THE ACCESSORY MINERALS OF THE WOLF MOUNTAIN GRANITE, LLANO COUNTY, TEXAS*

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Introduction

The present investigation was undertaken with several objectives. One was to establish definitely the accessory mineral assemblage of the Wolf Mountain granite mass as a possible aid to the sedimentary petrology of the Gulf Coast formations. Another objective was to sample various other igneous bodies in this same area in order to compare tentatively their assemblages with the above mentioned rock. However, the primary problem was to determine any bearing the accessory minerals of the Wolf Mountain granite might have upon the character of the mechanics of intrusion, and on the identification of related intrusive forms.

The Wolf Mountain granite intrusive, approximately thirty square miles in area, is located just north and west of Llano in what is generally known as the Central Mineral region of Texas. It has been mapped by two geologists, each of whom classified it as a different type of intrusion. In the United States Geological Survey Folio published on the Llano and Burnet counties of Texas. Sidney Paige described it as a batholith.[1] However, H. B. Stenzel has recently remapped this particular area and has reported it to be a phacolith. It was hoped that the distribution of the minerals would show a relationship of the type of intrusion that exists and thereby confirm or disprove one of these theories.

This area was favorable for the investigation of the heavy minerals. The formation is small enough and exposed sufficiently to facilitate sampling. The United States Geological Survey Folio of the region not only has served as a guide in locating the boundaries of the granite, adjacent crystalline rocks, and neighboring intrusive granite, but also has been most useful as a source of information concerning the general geology of the region. Also, Dr. H. B. Stenzel, of the Bureau of Economic Geology, of the University of Texas, has spent some time in recent years mapping the structure of the Wolf Mountain granite and its adjoining rocks, using the methods developed by Hans Cloos for the interpretation of the shape of igneous intrusions, and has generously allowed the use of his map for the present work.[2] A report of this work will be in-

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[1] Paige, Sidney, Description of the Llano and Burnet quadrangles, *U. S. Geol. Survey, Folio No.* **183,** 1912.

[2] Balk, R., Primary structures of granite massives, *Bull. Geol. Soc. Am.*, vol. **36,** pp. 679–696, 1925.

cluded in a Texas University publication on the structural geology of Texas, to be published shortly.

Field Work

The field work consisted of collecting samples from various crystalline rocks in the Central Mineral region. Traverses as shown on Fig. 1 were made across the Wolf Mountain granite in as many directions as travel by truck was possible, and the freshest samples obtainable were taken at distances ranging from a few inches to a few tenths of a mile apart, depending on the outcrops. Samples were also collected from the Bear Mountain granite near Fredericksburg, Texas, from a large granite exposure that extends from Lone Grove to the Colorado River on the Llano-Burnet road, from schist and gneiss near the Wolf Mountain granite contacts, and from various dikes in the vicinity of Llano, Texas. All these samples were plotted on a topographic map, locations being made from physiographic features, road intersections, and truck speedometer distances.

Laboratory Procedure

A sample was crushed in a Blake jaw rock-crusher to fragments of about 1/16 inch in diameter, and then pulverized on a buckboard until the material could pass through a 65-mesh sieve. Fifty grams of this was washed and decanted until all the rock flour had been removed. The sample was then dried, weighed, and sacked. Subsequently the heavy minerals were separated by the heavy liquid method, using bromoform.

Most of the samples were so flooded with biotite they had to be searched carefully before several grains of each mineral could be picked out for identification. After the identifications were satisfactorily made, the different minerals were counted in order to determine their percentages in relation to each other. As the entire sample was too large to be studied, it was reduced to 1/16 or 1/32 of its original size with the aid of a sample splitter. The reduced sample was scattered on a glass plate (3×4 inches) on which three sets of lines 1/16 inch apart were drawn, and immersed in xylol ($n=1.49$) and all the grains of the accessory minerals between the lines were counted as the plate was moved across the field of a microscope. The counts of the three sets of lines were averaged and tabulated (Fig. 2). The abundance, size, and shape of the biotite and hornblende fragments made a comparison with each of the accessory minerals impractical; so these two were estimated only in relation to the total heavy concentrate and to each other. Because of the difficulties encountered in recognizing magnetite with this method of counting, its percentage was estimated in relation to the total concentrate after it was extracted from the sample by a permanent magnet (Fig. 2).

The Accessory Minerals

The following accessory minerals were identified in the various igneous rocks studied: biotite, hornblende, magnetite, muscovite, apatite, zircon, titanite, monazite, rutile, chlorite, fluorite, garnet, tourmaline, brookite, ilmenite, and pyrite. There were also three minerals that could not be identified and may possibly be new species. Some of the biotite was of the unaltered brown variety, but most of it had been chloritized and appeared as grayish green flakes. Varying amounts of apatite were found in all but one sample. A few samples contained "dusty" or "dusky" apatite, so-called because of their many minute black inclusions. Euhedral crystals of zircon with numerous inclusions were found in every sample studied, but unusually fine examples were found in great abundance in the quartz porphyry and in one sample of the Lone Grove granite. Much difficulty was encountered in identifying titanite because of its optical properties and varying color. The titanite varied from a deep red color to a pale wine color, not only in different samples, but in the same sample. However, a few grains of the mineral in its various shades were sent to Dr. C. S. Ross, of the United States Geological Survey, who confirmed the identification.

Monazite appeared much like a yellow variety of zircon, but chemical and optical tests established its identity. Colorless fluorite was found in the quartz porphyry and colorless to deep purple fluorite was found in the Bear Mountain granite.

A very interesting discovery was a yellow, isotropic mineral with a high index of refraction, that constituted about 60 per cent of the microscopic accessories of the Bear Mountain granite. This mineral does not seem to correspond to any known mineral, but considerable work will be necessary before that can be definitely established. Only two grains of what appears to be brookite were found, so its identification may not be correct.

Interpretation of the Data

Figure 1 shows the outline of the Wolf Mountain phacolith, the location of the samples, and percentages of the diagnostic accessory minerals in this mass. Apatite, zircon, titanite, and monazite can be used to identify the Wolf Mountain and Lone Grove granites, but titanite and monazite were not found together except in very limited quantities and in only a few samples (Fig. 1). This restricted occurrence of titanite or monazite in the presence of the other cannot be explained at present.

Abundant purple fluorite and a yellow isotropic mineral with a high index of refraction are diagnostic of the Bear Mountain granite. The fluorite also has a significant bearing on the matter of determining the age of this mass in relation to the Wolf Mountain granite.

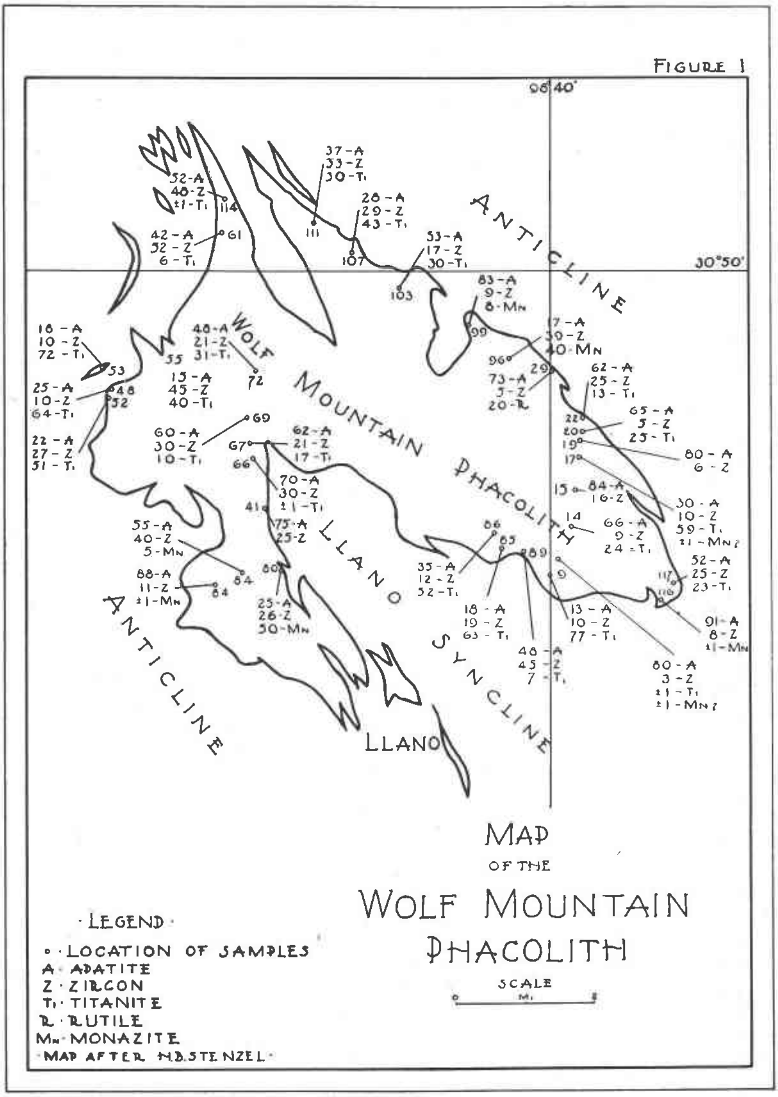

Fig. 1

The quartz porphyry contains abundant fluorite (Fig. 2) and from its field relationship is known to be younger than the Wolf Mountain

FIG. 2. ACCESSORY MINERALS
WOLF MOUNTAIN GRANITE

Estimated Per Cent of Heavy Concentrate					Per Cent of Microscopic Accessories Determined by Counting										Per Cent Heavy Concentrate
No.	B	H	Mg	Acc.	A	Z	Ti	Mn	R	G	T	Br?			
9	55	10	25	10	13	10	77					1 Grain			3.4
10	90		±1	9	80	5	±1	±1?							3.2
14	90		±1	9	66	9	24								3.2
15	90			10	84	16									8.6
17	50	25	5	20	30	10	59	±1?							7.8
19	90		±1	9	80	6		14							1.8
20	60	30	5	5	65	5	25								6.0
22	40	25	15	20	62	25	13								4.2
29	90	5		5	75	5			20	±1	1 Grain				7.2
96	85			15	17	39		44							7.2
99	90			10	83	9		8		±1					5.0
103	95			5	53	17	30								5.2
107	90	5		5	28	29	43								9.4
111	50	40	±1	9	37	33	30								18.0
114	90			10	52	48	±1								7.0
61	90			10	42	52	±6								4.6
55			85	15	15	45	40								2.2
53	60	±5	25	10	18	10	72								3.6
52	65		25	10	22	27	51								2.6
48	15	50	15	20	25	10	64								5.4
84	84			16	88	11		±1							7.6
82	90			10	55	40		5							8.0
80	95			5	25	25		50							1.8
41	80	±1	±1	18	75	25									7.0
66	90			10	70	30	±1								2.8
67	80		5	15	62	21	17								5.4
69	90		±1	9	60	30	10								7.4
72	90		±1	9	48	21	31								5.2
85	80	±10		10	18	19	63								5.0
86	90	5		5	36	12	52								5.0

FIG. 2. ACCESSORY MINERALS (*Continued*)

Estimated Per Cent of Heavy Concentrate					Per Cent of Microscopic Accessories Determined by Counting										Per Cent Heavy Concentrate
No.	B	H	Mg	Acc.	A	Z	Ti	Mn	R	G	T	Br?			
89	40	45		15	48	45	7								7.8
116	90		±1	9	91	8		±1							3.4
117	90			10	52	25	23								4.8

BEAR MOUNTAIN GRANITE

No.	B	H	Mg	Acc.	A	Z	Ti	Mn	R	G	T	Br	Fl	X	
	5		80	15	9	4							27	60	

QUARTZ PORPHYRY (LLANITE)

No.	B	H	Mg	Acc.	A	Z							Fl		
	5		80	15	5	70							25		

LONE GROVE GRANITE

No.	B	H	Mg	Acc.	A	Z	Ti								
122	5	80		15	36	40	24								
121	5	40	30	25		100									
120	95			5	43	17		37							

B—Biotite
H—Hornblende
Mg—Magnetite
Acc.—Accessory Minerals
A—Apatite
Z—Zircon
Ti—Titanite

Mn—Monazite
R—Rutile
G—Garnet
T—Tourmaline
Br—Brookite
Fl—Fluorite
X—Unidentified

granite. The Bear Mountain granite and the quartz porphyry possibly are of the same age as shown by the similarity of the accessory mineral assemblages. Both are low in biotite and apatite, and contain considerable amounts of magnetite, but the most convincing evidence in favor of such a possibility is the presence of large amounts of fluorite in both masses and the complete absence of fluorite in any other sample studied.

As mentioned before, Stenzel mapped the Wolf Mountain mass and described it as a phacolith since it has intruded into and assumed the shape of the Llano syncline (Fig. 1) with a pitch of approximately 16 degrees toward the southeast. Assuming Stenzel's work to be correct, the northwest side would be the truncated bottom of the phacolith and the southeast would be the topmost part.

Figure 1 shows a decided increase in the ratio of zircon to apatite at the northwest end of the granite, which would be the bottom of the mass. This can best be seen by noting the amounts of apatite in relation to zircon in the samples, beginning with No. 55 on the northwest end and continuing to Nos. 61, 111, 103, and 99 along the north margin of the phacolith. These show an increase in the ratio of apatite to zircon from .33:1 in No. 55 to 9.22:1 in No. 99. In the same manner, starting with No. 55 and going southeast to Nos. 72, 69, 67, 66, and 41, it will be seen that the ratio of apatite to zircon increases from .22:1 in No. 55 to 3:1 in No. 41.

There are several exceptions to this distribution, especially in Nos. 85, 86, and 89 which have approximately equal amounts of zircon and apatite although they are close to the top of the mass. Such exceptions are to be expected, however, and little importance has been given to their contradictory evidence. This concentration of zircon at the bottom of the phacolith can be explained by the fact that zircon has a higher specific gravity than apatite and would settle out faster.

Magnetite, an early crystallization mineral with a very high specific gravity, was also found concentrated near the bottom of the Wolf Mountain mass as shown by samples No. 55, 53, 52, and 48. This seems to corroborate the evidence presented by the zircon that the formation is a phacolith and not a batholith, as first described by Paige, for the reason that a batholith has no known bottom and therefore a distribution of heavier minerals such as found in the Wolf Mountain intrusion would not be expected.

In addition to the above distribution, there is a suggestion that titanite increases in abundance and deepens in color as the borders of the Wolf Mountain granite are approached. There are several exceptions to this condition, but such cases might possibly be caused by inclusions in the granite.

Conclusions

The following conclusions are listed as a result of the detailed examination of the accessory minerals of various igneous masses in the Central Mineral region of Texas.

1. The Wolf Mountain granite, Bear Mountain granite, and the quartz porphyry have different and distinguishable accessory mineral assemblages. On the other hand, the Wolf Mountain and Lone Grove granites are apparently of the same age and had a common parent magma.

2. The Bear Mountain granite is believed to be younger than the Wolf Mountain and Lone Grove granites, because of the abundance of fluorite found in the former. In view of the fact that both the quartz porphyry, known from field relations to be younger, and Bear Mountain granite contain important percentages of fluorite and a similar accessory mineral assemblage, it is possible that they are the same age.

3. The ratio of zircon to apatite seems to increase toward the bottom of the Wolf Mountain mass. This is probably caused by the higher specific gravity of zircon. Magnetite is also found concentrated on the bottom of the Wolf Mountain granite.

4. Apparently the percentage of titanite increases and the color deepens as the border of Wolf Mountain is approached.

5. The distribution of the zircon and magnetite seems to indicate that Wolf Mountain is probably a phacolith rather than a batholith.