WHITE MICA IN THE WISSAHICKON COMPLEX

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Abstract

The white mica described has unusual optical properties. The values of 2V are lower than those reported in the literature, and do not correlate with values that would be expected from the indices of refraction.

Information is given on the origin of the mica. Discussion and interpretation is further based on optical data, a Laue x-ray photograph, and chemical composition.

Introduction

The junior author, in the course of investigating the granitic rocks in the Wissahickon Valley (1), reported a white mica with unusually small optic axial angle. J. Berman (2) had previously called attention to a similar though rare mica from another locality in the Philadelphia area. The material in the Wissahickon Valley occurs in crystals sufficiently numerous and lage enough to permit easy collection and concentration.

The mica studied was collected in the valley of the Wissahickon Creek, a few hundred feet south of the contact between the Wissahickon formation and the mylonite member of the Baltimore gneiss. The white mica is found in the granitic rock and also in the adjacent Wissahickon schist. The mineral is best seen, however, in the granitic rock which is well exposed in an abandoned quarry on the west bank of the Wissahickon Creek. The granitic rock is a dike-like mass surrounded by the Wissahickon formation; it may be seen in Armstrong's (3) recent map, or in the older map of Bascom (4).

Field Description of the Host Rocks

Wissahickon Formation

The Wissahickon rock at the contact with the dike is a moderately coarse, well foliated mica schist. Associated with the coarse schist and

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alternating with it, parallel to the plane of the schistosity, is a fine-grained quartzitic biotite schist. In this latter facies the biotite is sparsely distributed through the rock and is aligned parallel to the regional strike of the foliation. The schists in the vicinity of the granitic dike have crystals of black tourmaline arranged parallel to the foliation. The largest tourmaline crystals measure 1 mm. by 3 mm.

The schistosity of the Wissahickon formation has an average strike of N. 60° E. and an average dip of 80° to the N.W. or S.E. The steep dips of the schistosity and the reversal of dip from N.W. to S.E. indicate that the Wissahickon formation at this locality has been subjected to isoclinal folding. It also shows shearing parallel to the axial plane. These relationships have been described elsewhere by the authors (5).

The Granitic Rock

Megascopically, the granite is a medium grained light grey rock. Quartz, white translucent feldspar, and books of white mica from 2 to 4 mm. in diameter are readily recognizable. The mica has no preferred orientation.

The rock occurs sporadically as sheared lenticular masses over an area of a few hundred feet in width, and extends parallel to the strike for about 2 miles from the Schulykill River to a little beyond the Wissahickon Creek. The long axes of the lenses are horizontal and parallel to the strike of the Wissahickon formation.

MICROSCOPIC DESCRIPTION OF THE HOST ROCKS

Wissahickon Formation

The composition of the biotite quartz schists in the vicinity of the granitic rock may be seen in Table 1. Accessory minerals include garnet, staurolite, tourmaline, zircon, epidote, magnetite, and kyanite.

TABLE 1. MODAL COMPOSITION OF FINE-GRAINED BIOTITE QUARTZ SCHIST

Specimen No.	AD32S	AD48SD
Biotite	10.5	8.0
Muscovite	30.0	16.5
Oligoclase	8.1	5.6
Quartz	43.2	65.5
Accessories	8.2	4.4

In thin sections the schistosity is clearly defined by the parallelism of the micas present. The isoclinal folding is also readily seen in the tight curvature of some of the mica flakes (Fig. 1). The quartz and oligoclase

crystals show a combination of cataclastic texture and sutured boundaries due to various degrees of recrystallization. The garnet and the staurolite have a poikioblastic texture, the former mineral shows considerable rotation.
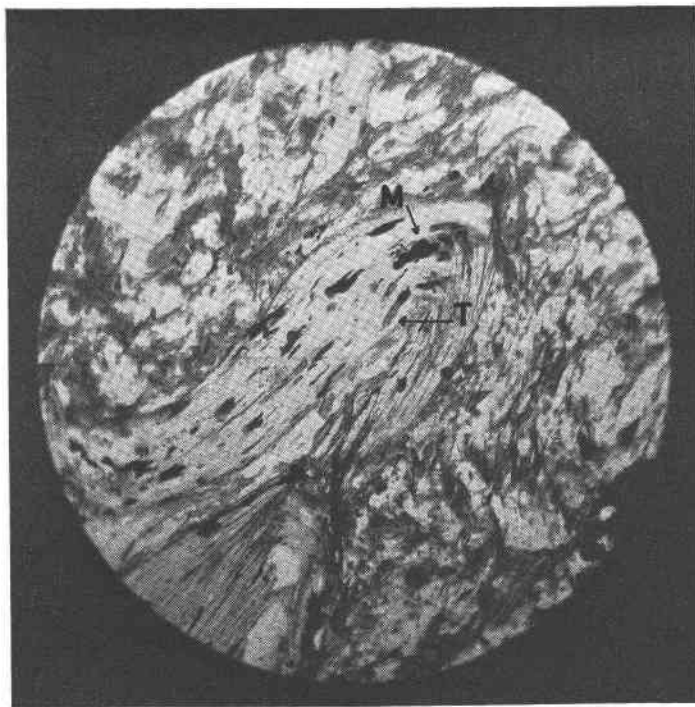

Fig. 1. Thin section of the Wissahickon schist adjacent to the granitic rock. Isoclinal folding of the mica and the distribution of tourmaline and magnetite parallel to the mica cleavage may be seen. T = tourmaline, M = magnetite.

The relationships of the biotite, white mica, tourmaline, and magnetite are of particular interest. The white mica and the biotite are interleaved parallel to the cleavage. It is difficult to interpret the replacement order in such a relationship, but it is assumed that the white mica is replacing the biotite, as it occurs always in greater quantity and is associated with such higher grade minerals as garnet and staurolite. The magnetite and tourmaline occur, often as euhedral crystals, distributed through the micas in parallel alignment to the cleavages (Fig. 1). The tourmaline is strongly pleochroic from colorless or pale mauve to dark blue-green. The indices of refraction of the tourmaline are $\epsilon = 1.632$ and

$\omega = 1.658$, which according to Winchell (6, p. 303), would indicate the following composition: dravite 50% and schorlite 50%.

The Granitic Rock

In thin section the granitic rock shows microcline, oligoclase, quartz and white mica. The accessory minerals include, in order of abundance, biotite, magnetite, epidote, and apatite. Both perthites and anti-perthites are present. The proportions of these minerals vary greatly from specimen to specimen, as may be seen in Table 2.

TABLE 2. MODAL COMPOSITION OF THE GRANITIC ROCK

Specimen No.	AD48SA	AD48SG	AD48SJ	AD46S	AD75S	AD-Q2
Microcline	0.00	20.5	26.6	0.0	0.0	26.9
Oligoclase	37.0	36.8	39.0	43.0	54.4	50.0
Quartz	45.0	33.0	15.0	41.5	29.2	14.6
White mica	16.2	6.4	12.3	15.3	15.9	4.7
Accessories	1.8	3.3	7.1	0.2	0.5	3.8
Size in mm.	0.2–2.0	0.2–3.0	0.5–2.0	0.2–2.0	0.1–1.0	1.2–3.0
Size crushed material in mm.	0.01–0.05	0.01–0.05	0.02–0.1	0.02–0.1		0.02–0.1

Under the microscope, the granitic rock shows a texture that is not apparent in the hand specimen. It is a texture that has been produced by a high degree of granulation and recrystallization. In thin section this is shown by sheared channel-ways that pass between large uncrushed mineral grains. The mineral material in the sheared channels is composed of fine grains of quartz and feldspar, which by later recrystallization have tightly sutured contacts. This granulated and recrystallized interlocking texture has been called by Anderson (7) a "pseudocataclastic" texture.

Two important replacement relationships must be noted. The first is the high degree of replacement of microcline by myrmekite. Often the myrmekites grow out from the sheared channels into the microcline. The second important replacement relationship occurs between oligoclase and the white mica, the latter replacing the former. The oligoclase crystals show fringes of white mica that penetrate the crystals. Often the white mica fringes are heavier and better developed when the mica is bordered on one side by a sheared channel-way. Many of the large complete crystals of white mica have the smooth oval shape of the unreplaced oligoclase. The myrmekites too show this type of replacement. The oligoclase of the myrmekite may be replaced by the white mica, leaving the quartz rods undisturbed, and in optical continuity, as they were in the

original myrmekite. Wherever white mica borders quartz, the contact is clearly and sharply defined.

The white mica shows a dual relationship to the biotite; the latter mineral is never present in large percentages as it is in the surrounding schists. In some sections white mica occurs interleaved with the rare biotite, suggesting that it also is replacing that mineral. In other sections the two micas appear to be independent of each other.

ORIGIN OF THE WHITE MICA

The field and microscopic data presented indicate a complex metamorphic background for the genesis of the white mica that is the main subject of this paper. The last stages of metamorphism were hydrothermal and pneumatolytic, as indicated by the tourmaline in the Wissahickon formation and the myremekitic textures in the granitic rock.

In the schist adjacent to the granitic rock, the white mica appears to replace the biotite. The magnetite and tourmaline are by-products of the replacement reaction. The excess iron released during the reaction was taken up by the magnetite, and some excess iron and magnesium were taken into the tourmaline.

The origin of the white mica in the granitic rock is clearly a late stage hydrothermal reaction. This is supported by the various replacement stages where the white mica replaces oligoclase, both primary oligoclase in the original mineralogy of the granitic rock, and secondary oligoclase in the myrmekites. The hydrothermal origin is also indicated by the frequent occurrence of the white mica adjacent to the sheared channelways of the rock. The lack of distortion of the white mica and its replacement of myrmekite also indicate that its origin is post shearing deformation.

J. Berman (2, page 90) speaking of the origin of what he called phengitic muscovite, symplectites, $2V = 35°$, found in the Springfield granodiorite says: the symplectite "occurs only where biotite and plagioclose are in contact, and . . . extends into the plagioclose from the biotite." This interesting relationship is not observed in the granitic rock of the Wissahickon Valley. Occasionally the white mica occurs interleaved with the rare biotite of the granitic rock, as it does in the schist, but usually it occurs with oligoclase without any connection with the biotite. This might suggest a dual origin for secondary white micas having low 2V values.

THE WHITE MICA

The mica from the schist and the granitic rock are much alike. Optical data on the mica from both rocks are given in Table 3.

Specimen AD48SA was selected for complete investigation as it was not intimately associated with biotite and five of the 2V measurements

TABLE 3. RANGE OF 2V AND INDICES OF REFRACTION OF MICA FROM THE SCHIST AND GRANITE*

Specimen Number	2V Range		
	Schist		
	2V	β	γ
AD21S	36°–47°	1.599	1.606
AD33SA	24°–48°	1.605	1.612
AD33SB	33°–44°	1.603	1.613
AD47SH	37°–41°	1.600	1.611
AD48SB[a]	39°–40°	1.598	1.607
AD48SD[b]	37°–47°	1.598	1.607
	Granite		
AD23S	28°–49°	1.598	1.605
AD46SB	29°–50°	1.598	1.605
AD47S	41°–46°	1.598	1.606
AD48SA[c]	26°–47°	1.604	1.611
AD48SC	24°–42°	1.602	1.611
AD48SF	25°–43°	1.603	1.610
AD48SI	22°–31°	1.598	1.606
AD48SJ[d]	25°–44°	1.599	1.606
AD74S	40°–47°	1.598	1.605
AD75S	29°–40°	1.604	1.612
AD85S	28°–40°	1.599	1.606

* Indices determined in white light by the immersion method. 2V was determined by six measurements on different mica plates with the U-stage.
[a] Schist at contact with the granite dike.
[b] Schist inclusion in the granite.
[c] Only one grain showed a 2V of 47°, the range in the other five grains was 26°–28°.
[d] The AD48S series are from the Wissahickon Creek quarry.

varied from 26° to 28°. Complete indices of refraction for this mica are:
$$\alpha = 1.573, \ \beta = 1.604, \ \gamma = 1.611.$$

2V as calculated from the foregoing indices is 48°.44′. This is considerably different from 2V as determined with the U-stage.

Laue photographs were made for specimens AD48SA with the incident beam normal to the cleavage. The resultant photographs show radial streaks or "asterism" (Fig. 2).
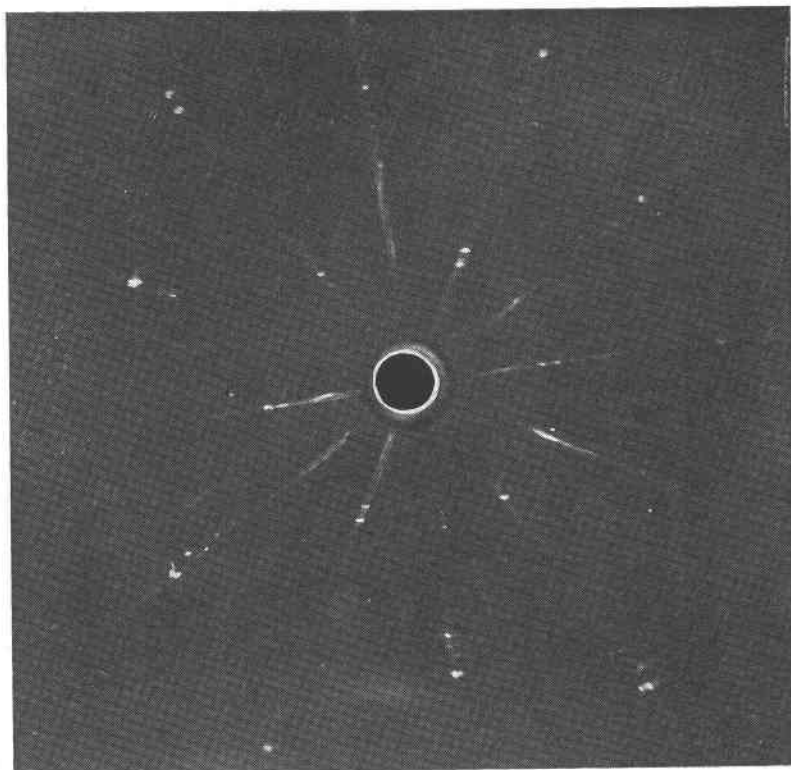
Fig. 2. Laue photograph of the white mica. Incident beam is normal to the cleavage.

Specimen AD48SA was submitted for chemical analysis, the results are shown in Table 4.

TABLE 4. CHEMICAL ANALYSIS OF WHITE MICA
(Analyst F. A. Gonyer)

SiO_2	46.10
TiO_2	2.04
Al_2O_3	30.54
Fe_2O_3	3.43
FeO	1.96
MnO	0.00
MgO	1.71
CaO	0.07
Na_2O	3.82
K_2O	6.54
H_2O+	3.83
F	0.05
	100.09

This analysis was recalculated to the formulae of Winchell, Volk, and Hallimond. The results are shown in Table 5.

TABLE 5. PER CENT MOLECULAR COMPOSITION IN TERMS OF THE END
MEMBERS OF WINCHELL, VOLK, AND HALLIMOND

End Members	Winchell	Volk	Hallimond
$H_4K_2Al_6Si_6O_{24}$	29.4	55.7	53.5
$H_4K_2(Fe''Mg)Al_4Si_7O_{24}$	53.6		
$H_6K_2(Fe''Mg)_2Al_4Si_6O_{24}$		27.2	
$H_4K_2Fe_2'''Al_4Si_6O_{24}$	17.0	17.1	
$H_4K_2(Fe''Mg)Al_4Si_6O_{22}$			46.5

Per cent of SiO_2 and Al_2O_3 not required or lacking to complete the formulae

Winchell		Volk		Hallimond	
SiO_2	Al_2O_3	SiO_2	Al_2O_3	SiO_7	Al_2O_3
−3.4	0	+0.8	−3.6	+0.8	0

Table 6 shows the molecular equivalents of the oxides of AD48SA computed on the basis of $SiO_2 + TiO_2 = 600$. This follows Hallimond's method (8, p. 306) as it gives a better means of comparison for minerals that have a constant number of silicon atoms in the molecule. Volk (9, p. 260) also recasts his analyses in this form.

TABLE 6

Al_2O_3	Fe_2O_3	FeO	MgO	$RO+R_2O_3$	RO	H_2O
226	16	20	36.	298	98	162

The end members of Winchell, Volk, and Hallimond are convenient symbols for expressing the composition of the muscovite system. They do not, however, give a true expression of the content of the individual unit cell. Therefore, the chemical analysis was also recast in terms of the structural formula suggested by H. Berman (10) in his recent reclassification of the silicates. The following formula is the result:

$(K Na)_{4.22} (MgFe'')_{1.14} (Al Fe)_{10.41} (SiTi)_{12.89} O_{41.1} (OH)_{6.9}$
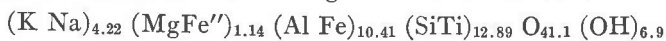
In terms of total $(Mg, Fe''', Fe'', Al'') + (Si, Al)$, this represents a variation of $+1.9\%$ from the theoretical formula as advanced by H. Berman.

INTERPRETATION

The low values obtained from 2V on the white mica of the granitic rock originally suggested that the mica was a phengite. This opinion was based on Winchell's diagram (6), on Volk's (9) revision of the muscovite group, and on the work of J. Berman (2).

Consideration of the indices of refraction of the white mica, Table 3, indicates two groupings, one with gamma about 1.611 and the other with gamma about 1.605. The ranges of 2V however seem to be independent of these two groups. According to Winchell's data on the muscovite system (6, p. 268) the beta indices are in the Mg-phengite range (1.59±) and the Fe″-phengite range (1.61±). In terms of Volk's (9, p. 263) recent work the high beta values also indicate an increasing amount of the Fe‴ muscovite molecule. When the indices of refraction of AD48SA are adjusted to the iron content diagram of Kunitz (11, p. 380), an iron content of about 4% is indicated. This checks closely with the total iron (Fe″+Fe‴) content as computed from the chemical analysis.

It is impossible however to get an adjustment on Winchell's composition diagram for the muscovite system, as the 2V value of the white mica, specimen AD48SA, is too low. Extrapolation would indicate a phengite content of near 90%. Volk's diagram on the relation of 2V to phengite content (9, p. 264) would also have to be extended to include the low 2V value of the white mica.

Perusal of the literature would indicate that no correlation can be established between indices of refraction and low 2V values.

Other factors were therefore investigated to explain the optical properties observed.

The work of Hendricks (12) on the structures of layered minerals and particularly the work of Hendricks and Jefferson (13) on the micas was taken as pertinent to the problem. Hendricks and Jefferson (13, p. 768) have stated that diffuse scattering of x-ray indicates random shift of the layers involved in the mica structure. A Laue photograph of the white mica shows "asterism" which Hendricks and Jefferson say is equivalent to the continuous Weissenberg curves which result from random shift (13, p. 767-768). It is thus indicated that the white mica has a structure involving random shift of the layers. It is interesting however to note that Hendricks and Jefferson state that this condition is not observed in muscovite (13, p. 767). Certainly there is a marked dissimilarity between the Laue photograph of muscovite given by Hendricks and Jefferson (13, p. 769) and by Jackson and West (14, p. 216) and the photograph of AD48SA. This type of behavior is characteristic of biotite, and the other micas.

Consideration of the foregoing would imply perhaps that the white mica was not a true muscovite. It might be suggested that the structure is an attribute of the replacement origin of the white mica. The degree of randomness of the structure would then perhaps be related to the degree of replacement. If random shift influences the optical properties this may explain the fact that 2V of the white mica is highly variable, as it would be influenced by the degree of random shift and the degree of replacement.

The questions raised by the foregoing optical and x-ray data make necessary a consideration of the chemical composition of the white mica.

It is known that as the phengite molecule increases in the muscovite system the value of 2V decreases. The magnesia content of the white mica, AD48SA, is not unusually high, though it may be considered moderately high. Some of the recent analyses published by Volk (9, p. 259) show much higher magnesia content, but these high magnesia muscovites have 2V values considerably higher than the mica being considered here. It would seem, therefore, that magnesia alone is not responsible for the abnormally low values of 2V previously given. Volk (9, p. 264) points out however that considerable amounts of ferric iron in combination with small amounts of phengite will cause a decrease in the value of 2V. An examination of the chemical analysis of AD48SA shows a high ferric iron content in combination with the magnesia. This then may explain the very low 2V value of the specimen, lower than values given by either Winchell or Volk, it does not however account for the variable nature of 2V.

It should be pointed out, however, that ferric iron alone without magnesia will reduce the size of 2V. The lowest 2V (with one exception to be noted later) for the muscovites reported on by Jakob (15, p. 445–446) is 36° 10′, the Fe_2O_3 content for this specimen, #14, is 3.85%, the MgO is only 0.74%.

Of particular interest is the unusually high soda content of the white mica, AD48SA. The ratio of soda to potash is approximately one to two. Published analyses (16 and 17 and bibliography) show that the usual soda-potash ratio for muscovite ranges from one to five to one to ten. The analyses published by Winchell (18, p. 421) include two that have similar soda-potash ratios. Out of 75 analyses published by Boeke (19 p. 86) only four have a soda-potash ratio of 1:2, and of these analyses only one has a soda content between 3 and 3.5%, none are over 3.5% (p. 116). On the other hand the soda-potash ratio is not sufficient to call the mica paragonite. Three analyses of paragonite recently published by Stevens and Schaller (20, p. 526) show for that mineral soda-potash ratios of from 3:1 to 7:1. The influence of this low soda-potash ratio on

optical properties is at present indeterminate. However, it is not probably great, as the lowest 2V for a muscovite reported by Jakob (15, p. 455–446, #18) is 29° 20′, the soda-potash ratio is 1:6. The high soda content of the white mica is probably due to its origin, the soda coming from the replaced oligoclase.

Summary and Conclusion

The white mica, AD48SA, has been described from as many view points as possible in the hope of giving a complete picture of all factors involved. The tectonic and paragenetic history of the host rock is complex which perhaps accounts in part for the peculiar properties of the mica.

A search of the literature has revealed no white mica with equivalent chemical and optical characteristics. The optics of the mica are abnormal in that the indices of refraction are fairly constant while the value of 2V shows wide variation. Chemically, it is interesting to note the unusually high soda content of the mica in combination with moderate magnesia and high ferric iron. The idea is advanced that random shift in the structural planes of the mica may have some bearing on the low and variable values of 2V. It also seems that Volk's statement that moderate amounts of magnesia in combination with ferric iron will decrease the value of 2V is correct. It is however impossible to say which of these factors, or combination of factors, is responsible for the effects observed.

In conclusion the following points may be made:

1. It is not always possible to get a good approximate chemical composition of a white mica from the present optical diagrams.

2. It is not advisable to deduce high phengite content of a muscovite in terms of 2V alone.

3. It is not always advisable to deduce high ferric iron in combination with moderate magnesia content from 2V alone.

4. None of the existent diagrams show the influence of ferric iron in decreasing 2V.

5. In view of the first three points it would seem that the only accurate way to determine the composition of a doubtful muscovite is by a chemical analysis.

6. It may be of value if future studies in the muscovite system take the genetic factor into consideration.

7. Low values for 2V in a white mica may be caused by five factors acting singly or in combination: high magnesia content, high ferric iron content, moderate magnesia and high ferric iron content, random shift in the lattice structure, and a hydrothermal replacement origin.

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