THE AMERICAN MINERALOGIST, VOL. 48, SEPTEMBER–OCTOBER, 1963

THE PETROLOGY OF THE NONEWAUG GRANITE, CONNECTICUT

ROBERT M. GATES AND PAUL E. SCHEERER, *Department of Geology, University of Wisconsin, Madison, Wisconsin.*

ABSTRACT

The Nonewaug granite in the Western Connecticut Highlands is a discordant, lenticular body nine miles long and three miles wide. It is a post-tectonic intrusive which crosscuts and partly granitizes the metasediments of the Hartland formation. The granite is characterized by 1) fine- to coarse-grained textural layering roughly parallel to the borders, 2) large to small graphic granite crystals in a fine- to coarse-grained matrix, and 3) plumose muscovite-quartz intergrowths. The granite is considered to be emplaced as a liquid or in a crystal mush state and to have crystallized in place, accompanied by slight movement.

The macroscopic and microscopic textural features of the granite indicate significant changes in the nature of the magma as crystallization progressed. The crystallization trend from a soda-rich granite to a potash-rich graphic granite to plumose muscovite and quartz is correlated with increasing water content and finally, perhaps a gas phase. It seems most probable that the minerals present, their proportions, and textures resulted from primary crystallization rather than from recrystallization in the subsolidus region.

Certain mineral textures are interpreted as critical in evaluating the course of crystallization of the granite. Using standard criteria for replacement, the following reactions are recognized: 1) quartz replaces microcline and albite, 2) albite replaces microcline, and 3) muscovite replaces microcline and albite. Two generations of each of the above four minerals can be distinguished. Most replacement reactions occur between a first and second generation mineral or between two second generation minerals. The graphic granite crystals and the plumose muscovite are an integral part of the granite and their origin must fit into a continuing sequence of events related to the crystallization of the entire granite body. The textural layering and the intermineral textures are explained by mild deformation producing dilatant areas in the granite during the crystal mush state.

INTRODUCTION

The purpose of this paper is to present mineralogical and textural evidence pertinent to the crystallization of a magmatic granite. The writers hope to escape argument on the magmatic versus metasomatic origin of the granite though such escape is difficult where the granite body occurs in middle to high rank metamorphic terrane. We will try to show that the granite was emplaced as a liquid or crystal mush and to discuss some of the textural features related to its emplacement and crystallization. The writers believe that the megascopic and microscopic textural features will provide some understanding of the crystallization of a natural granite—or, if such must be the case, the recrystallization in the subsolvus region. In Tuttle and Bowen's classification (1958, p. 129) the Nonewaug would be a Group IIC type granite.

The Nonewaug granite is only one of several granitic to ultrabasic bodies enclosed in the metamorphic rocks of the Western Highlands of

Connecticut. They range in age from Precambrian to middle Paleozoic. Structurally they range from pre-tectonic to post-tectonic, from discordant to concordant, and from disharmonious to harmonious (Walton, 1955). The Nonewaug granite was selected for this study since it is discordant, late to post-tectonic, and has not undergone any apparent post crystallization deformation.

Acknowledgments

The mapping of the Nonewaug granite was undertaken by the senior writer in 1948 and was completed during the field seasons of 1949 and 1951, under the sponsorship of the Connecticut Geological and Natural History Survey. Additional studies were made in the field periodically from 1952 to 1960. Preliminary reports were published in the Quadrangle Series of the Connecticut Geology and Natural History Survey in 1951 and 1954 (Gates, 1951, 1954). Field studies of the granite by the junior writer during the summer of 1958 were made possible by a grant from the C. K. Leith Memorial Fund. The laboratory investigations during the past twelve years were supported in large part by the Wisconsin Alumni Research Foundation. The writers are greatly appreciative of the continuing support of the Connecticut Geology and Natural History Survey and the Wisconsin Alumni Research Foundation.

The writers are indebted to Dr. S. W. Bailey of the University of Wisconsin for his advice and interpretation of *x*-ray data. Mr. Robert M. Cassie was engaged during the academic years 1960–62 in petrographic and mineralogic determinations and we gratefully acknowledge his excellent data.

General Geology

The Western Highlands of Connecticut are part of a belt of crystalline rocks lying between the Triassic rocks of the Connecticut River Valley and the lower Paleozoic rocks of the Hudson River Valley. The Highlands comprise the southern end of the Green Mountain Plateau. The Hartland formation, the host rock of the Nonewaug granite, is considered a correlative of the metasedimentary formations in Massachusetts and Vermont which form the eastern flank of the Green Mountain Anticlinorium. In Connecticut the Hartland tends to lap over the Green Mountain axis and extends in a belt of 2–20 miles wide from the Massachusetts border to Long Island Sound. The Nonewaug granite is a discordant, elliptical mass in metasedimentary mica quartzites and schists of the Hartland formation. It is only one of several granite and granite gneiss masses in the Hartland formation (Rice and Gregory, 1906; Agar, 1934; Gates, 1951, 1952, 1954, 1959, 1961; Rodgers, *et al.*, 1956, 1959;

Thede, 1958). Ultrabasic to intermediate bodies are also present in the Hartland (Cameron, 1951; Clarke, 1958). These granites, prior to the recent mapping program started after World War II, were collectively called the Thomaston granite and granite gneiss. They are all considered to be in the Mesozone of the earth's crust (Buddington, 1959).

Relations of the Nonewaug Granite to the Hartland Formation

General statement. The field relations of the Nonewaug granite show with reasonable certainty that the granite was emplaced in a liquid or crystal mush state along a major structural break in the Hartland formation. The granite is clearly discordant structurally and, in large part, has sharp contacts with the surrounding Hartland formation.

The Nonewaug granite is a lenticular, east-west trending body nine miles long and three miles wide, bounded on the north and west by relatively unaltered Hartland metasediments and on the south by a zone of mixed granite, granite gneiss, and variously altered rock types of the Hartland formation (Fig. 1). The granite body and its associated granite and pegmatite dikes in the surrounding metasediments have an average trend of N60E with a steep southeast dip. The foliation of the Hartland formation has various relations to the granite, but none conformable. Along the northern border the foliation strikes northeast, parallel to the granite contact, but dips northwest in contrast to the southeast dip of the granite and related dikes. On the west end and southwest side the Hartland formation strikes north to northwest, sensibly normal to the trend of the granite, and dips westward. The intrusion and alteration of the border rocks seems to depend in large part on their structural relations to the granite and on their original metasedimentary nature, *i.e.* mica quartzite or schist. In general, the relations of the border rocks and the granite become increasingly complex from the northeast counter-clockwise to the southeast.

The northern border. The mica quartzites and schists along the northern border are relatively unaffected by the granite and contacts are sharp. The foliation of the Hartland formation strikes N.45–75E. and dips 20–50° NW. The main granite and its satellitic dikes also strike northeast, but dip southeast, cleanly crosscutting the Hartland formation. Granite and pegmatite sills also occur near the border.

The southwest end. The relations of the granite and the Hartland formation change rather abruptly at the western end. The foliation of the Hartland formation swings from a northeast to a N.10–30°W. strike and

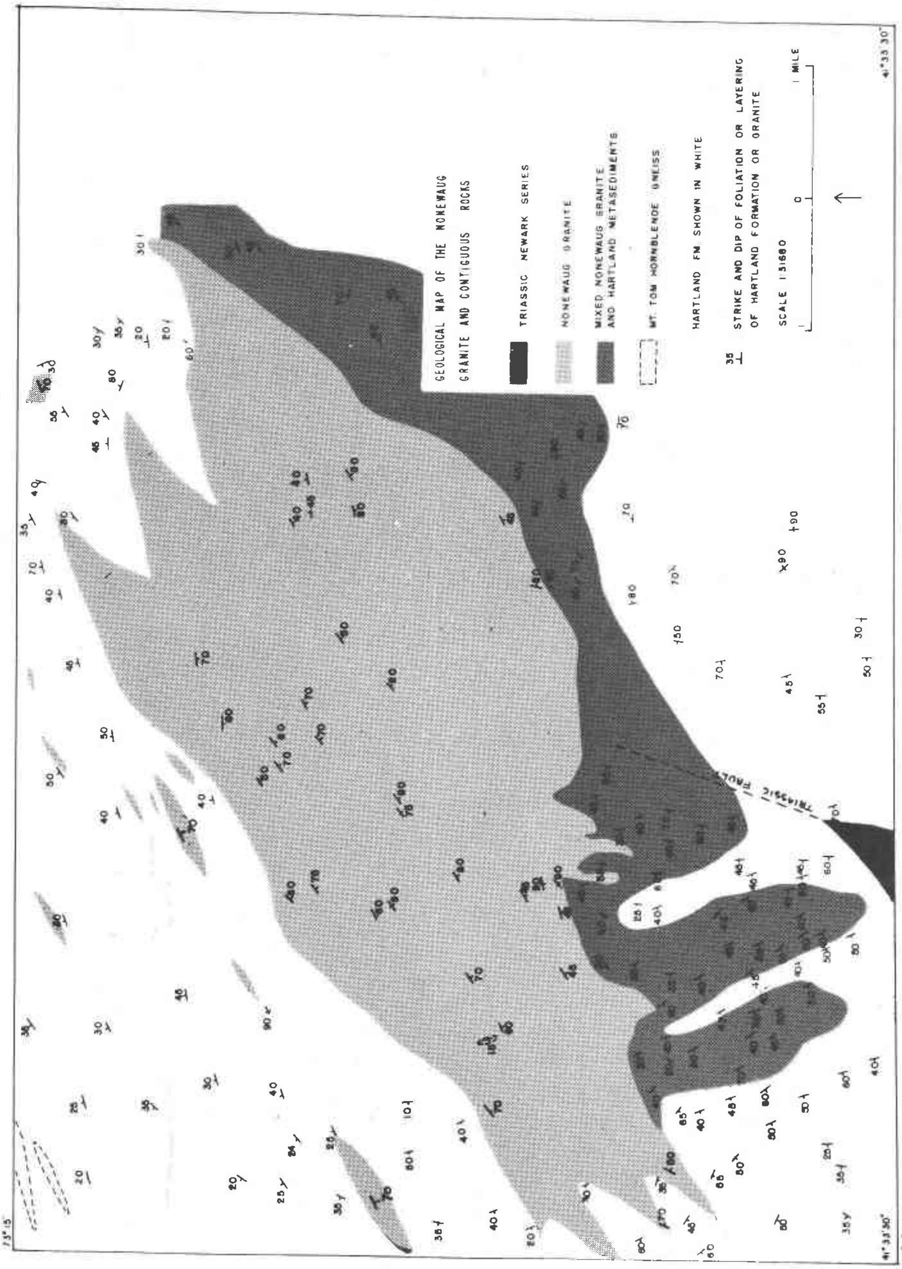

FIG. 1. Map of Nonewaug granite.

maintains a westward dip. The granite terminates in three major tongues crosscutting the Hartland formation at nearly right angles. Between the granite tongues are numerous sills and dikes of granite and pegmatite that have the same northeast strike and steep south dip as the main granite body. Some dikes terminate as sills by spreading out parallel to the foliation of the Hartland. The same relations between dikes and sills may also exist along the northern border, but considering the attitude of the foliation, surface exposures would reveal this only by coincidence.

The southwest border. The southern border is an interlayered mixture of granite and pegmatite dikes and sills, granitic gneisses, feldspathic metasediments, and some unaltered Hartland rock types. The structural relations here are much the same as those at the west end. The main granite and its associated dikes trend N.35–65°E. and dip steeply southeast. The foliation of the granitic gneisses (syn- or pre-tectonic granite sills and or granitized mica quartzites of the Hartland formation), feldspathic metasediments, and the unaltered metasediments strikes N.20–50°W. and dips southwest. These rocks are all cross cut by the main granite and its related granite and pegmatite dikes. In this area, by proper selection, it is possible to show a complete series from mica quartzite through feldspathic mica quartz gneiss to granitic gneiss.

The southeast border. The southeast half of the southern border probably is separated from the western half by an extension of a Triassic fault along the east side of the Pomperaug Valley (Gates, 1954). The rocks in this area are an intimate "marblecake" mixture of granite, pegmatite, granitic gneisses, feldspthic metasediments and minor quartzites and schists. The structural relations are complex compared to the western half if any consistent pattern is sought, but are very simple if the metasediments are considered as having yielded plastically. These metasediments appear to have been thoroughly "soaked," feldspathized and kneaded together with granite and pegmatite.

The northeast end. The northeast end of the Nonewaug granite appears similar to the western end, though not so well exposed, and terminates in several tongues accompanied by swarms of granite and pegmatite dikes and sills.

Summary. Regionally the Hartland formation is an isoclinally folded series of metasediments with foliation trending northeastward and dipping westward (Rodgers, *et al.*, 1956, 1959). Locally, in the vicinity of the Nonewaug granite, however, there is a major fold in the foliation. South of the granite the trend of foliation is not as clear and is complicated by the Triassic fault mentioned above. The general north trend of the foliation divides, part deflected northwest and part northeast around the east and west ends, respectively, of the granite. The field evidence (Gates, 1954) seems clearly to indicate that the Nonewaug granite and its associated dikes were emplaced passively along tension faults. The major fault does not have any obvious direct relationship to the isoclinal folds of the Hartland. However, the flexure in the regional trend of the Hartland foliation is undoubtedly related to the same tectonic forces that ultimately caused the rupture along which the granite was emplaced. The field relationship of the Hartland formation and the Nonewaug granite thus support the conclusion that the granite was emplaced dilatantly late in the last period of tectonism that affected this region.

Field Description

General statement. The textural and structural characteristics of the Nonewaug granite, as observed in the field, have an important bearing on any interpretation of its crystallization history. The lack of such features as chilled borders and zonal mineralogic or textural arrangements may be equally pertinent in their failure to provide evidence of any sequence in crystallization or to preserve "primary" mineralogic textures. The features of prime concern are:

1. Textural layering or banding consisting of layers which range in thickness from a fraction of an inch to several feet and in grain size from fine-grained to pegmatitic;
2. Graphic granite crystals which range in size from one-half inch to two feet and occur along well defined planes or in a random fashion;
3. Plumose intergrowths of muscovite and quartz.

During the mapping, the layering of the different textures and the planar distribution of the graphic granite megacrysts provided the major data on the structure of the granite body. However, no sequence of layering occurs as a mappable unit.

Layering of the granite. The layered nature of the granite is due primarily to variations in the coarseness of textures (Fig. 2). There is no obvious gneissosity. The textures range from fine-grained to pegmatitic; in fact, in many places the Nonewaug granite has most of the characteristics of a pegmatite. There is a sympathetic relationship as would be expected between the grain size and the thickness of the layers. Typically where the textural variations between layers are slight, the granite is fine- to medium-grained and the layers are thin. Where the textural variations are marked, *i.e.*, medium-grained vs pegmatitic, the layers are much thicker, commonly a foot or more. The fine textural layering is most common along the borders of the main granite and especially in the narrow tongues at the northeast and southwest ends. The coarse layering, also more common near the borders, is also found in the central part of the granite, usually near roof pendants or screens of mica-quartz schist and mica-granite gneiss. An unlayered, medium-grained granite occurs in

FIG. 2. Photo of layering of the granite.

continuous outcrop for over a quarter of a mile across the trend of the main body in the central portion. Also, the small protuberences along the central part of the southern border are generally homogeneous, medium-grained granite. Generalizations regarding the spatial relations of the layered granite to the granite body as a whole are fraught with exceptions.

Graphic granite crystals. The graphic granite crystals have three general modes of occurrence:

1) in pegmatitic layers in the granite, 2) as megacrysts randomly distributed in the relatively finer-grained granite, and 3) as megacrysts concentrated in narrow layers throughout the granite.

The graphic granite crystals in the pegmatitic layers are not notably different from those found in many pegmatites and are of little specific use in this study, but the megacrysts in the homogeneous granite have features which pertain to their origin. The graphic granite megacrysts range in size from less than an inch to two feet and in shape from anhedral to euhedral. There is no rigid relationship between size and shape, but generally the larger megacrysts tend to be more nearly euhedral. All of the constituents of the granite matrix, as well as patches of the granite itself, are poikilitically included in the megacrysts. The subhedral to anhedral megacrysts have vague outlines and tend to blend into the enclosing granite. The inner part of the larger megacrysts tends to be relatively free of included material, whereas the outer portions contain abundant inclusions. The outer parts of some larger megacrysts and some smaller anhedral megacrysts poikilitically include so much matrix that they are recognized only by the reflection of the microcline cleavage. Other graphic granite megacrysts are recognized in glacially scoured and weathered outcrops by their positive relief with respect to the surrounding fine- to medium-grained granite.

The general attitude of the main granite body was determined on the basis of the textural layering and the planar distribution of the graphic granite megacrysts. The average trend of the layering is N.60°E. with dips ranging from 35–80°SW. In general the attitude of the layering is similar to the strike and dip of the granite and pegmatite dikes in the surrounding metasediments and is conformable to the borders of the main granite.

Plumose muscovite-quartz intergrowths. The plumose muscovite-quartz intergrowths are scattered throughout the main granite body, but are largest and most abundant in a broad zone throughout the central part. There is an empirical association of plumose muscovite-quartz and graphic granite crystals. Although graphic granite crystals occur without plumose muscovite-quartz, the reverse is seldom found. Orville's (1960, p. 1474, Fig. 5) observations on plumose muscovite in the Black Hills pegmatites appear to be similar although he also finds concentrations along the borders of the pegmatites in contact with mica-quartz schist.

The plumose muscovite-quartz intergrowths occur as spherical, hemispherical, conical, and "feather-duster" aggregates ranging in size from less than an inch to 18 inches. Each "plume" is composed of muscovite flakes aligned roughly like the barbs of a feather in a matrix of quartz with a single orientation. The plumose aggregates may occur in a matrix of fine-grained to pegmatitic granite just like the graphic granite crystals.

Other granite rock types. Though the layered granite, graphic granite megacrysts, and plumose muscovite are most interesting and distinctive in the field, there is no intention to minimize the occurrence of homogeneous, fine- to medium-grained granite and of patchy granite and pegmatite, both of which are rather common. The homogeneous granite is the least common type in the main granite mass, but occurs commonly as dikes and sills in the surrounding metasedimentary rocks. Patchy granite and pegmatite is an irregular and intergrading mixture of fine-grained to pegmatitic granite. There are no sharp boundaries between the different textures, nor is there any regular distribution of the fine- or coarse-grained types. The general pattern can be described best as a brecciated crystal mush with the finer-grained granite forming amoeboid masses in a pegmatitic host. The patchy granite and pegmatite is similar in its textural variations to the layered granites, with the fundamental difference being the distribution of the various textures. The mixed granite and pegmatite is the most common rock type in the central part of the intrusive.

Modal Composition

General statement. The mineralogical composition of the Nonewaug granite was obtained by modal analyses of the fine- to coarse-grained types, by *x*-ray and optical studies of all essential minerals, and by a chemical analysis of the microcline. Modal analysis of the very coarse-grained to pegmatitic granite was not attempted due to the obvious difficulties of sampling and sectioning. The range of composition of the fine- to coarse-grained granite, not only between, but also within individual samples, emphasized the impracticality of modal analysis of the inequigranular coarser grained rocks. However, megascopic estimates in the field and laboratory of the composition of the very coarse-grained to pegmatitic granite indicate that it is richer in microcline than the finer-grained granite. Most plagioclase compositions were determined in thin sections using the five-axis Universal Stage and Federow's migration curves (Emmons, 1943) and by extinction angles in grains oriented normal to crystallographic "*a*" (Emmons *et al.*, 1953, p. 31). Refractive indices were determined on selected grains using the Universal Stage and double variation immersion methods (Emmons, 1943).

Microcline was found by chemical analysis (Hewlett, 1959) and by $\bar{2}01$ *x*-ray reflections to have 7.5% albite in solid solution. Plagioclase ranges from 0–15% anorthite. *X*-ray analysis, using the diffractometer, showed the muscovite to be single phase and to contain little, if any, sodium.

Fine- to coarse-grained granite. Table 1 gives the modal composition of twenty-two selected representative samples of the fine- to coarse-grained granite. The variability of composition between samples and between different but parallel sections of the same sample is shown in colums 4 and 5 respectively. The variable modal composition is a characteristic of the granite and is apparently unrelated to the borders of the body. In spite of this variability the modal compositions shown on the potash

TABLE 1. MODAL COMPOSITION[1] OF FINE- TO COARSE-GRAINED NONEWAUG GRANITE

	1	2	3	4	5
Microcline	19.8	21.7	20.0	0–43	0–39
Plagioclase	37.3	41.0	42.7	17–54	17–48
Quartz	33.9	37.3	37.3	27–40	27–38
Muscovite	8.9			3–15	2–10
Biotite	1.1			0–2.3	1–2.5
Apatite and other acc.	0.1				

1. Average modal composition based on 30,000 points, 22 samples and 44 thin sections.
2. Average modal composition based on microcline, plagioclase and quartz recalculated to 100%.
3. Average of column 2 recalculated to account for 7.5% plagioclase in solution in microcline as indicated by chemical and x-ray analysis of one sample.
4. Range of composition between 22 samples.
5. Maximum range of composition between thin sections of a single hand sample.

[1] Volume per cent.

feldspar-albite-quartz diagram of Fig. 3 are in good agreement with the modal analyses of 260 thin sections of granite from the eastern United States (Chayes, 1951). The average composition has only 5–7 per cent less potash feldspar than the normative Or-Ab-Qtz of the 571 plutonic rocks from Washington's tables shown by Tuttle and Bowen (1958, p. 79). A recalculation of the modal analysis subtracting from the total the anorthite content of the plagioclase and shifting the 7.5 per cent albite in solid solution in the microcline to the albite content does not change appreciably the composition of the granite. Thus, it seems entirely reasonable that the Nonewaug granite is comparable both chemically and mineralogically to the magmatic granites as defined by Chayes (1951, 1957) and Tuttle and Bowen (1958).

Perhaps of more significance than the relative amounts of the feldspars is the variation in the composition of the plagioclase in different textural varieties of the granite. The plagioclase occurring as discrete grains, as unoriented inclusions in microcline, or in perthitic intergrowth ranges in composition from 0–15_{an}. Excluding the perthitic plagioclase, the modal peak for the fine- to coarse-grained granites falls between 6–10_{an}. This composition includes 60 per cent of the 340 plagioclase determinations. The plagioclase poikilitically included in microcline is significantly more sodic. Its modal peak is between 0–5_{an} with 75 per cent of the 74 determinations falling in this range. The plagioclase in perthitic intergrowths

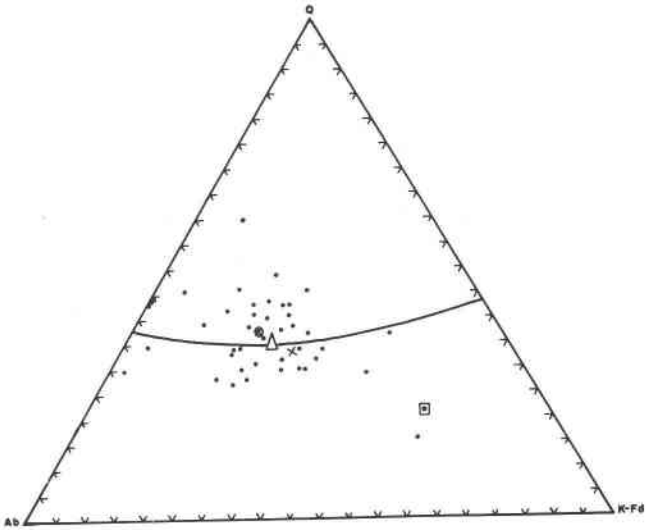

FIG. 3. Modal composition of Nonewaug granite and graphic granite crystals plotted on liquidus of synthetic granite system. Liquidus data after Tuttle and Bowen (1958). Dots represent individual modal compositions of Nonewaug granite with all plagioclase plotted as A6, and with micas and accessories eliminated. ⊗ represents average modal composition of fine- to coarse-grained granite exclusive of graphic granite crystals. ⊡ is modal composition of graphic granite crystals. × is composition of entire granite assuming $\frac{1}{4}$ graphic granite and $\frac{3}{4}$ granite. △ is synthetic granite minimum at 2000 A P H_2O.

also ranges in composition between 0_{an} and 15_{an} but 83 per cent of the 147 determinations fall between 0–5_{an}. Twenty per cent of the total is 0_{an}. Refractive index determinations on eight plagioclase grains representative of the types mentioned above confirmed the compositional range based on extinction angle measurements made in sections oriented normal to a.

Graphic granite megacrysts. The composition of the graphic granite crystals was determined by modal analysis of selected megacrysts which contained a minimum of unoriented quartz, albite, and other included material. Essentially the analyzed crystals are composed of microcline perthitic albite and quartz with the standard cuneiform pattern. Sections were cut parallel to the front, side, and basal pinacoids (100, 010 and 001) to avoid bias due to the preferred orientation of the albite and quartz intergrowths. Table 2 and Fig. 3 show the results of these analyses. The microcline contains 5% albite in solid solution based on x-ray diffraction study using $\bar{2}01$ reflections. This composition is comparable to that determined by Simpson (1962), p. 1126 for the graphic granite of the Ramona pegmatites. It is obvious that the graphic granite megacrysts are richer in microcline and poorer in quartz and albite than the average fine- to coarse-grained granite.

TABLE 2. MODAL COMPOSITION[1] OF GRAPHIC GRANITE MEGACRYSTS

	1 Sect. 11 (100)	2 Sect. 11 (001)	3 Sect. 11 (010)	4 Ave.	5 Or-Pl-Qtz=100
Microcline	60.0	61.6	64.1	62.0	59.2
Plagioclase	15.5	18.0	16.0	16.1	19.3
Quartz	23.5	20.4	19.9	21.3	21.5
Muscovite	1.4	0.0	0.0	0.6	
Biotite	0.1	0.0	0.0	0.0	

1. Based on 3016 points.
2. Based on 1470 points.
3. Based on 1929 points.
4. Average of 1, 2 and 3.
5. Or-Ab-Qtz recalculated to 100% and taking into account 5% albite in solution in microcline.

[1] Volume per cent.

The total contribution of the graphic granite megacrysts to the composition of the entire granite mass is difficult to estimate since the graphic granite crystals range in size from a fraction of an inch to two feet across and occur in such a random and irregular way. Further, the graphic granite megacrysts themselves vary in composition due to included grains of plagioclase, quartz, micas and irregular patches of granite. Many large microcline crystals contain quartz in unoriented, non-graphic intergrowths which differ from the graphic granite only in the lack of the cuneiform nature of the quartz rods. The analyses show, however, that the addition of the graphic granite crystals to the matrix granite would tend to move the bulk composition of the granite mass toward the 1/3 Or-1/3

Ab-1/3 Qtz of the ideal granite (Tuttle and Bowen, 1958). If the graphic granite crystals are assumed to compose one-quarter of the whole mass, the granite body assumes the ideal granite composition.

Plumose muscovite-quartz intergrowths. The plumose muscovite-quartz is an unusual intergrowth which probably constitutes a very small fraction of the granite mass. It is estimated to be much less than one per cent of the total. Modal analyses of three plumose muscovite-quartz samples show them to be composed of nearly equal proportions by volume of quartz and muscovite (Table 3). *X*-ray studies show the mica to be a single phase and essentially pure K muscovite. The maximum deviation

TABLE 3. MODAL COMPOSITION[1] OF PLUMOSE MUSCOVITE-QUARTZ INTERGROWTHS[2]

Muscovite	Quartz	Biotite
49.1	50.7	.2

[1] Volume per cent.
[2] Based on 4426 points.

from this average is less than one per cent. Orville (1960, p. 1475) also finds a similar composition for the plumose muscovite in the pegmatites of the Black Hills, South Dakota. The plumose muscovite-quartz intergrowths can be considered as chemically similar to microcline. By the addition of a mole of water three moles of potash feldspar can be converted to equal volumes of muscovite and quartz with the loss of two potassium ions. The effect of the quartz-muscovite intergrowth on the bulk chemical composition of the granite is insignificant.

TEXTURAL FEATURES OF THE ESSENTIAL MINERALS

General statement. In the preceding sections the following conclusions were drawn on the basis of field relations and observations:

1) The Nonewaug granite was emplaced dilatantly; 2) The textural layering and other planar features are due to movement during emplacement when the granite was in a crystal mush state; and 3) There was no appreciable post-crystallization deformation of the granite.

Assuming that these conclusions are valid, the intergrowths and intermineral textural relations should be those of a syn- to post-tectonic magmatic granite. The characteristics of individual mineral textures will be discussed with this environment in mind.

The same intermineral textures or relationships are found in all types of the Nonewaug granite from the fine-grained to the pegmatitic and graphic granite crystals. However, certain relationships are more common in one type of granite than in another. The xenomorphic granular texture is common in all varieties of the granite and is particularly characteristic of the fine- to medium-grained granite. The intermineral relations described below are statistically subordinate but are present in essentially all thin sections studied.

The principal minerals composing the Nonewaug granite, in addition to the normal smooth boundary relations, show grain boundary relations and other textures or "intergrowths" which are interpreted as replacement reactions which reflect in large part changes in the course of crystallization of the granite or the nature of the crystallizing fluid. Though the replacement textures are present in all types of granite, they are more common in the medium- to coarse-grained types and are particularly characteristic of the graphic granite crystals. The writers are aware that replacement textures can, in any specific case, be interpreted in more than one way and may also be interpreted as a recrystallization feature. Replacement textures between plagioclase and microcline are particularly subject to alternate interpretations or as an unmixing phenomenon. However, field relations do not indicate any basis for expecting recrystallization after solidification. Nor does the distribution of the "replacement type" textures between feldspars have the uniform distribution one might reasonably expect from the unmixing of a one feldspar granite. The replacements recognized in the Nonewaug granite are

1) microcline by quartz, 2) microcline by plagioclase, 3) plagioclase by quartz, and 4) microcline and plagioclase by muscovite.

The fourth reaction is quantitatively very subordinate. Each of these intermineral textures will be described and illustrated.

Microcline. Microcline occurs as small, discrete non-perthitic grains .1 mm across at one extreme to large, 1–2 foot perthitic graphic granite crystals poikilitically including randomly oriented quartz, albite, and muscovite at the other. The textural relations between microcline and the other principal minerals tend to be more complex in the graphic granite megacrysts where all the interrelated reactions are seen. The same individual intermineral relations, however, can be seen where only microcline and one other mineral are involved. Potash feldspar, now microcline, appears to have crystallized early along with quartz and plagioclase in the fine- to medium-grained granite, to have developed later the perthitic graphic granite megacrysts and in the last stages of crystallization, to have been particularly vulnerable to replacement by albite and quartz.

1. Microcline-plagioclase relations: the relations between these two

minerals are extremely varied and indicate a complex crystallization history. The two minerals occur in two types of perthitic intergrowths which tend to intergrade. They also exist side by side as discrete grains with a smooth anhedral boundary. The boundary may also show a "replacement" texture, interpreted here as plagioclase replacing microcline. The plagioclase also occurs as unoriented grains poikilitically included in microcline.

The more simple perthitic intergrowth is characterized by fine films

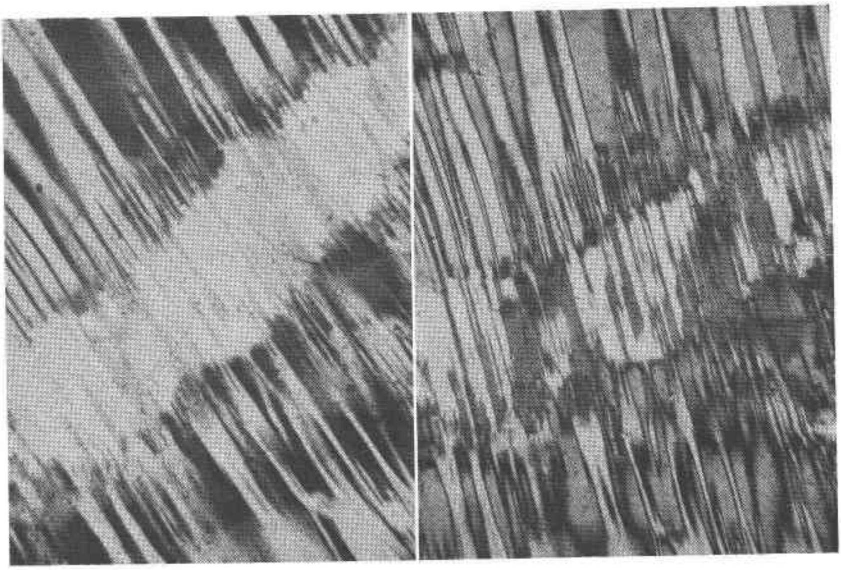

FIG. 4a. Graphic granite crystal showing irregular patches of perthitic plagioclase. Note irregular microcline-albite border and patchy twinning of albite. 315×.
FIG. 4b. Same as 4a, rotated to show similarity of microcline and albite twinning. 315×.

and stringers of albite oriented along simple crystallographic planes in the microcline. These are typical of the generally accepted exsolution perthite (Anderson, 1928, pp. 149–150). The other type of perthite has larger, irregular veins and patches of albite with little geometric pattern in the microcline. The interface between albite and microcline is quite irregular and commonly "islands" of microcline are enclosed in the albite. The typical albite is indistinctly twinned in a pattern similar to the grid twinning of microcline (Figs. 4a, 4b). This type of perthite is considered to be, at least in part, a replacement of microcline by albite (Gates, 1953). The same pattern could result from diffusion of sodium and into selected areas from the original alkali feldspar. The replacement is commonly localized along the pre-existing albite films and stringers that were unmixed from the originally homogeneous alkali feldspar.

The microscopically visible perthitic albite ranges from a trace amount in the fine- to medium-grained microcline to 20–25 per cent in the large graphic granite crystals (Fig. 5). A chemical analysis and $\bar{2}01$ x-ray reflections of the non-perthitic microcline from the medium-grained granite show $7\frac{1}{2}$ per cent albite in solid solution (Hewlett, 1959). The $\bar{2}01$ x-ray reflections[1] of several microcline grains from perthitic microcline crystals indicate 5 per cent albite in solid solution.

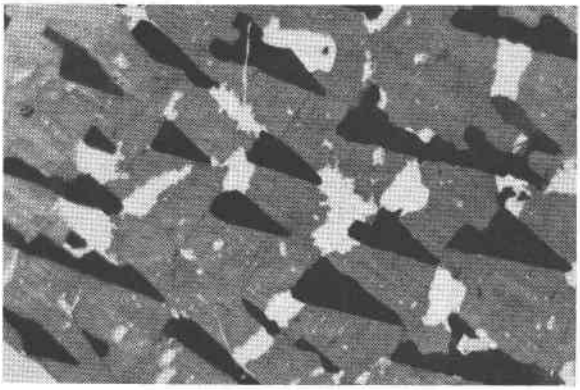

FIG. 5. Graphite granite crystals showing relations of microcline, quartz, and albite. Quartz is black, microcline is gray, and albite is white. Crossed polars, 26×.

The relationship between microcline and albite discussed below where the two are not in a classical perthitic intergrowth provides ample grounds for debate with little chance for an unequivocal decision. The writers are aware of the many statements sprinkled throughout the literature of the past half century interpreting the textures (Figs. 6, 7) described as 1) microcline replaced by plagioclase, 2) plagioclase replaced by microcline, or 3) unmixed perthitic or anti-perthitic feldspar. The observations given here lead the writers to the conclusion that microcline is replaced by albite.

a). A complete series can be found from microcline grains with only slight corrosion or embayment by albite around the borders to plagioclase crystals in which microcline occurs as a few "islands" in an albite host (Gates, 1953). Irregular veins and stringers of albite in microcline are common, but veins of microcline in albite were not found. In the re-

[1] X-ray studies by Dr. S. W. Bailey and Miss Judith Smith.

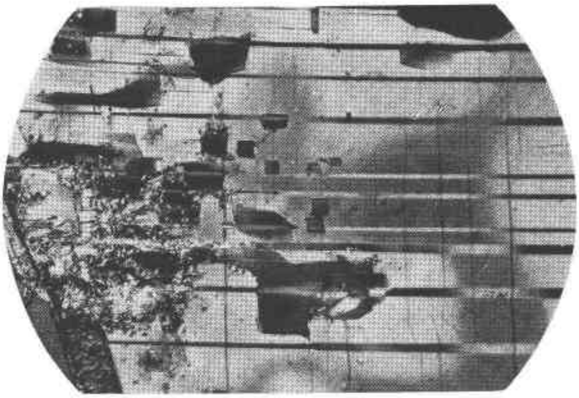

FIG. 6. Microcline almost completely replaced by plagioclase. The polysynthetically twinned material is plagioclase; small, dark, angular blocks are microcline. The albite twin lamellae are continuous in the plagioclase and the microcline. Crossed polars, 210×.

placement series the microcline and plagioclase are in crystallographic continuity and each feldspar has a single optical orientation. The angular or rectangular patches of microcline in the albite have the optical orientation of the main part of the microcline grain. The suggestion has been made elsewhere (Gates, 1953) that the common rectangular shape of the microcline patches results from the preferential replacement by albite along the albite and pericline twin lamellae of the microcline.

Granite samples are abundant which contain two types of albite. One type is clean with sharp extinction, and well-developed twinning. The

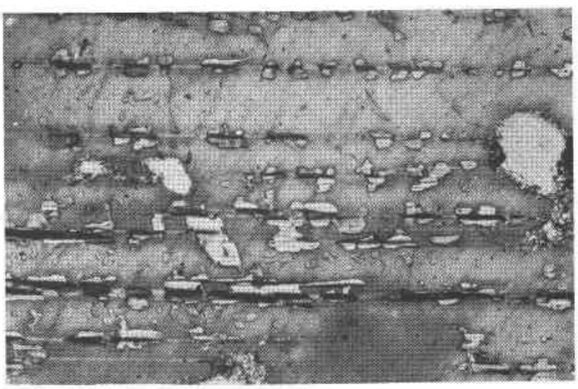

FIG. 7. Microcline remnants in plagioclase host. The matrix is plagioclase; small, cross-hatched fragments are microcline. The light streaks are indistinct twin lamellae (010) inherited from the microcline. Crossed polars, 60×.

second type is typically dusty, sericitic and cloudy-appearing, with poor extinction and ill-defined twinning. Typically the second type has irregular patches or areas of microcline and is considered to be of replacement rather than primary origin. The textures shown in Figs. 6 and 7 illustrate an advanced stage of albite replacement. Seldom are the microcline patches uniformly distributed in the albite host. This pattern is quite different from the perthitic or antiperthitic texture developed by the unmixing of a sodic alkali feldspar (Gates, 1953, Figs. 5, 6, 7, Plate 8).

Unoriented plagioclase grains included in a microcline crystal show little, if any, indication of replacement by microcline even where there is abundant additional plagioclase in crystallographic continuity with the microcline showing replacement textures. Any reaction rims which are found between enclosed unoriented plagioclase in microcline are generally albitic and probably related to perthitic albite unmixed from the microcline with which they are in crystallographic continuity. The apparent stability of the unoriented inclusions of plagioclase in microcline where the microcline-albite replacement relations given above are also present supports the conclusion that the plagioclase is replacing microcline.

2. Microcline-quartz relations: The contacts between microcline and quartz in the fine- to coarse-grained granitic textured rocks are typically sharp, but may be irregular. This is also true of quartz grains poikilitically included in the larger microcline crystals. Microcline is not found as inclusions in quartz except in the pegmatites and the large graphic granite crystals. Interest in the microcline-quartz relationship centers in the graphic granite crystals where the quartz occurs both as unoriented inclusions and as oriented or sub-oriented cuneiform rods. The quartz rods tend to have straight line boundaries on at least two of the three sides in their semi-triangular cross section. The third side is commonly irregular (Fig. 5). In sections cut parallel to the length of the rod the microcline-quartz contacts are sharp but very irregular in outline. Microcline does occur as isolated grains in the quartz rods but has the optical orientation of the microcline megacryst.

3. Microcline-muscovite relations: Muscovite and microcline occur side by side in the fine- to coarse-grained granite with straight and sharp borders parallel to the muscovite cleavage and rounded to irregular borders at the ends of the mica flakes. In the coarser-grained granite the terminations of the muscovite flakes commonly show an irregular or frayed end of a vermicular-like intergrowth. The vermicular intergrowth consists of microcline and muscovite with quartz commonly occurring as a rim between them. This is similar to the vermicular intergrowth of plagioclase and muscovite shown in Fig. 8. The quartz at the interface between muscovite and microcline is most readily explained as the silica

which would have been released by the replacement of microcline by muscovite.

Plagioclase. Albite is the major feldspar in the fine- to coarse-grained granite and tends to occur largely as discrete anhedral grains. As the grain size of the granite increases, the relationship of the albite to the other essential minerals becomes increasingly complex. In addition to discrete anhedral grains, albite is found

a) poikilitically included in microcline, b) in normal perthitic intergrowths with microcline, c) in a co-oriented intergrowth with subordinate, irregular patches of microcline (Figs. 6, 7), and d) in graphic and myrmekitic intergrowths with quartz.

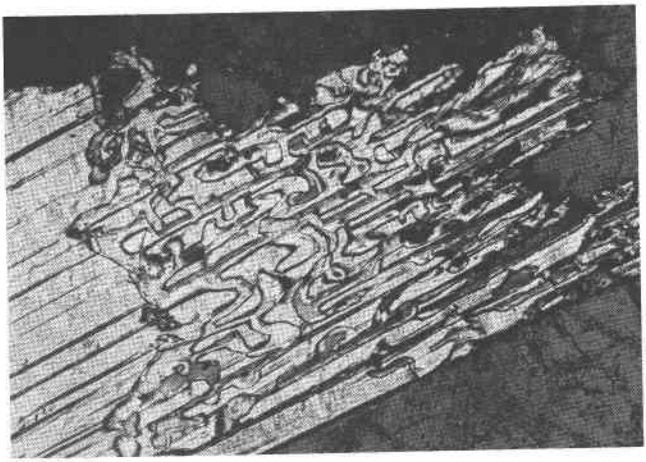

FIG. 8. Vermicular reaction rim of muscovite and plagioclase. Crossed polars, 60×.

The relationship between plagioclase and microcline is given above in the section on microcline.

1. Plagioclase-quartz. One of the most striking textural features of the granite is the border between quartz and albite. Although many contacts between these minerals are smooth curves, the striking ones are serrated borders which resemble the toothed edge of a saw (Fig. 9). The serrated borders are present only where plagioclase twin lamellae are in contact with quartz. The quartz appears to penetrate or replace the plagioclase selectively along the (010) and (001) planes. In many cases the serrations appear to be related to alternate sets of twin lamellae, *i.e.*, one set projecting into the quartz and the alternate set penetrated by quartz (Fig. 9). The (010) plane appears much more susceptible to replacement than (001), but where both albite and pericline or acline twinning are present, serrated borders against quartz are present along both types of twins.

However, it seems more likely that the apparent vulnerability along (010) and (001) is related to weak bonding rather than to twinning.

The serrated borders between quartz and plagioclase are found in all the modes of plagioclase given above. Of particular interest are the serrated borders between the cuneiform quartz rods of the graphic granite crystals and both the unoriented albite inclusions and the unmixed perthitic albite. Many contacts between the quartz rods and both types of plagioclase are smooth but some serrated borders are found in all sections. If the serrated contacts represent replacement by quartz, then the cuneiform graphic quartz rods must have formed, in part at least, by replacement.

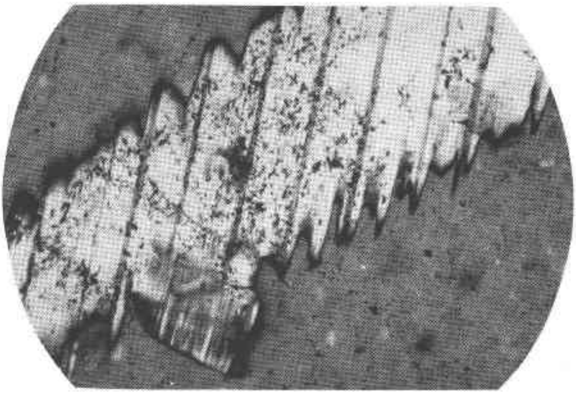

FIG. 9. Serrated plagioclase-quartz border. Note twin lamellae in center of each point. Plagioclase is white, quartz is gray, and small patch of microcline is cross hatched. Crossed polars, 90×.

2. Plagioclase-muscovite. In general the borders between plagioclase and muscovite are similar to those between microcline and muscovite. Vermicular intergrowths of plagioclase and muscovite (Fig. 8) are present in many sections. Muscovite flakes terminating in plagioclase are commonly frayed or ragged in appearance. The interpretation given here is that muscovite replaces the plagioclase.

Quartz. Quartz typically occurs as discrete anhedral grains in fine- to medium-grained xenomorphic granular granite. In addition it occurs as poikilitic inclusions in larger microcline crystals, as cuneiform rods in graphic granite, and in the plumose muscovite-quartz intergrowths. The intermineral relations in general are discussed above and the graphic granite and plumose muscovite are discussed below.

Graphic Granite Crystals

General Statement. The several modes of occurrence (see p. 1046) of the graphic granite crystals all indicate that they formed late in the crystallization history of the granite. Whether they formed as a result of "granite minimum" crystallization, semi-porphyroblastic or porphyritic crystallization, replacement, or some other means is not at all certain. However, the textural features given below indicate that they formed in a crystal mush from a volatile enriched magma concentrated locally by structural activity. A coexisting or later gas phase (Jahns and Tuttle, 1962) may account for the replacement features characteristic of the final crystallization.

The mineralogic and textural features of the graphic crystals are similar in all the modes; the major variations are in the relative amounts of the essential minerals, the amount of included material, and the coarseness of texture. The essential minerals of all graphic crystals are microcline, perthitic albite, and quartz. Plagioclase-quartz graphic intergrowth are present in subordinate amounts. The major inclusions in the graphic crystals are diversely oriented sodic plagioclase, quartz, muscovite, biotite, and clots of fine- to medium-grained granite. The amount of poikilitically included material ranges from none to so much that the graphic megacrysts are recognized in outcrop only by the microcline cleavage. The variation in the ratio of the essential minerals is largely related to the quartz content which increases as the intergrowth becomes more regular and the quartz becomes more geometric in cross section.

Composition. The range in size of the graphic granite megacrysts from a half an inch across to more than two feet makes any modal analysis difficult and questionable. This problem is complicated further by the diversely oriented inclusions which are unrelated to the graphic intergrowth proper. However, a modal analysis was made of a representative part of a four inch megacryst which was free of inclusions and had a regular, well-developed graphic texture. Sections cut parallel to the front, base, and side pinacoids were analyzed and averaged (Table 2). The average given in Table 2 may be considered as the ideal composition for the graphic granite which is seldom attained here, but is common in many pegmatites (Simpson, 1962).

The most abundant inclusions are subhedral crystals of plagioclase. The composition of the diversely oriented plagioclase crystals range from $0\text{–}15_{\text{an}}$, but 75% of the seventy-four determinations made are between 0 and 5_{an}. Thus, the mode for the included plagioclase is definitely more sodic than for the normal fine- to medium-grained granite.

If the poikilitically included material is disregarded, the graphic granite crystals are composed essentially of microcline, albite, and quartz. Of these minerals the quartz is the most variable. The amount of quartz tends to increase as the graphic intergrowth becomes more regular, reaching its maximum in the classic type intergrowth shown in Fig. 5. The plagioclase of the perthitic intergrowth is more variable in some respects than quartz, but is not systematic in its variations. Generally the plagioclase of the perthite occurs as irregular patches in the microcline and with surprising frequency occurs as stringers between the quartz rods. In good, uniform graphic crystals the perthitic plagioclase may compose as little as 7 per cent of the total. The composition of the plagioclase is generally less than 5_{an}. The microcline of a graphic granite crystal was found to contain 5% albite in solid solution using the x-ray $\bar{2}01$ method. This is slightly less sodic than the non-perthitic microcline which occurs as discrete grains in the fine- to medium-grained granite.

Texture. The graphic granite crystals discussed here can be described as microcline-perthite megacrysts in an intergrowth with quartz. The quartz is of paramount interest since the microcline perthite relationship is more or less fixed by their common crystallography. The quartz ranges in amount, shape, and orientation within rather wide limits. Textural studies reveal a somewhat systematic relationship between these three variables. In general as the percentage of quartz increases, the geometric nature of its borders becomes more pronounced and the optical orientation of the quartz rods becomes more uniform. Where the quartz content is low, the cross section is irregularly rounded to amoeboid and every quartz "rod" or bleb may have a different orientation. Where the quartz content reaches its maximum around 24 per cent by volume, the rods tend to be triangular and to have a common orientation over a large area.

The optical and geometric orientation of the quartz with respect to the microcline was studied in thin sections cut parallel to the major crystallographic directions of the microcline. Usually, in the more regular graphic intergrowths, one optical orientation encompasses the majority of the rods with the remainder falling into two or more groups, each having a common optical orientation. In the less geometric intergrowths the optical orientation was more diverse. Similarly the geometric orientation of the triangular outlines of the quartz rods relative to the crystallographic directions of the microcline were studied in sections cut normal to the rods. The generalization is drawn that the altitude of the triangle is roughly parallel to (010), but the sides of the triangles have no fixed relationship to any crystallographic direction. The exceptions are numerous; in one section there are two sets of triangles, one with the altitudes parallel to (010) and the other parallel to (001). The corollary follows that the angles of the triangles are not constant even in the more regular intergrowth. The apex angle ranges from about 18 to 30 degrees. Also, one side of the triangle is usually incomplete or irregular. In sections cut parallel to the rods, the geometric pattern is missing. The rods appear worm-like, but not of constant width. In general the writers concur with others (Wahlstrom, 1939, pp. 689–692; Hedland, 1958, pp. 50–51; Simpson, 1962) that regardless of their origin there is little or no fixed crystallographic control on the optical or geometrical orientation of the quartz rods.

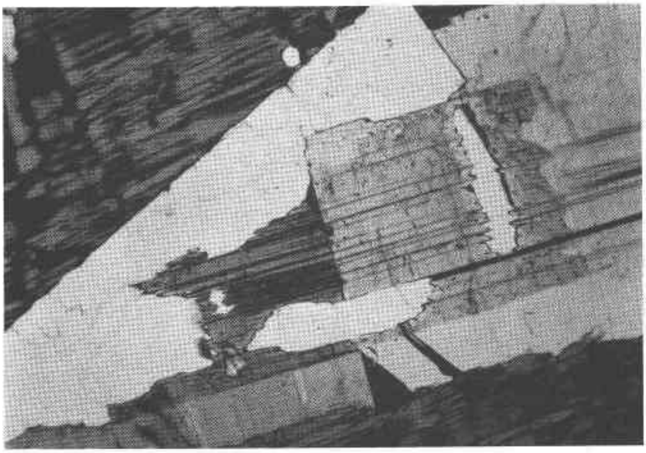

FIG. 10. Serrated borders between graphic quartz rod (white) and plagioclase crystal poikilitically included in microcline. Crossed polars, 30×.

Quartz-plagioclase relationship. The relationship of the quartz rods to the two generations of plagioclase (the poikilitically included plagioclase and the unmixed perthitic albite) afford the best clues to the crystallization sequence of the graphic intergrowths. The quartz rods protrude into, embay, and poikilitically include euhedral plagioclase crystals which were originally poikilitically included in the host microcline megacryst. It is not uncommon for the quartz to show a serrated border against selected parts of the plagioclase inclusion although smooth contacts are the rule (Fig. 10). The quartz rods also appear to invade the unmixed perthitic albite, but it is also possible that the albite unmixed around the pre-existing quartz. However, many cases can be found where the graphic quartz rods, protruding into unmixed perthitic albite, have the serrated contact against the albite (Fig. 11). Additional indications of the late nature of the quartz are rods which extend beyond the microcline host and into contiguous minerals. Several examples were noted where a graphic quartz rod extended into an adjacent plagioclase grain and developed the serrated border. In each case the interpretation is that the quartz, in part at least, is not only later than the microcline but later than the albite unmixed from or replacing the microcline during the formation of perthite.

Plumose Muscovite-Quartz Intergrowth

General statement. Plumose intergrowths of muscovite and quartz are not so uncommon as their rarity in the literature indicates (Orville, 1960).

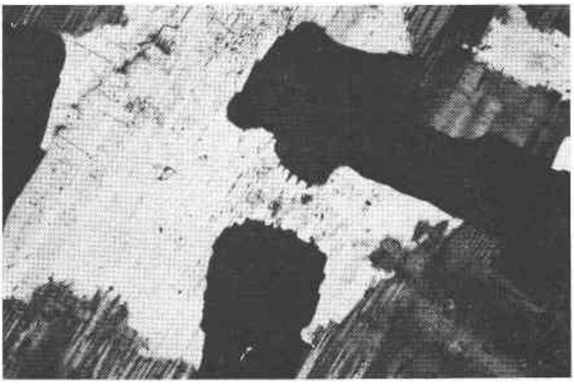

Fig. 11. Serrated borders between graphic quartz rods (black) and perthitic albite (light gray, faintly twinned). Microcline host is dark gray and twinned. Albite and microcline are crystallographically continuous. Crossed polars, 30×.

The field relations and general occurrence of these intergrowths shed little light on their origin, but the detailed border textures may be significant. The conclusion that the plumose muscovite-quartz intergrowth is the last assemblage in the granite to crystallize is supported by the relations of the intergrowth minerals to the contiguous minerals of the granite.

Texture. The plumose intergrowths of quartz and muscovite occur as irregular, spherical, hemispherical, or feather-duster like masses in the granite. In general they are interstitial to the other minerals and commonly plagioclase, quartz, and small clots of fine-grained granite. A typical associate of the plumose intergrowths is graphic quartz and plagioclase in which the plagioclase-quartz interface is serrated as described above (Fig. 12). The contacts between the muscovite and quartz of the plumose intergrowth and the minerals of the granite are typically smooth or undulatory giving no clue as to the sequence of crystallization of the various minerals. However, the indications of late crystallization of the plumose intergrowth are indicated by the following features.

1. The plumose intergrowths have as inclusions all other minerals of the granite as well as small clots of the granite itself. In addition the plumose intergrowth occurs interstitially and commonly has long tongues penetrating or embaying the surrounding rock.

2. Where the border between the quartz of the plumose intergrowth and plagioclase (either included or outside the plume) is not a smooth one, it is serrated in the manner discussed above indicating replacement of plagioclase by quartz (Figs. 9, 10, 11, 12).

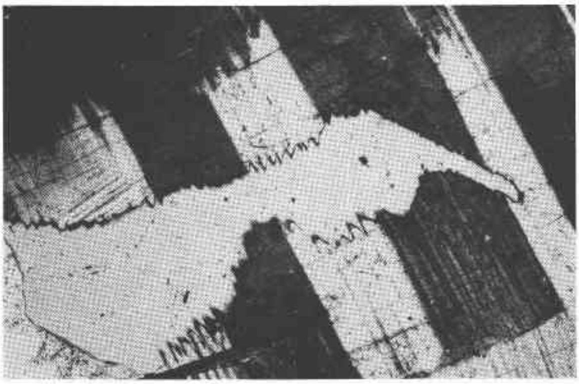

FIG. 12. Serrated borders between graphic quartz (white) and plagioclase (twinned) in a graphic quartz-plagioclase crystal adjacent to plumose-muscovite-quartz. Crossed polars, 30×.

3. Near the borders of the plumose intergrowth the muscovite flakes of the plume are found to extend into the surrounding microcline, plagioclase or quartz. This penetration is generally less than half the length of the entire flake.

4. In one case where graphic microcline-quartz and a plumose intergrowth are in contact, a cuneiform quartz rod of the graphic crystal is partially enclosed by the plumose muscovite-quartz. The relations indicate minor replacement of microcline by quartz and muscovite.

5. The unusually common association of graphic plagioclase and quartz with the cuneiform quartz typically having deeply serrated borders against plagioclase may also be related to a late aqueous silica rich stage of crystallization.

Discussion of the Crystallization of the Granite

General Statement. The average composition of the Nonewaug granite calculated in terms of albite, K feldspar, and quartz approximately coincides with the synthetic granite minimum of Tuttle and Bowen (1958). The additional components of muscovite and anorthite average less than 10 per cent of the total and must be considered normal constituents of a natural granite. Thus, the granite should be expected to follow the course of crystallization predicted by laboratory experiments if variations in temperature, pressure and water content are taken into consideration.

The Nonewaug granite has many characteristics of pegmatites in that locally it is very coarse-grained and contains large graphic granite crystals. It is not like the more intensively studied pegmatites in that it is neither zoned, regularly layered, nor contains the accessory minerals commonly associated with pegmatites, such as tourmaline. However, as with the structurally less complex pegmatites, it is possible to establish a sequence of crystallization of the various textural types based on their relations to each other. The sequence established is from fine-grained to coarse-grained to pegmatitic as one would expect. In this sequence the major compositional change is from a plagioclase-rich fine-grained granite to a K feldspar-rich pegmatitic granite. The fine-grained granite represents the first to crystallize and may be analogous to the sodic aplites of Jahns and Tuttle (1962) which they attribute to rapid crystallization of the magma during the escape of the volatile constituents. The coarse-grained granite and pegmatite represent successive separation of the fluid fraction (hydrous silicate magma and/or gas) in response to structurally produced zones of low relative pressure. The increase of K feldspar in the coarse-grained granite suggests a preferential transport of potassium over sodium with increasing volatiles. The plumose muscovite-quartz intergrowths represent the final stage of crystallization.

Structure. The Nonewaug granite was passively emplaced along a major flexure and fault in the Hartland formation in a series of continuing injections. This is indicated by the fine- to medium-grained, thinly layered granite not only at the borders but within the main body. Repeated movement along the fault, when the granite was a crystal mush, tended to concentrate the still liquid phase along zones of dilation producing the coarse-grained or pegmatitic granite. Elsewhere the movement "brecciated" the crystal mush to produce the large areas of patchy fine- to coarse-grained granite and pegmatite. The coarse-grained graphic granite bearing parts of the granite probably correspond to the hanging wall side (Simpson, 1962; Statz and Trites, 1955) or the upper layer of the Black Hills layered pegmatites (Orville, 1960). The graphic granite crystals grew in fluid dilation zones, layers and areas which developed late in the crystallization history of the granite.

Fine- to coarse-grained granite. In the normal granite (i.e. that free of large microcline or graphic granite crystals) it seems apparent that plagioclase, potash feldspar (microcline) and quartz crystallized side by side. The plagioclase to microcline ratio ranges from 1.5–2.0 and averages about 1.7. In the fine-grained, thinly layered border phase the plagioclase is the most calcic being about 15_{an}. The microcline is not noticeably perthitic, but does contain 7.5 per cent albite in solid solution (Hewlett, 1959, sample #8). The typical xenomorphic granular texture indicates contemporaneous crystallization of the three components. It has been suggested by Orville (1960) based on the work of Yoder *et al.* (1956, 1957) that the presence of a small amount of anorthite in the plagioclase might raise the crest of the solvus between potash feldspar and plagioclase enough to cause the two feldspars to crystallize side by side. The initial plagioclase to crystallize was about 15_{an} which would support this theme. During crystallization the plagioclase became progressively more sodic to about 3_{an}. The plagioclase unmixed from the potash feldspar is 0–5_{an}. Certainly the textures, general structure, and geologic history suggest primary crystallization of the two feldspars up to the point where the larger graphic granite crystals began to form. The serrated borders between quartz and plagioclase and the vermicular muscovite-feldspar intergrowths are very subordinate and most likely represent the effect of the interstitial fluid at the end of crystallization.

Graphic granite-bearing granite and pegmatite. The graphic granite crystals occur in all types of granite from fine-grained to pegmatitic, but are most abundant and largest in the coarse-grained granite and pegmatite areas or layers. Field and petrographic study shows that the graphic granite crystals poikilitically include quartz, plagioclase, micas, and clots of the fine-grained granite. The graphic granite crystals are considered to have developed in zones in a crystal mush where the structural activity concentrated the interstitial magmatic liquid. Here the large microcline crystals grew and poikilitically included all earlier formed minerals. The included plagioclase crystals range from 15–0_{an}, with a pronounced modal peak around 4–5_{an}. It is possible if not probable, that the quartz of the graphic granite crystallized with the potash feldspar in large part. The textural features indicate that the albite of the microcline perthite is controlled in part during unmixing by the graphic quartz rods (Fig. 5). The "unmixed" albite occurs largely between the rods. The relationship of the serated borders between graphic quartz rods and unmixed perthitic albite as here interpreted would contradict that. However, the contradiction is resolved if the quartz continues to crystallize possibly from a gas or dilute aqueous siliceous fluid after the albite has unmixed in the subsolidus region. The crystallization trend is thus from early and quantitatively subordinate potash feldspar with about 7.5% albite in solid solution to a more sodic quantitatively predominant potash feldspar (approx. Or_{70} Ab_{30}) crystallizing in irregular to graphic pattern with quartz. Apparently, plagioclase crystallizes side by side with the potash feldspar throughout. In the final stages, presumably in the subsolidus region the bulk of the soda in the potash felspar unmixes to form the perthitic microcline during which time there are dilute siliceous solutions (gaseous?) present to continue the growth of the quartz and in part to replace the unmixed albite. The suggestion of Jahns and Tuttle (1962) that sodic aplites associated with potassic pegmatites may be explained by a "segregation of the major alkalis in the presence of silicate melt and coexisting aqueous gas" may well explain the relations between the fine- and coarse-grained layers of the Nonewaug granite. The intimate interlayering and intermixing of the fine- and coarse-grained granite with the ratio of plagioclase to potash feldspar reversing certainly indicate a separation of sodium and potassium in a fluid medium. A change in the concentration of water and volatiles could explain the crystallization of potassic feldspar and quartz in graphic intergrowths instead of in discrete grains. The crystallization of the entire graphic granite crystal may be gaseous as suggested by Simpson (1962), but it seems that there must be a significant change in the character of the residual fluid in the final stages to explain the serrated quartz-plagioclase borders.

Plumose muscovite-quartz intergrowth. The plumose muscovite-quartz intergrowths are considered to represent the very last stage of crystallization for the reasons given in the section on textures. Chemically this intergrowth may be considered the hydrous equivalent of potash feldspar with the loss of two-thirds of the potassium. It seems most likely that this represents a slightly later but largely contemporaneous crystallization with the last stage of the graphic granite. The extensive replacement of plagioclase by quartz adjacent to many of the plumes corroborates this conclusion. The plumose texture may be vaguely explained as analogous to the radial pattern of feldspars in spherulites. They might have crystallized from a watery gelatinous mass.

In summary, it is suggested that to a large degree plagioclase, quartz, and potash feldspar crystallized side by side from the inception of crystallization to its end. The change in the relative amounts of the constituents and their textural relations can best be explained by a change in the character of the crystallizing magma. The total crystallization must take place close to the thermal valley of petrogeny's residua system. The separation of the finer grained granite from the coarser grained to pegmatitic granite is structurally controlled and probably involves successive separation of a more aqueous magma as crystallization progresses.

References

Agar, William (1934) The granites and related intrusives of western Connecticut. *Am. Jour. Sci.*, 5th Series, **27**, 354–373.

Anderson, Olaf (1928) The genesis of some types of feldspar from granite pegmatites, *Norsk Geol. Tids.* **10**, 116–207.

Boone, Gary M. (1962) Potassic feldspar enrichment in magma: Origin of syenite in Deboullie District, Northern Maine. *Geol. Soc. Am. Bull.* **73**, 1451–1476.

Buddington, A. F. (1959) Granite emplacement with special reference to North America, *Geol. Soc. Am. Bull.* **70**, 671–747.

Cameron, E. N. (1951) Preliminary report on the geology of the Mt. Prospect Complex. *Connecticut Geol. Nat. Hist. Survey Bull.* **76.**

Chayes, F. (1951) Modal composition of granites. *Carnegie Inst. Washington Year Book* **50,** 41.

——— (1957) A provisional reclassification of granite. *Geol. Mag.* **94,** 58–68.

Clarke, J. W. (1958) The bedrock geology of the Danbury Quadrangle, *Connecticut Geol. Nat. Hist. Survey Quad. Rept.* **7,**

Emmons, R. C. (1943) The five axis Universal Stage, *Geol. Soc. Am. Mem.* **8.**

——— et al. (1953) Selected petrogenic relationships of plagioclase. *Geol. Soc. Am. Mem.* **52.**

Gates, Robert M. (1951) The bedrock geology of the Litchfield Quadrangle, Connecticut. *Connecticut Geol. Nat. Hist. Survey, Misc. Series* 3.

——— (1953) Petrogenic significance of perthite: Selected petrogenic relationships of plagioclase. *Geol. Soc. Am. Memoir* **52,** 55–69.

——— (1954) The bedrock geology of the Woodbury Quadrangle, Connecticut. *Connecticut Geol. Nat. Hist. Survey, Quad. Rept.* **3.**

——— (1959) The bedrock geology of the Roxbury Quadrangle, Connecticut. *U. S. Geol. Surv. Quad. Map* **GQ 121.**

——— (1961) The bedrock geology of the Cornwall Quadrangle, Connecticut. *Connecticut Geol. Nat. Hist. Survey Quad. Rept.* **11.**

——— and William C. Bradley (1952) The geology of the New Preston Quadrangle, Connecticut. *Connecticut Geool. Nat. Hist. Survey Misc. Series* **5.**

Hedlund, D. C. (1958) Graphic granites from selected zoned pegmatites of the Bryson City District, North Carolina. Univ. Wisconsin, unpubl. Ph.D. Thesis.

Hewlett, C. G. (1959) Optical properties of potassic feldspars. *Bull. Geol. Soc. Am.* **70,** 511–538.

Jahns, R. H. and O. F. Tuttle (1962) Layered pegmatite-aplite intrusions (abs.). *Am. Mineral.* **47,** 194.

Orville, P. M. (1960) The petrology of several pegmatites in the Keystone District, Black Hills, South Dakota. *Bull. Geol. Soc. Am.* **71,** 1467–1490.

Rice, W. N. and H. E. Gregory (1906) Manual of the geology of Connecticut. *Connecticut Geol. Nat. Hist. Survey Bull.* **6.**

Rodgers, John, R. M. Gates, E. N. Cameron and R. J. Ross, Jr. (1956) Preliminary geological map of Connecticut. *Connecticut Geol. Nat. Hist. Survey.*

——— R. M. Gates and J. Rosenfeld (1659) Explanatory text for preliminary geological map of Connecticut, 1956. *Connecticut Geol. Nat. Hist. Survey Bull.* **84.**

Simpson, Dale R. (1962) Graphic granite from the Ramona pegmatite district, California, *Am. Mineral.* **47,** 1123–1137.

Staatz, M. H. and A. F. Trites (1955) Geology of the Quartz Creek pegmatite district, Gunnison County, Colorado. *U. S. Geol. Survey, Prof. Paper* **265,**

Thede, Ray (1958) The petrology of the Thomaston granite at Reynolds Bridge, Connecticut. Univ. Wisconsin, unpubl. M.S. Thesis.

Tuttle, O. F. and N. L. Bowen (1958) Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O. *Geol. Soc. Am. Mem.* **74.**

Wahlstrom, E. E. (1939) Graphic granite. *Am. Mineral.* **24,** 681–698.

Walton, Matt (1955) The emplacement of granite. *Am. Jour. Sci.* **253,** 1–18.

Manuscript received, March 5, 1963; accepted for publication, May 6, 1963.