THE AMERICAN MINERALOGIST, VOL. 45, JULY-AUGUST, 1960

IRON-RICH MUSCOVITIC MICA FROM THE GRANDFATHER MOUNTAIN AREA, NORTH CAROLINA*

MARGARET D. FOSTER, BRUCE BRYANT, AND JOHN HATHAWAY,
U. S. Geological Survey, Washington 25, D. C.

ABSTRACT

The metamorphic arkoses and arkosic quartzites in the Grandfather Mountain area, North Carolina, contain green micas that have high indices of refraction with the β index ranging from 1.603 to 1.619. Detailed study of mica having the highest indices of refraction showed that it is dioctahedral in character, falling between muscovite and phengite in the trisilicic-tetrasilicic dioctahedral potassium mica series, with considerable proxying of Fe^{+3} for octahedral Al. The green color and high indices of refraction are attributed to the high iron content and to the presence of both Fe^{+3} and Fe^{+2} (8.11 per cent Fe_2O_3 and 2.55 per cent FeO).

INTRODUCTION AND REGIONAL GEOLOGY

In the course of geologic mapping in the Grandfather Mountain area, North Carolina, (one of us (B. B.)) observed rocks containing a fine-grained green mica. The green aspect of the rocks strongly suggests the presence of chlorite in addition to mica. However, thin section study showed that no chlorite is present; the green color of the rocks is due entirely to the mica. Preliminary optical study showed that the mica is muscovitic in type but has much higher indices of refraction than usual in such micas. The high indices of refraction, and the color, incited our interest in making a more detailed study of this mica.

The Grandfather Mountain area is on the eastern edge of the Blue Ridge province 56 miles northeast of Asheville, N. C. The area is underlain by early Precambrian basement rocks and late Precambrian and early Cambrian sedimentary and igneous rocks. These rocks are surrounded by early Precambrian schists, amphibolites, gneisses, and granitic rocks. Keith (1903) interpreted the structure of this area as a complex synclinal downfold bordered by opposing thrusts. A. I. Jonas and G. W. Stose (Geologic map of the U. S., 1932) first recognized this structure as a window, and the present workers agree with that interpretation. For a summary of the regional geology see King (1955).

Retrogressive metamorphism of the basement rocks has produced a cataclastic foliation and recrystallization with development of new biotite and albite in rocks of appropriate composition both within the window and in the upper plate adjacent to the window. Progressive metamorphism in the late Precambrian and early Cambrian rocks was of the same grade.

In the window two sequences of sedimentary rocks are recognized:

---

* Publication authorized by the Director, U. S. Geological Survey.

an autochthonous sequence unconformably overlying the basement rocks and an allochthonous sequence in thrust contact with members of the allochthonous sequence and the basement rocks (Reed and Bryant, 1958). The upper sequence consists of arkosic quartzite, phyllite, and quartzite underlying dolomite, which appears to be equivalent to the Shady dolomite of the Valley and Ridge province. The lower sequence consists of an interbedded and interlensing sequence of meta-arkose, calcareous biotite phyllite, phyllite, metasiltstone, metagraywacke, and greenschist.

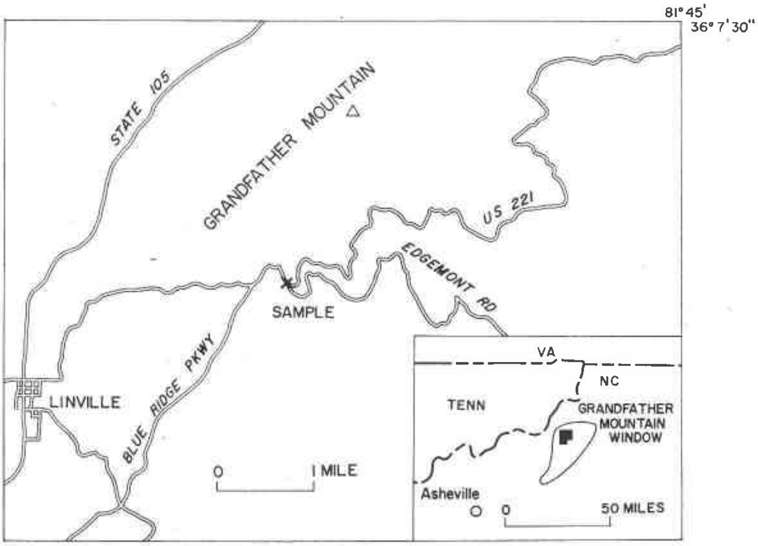

FIG. 1. Location of sample.

THE GREEN MICA

Most of the metamorphosed arkoses and arkosic quartzites in both sequences contain green muscovitic mica; the rocks range from light greenish-gray to green. The β index of the mica from some of the greener rocks ranges from 1.603 in some specimens to 1.619 in others. A sample containing mica of the highest index of refraction found was chosen for further study.

The sample selected was collected from a roadcut on U. S. Highway 221 about 1,000 feet southeast of the junction with the Edgemont road on the southeast side of Grandfather Mountain one-half mile east of the crest of the Blue Ridge (Fig. 1). This specimen is a green micaceous arkosic quartzite from the lowest member of the autochthonous sequence.

The rock displays cleavage cutting bedding at an angle of 15°. Green mica is concentrated along the cleavage planes, which are as much as 2 mm. apart in the coarser beds. Quartz and microcline clasts up to 2 mm. and plagioclase clasts up to 0.7 mm. in diameter occur in a matrix of recrystallized quartz which has an average grain size of 0.1 mm. Feldspar at least as small as 0.1 mm. retains its clastic outline, whereas quartz as large as 0.3 mm. is recrystallized and participates in mosaic texture. The mica is well aligned parallel to the cleavage and from 0.02 to 0.5 mm. long. It includes aggregates of sphene and leucoxene.

Mode of sample

quartz	45.8
potassium feldspar	14.5
plagioclase	8.1
green mica	29.2
sphene and leucoxene	1.7
epidote	.3
apatite	.3
zircon	tr.

Optical properties

The green mica has the following optical properties:

$\alpha = 1.580 \pm 0.001$ (colorless)
$\beta = 1.6195 \pm .0005$ (light green)
$\gamma = 1.6230 \pm .0005$ (light green)
$\gamma - \alpha = .043 \pm .01$
optic sign = negative
$2V = 35° \pm 3°$

The indices were determined with Na light in oils graduated in two thousandths. The α index was determined on the spindle stage (Wilcox, 1959) and the optic axial angle by Mallard's method.

SEPARATORY PROCEDURE

The sample was crushed and divided into two fractions: 100–200 mesh and 200–400 mesh. The mica was separated by a process of repeated treatment in a Bendix ultrasonic transducer and separation in a Frantz isodynamic separator. Each fraction was treated for two 20-minute intervals in the ultrasonic transducer and run through the isodynamic separator with 25° forward tilt and 15° side tilt at 1.0 amperes. The magnetic fraction from this run was treated again in the transducer and run through the separator at 0.9 amperes. This process was repeated, at each run decreasing the amperage by about 0.1 ampere. The treatment in the ultrasonic transducer shredded the mica flakes and freed minute inclusions of sphene, quartz, and feldspar which went into suspension and were decanted.

An amperage of 0.55 separated the green mica from the less magnetic constituents. This fraction was run again at 0.45 amperes to remove magnetite, yielding a concentrate of about 99% mica in the 200–400 mesh fraction, and about 98% in the 100–200 mesh fraction. The impurities were very fine grained, but were probably chiefly sphene and leucoxene.

X-RAY ANALYSIS

Both *x*-ray powder photographs and diffractometer patterns were used in the examination of the green mica. Two different diffractometers were used, operated at the following settings:

Radiation: Cu/Ni
KVP—40; MA—20
Scanning speed $\frac{1}{8}$° per minute
Low 2θ cutoff
Divergence slit 1°
Receiving slit 0.003 inch
Scatter slit 1°

Scale factor 4
Multiplier 1
Time constant 4
Sample length 20 mm.

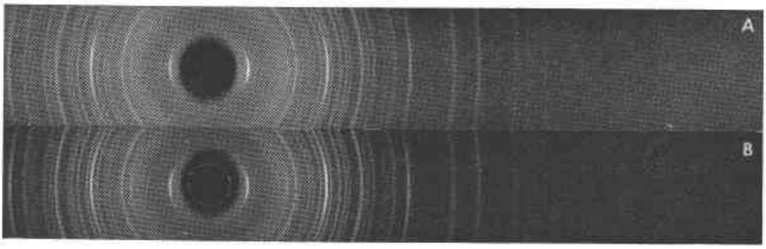

FIG. 2. *X*-ray powder photographs of: (A) Green mica from the Grandfather Mountain area, N. C., and (B) 2M Muscovite, Ontario 114.59 mm camera, CuKα, Ni filtered radiation.

The powder photographs were made of both relatively coarse and of finely ground material, with 114.59 mm. diameter cameras using exposures of about 12 hours.

The similarity between the green mica and 2M muscovite is shown in Fig. 2. Some slight differences may be noticed between the patterns, in particular the spacing of the 060 reflection. Other differences became apparent when an attempt was made to index the pattern by comparison with the muscovities listed in the ASTM *x*-ray diffraction data card file (1958). It was found necessary to calculate provisional unit-cell parameters using assumed indices. This unit cell is confirmed by the good agreement of the observed and calculated spacings shown in Table 1.

The a_0 and b_0 dimensions are larger than normal for muscovite, whereas the c_0 dimension is slightly smaller:

TABLE 1. X-RAY DATA FOR GREEN MICA FROM GRANDFATHER MOUNTAIN AREA, NORTH CAROLINA

a_0 5.249Å b_0 9.064Å c_0 19.991Å $\beta=95°45'$

hkl	*d* (calc.)	*d* (obs.)	I/I$_1$
002	9.945	9.958	100[1]
004	4.972	4.972	19[1]
110	4.525	4.525	50
$11\bar{1}$	4.497	4.498	73
021	4.419	4.421	18
111	4.331	4.326	20
022	4.124	4.130	15
112	3.990	3.992	10
$11\bar{3}$	3.898	3.897	51
023	3.742	3.748	46
113	3.595	3.590	8
$11\bar{4}$	3.501	3.501	75
024	3.350	3.349	85
006	3.315	3.316	100[1]
114	3.211	3.208	94
115	3.126	3.120	14
025	2.990	2.993	100
115	2.867	2.864	79
$11\bar{6}$	2.793	2.792	64
200	2.611	2.612	29
$13\bar{1}$	2.610		
131	2.576	2.579	90
$11\bar{7}$	2.506	2.504	20
132	2.499		
008	2.486	2.486	12[1]
204	2.413	2.409	32
027	2.407		
133	2.392	2.394	36
134	2.268	2.266	12
040	2.266		
135	2.237	2.242	9
204	2.222	2.217	7
$20\bar{6}$	2.159	2.158	18
135	2.137	2.139	36
223	2.087	2.081	4
044	2.062	2.060	3
$22\bar{5}$	2.044	2.043	5
$24\bar{3}$	1.9897	1.9897[2]	80[1]
00·10	1.9889		
$13\bar{7}$	1.9742	1.9741	55
$22\bar{6}$	1.9491	1.9517	21
$11\cdot\bar{1}0$	1.8819	1.8830	8
$13\bar{8}$	1.8488	1.8471	3
02·10	1.8213	1.8195	5
$22\bar{8}$	1.7506	1.7480	10
$11\cdot\overline{11}$	1.7316	1.7314	13
$13\bar{9}$	1.7313		
$31\bar{2}$	1.7131	1.7134	13
150	1.7127		
227	1.6995	1.6998	8
20·10	1.6646	1.6631	30
312	1.6577	1.6578	10[1]
00·12	1.6574		
139	1.6477	1.6485	64
$12\cdot\overline{11}$	1.6440	1.6442	5
$31\bar{5}$	1.6298	1.6276	8
228	1.6054	1.6047	14
049	1.5822	1.5818	5
155	1.5546	1.5608	13
13·10	1.5462	1.5456	5
$13\cdot\overline{11}$	1.5235	1.5239	20
060	1.5108	1.5107	36
$24\bar{7}$	1.5105		
331	1.4952	1.4939	2
061	1.4937		
335	1.4527	1.4515	15
$15\bar{8}$	1.4326	1.4316	8
00·14	1.4206	1.4198	12[1]
$33\bar{6}$	1.4201		
11·13	1.4126	1.4112	10
065	1.4123		
158	1.3892	1.3882	5
066	1.3747	1.3757	8
$13\cdot\overline{13}$	1.3504	1.3506	44
04·12	1.3378	1.3376	31
11·14	1.3230	1.3223	15
22·13	1.3217		
400	1.3055	1.3042	21
20·14	1.3040		
13·13	1.2926	1.2931	7
04·13	1.2680	1.2689	8
170	1.2569	1.2568	9
$35\bar{2}$	1.2571		
351	1.2475	1.2485	5
00·16	1.2431	1.2431	9[1]
173	1.2295	1.2289	4
353	1.2177	1.2174	10
$35\bar{7}$	1.1804	1.1807	3
22·14	1.1587	1.1580	8
$11\cdot\overline{17}$	1.1573		
$24\cdot\overline{14}$	1.1302	1.1294	8
357	1.1190	1.1194	5
31·12	1.1189		
083	1.1169	1.1175	4
22·17	1.0781	1.0776	3
$35\cdot\overline{11}$	1.0681	1.0677	2
$20\cdot\overline{18}$	1.0563	1.0566	4
13·17	1.0485	1.0483	14
429			
$33\cdot\overline{15}$	1.0417	1.0416	3
$51\bar{1}$	1.0416		
282	1.0296	1.0296	5
$37\bar{4}$	1.0294		
373	1.0172	1.0173	2
$33\cdot\overline{16}$	1.0029	1.0028	2
$11\cdot\overline{20}$	.98944	.98961	10

Plus at least 22 additional weak lines.

---

[1] The strongest 00*l* and *hkl* lines were each assigned an intensity of 100 because preferred orientation could not be eliminated in the specimens used and the true intensity relationships between 00*l* and *hkl* reflections could not be determined. The intensities of all of the 00*l* reflections are relative to the 002.

[2] $\lambda=1.54050$Å for this and all smaller spacings. For large spacings $\lambda=1.5418$Å.

	a_0	b_0	c_0	β
Green mica	5.249 Å	9.064 Å	19.991 Å	95°45′
Muscovite[1]	5.19 Å	9.03 Å	20.05 Å	95°46′
Synthetic 2M muscovite[2]	5.189 Å	8.995 Å	20.097 Å	95°11′

The b_0 dimension calculated from the structural formula of the green mica by the method described by Brown (1951, p. 160, 161) is in good agreement with the observed b_0.

Calculated: $b_0=9.066$Å
Observed: $b_0=9.064$Å

A further difference between the green mica and normal muscovite lies in the relative intensities of the 00*l* reflections:

		I/I_1	
	002	*004*	*006*
Green mica (oriented aggregate)	100	19	100
Muscovite[1]	95	31	100
Synthetic 2M muscovite[2]	>100	55	>100

The intensities I/I_0 for a mica having the composition of the green mica calculated by the method of Brown (1955) for an oriented aggregate in which 8 per cent of the particles behave as a randomly oriented powder (amount necessary to produce equal 002 and 006 intensities) are as follows:

3 Al:1 Fe in octahedral coordination: *002*(100); *004*(23); *006*(100).

As more iron would tend to depress the intensity of the 004 reflection and the green mica studied has slightly more total iron than the 3:1 ratio used in the calculation, the observed intensity of 19 (for 004) is in good agreement with that calculated.

The *x*-ray data for the green mica reveal a larger a_0 and b_0 but slightly smaller c_0 than for the usual muscovite. The b_0 dimension and the relative intensities of the 00*l* reflections are in close agreement with those calculated for a material of the composition of the green mica.

CHEMICAL COMPOSITION

The chemical analysis of the green mica was carried out by standard methods by one of us (MDF) except for determination of Na and K, which were made by means of the flame photometer by Ivan Barlow U. S. Geological Survey. The analysis, which is given in the first column of Table 2, shows the presence of a small amount of TiO_2 and CaO. As the sample contains a small amount of impurities, which are probably

---

[1] Gillery, 1956.

[2] Yoder and Eugster, 1955, p. 246.

TABLE 2. ANALYSIS OF GREEN MICA

	As determined	Constituents in mica	Adjusted to 100 per cent
SiO_2	47.28	47.08	47.62
TiO_2	.30	—	—
Al_2O_3	24.46	24.46	24.74
Fe_2O_3	8.02	8.02	8.11
FeO	2.52	2.52	2.55
MgO	1.86	1.86	1.88
MnO	.08	.08	.08
CaO	.14	—	—
Na_2O	.11	.11	.11
K_2O	10.6	10.6	10.72
H_2O	4.00	4.00	4.05
F	.14	.14	.14
Total	99.51	98.87	100.00
−O=F	.06		
	99.45		

Specific gravity 2.879.

chiefly sphene and leucoxene, the TiO_2 and CaO reported in the analysis are attributed to these impurities. Sphene and leucoxene also contain SiO_2, consequently 0.20 per cent SiO_2 was deducted from the SiO_2 reported as attributable to these impurities. The adjusted analysis, calculated to 100 per cent, given in Table 2 column 3, yields the following calculated formula for the green mica,

$$\Big[\underbrace{\overset{-.25}{(Al_{1.27}\overset{+3}{Fe}_{.42}\overset{+2}{Fe}_{.15}Mg_{.19})}}_{2.03}\overset{-.73}{(Si_{3.27}Al_{.73})}O_{10}(OH)_2\Big]^{-.98}(K_{.94},Na_{.02})^{+.96}_{.96}.$$

The points of particular interest in this formula, as compared to that of muscovite,

$$\Big[\overset{.00}{Al_{2.00}}\overset{-1.00}{(Si_{3.00}Al_{1.00})}O_{10}(OH)_2\Big]^{-1.00}K^{+1.00}_{1.00},$$

are, (1) the octahedral-tetrahedral charge relation, (2) the higher Si and lower tetrahedral Al, (3) the number of octahedral sites occupied by bivalent cations, and (4) the relatively high Fe^{+3} content.

The composition of some of the high silica sericites and their relation to muscovite was explained by Schaller (1950, p. 407–415) as due to their being members of a trisilicic-tetrasilicic series. Foster (1956, p. 67–77) showed that this series, of which muscovite is the trisilicic end member, is characterized by a gradual shift in the seat of the inherent unit charge from the tetrahedral layers to the octahedral layer. This shift is brought about by the replacement of octahedral aluminum by bivalent cations, usually Fe^{+2} and Mg. As this replacement is ion for ion, and the total number of octahedral cations remains the same, there is a deficiency in positive octahedral charges necessary to neutralize the anions associated with this layer, and it develops a negative charge, this charge being the greater the greater the replacement of trivalent cations by bivalent cations. Coincident with this replacement and the development of a negative charge on the octahedral layer, there is an equivalent decrease in the negative tetrahedral charge, due to increase in Si and decrease in tetrahedral Al. Replacement of half the octahedral trivalent cations by bivalent cations produces the tetrasilicic end member, in which all the inherent unit-layer charge is on the octahedral layer, and the tetrahedral layers, completely filled by Si, are neutral, as illustrated below:

$$[\overset{.00}{\mathrm{Al}_{2.00}}(\overset{-1.00}{\mathrm{Si}_{3.00}\mathrm{Al}_{1.00}})\mathrm{O}_{10}(\mathrm{OH})_2]^{-1.00}\mathrm{K}^{+1.00}_{1.00},\ \text{(muscovite)};$$

$$\searrow$$

$$\text{(phengite)},\ [\underbrace{\overset{-.50}{(\overset{+3}{\mathrm{R}}_{1.50}\overset{+2}{\mathrm{R}}_{.50})}}_{2.00}(\overset{-.50}{\mathrm{Si}_{3.50}\mathrm{Al}_{.50}})\mathrm{O}_{10}(\mathrm{OH})_2]^{-1.00}\mathrm{K}^{+1.00}_{1.00};$$

$$\searrow$$

$$\text{(celadonite)},\ [\underbrace{\overset{-1.00}{(\overset{+3}{\mathrm{R}}_{1.00}\overset{+2}{\mathrm{R}}_{1.00})}}_{2.00}\overset{.00}{\mathrm{Si}_{4.00}}\mathrm{O}_{10}(\mathrm{OH})_2]^{-1.00}\mathrm{K}^{+1.00}_{1.00}.$$

In the formula for the green mica from the Grandfather Mountain area, North Carolina, about one-fourth of the negative inherent unit-layer charge of 0.98 is on the octahedral layer—three-fourths on the tetrahedral layers. Thus this mica falls about halfway between muscovite and phengite in its octahedral-tetrahedral charge relationship. The R^{+2} ions responsible for the octahedral charge are made up almost equally of Mg and Fe^{+2}.

Trivalent iron and total iron are much higher than is usually found in micas in the muscovite-phengite part of the series. As Foster has pointed out, this end of the series is characterized by aluminum; it is the tetrasilicic end of the series that is characterized by iron—both ferric and ferrous. No analysis of a muscovitic mica was found in the literature that contained as much Fe_2O_3, or as much total iron as Fe (7.57 per cent) as was found in this specimen. The highest Fe_2O_3 recorded is in an analysis reported by Clarke (1908, p. 286), which reports 6.10 per cent Fe_2O_3. However, as no FeO is reported, this figure probably represents total iron as Fe_2O_3 and not necessarily that present as Fe_2O_3. Total iron as Fe in this analysis is 4.27 per cent, an amount lower than that found in an analysis reported by Ginzburg (1920, p. 9), which contains 5.64 per cent Fe_2O_3, and 1.27 per cent FeO. Total iron as Fe in this analysis is 4.94. A third analysis (Tolman and Goldich, 1935, p. 236) has a higher total iron as Fe content, 5.54 per cent, but is lower in Fe_2O_3, 3.94. Thus the mica herein studied is unique, for its position in the series, in its content of Fe_2O_3 and of total Fe.

Relation between Indices of Refraction and Iron Content

Winchell (1951, p. 368) concluded that the mean index (that is, the intermediate principal index, β) of muscovitic micas increases rapidly with increase in ferric iron content. Volk (1939, p. 263) agreed with Winchell's conclusion. Both Winchell and Volk used a three component diagram for plotting end member compositions of which the micas studied were presumed to be composed, Winchell using the end members muscovite, $KAl_2(Si_3Al)O_{10}(OH)_2$, ferrimuscovite, $K(AlFe^{+3})(Si_3Al)O_{10}(OH)_2$, and picrophengite, $K(Al_{1.5}Mg_{0.5})(Si_3Al)O_{10}(OH)_2$, and Volk using the end members muscovite, ferrimuscovite, and phengite $K[Al(Fe^{+2}Mg)](Si_3Al)O_9(OH)_3$. Of these end members only muscovite occurs in nature; the others, ferrimuscovite, picrophengite, and phengite are hypothetical and were postulated for the purpose of interpreting the composition of dioctahedral micas in terms of end members. However, neither Winchell's nor Volk's diagram showed a close relationship between ferric iron content and mean index; both showed considerable scatter of points. None of their micas had as high an index nor as high a content of ferric iron as the green mica herein studied. The relation between the β index and Fe_2O_3, in terms of molecular equivalents and between the β index and (Fe_2O_3+Fe), in terms of molecular equivalents in a number of muscovitic micas is shown in Fig. 3. The unnumbered points in this diagram represent micas used by Volk that contained both Fe_2O_3 and FeO; the numbered points represent some muscovitic micas reported in the literature for which both analyses and indices of refraction are given. The numbers refer to analyses given in Table 3. Although a very general trend toward increase in β index with increase in Fe_2O_3 and with increase in (Fe_2O_3+FeO) content is suggested, the relationship is not close and it would not be feasible to try to predict even the approximate iron content from the β index or vice versa for muscovitic micas. However, the points representing the much higher β index and iron content of the North Carolina mica are in line with the general upward trend of the points representing these properties in other micas.

Cause of Color

A semiquantitative spectrographic analysis by John C. Hamilton of the U. S. Geological Survey, shows that the green mica from North

Carolina contains between 0.002 and 0.005 per cent V, between 0.001 and 0.002 per cent Ni, between 0.0005 and 0.001 per cent Cr, and between 0.0002 and 0.0005 per cent Cu. The amounts of these elements present seem too low to account for the color, and Fe remains the most probable cause of the green color in this mica.

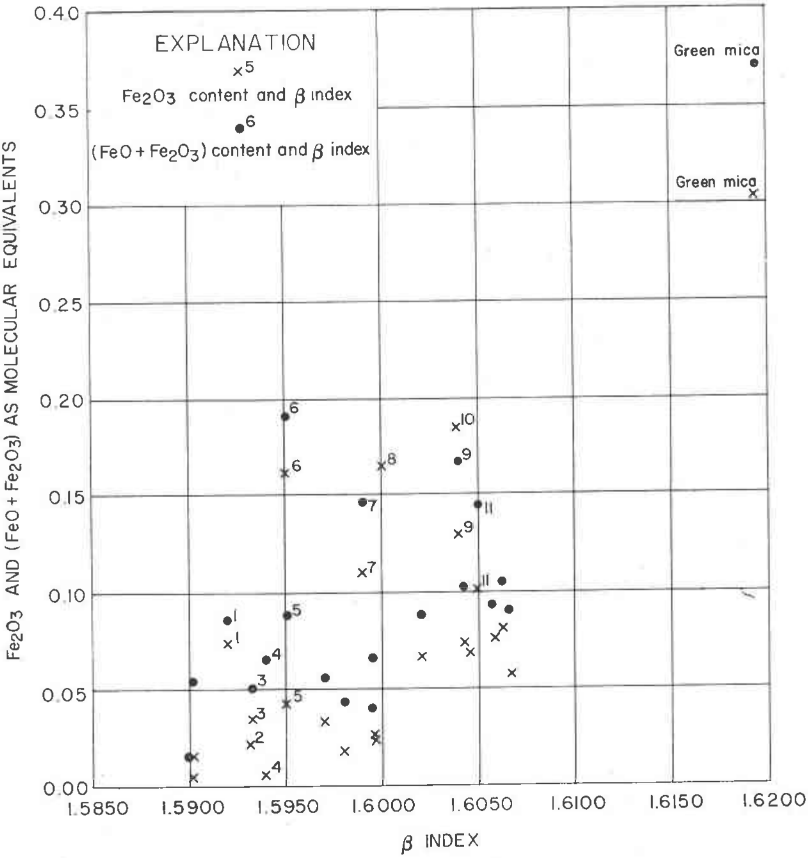

FIG. 3. Relation between Fe_2O_3 and ($FeO+Fe_2O_3$) content and β index in muscovite micas.

Fersman (1937, p. 201–204) showed that the color of many minerals depends on the relative proportions of different valences of the same atom. Thus, he states that Fe^{+2} alone is characterized by yellow-green, and Fe^{+3} alone by reddish brown, but that both ions in the same mineral depresses the color to a deep blue or black. Grigoriev and Kotulsky (1941) also found that the presence of Fe^{+2} and Fe^{+3} together produces a

TABLE 3.—ANALYSES OF MUSCOVITIC MICAS, OTHER THAN VOLK'S, USED IN PREPARATION OF FIGURE 3, ARRANGED IN ORDER OF INCREASING β INDEX

	Per cent										
	1	2	3	4	5	6	7	8	9	10	11
SiO_2	45.56	44.87	45.12	44.77	45.50	45.84	50.79	43.67	44.73	46.10	45.66
TiO_2	0.47	0.02	0.51	0.00	0.20	—	1.10	0.72	0.34	2.04	0.31
Al_2O_3	35.78	37.72	34.19	35.36	33.20	31.11	26.53	29.76	30.67	30.54	31.80
Fe_2O_3	1.92	.54	.85	.28	1.03	4.31	2.94	4.36	3.42	3.43	2.69
FeO	.51	none	.64	2.13	1.41	1.06	1.34	none	1.42	1.96	1.53
MnO	.11	trace	.02	.15	.04	.04	.05	.59	.02	.00	—
MgO	.94	.32	.92	.87	.96	1.10	2.80	1.19	1.56	1.71	.92
CaO	—	.36	.25	.00	trace	trace	—	.06	none	.07	.09
Na_2O	1.07	1.04	.71	.95	.52	2.27	1.01	.54	.53	3.82	.60
K_2O	10.03	9.83	10.33	10.81	10.49	9.66	9.71	10.00	10.18	6.54	10.34
H_2O^-		.38	1.57		1.10			2.24	1.43		.36
	3.72			4.54		4.49	3.90			3.83	
H_2O^+		4.72	5.05		5.37			6.28	5.17		5.32
F	—	n.d.	.05	.15	.18	.15	—	.95	.02	.05	.37
Total	100.11	100.24[1]	100.32[2]	100.01	100.12[3]	100.03	100.17	100.41[4]	100.23[5]	100.09	99.99
β index	1.592	1.5930	1.5932	1.5938	1.595	1.595	1.599	1.595–1.607	1.604	1.604	1.605–1.606

[1] Includes 0.27 per cent Cr_2O_3, 0.09 per cent V_2O_3, 0.08 per cent P_2O_5, and trace of Li_2O.

[2] Includes 0.01 per cent V_2O_3 and 0.10 per cent P_2O_5.

[3] Includes 0.04 per cent BaO, 0.05 per cent P_2O_5, and 0.03 per cent S.

[4] Includes 0.05 per cent BaO.

[5] Includes 0.66 per cent BaO, 0.02 per cent V_2O_3, 0.03 per cent P_2O_5, and 0.03 per cent S.

1. Claro, Tessin, Jakob, 1925, p. 445, no. 11.
2. Whitcombe Valley, Mikonui, New Zealand, Hutton, 1940, p. 330B.
3. Duffer Creek, Westland, New Zealand, Hutton, 1940, p. 330B.
4. Finnbo, Dalecarlia, Sweden, Eckermann, 1927, p. 231.
5. Mariner's Peak, South Westland, New Zealand, Hutton and Seelye, 1945, p. 161.
6. Mansjö Mountain, Sweden, Eckermann, 1927, p. 231.
7. Rossa, Val Calanca, Tessin, Jakob, 1925, p. 445, no. 18.
8. Ultevis district, Jokkmokk, Sweden, Ödman, 1950, p. 18.
9. Henry Pass, George Sound, New Zealand, Hutton and Seelye, 1945, p. 161.
10. Wissahickon Valley, Philadelphia, Pa., Postel and Adelhelm, 1944, p. 285.
11. Mattawan Township, Nipissing District, Ontario, Ferguson, 1943, p. 40.

darker color than either alone. Depth of color produced by Fe^{+2} and Fe^{+3} together, or by either alone, also depends on the amounts present. Another factor affecting the color produced by coloring ions in minerals is crystal structure (Grum-Grzhimailo, 1945, p. 933–46). Iron is responsible for green colors in biotites (Hall, 1941, p. 29–33) and for the green color in glauconite. In both of these minerals Fe is usually present both as Fe^{+2} and Fe^{+3}. Wyoming bentonite, which consists almost entirely of montmorillonite, is olive-green when Fe^{+3} predominates over Fe^{+2}, but is blue-gray when Fe^{+2} predominates over Fe^{+3} (Foster, 1956, 1003). In glauconite also, Fe^{+3} is ordinarily in excess of Fe^{+2}. As these minerals have the same crystal structure as the mica from North Carolina, it is concluded that its green color is due to the presence of both Fe^{+3} and Fe^{+2}, with Fe^{+3} predominant over Fe^{+2}.

SUMMARY

A detailed study of a green mica associated with metamorphosed arkoses and arkosic quartzites in the Grandfather Mountain area, North Carolina, showed it to be a dioctahedral potassium mica about midway between muscovite and phengite in its layer charge relationship. For its place in the trisilicic-tetrasilicic dioctahedral mica series, this mica is unusually high in content of ferric iron and of total iron. Its high indices of refraction are attributed to this high iron content, and its color is attributed to the presence of both Fe^{+3} and Fe^{+2} in the structure, with Fe^{+3} predominant over Fe^{+2}.

ACKNOWLEDGMENTS

Our appreciation is expressed to John C. Reed, Jr., coworker on the Grandfather Mountain project, and to Leonard B. Riley, both of the U. S. Geological Survey, for their encouragement and interest.

REFERENCES

BROWN, G. (1951), The mica clay minerals, Part II Nomenclature of mica clay minerals: *in* G. W. Brindley, ed., X-ray identification and crystal structures of clay minerals: London, The Mineralogical Society, 155–172.

——— (1955), The effect of isomorphous substitutions on the intensities of (00*l*) reflections of mica- and chlorite-type structures: *Mineralog. Mag.* **30,** 657–665.

CLARKE, F. W. (1910), Analyses of rocks and minerals from the laboratory of the United States Geological Survey, 1880–1908: *U. S. Geol. Survey Bull.* **419,** p. 286.

ECKERMANN, HARRY VON (1927), The optical and physical properties of two Swedish muscovites: *Geolôg. Fören. Stockholm Förh.* **49,** 229–234.

FERGUSON, R. B. (1943), Muscovite from Mattawan Township, Nipissing District, Ontario: *Univ. Toronto Studies, Geol. ser. no.* **48,** 31–41.

FERSMAN, A. E. (1937), The color of minerals: *Acad. sci. U.S.S.R. Comptes rendus,* **17,** 201–204.

FOSTER, M. D. (1956), Correlation of dioctahedral potassium micas on the basis of their charge relations: *U. S. Geol. Survey Bull.* **1036-D,** 67–77.

GILLERY, F. H. (1956), Muscovite: X-ray powder data file Am. Soc. for Testing Materials, Philadelphia, cards 6-0263, 6-0264; *X-ray powder data file* **1958,** *Am. Soc. for Testing Materials, Philadelphia.*

GINZBURG, I. I. (1920), Mica, its properties, application, and distribution in Russia, Materials to the knowledge of the natural productive forces of Russia: *Petrograd, no.* **34,** 128 p., 40 figs.

GRIGORIEV, D. P., AND KOTULSKY, A. V. (1941), Diagram showing dependence of coloration of magnesian-ferriferous micas on the content of iron oxides: *Akad. Nauk. S.S.S.R. Doklady* **31,** 691–693.

GRUM-GRZHIMAILO, S. (1945), The effect of the structure of crystals on the color produced by chromium, manganese, iron, nickel, cobalt, and copper: *Acta Physicochim. U.R.S.S.,* **20,** 933–946.

HALL, A. J. (1941), The relation between colour and chemical composition in the biotites: *Am. Mineral.* **26,** 29–33.

HUTTON, C. O. (1940), Optical properties and chemical composition of two micas from Westland, South Island, New Zealand: *New Zealand Jour. Sci. and Technology, no. 6B,* **21,** 330B–331B.

HUTTON, C. O., and SEELYE, F. T. (1945), Contributions to the mineralogy of New Zealand, Part 1: *Roy. Soc. New Zealand Trans.* **75,** 160–168.

JAKOB, JOHANN (1925), Beiträge zur chemischen Konstitution der Glimmer. II. Mitt.-Die Muskovite der Pegmatite, I. *Zeits. Kriste.* **62,** 443–453.

KEITH, A. (1903), Description of the Cranberry quadrangle (N. C.-Tenn.): *U. S. Geol. Survey Geol. Atlas, Folio* **90.**

KING, P. B. (1955), A geologic section across the southern Appalachians—an outline of the geology in the segment in Tennessee, North Carolina, and South Carolina, *in* Russell, R. J., ed., Guides to southeastern geology, p. 332–37, geol. map.

ÖDMAN, O. H. (1950), Manganese mineralization in the Ultevis district, Jokkmokk, north Sweden. Part 2: Mineralogical notes: *Sveriges Geolög. Undersökning Årsbok,* **44,** 28 p.

POSTEL, A. W., AND ADELHELM, WILLIAM (1944), White mica in the Wissahickon complex: *Am. Mineral.* **29,** 279–290.

Reed, J. C., JR., AND BRYANT, BRUCE (1958), Stratigraphy of the western part of the Grandfather Mountain window, North Carolina (abs.): *Geol. Soc. Amer. Bull.* **69,** 1633.

SCHALLER, W. T. (1950), An interpretation of the composition of high-silica sericites: *Mineralog. Mag.* **29,** 406–415.

TOLMAN, C., AND GOLDICH, S. S. (1935), The granite, pegmatite, and replacement veins in the Sheahan quarry, Graniteville, Missouri: *Am. Mineral.* **20,** 236.

VOLK, G. W. (1939), Optical and chemical studies of muscovite: *Am. Mineral.* **24,** 255–266.

WILCOX, R. E. (1959), Use of the spindle stage for determination of the principal indices of refraction of crystal fragments: *Am. Mineral.* **44,** 1272–1293.

WINCHELL, A. N., AND WINCHELL, H. (1951), Elements of optical mineralogy, Part II, 4th end.: John Wiley and Sons, Inc., New York, 368.

YODER, H. S., AND EUGSTER, H. P. (1955), Synthetic and natural muscovites: *Geochim. et Cosmochim. Acta,* **8,** 225–280.

Manuscript received September 1, 1959.