area, but it is rare elsewhere. Small amounts of beryl and apatite were noted in half a dozen or so pegmatites. A beryl locality on Moody Mountain has been described by Jurgensen (1960).

Beside the prospect mentioned above, pegmatite bodies in Great Brook have been opened as mica prospects. The books of muscovite, although many are as much as six inches across, are only of scrap quality.

Gabbro

Three small bodies of rock are mapped as gabbro. An altered gabbro crops out in Meadow Brook, Newry, just inside the quadrangle boundary (OSM 426). This is an extension or an outlier of the gabbro body described by Shainin and Dellwig (1955) from Newry Hill. The rock is

Table 15. Estimated modes of gabbros and hornblendites.

	350	426	550	81	277
Plagioclase	12	40	30		
Biotite	30		1	5	
Hornblende	56	56	66	}75	65
Cummingtonite				}	
Chlorite		3		10	30
Sphene		T	2		
Apatite	2		T	5	T
Opaques	T	1	1	5*	5
An content of plag.	and.	and.	53		

* Opaques of OSM 81 are magnetite and pyrrhotite major, pyrite and chalcopyrite minor.

OSM 350 Coarse-grained black melagabbro.
1600' elev. in brook east of bench mark, Old Blue Mtn., T C.

OSM 426 Medium-grained gray gabbro.
1370' elev. in Meadow Brook, Newry.

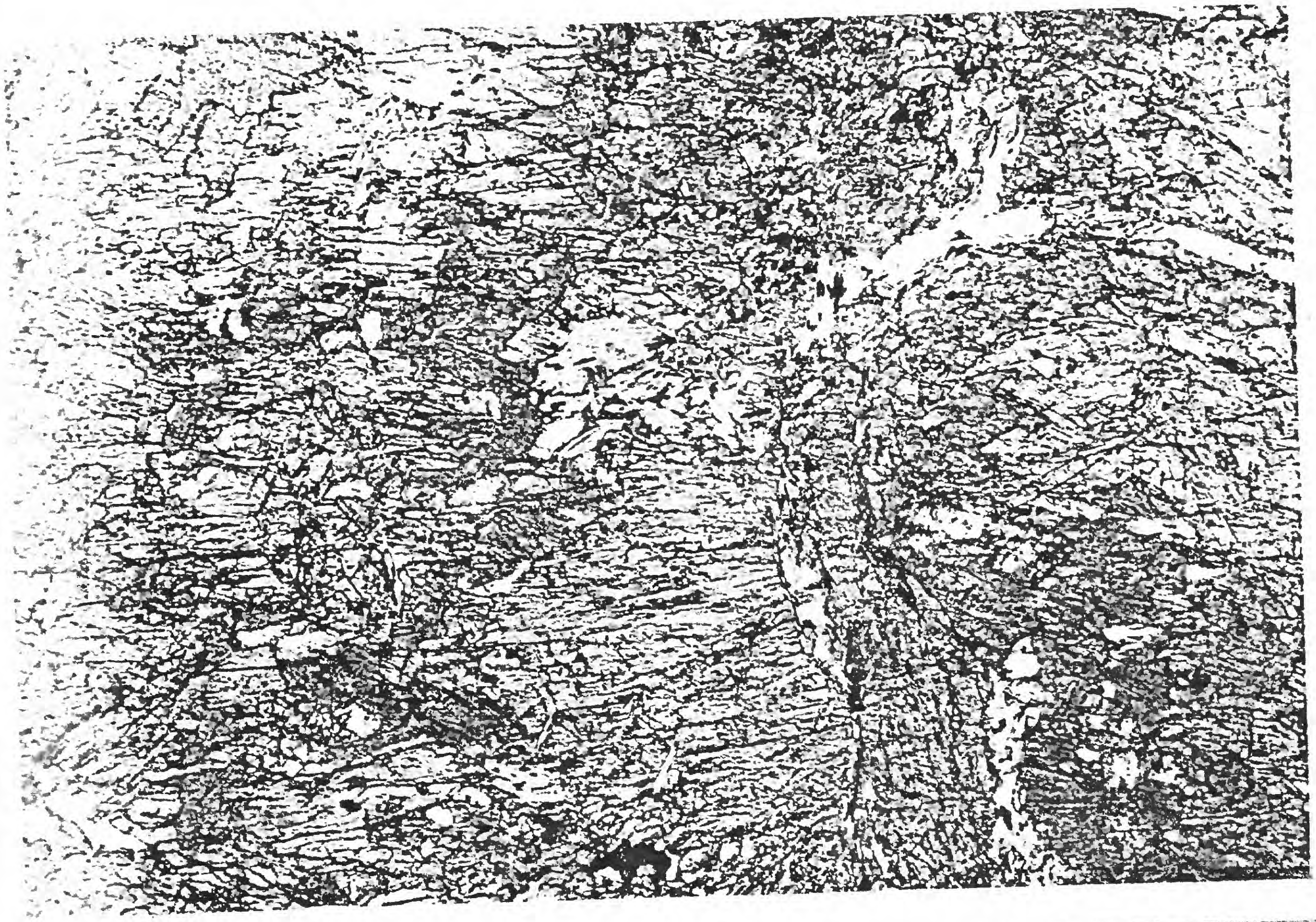
OSM 550 Coarse-grained gabbro.
1680' elev. in brook west of Sable Hill, Grafton.

OSM 81 Coarse-grained matted hornblendite.
1500' elev. in brook south of summit, Sawyer Mtn., N. Surplus.

OSM 277 Medium-grained hornblendite.
1900' elev. NNE of summit of hill SW of Whitecap Bk., Grafton.

PHOTO 35. Gabbro, OSM 426. Light gray areas are pale green hornblende; darker gray is sericitized feldspar. Veins of clear mineral in upper right are orthoclase. x15.

PHOTO 36. Gabbro, OSM 550. Dark grains are hornblende; light areas are fine-grained plagioclase; nearly opaque grains are sphene. White spots are holes in section. x15.



composed of about equal amounts of pale green actinolite and andesine (now largely sericitized) with minor chlorite and traces of sphene, opaque minerals and carbonate minerals. The actinolite has apparently replaced the original mafic minerals, but the texture suggests that of the original igneous rock (photo 35). The actinolite crystals are up to 2 cm across, but are all anhedral, in contrast to the fine prisms well known from the alteration zone on the other side of the gabbro body on Newry Hill. The altered gabbro is cut by granitic pegmatite dikes and, on a microscopic scale, by veinlets of potassic feldspar.

A melagabbro occurs near the base of Old Blue Mountain, T. C. (OSM 350). A thin section of one specimen showed about 55% pale green amphibole, 30% biotite, 12% andesine and minor apatite and opaque minerals. The amphibole and biotite probably replace primary mafic minerals. The texture of the rock is massive with amphibole grains about 1 cm across. The melagabbro is intruded by felsic granites of the New Hampshire plutonic series.

A gabbro west of Sable Hill, Grafton, consists of about 65% hornblende, 30% labradorite and minor sphene, biotite, and opaque minerals (OSM 550, photo 36). The hornblende resembles that of the amphibolites, although it is somewhat lighter in color. Hornblende grains about 1 cm across are set in a matrix of fine-grained plagioclase. The present texture and mineralogy may be the result of metamorphic processes, but the considerably greater coarseness than is found in any other amphibolites suggests that the protolith was an intrusive rock.

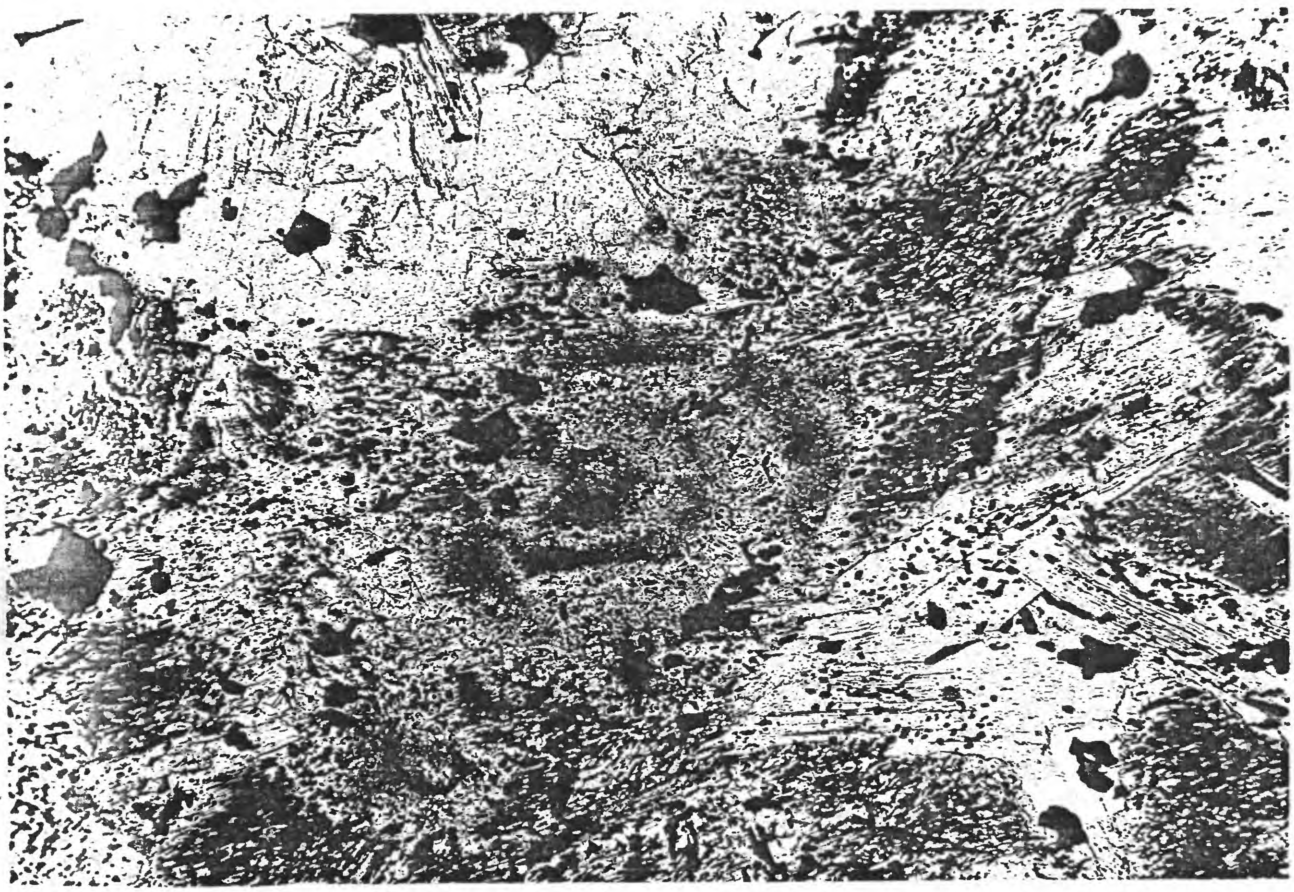
These three rock bodies have been grouped together for convenience rather than because of any clear genetic relationship. The first two bodies are older than the felsic intrusives of the New Hampshire plutonic series and are presumably younger than the Littleton formation. They may be early phases of the New Hampshire series, perhaps of similar age to the Umbagog granodiorite. The gabbro in Grafton may be of the same age but is more probably a shallow intrusive comagmatic with the Whitecap Brook volcanics.

Hornblendite

Hornblendite occurs on the south side of Sawyer Mountain, North Surplus (OSM 81). Only a single outcrop was found, but blocks up to 15 feet across occur in float on the hillside. The rock is composed of about 75% amphiboles, about 10% chlorite and 5% each of biotite, apatite, and opaque minerals. The amphiboles form grains up to three inches long arranged in a matted texture that makes the rock extremely tough. The amphiboles are a pale green actinolite and a white cummingtonite in homoaxial intergrowth, with the cummingtonite usually nearer the rim. In polished section magnetite and pyrrhotite are seen to be the dominant opaque minerals with pyrite and chalcopyrite less abundant.

The present mineralogy and texture are secondary. The original texture is indicated by lines of magnetite grains that outline the positions of the original phenocrysts in a pattern unrelated to the present texture. More or less equant zoned crystals, whose ghosts are

PHOTO 37. Hornblendite, OSM 81. The fine-grained magnetite in the center, now enclosed within several hornblende grains, outlines the ghost of a zoned crystal, perhaps olivine. x60.



outlined by magnetite, were probably olivine (photo 37).

The outcrop is cut by a dike of a granitic rock of the New Hampshire plutonic series. The hornblendite is probably a peridotite that was altered during granite emplacement and regional metamorphism. Green (1960) found two small peridotite bodies near Umbagog Lake about ten miles to the west.

A few outcrops of chloritic hornblendite occur associated with the ~~Whitecap Brook~~ amphibolite southwest of Whitecap Brook (OSM 277) and on Hemenway Ridge, in areas too small to show on the geologic map. Like the gabbro mentioned in the previous section, these may be related to the Whitecap Brook vulcanism or may be later intrusives.

Post-metamorphic intrusives

About twenty-five post-metamorphic intrusive bodies were found in the quadrangle (fig. 6). All except one are dikes too small to appear on the scale of the geologic map. A volcanic vent composed of basaltic breccia is exposed over a distance of several hundred yards in a tributary to Black Brook, Grafton. This body is similar to volcanic vents described by Fowler-Billings (1944) from the Mount Washington area.

The vent is composed of a breccia of basalts differing in grain size, abundance of phenocrysts, color, and other details (photo 38). Xenoliths of granitic rocks also occur. The commonest variety of basalt appears in hand specimen as a dark aphanitic rock. Under the microscope the groundmass is seen to consist of a rather fine-grained subophitic

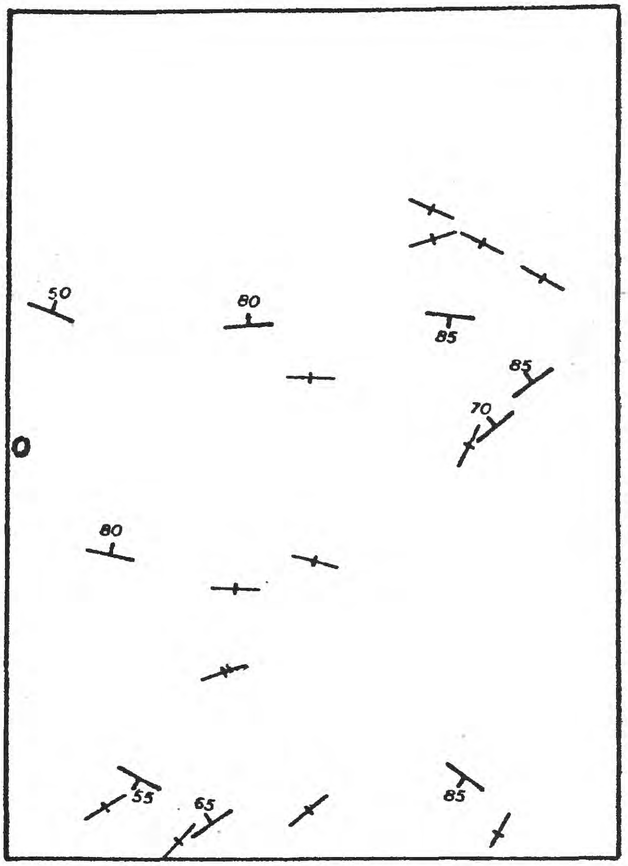
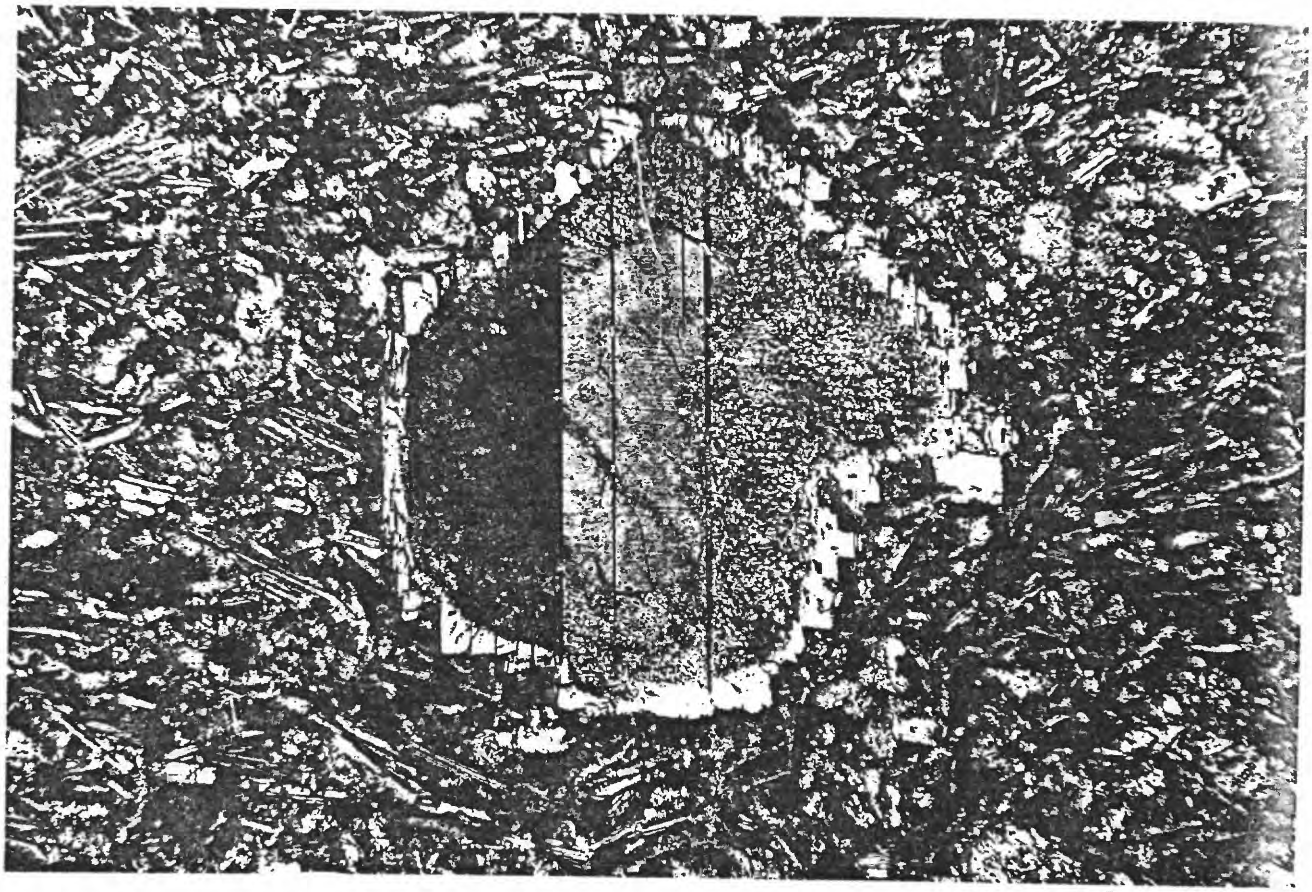


FIGURE 6. Location and attitudes of post-metamorphic dikes in the Old Speck Mountain quadrangle. Circle near west border indicates a volcanic vent.

PHOTO 38. Basaltic breccia from volcanic vent. Thin section photographed in reflected light. x3.5

PHOTO 39. Basalt from volcanic vent. Plagioclase megacryst has a sodic core with a corroded margin, surrounded by a calcic rim. Groundmass consists mostly of plagioclase, augite, and magnetite. Crossed nicols. x60.



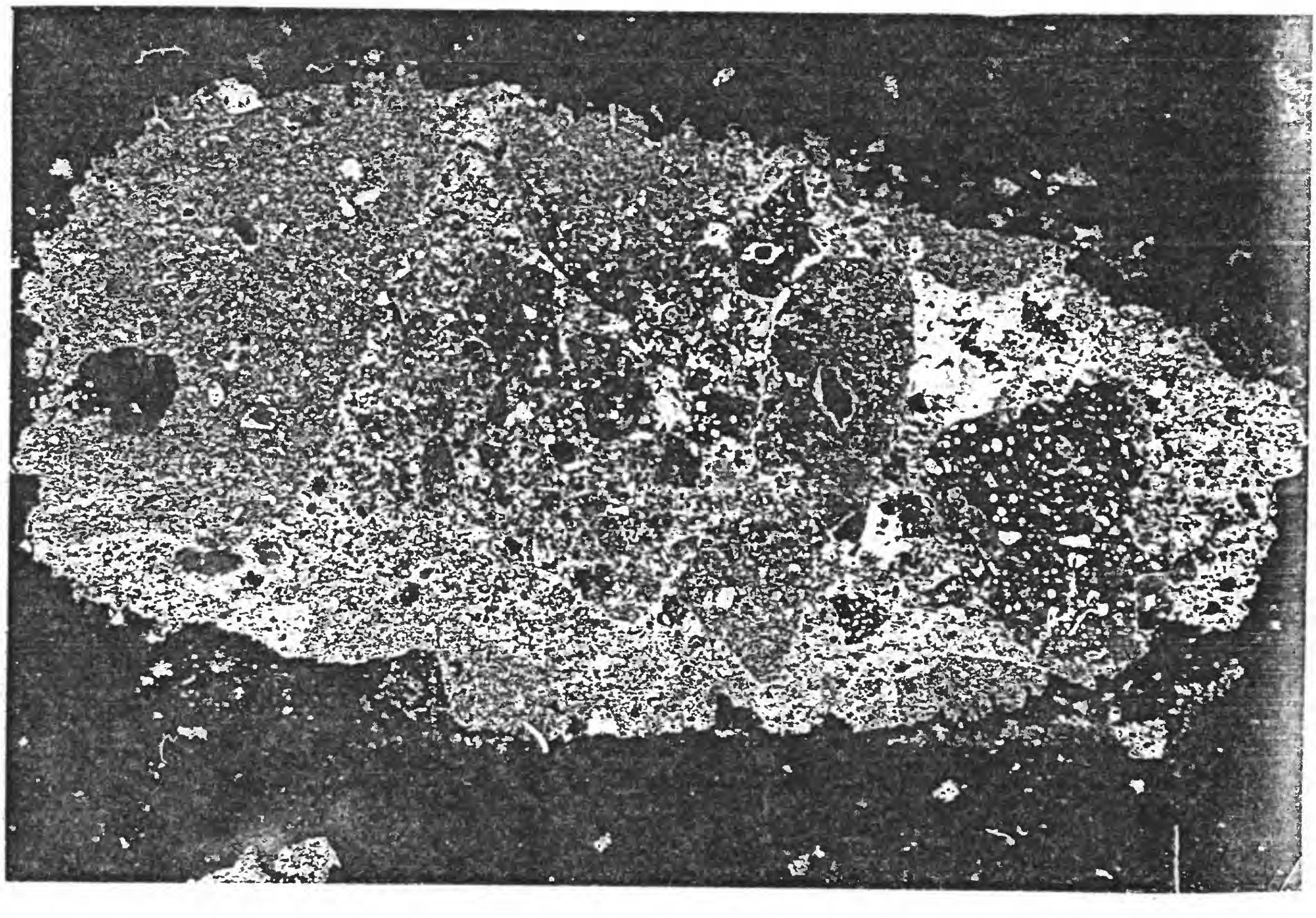
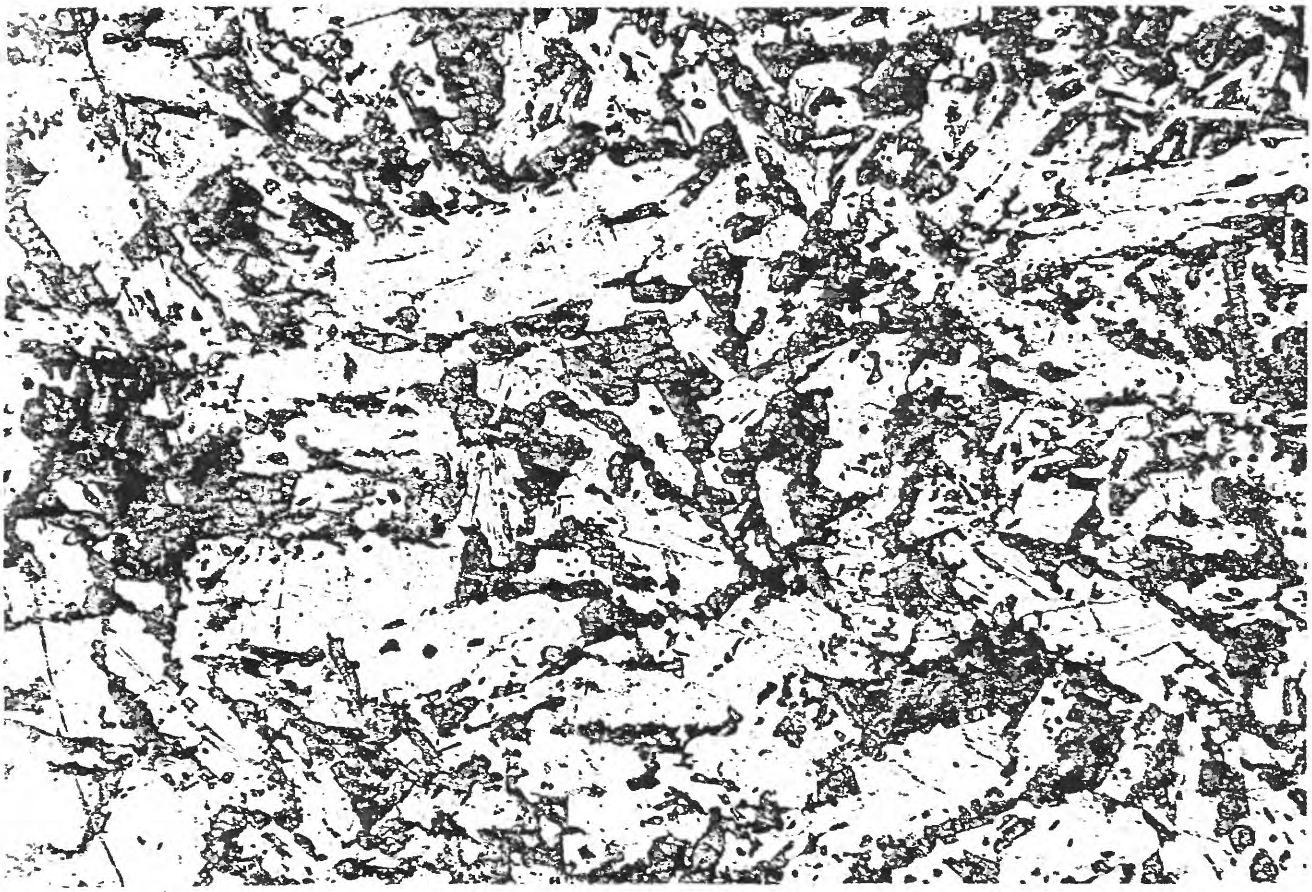
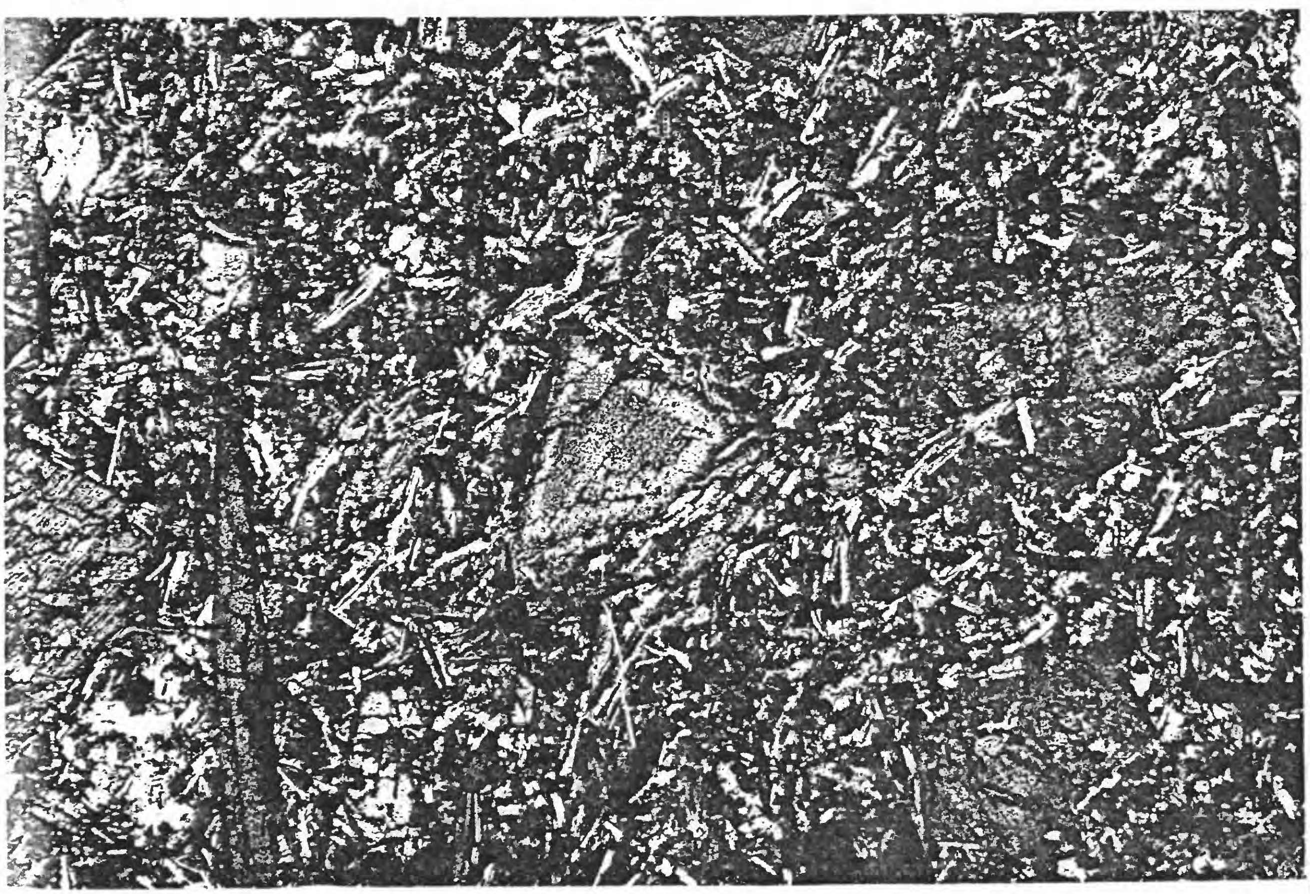


PHOTO 40. Diabase, east of Powers Cemetery, Newry. Plagioclase and augite with minor biotite and opaque minerals. x20.

PHOTO 41. Camptonite, Upton. Phenocrysts are mostly barkevikite, some are augite. Groundmass is plagioclase, barkevikite, and magnetite. Crossed nicols. x20.





intergrowth of plagioclase and augite, with a small amount of brown biotite, magnetite, and calcite. Phenocrysts are pigeonitic augite, barkevikitic hornblende, (in large part replaced by serpentine and carbonate), plagioclase, and quartz. The olivine phenocrysts are commonly surrounded by a heavy augite rim and the hornblende by a rim of augite and opaque minerals. The quartz and at least some of the plagioclase megacrysts are xenocrysts from the granitic country rock. Quartz grains are surrounded by a reaction rim that is now largely carbonatized. Megacrysts of plagioclase show a sodic core with a corroded margin, surrounded by a much more calcic rim (photo 39). These are presumably zenocrysts that have reacted with the more calcic liquid.

Post-metamorphic dikes range in thickness from two inches to twenty feet. Most are of basaltic composition, with a diabasic texture developed in the wider dikes. Camptonite and bostonite dikes also occur.

The thinner basalt dikes are composed of a fine-grained material, presumably devitrified glass, with feldspar microlites. Metacrysts of sodic plagioclase with calcic rims, like those in the volcanic vent, are common. Mafic minerals do not usually occur in the thinner basalt dikes, but some augite is found. Calcite and chlorite occur in amygdules and scattered through the groundmass.

Specimens from the larger dikes are diabase, consisting mostly of rather coarse laths of labradorite and grains of pigeonite (photo 40). Chlorite and calcite are abundant, probably replacing primary mafic minerals, although there are no recognizable pseudomorphs. The chlorite contains minute isotropic grains, perhaps garnet or perovskite.

In one diabase dike the augite is associated with a small amount of biotite and a trace of hornblende and in another it is completely replaced by green hornblende with some biotite. The feldspar in both is fresh and zoned. These dikes were apparently subjected to the waning stages of metamorphism.

A camptonite sill several feet thick in Upton contains brown hornblende (barkevikite) in a continuous range of sizes from one half centimeter down to microlite size (photo 41). Phenocrysts of augite are less abundant. Some of these contain rounded and resorbed cores of olivine, now completely altered. The groundmass is composed of rather large plagioclase microlites, barkevikite, anhedral patches of orthoclase containing plagioclase microlites, opaque minerals and interstitial calcite. Amygdules are composed of calcite and analcite.

Several other dikes with brown hornblende show camptonitic affinities but are finer-grained. One dike contains well rounded phenocrysts of hornblende up to 3 cm in diameter.

Two light-colored dikes in upper Moody Brook are of bostonitic affinities. One consists of small plagioclase microlites in a light colored, extremely fine-grained groundmass. The other consists mostly of somewhat larger plagioclase microlites and contains some biotite flakes in the groundmass. The textures of both are trachytic or bostonitic.

Contact effects of the post-metamorphic intrusives are very slight. A three-foot dike intruding biotitic granulite caused complete sericitization of the plagioclase of the wall rock for several inches, but did not affect the biotite. A fifteen-foot dike partially sericitized the plagioclase and completely chloritized the biotite of the granite wall rock. Granitic gneiss near the vent contains fluorite, which was probably introduced during vulcanism.

The post-metamorphic intrusives of northern New England are generally correlated with the White Mountain plutonic series, which recent radioactive age dating suggests ~~is~~ Triassic. The partially metamorphosed dikes suggest, however, an older age, so the intrusive history may have extended over a long span of time.

STRUCTURE

General Statement

There are two structural divisions to the Old Speck Mountain quadrangle, the Bronson Hill anticline, approximately coextensive with the area of the Ordovician (?) formations, and the Mahoosuc syncline, approximately coextensive with the area of the Littleton formation. The internal structure of both areas is complex. The granitic gneiss of the Oliverian plutonic series forms sheets conformable with the Bronson Hill anticline. The Andover pluton, which includes most intrusives of the New Hampshire plutonic series, is semiconformable with the Mahoosuc syncline. The Umbagog granodiorite forms another semiconformable pluton.

Major structures were determined essentially from map pattern, bedding and foliation attitudes and small scale lineations. Features indicating primary top directions and features indicating a sense of rotation, such as asymmetric crinkles or bedding-cleavage intersections were found too infrequently to contribute significantly to the synthesis.

Bronson Hill Anticline

The anticlinal area is an extension of the Bronson Hill anticline (Billings 1956) which extends the length of New Hampshire and apparently continues southward to Long Island Sound. Through New Hampshire, and probably beyond also, the anticline consists of a series of domes of granitic gneiss (the Oliverian plutonic series) mantled by Ammonoosuc volcanics, with younger strata occurring on the flanks and in axial depressions between the domes. Northwestern Grafton contains a typical segment of the Bronson Hill anticline, with the northeast plunging nose of the Jefferson dome, the northeasternmost and the largest of the domes of Oliverian, mantled successively by Ammonoosuc volcanics and Partridge formation. Further northeast along the axis of the anticline Albee formation crops out, which it nowhere does in the New Hampshire part of the anticline.

The Bronson Hill anticline, or at least the segment within the Old Speck Mountain quadrangle, is a complex structure (fig. 7). In unravelling it two basic assumptions are made. Firstly, the stratigraphic sequence of Albee, Ammonoosuc, Partridge, and Littleton and the general map pattern of these formations must be accepted as correct. Secondly, the base of the Littleton must be regarded as at most a moderately angular unconformity. A corollary of this is that the Ordovician (?) strata must face into the unconformity. This assumption is strongly supported by the parallelism of attitudes on opposite sides. Moreover, elsewhere in New England that Silurian or Devonian strata overlie older Paleozoic strata the angularity of the unconformity is rarely more than slight.

Parallel contacts involving the same two formations indicate that the axis of a tight or isoclinal fold lies between. Where these contacts describe bends together second generation fold are indicated. A synclinal* axis extends along the band of Partridge formation from its westernmost outcrop in the village of Upton about a mile outside the Old Speck Mountain quadrangle to the point east of York Pond where the Partridge splits into two prongs. An anticlinal axis extends from the tip of one of the northeastern prongs of Albee into the main body, where it bends sharply and extends into the other prong. A set of second generation folds trend northeast-southwest, together giving an anticlinorial character to the Bronson Hill anticline. These include an antiform running through the bulge of Ammonoosuc volcanics near the north end of Back Street, the isolated area of Ammonoosuc, and the northeastern prong of Partridge; a synform about a half mile south of this; an antiform (which may be considered the central fold of the Bronson Hill anticlinorium) running from upper Cedar Brook onto the southwest part of East B Hill, and a synform running through the middle of the area of Albee formation and the tongue of Ammonoosuc between the prongs of Albee.

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* Nomenclature of folds in complex structures has not been satisfactorily systematized. In the following pages "anticline" and "syncline" will be used for folds in which the older and younger strata respectively are in the core without regard to whether the closure is upward or downward. The term "simply overturned" will be used for folds in which one limb has been rotated more than 90°. "Inverted" will refer to folds in which both limbs have been rotated more than 90°. "Antiform" and "synform" will refer to the second generation folds which, since they deform isoclinal sequences, have the <u>form</u> of simple folds without regard to the age of the strata involved. An exception is made for the Bronson Hill anticline, which, to be completely consistent, should be called an antiform in this area.

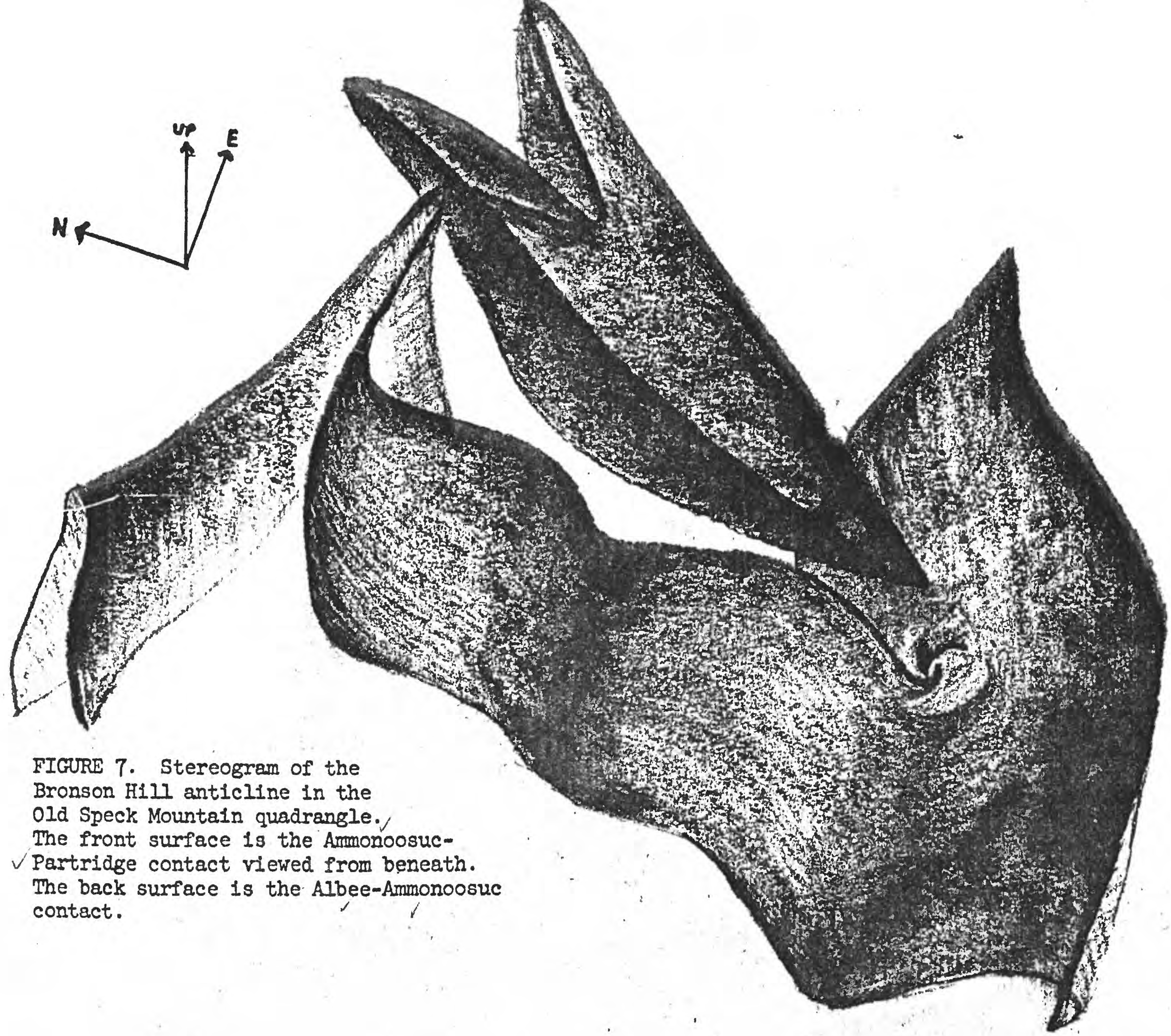
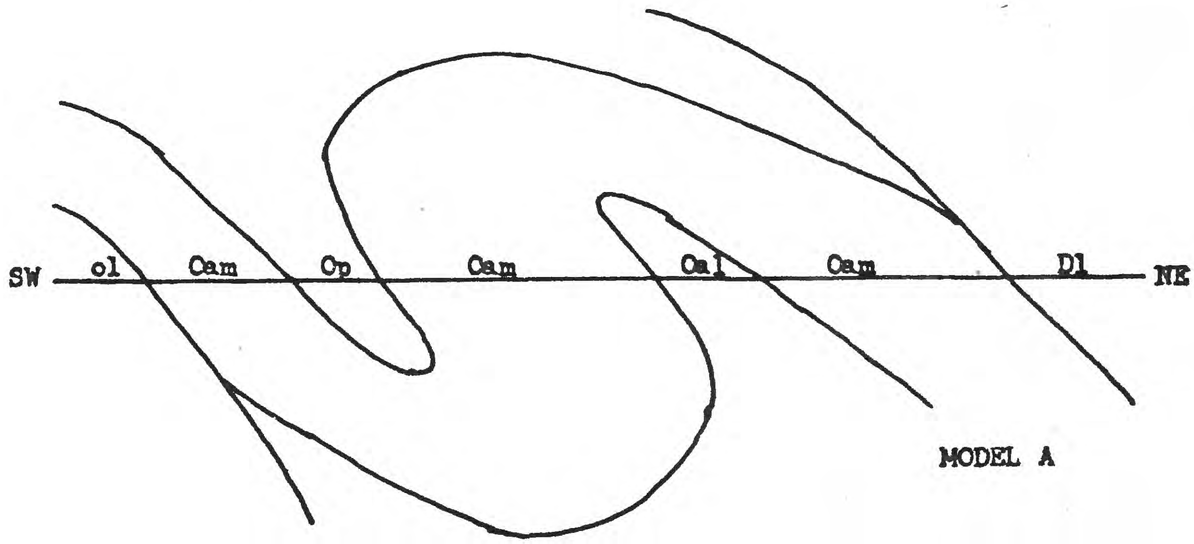


FIGURE 7. Stereogram of the Bronson Hill anticline in the Old Speck Mountain quadrangle. The front surface is the Ammonoosuc-Partridge contact viewed from beneath. The back surface is the Albee-Ammonoosuc contact.



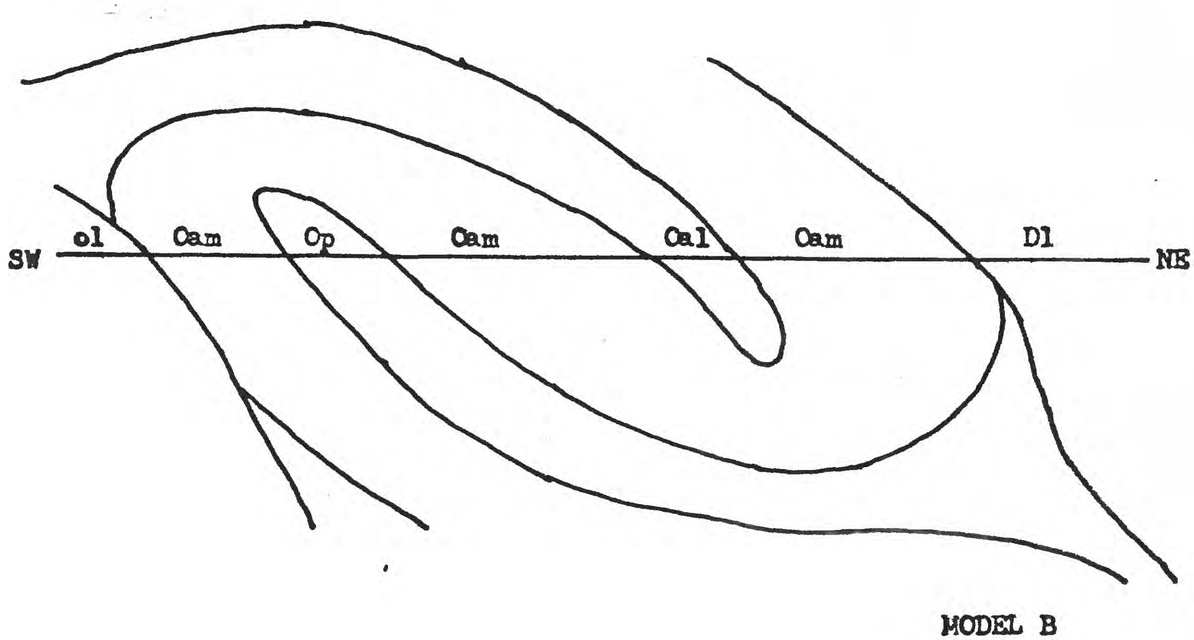


FIGURE 8. Diagrammatic sections of alternative structures of the Bronson Hill anticline.

The prevailing dips and lineations are radially away from the Jefferson dome, which in general means toward the northeast. An exception is in the Dunn Notch area, near the prongs of Albee, where lineations are to the northwest. Lineations plunging southwest are rare everywhere. For this reason it is assumed that the general plunge of all major structures, or intersections of major non-plunging structures, are to the northeast. Two reasonable structural models are consistent with these assumptions (figure 8).

Structural model A. The Partridge formation lies in a syncline simply overturned to the west. Southeast of York Pond the tight synclinal structure ends, so that a horizon such as the base of the Partridge opens downward and outward to dip southeastward under the Littleton formation. The Albee then must lie in an anticline simply overturned toward the west. This anticline is folded about a second generation synclinal axis, so that the resultant structure as a whole plunges to the northeast. If the axis of the first fold were originally horizontal, after refolding the map pattern of the Albee would show a "V" pattern with the ends of the "V" extending indefinitely and widening to the northeast. If the original axis had been inclined, one of the ends of the "V" would be closed but the other would extend indefinitely. Actually, both prongs narrow and pinch out. This would indicate that (if model A were correct) the plunge of the first axis after folding as well as the intersection of the first and second axial planes are to the northeast. This could arise only from very unlikely circumstances, such as the first fold axis being originally doubly plunging away from the point where the second fold axial plane later intersected it. This is the chief difficulty with model A.

Structural model B. The Partridge lies in an inverted syncline, opening downward and to the east. The Albee lies in an inverted anticline opening upward to the west. The axial plane of the first fold in the Albee is, as in model A, folded about a synformal axis trending northeast-southwest. If the axis of the first fold had been essentially horizontal, after second folding the Albee map pattern would be "V" shaped with both prongs narrowing to a point to the northeast, as is actually the case. The direction of plunge of the first fold axis in the tips of the prongs would be gently to the southwest.

The difficulty with model B, a difficulty shared with all downward facing structures, is that it is incomplete in itself. Any downward facing structure can only be a local distortion of stratigraphic horizons which over a larger area are generally right side up. The root zone for the Albee anticline presumably lies back to the southwest on the Jefferson dome, probably somewhere where the Albee is replaced or displaced by Oliverian granitic gneiss. The Partridge syncline presumably dips east out of sight, passing deep under Deer Hill and opens out into the southeast dipping right side up, under the northwest limb of the Mahoosuc syncline somewhere below the surface to the east. On the surface the bottom and top contacts of the Partridge formation abruptly cease to be affected by the isoclinal folding beyond a point southeast of York Pond.

The critical area for discrimination between models A and B is the anticlinal area of Albee. In model A the noses of the two prongs should plunge to the northeast, whereas in model B they should plunge to the southwest. The lineations measured in the field are suggestive of model B, but they are not definitive.

An attempt was made to supplement the measured lineations by beta diagrams, giving the directions of intersections of attitudes of bedding planes (Sander 1948). Diagrams were prepared for two areas. Figure 9 gives the intersections of 28 bedding attitudes measured in the Dunn Notch area, including those from north of the West Branch and southwest of the road and those just east and north of the sharp turn in the road. This is essentially the area of the southern prong of the Albee formation. Figure 10 gives the intersection of 29 bedding planes from East B Hill, except the lower west slope, and from the southwest lower portion of Spruce Mountain. Beta lineations in this area should be dominated by the intersection of the axial planes of the earlier anticlinal and the later synformal folds.

The greatest concentration of beta lineations for the Dunn Notch area has a gentle southwest plunge. Under model B these would correspond to the present plunge of the axis of the earlier anticline. This maximum can not be explained under model A. A concentration of beta lineations with steep plunges to the north, northwest, or northeast would parallel the intersection of the earlier anticline and the later synform. As expected, the concentration of beta lineations in this direction is much more marked in the East B Hill than in the Dunn Notch area. For the Dunn Notch

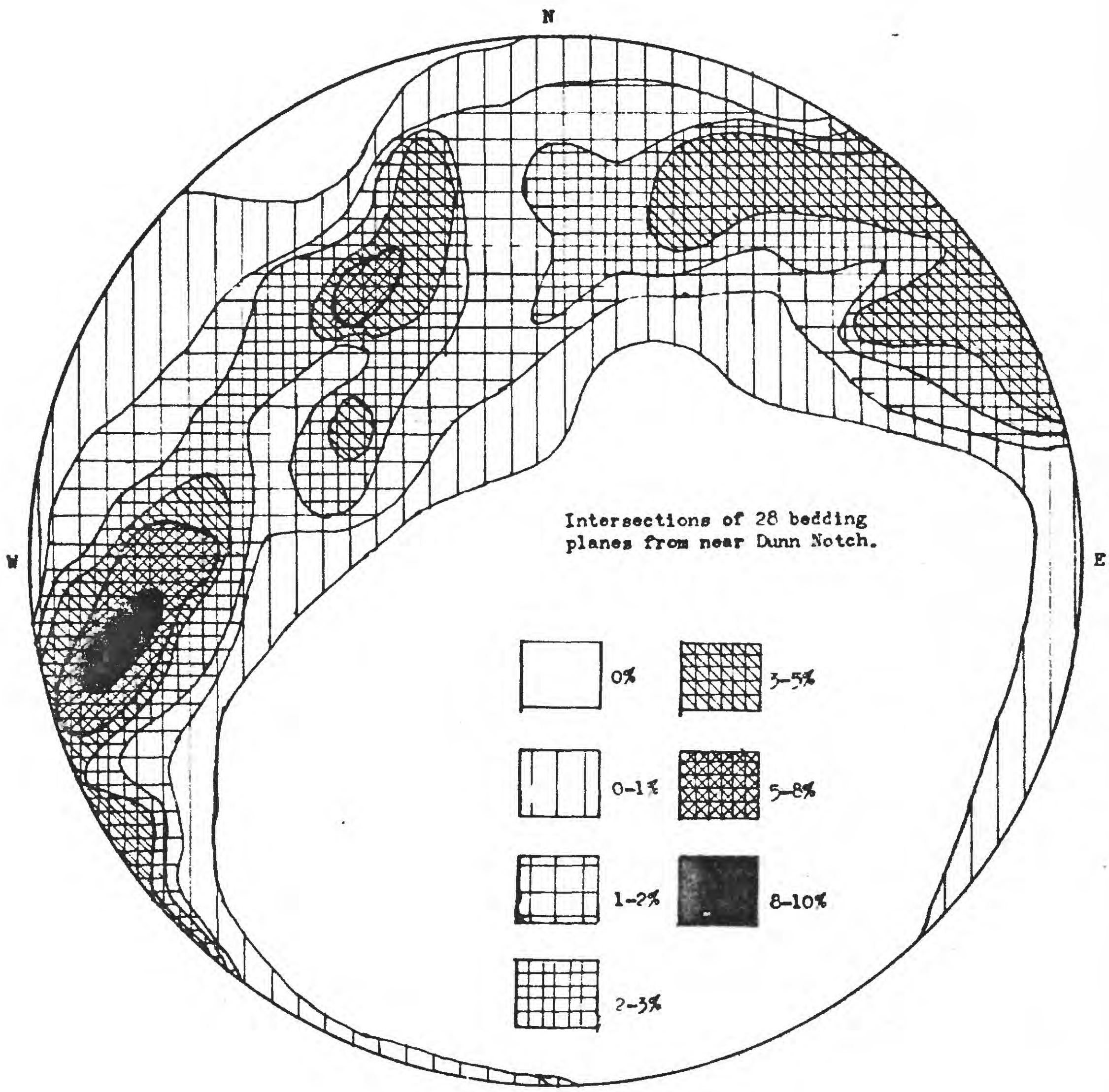

N
W
E
Intersections of 28 bedding planes from near Dunn Notch.
0%
3-5%
0-1%
5-8%
1-2%
8-10%
2-3%

FIGURE 9.

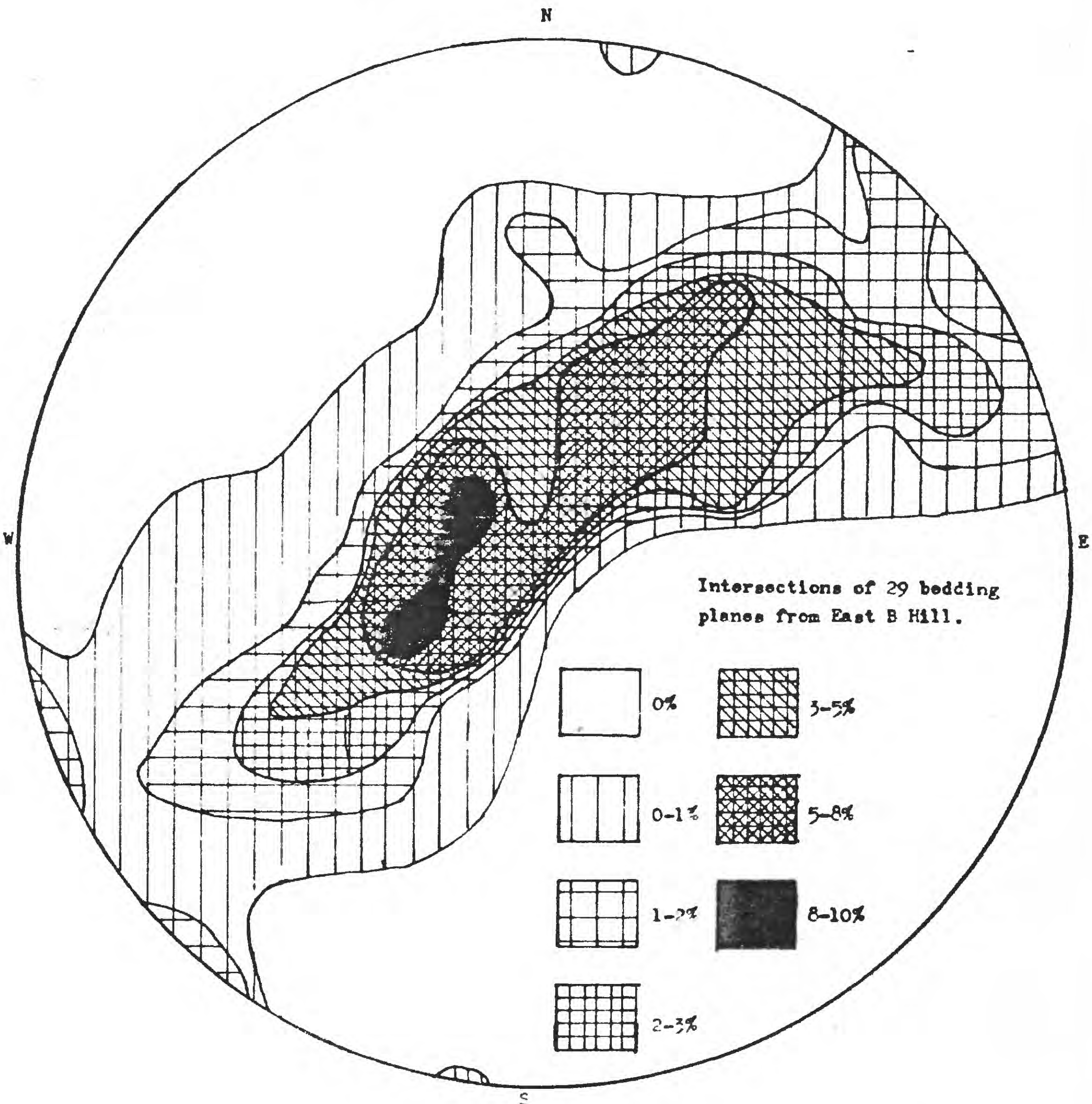

N
W
E
S
Intersections of 29 bedding planes from East B Hill.
0%
3-5%
0-1%
5-8%
1-2%
8-10%
2-3%

FIGURE 10.

area (and perhaps the East B Hill area also) there seem to be both northeast and northwest maxima. No explanation is offered for this. The main point, however, is that the beta diagrams suggest model B rather than model A.

Structure B could have been produced by a reasonable mechanism, while structure A, even aside from the difficulties with the map plan of the area of Albee, can not be related in any reasonable way to the general structural pattern. The first folds of model B might be "flowage folds" developed as a consequence of the growth of the Jefferson dome. As the dome rose the strata on the flanks would have formed into flat-lying folds with their axes parallel to the margin of the dome. As the dome continued to rise, the axial planes of these folds would have been tilted outward so that they dipped away from the dome as inverted folds. The resultant pattern would resemble the "Christmas tree folds" about the Vermont gneiss domes. This very resemblance, however, suggests that the history just proposed should be received with caution. Rosenfeld (1960) has shown that, contrary to established ideas, much of the isoclinal folding actually predated the growth of the Vermont domes. In the Old Speck Mountain quadrangle there is no direct evidence as to the relative age of the first generation folding and the beginning of rise of the Jefferson dome. The presence, however, of northwest-southeast structures in the Mahoosuc syncline, at least one of which may be a direct continuation of a first fold axis from the Bronson Hill anticline, suggests that the first folding is not entirely a consequence of the growth of the Jefferson dome.

In conclusion, the writer believes that the map pattern of the Albee formation, the evidence of the beta diagrams, and perhaps the availability of a reasonable method of generation, indicate that the geometrically more complex model B is considerably more probable than the geometrically simpler model A.

Northeast of the area of Albee formation the structure of the Bronson Hill anticline is indistinct. The two prongs of Albee bend so as to suggest the presence of antiformal axes just beyond their ends. Further northeast the appearance of Littleton as far north as South Arm of Richardson Lake would seem to indicate the wrapping of the younger strata around the plunging Bronson Hill anticline. The actual anticlinal structure, however, is hardly evident this far northeast.

As shown on the map, the base of the Whitecap Brook amphibolite describes a straight line across Grafton into Andover North Surplus, apparently unaffected by the synclinal axis in the Partridge formation. However, glacial deposits in the Swift Cambridge valley cover the critical area where the Partridge formation splits from the isoclinal into homoclinal belts extending to the southwest and northeast. The Littleton could be folded northwestward into the syncline, but be concealed by surficial deposits. A mile south of this area, in the vicinity of the cliff just west of Grafton Notch known as Eyebrow Ledge, there is a synclinal fold in the Littleton formation opening southward with a nearly vertical axis (clearly shown on the geologic map). This syncline may be the extension of the syncline in the Partridge. If so, the Eyebrow Ledge area exhibits a segment of the syncline intermediate between the inverted syncline to the north and a right side up syncline.

The absence of Ammonoosuc volcanics between the Albee and Partridge formations between Whitecap Brook and the Swift Cambridge River is attributed to tectonic thinning. The separation of the Deer Hill area of Partridge from the main body could be the result merely of the unconformity at the base of the Littleton cutting somewhat deeper in the section, as occurs at the ends of the belt of Partridge to the northeast and the southwest. The sharp bend in the unconformity south of Deer Hill, together with the opposite bend in the Ammonoosuc-Partridge contact, suggests, however, that the thickness and shape of the Deer Hill body is in part a result of tectonic flowage.

The antiformal and synformal axes are themselves somewhat curved. In particular, the south end of the synformal axis passing through the Albee seems to be bowed outward from the Jefferson dome.

With the exception of the northeast end of the Jefferson dome, the Oliverian domes of New Hampshire have fairly simple contacts against the Ammonoosuc volcanics. For this reason the Oliverian has been interpreted as occurring in a folded sheet within (or perhaps at the base of) the Ammonoosuc. Actually, since only the upper contact of the sheet is anywhere exposed, it is impossible to say where the base of the Oliverian lies. In the Old Speck Mountain quadrangle the easternmost large body of Oliverian granite gneiss is a sheet within the Ammonoosuc volcanics. Reconnaissance in the Milan quadrangle by Billings (1955) and the writer, as well as the aeromagnetic pattern (Bromery, Kirby, and Vargo, 1957), indicate that the alternation of sheets of Oliverian and Ammonoosuc continues westward into New Hampshire. It is possible that, just as in the simpler domes to the southwest, the Oliverian-Ammonoosuc contact, wherever exposed, represents essentially a single horizon with the Ammonoosuc on the upper side. If so, each sheet of Oliverian must lie in an anticline and each sheet of Ammonoosuc in a syncline. If each sheet of Oliverian is a digitation of the main mass of Oliverian to the southwest, then the pattern of the northeast part of the Jefferson dome is a succession of inverted folds transverse to the trend of the Bronson Hill anticline, quite similar to those involving the Partridge and Albee to the northeast. The curvature of the sheets indicates that they are arched into an antiformal structure.

If the anticline of Albee formation is a digitation off the dome, it indicates that the doming is the expression of a more deep seated structure than would be produced merely by the emplacement of laccolithic bodies of Oliverian granite gneiss within the Ammonoosuc volcanics, a possibility that could not have been excluded elsewhere on the Bronson Hill anticline, where the involvement of the Albee is not evident.

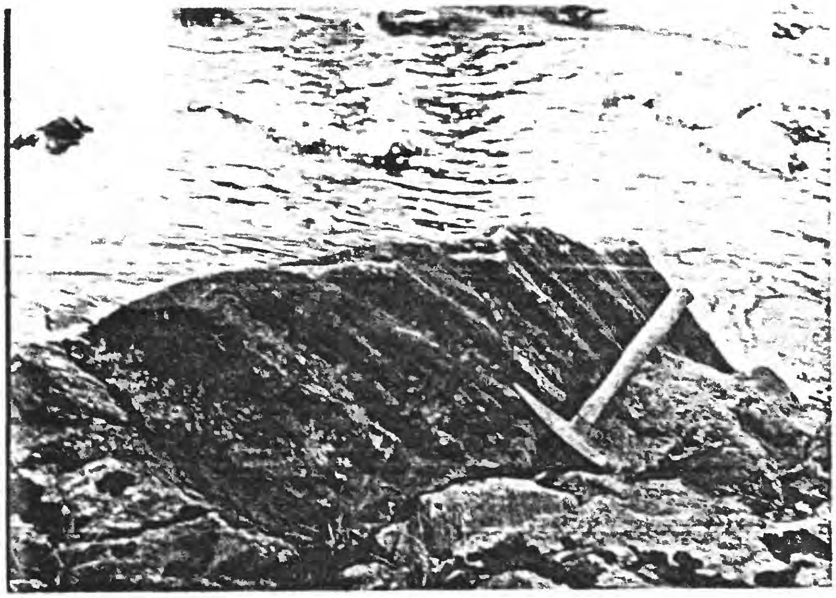
In the Bronson Hill anticline the cleavage is usually parallel to the bedding. Where it deviates from the bedding it is usually parallel to the axial planes of the second generation folds. For example, where the northern prong of Albee crosses the East B Hill Road, near the intersection of the synformal axis and the anticlinal axis, the bedding trends

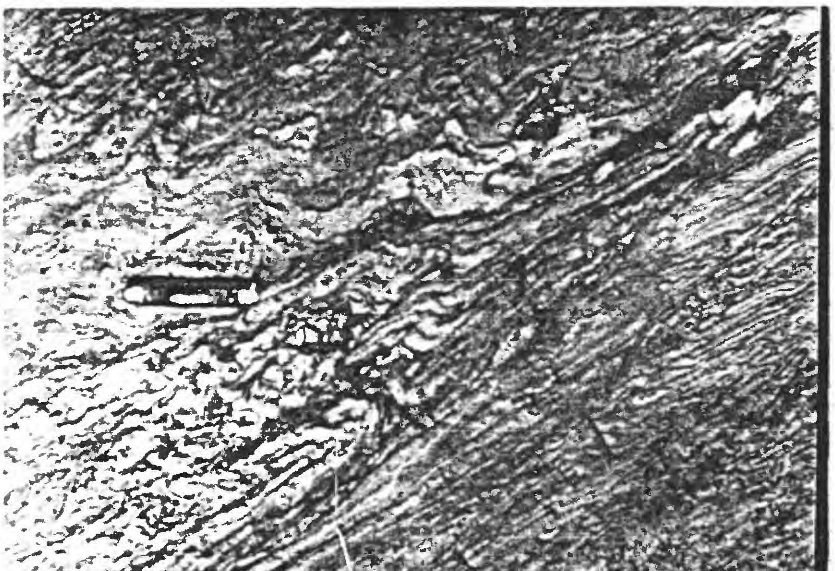
N. 65° W. dipping 60° NE., while the shear cleavage strikes N. 60° E. dipping vertically.

Minor features related to the first generation folding were only doubtfully recorded. One possible locality is along the Swift Cambridge River just north of the Upton-Grafton town line. Here the Ammonoosuc volcanics consist of finely bedded feldspathic schist with beds of dense amphibolite from a few inches to several feet thick. The trends of the amphibolite beds do not everywhere coincide with those of the adjacent schists. Clearly discordant contacts may be seen. The degree of divergence, however, increases with the thickness and massive character of the amphibolite. This suggests that the amphibolite sheets were originally conformable and that the present discordant relationships are the result of the greatly differing competence of the schists and meta-basalt during deformation. The amphibolite beds and the general trend of the bedding and schistosity in the schists describe open folds of some tens of yards amplitude and wavelength with more or less vertical axial planes striking northeast-southwest with a northeast plunge. In detail, however, there is a very intricate folding in the schists associated with a crenulation of the margins of the amphibolite beds (photo 47). This folding appears too tight to be associated genetically with the open folding, One small fold that could be traced out is nearly isoclinal with an axial plane trending east-west, dipping 45° to the north, and with an axis probably plunging steeply (photo 43). A foliation apparently parallel to the axial planes of folds such as these is deformed into the open folds.

PHOTO 42. Dike or sill of amphibolite cutting schist of the Ammonoosuc volcanics. The crenulations on the surface of the amphibolite parallel intricate tight folding in the schist. On Swift Cambridge River 0.2 mile north of Upton-Grafton town line.

PHOTO 43. Isoclinal Fold in quartz-feldspathic schist of the Ammonoosuc volcanics. Same locality as photo 42.





The tight folding is believed associated with the early deformation and the open folding with the later. The openness of the later folding indicates that its intensity was less here than in most areas, where minor structures related to early folding was either destroyed or rotated so close to parallelism with the later structures that they are unrecognizable.

The distinction that has been made between the stages of folding does not necessarily imply that the structural development of the Bronson Hill anticline was not a continuous process. All phases of deformation may be related to the growth of the Jefferson dome. The early folds may be digitations off the dome or perhaps ordinary folds formed by the north-eastward push of the growing dome. The second generation folds, with their dipping axial planes (particularly shown by the synform in the Albee), suggest a combination of upward forces and compression in a northwest-southeast direction. The convergence of the axes to the northeast suggests that the folds were produced by the constriction of the growing Jefferson dome between the buttresses of the Umbagog pluton (probably already emplaced) and the Andover pluton (probably forming simultaneously). This constriction causes the Bronson Hill anticline to have an anticlinorial character here, much more so than in New Hampshire. Finally, continued growth of the dome bowed outward the axial plane of at least the major synform.

Detailed mapping more recent than the 1955 geologic map of New Hampshire has brought out nappe-like structures elsewhere in the Bronson Hill anticline, so that complexity of the structure proposed in the Old

Speck Mountain quadrangle is not without precedent. In the Skitchewaug area of New Hampshire and Vermont an older nappe has been arched by the Bronson Hill anticline and is deformed by folds parallel to the anticline (Thompson 1956). At the south end of the Swanzey dome on the Massachusetts-New Hampshire state line a "V"-shaped body of Partridge is surrounded by Ammonoosuc, with the point of the "V" and the plunge directed away from the dome. This is tentatively interpreted by P. Robinson (personal communication) as an arched inverted syncline, analogous to that occupied by the Partridge in the Old Speck Mountain quadrangle.

Near the beginning of this section it was stated that in unravelling the structure the stratigraphic sequence of Albee, Ammonoosuc, Partridge, and Littleton must be accepted as correct. It may be well to examine this assumption at this point. The stratigraphic column proposed for the Old Speck Mountain quadrangle matches the standard New Hampshire sequence and differs from that in the areas to the northwest in a systematic and explainable matter. It is still possible, of course, that facies changes render the stratigraphic sequence invalid in this quadrangle. The Ammonoosuc, as it is directly traceable into New Hampshire, is unassailable. If the "Albee" were only a lens of metasedimentary rocks within the Ammonoosuc, the general outlines of the structure proposed above could still be determined from the relationships of the Ammonoosuc and Partridge. If the "Partridge" were a lens in the Ammonoosuc, the type of structure could be determined, if in less detail, by the relationships of the Albee and Ammonoosuc. If use of the regional stratigraphy were completely rejected, the map pattern and the minor structures would still indicate that a complex cross-folded structure exists in this area, although little hope of determining its exact nature would remain. If not only the stratigraphic assignment but the actual mapping of this study were rejected a simple structure would be possible, but simplicity has neither an inherent virtue nor, in this case, a probability that would justify the rejection of evidence that it necessitates.

Mahoosuc Syncline

The second major structural division of the quadrangle, approximately coextensive with the area of Littleton formation, is here named the Mahoosuc syncline. The axial trace of this fold extends from Gooseeye Mountain, in the extreme southwest of the quadrangle, northeastward toward the village of Andover, approximately parallel to the axial trace of the Bronson Hill anticline. The fold is open, with the northwest limb striking northeast and dipping nearly vertically and the opposite limb striking east and dipping gently to the north. The curvature of the axial region is rather sharp in the Mahoosuc Range, particularly near Gooseeye Mountain, and rather open farther northeast. Most of the central region of the fold is occupied by the Andover pluton, but the many screens, pendants, and even small inclusions of metamorphic rocks nearly all have attitudes consistent with the structure. The plunge, as determined by linear features such as crinkles, minor fold axes, and mineral streaking, is to the northeast at intermediate angles.

The Mahoosuc syncline is the extension of a syncline that includes the Presidential and Mahoosuc Ranges in New Hampshire (Billings 1956). An axial culmination is located near Gooseeye Mountain, so the northeast plunge is a feature only in the Old Speck Mountain quadrangle.

Interruption of traceable strata by intrusives prevented the elucidation of the internal structure of the Mahoosuc syncline. Some small folds that could be mapped suggest that the Mahoosuc syncline has a complicated internal structure, perhaps even comparable to that of the Bronson Hill anticline. One such fold is the steeply plunging isoclinal fold involving the interbedded schist and quartzite and the two mica schist units near the West Branch of the Ellis River in western Andover. Another well established isoclinal fold is the one near Eyebrow Ledge mentioned as a possible extension of the syncline in the Partridge formation across the Bronson Hill anticline. Although, except for the axial region, most of this fold has been destroyed by intrusives, the axial plane seems to curve toward Old Speck Mountain as if it were an older structure deformed by the Mahoosuc syncline.

In the township of Riley a number of small folds with nearly horizontal axes trend WNW.-ESE., nearly at right angles to the axial trace of the Mahoosuc syncline. Several of these are magnificently exposed in Bull Branch, between Miles Notch Brook and Gooseeye Brook, where they involve thin-bedded calc-silicate granulite (figures 11, 12-photos 44, 45). These folds have amplitudes of several yards and wave lengths of tens of yards. The northeast limbs of the anticlines are gently dipping but the

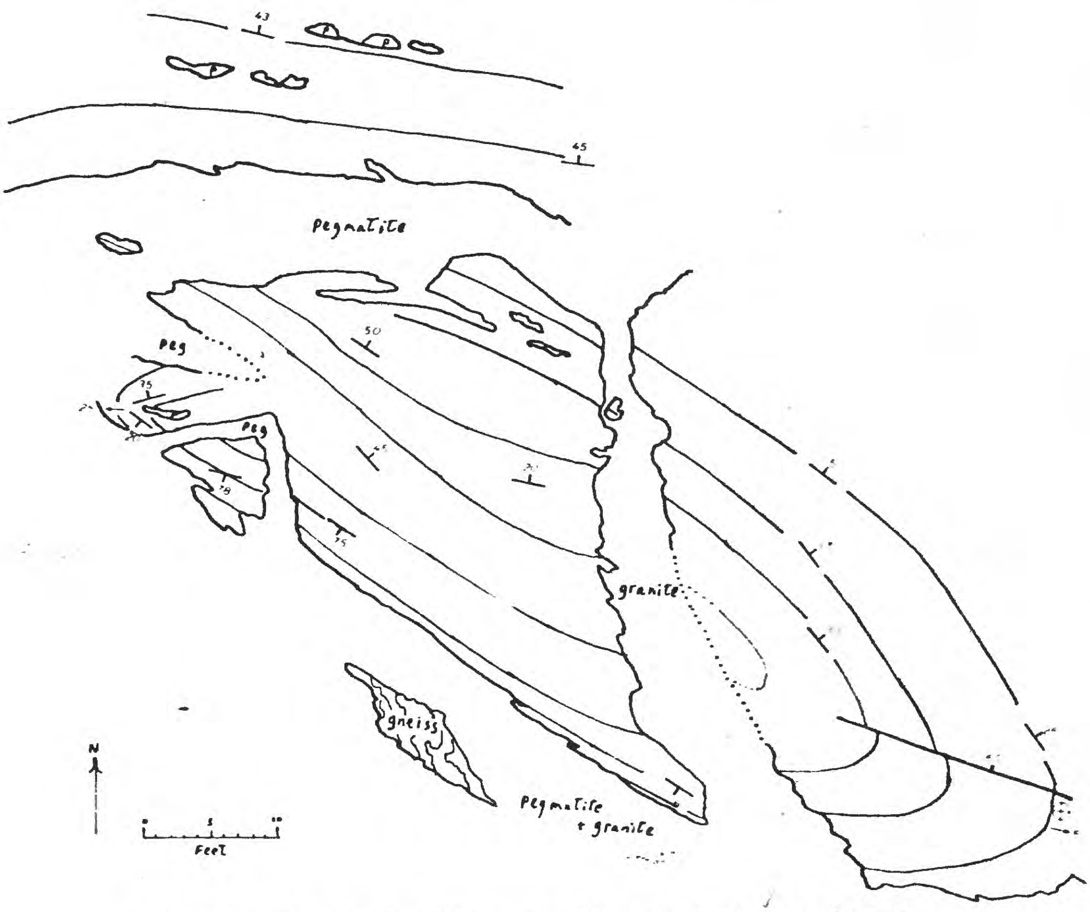


FIGURE 11. Fold in calc-silicate granulite of the Littleton formation. Bull Branch, 0.6 miles above Miles Notch Brook.

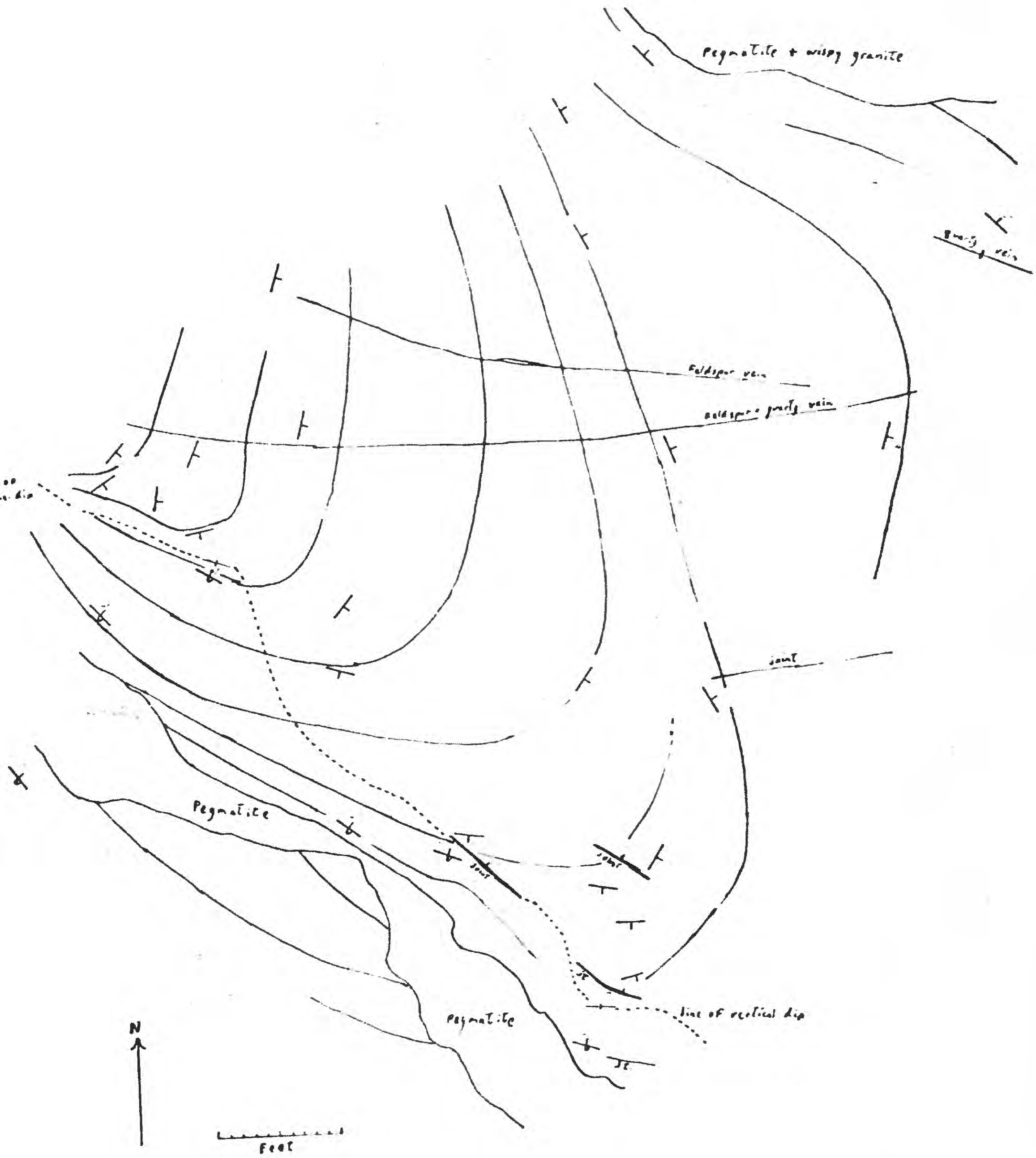
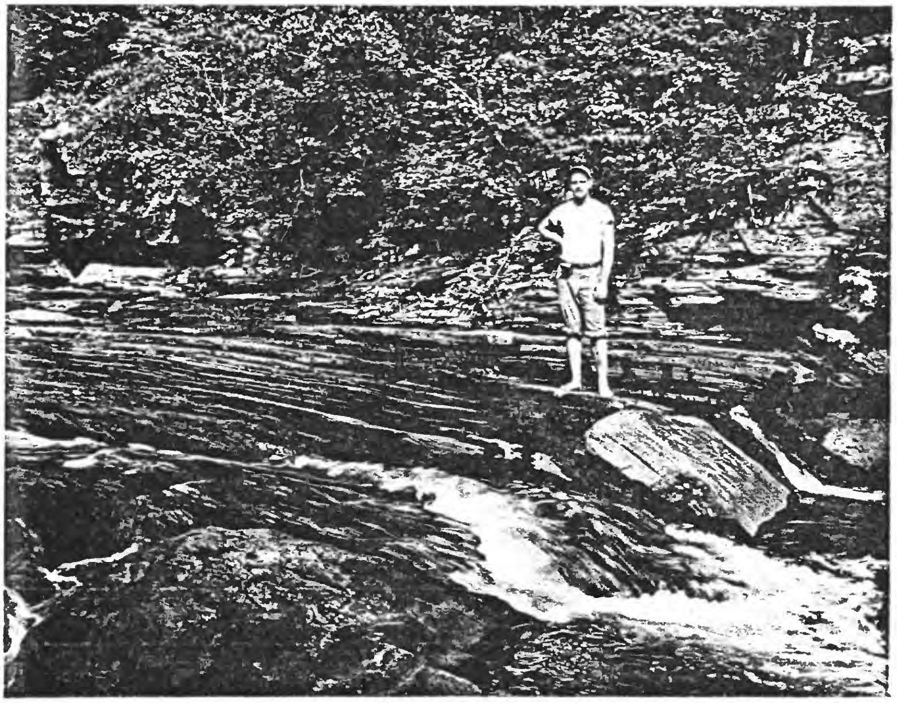
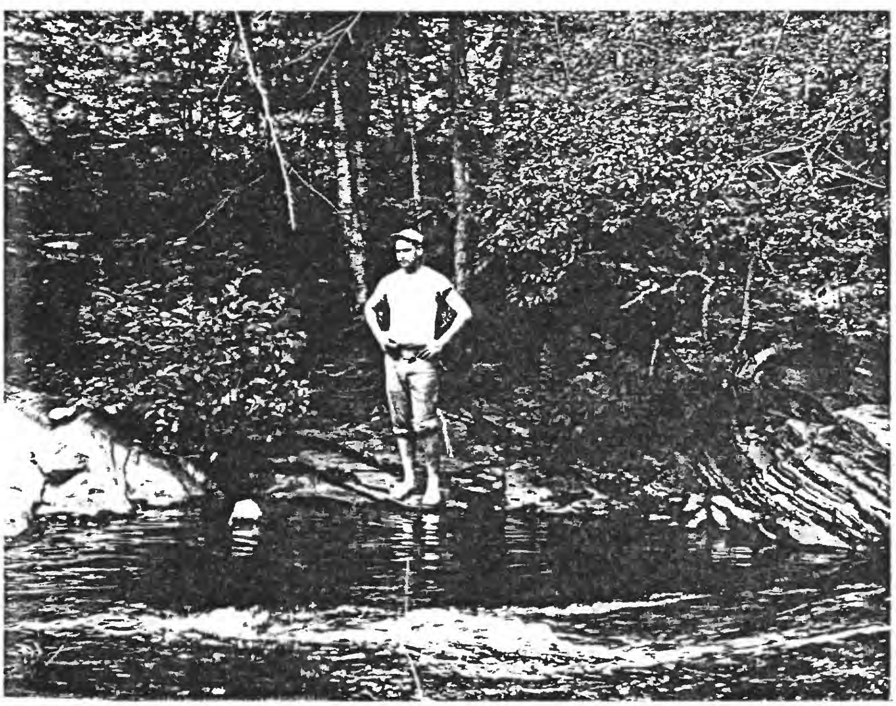


FIGURE 1?. Fold in calc-silicate granulite of the Littleton formation. Bull Branch, 0.? mile above Miles Notch Brook.

PHOTOS 44 and 45. Views southeastward and northwestward along crest of fold in calc-silicate granulite of the Littleton formation mapped in figure 12. The axis in photo 45 paases under bush at left.





opposite limbs are steep or overturned. These folds are approximately parallel to the first generation folds of the Bronson Hill anticline. Their age relation to the Mahoosuc syncline is indeterminate; they could have developed with it as contemporaneous features, or have been superimposed on it, or be preexisting transverse structures. Transverse folds with northwest trending axes also occur in nearby parts of the Gorham quadrangle (M. P. Billings, personal communication).

Structures of the Intrusive Rocks

Plutons of the Oliverian series. The origin of the granitic gneiss of the Oliverian is problematical. No clear evidence of its intrusive nature, such as dikes in the country rock or disoriented xenoliths, was found. The sheets of granite gneiss in Grafton are conformable with the enclosing Ammonoosuc volcanics and may be sills injected into it, or recrystallized volcanics, or both. As said above, it is possible that each sheet marks an anticline in an isoclinally folded sequence rather than successive sills in a homoclinal sequence.

The smaller bodies to the northeast have more irregular outlines and may be cross-cutting. Their assignment to the Oliverian plutonic series is doubtful; they may be more closely related to the Andover pluton with their Oliverian-like features due to ingestion of volcanic material.

Umbagog pluton. The contact of the Umbagog granodiorite against the older metamorphic rocks is smooth and sharp, with very few inclusions of metamorphic rocks in the granodiorite or dikes of granodiorite in the metamorphic rocks.

The outer contact of the pluton is exposed at only a few places in the Old Speck Mountain quadrangle, but the attitudes in the metamorphic rocks and the sharp break on the aeromagnetic pattern indicate a steep contact, perhaps dipping under the granodiorite. Near the mouth of Greenwood Brook is a patch of essentially flat-lying strata, highly metamorphosed and partly transformed to migmatitic gneiss, surrounded by ~~Umbagog~~ granodiorite. If this were a block isolated by magmatic stopping it would be expected to be somewhat broken and intruded. No dikes of granodiorite, however, were found cutting it. It is therefore probably a part of the roof of the pluton. The pluton thus appears to be a more or less cylindrical plug with a flat-lying roof. The margin cuts formational boundaries (especially in the Milan quadrangle) at a small angle, but the general concordance with the country rock suggests that the pluton was emplaced by forceful intrusion. The age relative to the regional structure is uncertain.

Andover pluton. The Andover pluton, which includes all but small outlying bodies of granitic rocks of the New Hampshire plutonic series, is a much more complex body than the Umbagog pluton. The topographic basin around Andover, extending into the Rumford quadrangle, is apparently rather free of metamorphic inliers, but the western, mountainous part of the pluton contains many screens, roof pendants, and inclusions of the country rock. Mapping in this area on almost any more detailed scale would show still smaller inclusions of country rock and apophyses of granite. The distribution of petrographic types within the pluton is equally complex.

Despite the complexity, the overall pattern is one of conformity with the regional structure. The pluton as a whole lies in the center of the Mahoosuc syncline. The outlines and attitudes of the metamprphic inliers shown on the map, and indeed of the majority of inclusions down to those a few feet or even inches long, are consistent with the local trend in the synclinal structure. The internal structure of the pluton shows a general parallelism also. For example, the summit of Baldpate Mountain is a completely exposed expanse of parallel sheets of biotitic granodiorite and pegmatite, each a few yards or feet thick, dipping at a steep angle to the east, as do the metamorphic rocks in the vicinity.

Most contacts with country rock, except those of "wispy granite" and gneiss, are sharp. With the exception of the "wispy granite"-near gneiss and the pinkish granite resembling that of the Oliverian plutonic series associated with the Ammonoosuc volcanics, the type of granitic rock is independent of the type of wall rock. The textures of the granites are consistent with a magmatic origin, although not definitive. Foliation is in most places weakly developed and could well represent a flow structure. The writer's hypothesis of the origin of the sphene-flecked diorite (appendix A) requires a magmatic origin for at least this rock.

It is concluded that the Andover pluton was emplaced by the intrusion of magma from below. In at least the western part, the pluton consists of a multitude of more or less parallel sheets, that were preferentially emplaced along the bedding or cleavage planes of the country rock. Emplacement apparently took place over a long enough period of time so that earlier sheets were at least semiconsolidated by the time later ones were injected. Thus screens and blocks of metamorphic rocks that may be totally surrounded by granite, were at no time entirely enclosed in fluid magma, so that their original orientation is preserved. Those sheets that were injected into earlier formed granite rather than into country rock commonly have the same orientation, probably as a result of continued injection of new sheets along surfaces between older sheets.

The orientation of the screens of metamorphic rocks indicates that the regional structure was nearly completely developed before intrusion of the western part of the pluton. On the other hand, there are occurrences of schist with granitic sills deformed together into open folds in which quartz veins occur in the sills along the axial planes. This indicates that at least some of the folding occurred after injection of the sills. The emplacement of the Andover pluton was thus probably contemporaneous with the later stages of development of the Mahoosuc syncline, the folding causing dilation in the axial region, which was immediately followed by intrusion. For this reason, although there may have been some foundering, particularly in the eastern part of the pluton, most of the Littleton formation is probably still preserved.

Post-metamorphic intrusives. The attitudes of about two dozen post-metamorphic dikes (including some sets of several close parallel dikes) are shown on figure 6. Of these only one, the low-dipping one in the northwest, is a sill; the rest are cross-cutting dikes in either granitic or metamorphic rocks. They are generally straight, although occasionally offset into parallel courses. Almost all are parallel to the dominant joint set in their vicinity. They were apparently emplaced by wedging apart of the country rock. There is no evidence of any deformation later than the dikes.

The volcanic plug in Grafton is only exposed in a single brook section, so that its outline is unknown. There are some basaltic dikes associated. The plug probably marks the site where a dike reached the surface, causing volcanic eruptions that brecciated the country rock and widened part of the dike into a pipe.

Faults

Both faults that were mapped are post-metamorphic and are marked by brecciation and silicification. One of these forms part of the northern contact between Ammonoosuc volcanics and Partridge formation in Upton. The easternmost outcrop of silicified breccia was found several yards west of the quadrangle boundary, but the fault is inferred to extend eastward between amphibolite of the Ammonoosuc and quartz-mica schist of the Partridge. Farther east, near the Swift Cambridge River, adjacent parts of both formations are feldspathic metasedimentary rocks with a gradational contact that shows no faulting.

The other fault extends over the top of Wyman Mountain to Moody Brook, and probably up Moody Brook and down the brook on the northeast side of Hall Mountain. This fault places Littleton and granitic rocks in in juxtaposition, although each occurs on both sides of the fault, and may separate Littleton from Ammonoosuc near Moody Brook. To the northeast, the fault lies within the Ammonoosuc volcanics. On Wyman Mountain there is an intensely silicified zone many yards thick. The Hall Mountain segment is less silicified, but shows some interesting hydrothermal alteration (page 176).

The silicified zones in Morse Brook, Grafton, and on Black Cat Mountain, T C, (page 175) are probably faults, but they show no juxtaposition of different units or other evidence of significant displacement.

Joints were not systematically mapped. Inasmuch as the post-metamorphic dikes follow the dominant joint directions, figure 6 indicates the general joint pattern.

Other lineaments clearly shown on the aerial photographs may be joint directions or fault zones. A particularly prominent one follows the Dead Cambridge River-Sawyer Notch valley.

PETROLOGY OF THE METAMORPHIC ROCKS

Introduction

All the stratified rocks in the Old Speck Mountain quadrangle have been regionally metamorphosed to an intermediate grade. The sillimanite isograd shown on the geologic map was drawn at the first appearance of sillimanite. It separates two areas of staurolite zone metamorphism, a large one in the west-central part of the quadrangle and a small one on Puzzle Mountain in the southeast, from the sillimanite zone that includes most of the quadrangle. The limit of persistence of staurolite in the sillimanite zone is also mapped; it extends the area of staurolite-bearing rocks considerably in the southeast and slightly in the west-central areas.

The metamorphic rocks may be divided into two principal groups, pelitic schists and mafic rocks. The pelitic schists include original shales, sandstones, and some felsic or altered volcanic rocks. They are characterized by quartz and muscovite and some minerals from the following: biotite, chlorite, garnet, staurolite, andalusite, kyanite, sillimanite, plagioclase. A small group of rocks that do not contain muscovite but do contain gedrite or cordierite are treated as an appendage to the pelitic schists.

The mafic rocks are characterized by hornblende and may contain cummingtonite, gedrite, plagioclase, potassic feldspar, quartz, biotite, chlorite, garnet, augite, and epidote. Most were originally basaltic volcanic rocks but calc-silicate granulites, which were originally calcareous or dolomitic sandstones and shales are mineralogically similar.

A final section discusses the effect of retrograde metamorphism.

Mineral Determinations

<u>Muscovite</u>. Basal spacings of muscovites from ten specimens were measured. The (006) reflection was measured in oscillating diffractometer runs of 1/4°/min, using the $(10\bar{1}1)$ reflection of quartz as an internal standard. The spacings for (002) are:

9.914 Å	OSM 25	quartzite (table 3)
9.925	OSM 431	two mica schist, Meadow Bk., Newry
9.942	OSM 382	hydrothermally altered schist, Moody Bk.
9.945	OSM 473	white granulite (table 2)
9.948	OSM 505	two mica schist (table 11)
9.950	OSM 32	two mica schist (table 5)
9.956	OSM 104	two mica schist (table 5)
9.964	OSM 395	two mica sillimanite schist, Upton
9.966	OSM 264	two mica schist, Great Brook, Newry
9.978	OSM 21	two mica quartzite (table 5)

These may be compared with the basal spacings of two muscovites determined by Rosenfeld, Thompson, and Zen (1958):

9.918 Å $K_{60.8}Na_{38.4}Ca_{0.8}$ (mol per cent), Gassetts, Vt.

9.981 from the biotite zone, Danby, Vt., presumably nearly pure $KAl_3Si_3O_{22}(OH)_2$.

The basal spacing of muscovite decreases with increasing content of Na. Other variable components, such as Ca, Mg, or Fe, also affect the basal spacing and the variation is not known to be linear even in the pure $KAl_3Si_3O_{22}(OH)_2$–$NaAl_3Si_3O_{22}(OH)_2$ series. The basal spacings may be taken as indicative of the Na content but precise compositions can not be assigned.

No paragonite was found in any specimens.

<u>Biotite, chlorite, and garnet</u>. FeO/MgO ratios in such minerals as biotite, chlorite, garnet, and staurolite are commonly determined from the refractive index. Other variations in composition also have an influence. MgO/MgO+FeO ratios for biotite and chlorite in table 16 were obtained from Tröger's (1956) tables with the assumptions that one-third of the tetrahedral positions are occupied by Al atoms and that the effect of TiO_2 and Fe_2O_3 is negligible. Albee's empirical curve for the relation of the FeO/MgO ratio and refractive index for metamorphic chlorites gave essentially the same compositions. The only check on the accuracy of these results is provided by OSM 64. The refractive indices indicate a considerably greater content of FeO in both biotite and chlorite than chemical analysis (table 4) shows present in the entire rock. Fe_2O_3 and TiO_2 must be the components responsible for the high refractive indices of biotite and chlorite in this rock.

Biotites of the pelitic schists are reddish-brown in thin section, with the intensity of the color increasing with the refractive index. Biotites of the mafic rocks vary from reddish-brown to greenish-brown. According to Hayama (1959) a reddish-brown color indicates a TiO_2 content of at least 2-1/2% and a low or moderate FeO/Fe_2O_3 ratio. Again the biotite of OSM 64, which, though very pale, is of a reddish-brown hue, suggests that this should be taken with caution.

The compositions of garnets were obtained from the refractive index, the unit cell edge, and in one case chemical analysis for MnO, with the use of the diagrams of Sriramadas (1957). It was assumed that almandine,

Table 16. Physical properties and estimated compositions of biotites, chlorites, and garnets.

	Biotite		Chlorite		Garnet		
	γ	mg	γ	mg	n	d_o	comp.
OSM 21	1.654	.22					
OSM 33	1.645	.32	1.625	.53			
OSM 104	1.645	.32					
OSM 32	1.633	.42	1.625	.53	1.810	11.55_2	80% alm 10% pyr 10% gro
OSM 155	1.616	.61	1.610	.67			
OSM 156	1.615	.62	1.603	.76			
OSM 64	1.590	.84	1.594	.83			
OSM 365 (rock)					1.810	11.55_6	80% alm 10% pyr 10% gro
OSM 365 (garnet-rich lens)					1.804	11.54_4	75% alm 15% pyr 10% gro

mg = MgO/MgO+FeO

pyrope, and grossularite (and spessartite in the garnet analyzed for MnO) are the only components present in significant proportions.

Amphiboles. Three hornblendes and one gedrite were analyzed by Jun Ito. The gedrite is discussed in detail in appendix B. Compositions and optical properties of the hornblendes are given in table 17. The first two, from the Whitecap Brook amphibolite, are typical in appearance of all the hornblendes of mafic rocks in this quadrangle. The atomic ratios indicate that these fall about midway in the range for each of the major substitutions that can take place in hornblende. That is, the alkali position is about half filled, the coupled substitution of Al in the tetrahedral and octahedral positions is about half the maximum, and MgO and FeO are about equally abundant. The third hornblende is from a unique quartz-rich rock in the Ammonoosuc volcanics.

The refractive indices of other hornblendes and cummingtonites were measured (table 18) and MgO/FgO+FeO ratio were determined from standard tables, but little reliance should be placed on the accuracy of compositions so obtained.

Table 17. Composition and properties of hornblende.

	OSM 2	OSM 11	OSM 542		OSM 2	OSM 11	OSM 542
SiO_2	44.15	41.34	48.77	Si	6.57	6.23	6.98
TiO_2	1.39	2.22	0.40	Al^{iv}	1.43	1.77	1.02
Al_2O_3	12.54	13.06	9.91	Al^{vi}	.77	.55	.65
Fe_2O_3	3.78	3.82	2.35	Ti	.16	.25	.04
FeO	12.82	16.43	8.76	$Fe^{\cdot\cdot\cdot}$	.42	.43	.25
MnO	0.19	0.30	0.19	$Fe^{\cdot\cdot}$	1.60	2.07	1.05
MgO	9.55	8.66	15.20	Mn	.02	.04	.02
CaO	11.75	10.52	12.03	Mg	2.12	1.94	3.24
Na_2O	2.01	1.81	0.92	Ca	1.67	1.70	1.84
K_2O	0.36	0.38	0.30	Na	.58	.53	.26
H_2O-	} 1.76	} 1.67	-	K	.07	.07	.06
H_2O+			1.57	H	1.74	1.68	1.50
Cr_2O_3	-	0.02	-				
V_2O_5	-	0.01	-				
ZrO_2	-	0.05	-				
TOTAL	100.30	100.29	100.40				

Jun Ito, analyst.

OSM 2 $(Na_{.34},K_{.07})_{.41}(Ca_{1.67},Na_{.24},Fe_{.07},Mn_{.02})_2(Fe_{1.53},Mg_{2.12},$
$Fe^{\cdot\cdot\cdot}_{.42},Ti_{.16},Al_{.77})_5(Si_{6.57},Al_{1.43})_8O_{22}(OH_{1.74},O_{.26})_2$

OSM 11 $(Na_{.51},K_{.07})_{.58}(Ca_{1.70},Na_{.02},Fe_{.24},Mn_{.04})_2(Fe_{1.83},Mg_{1.94},$
$Fe^{\cdot\cdot\cdot}_{.43},Ti_{.25},Al_{.55})_5(Si_{6.23},Al_{1.77})_8O_{22}(OH_{1.68},O_{.32})_2$

OSM 542 $(Na_{.26},K_{.06},Ca_{.09})_{.41}(Ca_{1.75},Fe_{.23},Mn_{.02})_2(Fe_{.82},Mg_{3.24},$
$Fe^{\cdot\cdot\cdot}_{.25},Ti_{.04},Al_{.65})_5(Si_{6.98},Al_{1.02})_8O_{22}(OH_{1.50},O_{.50})_2$

	OSM 2		OSM 11		OSM 542	
X	1.658	light olive	1.666	light olive	1.637	olive
Y	1.675	dark green	1.678	brownish green	1.648	grayish green
Z	1.681	dark green	1.685	green	1.657	grayish green
abs.	$X < Y = Z$		$X < Y = Z$		$X < Y = Z$	
$Z \wedge c$	16°		18°		18°	
Density	3.24		3.27		3.14	

Indices determined to ±0.002.

Pelitic schists

The following assemblages were observed in pelitic schists:

quartz-muscovite
quartz-muscovite-biotite
quartz-muscovite-biotite-chlorite
quartz-muscovite-biotite-chlorite-garnet
quartz-muscovite-biotite-chlorite-garnet-staurolite
quartz-muscovite-biotite-chlorite-kyanite-andalusite
quartz-muscovite-biotite-garnet
quartz-muscovite-biotite-garnet-staurolite
quartz-muscovite-biotite-garnet-staurolite-sillimanite
quartz-muscovite-biotite-garnet-sillimanite
quartz-muscovite-biotite-staurolite
quartz-muscovite-biotite-staurolite-sillimanite-andalusite
quartz-muscovite-biotite-silimanite

Plagioclase occurs with most of these assemblages. The listed minerals are essentially phases in the system K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O. The presence of plagioclase depends on the content of the components Na_2O and CaO. Na_2O enters into muscovite, but this mineral is present in all assemblages, so the distribution of Na_2O does not affect equilibria between the listed minerals. CaO enters into garnet, so the presence of plagioclase can affect equilibria involving garnet, but the effect was not systematically studied. The content of H_2O is regarded as an externally imposed factor of equilibrium ("humidity") rather than a determining component of the system.

According to the mineralogical phase rule no more than five phases can coexist stably in a system with five determining components. Most of the assemblages listed above meet this criterion; others have one extra phase. In some rocks, particularly those with two polymorphs of Al_2SiO_5, this indicates disequilibrium. In other rocks the garnet probably contains sufficient CaO to make it a determining component of the system, increasing the number of possible phases by one.

The presence of quartz and muscovite in all assemblages allows the use of the graphical treatment of Thompson (1957). The phases that coexist with quartz and muscovite are shown on a triangle that is the projection of phase space from muscovite to the A-F-M face of the K-A-F-M (K_2O-Al_2O_3-FeO-MgO) tetrahedron. The optical determinations of the preceding section together with findings in studies elsewhere indicate that the FeO/MgO ratio in minerals increases in the order chlorite-biotite-staurolite-garnet.

Some of the assemblages are compatible, that is, they can exist at the same externally imposed conditions provided the bulk compositions are different. These assemblages can be used to draw complete equilibrium A-F-M triangles. Other assemblages are incompatible. A reaction must occur between these. When all are considered, the triangles for each ensemble of assemblages can be placed on a plot of pressure versus temperature in fields separated by curves representing reactions, to form a petrogenetic grid. The placement of equilibrium triangles on the grid is assisted by the fact that the reactions are of two types. The three polymorphic inversions of Al_2SiO_5 are insensitive to the humidity, so the curves representing them are nearly straight lines with fixed positions on the P-T plot. Their pattern around the triple point as determined from entropy and volume relationships (Miyashiro 1949, Thompson 1955) and experimentally seems to fit many regions of progressive metamorphism. The other reactions all involve a change in the amount of combined H_2O. These reactions appear on a P-T diagram as curves convex toward higher temperatures and pressures (Thompson 1955). Under different conditions of humidity the location of these curves will vary, but their general shape will be little changed.

The ratio of FeO + MgO to Al_2O_3 is rather high in all specimens. Because of this all assemblages (except the unique simple quartz-muscovite pair) contain biotite.

Progressive metamorphism. A single specimen (OSM 153), from near the center of the larger area of staurolite zone metamorphism, contains the assemblage biotite-garnet-chlorite (plus quartz and muscovite). If these phases really belong in the system K_2O-Al_2O_3-MgO-FeO-SiO_2-H_2O the assemblage requires an equilibrium triangle such as I in figure 13. Equilibria in the more aluminous upper part of the triangle are not known; staurolite is presumably stable and either kyanite or andalusite may be the aluminum silicate mineral.

With increasing temperature and pressure a dehydration reaction decreasing the field in which assemblages containing the hydrous mineral chlorite can occur. Such a reaction would result in an equilibrium triangle such as II in figure 13. The three phase assemblages biotite-garnet-staurolite and biotite-chlorite-staurolite and the two phase assemblage biotite-staurolite (each plus muscovite and quartz) now become stable. Biotite-garnet-staurolite (OSM 436, table 8; OSM 543, table 13) occurs and biotite-staurolite probably occurs but biotite-chlorite-staurolite

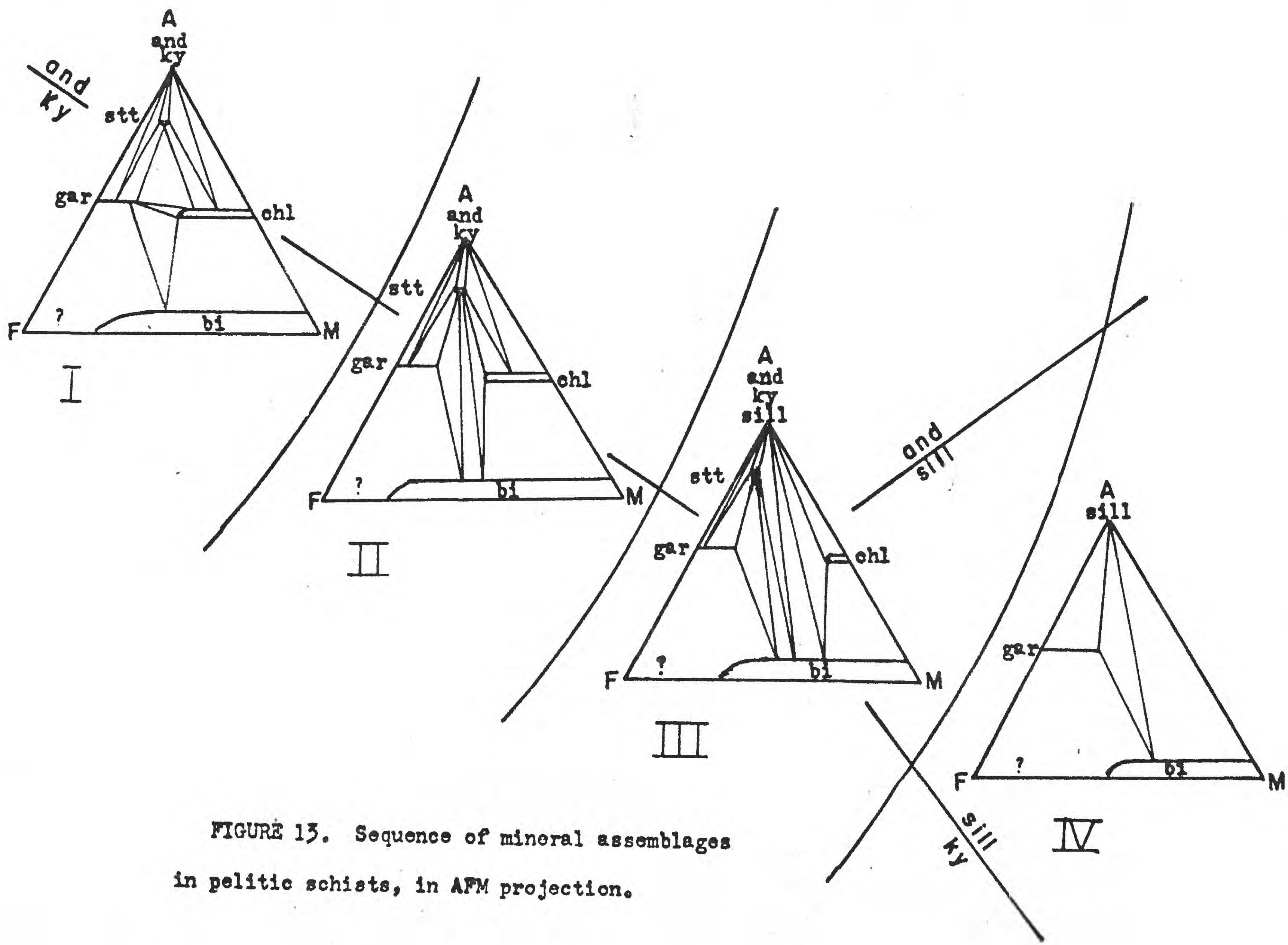


FIGURE 13. Sequence of mineral assemblages in pelitic schists, in AFM projection.

was not found. On the other hand, a number of specimens with the assemblage biotite-garnet-staurolite-chlorite were found (OSM 32, 33, 284, table 5; OSM 17, table 1). This could be a result of reaction A not proceeding to equilibrium. More likely, however, it indicates that the five component system is insufficient to treat this assemblage. Some other component (probably CaO, possibly MnO) enters the garnet in sufficient quantity to stabilize an additional phase. The garnet from OSM 32 was estimated to contain 10% of grossularite. The prevalence of this assemblage raises doubts as to the validity of treating the assemblage of the preceding paragraph as in the six component system. Even after the equilibria of triangle II prevail in the six component system, the assemblage biotite-garnet-chlorite would be stable with the garnet containing another component (and with more magnesian biotite and chlorite). OSM 153 thus does not necessarily indicate a lower grade of metamorphism than a specimen such as OSM 32.

A further reaction reduces the field accessible to chlorite by permitting the assemblages biotite-staurolite-aluminum silicate, biotite-chlorite-aluminum silicate, and biotite-aluminum silicate (triangle III). Assemblages biotite-staurolite-andalusite-sillimanite (OSM 4, table 6), biotite-staurolite-sillimanite (OSM 328, table 11), and biotite-chlorite-kyanite-andalusite (OSM 64, table 3) were found. The association of two polymorphs of Al_2SiO_5 probably indicates disequilibrium although it is possible that minor components in one or the other make the pairs stable. The presence of all three polymorphs in various of these assemblages indicates that boundary between the fields represented by triangles II and III must lie to the left of the triple point.

With increasing metamorphism chlorite and staurolite become unstable in assemblages with quartz and muscovite (triangle IV). Which mineral reaches the limit of its stability first is not certain. The commonest assemblage for peltic schists in most of the quadrangle is biotite-garnet-sillimanite, but simpler assemblages without garnet or without sillimanite also occur. The assemblage biotite-garnet-staurolite-sillimanite (OSM 267, table 11) may be due to disequilibrium or to the presence of an extra component in the garnet.

The association of staurolite and sillimanite shows that the curve for the decomposition of staurolite passes to the right of the Al_2SiO_5 triple point. This association occurs wlsewhere (Chapman 1952) but is uncommon enough to lead Francis (1956) to draw the curve for the decomposition of staurolite through the triple point. This may indicate that the humidity in the Old Speck Mountain quadrangle was somewhat higher than common in metamorphic terranes, increasing the temperature and pressures of the staurolite breakdown. However, it is only when the pressure-temperature gradient passes close to the triple point, as it did during metamorphism in this quadrangle, that the field in which both sillimanite and staurolite are stable will be encountered.

At still higher pressures and temperatures muscovite decomposes, allowing the association of sillimanite and potassic feldspar. Quartz-orthoclase-sillimanite-biotite-garnet assemblages without muscovite occur in boulders along the lower course of Bull Branch. The source area is presumably in the Mahoosuc Range within the quadrangle, but no such rock was found in outcrop.

Potassium metasomatism. It has been implied in the previous pages that H_2O was the only component for which the content was variable during metamorphism. There is, however, evidence that the K_2O content of some rocks also varied.

OSM 181 (table 5) consists of quartz, muscovite, biotite, and chlorite. The biotite grains are oriented with their cleavage planes normal to the bedding, in this area an unusual orientation for biotite but common for chlorite. The grains consist of an inner part full of inclusions and a thin clean outer zone (photo 46). A few remnants of chlorite make it clear that all the biotite except the outer zones is pseudomorphous after chlorite. With such a simple assemblage, potassium must have been introduced from elsewhere.

Pseudomorphs after staurolite were found; they are composed almost entirely of muscovite. Crystals of sillimanite occur replacing the muscovite and particularly at the boundaries between grains in the pseudomorphs. These indicate that the pseudomorphs formed during prograde and not retrograde metamorphism. The replacement can not be explained by balanced reactions such as:

2 staurolite+5 quartz $\rightarrow$ 2 garnet+7 sillimanite+ 2 H_2O

6 staurolite+7 quartz+4 muscovite $\rightarrow$ 4 biotite+ 31 sillimanite+ 6 H_2O

The replacement probably involved large scale introduction of

PHOTO 46. Two mica schist of the Partridge formation, OSM 181. The groundmass is quartz and muscovite. The dark megacrysts are biotite. The megacryst in upper right center is chlorite with an outer zone of biotite. The basal cleavage is parallel to the biotite-chlorite contact; the foliation is carried through the chlorite by lines of opaque minerals. Other biotite megacrysts show a dirty core pseudomorphous after chlorite and a clean outer zone of newly formed biotite. x60.

PHOTO 47. Staurolite-kyanite schist of the Partridge formation, OSM 478. Highly poikilitic mineral in left half of field is staurolite. Poikilitic mineral in upper right, lower right, and in center of staurolite is kyanite. Light gray mineral in center is chlorite. Dark-rimmed mineral in center is fibrolitic sillimanite. Other gray grains are biotite. Light minerals are quartz and plagioclase. x25.

potassium, so that muscovite rather than sillimanite was the principal product.

The textural relations of sillimanite are also difficult to reconcile with a simple process of metamorphism. If no metasomatism occurred most of the sillimanite should have formed together with biotite from the decomposition of staurolite and perhaps chlorite. The first appearance of sillimanite is usually as fine needles growing from the boundaries of quartz or plagioclase grains. At this stage the needles are so small that surface effects may be a major factor in their stability and determine their location. The first sillimanite present in more than trace amounts forms fibrolitic aggregates in biotite. The sillimanite typically occurs in one portion of an otherwise homogeneous knot or biotite grains or even in a portion of a single grain. The appearance is strongly suggestive of the sillimanite having actually replaced the biotite, like a blight on a plant leaf, rather than having grown simultaneously. Fibrolitic aggregates appear in muscovite at a higher grade of metamorphism. In specimens from the Mahoosuc Range where the replacement of both micas by sillimanite has been most extensive, garnet also is particularly abundant. This suggests a reaction such as:

$$\text{biotite} + \text{muscovite} \rightarrow \text{garnet} + \text{sillimanite} + 2\ \text{quartz} + 2\ H_2O + K_2O$$

where K_2O is a mobile component that was removed from the rock just as the H_2O was. K_2O could have been mobile without being a perfectly mobile component in the sense of Korzhinskii (1959). That is, the amount present in the rock at a certain time rather than its chemical potential was a factor of equilibrium. The maximum number of phases that could coexist at equilibrium is not diminished from the case where the amount of K_2O is considered constant, as was done by Thompson (1957).

Muscovite-free assemblages. A few rocks with neither muscovite or hornblende may be considered together. These have the assemblages:

OSM 478 quartz-biotite-chlorite-staurolite-kyanite-sillimanite
OSM 226 quartz-biotite-chlorite-gedrite
OSM 73 quartz-biotite-chlorite-gedrite-cordierite
OSM 77 quartz-biotite-chlorite-gedrite-garnet
OSM 72 quartz-biotite-chlorite-staurolite-cordierite-sillimanite

The first is from the Partridge formation in Upton, the others from the Ammonoosuc volcanics near the head of Black Brook, all near the sillimanite isograd. OSM 77 is discussed in detail in appendix B.

With quartz and biotite present in all assemblages, the remaining phases can be considered as belonging to the FeO-MgO-Al_2O_3 system. In OSM 478 the association of kyanite and sillimanite must be due to disequilibrium. In OSM 72 the excessive number of phases points to the same. As the equilibrium triangles indicate (figure 14) the assemblages of OSM 478, OSM 77, and OSM 226 are compatible, for rocks of different composition. The assemblage of OSM 73 is incompatible with OSM 478 and 77 if the phases are actually all within the FeO-MgO-Al_2O_3 system, as seems to be the case.

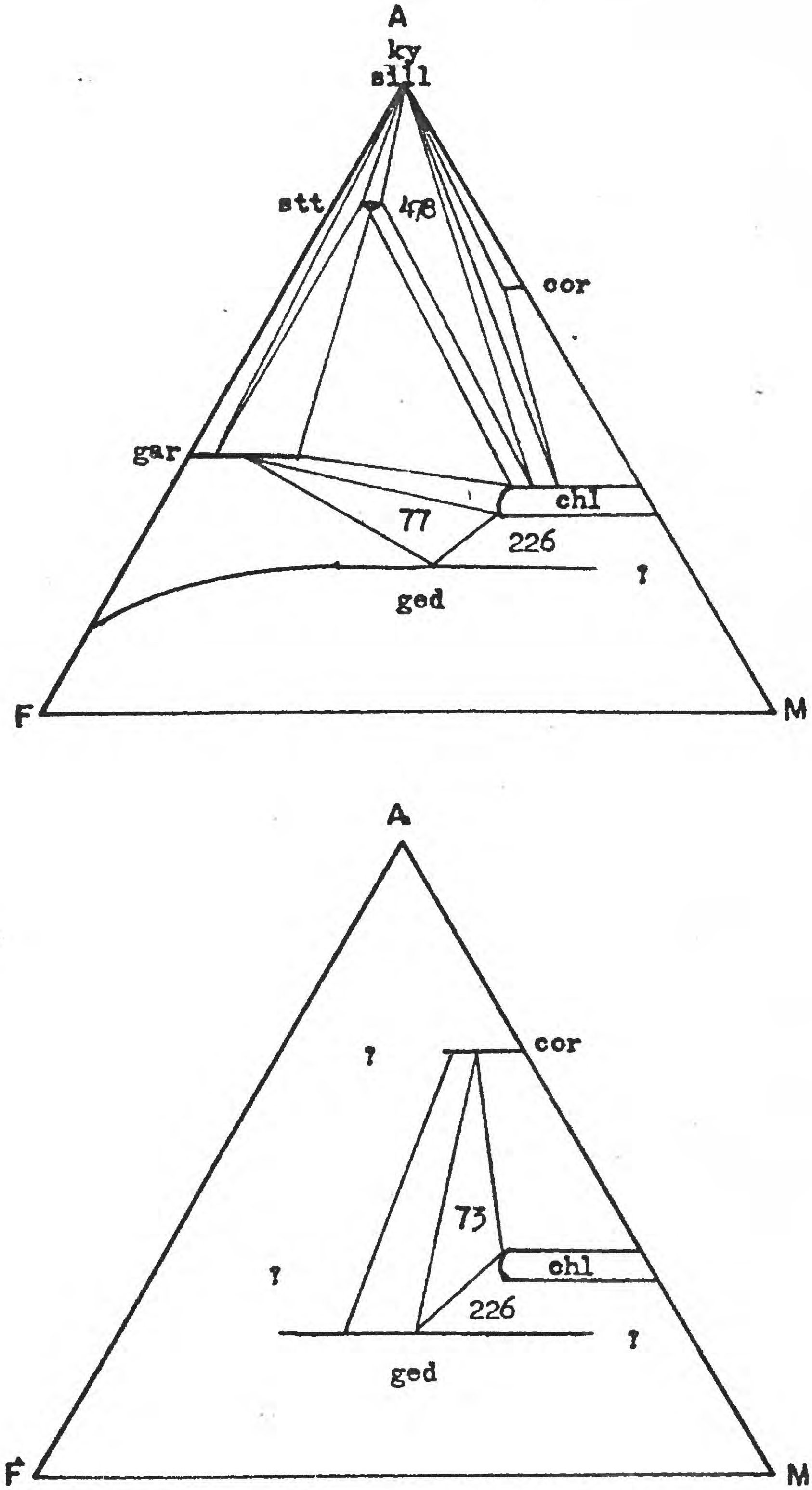


FIGURE 14. Mineral assemblages of muscovite-free schists.

Mafic rocks

Most of the Whitecap Brook ~~member~~, much of the Ammonoosuc volcanics, and dikes in the Albee formation consist of amphibolite produced by the metamorphism of basaltic rocks. The amphibolites all contain hornblende; other mafic minerals are cummingtonite, gedrite, biotite, chlorite, garnet, augite, and epidote. The assemblages in which these have been found are listed below, together with the number of specimens examined that show each assemblage. Plagioclase occurs with all these assemblages, quartz with most, and potassic feldspar with some.

2 hornblende-cummingtonite
1 hornblende-cummingtonite-gedrite
2 hornblende-cummingtonite-biotite
2 hornblende-cummingtonite-chlorite
1 hornblende-cummingtonite-biotite-chlorite
1 hornblende-cummingtonite-gedrite-biotite-chlorite
2 hornblende-cummingtonite-biotite-garnet
16 hornblende-biotite
5 hornblende-biotite-chlorite
4 hornblende-chlorite
1 hornblende-garnet
4 hornblende-augite
1 hornblende-augite-epidote
1 hornblende-chlorite-epidote
1 hornblende-biotite-epidote
1 hornblende-biotite-augite

Complex assemblages are uncommon. The assemblage hornblende-cummingtonite-biotite-garnet-plagioclase-quartz, found in two specimens, and hornblende-cummingtonite-gedrite-biotite-chlorite-plagioclase, found in one, have one less than the maximum number of phases allowed by the mineralogical phase rule if the determining components are seven: MgO, FeO, CaO, Na_2O, K_2O, Al_2O_3, SiO_2. The abundant possibilities for solid

TABLE 17. Optical data on coexisting mafic minerals.

	OSM 466	OSM 483	OSM 469
hornblende	$\gamma = 1.688$		$\gamma = 1.670$
cummingtonite	$\gamma = 1.688$	$\gamma = 1.674$	$\gamma = 1.663$
garnet	$n = 1.808$		
chlorite			$\gamma = 1.605$

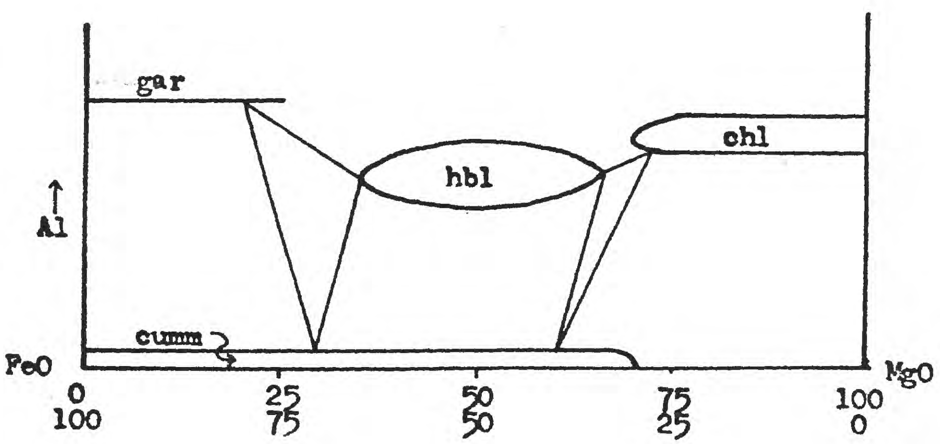


FIGURE 15. Assemblages of mafic minerals of table 17. FeO/MgO ratios are based on optical determinations.

solution in the minerals reduce the usual number of phases greatly. The simple pair hornblende-biotite is the commonest association of mafic minerals.

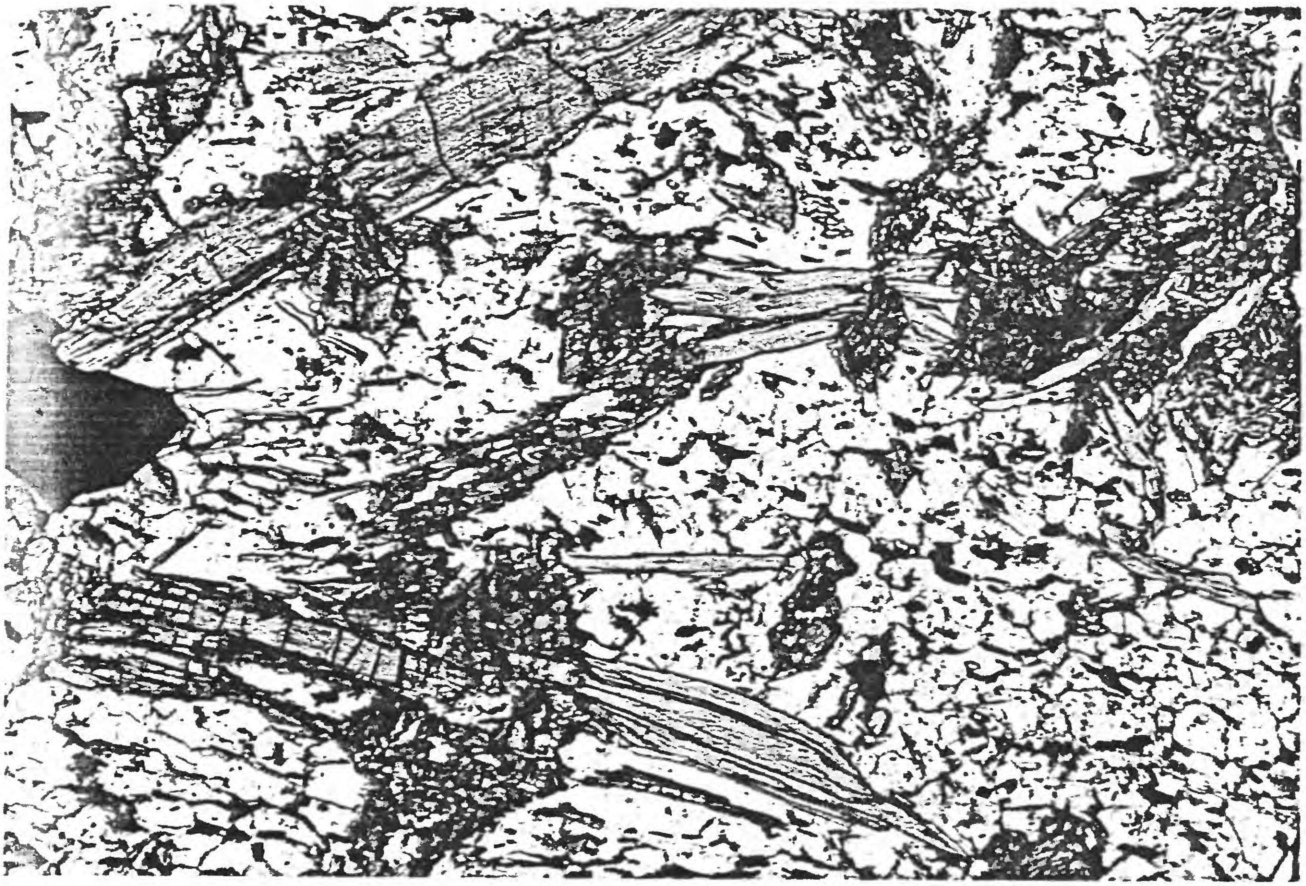
The two amphiboles cummingtonite and hornblende commonly form homoaxial intergrowths; composite grains often appear as complex patchworks of the two minerals. Optical data for minerals from the assemblages hornblende-cummingtonite-garnet, hornblende-cummingtonite, and hornblende-cummingtonite-chlorite are given in table 18, and the compositions estimated from these are shown in figure 15. OSM 469 and 466 are from near the sillimanite isograd, the former on the low grade side and the latter on the high grade side; OSM 483 is from farther into the sillimanite zone, so the equilibria are not strictly comparable. As would be expected the amphiboles associated with garnet are richer in FeO and those associated with chlorite are richer in MgO. The slightly more siderophile tendency of cummingtonite compared with hornblende agrees with the majority of determinations elsewhere.

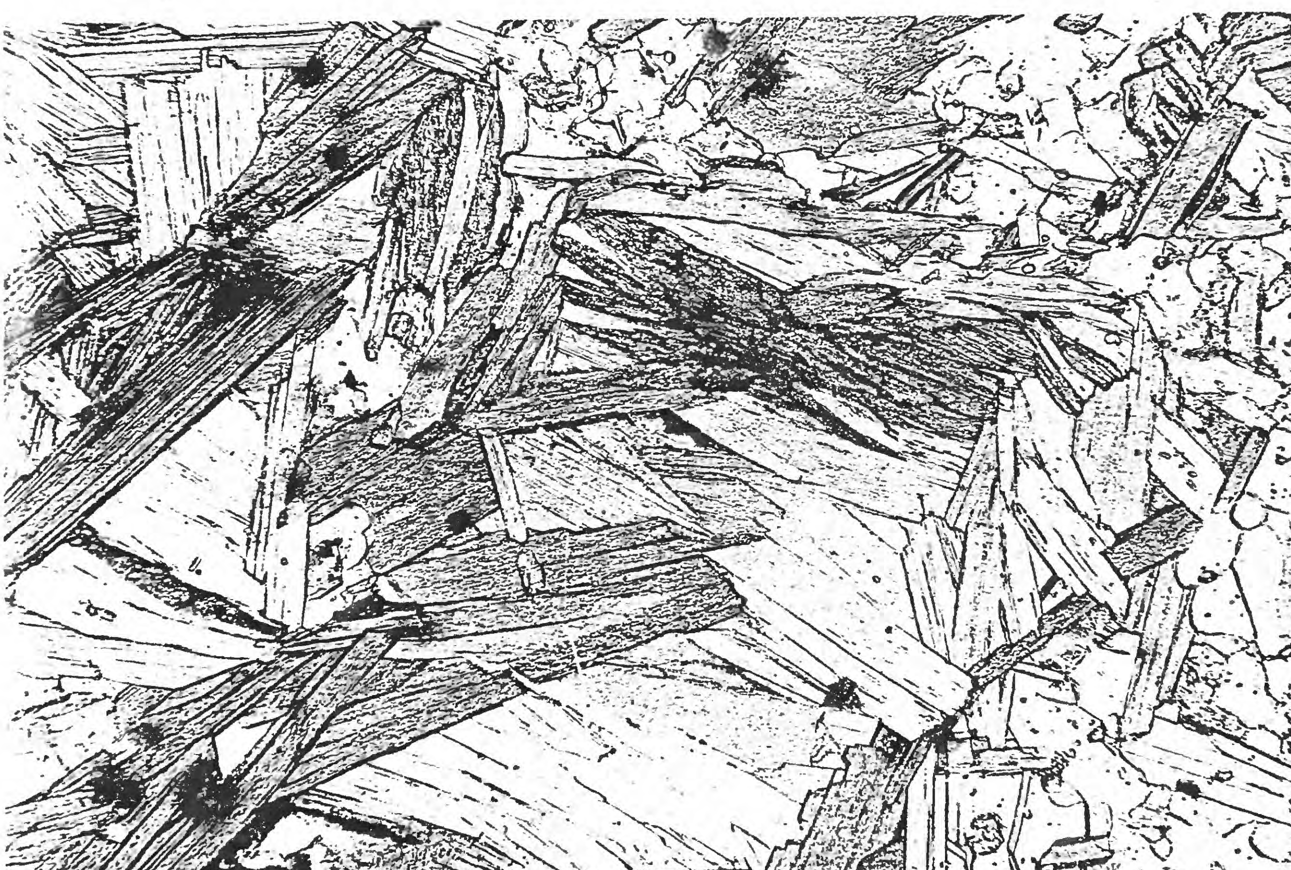
Garnet-bearing amphibolites are uncommon, despite the fact that the metamorphic rocks in most or all of the quadrangle would be classified in the almandine amphibolite facies of Turner (Fyfe, Turner, and Verhoogen 1958). The greater abundance of chlorite than of garnet indicates a generally high MgO/FeO ratio.

Epidote is rather uncommon. It is fairly abundant in similar and correlative amphibolites in the Milan quadrangle, so its scarcity here may indicate a higher grade of metamorphism at which calcium is sufficiently

PHOTO 48. Gedrite schist of the Ammoncosuc volcanics, OSM 309. Most of the gray grains are gedrite. The long crystal at upper left contains gedrite, cummingtonite, and hornblende in homoaxial intergrowth as sketched below. Gray grains in left center and bottom center are chlorite. x20.

PHOTO 49. Biotite schist of the interbedded schist and quartzite unit of the Littleton formation, OSM 482. Biotite is partially replaced by prehnite (large bundles are in center and upper right of center). x60.





accomodated in plagioclase to eliminate epidote from many assemblages.

Augite occurs in several localities with hornblende and at one with epidote also. It is commonly regarded as an indicator of higher grades of metamorphism although it does occur in metabasaltic amphibolites similar to those of the Old Speck Mountain quadrangle in New England (Billings 1941) and elsewhere.

Retrograde metamorphism

Retrograde alteration was not an important process in this quadrangle. The commonest effects are the sericitization of feldspar (particularly calcic plagioclase) and chloritization of biotite.

Chloritization is usually localized along some of the cleavage planes resulting in irregularly interlayered biotite and chlorite, although in some specimens the biotite is completely replaced. Commonly grains of orthoclase lie in the cleavage planes of the altered mica. As the assemblage chlorite-orthoclase is stable only in the very lowest grades of regional metamorphism, the chloritization must have occurred no earlier than the waning stages of the metamorphism. Chloritization also affects staurolite and garnet, but even less commonly and extensively than biotite.

Sillimanite and the less common kyanite and andalusite are almost invariably fresh. This contrasts with the extensive sericitization of sillimanite and andalusite in comparable areas in New Hampshire and elsewhere.

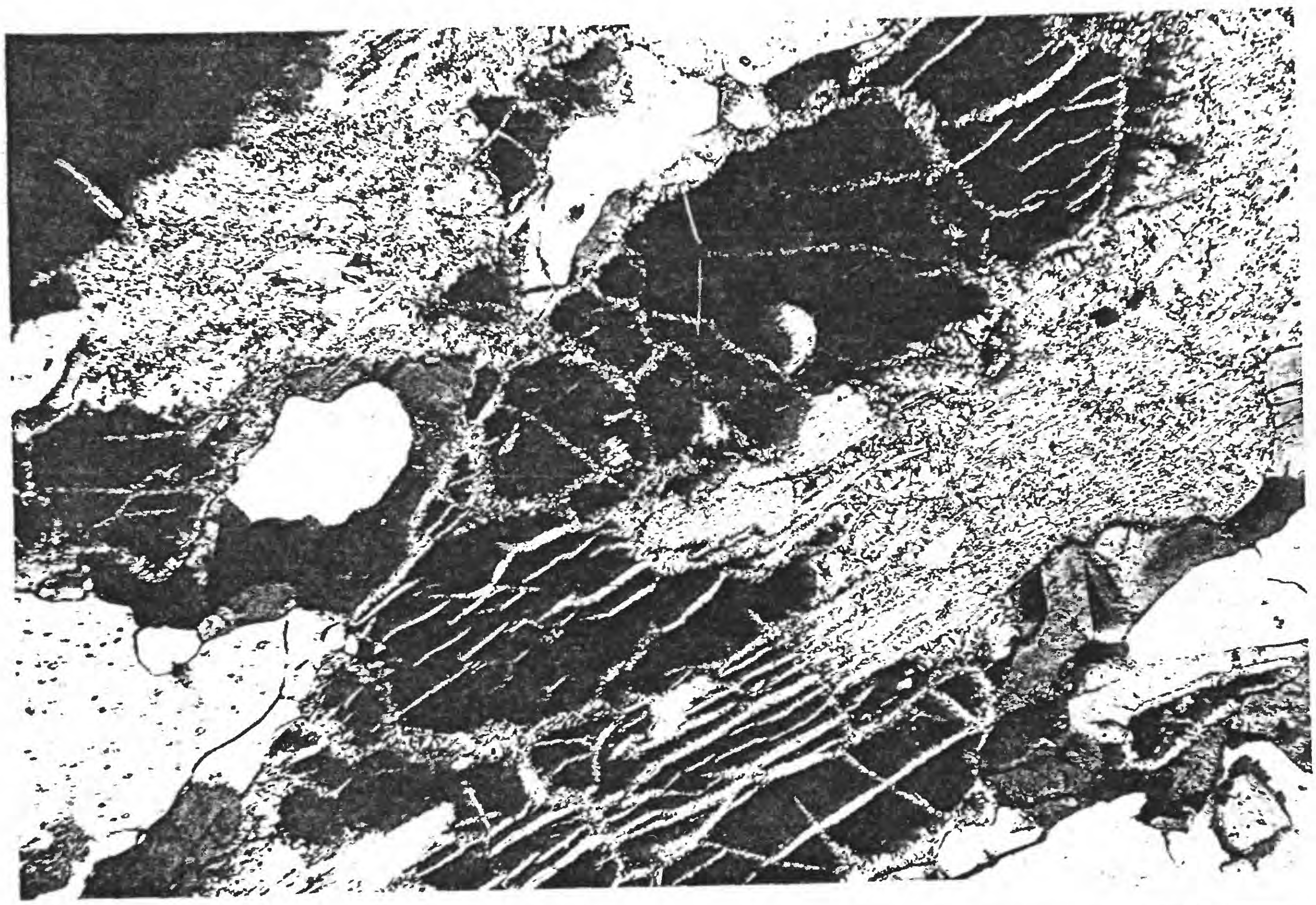
Cordierite has been almost entirely replaced by alteration products (photos 50, 51). The alteration was a two stage process. The first product is a light-brown perfectly isotropic substance with a refractive index greater than Canada balsam. Werner Schreyer (personal communication) has obtained an x-ray diffraction pattern of muscovite and chlorite from similar material also occurring as an initial product of the alteration of cordierite. The writer obtained a muscovite x-ray pattern for this material, but the possibility of contamination by associated coarse muscovite can not be ruled out. This substance is in turn replaced by sericite of detectable grain size, with the plates typically oriented normal to cracks.

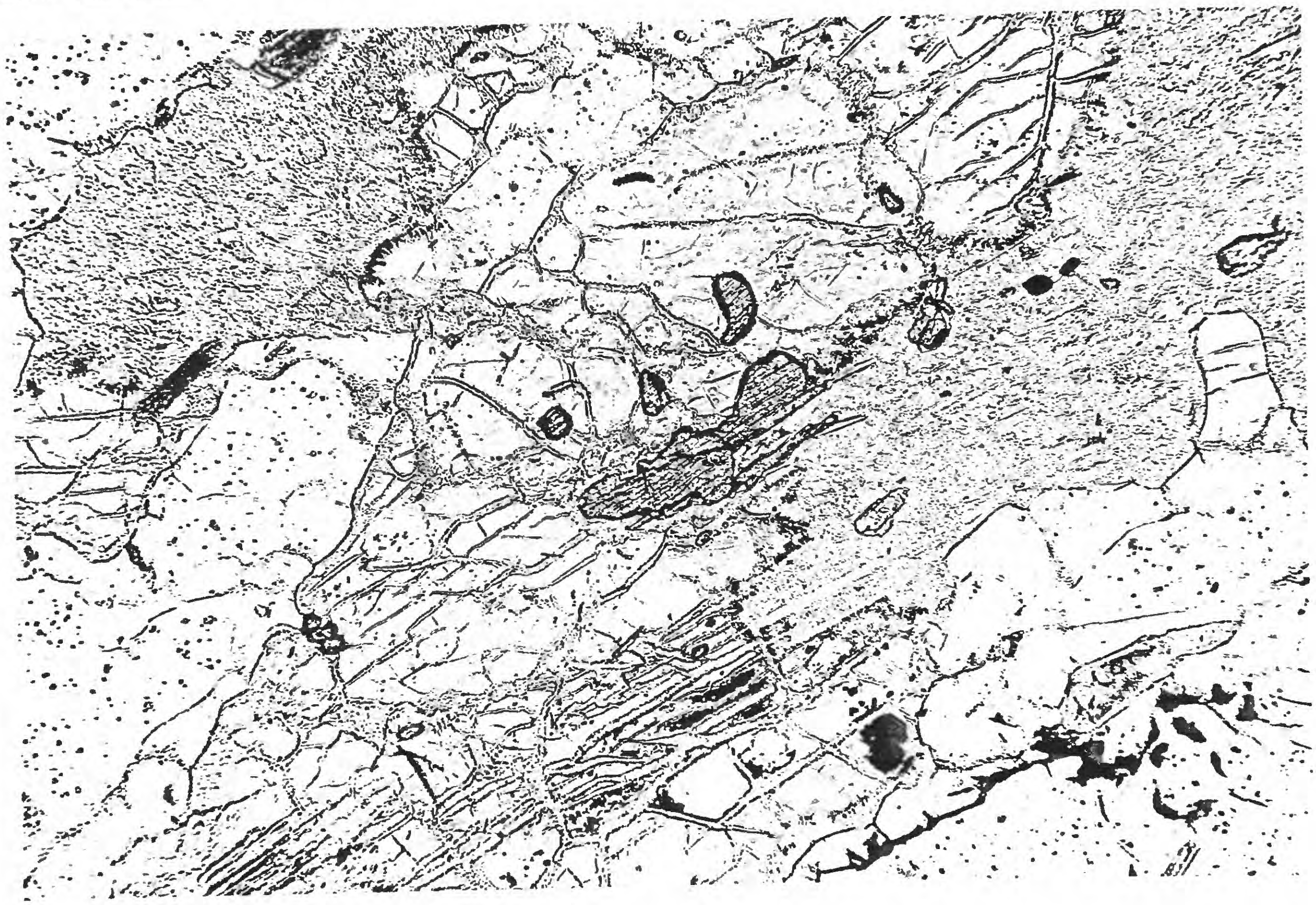
Anthophyllite is partly altered to a brownish substance of low bi-refringence that may be a serpentine or a chlorite. Hornblende and cummingtonite remain fresh.

A remarkable process is the prehnitization of biotite. This was noted in metamorphic rocks from several localities in which biotite is associated with hornblende and calcic plagioclase. In the incipient stage prehnite grains grow along the cleavage planes of biotite. At this stage the process is perhaps more the growth of the new mineral in a preferred location rather than a replacement, since the biotite flakes are occasionally bowed outward to accomodate the prehnite. In a more advanced stage, however, biotite is completely replaced by a plumose aggregate of prehnite (photos 49, 17).

Hjelmqvist (1937) reported prehnite formed in partly or completely chloritized biotite in calcic rocks of several types in Sweden. The

PHOTOS 50 and 51. Altered cordierite-bearing rock of the Ammonoosuc volcanics in plane polarized light and between crossed nicols. The isotropic material has replaced cordierite and is in turn partially replaced by sericitic muscovite (right, upper left, and veinlets in the isotropic material). High relief grains in center are staurolite that were formerly surrounded by cordierite. White areas (lower right and elsewhere) are quartz and plagioclase. x60.





biotite in some of the occurrences in Old Speck Mountain quadrangle is free from chlorite, so that prehnitization is independent of chloritization.

Neither the chemical compositions nor the crystal structures of biotite and prehnite suggest the reason for the replacement. The optic orientation of most of the prehnite is constant with respect to the cleavage of the biotite. According to Hjelmqvist, the (001) faces of the two minerals are in contact. Prehnite has a phyllosilicate structure (Belov 1958), but there seems to be no special relationship to the biotite lattice that would cause epitaxy.

Prehnite also occurs in veins cutting amphibolite. Usually these are of microscopic size, but drusy coatings with individual crystals distinguishable to the naked eye were found in the new road cut on the East B Hill Road above Dunn Notch.

Mineralized Veins

A vein along Morse Brook, Grafton, at an elevation of about 1250 feet, has become a popular collecting locality for surfaces covered with stubby quartz crystals and barite plates (Shaub 1959). Limonite, wad, and fine grained sericite also occur. The principal vein is over ten feet wide and a hundred yards long and smaller parallel veins are present. The veins are composed of brecciated granite and pegmatite with extensive quartz crustification and many vugs. Along strike the veins grade into pegmatite, but it is not clear whether the two formed during a continuous process or whether the vein is much the younger.

The southwestern segment of the Wyman Mountain-Hall Mountain fault zone is marked by intense silicification. Where the fault zone crosses Moody Brook an altered schist composed of quartz, plagioclase, muscovite, pyrite, and carbonate occurs. The carbonate is optically homogeneous, but x-ray diffraction study of isolated grains indicates that two minerals are present. The dominant phase is a member of the magnesite-siderite series with nearly equal amounts of the two components. The less abundant phase, presumably exsolved in a submicroscopic intergrowth, is dolomite. Members of the siderite-magnesite series react with quartz rather early in progressive regional metamorphism (sideroplesite schist is metamorphosed to cummingtonite schist at about the garnet isograd in the Homestake area of South Dakota according to Noble 1939), so the mineralization must have occurred after the climax of regional metamorphism. Temperatures must have been sufficiently elevated, however, to allow a considerable amount of calcium to enter into solid solution in the magnesite-siderite, which was later exsolved as dolomite.

Intensely silicified rocks, with drusy quartz vugs, occur on the northeast slope of the north knob of Black Cat Mountain, T. C. The zone of silicification is apparently quite extensive although more float than outcrop was found.

PHYSIOGRAPHY AND GLACIAL GEOLOGY

A belt of high mountains extends from the White Mountains of New Hampshire northeastward to the Blue Mountains of Maine. A parallel mountain belt extends from Vermont across northern New Hampshire to the Boundary Mountains of Maine and Quebec. The Old Speck Mountain quadrangle lies partly in the southeastern mountain belt and partly in the low lands between the belts, the high lands roughly corresponding to the area of Littleton formation and sillimanite zone metamorphism, and the low lands to the area of Ordovician (?) formations and staurolite zone metamorphism. In the larger region, the geologic control of the physiographic pattern can not be this simple, although the belts generally parallel the regional strike.

In more detail the correlation of topography and geology is rather poor. Large basins underlain by the Umbagog and Andover plutons extend into the quadrangle. Apparently, although the granitic rocks themselves are quite susceptible to erosion, the metamorphosed rocks just outside the plutons are particularly resistant. For this reason, the western part of the Andover pluton, which contains many inclusions and roof pendants, is mountainous. In the metamorphic rocks, there is little close correlation of geology with topography. Some hills, for example Surplus Mtn., are aligned parallel to strike, but only a few ridges large enough to appear on the map can be regarded as true strike ridges; the east-west ridge of Gooseeye Mountain bending northwest into the Milan quadrangle is a conspicuous example.

The entire quadrangle was covered by the continental ice sheet. Figure 16 shows the direction of striations, except those obviously controlled by local channelling. Polished and striated surfaces are rather rare, as those that formed have apparently been destroyed except in special circumstances. In one case, an outcrop of sulfidic schist of the Partridge formation along the Swift Cambridge River shows glacial striae on top of which nodules of pyrite have grown. These indicate that the outcrop was buried under sediments of low Eh, and has been only recently exhumed. In another case, broken blocks that have fallen into a pit-like cave formed by opened joints on the side of Surplus Mountain have striae preserved, while the exposed surfaces of outcrops nearby show none. Crescentic gouges occur in an abandoned channel of Bull Branch at Ketchum. The form of the knobs of Sunday River Whitecap as viewed from the north suggest smoothed stoss and plucked lee slopes. The low hills developed in the Umbagog pluton are oriented as if they were sculptured by ice action.

Mountain glaciation apparently occured on Old Speck Mountain. Speck Pond has a rock lip and, according to report, a depth of 250 feet. It is apparently a cirque, perhaps cut, as Leavitt and Perkins (1935) suggest, by a mountain glacier remaining after melting of the continental ice sheet. The broad smoothly rounded basin on the upper slope of the north side of Old Speck Mountain, sharply contrasting with the narrow valley of the brook on the lower slope, suggests incipient cirque action (Frontispiece).

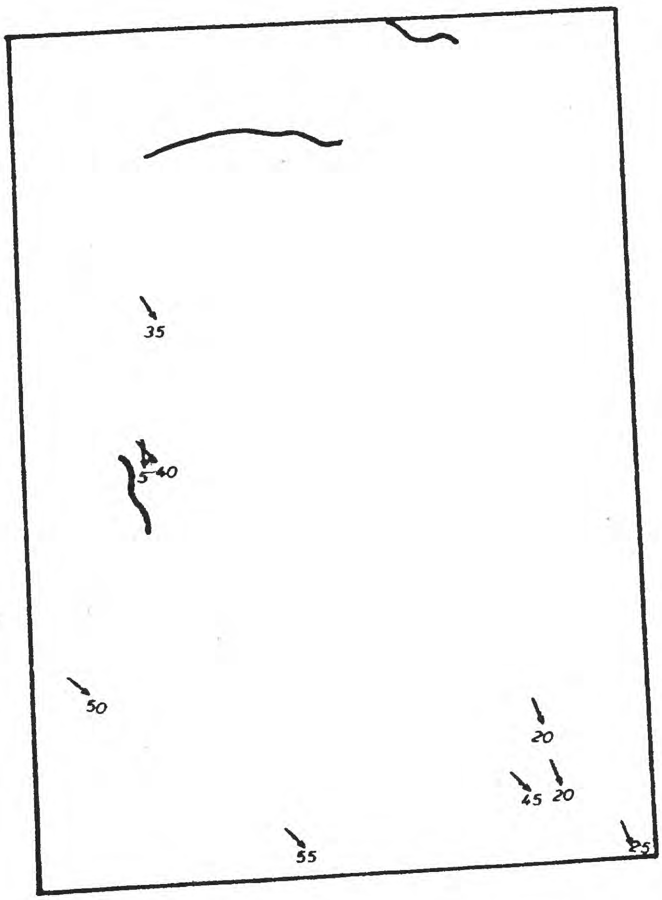


FIGURE 16. Glacial striations and eskers in the Old Speck Mountain quadrangle.

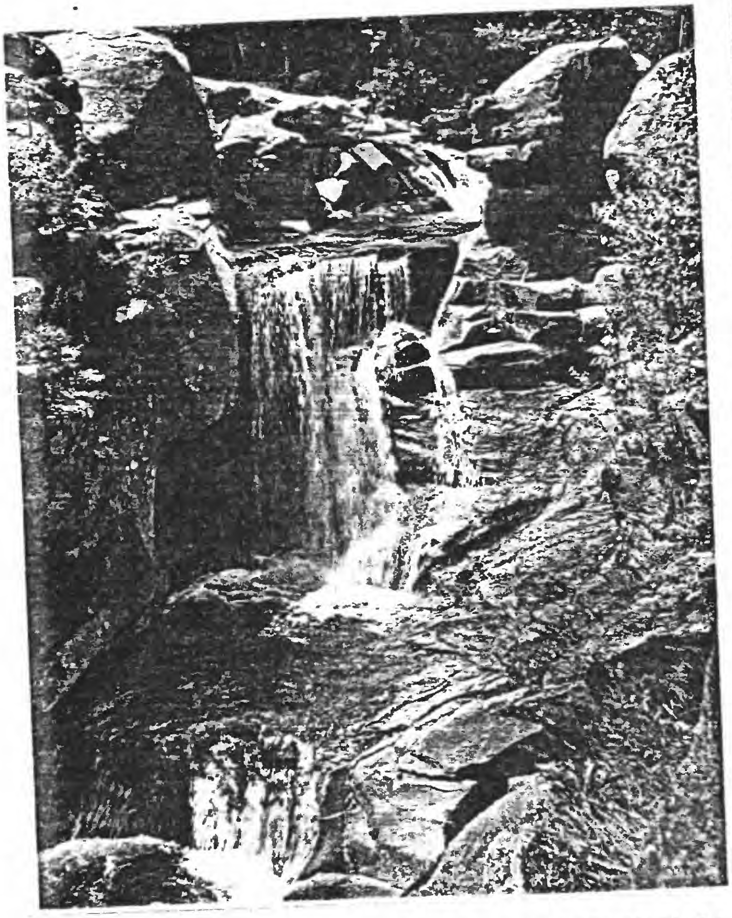
Constructional glacial features are more obvious in the quadrangle. Ground moraine covers much of the surface and stratified drift is present in the stream valleys. The areas of extensive surficial cover are indicated by dotted contacts between the bedrock units on the geologic map. An esker follows the Swift Cambridge valley north of Grafton Notch, another extends from east of C Pond down the Dead Cambridge River, and a third from the head of Black Brook into Richardson Lake at South Arm (figure 16). An esker following the Bear River was mentioned by Leavitt and Perkins, but was not noticed during the present study. The flat swampy areas in Grafton and along the Dead Cambridge are probably underlain by sediments deposited in glacial lakes (Glacial Lake Cambridge of Leavitt and Perkins).

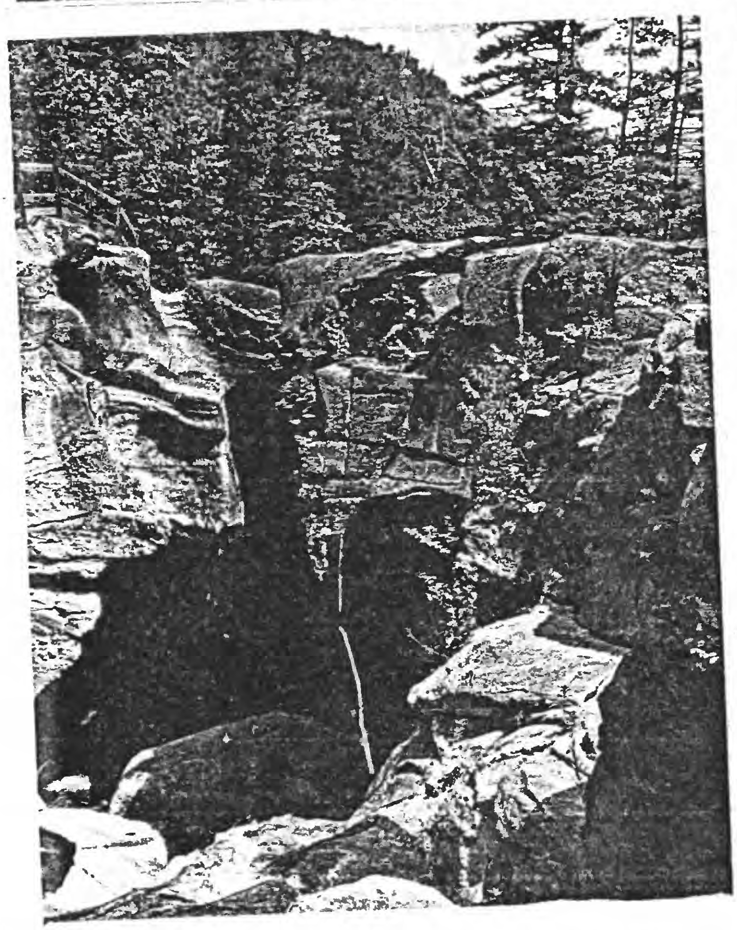
Drainage patterns have been disturbed by glaciation. Glacial deposits at South Arm block a pre-glacial watercourse that flowed southeastward from the Magalloway River along Richardson Lake and down Black Brook and the Ellis River. A more local effect of glaciation was the displacement westward of the Sawyer Brook-Dead Cambridge River divide. The divide is now formed by ragged mounds of glacial debris. The uppermost part of Sawyer Brook has a course parallel to Mountain, Greenwood, and other brooks and would seem to have been a higher tributary of the ancestral Dead Cambridge River. At the north base of Hall Mountain, south of the area enclosed by the 1320' contour is a remarkably deep and narrow flume cut in granite, now occupied only by the rill that flows down Hall Mountain and then turns to the east. The flume was certainly cut by a much larger stream, perhaps a temporary outlet draining the ice sheet or Glacial Lake Cambridge eastward through Sawyer Notch.

The melting ice sheet and perhaps Glacial Lake Cambridge drained southward through Grafton Notch when drainage to the northwest was blocked by ice. The spectacular flumes and potholes of Screw Auger Falls, Moose Cave, and The Jail along the upper Bear River were probably cut by melt water in a relatively short time (photos 52, 53). Leavitt and Perkins have suggested that Mahoosuc Notch (photo 33) was a similar outlet for a proglacial lake dammed by ice to the west. It seems unlikely, however, that the ice sheet would have melted westward from the Mahoosuc Range without opening to the southwest. Moreover, the angular blocks that choke the bottom of Mahoosuc Notch suggest that there has been no great flow of water through the Notch in post-Glacial times.

Crosby and Crosby (1925) used Moose Cave, Mother Walker Falls, Mahoosuc Notch and several small box canyon-like notches across the crest of the Mahoosuc Range and of Sunday River Whitecap as type examples of "keystone faults", grabens formed by the downdropping and crushing of wedge-shaped blocks along fractures opened during earthquakes, those in this area being of post-Glacial age. There is little evidence to support such a hypothesis. The curvature, although slight, and the abraded surfaces of the walls of Moose Cave, even high above the present water level, indicate erosion by turbulent water, probably controlled by the presence of a less competent pegmatite vein. Some of the smaller notches, as well as Mahoosuc Notch itself, seem to be controlled by joints, but there is no evidence to indicate that they were not cut by normal fluviatile, mass wasting, and

PHOTOS 52 and 53. Views upstream and downstream of Screw Auger Falls. Rock is biotitic quartz monzonite.





glacial processes. Mahoosuc Notch, is, as the Crosbys pointed out, at the drainage divide, so that no throughgoing stream could occupy it. This suggests to the writer, rather than a recent catastrophic origin, that the Notch is very ancient, cut by some stream antecedent or superimposed to the Mahoosuc Range.

SUMMARY OF GEOLOGIC HISTORY

The stratified rocks of the Old Speck Mountain quadrangle are of the graywacke-shale assemblage and associated volcanics that were deposited in the eugeosynclinal zone of the Paleozoic Appalachian geosyncline. (Cady 1960).

The three oldest formations now exposed are probably of Ordovician age. The oldest, the Albee formation was deposited as a feldspathic shaly sandstone, probably in part composed of volcanic detritus. By a rather gradual transition these beds were succeeded by waterlain intermediate and felsic pyroclastics that form the Ammonoosuc volcanics. Probably at this time the underlying Albee formation was injected by basalt sills and dikes. Nonfeldspathic sandy shales and shaly sandstones of the Partridge formation were deposited above the Ammonoosuc volcanics. This formation was largely deposited in a reducing environment, so that iron sulfides and free carbon are present and locally abundant.

A hiatus in deposition, corresponding to the Upper Ordovician Taconic orogeny, followed the laying down of the Partridge formation. During this period uplift, gentle flexure and erosion occurred, so that the Partridge formation was entirely removed from parts of the area when deposition resumed.

The succeeding period of deposition, in which the Littleton formation was laid down, probably extended from the Late Silurian into the Early Devonian ~~period~~. Along what is now the northwest margin of the Littleton formation, deposition began with the extrusion of basaltic lava of the Whitecap Brook ~~member~~. The lava formed piles a few miles across, at least in part under water, rather than a continuous sheet. Graywacke, probably containing some volcanic detritus, was deposited above and between the volcanic piles. Deposition of pebble conglomerates and coarse quartz sands probably followed a minor hiatus in deposition. The source area of the conglomerate was to the northwest, suggesting that the Ordovician (?) strata nearby were not completely submerged by the sea. To the south dolomitic sandstone and shale were deposited at about this time. Following these interbedded shale and sandstone and finally rather pure shale were deposited.

Most of the folding, intrusion, and metamorphism can be assigned to the Acadian orogeny, of Middle or Late Devonian time. The earlier folding, at least in the west-central part of the quadrangle, was along northwest-southeast axes. These folds probably formed as recumbent digitations on the end of the Jefferson dome. Later folding along northeast-southwest axes established the general pattern of the Bronson Hill anticline and the Mahoosuc syncline. The Umbagog granodiorite was emplaced early in the orogenic period, if indeed it is not even older. The granitic gneiss of the Oliverian plutonic series in the Jefferson dome is apparently an older rock that was affected by the regional deformation. The Andover pluton formed by a succession of many small intrusions. Most are younger than the main period of folding but some are older than at least the latest folding. Metamorphism to the staurolite and sillimanite grades was probably simultaneous with folding and intrusion.

Small dikes, mostly basalt with some lamprophyre, were intruded after the orogenic period, probably during the Triassic. A volcanic vent suggests that extrusives, now completely removed by erosion, may have covered the surface. Minor faulting and vein mineralization may have occurred at this time.

Aside from this episode, the history of the area between the Acadian orogeny and the Quaternary is a blank, but must have been one of extensive erosion.

During at least the Wisconsin stage of the Pleistocene epoch the quadrangle was covered by the continental ice sheet which flowed southwest. Mountain glaciation probably occurred on Old Speck Mountain.

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