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OCCURRENCES OF LEUCOGRANOGABBRO AND ASSOCIATED IGNEOUS ROCKS IN THE WICHITA MOUNTAINS, OKLAHOMA

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ABSTRACT. A gabbro-granophyre complex of Precambrian age is exposed in the Wichita Mountains in southwestern Oklahoma. The complex probably forms horizontal sheet-like intrusions. Between the gabbro and granophyre a narrow zone of "intermediate rock" composed of leucogranogabbro, granogabbro, granodiorite, leucosyenogabbro, and syenogabbro exhibits peculiar mineralogical and textural characters. Field occurrences and petrographic studies indicate that these rocks originated as alteration products of the gabbroic rocks through contact action of a granophyric melt. As a result of the contact action, a uniform intermingling of gabbro and granophyre, together with partial granitization and hybridization, took place in the "intermediate zone." This paper presents a detailed account of the field occurrence, mineralogy, and petrography of the leucogranogabbro and associated igneous rocks.

INTRODUCTION

Although geological work has been done in the Wichita Mountains of southwestern Oklahoma by the State Geological Survey and by individual geologists, the spectacular development of the "intermediate rock" that occurs as a narrow zone between gabbro and granophyre of Precambrian age in the Wichita Mountains was not recognized there until recently (Huang, 1953). This narrow zone is composed of leucogranogabbro, granogabbro, granodiorite, leucosyenogabbro, and syenogabbro.[1]

Though Hoffman (1930, p. 32-35) studied the granogabbro of the Wichita Mountains and Johannsen adopted it as one of the representative types in his classification of igneous rocks (1939, p. 367-369), the occurrences of the leucogranogabbro and its related features were neglected by Hoffman and subsequent workers.

This paper presents a detailed account of the mineralogy, petrography, and related characters of the "intermediate rock." It is hoped that the present investigation may contribute to the petrology of the Wichita Mountains igneous complex, Oklahoma.

All optical measurements were made on a universal stage. In some sections of pyroxene and amphibole, extinction angles were determined according to Turner's method (1942); otherwise, the method of Burri (Haff, 1941) was frequently used. Refractive indices were determined by means of immersion methods, using sodium light.

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FIELD OCCURRENCE

The igneous rocks in the Wichita Mountains comprise a stratiform complex in which intrusions of granophyre cross-cut and overlie anorthosite and gabbro. The complex probably forms horizontal sheet-like intrusions. A

[1] For convenience, Johannsen's terms are adopted to denote the mineralogical composition of the "intermediate" rocks of the area under investigation.

narrow zone of "intermediate rock" composed of leucogranogabbro, granogabbro, granodiorite, leucosyenogabbro, and syenogabbro crops out along the general contact areas between the gabbro and granophyre. Many small patches of this "intermediate rock" occur in widely scattered localities in the area. A large outcrop of leucogranogabbro is at Twin Mountain; an outcrop composed of syenogabbro and granogabbro in Sec. 30, T. 4 N., R. 15 W.; leucogranogabbro and granogabbro in Sec. 8, T. 4 N., R. 14 W.; and leucosyenogabbro in Sec. 23, T. 3 N., R. 14 W. An excellent contact zone between gabbro and granophyre is found in Mount Sheridan. Here the contact zone ranges up to nearly 80 feet in width.

Most exposures of the leucogranogabbro and associated igneous rocks cover less than a quarter of a square mile and occur as low hills. Some are inliers surrounded by Permian red beds and recent deposits. The location of these rocks is indicated in figure 1. Many of the features described below are shown in a number of localities, but in order to present a comprehensive picture the descriptions are generalized.

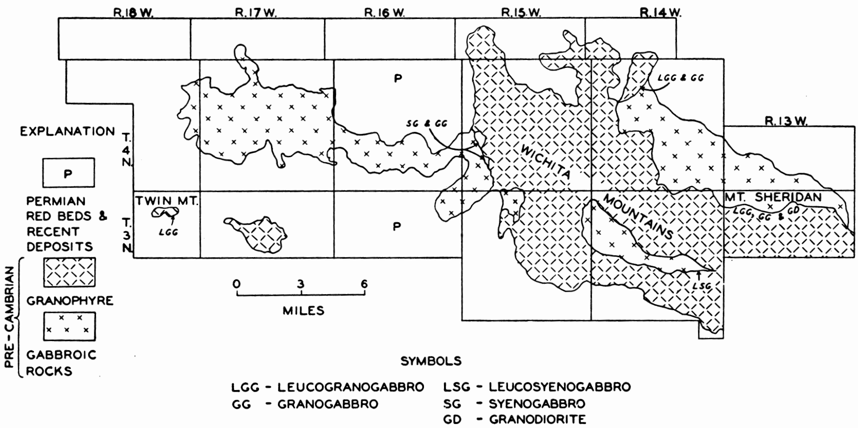


FIG. 1 SKETCH MAP SHOWING THE LOCATION OF LEUCOGRANOGABBRO AND ASSOCIATED IGNEOUS ROCKS, WICHITA MOUNTAINS, OKLA.

General nature of the contact effects.—The contact relations between gabbroic rocks and granophyre are complex and variable. Each feature is so involved with others that it can hardly be separated for description. In Mount Sheridan and elsewhere a well-defined contact is irregular on a small scale, but regular on a large scale (pl. 1-A). Although the phenomena are of great variety, they may all be regarded as the result of the attack and penetration of gabbroic rocks by a granophyric melt. They are closely allied, and their effects often merge, but the obvious results may be distinguished.

First is the attack and penetration of gabbroic rocks by a group of distinct but ramifying quartzo-feldspathic veinlets, ranging in width from 1-3 inches down to almost invisible seams. They bear a close resemblance in many respects to the reticulating stockworks of ore deposits, so that small masses of gabbro are intersected by many veinlets, at places nearly parallel, elsewhere crossing and interlacing in all directions. The granitic materials have worked along cracks, joints, or blocks. Many other examples of this type of penetration may be described, and though they differ endlessly in detail, their major features are in most places much the same.

In a subsequent stage of penetration the main granitic dikes and veinlets finally break up into stringers in gabbroic rocks in the most intricate manner. Some granitic veinlets are nearly pure; elsewhere disintegration products of gabbroic rocks contaminate them greatly. At places the veinlets become dark. because bits of gabbro are scattered throughout them. Separate crystals of basic feldspar and pyroxene are associated with such magmatically incongruous minerals as quartz and alkalic feldspar. Finally a small mass of mixed rock. containing many ramifying veinlets and dikes, often intervenes between gabbro and granophyre. Commonly, a uniform, light gray matrix of modified gabbroic rock encloses large and small "islands" of less altered rock. This may be regarded as a second result of the intrusion of the granophyric melt.

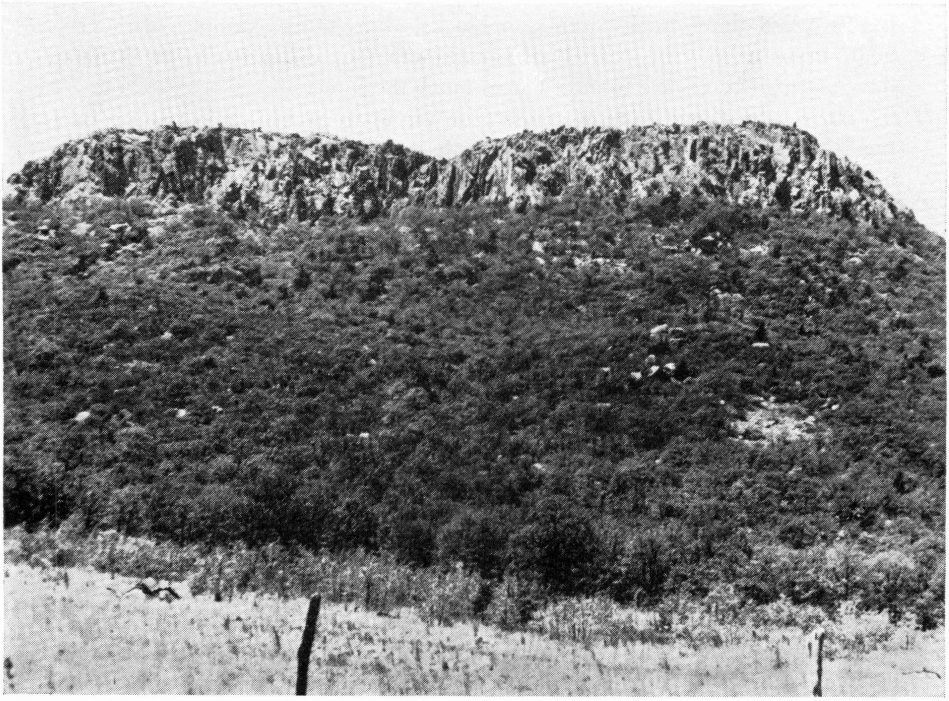
A third result is the appearance of granitic material in the most minute interstices in masses of gabbroic rocks. At many places, swarms of riebeckite-bearing pegmatite veins and dikes up to 6.5 feet in width occur in the mixed rocks. The formation of these features together with the development of micrographic intergrowth and myrmekite to be described later is considered analogous to that of large-scale pegmatitization.

In banded anorthosite and gabbro, the granophyre sends small stringers and irregular protuberances along the bands. The great alteration of the banded rocks is attributed to their original structure, which is especially favorable for impregnation by granitic solutions. At many places the resulting products are uniform-looking altered rocks; at others, the irregular action has left nodules of nearly unaltered gabbroic rocks, of ghostly patches less contaminated than their surroundings; at still others the contamination has gone so far that rather large masses of rock have become more granitic than gabbroic. Rocks obviously intermediate in composition between gabbro and granite are assumed to represent a uniform intermingling of gabbro in granophyre, together with partial granitization and hybridization.

Textural features of the impregnated rocks.—The textures of these rocks are of two general types: (1) inhomogeneous and (2) uniform. In many exposures these types are closely associated, but the effects are fairly distinct. In the first, the gabbroic rocks are penetrated by pegmatite dikes, veinlets, and threads of granitic material. In the second, large masses of gabbroic rocks have been thoroughly modified in composition and have developed a uniform appearance resembling granite. This latter type of texture is by far the most abundant and dominant.

In appearance the mixed rock altered by veinlets is gray and reddish and of medium to fine, even grain, reminding one of the xenolithic "ghosts" found in masses of granitized rock. In some of the uniform mixed rocks a vague and almost imperceptible dappling or streakiness may be seen on close examination, but in many instances even this is absent. The original banded structure of anorthosite now converted to a mass of uniformly contaminated leucogranogabbro at Twin Mountain may be preserved (pl. 1-B), but it naturally

PLATE 1



A

B

C—

A. Mount Sheridan from the northeast, showing the contact between the barren granophyre and the heavily wooded gabbroic rocks. Here the contact is irregular on a small scale but regular on a large scale; it is well defined.

B. Leucogranogabbro at Twin Mountain, showing the parallelism of feldspar tablets.

C. Leucogranogabbro at Twin Mountain, showing the unusually coarse feldspar crystals and pseudo-porphyritic texture. The original banded structure of anorthosite now converted to a mass of uniformly contaminated leucogranogabbro has lost its sharpness as the amounts of granitic materials introduced became abundant.

loses sharpness as the amounts of granitic material introduced became abundant (pl. 1-C).

Typically, the thoroughly mixed and impregnated rocks are dark gray to reddish rocks, medium grained, and occasionally pseudo-porphyritic and pseudo-diabasic. Very coarse varieties are also present but pass imperceptibly into rocks of normal grain size. The plagioclase laths occasionally reach the size of 18.5 cm in length and 2 cm in thickness (pl. 1-C), but the average size is 5 mm x 3 mm.

In Sec. 30, T. 4 N., R. 15 W., the syenogabbro and granogabbro have undergone uralitization. This process is especially intense along the joints and shattered areas of the outcrop. Amphibole needles are developed in the cracks and cleavages of clinopyroxene grains. Magnetite grains are scattered throughout. Alteration of feldspar is by no means as common or intense as that of the clinopyroxenes, but even in the freshest mixed rock an incipient alteration takes place at the center of the large feldspar crystals. Occasionally the alteration is intense, and the large feldspar crystal loses its pinkish color and becomes packed with small crystals which cannot be identified megascopically. The nature of uralitization on these mixed rocks is best studied under the microscope and it will be described later.

MINERALOGY

The chief minerals of the leucogranogabbro and associated igneous rocks are plagioclase, orthoclase, microperthite, quartz, clinopyroxenes, orthopyroxene, and amphiboles. Considerable amounts of tremolite-actinolite and pleochroic green or brown hornblende, magnetite, epidote, and chlorite accompany the altered clinopyroxenes. Table 3 shows the selected modal analyses of the rocks.

Feldspar.—Plagioclase, generally lath-like, normally constitutes over half the volume of the rock. Except for a few very large crystals, the grain size averages 4 mm x 5 mm and is comparable to the associated mafic minerals. The total range in composition is from An_{58} to An_{70}, but the great majority is near An_{68}. Thus, the plagioclase is labradorite.

Twinning is widely developed, and twinning laws were determined by the migration curves (Turner, 1947). Albite twinning is the most abundant; but Carlsbad, Ala, Pericline and complex twinning are also present. Some plagioclase crystals occur as slender zoned laths, but most are unzoned, or occasionally occur as poikilitic crystals of more uniform composition. The laths were formed by crystallization in a magma undergoing movement, whereas the unzoned and poikilitic habits are ascribed to crystallization in a quiescent magma. The zoned crystals have compositions ranging from An_{70} to An_{50}, and the average ranges from An_{68} to An_{58}. Sharply defined zones present; but the transition in composition from the core to the edge is commonly gradual.

Andesine with An_{32-36} occurs as laths exhibiting twinning. It is confined to granodiorite, where contamination of gabbroic rocks by granophyric melt has produced a rock more granitic than gabbroic.

A little albite occurs in the granogabbro and syenogabbro. Vermicular and scalloped masses of albite anastomose through the borders and cores of orthoclase and plagioclase in a very complex manner. In myrmekite the albite is cloudy, contains sericite inclusions, and forms rosettes radiating from a central crystal, which commonly has both polysynthetic and Carlsbad twinning. The central crystal and the radiating rosettes include blebs and hook-like masses of quartz all of which show uniform optical orientation over small segments of a single rosette, though in cases two or three such quartz crystals are required to compose the entire rosette. The albite of these rocks has extinction angles as large as 15° in the zone normal to 010, and indices of refraction are all lower than 1.537. The feldspar is therefore at least as sodic as $Ab_{95}An_5$.

Most of the more sodic feldspars, albite-oligoclase with An_{9-22}, are perthitic. Two types of microperthite were noted: vein microperthite and patch microperthite; the latter predominates. The vein microperthite consists of albite-oligoclase in narrow, even-spaced lamellae in orthoclase, whereas the patch type is composed of albite-oligoclase irregularly intergrown with orthoclase. Part of the albite-oligoclase replaced the host as islands of orthoclase were found in the albite-oligoclase. Microperthite crystals vary in size considerably and average 1.5 mm x 1.8 mm in dimensions.

Orthoclase free from perthitic intergrowth occurs in small amounts. Most crystals are untwinned, but are turbid owing to inclusions of sericite. The orthoclase crystals vary in size from small to large, 1.2 mm x 2.6 mm, and average 0.3 mm x 0.8 mm. Traces of microcline are confined to granodiorite and granogabbro.

Clinopyroxene.—A small amount of clinopyroxene occurs in leucogranogabbro, but it increases in amount in granogabbro. Clinopyroxene forms subhedral crystals averaging 1.4 mm and up to 2.8 mm in diameter. It is usually colorless in thin section, but occasionally it is pale green with no pleochroism. The presence of partings on both (100) and (001) makes the variety name diallage appropriate.

The extinction angle and 2V were measured in every thin section; β index was determined when the mineral was available. The chemical composition of the mineral based on Hess' method (1949) are shown as follows:

TABLE 1

Optical Data on Clinopyroxenes

Specimen	2V	$Z \wedge c$	β index	inferred composition
H-25	44°-49°	42°-46°	1.682 ± 0.003	$Wo_{42}En_{48}Fs_{10}$
H-31	52°-54°	45°	1.688 ± 0.002	$Wo_{41}En_{43}Fs_{16}$
H-42	52°-53°	45°-48°	1.692 ± 0.002	$Wo_{39}En_{41}Fs_{20}$

Inclusions are seldom present. Possible exsolution of orthopyroxene may exist but could not be positively demonstrated. Uralitization of clinopyroxene along cleavages and cracks produced secondary hornblende, which in turn changes to chlorite (pl. 2-A).

Orthopyroxene.—The mineral occurs as oblong-shaped crystals which average about 0.2 mm by 1.3 mm in dimensions. The orthopyroxene was determined with Hess and Phillips' curve (1940). Optical properties of orthopyroxene are: (–) 2V = 63°, N = 1.702 ± 0.003, faintly pleochroic: X = pinkish, Y = colorless, and Z = pale to greenish. These data indicate hypersthene with an enstatite content of $En_{73}Of_{27}$.

Some hypersthenes contain schiller inclusions, which are composed of fine needles arranged parallel to the c-axis. The hypersthene is commonly fresh, but not infrequently shows alteration to tremolitic amphibole and green serpentine-like mineral.

Amphibole.—This mineral occurs in considerable amounts in granodiorite and some uralitized syenogabbro and granogabbro. The optical angle, $Z \wedge c$, and the β index were determined. Exact compositions from optical data are impossible to obtain, but approximate compositions, according to Sundius (1946), are shown in table 2.

TABLE 2
Optical Data on Amphiboles

Specimen	Pleochroism		2V	$Z \wedge c$	β index	$\frac{Mg}{Mg+Fe}$	Related En	Related An
				Tremolite-actinolite				
H-25	colorless		–85°	17°-20°	1.618 ± 0.003	90%		58
H-48	greenish		–78°-85°	14°-20°	1.635 ± 0.003	75%	73	70
				Hornblende-pargasite				
	X	Y = Z						
H-31	yellow	green	–80°-82°	13°-16°	1.636 ± 0.003	80%	73	62
H-46	bluish	green	–64°-88°	12°-15°	1.670 ± 0.003	50%		36
H-52	brown	yellow	+84°	13°-15°	1.662 ± 0.002	60%		36
H-56	green	grass-green	–76°	13°-16°	1.654 ± 0.001	65%		68

Amphiboles vary in appearance. The primary amphibole is subhedral to euhedral and is quite fresh. The secondary amphibole which was formed by uralitization is poikilitic, and anhedral (pl. 2-B). Grain size of primary hornblende is of the magnitude of 1.2 mm x 0.3 mm; others vary with the stage of uralitization and the original size of clinopyroxene, up to 1.5 mm in length. Pleochroism is distinct: X = yellowish green, Y = Z = green to blue-green; (–)2V = 80, $Z \wedge c$ = 16°. Some hornblende is brown and is rich in minute iron inclusions. The mineral occurs in irregular patches without any crystal form and is invariably associated with clinopyroxene which has undergone uralitization.

Other accessory minerals are quartz, apatite, sillimanite, biotite, sphene, and zircon; secondary minerals include ilmenite, magnetite, serpentine, epidote, sericite, uralite. Quartz occurs in considerable amount in rocks near the granophyre while apatite is particularly abundant in rocks adjacent to the pegmatite contact. Except for epidote and serpentine, most of these minerals are euhedral to subhedral.

TABLE 3

Selected Modal Analyses of the Leucogranogabbro and Associated Igneous Rocks in the Wichita Mountains, Oklahoma

	1 Leuco-granogabbro	2 Grano-gabbro	3 Uralitized granogabbro	4 Grano-diorite	5 Leuco-syenogabbro	6 Syeno-gabbro
Quartz	8.7	8.0	8.8	13.8	tr.	tr.
Orthoclase	2.2	3.4*	1.2	5.8*	8.4	5.2
Microperthite	15.4	15.2	13.5	5.2	tr.	tr.
Labradorite	70.7	54.0	30.0	tr.	90.0	68.0
Andesine				36.0		
Clinopyroxene	1.0	7.5	3.5	2.5		4.8
Orthopyroxene		5.2	4.5			5.2
Amphibole	0.5	2.2	14.5	27.0	1.4	4.2
Sillimanite		tr.	tr.			
Biotite	tr.	0.5	1.4	1.5		2.6
Zircon	tr.		tr.	tr.		tr.
Sphene	tr.	tr.	tr.	2.1		2.4
Apatite	1.5	2.0	4.6	4.5	tr.	2.5
Magnetite	tr.	0.5	6.2	1.5	tr.	2.6
Ilmenite			tr.	tr.		
Chlorite		tr.	6.5**	0.1	0.2	tr.
Epidote	tr.	1.5	2.3	tr.		2.5
Sericite	tr.	tr.	0.5		tr.	
Uralite			1.5			tr.
Serpentine		tr.	1.0			tr.

tr.—trace.

*Trace amount of microcline is included, and small amounts of albite were found in granogabbro and syenogabbro.

**Considerable amount of penninite is included.

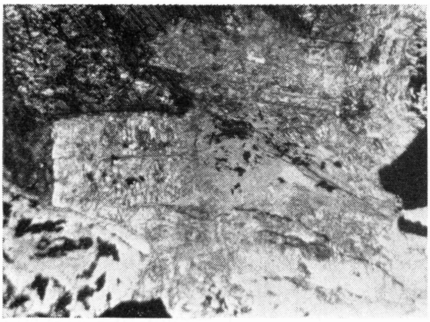
1. Leucogranogabbro, Twin Mountain.
2. Granogabbro, NE corner Sec. 8, T. 4 N., R. 14 W.
3. Uralitized granogabbro, Sec. 30, T. 4 N., R 15 W.
4. Granodiorite, Mount Sheridan.
5. Leucosyenogabbro, Sec. 23, T. 3 N., R 14 W.
6. Syenogabbro, Sec. 30, T. 4 N., R. 15 W.

PETROGRAPHY

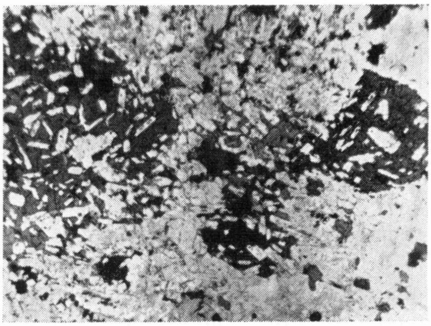
In describing the petrography of the rocks, the following features are worthy of attention:

(1) Different habits of the quartz crystals indicate that the history of crystallization of quartz was complex. Some quartz, with euhedral shape, occurs in the orthoclase as inclusions; large subhedral quartz grains are present, but the majority occur as anhedral grains and are generally interstitial. Others have penetrated and replaced plagioclase and orthoclase in myrmekitic-like blebs or have formed "brain-coral" myrmekite (pl. 2-C) and and graphic intergrowth (pl. 2-D and E). These graphically intergrown quartz and myrmekitic quartz are believed to be the latest formation of quartz. Thus, four stages of quartz deposition, each with its own particular habit, are indicated.

PLATE 2



A



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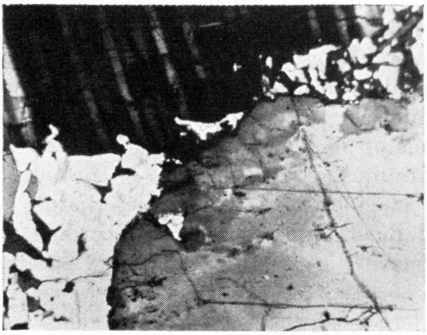

C

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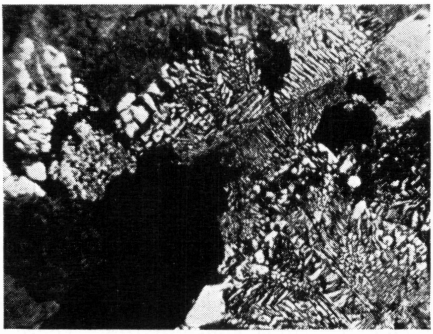

E

A. Uralitized clinopyroxene crystals in granogabbro, Sec. 30, T. 4 N., R. 15 W., Wichita Mountains.

X 24, ordinary light.

B. Poikilitic hornblende in uralitized granogabbro, Sec. 30, T. 4 N., R. 15 W., Wichita Mountains.

X 24, ordinary light.

C. "Brain-coral" myrmekite in leucogranogabbro, Twin Mountain.

X 80, nicols crossed.

D. Gradual development of micrographic intergrowth of quartz and feldspar. Note that the quartz grains are in fine-grained and finger-like patterns. Leucogranogabbro, Twin Mountain.

X 34, nicols crossed.

E. Spectacular development of micrographic texture in leucogranogabbro. Twin Mountain. The feldspar grains form the host within which quartz ramifies in a fingering pattern or appears as parallel streaks. Note that one feldspar grain still retains Carlsbad twinning.

X 34, nicols crossed.

(2) The gradual development of graphic intergrowths of quartz and plagioclase by replacement of feldspar is noteworthy. All stages are present from corroded crystals to small scattered relics in optical continuity. Residual pools of feldspar often have wispy sericite developing on or near the replacement front, probably representing a part of the liberated K_2O and Al_2O_3. In the more advanced stages, graphic intergrowth is then evolved by the development of fine-grained, diamond-shaped, fingering-like patterns. Either the orthoclase or the plagioclase may form the host within which quartz ramifies in a fingering pattern or appears as parallel streaks. Considerable areas of quartz are optically continuous. Many large crystals of plagioclase still retain their oscillatory zoning and Carlsbad twinning (pl. 2-E). From this description it is recognized that graphic texture in this particular instance is not necessarily a result of crystallization of a magma of eutectic composition.

(3) A characteristic feature of the leucogranogabbro and associated igneous rocks adjacent to granophyre and pegmatite contacts is the development of myrmekitic intergrowth of plagioclase and highly vermicular quartz. Many myrmekites develop where crystals of plagioclase are in direct contact with orthoclase or microperthite, and are thus generally held to be a product of replacement of potash feldspar by plagioclase. A similar description is given by Tilley (1921, p. 87-88) and Read (1931, p. 149). According to Tilley (p. 88), the formation of myrmekite in granitic rocks is a special phase of albitization.

As already noted, the impregnated rocks in the Wichita Mountains are cut by riebeckite-bearing pegmatites. The albite solution essential to replacement may be derived not only from residual magma extracts but also from the pegmatitic fluids reacting upon the invaded rocks. The development of myrmekite in all the sections examined is significant. Where the myrmekite occurs on the borders of orthoclase, it indicates the presence of albitizing solutions. The development of the incipient and other forms of albite is probably also caused by the presence of such solutions, and occurs in the same phase of alteration as the myrmekite. These changes were accompanied by considerable sericitization of the feldspars and the chloritization of biotite and hornblende. Some epidote is clearly secondary and has replaced the plagioclase and other constituents.

It is evident that the igneous rocks as a whole have been subjected to some hydrothermal changes since consolidation. These changes include an addition of soda to form myrmekite and incipient albite, the addition of silica to form quartz, and the addition of lime to form epidote. It is suggested that these hydrothermal changes in the igneous rocks were produced by the residual magma extracts, which acted upon the consolidated portions of the rock. In other words, the changes were deuteric, or epi-magmatic.

Gilluly, from the field and microscopic evidence, has discussed and described similar changes in a diorite related to the origin of albite granite near Sparta, Oregon (1933, p. 71-81). He considers it probable that the formation of the myrmekite in albite granite indicates the existence of post-magmatic albitic solutions. He reviews the literature on the subject giving many references on its formation. He considers the presence of lobate quartz as evidence of silicification, and also the widespread occurrence of epidote, rather than other mafic minerals, as suggesting hydrothermal processes (p.74).

(4) The association of brown and green hornblende calls for comment. Walker (1940) described brown and green uralite hornblendes in Palisade diabase. Shand (1942) found that brown and green hornblendes occurred in both the diorites and norites of Cortlandt, New York, and suspected the only reason for the color to be the degree of alteration. The useful criterion for the separation of hornblende was crystal habit, prismatic indicating an early crystallization, and poikilitic, a later deuteric one. Kunitz (1930) thought titania is the probable cause of brown pleochroism in basaltic hornblendes.

Brown poikilitic hornblende, then, is not necessarily primary because of its color, which may be due to alteration or presence of titania, but rather the result of later deuteric action, which is also responsible for the poikilitic green hornblende. Optical properties cannot be used to differentiate poikilitic from prismatic and brown from green. The only valid criterion is external crystalline form. In the light of this discussion, the writer found Shand's (1942, p. 416) observation of color due to degree of alteration is the easiest to accept.

(5) As already noted, the syenogabbro and granogabbro in Sec. 30, T. 4 N., R. 15 W, have undergone uralitization. In the first stage of this alteration, clinopyroxenes have become decomposed, then amphibole needles have developed around the edges, cracks and cleavages of clinopyroxene grains. As uralitization proceeds, the mafic minerals are completely replaced by fibrous aggregate of amphiboles. Magnetite is thrown out in the process and forms small grains along cleavages, or is scattered in the relics of clinopyroxene grains. The original structures and inclusions are preserved, and the amphibole pseudomorph looks exactly like clinopyroxene in ordinary light. Diallage appears to change directly to pale green uralitic amphibole, which commonly reacts with plagioclase to form a deeper green border. Hypersthene changed first to fibrous aggregates of colorless tremolitic amphibole, which reacted with adjacent plagioclase to form green borders, and subsequently changed completely to green uralite and serpentine.

In the advanced stage of uralitization, all clinopyroxene structures disappeared, and the uralite recrystallized to a deeper green and more pleochroic hornblende. Magnetite and ilmenite collected into clots associated with amphiboles. Remnants of clinopyroxene were retained.

In the final stage of uralitization, small amphibole needles developed in the feldspars. Hornblende was replaced by aggregates of anomalous blue penninite, and epidote makes its appearance.

The uralitized rocks have been derived from the gabbroic rocks, after their consolidation, by the action of residual liquids and vapors from the invading granophyric melt. Intrusion of granite accompanied by pegmatite and aplitic dikes could conceivably have caused such uralitization by pneumatolytic action, as the uralitized rocks are commonly cut by dikes, and usually occur along joints and shattered areas of the outcrop. Small amounts of silica must have been introduced during the process of uralitization, as some feldspar grains had been replaced by late quartz; a similar conclusion has been given by Oliver in his studies of uralitization on Sudbury norite (1951, p. 427-429).

Read (1935, p. 606) described the chemical analysis of the uralitized quartz-gabbro as having higher percentage of H_2O than the normal quartz-gabbro. It appears that the introduction of water could have produced such a change just described.

In view of the intense hydrothermal activity in the Wichita Mountains, it is believed, then, that the uralitization of the syenogabbro and granogabbro is due to the permeation of liquids and vapors of the invading granophyric melt through the gabbroic rocks.

ORIGIN OF LEUCOGRANOGABBRO AND ASSOCIATED IGNEOUS ROCKS

Field occurrences and petrographic studies show that the leucogranogabbro and associated igneous rocks are not differentiated in their present forms from one magma, but represent altered products of the gabbroic rocks through contact action of a granophyric melt. These rocks obviously intermediate in composition between granite and gabbro are assumed to represent a uniform intermingling of gabbro and granophyre, together with partial granitization and hybridization. The following features are highly significant and support the view just set forth.

Field relationships.—The leucogranogabbro and associated igneous rocks contaminated with granitic materials and veined with pegmatites, as described, occur as "intermediate rock" along the contacts between gabbroic rocks and granophyre throughout the Wichita Mountains, Oklahoma. At Twin Mountain and elsewhere masses of anorthosite are converted to mixed rocks by granophyric impregnation. Riebeckite-bearing pegmatites occur in the rocks near the contact. Away from the contact, veins and nests of pegmatite are absent, but separate crystals of basic feldspar in anorthosite are associated with such magmatically incongruous minerals as quartz, orthoclase and microperthite. Commonly, a uniform, light gray to reddish-gray matrix of modified anorthosite encloses large and small "islands" of less altered rock. In many places, however, the anorthosite mass is thoroughly impregnated and mixed with granophyric materials, leading to the development of leucogranogabbro and leucosyenogabbro.

In Mount Sheridan and elsewhere the gabbroic rocks are altered by a group of distinct but ramifying quartzo-feldspathic veinlets resembling the reticulating stockworks of ore deposits. Many quartzo-feldspathic veinlets are pure; elsewhere disintegration products of gabbroic rocks contaminate them greatly. The occurrence of these veinlets in the gabbro illustrates the contact action of a granophyric melt when in non-equilibrium with the rock. Pseudodiabasic texture of the "intermediate rock" may develop near the gabbro, but it becomes less prominent away from it. Granophyric materials are found in the minute interstices in masses of gabbroic rocks. The rocks are converted to granogabbro and syenogabbro. At places the contact action has gone so far that a mass of rock has become more granitic than gabbroic, developing granodiorite.

Thus, the field relationships alone unequivocally indicate that transformation of anorthosite into leucocratic mixed rocks and gabbro to melanocratic mixed rocks was a result of contact action of the intruded granophyric melt on the solidified gabbro. Perhaps both mechanical and chemical processes were responsible for the peculiar mineralogical and textural features of the "intermediate rock." Mechanical processes are indicated by fracture fillings and sporadic occurrence of lit-par-lit injections.

The dominant genetic process appears to be introdution of granophyric materials through chemical processes, i.e., diffusion. Intermixture of two different materials and partial granitization occurred under conditions of contact alteration. Here, gabbro and granophyre differ greatly in composition, and it is concluded that these differences were in large part responsible for the chemical processes (Ramberg, 1945, p. 106). In addition, a temperature gradient between the hot granophyre and solidified gabbro probably existed. These two factors, temperature and composition, are regarded as the greatest factors in the chemical activity gradients.

The importance of large-scale impregnation and soaking of the surrounding rocks during granitic invasions is well known. In the present area, the magmatic impregnation responsible for the formation of the leucogranogabbro and associated igneous rocks was related also to the pegmatitic phase of igneous intrusion as evidenced by the field occurrence of the rocks.

Presence of micrographic intergrowth and myrmekite.—The development of micrographic texture and myrmekite in the leucogranogabbro and associated igneous rocks has already been described. Numerous descriptions of more or less similar micrographic intergrowths of all kinds are found in the literature, and appear to be highly characteristic of rocks formed near igneous contacts as a result of incomplete reaction between magmatic fluids and invaded rocks. Such intergrowths also indicate a potency of granitization processes. In view of the above facts, it is concluded that the intergrowths described in the mixed rocks originated during the later stages of the pegmatitic phase of reaction. Quartz partially replaced original plagioclase, orthoclase, microperthite or biotite, large crystals of which now act as hosts to the graphic or vermicular quartz inclusions.

Quartz fabrics.—The banded structure of anorthosite now converted to leucogranogabbro and leucosyenogabbro is locally preserved, and parallelism of plagioclase tablets is well developed in some areas of the rock. This parallelism of feldspar is discernible megascopically only in the most favorable cases, but under the microscope is often seen even in random sections. It follows, therefore, that there is a strong indication that its occurrence is not a matter of chance but that it is related in origin to magmatic flow (Walper, 1951. p. 51) at the time the basic magma was emplaced.

Fabric diagrams were made showing the distribution of 180 quartz axes in leucogranogabbro. Three thin sections were cut from a selected specimen parallel to three planes at right angles to one another. The vertical line of figure 2-A indicates the section parallel to the trends of bands. Three fabric diagrams, all from one specimen, are shown in figure 2. These diagrams appear to have a completely haphazard arrangement of fabric elements.

In the writer's previous studies, the olivine in flow-banded troctolites shows marked preferred orientation with Y and Z in the plane of banding

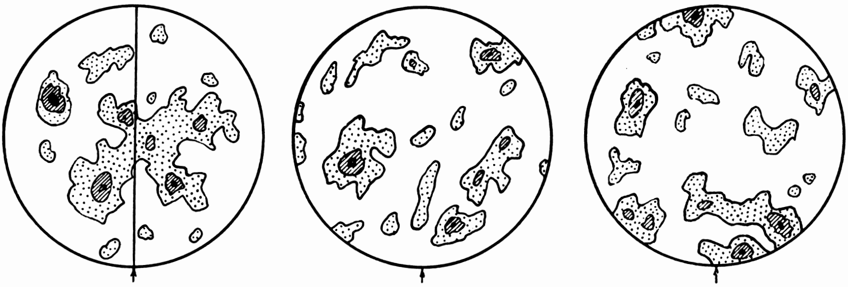

Fig. 2. Petrofabric diagrams showing the plot on each of the optic axes of 180 quartz crystals. Contour intervals: 1-2%, 2-4%, and over 4%. Diagrams are from three mutually perpendicular thin sections, cut from one specimen of leucogranogabbro at Twin Mountain. The vertical line of figure A indicates the section parallel to the trends of bands.

(Huang and Merritt, 1952), and the feldspar grains in banded anorthosite have their faces (010) preferably parallel to the plane of banding (Huang 1954). Petrofabric studies of quartz indicate that it is susceptible to reorientation when subjected to deforming influence and movement (Turner, 1948, p. 192, 211). Hence the completely haphazard quartz diagrams of the leucogranogabbro from Twin Mountain appear to indicate that the positions of the quartz crystals are unrelated to the force which has produced the preferred orientation of olivine and plagioclase parallelism.

From the foregoing analyses of the haphazard orientations of quartz and from the fact that most quartz grains are characteristically interstitial fillings, it is clear that the intrusion of the granophyric materials and the attendant injection of pegmatitic fluids into the already solidified anorthosite was a result of late magmatic impregnation along and across the bandings. These bandings are avenues of weakness, along which the fluid felsic materials are most capable of intimate penetration.

Mineralogical features.—Leighton stated (1954, p. 433) that chemical investigation failed to distinguish between a primary or secondary origin for the "intermediate rock." The writer thus has emphasized the field and petrographic nature of the rocks for the interpretation of origin. The following mineralogical features are highly significant.

The sillimanite of the granogabbro is strictly confined to the area immediately adjacent to pegmatite contacts, and it may be reasonably inferred that one of the conditions essential for its development was through permeation of pegmatitic fluids. Though the writer (Huang and Merritt, 1954, p. 563) interprets the presence of sillimanite in anorthosite and considerable amounts of spinel in the associated troctolites of the Wichita Mountains as products of the assimilation of argillaceous sediment, the occurrence of sillimanite clearly derived from pegmatite in the granogabbro does not seem to indicate conclusively that the production of this mineral was due to assimilation of argillaceous sediment. The fact that andalusite and sillimanite in granitic rocks are not always contamination products has been critically discussed by Hills (1938). From the field and petrographic evidence, the presence of sillimanite in granogabbro indicates conclusively that the pegmatites were injected into the invaded rocks, and that the sillimanite is derived from the pegmatitic phase of igneous intrusion.

The abundance of apatite in the "intermediate zone" indicates alteration. Nockolds (1933) believed that concentration of apatite in basic rocks intruded, or included, by acidic magmas is a result of volatile action.

Sphene, while not found in gabbroic rocks and granophyre of this area, does occur in the leucogranogabbro and associated igneous rocks. That the sphene crystals are commonly associated with quartzo-feldspathic materials is no doubt to emanations from the adjacent masses of granophyre and pegmatite.

The abundance of hornblende in granodiorite, as compared to the paucity of that mineral in granophyre of the area, clearly indicates that it has been formed in the presence of hydrous fluids at the end stage of granitic action.

The blotchy appearance of amphibole crystals with their variability of pleochroism and other optical properties in uralitized mixed rocks is hardly suggestive of primary origin. The blue-green patches on many amphibole crystals suggest introduction of soda. Also, the occurrence in felty aggregates and irregular crystals suggests alteration processes after pyroxenes. Clots of magnetite and ilmenite were thrown out in the processes.

Ghostlike remnants of plagioclase in the intermediate zone show considerable epidote and sericite. The lime in the epidote suggests that the plagioclase was formerly more calcic.

The peculiar albitic stringers cutting through more basic plagioclases illustrate the action of sodic solution, a phenomenon similar to that of metasomatic albite granite near Sparta, Oregon (Gilluly, 1933, p. 68).

Introduction of silica is abundantly indicated by the quartz replacement of feldspar. The evidence of quartz replacement in the intermediate zone may indicate that granophyric interstices in the mixed rocks also originated through replacement.

SUMMARY AND CONCLUSIONS

The Precambrian igneous rocks in the Wichita Mountains of southwestern Oklahoma comprise a stratiform complex in which intrusions of granophyre cross-cut and overlie anorthosite and gabbro. The complex probably forms horizontal sheet-like intrusions.

Between the gabbro and granophyre a narrow zone of "intermediate rock" composed of leucogranogabbro, granogabbro, granodiorite, leucosyenogabbro and syenogabbro exhibit peculiar mineralogical and textural characters. Field occurrences and petrographic studies indicate that these rocks originated as alteration products of the gabbroic rocks through contact action of a granophyric melt. The nature of the contact effects and patterns of injection of granitic materials in the gabbroic rocks are of great variety in detail, but they may be regarded as variations of injection of distinct granitic veinlets, disintegration of gabbro in granophyre, and chemical processes, i.e., diffusion of granitic materials in gabbroic rocks.

The field relations clearly indicate that the transformation of anorthosite into leucocratic mixed rocks (leucogranogabbro and leucosyenogabbro) and gabbro into melanocratic impregnated rocks (granogabbro and syenogabbro) was largely due to percolating magmatic fluids thoroughly permeating the invaded rocks by contact action. Where the contact action has gone so far a mass of rock has become more granitic than gabbroic, leading to the development of granodiorite.

Finally, the association of the layered gabbroic intrusions and granophyre with an "intermediate zone" in the area studied is in common with those of Bushveld, Duluth, Pigeon Point, Sudbury, North Wisconsin and other complexes of the world, and the granophyre is thus presumably not just an entirely fortuitous later granite intrusion but has some genetic connection with the gabbroic rocks.

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