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A COLORIMETRIC CLASSIFICATION OF AUSTRALIAN PEGMATITIC MUSCOVITE

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ABSTRACT

Absorption curves have been determined for the two vibration directions in the basal plane of high-quality pegmatitic muscovite from the Harts Range, Central Australia. These show that the important absorption features, which include maxima and very distinctive examples of pleochroism, occur chiefly in narrow spectral regions between 420 mμ and 520 mμ. It can be shown that the curves are composed of several empirically independent variables which are in turn independent of overall color intensity. The inadequacy of the usual grouping into "greens" and "reds" is shown and a classification has been derived to include important features which are not normally observed or appreciated. Precision optical crystallographic measurements reveal correlations of 2V and refractive indices with the independent absorption features and, together with some chemical analyses, indicate that the proposed classification probably relates more to very small structural differences rather than to composition differences.

INTRODUCTION

Although muscovite is generally colorless in thin section, its absorption is normally strong enough for color differences to be seen in large sheets approximately 0.5 mm thick. Pegmatitic muscovites which yield this type of sheet mica occur in the Harts Range of Central Australia and have been described by Hodge-Smith (1932), Brazenall (1934), Owen and Turnbell (1947) and Joklik (1955). In keeping with the practice of other countries, they are generally referred to as green or ruby, but color descriptions commonly include other terms such as buff, brown and red.

This simple color classification of muscovite has not always proved satisfactory for predicting electrical properties and an account of this is given by Jahns and Lancester (1950) and Jahns *et al.* (1952) in their description of muscovite from sources other than Australian. Difficulties of this system eventually led Judd (1945) to define an empirical distinction between ruby and green muscovite by using color co-ordinates. Even so, Dhar *et al.* (1959) have shown that although green muscovite has a much lower volume resistivity than ruby muscovite, there is not much correlation between this resistivity and the visual properties by which the mica is normally classed. Also, this empirical distinction does not take into account the obviously visible differences which commonly occur, as for example between some typical Indian ruby muscovites and the Harts Range ruby muscovites.

Partly as a result of relying on these commonly used color descriptions, there are difficulties from other points of view.

Thus, within single muscovite books, although growth patterns comprising different shades of one color and the distinctly lighter coloring of margins are two common features readily accounted for, there is no simple explanation for markedly different hues which occur within only some of the individual unaltered books in a single zone of a pegmatite. Even though reasonably constant muscovite colors within single mica shoots are common features, in some pegmatite regions it is difficult to relate the colors clearly with the regional distribution of the containing pegmatites. In spite of the very large number of identifiable colors in book muscovite and the known good relationships of color with distribution, as for example those described by Jahns and Lancaster (1950), the use of muscovite as a geochemical indicator in prospecting for ores is very limited.

Some color-composition correlations have been obtained but these are confined to major color and composition differences. For instance, the rose coloring in some special non-pegmatitic muscovite was attributed partly to a high manganese content by Heinrich and Levinson (1953) and a high chromium content giving a strong green coloration is described by Lazarenko (1955). Apart from such special instances of color iron is regarded as the coloring element in muscovite, and Nikitin (1952) related color intensity with iron content to explain zonal coloring in large ruby colored muscovite crystals. However, it is clear from the numerous published analyses with accompanying color descriptions that there is no really satisfactory correlation between iron content and color in muscovites.

The fact that crystal structure as well as color could be important as a guide to electrical properties is allowed for by the inclusion of the apparent optic axial angle in specifications (ASTM, D351) for natural mica and a simple method for determining this angle has been described by Ruthberg (1961). However, clear relationships of structure with color and electrical properties have not been shown.

The above descriptions indicate the probable significance of structure as a determinative factor of the colors, and, although some work has been published to this effect, this latter work is still insufficient to account for the numerous colors which can occur in muscovites with virtually identical compositions. Melankholin (1948) obtained absorption curves for a number of micas and concluded that absorption in muscovite was influenced by iron occurring in both octahedral and tetrahedral sites. Also from a study of absorption curves, Grum-Grzhimailo *et al.* (1955) concluded that absorption in muscovite is not linearly related to the Fe_2O_3 and FeO contents and that lattice parameters appear to affect the absorption. Structural variations which could be applicable to these required interpretations of color in terms of structure are available as the known polymorphic forms described by Yoder and Eugster (1955), Smith and Yoder (1956) and Radoslovich (1959). However, these would not necessarily be usable for a simple color-structure correlation, since it appears from the descriptions and discussions by Hendricks and Jefferson (1939), Axelrod and Grimaldi (1949), Levinson (1953), Heinrich and Levinson (1955 a, b, c) and Smith and Yoder (1956) that it is unlikely that polymorphs, other than the 2M, would be common in unaltered pegmatitic muscovites having compositions approaching that of the theoretical muscovite.

The present study was therefore designed to obtain detailed information on the absorption of the Harts Range pegmatitic muscovites and relate this to optical crystallographic properties which, although not expected to give the exact nature of structural differences which might exist, could indicate a system of classifying specimens probably according to structural trends related to color characteristics; analytical data were intended primarily for verifying the inadequacy of composition differences to account for absorption differences.

DESCRIPTION OF COLORS

These Harts Range muscovites are mostly shades of reddish-brown to greenish-brown, but there are some which are better described as different shades of green. The intensity of coloring ranges between the two extremes of faintly tinged greenish or reddish color to very dark greenish-brown; this latter, even as moderately thin sheets, is almost black. However, most muscovite crystals yield sheets which fall within a narrow range of color intensity.

There are recognizable major trends, in both the hue and in the intensity of colors, which at first suggest a number of color groups not generally noticed. Irrespective of the manner in which such trends are used for grouping specimens, a few colors sometimes observed in hand specimens do not fall into any recognizable group. This may only be clear when using ideal lighting conditions, and possibly because of limitations imposed by ordinary lighting conditions, there are no distinct relationships between the hues and (1) the position of muscovite crystals within pegmatites, (2) the structure of the containing pegmatites and (3) the size of muscovite crystals. It possibly also accounts for the fact that color intensity of muscovites is not clearly related to their size, their associated minerals and to pegmatite zoning.

Many crystals yield sheets which are not uniformly colored, and the combined variations of hue and intensity of colors are shown as many forms of color distribution ranging from regular, sharply defined growth zones to poorly defined patches of color. Such distributions of color are not necessarily consistent throughout the whole of the distance along the *c*-axis, and a change of color in any one direction does not necessarily involve a simultaneous change in hue and intensity.

SELECTION OF SPECIMEN MATERIAL

The above observations indicated the necessity of finding major and minor color differences between large specimens. Selection of these was therefore made from several hundred high quality sheets which represented aspects of color described above as well as taking into account their distribution throughout the mica field.

Each specimen intended for absorption studies was a three-centimeter square cut from a large, flat and uniformly colored sheet of clear muscovite, the surfaces of which were prepared by cleaving off scratched or otherwise inferior outer layers. The choice of the position from which to cut the squares was aided in the first instance by selecting the center of a large area over which preliminary optical tests failed to detect any changes in crystallographic properties.

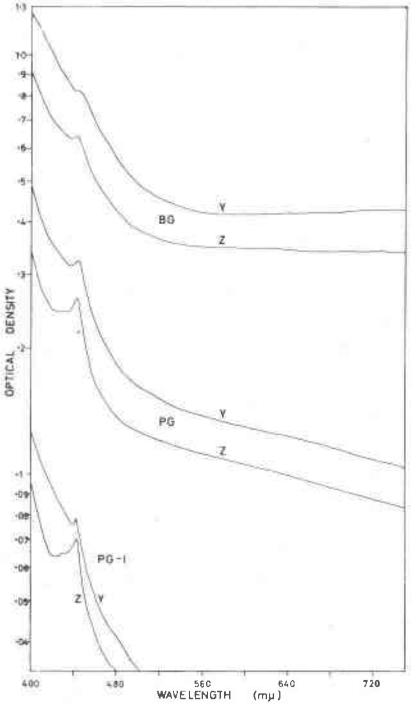
Material for precision optical studies was chosen from a succession of cleavage flakes taken from the central and side portions of the three-centimeter squares used for absorption measurements; this gave a means of detecting any non-uniformity which might occur within a specimen. It was eventually found, however, that the plates were uniform throughout both their thickness and their width.

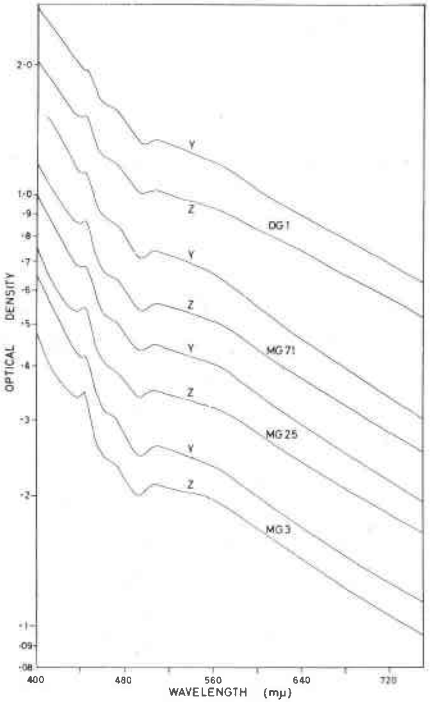
Material for chemical and spectrographic analysis consisted of cuttings from the immediate surroundings of the squares and cleavage flakes taken from the squares themselves.

METHOD OF ABSORPTIOMETRIC STUDY

Color was measured as absorption on a Beckman Model DU spectrophotometer by setting the mica plate upright on a removable base which replaced the standard 1 cm cell holder.

Absorption data for both the Y and the Z-vibration directions were obtained by polarizing the exit beam. The normal to the mica plate was inclined at a small angle to the light path to avoid interference. Absorption was measured as optical density at numerous wavelengths in the 400–700 mμ region. The selected wavelengths were at 10 mμ intervals in the longer wavelength region and, depending on details sought, at 5 mμ and 2 mμ intervals in the shorter wavelength region. Measured optical densities were corrected for reflection losses, converted to densities corresponding to a standard thickness of 0.381 mm (15×10^{-3} inches), and then plotted on a logarithmic scale against a linear wavelength scale to give the λ-log D curves shown in Figs. 1–10 and referred to henceforth as absorption curves. This method of plotting, described by Mellon(1950),





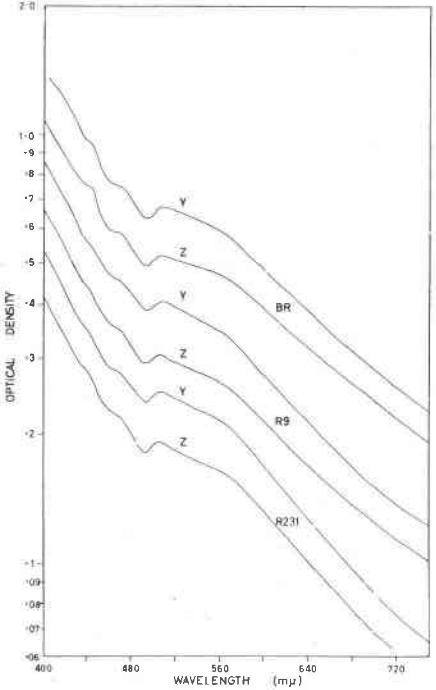


FIG. 1. Absorption curves for the two principal vibration directions in the basal plane of some typical PG color group specimens of muscovite from the Harts Range.

FIG. 2. Absorption curves for the two principal vibration directions in the basal plane of some typical MDG color group specimens of muscovite from the Harts Range.

FIG. 3. Absorption curves for the two principal vibration directions in the basal plane of some typical R color group specimens of muscovite from the Harts Range.

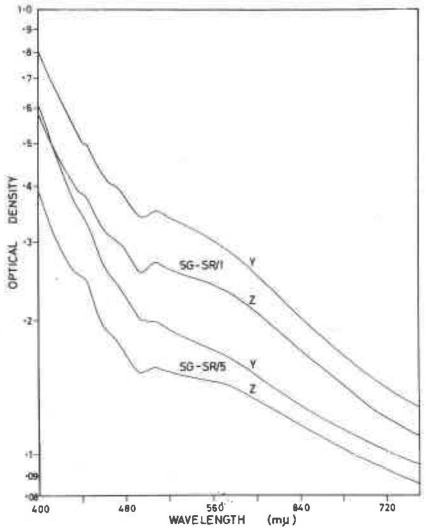


FIG. 4. Absorption curves for the two principal vibration directions in the basal plane of a typical reddish member and a typical greenish member of the SG-SR color group muscovite specimens from the Harts Range.

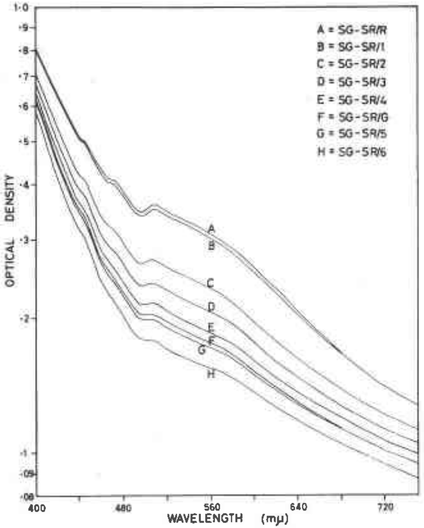


FIG. 5. Absorption curves for the Y-vibration direction in a number of SG-SR color group specimens of Harts Range muscovite. They show the changes in absorption features with increasing color intensity.

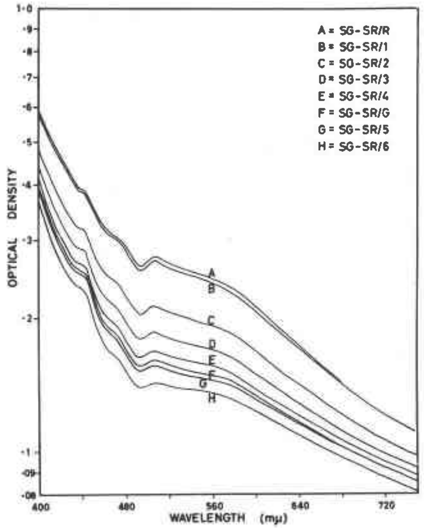
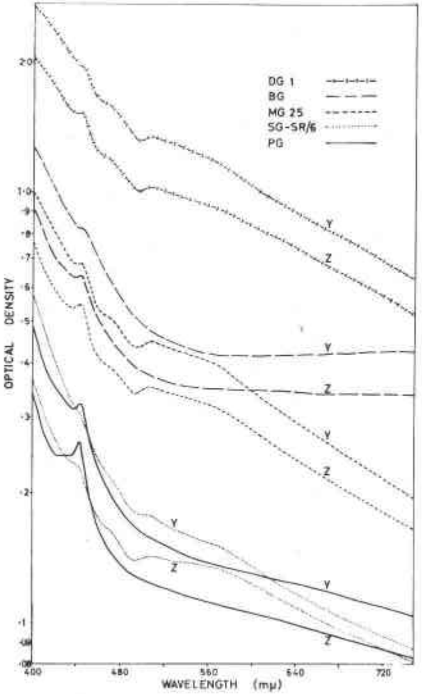
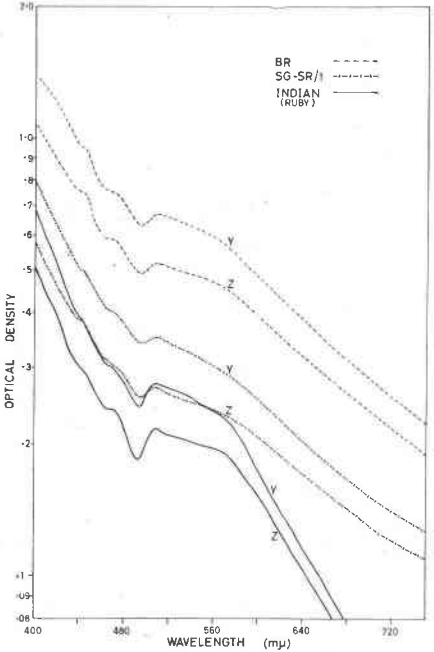


FIG. 6. Absorption curves for the Z-vibration direction in a number of SG-SR color group specimens of Harts Range muscovite. They show the changes in absorption features with increasing color intensity.





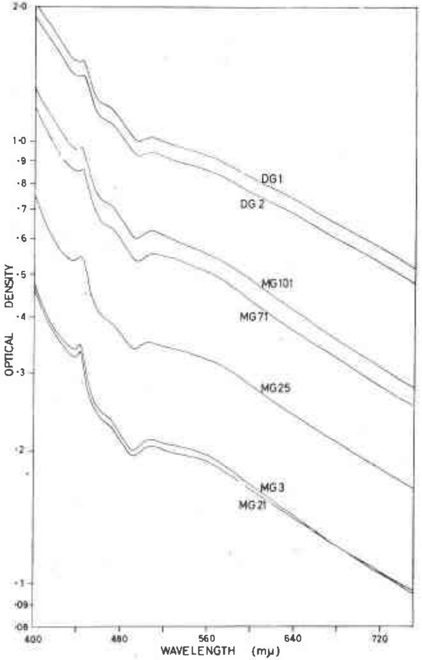
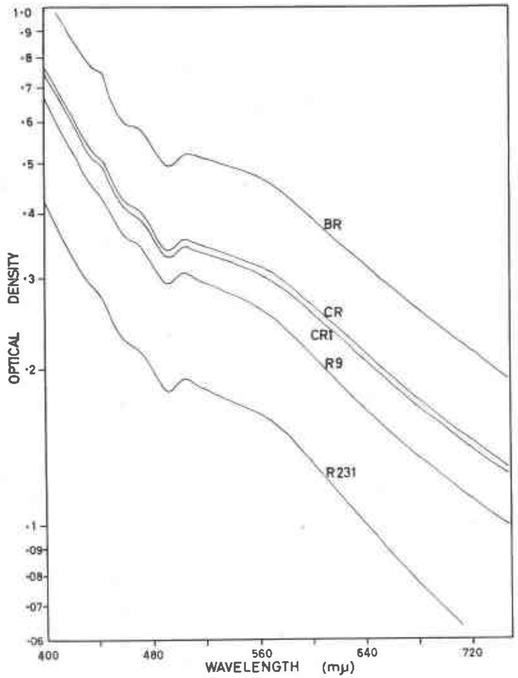
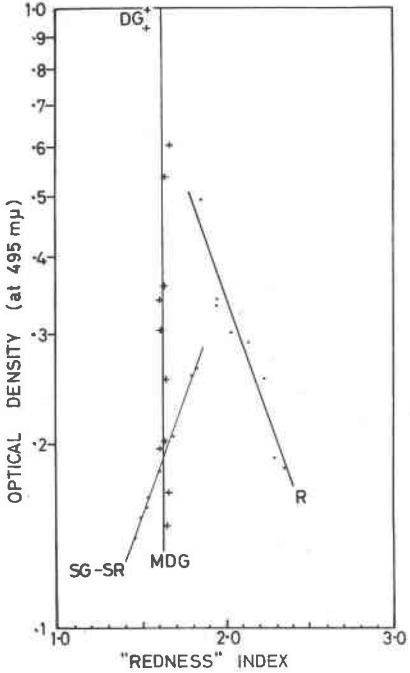


FIG. 7. Absorption curves for the two principal vibration directions in the basal plane of a selection of typical Harts Range muscovites with a greenish hue.

FIG. 8. Absorption curves for the two principal vibration directions in the basal plane of two typical Harts Range muscovites with a reddish hue and a typical Indian ruby muscovite.

FIG. 9. Absorption curves for the Z-vibration direction in a number of MDG color group specimens of Harts Range muscovites. They show the small changes in some absorption features and the constancy of others with increasing color intensity.





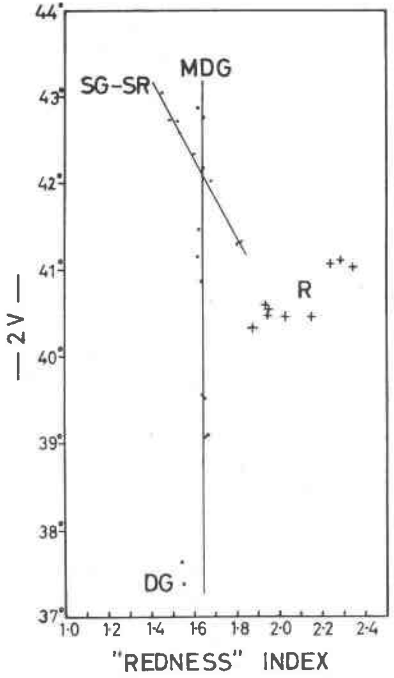


FIG. 10. Absorption curves for the Z-vibration direction in a number of R color group specimens of Harts Range muscovites. They show the nature of absorption features in relation to increasing color intensity.

FIG. 11. Color intensity—hue ("redness") relationship in the R, MDG and SG-SR color groups of Harts Range muscovites. DG specimens are indicated to show their position within the MDG group.

FIG. 12. Optic axial angle—hue ("redness") relationship in the R, MDG and SG-SR color groups of Harts Range muscovites. DG specimens are indicated to show their position within the MDG group.

allowed direct and simple comparison of the absorption features irrespective of the intensity of coloring and did not necessitate cleaving specimens to any required thicknesses.

To check the nature of the absorption and reflection losses, optical densities were also obtained for six thicknesses at four widely spaced wavelengths in seven specimens. Optical density plotted against thickness gave a straight line graph for each wavelength and from these results the measured and calculated reflection losses agreed. Calculations showed that absorption, derived from the small component of the X-vibration direction and resulting from the small inclined angle at which the mica plate was set, would be negligible and this was confirmed by experiment.

For comparative purposes, curves were obtained for a specimen of top quality Indian ruby muscovite (included in Fig. 8).

Color intensity for some correlation purposes was expressed numerically (Table 1) as the optical density, for a specimen of standard thickness, at a specific wavelength in the Z-vibration direction although the same results would have been obtained by using values for the Y-vibration direction. For similar purposes hue was described in terms of the redness of specimens as all the curves showed that the ultimate observed colors were due to the relative absorbences in the red and green regions and not to details in their shapes. Hence, numerical expressions of redness (Table 1) were obtained as the ratios of the optical densities at two specific wavelengths, one (680 mμ) in the red and one (495 mμ) in the green spectral regions.

Method of Optical Crystallographic Study

Materials for study were mounted on a Bausch & Lomb five-axis universal stage fitted with temperature cells. Refractive indices of liquids were measured on a Bellingham & Stanley Abbe refractometer, the single variation method of Emmons (1943) being used in a modified form and retaining temperature as the control method. By means of a constant-temperature water circulator the principle of recirculating distilled water, as described by Hurlbut (1947), was used for temperature control, but the universal stage and refractometer were connected in parallel rather than in series. A rapid and uniform flow through both instruments was thus assured and a temperature gradient between the two instruments avoided. The temperature was controlled to better than ±0.1° C.

Preliminary determinations of β and γ were made by standard methods after which the following modified procedure was used; this was a modification in so far as the indices were not determined entirely on the principle of the disappearance of the Becke bright line.

For each separate mica index determination a mixture of alpha-bromonapthalene and clove oil was adjusted to read, at room temperature, approximately .002 above that particular mineral index being sought. From there on, the index of the liquid was adjusted by temperature control to be very slightly above that of the mineral index to the extent that the

TABLE 1. NUMERICAL EXPRESSION OF COLOR (HUE) AS "REDNESS"

	Sample	Optical Density[1] (D)		"Redness" Index (D_{495}/D_{680})
		$\lambda=495\ m\mu$	$\lambda=680\ m\mu$	
R group	BR	.492	.262	1.88
	R17	.341	.175	1.95
	CR	.341	.175	1.95
	CR1	.331	.170	1.94
	RR	.300	.148	2.03
	R9	.292	.135	2.16
	R121	.290	.135	2.15
	PP4	.254	.113	2.24
	R131	.188	.082	2.29
	R231	.181	.077	2.35
MDG group	DG1	1.000	.650	1.54
	DG2	.924	.604	1.53
	MG101	.602	.359	1.68
	MG72	.600	.359	1.67
	MG8	.535	.327	1.64
	MG71	.535	.325	1.65
	MG15	.358	.218	1.64
	MG25	.340	.210	1.62
	MG35	.303	.187	1.62
	MG22	.253	.153	1.65
	MG3	.201	.122	1.65
	MG21	.196	.122	1.62
	MG4	.166	.100	1.66
	MG6	.147	.089	1.65
SG-SR group	SG-SR/R	.264	.144	1.83
	SG-SR/1	.257	.143	1.80
	SG-SR/2	.205	.121	1.69
	SG-SR/3	.180	.122	1.61
	SG-SR/4	.164	.106	1.54
	SG-SR/G	.157	.103	1.53
	SG-SR/5	.152	.102	1.49
	SG-SR/6	.140	.096	1.46

[1] For standard thickness of specimen and in the Z-vibration direction; these densities in effect represent color intensities as the absorption curves are so much alike in these groups.

bright line was only just discernable. This required a rise of only a few degrees above room temperature; thus by holding the temperature steady for a few minutes any temperature lag and errors arising from working at too high a temperature were avoided. The refractometer reading was then noted. The liquid index was again adjusted by temperature control as above but with the relative refractive indices reversed and the refractometer reading again noted. These two readings were commonly .0005 to .0006 apart and the midway value was taken as the required mineral index; when .0006 apart, the choice of one out of the two possible middle figures was guided by results of repeated measurements and checked by calculating 2V from refractive indices and comparing it with measured 2V.

The reliability of the above measuring method was checked by using it to measure refractive indices of glass fragments taken from test plates whose indices had been measured directly by the contact method on the same refractometer; the two sets of figures were identical in each instance. Also, it was found that repeated measurements on a given mica specimen seldom differed by more than 1 in the fourth decimal place.

With strict care in manipulation, meticulous attention to standardization of procedure and adjustment of equipment and by very many repetitions of each determination, 2V values were obtained with a greater precision than that described by Fairbairn and Podolsky (1951). By this means some particularly small differences between specimens were obtained. Such precise determinations were required for more than just the correlations with small absorption differences. They allowed a check on the validity of absolute differences in refractive indices since a change of approximately 0.4° in 2V accompanies a change of .0001 in the partial birefringence γ-β. That is, the measurable differences in 2V can show the existence of refractive index differences which are normally beyond detection, and this was sometimes used as a guide in checking, as described above, which of the two indices was the correct one when direct measurements gave a choice.

METHODS OF ANALYSIS

Complete chemical analyses (Table 2) were carried out in the first instance by G. C. Carlos[1] using the standard methods. Partial analyses (Table 3) were later carried out by the author so that the determinations of the four appropriate constituents of the complete analyses were repeated to ensure uniformity of results; total iron, manganese and titanium were determined colorimetrically using a Beckman spectrophotometer.

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[1] Mineragraphic Section, C.S.I.R.O., Melbourne, Australia.

Table 2. Chemical Analyses of Muscovites

(Analyst: G. C. Carlos)

	BR	CR	R9	RR	PR4	R131	DG2	MG101
SiO_2	44.90	45.43	44.85	45.40	45.36	44.91	44.97	44.33
Al_2O_3	32.95	32.83	34.22	32.58	34.63	34.62	30.12	32.33
Fe_2O_3	3.95	3.36	2.11	2.97	2.24	2.17	5.48	5.12
FeO	1.03	1.36	1.17	0.90	1.28	0.88	1.87	0.94
MgO	0.98	0.98	1.16	2.01	0.94	0.92	1.31	1.22
CaO	0.36	0.22	0.08	0.14	0.19	0.04	0.15	0.35
K_2O	10.00	9.75	10.50	9.79	9.65	10.48	9.78	9.70
Na_2O	0.40	0.66	0.53	0.69	0.40	0.52	0.66	0.47
TiO_2	0.23	0.23	0.28	0.27	0.33	0.43	0.35	0.40
MnO	0.19	0.14	0.07	0.16	0.08	0.09	0.20	0.09
P_2O_5	tr	tr	tr	tr	tr	tr	tr	tr
H_2O^+	4.65	4.65	5.03	4.63	4.58	4.63	4.66	4.65
F	0.19	0.21	0.19	0.30	0.20	0.18	0.31	0.22
Cl	0.04	0.05	0.04	0.04	0.03	0.03	0.06	0.05
	99.87	99.87	100.23	99.88	99.91	99.90	99.92	99.87
−O=F, Cl	.08	.09	.08	.13	.08	.08	.13	.09
	99.79	99.78	100.15	99.75	99.83	99.82	99.79	99.78

	MG15	MG35	MG22	MG21	SG-SR/G	BG	PG	Indian ruby
SiO_2	44.98	45.02	44.86	44.86	45.11	44.64	44.80	44.55
Al_2O_3	32.48	33.62	33.33	34.53	33.54	33.25	32.72	37.14
Fe_2O_3	5.72	4.31	3.81	3.74	2.42	4.74	5.87	1.68
FeO	0.95	0.78	0.80	0.56	1.33	1.60	0.59	0.88
MgO	1.03	0.95	0.78	0.76	1.29	0.42	0.44	0.52
CaO	0.16	0.20	0.12	0.14	0.05	0.00	0.18	0.47
K_2O	9.70	9.01	10.32	9.70	10.12	9.60	9.59	7.34
Na_2O	0.60	0.40	0.56	0.45	0.53	0.30	0.30	1.04
TiO_2	0.22	0.49	0.22	0.10	0.07	0.51	0.38	0.52
MnO	0.09	0.11	0.11	0.09	0.10	0.09	0.11	0.01
P_2O_5	tr	tr	tr	tr	tr	tr	tr	tr
H_2O^+	4.68	4.63	4.69	4.67	5.00	4.62	4.62	5.84
F	0.21	0.25	0.28	0.27	0.21	0.17	0.26	—
Cl	0.04	0.04	0.02	0.05	0.05	0.03	0.04	—
	99.86	99.81	99.90	99.92	99.82	99.97	99.90	99.99
	.09	.10	.12	.11	.09	.07	.11	—
	99.77	99.71	99.78	99.81	99.73	99.90	99.79	99.99

TABLE 3. PARTIAL CHEMICAL ANALYSES OF MUSCOVITES

Sample	MnO	TiO_2	FeO	Fe_2O_3
BR	0.19	0.23	1.03	3.95
CR	0.14	0.23	1.36	3.36
RR	0.16	0.27	0.90	2.97
R9	0.07	0.28	1.17	2.11
R131	0.09	0.43	0.88	2.17
PR4	0.08	0.33	1.28	2.24
DG2	0.20	0.35	1.87	5.48
MG101	0.09	0.40	0.94	5.12
MG15	0.09	0.22	0.95	5.72
MG35	0.11	0.49	0.78	4.31
MG22	0.11	0.22	0.80	3.81
MG21	0.09	0.10	0.56	3.74
SG-SR/1	0.03	0.13	1.44	2.36
SG-SR/2	0.03	0.09	1.29	2.37
SG-SR/4	0.04	0.09	1.30	2.52
SG-SR/G	0.06	0.07	1.33	2.42
SG-SR/6	0.05	0.06	1.22	2.54
BG	0.09	0.51	1.60	4.74
PG	0.11	0.38	0.59	5.87

Routine methods for quantitive spectrographic analysis were used for determining trace elements (Table 4) on a large Hilger quartz spectrograph. Later checking of some results by chemical analysis showed that the true values would probably lie within ±40% of the reported values. Repeatability of determinations was within 30% of these latter.

ABSORPTION RESULTS AND CLASSIFICATION

The absorption curves in Figs. 1–10 show that in all the muscovites the greatest absorption occurs in the extreme violet region, that the most important absorption characteristics occur in the blue and blue-violet regions, and that differences between specimens may be made more conspicuous by the nature of the differences in absorption for the two vibration directions in the basal plane. As regards this latter feature, the curves show that all muscovites have measurable pleochroism and this can be expressed in terms of both the shapes of the curves and the relative intensities of coloring for the two vibration directions.

Parts of the curves have characteristic shapes which are developed to a greater or less extent in some specimens and are absent in others, and this serves as a basis for classifying the muscovites. These characteristics are:

1. Absorption maximum at 443 mμ.
2. Trace of an absorption maximum at 470 mμ
3. Absorption maximum at 508 mμ
4. Pleochroism (expressed as shape of parts of curve.)
5. Redness (ratio of red to green absorption).

The derivation of the different color groups or sub-groups from the relative expression of these characteristics is described below. The groups have some faint semblance of recognizable colors, so that from these, appropriate symbols were selected to give the following nomenclature:

PG = pure green
BG = blue-green
DG = dark green
MG = medium green
R = reddish
SG-SR = greenish-reddish series
MDG = medium and dark green.

Differences suggested by these symbols are great exaggerations of differences observed by eye and are commonly doubtful even under ideal lighting conditions. For example it is extremely difficult, if not impossible, to observe any differences between R color group specimens and reddish specimens of the SG-SR color group, but as shown by the descriptions below, the curves give clearly defined differences.

DERIVATION OF THE CLASSIFICATION

The derivation of the grouping is based in the first instance on the absorption maxima.

In Fig. 1 there are no undulations or absorption peaks at 470 mμ and at 508 mμ whereas these are characteristic of all other specimens. This alone

TABLE 4. SPECTROGRAPHIC ANALYSES (PPM BY WEIGHT)

Sample	V	Cr	Ni	Sample	V	Cr	Ni
BR	30	1	3	DG2	30	1	1
CR	10	10	1				
RR	10	30	nd	MG101	10	nd	nd
R9	70	70	1	MG15	10	nd	nd
R131	30	3	nd	MG35	10	1	nd
BG	20	nd	nd				
				SG-SR/1	tr	tr	nd
PG	40	nd	nd	SG-SR/6	tr	tr	nd

is sufficient to place such micas clearly in one group, the PG group, which may possibly in turn be regarded as subdivided according to whether or nor there is a distinct change in redness, but this is discussed later.

In all specimens other than the PG and BG specimens, the maximum at 443 mμ is either sharply defined (Fig. 2) or occurs only as an undulation in the curve (Fig. 3). This undulation is in effect a "trace" of the maximum but the two different modes of occurrence of the same feature are sufficient to divide the specimens into two appropriate major classes, within each of which the intensity of the peak or its "trace" is variable. Thus, there is on the one hand the major class made up of MG and DG specimens in which the maximum is sharply defined and which constitute the MDG color group, and on the other hand there is the major class comprising all the remaining specimens in which the maximum occurs only as a "trace."

These latter specimens can in turn be divided into the R and SG-SR color groups (Figs 3 and 4 respectively) on the basis of the maximum at 508 mμ; in the latter group this maximum is more strongly developed in the Z than in the Y-vibration direction whereas it is equally developed in the two vibration directions in the former group. Hence all the muscovites can be divided into four color groups which are defined as follows:

PG	color group	In which there is only one absorption maximum and this is at 443 mμ.
MDG	color group	In which a sharply defined absorption maximum at 443 mμ is accompanied by an absorption maximum at 508 mμ.
R	color group	In which an undulation in the curve representing a "trace" of a maximum at 443 mμ is accompanied by an absorption maximum at 508 mμ and in which this latter is equally developed for the two vibration directions in the basal plane.
SG-SR	color group	In which an undulation in the curve representing a "trace" of a maximum at 443 mμ is accompanied by an absorption maximum at 508 mμ and in which this latter is more prominant in the Z than in the Y-vibration direction.

Specimens belonging to the latter three groups are common, this having been checked by studying in considerable detail many more samples than those recorded in this present work, so that the groups are considered to be major color groups. PG and BG specimens on the other hand are rare and have not been so fully investigated so that they must be regarded as constituting a minor color group in which correlations cannot be defined as clearly as they can be in the major groups.

DISCUSSION ON THE CLASSIFICATION

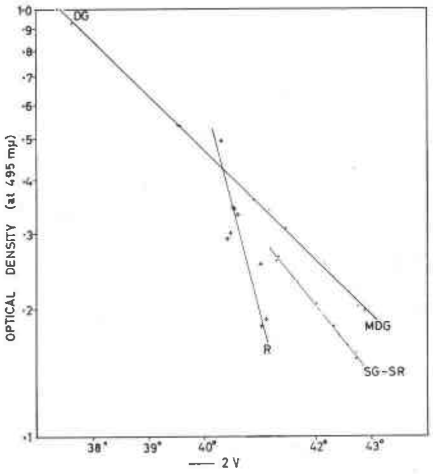
Absorptiometric properties. Apart from many correlations which later will be shown to occur within these color groups, there is further evidence in support of the grouping system described above.

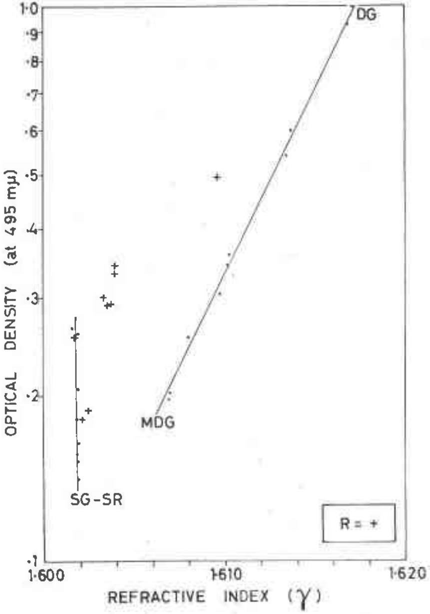
Apart from the DG members, MDG group specimens are separated from SG-SR and R group specimens by the fact that irrespective of the color intensity of the former, the overall gradient of the curve, and hence the hue or "redness," is virtually constant; this is not so in the latter two groups, as shown in Table 1 and Fig. 11. Furthermore, and again shown in Fig. 11, these latter two groups are separated by their opposite trends in this color intensity—redness relationship.

The R group specimens are clearly separated from SG-SR specimens by the relationship of the maximum at 508 mμ to the color intensity; in the SG-SR group, the maximum increases as the color intensity increases (Figs. 4, 5, 6) and the range of this latter is relatively small, but in the R group, the maximum is constant (Fig. 10)—as it is also in the MDG group except for DG specimens (Fig. 9)—and this is over a wide range of color intensity.

The PG group specimens (Fig. 1) show a strong "pleochroic" feature by the shapes of their two curves in the region below 450 mμ, whereas this form of pleochroic expression in the same region is only faintly shown or is absent in all other specimens. Greenish members of the SG-SR group have a particularly small color intensity difference for the two vibration directions while the reddish members conform to the order of color intensity differences shown by all other specimens outside this group; this constitutes a relatively major change of pleochroism (as color intensity) with change of color intensity not shown in the other groups. Although these relationships are not made obvious by comparing Figs. 3 and 4, they become more apparent by comparing specimen SG-SR/6 with PG or MG25 in Fig. 7.

Subdivision of the groups may ultimately be established along the lines described below although much more data will be needed to make such divisions clear. Within the MDG group, particularly dark specimens, such as DG1, Fig. 2, may constitute a sub-group in which the overall gradient is slightly less than it is for the other members of the MDG group as shown in Fig. 11, and in which the intensity of the maximum at 508 mμ is less than it is for these other members. However, in other features, these very dark specimens conform to the MG specimen characteristics and, in being classed as such to give the MDG group, extend the color intensity range well beyond that indicated by only the MG specimens in Figs. 2 and 9. PG and BG type specimens are assumed to belong to a single group, perhaps with BG ones constituting a sub-group, rather than considering them as belonging to two completely different groups. Exceptionally pale color and limited thickness enabled only the shorter wavelength region of sample PG-1, Fig. 1 to be studied but the available details of the curve are sufficient to suggest placing this speci-





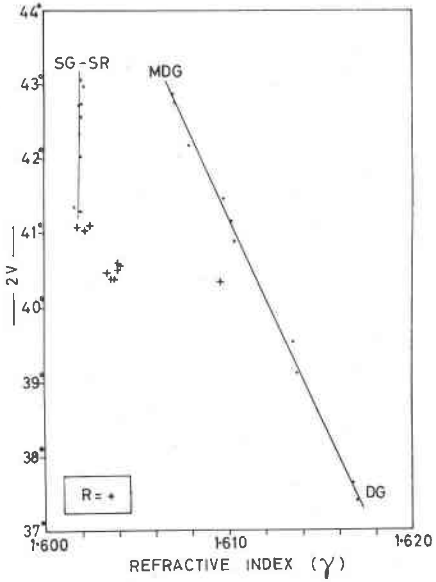


FIG. 13. Color intensity—optic axial angle relationship in the R, MDG and SG-SR color groups of Harts Range muscovites. DG specimens are indicated to show their position within the MDG group.

FIG. 14. Color intensity—refractive index relationship in the R, MDG and SG-SR color groups of Harts Range muscovites. DG specimens are indicated to show their position within the MDG group.

FIG. 15. Optic axial angle—refractive index relationship in the R, MDG and SG-SR color groups of Harts Range muscovites. DG specimens are indicated to show their position within the MDG group.

men in with the PG type specimens to form a color group showing an appreciable color intensity range. By virtue of the decrease in absorption at 422 mμ for the Z-vibration direction in sample PG-1, the maximum at 443 mμ in this sample is greater than in sample PG which is the darker of the two. This same maximum is only weakly developed in sample BG which in turn is much darker than PG and PG-1. Thus, when the three samples are arranged in order of increasing color intensity as in Fig. 1, this absorption maximum shows a decreasing intensity and the most outstanding characteristic of PG, namely the flatness of part of the Z-direction curve, is lost in BG in one sense and lost in PG-1 in the opposite sense to that of BG. This combined with the fact that the maximum is clearly stronger in the Z than in the Y-vibration direction for all the specimens, indicates that BG specimens are in effect members of the PG group. The unchanging optical density above 560 mμ in BG specimens would then appear to be a continuation of a trend, similar to the type of trend shown in the R group, whereby the overall curve gradient above this wavelength decreases with increasing depth of color.

Visual pleochroic properties were studied but failed to show differences between specimens, which were revealed by the absorption measurements. Thick sections cut normal to the cleavage were used for checking the weakness of the absorption for the X-vibration direction compared with the absorption in the other two directions. The pleochroic scheme is clearly $Y>Z>X$ but no significant differences between specimens can be based on this using, for example, differences between absorption figures (Weissberger, 1949, p. 955) which are a function of pleochroism. These figures are distinct for specimens, of the standard thickness, in which the optical density at about 500 mμ is approximately equal to or greater than 0.3 for the Z-vibration direction. The importance of this lack of visible difference is well illustrated by reference to Fig. 7; pleochroism, as color intensity, is clearly different for specimens SG-SR/6 and PG, but observation under polarized light for the specimens of the same thickness did not show any differences in absorption figures.

The inadequacy of classifying muscovites as "green" or "ruby" can be illustrated by the selection of curves shown in Figs. 7 and 8. These show

> (1) the wide range of hues and intensities of colors that can occur among greenish or among reddish colored specimens, (2) the distinct differences which may exist between two specimens with the same hue, the same color intensity and which occur in the same broad color division, for example PG and SG-SR/6, (3) how two specimens such as MG 25 and BG although totally different on the basis of absorption features, other than their hues, would be classed as one under the system of two broad color divisions.

Other evidence for the validity of the grouping purely on an absorption measurement basis is obtained by placing the curves, of a single vibration direction, for members of a color group on the same graph as in

Figs. 5, 6, 9, 10. These show some clearer trends among absorption features, within each of the main color groups, over and above those described earlier and they include numerous details which would not be seen by the eye. A summary of these trends combined with those already shown from a study of the two curves for each specimen (Figs. 2, 3, 4) can be simply expressed by relating absorption features to increasing color intensity within each of the three major color groups as described below. Although the same amount of data is not available in the case of the minor color group PG, it can, by reference to earlier descriptions and Fig. 1, be similarly summarized, so that the four color groups have their trends described as follows:

As the color intensity in the MDG color group increases—
- the hue does not change (except for DG specimens);
- the intensity of the absorption maximum at 443 mμ in the Z-vibration direction decreases slightly;
- "pleochroism", as color intensity, increases more than in the R group and less than in the SG-SR group;
- the absorption maximum at 508 mμ is constant (except for DG specimens);
- the "trace" of the absorption maximum at 470 mμ is constant.

As the color intensity in the SG-SR color group increases—
- the hue changes from green to red;
- the intensity of the "trace" of the maximum at 443 mμ in the Z-vibration direction decreases;
- "pleochroism," as color intensity, increases more than in the R and MDG groups;
- the absorption maximum at 508 mμ increases;
- the "trace" of the absorption maximum at 470 mμ clearly sharpens in the Y but not in the Z-vibration direction.

As the color intensity in the R color group increases—
- the hue changes in the direction of decreasing redness;
- the intensity of the "trace" of the maximum at 443 mμ in the Z-vibration direction increases;
- "pleochroism," as color intensity, increases the least of the three major color groups;
- the absorption maximum at 508 mμ is virtually constant;
- the "trace" of the absorption maximum at 470 mμ in the Z-vibration direction sharpens slightly.

As the color intensity in the PG color group increases—
- the redness decreases;
- the intensity of the absorption maximum at 443 mμ in the Z-vibration direction decreases;
- "pleochroism," as curve shape, in the region below 450 mμ becomes less emphasised.

Chemical Composition. High manganese and high manganese plus high barium are examples of composition features peculiar to some muscovites such as those described by Heinrich and Levinson (1953) and Hirowatari (1957) respectively. The complete chemical analyses in Table 2 do not reveal any comparable features in the Harts Range muscovites or the Indian sample.

Apart from iron, the metals present which may produce visible colors in minerals are manganese, titanium, vanadium, chromium and nickel but from Tables 3 and 4 it can be seen that the quantities of these latter four elements cannot be correlated with color intensity, hues and the magnitude of the individual absorption features such as for example the peaks at 443 mμ and at 508 mμ. This is to be expected since the large amounts of iron would mask any absorption features due to the trace constituents, or even the minor constituents, assuming they were adding to the coloring of the mineral. Manganese produces strong pink coloration in muscovite, but this depends, as shown by Heinrich and Levinson (1953), on the absence of Fe^{2+} and the predominance of Mn^{3+} over Fe^{3+}. The reddish coloring in the Australian muscovites must therefore be attributed to some other agent or agents operating in conjunction with iron absorption, and the ineffectiveness of manganese in this respect is at least partly substantiated by referring to the Indian sample; this latter has the least manganese of all the samples analyzed although it has by far the strongest red coloration.

The limited relationship of iron content with absorption can be shown by referring to Tables 1, 2 and 3 and to Figs. 1, 6, 9 and 10. Taking into consideration all the samples as a whole, there is no relationship of the iron content with hue or with color intensity. Only within a color group can the iron content in some instances be correlated approximately with color intensity and some absorption trends. For example, ferric iron tends to increase as color intensity increases in the R group and this same trend, although not so well shown, does exist in the MDG group. However, in the SG-SR group this ferric iron is virtually constant over the appreciable absorption range, and the trend referred to is reversed in the PG group.

Ferrous iron content in the R group is irregular and yet has some semblance of order within the MDG and SG-SR groups. Failure to relate this component with hue is shown in many instances, especially when all specimens are grouped as a whole. For example, increasing ferrous iron suggests increasing red coloration in the SG-SR group; this relationship is the same when comparing MG21 and BR but is clearly reversed in the case of PG and BG.

The Fe_2O_3/FeO relationship shown in Table 5 is not related to the overall absorption in the MDG and R groups although it may be so in the SG-SR group. If the MDG group is compared with the R group, there is a suggestion that increasing green coloration is related to this ratio, but such a relationship is shown to be incorrect in a number of instances. For example, PG and SG-SR/6, compared in Fig. 7 have virtually the same overall color intensity and rather similar hues, but the ferric-ferrous ratio is decidedly different for the two specimens.

TABLE 5. FERRIC-FERROUS IRON RELATIONSHIP

Sample	Fe_2O_3/FeO	Sample	Fe_2O_3/FeO
BR	3.8	SG-SR/1	1.6
CR	2.5	SG-SR/2	1.8
RR	3.3	SG-SR/4	1.9
R9	1.8	SG-SR/G	1.8
PR4	1.8	SG-SR/6	2.1
R131	2.5		
DG2	2.9	BG	3.0
MG101	5.5	PG	10.0
MG15	6.0		
MG35	5.5		
MG22	4.8		
MG21	6.7		

Tables 1 and 6 show that the ratio $(FeO+MgO)/Fe_2O_3$ cannot be related to hue and color intensity, although within the MDG group itself, its relatively small changes in value conforms in some measure to the persistent redness, especially when referred to the MG members.

Recalculations of percentages of FeO, Fe_2O_3 and MgO to show ratios and summations of the metal atoms Fe^{2+}, Fe^{3+} and Mg^{2+} did not suggest any need to reconsider the above discussions.

It can thus be concluded from the above descriptions that composition differences are not important in either this present classification or in the classical broader division into green and ruby specimens. It is only within groups defined by the absorption differences revealed in this study that composition is significant and even then it is the iron alone, in one or other state of oxidation, which shows only a limited relationship with absorption. It is in this respect that some more fundamental differences,

TABLE 6. RELATIONSHIP OF MgO, FeO AND Fe_2O_3

Sample	$\frac{FeO+MgO}{Fe_2O_3}$	Sample	$\frac{FeO+MgO}{Fe_2O_3}$	Sample	$\frac{FeO+MgO}{Fe_2O_3}$
BR	.509	DG2	.580	SG-SR/G	1.082
CR	.697	MG101	.422		
RR	.980	MG15	.346	BG	.426
R9	1.104	MG35	.402		
PR4	.991	MG22	.415	PG	.176
R131	.829	MG21	.353		

especially between the groups, must be found to account for the differences in the absorption of iron. What some of these fundamental differences could be are suggested in a later discussion, but the existence of such differences is clearly illustrated by the nature of the optical crystallographic properties.

Optical crystallographic properties. In marked contrast to the lack of clear composition-absorption relationships, there are, within the major groups, important and distinct correlations of optical crystallographic properties (Table 7) with absorption properties (Table 1 and Figs. 2–6, 9, 10). With such small ranges in the former this is perhaps surprising but it is clearly shown by relating hues with 2V (Fig. 12) and more important still by relating color intensities with 2V (Fig. 13) and with refractive indices (Fig. 14). These show that, in two groups at least, absorption characteristics are directly governed by the fundamental differences which control the characteristic trends of the optical crystallographic properties and that a classification based on finer absorption features alone is closely allied to that based on the optical crystallographic properties.

This corresponds to some extent to the grouping determined in the 2V-refractive index relationsip shown in Fig. 15, but as such a relationship has been shown by Winchell (1945) to be closely allied to composition, and this is not exactly so in the present instance from the study of Tables 2, 3, and 7, the more reliable correlations for seeking the basis of differences in iron absorption are those relating absorption features with only one of the optical crystallographic properties. An instance of the importance of this is shown by comparing MG22 with PG in Table 7; when plotted on the basis of their 2V-refractive index relationship in Fig. 15 they are very close and would also be close on Winchell's basis of classification, and hence identical in composition, but from the nature of their absorption curves it is clear that they are in fact fundamentally and vastly different.

The fact that grouping of samples according to either one or the other of their optical crystallographic properties conforms to that based on absorption features can be still further verified. Thus, (1) the SG-SR specimens have, compared with MDG and R specimens, a small refractive index range (2) a particularly small range of 2V values over an appreciable color intensity range distinguishes R specimens from SG-SR and MDG specimens (3) the same hue occurring over a range of 2V values distinguishes the MDG group from the R and SG-SR groups (4) the changes in hue accompanying changes in 2V are opposed to one another in the R and SG-SR groups (5) a distinct range in hue with an almost constant value for refractive indices distinguishes the SG-SR group.

Table 7. Optical Crystallographic Properties of the R, MDG, SG-SR and PG Color Groups. (Arranged in order of decreasing color intensity downwards within each group)

Sample	2V	Refractive Index			Birefringence	
		γ	β	α	γ-α	γ-β
BR	40.34°	1.6096	1.6045	1.5694	.0402	.0051
CR	40.51°	1.6040	1.5991	1.5657	.0383	.0049
R17	40.55°	1.6041	1.5992	1.5655	.0386	.0049
CR1	40.60°	1.6040	1.5991	1.5654	.0386	.0049
RR	40.46°	1.6034	1.5985	1.5650	.0384	.0049
R121	40.37°	1.6038	1.5989	1.5653	.0385	.0049
R9	40.37°	1.6036	1.5987	1.5650	.0386	.0049
PR4	41.09°	1.6018	1.5968	1.5638	.0380	.0050
R131	41.11°	1.6025	1.5975	1.5644	.0381	.0050
R231	41.03°	1.6022	1.5973	1.5643	.0379	.0049
DG1	37.39°	1.6170	1.6122	1.5736	.0434	.0048
DG2	37.63°	1.6168	1.6120	1.5736	.0432	.0048
MG101	39.11°	1.6137	1.6087	1.5717	.0420	.0050
MG72	39.08°	1.6137	1.6088	1.5719	.0418	.0049
MG8	39.57°	1.6135	1.6084	1.5716	.0419	.0051
MG71	39.53°	1.6135	1.6084	1.5714	.0421	.0051
MG15	40.88°	1.6103	1.6050	1.5695	.0408	.0053
MG25	41.17°	1.6102	1.6049	1.5696	.0406	.0053
MG35	41.48°	1.6098	1.6044	1.5691	.0407	.0054
MG22	42.18°	1.6079	1.6024	1.5680	.0399	.0055
MG3	42.76°	1.6071	1.6016	1.5676	.0395	.0055
MG21	42.87°	1.6070	1.6014	1.5673	.0397	.0056
SG-SR/R	41.34	1.6015	1.5966	1.5638	.0377	.0049
SG-SR/1	41.30°	1.6020	1.5972	1.5649	.0371	.0048
SG-SR/2	42.03°	1.6020	1.5972	1.5648	.0372	.0050
SG-SR/3	42.34°	1.6019	1.5968	1.5645	.0374	.0051
SG/SR/4	42.57°	1.6020	1.5968	1.5644	.0376	.0052
SG-SR/G	42.73°	1.6019	1.5967	1.5645	.0374	.0052
SG-SR/5	42.71°	1.6020	1.5968	1.5643	.0377	.0052
SG-SR/6	43.06°	1.6020	1.5967	1.5641	.0379	.0053
SG-SR/T	42.98	1.6023	1.5970	1.5645	.0378	.0053
BG	40.34°	1.6126	1.6075	1.5711	.0415	.0051
PG	42.02°	1.6081	1.6028	1.5676	.0405	.0053
PG-1	43.00°	—	—	—	—	—

From Figs. 12, 13 and 14 showing these correlations and the above descriptions, it follows that the nature of minor absorption features can be related to optical crystallographic properties in a manner peculiar to each of the color groups. Thus, over a given color intensity range, a relatively large change in 2V values is accompanied by the presence of the maximum at 443 mμ in the MDG group but in the R group, the small change in 2V values is accompanied by the "trace" only of this maximum. Again, the almost unchanging refractive index in the SG-SR group accompanies this latter's distinctive pleochroic feature at 508 mμ shown in Fig. 4 and its changing intensity of this maximum with changing color intensity shown in Figs. 5 and 6.

Independence of absorption features. The classification is based on the degree of expression of five curve characteristics described earlier. These are independent of one another and an example of the derivation of this independence is given below by referring to the nature of the absorption maximum at 443 mμ.

In the MDG group it is weak and accompanies the 508 mμ and 470 mμ maxima but in the PG group it is strong and not accompanied by the other two. Its intensity decreases with increasing color intensity within the MDG group but shows the reverse trend in the R group. In either case, this change is not accompanied by a change in the 508 mμ maximum (except for the DG specimens). Also, it is virtually non-existent in the Y direction of greenish SG-SR specimens. Hence, its intensity is independent of color intensity, hue and the other two maxima. Its different expression in the two vibration directions gives a variable pleochroic feature which in turn is independent of all other absorption features. Thus, it is strongly expressed as such in PG, weakly so in SG-SR and MDG and absent in lightly colored R samples, and its relationship of increasing intensity with decreasing color intensity in the MDG, SG-SR and PG groups is not shown in the R group.

The above described pleochroic feature is only one of three of importance in this study, the other two being (1) the different intensity of the 508 mμ maximum for the Y and Z-vibration directions in the SG-SR group and (2) the color change shown by the different gradients for the two curves above 510 mμ in the SG-SR group; these latter two features are independent of all other absorption features.

By this above method, it can be seen that the absorption curves are composed of many empirically independent variables which include hue, maxima, and expressions of pleochroism, and that these variables are, at least to some extent, independent of overall color intensity.

SIGNIFICANCE OF CORRELATION AND THE CLASSIFICATION

A most significant fact about the correlations is the manner in which different sets of absorption features can themselves be correlated with each other. By this means they enhance and confirm the basis of the classification which was derived in the first instance by a few elementary differences and which has made it possible to group specimens non-arbitrarily and enabled the development of a system of differentiating between specimens not normally distinguishable. Still further enhancement is given by the correlations of these absorption features with optical crystallographic properties. This classification may require amendments in the light of subsequent measurements on other specimens revealing absorption features so far not obtained, but it is felt that the samples studied were sufficiently representative to give the main points for initiating a system of classifying.

Whatever the absorption features are due to, it is clear from the point of view of petrological-mineralogical relationships that the detailed absorption data, including the correlations of absorption features with one another, are much more comprehensive and of more potential value than data provided by observable colors. This is even still more important in view of instruments now becoming available. Although the more recent recording-type spectrophotometers may not be able to reveal accurately some of the minor differences discussed earlier, they nevertheless make it possible to determine quickly many of the identifying absorption features. In this respect also, the classification itself, even if later amended, should be more applicable to petrological problems than is the present system which depends on observable colors. Again petrologically, a much greater value of the correlations between optical crystallographic and absorption properties is now apparent in view of the equipment, described by Ruthberg (1961), which gives a rapid means of measuring 2V indirectly but with reasonable accuracy on large specimens.

Another significance of the correlations is that they can be used to suggest some explanations for the different colors in muscovites. It can be concluded from the above descriptive role of composition that iron is the effective coloring agent and that it is the nature of its absorption, determined by some fundamental physical property, which characterizes a number of groups. This concept of iron as the coloring agent is partly confirmed by the frequent occurrences of the three absorption maxima, or their traces, in that these probably correspond to the three maxima, described by Melankholin (1946), occurring at 450 mμ, 480 mμ and 515 mμ in a number of crystalline compounds containing ferric iron. However, even though the iron content determines, to some extent, the intensity of the overall absorption, it is by no means the only factor influencing this aspect of color and it bears little if any relationship to hue. Also, the magnitude of any one of the three maxima or any of the expressions of pleochroism cannot be related to composition. This then leads to the question of the manner in which absorption due to iron could be modified in muscovite.

The simultaneous occurrence of the two states of oxidation of iron will, as pointed out by Weyl (1951), intensify absorption due to this metal. This, and the possibly independent absorptions due to Fe^{2+} and Fe^{3+} are at best only three of the numerous factors which must determine the nature of the absorption. The earlier discussion showed there is a basis for inferring that not only are there more than three such factors but that they must be able to influence the iron absorption independently of one another. It thus appears from the instances of close correlations between absorption and optical crystallographic properties that structure, which has such a strong influence on the latter, is exerting a decided influence on the iron absorption in some cases at least and it is doing so in more than one way to account for the independent expressions of absorption. That is, there appear to be a number of minor structural differences. The fact that they could be insignificant compared with the established polymorphic differences is apparent from the evidence that possibly the 2M polymorph is the only one likely to be encountered on a major scale in unaltered primary muscovites when the composition is close to the ideal composition, which is the case with all these Harts Range muscovites. This was partly, although so far not clearly, confirmed by Weisenberg *x*-ray diffraction patterns[1] which failed to show any differences between representative samples except for some apparent anomalies in the case of the reddish member of the SG-SR group; more detailed *x*-ray examinations will be needed to clarify this evidence. Thus, some of the absorption characteristics may be accounted for by minor structural features. An example of this would be that suggested by Melankholin (1948), namely the occurrence of iron in both tetrahedral and octahedral sites. The absorption curves for muscovite containing ferric iron atoms distributed in this manner would tend to show differences from curves for the same mineral containing the same ferric iron content but which was all concentrated in the octahedral layer. More recently, Crowley and Roy (1960) have described, from results of *x*-ray work, the existence of an important minor structural feature capable of variations within the limits of a single muscovite polymorph. This is an order-disorder phenomenon which involves the Al and Si oxygen tetrahedra, which is a function of pressure and which is related to substitutions or defects in the octahedral layer. Even if differences of this type are relatively small in natural muscovite, they could influence absorption of ferrous and ferric iron.

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[1] *X*-ray work carried out by Dr. W. S. Simpson of the Wool Research Organisation, New Zealand.

Within this phenomenon, furthermore, replacement of Al^{3+} ions by Fe^{3+} ions in the tetrahedral layer provides an additional variable. Again, where grain size effects were distinguished from other effects in the differential thermal analysis work by Bishui *et al.* (1961), it was shown that peak positions in green muscovite were different from peak positions in ruby muscovite; this suggests the existence of another suitable variable feature of structure in the octahedral layer.

Hence, from the number of independently expressed absorption features of absorption, it seems there could be a number of minor structural peculiarities, which can exist in these muscovites, and that the combinations of these, together with their degrees of magnitude, determine groups into which at least the majority of specimens can be placed. The grouping could well reflect therefore a fundamental structural classification determined in the first instance by the nature of the absorption curves but confirmed at least to some extent by correlations with optical crystallographic properties within each group.

From a petrological point of view, detailed information on the physical and chemical items in an environment could eventually be sought in terms of these absorption features. From other published work it appears that environment will at least partly determine the muscovite polymorph. Similarly, but on a smaller scale, the absorption differences within these pegmatitic muscovites could, inasmuch as they have been considered to depend on minor structural differences, reflect minor environmental differences in the containing pegmatites during crystal growth. In this respect the commonly visible growth zones involving color intensity changes make it clear that there were some such frequent changes in many muscovite books. Thus, each individual absorption feature could be available for correlating with a specific set of conditions. Alternatively, each feature, as an independent variable, could conceivably be related to an individual item of the environment. Establishing such relationships might be partly simplified in view of the nature of the specimens studied. They were from large clear uncracked and undistorted crystals so that they probably grew under relatively stable conditions and it is unlikely that post crystallization conditions involving movement greatly affected them.

CONCLUSIONS

The study of pegmatitic muscovite from the Harts Range of Central Australia has shown the following points:-

1. Absorption measurements have revealed important, but previously unrecognized, features of coloring in muscovite.
2. These muscovites can be classified by their absorption properties in such a manner

as to group specimens on the basis of fundamentally important properties rather than on an empirical basis. So far, there appear to be at least four such groups which can be defined in the following manner:

- (a) The PG color group—in which there is only one absorption maximum and this is at 443 mμ.
- (b) The MDG color group—in which a sharply defined absorption maximum at 443 mμ is accompanied by an absorption maximum at 508 mμ.
- (c) The R color group—in which an undulation in the curve representing a "trace" of a maximum at 443 mμ is accompanied by an absorption maximum at 508 mμ and in which this latter is equally developed for the two vibration directions in the basal plane.
- (d) The SG-SR color group—in which an undulation in the curve representing a "trace" of a maximum at 443 mμ is accompanied by an absorption maximum at 508 mμ and in which this latter is more prominent in the Z than in the Y-vibration direction.

3. A classification based on absorption properties may reflect a structural classification for these particular muscovites.
4. There are some close correlations between optical crystallographic and absorption properties in muscovites.
5. There are a number of independently expressed absorption features which determine the colors of muscovites.
6. Irrespective of the color of muscovite with a normal composition, the pleochroic scheme is always $Y>Z>X$.
7. There can be major differences in the shapes of the absorption curves for the two principal vibration directions in the basal plane of a specimen.
8. Small, petrologically significant differences in muscovites might eventually be established, if made in terms of absorption curves rather than in terms of recognizable colors.

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