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CHROMIAN MUSCOVITE FROM THE SERRA DE JACOBINA, BAHIA, BRAZIL[1]

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ABSTRACT

Green quartzite and conglomerate along the western front of the Serra de Jacobina in northeastern Brazil derive their color from finely disseminated chromian muscovite. The quartzite forms part of the high metamorphosed Jacobina Series of probable Precambrian age. Green quartzite layers are concentrated near the zone of the Jacobina fault, and grade to colorless, muscovite-bearing quartzite away from the fault. Field evidence does not support magmatic introduction of chromium. Instead, two more probable sources of chromium are (1) detrital chromite in original quartz sandstone beds, and (2) chromium leached from ultramafic rocks by hydrothermal solutions in the Jacobina fault zone and introduced into adjacent quartzite layers. Witwatersrand-type gold-uranium deposits in the same zone provide further indication of hydrothermal activity, although the relation between this mineralization and development of chromian muscovite is not definitely established.

Chemical, optical and *x*-ray data for the mica are presented. Chemical analysis was done both by *x*-ray fluorescence and by standard methods. The unit-cell parameters were determined by automatic least-squares refinement using a recently developed computer program.

INTRODUCTION

In the course of reconnaissance mapping of the southern part of the Serra de Jacobina (Jacobina range) in the state of Bahia in northeastern Brazil, it was noted that isolated layers of quartzite and quartz conglomerate in the western part of the range have a distinctive green color in outcrop. This color has been found to be caused predominantly by chromian muscovite disseminated throughout the host rocks. The mineral was recognized in the Jacobina range by White (1961); the "green chlorite" noted by Bateman (1958) in conglomerate at the Canavieiras gold mine is probably chromian muscovite.

In view of the abundance of this mica in the Jacobina range, and of the relatively few descriptions of chromian muscovite in the literature, it was decided to present pertinent data on this mica and its occurrence. A new feature in the chemical analysis of the mica is the use of *x*-ray fluorescence, the results of which were found to agree well with those attained by standard chemical methods. The *x*-ray data represent one of the first applications to a mica of a recently developed computer program for least-squares unit-cell refinement.

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Geologic Relationships

The Serra de Jacobina is a sequence of north-trending, steeply tilted, metamorphosed siliceous and pelitic rocks (Jacobina Series) of Precambrian(?) age which are intruded by ultramafic sills and mafic plugs (Leo *et al.*, in press; Fig. 1). The metamorphic grade mostly corresponds to the upper amphibolite facies, and increases somewhat toward the southern end of the range. Both sides of the range are in fault contact with older granitic rocks which are mostly gneissic, but show abundant evidence of palingenesis and remobilization.

The chromian muscovite is restricted to the Serra do Córrego Formation (Leo, *et al.*, in press), about 2000 meters of quartzite with conglomerate layers that are thicker and more abundant toward the bottom of the section. The lower part of the formation is truncated on the west by the Jacobina fault, a high-angle thrust fault. The presence of gold and uranium in some of the conglomerate horizons has caused this unit to be compared with gold-uranium deposits of Blind River, Ontario, and the Witwatersrand and other localities in South Africa.

Green, chromian muscovite-bearing layers of quartzite and conglomerate are distributed throughout about 1000 meters of the Serra do Córrego Formation adjacent to the Jacobina fault, and show a relative increase toward the bottom of the formation in the westernmost ridge of the range. The proportion of green to white quartzite is estimated to be about 1:10. Green quartzite and conglomerate are commonly flanked by white quartzite, although some gradation of color through light-green layers was noted. White quartzite generally contains colorless mica regarded as ordinary muscovite, and several beds of gray-white quartz-muscovite schist occur in the western ridge. Green mica is present in gold-bearing conglomerate layers, but it cannot be stated with certainty that the mica is restricted to such layers. In other words, the relationship, if any, between gold-uranium mineralization and distribution of chromian muscovite is not known.

An irregular band of rock consisting of quartz and white mica with one or more of the aluminosilicate polymorphs flanks the range on the west and is regarded as a metamorphosed saprolith on the granitic gneiss. No chromian muscovite was noted in this rock.

Chromian muscovite in green quartzite is disseminated in tiny flakes with a weak but distinct pleochroism from bluish green to colorless. The principal accessory mineral in the heavy fraction is rutile, which forms euhedral prisms and occurs as sparse inclusions in the mica. Other accessory minerals, mostly not detected in thin section, include green tourmaline (locally very abundant), zircon, kyanite, andalusite (?) and a small amount of opaque material. The latter proved to be largely metallic iron, apparently introduced during grinding; x-ray fluorescence examination gave no indication of chromite. An attempt to identify apparent opaque inclusions in green quartzite by means of the electron probe likewise yielded negative results.

TERMINOLOGY OF CHROMIAN MUSCOVITE

Green, muscovite-like mica with appreciable amounts of Cr_2O_3 has been variously referred to as fuchsite, mariposite, or chromian (chrome-, chromiferous) muscovite. The matter has been discussed by Hutton (1942) and Whitmore *et al.* (1946). The latter suggest the term *chromian muscovite* to denote those chrome-bearing micas with a clearcut muscovite structure which have generally been referred to as fuchsite. This usage is adopted for the green mica from the Serra de Jacobina. Green chromian mica from various localities, referred throughout the paper, will be denoted by the more general term *chrome mica.*

SEPARATORY PROCEDURES

Green quartzite (Spec. JL-139, Fig. 1) was crushed to (−) 300 mesh, elutriated in a large beaker, and centrifuged repeatedly in bromoform diluted with acetone. A total of about 450 mg. of pure mica was obtained, the specific gravity of which was determined by means of a curve relating density and refractive index of the bromoform-acetone mixture. The chief impurity of the final fraction consisted of minute inclusions of rutile, tourmaline and opaque material, which were estimated to represent less than 0.5 per cent of the total. Nevertheless, as at least some of the TiO_2 in the analysis is attributable to rutile inclusions, all TiO_2 has been eliminated in the calculation of the structural formula.

CHEMICAL AND X-RAY FLUORESCENCE ANALYSIS

The analytical data in Table 1 were obtained by conventional chemical analysis and by x-ray fluorescence spectroscopy. Because of the small amount of sample, the fusion-heavy absorber method of preparation reported by Rose *et al.* (1962, 1963) was modified for the analysis of a 50-milligram sample (Rose *et al.*, 1964) (Table 1, col. 1). The determination of Cr_2O_3 required the preparation of a series of standards by the successive dilution of pure sesquioxide in NBS-97, flint clay. The values for SiO_2, Al_2O_3, Cr_2O_3, and F in column 2 were determined spectrophotometrically.

The value for water represents total water, no separate determination of H_2O^- having been made, and is clearly too high for a muscovite struc-

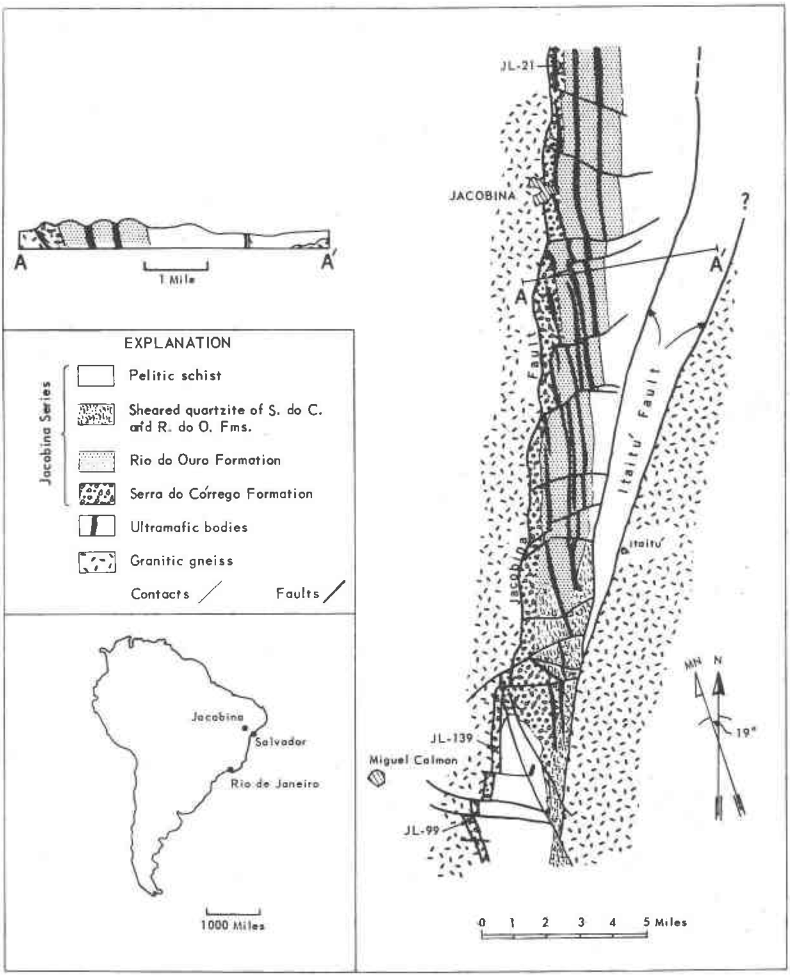

FIG. 1. Geologic map of the southern part of the Serra de Jacobina. Numbers refer to localities in text.

ture. For this reason, the structural formula was calculated on the basis of the theoretical (O, OH, F) content, as outlined by Foster (1960; pers. comm.). This calculation suggests a value for H_2O^+ of approximately 4.3%. The sum of the alkalies is also a little too high; as all determinations were made in duplicate, no immediate explanation for this is apparent.

Semiquantitative spectrographic analysis gave Ba 0.07%, Sr 0.02%, V 0.02%, Ni 0.0015% and traces of Mn, B, Cu, Ga, Pb and Zr.

TABLE 1. CHEMICAL AND *X*-RAY FLUORESCENCE ANALYSIS OF CHROMIAN MUSCOVITE FROM THE SERRA DE JACOBINA, BRAZIL

	(1) *x*-ray fluorescence	(2) Chemical	(3) Average of (1) and (2)	(4) Recalculated $-TiO_2$	(5) Atomic Proportions		
SiO_2	43.5	43.3	43.4	43.9	Si	6.008	8.00
Al_2O_3	33.5	33.3[2]	33.4	33.8	Al	1.992	
TiO_2	0.8	n. d.	0.8	—	Al	3.460	3.94
Cr_2O_3	4.0	3.9	4.0	4.0	Cr	0.433	
Fe_2O_3	0.4[1]	0.25	0.25	0.25	Fe^{+3}	0.025	
FeO		0.14	0.14	0.14	Fe^{+2}	0.017	
MgO	<0.01	0.01	—	—			
MnO	<0.01	n. d.	—	—			
CaO	0.3	n. d.	0.3	0.3	Ca	0.045	2.17
Na_2O	n. d.	0.95	0.95	0.96	Na	0.255	
K_2O	10.5	10.7[3]	10.6	10.7	K	1.867	
H_2O	n. d.	5.7[4]	5.7	5.8	OH	5.296	5.35
F	n. d.	0.13	0.13	0.13	F	0.058	
Total			99.67	99.98			
Less 0 for F				0.05			
				99.93			

Structural formula on basis of $O=20$ and $(OH+F)=4$:

$$(K_{1.87}Na_{0.26}Ca_{0.05})(Al_{3.46}Cr_{0.43}\overset{+3}{Fe}_{0.03}\overset{+2}{Fe}_{0.02})(Al_{1.99}Si_{6.01})O_{20}(OH, F)_4$$

[1] Total Iron as Fe_2O_3.

[2] Determination by Marian Schnepfe.

[3] Determination by L. Shapiro.

[4] Total water (see text).

X-RAY AND OPTICAL DATA

An *x*-ray powder pattern of analyzed chromian muscovite was prepared by Dora von Limbach of the U. S. Geological Survey (Table 3). An internal silicon standard was used to determine the film shrinkage correction. The mica was found to have a $2M_1$ structure, in agreement with chromian muscovites described by Clifford (1957) and Dietrich (1958).

Calculation of d-spacings and unit-cell parameters (Table 2) was carried out by Malcolm Ross, U. S. Geological Survey, using the new computer program developed by Evans *et al.* (1963). The unit-cell parameters were arrived at by automatically repeated least-squares refinement using thirteen unambiguous reflections denoted by asterisks in Table 3.

Table 2. Unit Cell[1] and Optical Data for Analyzed Chromian Muscovite from the Serra de Jacobina, Brazil

CuKα radiation, $\lambda = 1.5418$ Å

Monoclinic	
a	5.204±0.004 Å
b	9.018±0.007 Å
c	20.063±0.005 Å
	95°47′±3′
Space group:	*C*2/ or *Cc*
V	936.8 Å^3
Structure type:	$2M_1$
Density (obs.)	2.86–2.87 g/cm^3
Density (calc.)	2.85 g/cm^3
Optical properties (Na light at 23° C.)	
α	1.568±0.003
β	1.606±0.002
λ	1.610±0.002
2V (obs.)	(−)30°−35°
2V (calc.)	(−)35°
Pleochroic scheme:	
X=colorless	
Y=pale yellowish green	
Z=pale bluish green	
Dispersion: r>v distinct	

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[1] Determined by least-squares refinement of the *x*-ray powder data denoted by asterisks in Table 3, using a computer program written by Evans *et al.* (1963).

Indices of refraction were determined by the immersion method with sodium light. The optic angle was obtained by means of a spindle stage (Oppenheim, 1962), and was also calculated from the indices of refraction. The determined values are in general agreement with those reported for chrome micas by Whitmore *et al.* (1946), and elsewhere in the literature.

Origin of the Chromian Muscovite

Although no detailed study of the field relations of chromian muscovite-bearing rocks was undertaken, it is worthwhile to speculate regarding the origin of the mineral in the basis of the general geology of the Jacobina range, and in the light of what is known about occurrences of chrome mica in other parts of the world.

According to an empirical three-fold classification established by Whitmore *et al.* (1946), fuchsite and/or mariposite may occur (1) associated with quartz, ankerite, sulfides, and gold, as in some of the large gold-bearing districts of Canada and the Mother Lode of California; (2) with

TABLE 3. *X*-RAY POWDER DATA FOR ANALYZED CHROMIAN MUSCOVITE FROM THE SERRA DE JACOBINA, BRAZIL

Calculated[1]		Measured[2]	
hkl	d (Å)	d (Å)	I[3]
002	*9.981	9.933	100
004	*4.990	4.993	50
020	4.509	4.475	50
110	4.490		
$\bar{1}11$	4.465		
021	4.398		
111	*4.301	4.294	10
$\bar{1}12$	4.236		
022	*4.109	4.114	10
112	*3.967	3.973	5
$\bar{1}13$	*3.883	3.880	20
023	*3.733	3.731	20
113	3.580		
$\bar{1}14$	*3.493	3.496	25
024	3.346	3.336	100
006	3.327		
114	*3.202	3.203	25
$\bar{1}15$	3.122		
025	*2.989	2.988	30
115	*2.862	2.861	25
$\bar{1}16$	*2.792	2.792	20
026	2.677		
130	2.600	2.590	5
$\bar{1}31$	2.595		
200	2.589		
$\bar{2}02$	2.570	2.565	40
116	2.568		
131	2.561		
$\bar{1}32$	2.547		
$\bar{1}17$	2.508		
008	*2.495	2.496	10
132	2.485		
$\bar{1}33$	2.464	2.450	5
202	2.448		
027	2.410		
$\bar{2}04$	2.399	2.397	15
133	2.381		
$\bar{1}34$	2.355		
117	2.317		
$\bar{1}18$	2.267		
134	2.259		
040	2.255	2.244	5
$\bar{2}21$	2.253		
220	2.245		
041	2.240		
$\bar{2}22$	2.233		
$\bar{1}35$	2.231		
221	2.210	2.198	2
204	2.209		
042	2.199		
$\bar{2}23$	2.186		
028	2.183		
$\bar{2}06$	2.151	2.146	5
222	2.151		
043	2.135	2.129	25
135	2.130		
$\bar{2}24$	2.118		
118	2.104		
$\bar{1}36$	2.101		
223	2.073		
$\bar{1}19$	2.061		
044	2.055	2.043	10
$\bar{2}25$	2.034		
136	2.000		
0, 0, 10	1.996	1.996	40
		1.969	5
		1.946	5
		1.731	5
		1.664	5
		1.601	5
		1.556	5
		1.523	5
		1.501	20
		1.452	5
		1.426	5
		1.393	5
		1.353	15
		1.338	10
		1.322	5
		1.293	10
		1.278	2

[1] Calculated from the unit-cell data given in Table 2. Reflections marked with an asterisk are those which were used for least-squares refinement of the unit-cell parameters.

[2] CuKα radiation, Ni filter ($\lambda = 1.5418$ A). Camera diameter: 114.59 mm. Lower limit 2θ measurable: approximately 11.0 Å. Film internally calibrated with silicon.

[3] Intensities estimated visually.

biotite or actinolite; and (3) associated with corundum and kyanite in high-grade schist. In each case, formation of the chrome mica is related either to replacement of pre-existing rocks, or to hydrothermal solutions emanating from magmatic intrusions which may vary in composition from ultramafic to granitic. A more recent discussion by Geijer (1963) generally supports the interpretation of Whitmore *et al.*, although it downgrades category (2).

The occurrence of chromian muscovite in the Jacobina range does not fit neatly into any of the above categories. Although its development in gold- and uranium-bearing conglomerate does suggest an affinity with case (1), an important distinction is that in nearly all published descriptions of chrome mica (fuchsite or mariposite) in gold districts, the mica is associated with abundant ankerite or dolomite which have replaced preexisting, mostly mafic or ultramafic rocks (Cooke, 1922; Knopf, 1929; Simpson, 1936). These conditions do not correspond to the situation in the Jacobina range, where there is little if any evidence of carbonate or other replacement related to chromian muscovite-bearing rocks. On the other hand, in descriptions of the gold-uranium districts of Blind River, Ontario, and Witwatersrand and Dominion Reef, Transvaal, which are geologically most closely comparable to the Jacobina area (Ramdohr, 1958), there is no mention of chrome mica, although isolated references to green quartzite or conglomerate do occur (Roscoe, 1957; Ramdohr, 1958).

Chrome mica in kyanite-bearing rocks, of metamorphic grade comparable to that of the Jacobina Series, has been described from the Transvaal (Partridge, 1937) and Baker Mountain, Virginia (Dietrich, 1958; Espenshade and Potter, 1960). Partridge cites a consistent relationship between the distribution of chrome mica and adjacent granitic intrusions, and concludes that chromium was introduced by the granitic magma. No definite conclusion is reached in the case of the Baker Mountain occurrence. Hutton (1942, p. 64) attributes the development of fuchsite in chlorite-zone schists of Western Otago to permeating solutions from deep-seated ultramafic intrusions.

Most other published descriptions of chrome mica, discounting instances in which chromium is thought to be derived from replaced mafic or ultramafic rocks, likewise consider nearby intrusions to be the source of the necessary chromium. In this connection, it may be noted that a magmatic source of mafic or ultramafic composition appears much more reasonable than granitic intrusions, with Cr-contents of the order of 1–2 ppm (Froelich, 1960).

In the Jacobina area the question of the origin of chromium cannot be definitely resolved on the basis of available information. The high concentration of Cr in green quartzite (Table 4), and the concentration of the latter in a zone adjacent to the Jacobina fault, speak for introduction of chromium by hydrothermal solutions moving along the fault zone. On the other hand, the distribution of chromian muscovite in intermittent quartzite and conglomerate layers flanked by chromium-free rocks sug-

TABLE 4. CHROMIUM CONTENT OF GREEN QUARTZITE FROM THE SERRA DE JACOBINA,[1] AND OF OTHER QUARTZITES AND SANDSTONES

Location or description	Cr content ppm
Specimen JL-21, green quartzite 6.5 km. north of Jacobina (Fig. 1).	160
Specimen JL-139, green quartzite from westernmost ridge of range 2.5 km. north of Miguel Calmon-Sapucaia road (Fig. 1).	560
Specimen JL-99, green quartzite from westernmost ridge of range, 0.5 km. south of Miguel Calmon-Sapucaia road (Fig. 1).	1,200
Average of 10 German quartzites (after Froelich, 1960, p. 232).	150
Geometric mean of 289 sandstone samples from Colorado Plateau (Shoemaker *et al.*, 1959, Table 1).	7

[1] Quantitative spectrochemical analyses by S. Berman, U. S. Geological Survey.

gests an original chrome-rich composition of the layers in question. The fact that no green mica occurs in quartz-aluminosilicate rocks west of the Jacobina fault appears to reinforce this hypothesis. As already pointed out, no evidence of detrital chromite was found in the heavy concentrate of green quartzite. This in itself, however, cannot be regarded as proof that such chromite was never present, partly because of the small number of samples studied, and also because any original chromite could have reacted completely with available silica, alumina, and alkalies to form chromian muscovite.

Magmatic introduction of chromium, the mechanism most commonly proposed for occurrences of chrome mica throughout the world, was probably not an important process in the Jacobina range. First, most exposed contacts between granitic rocks and quartzite are faults; in the southeastern part of the range, where an intrusive relationship is fairly probable, there is no development of chrome mica. Second, no evidence of granitic emanations such as pegmatites, granitic dikes, or even disseminated feldspar grains occur in quartzite throughout the range. Finally, there is no consistent relationship between ultramafic sills and dikes in the Serra do Córrego Formation and distribution of chromian muscovite. Moreover, the thick quartzite unit (Rio do Ouro Formation) that overlies the Serra do Córrego Formation also contains ultramafic sills, but is devoid of chromian muscovite (Fig. 1). Spectrographic analyses of nine samples of ultramafic rocks throughout the range, nevertheless, show Cr contents of 0.16% to 0.96%. Thus one may speculate that, although no significant amount of chromium was carried into the wall rocks by ultramafic magma or its derivatives, chromium may well have been leached from ultramafic rocks in the zone of the Jacobina fault and redistributed in adjoining quartzite and conglomerate. Sizable chromite deposits are associated with ultramafic intrusions along the west front of the Jacobina range near Campo Formoso, about 60 km northeast of Jacobina, and smaller deposits occur east of the range near Saúde, about 30 km northeast of Jacobina (Alves de Souza, 1942).

Available evidence thus suggests that detrital and/or hydrothermally introduced chromium may have contributed to the formation of chromian muscovite in the Jacobina range. Regional geologic relationships (Leo *et al.*, in press) indicate that the Jacobina series underwent an extended period of metamorphism, during which the Jacobina fault began to form. Any detrital chromite in quartz and conglomerate beds probably recrystallized during this period with available silica, alumina, and alkalies to form chromian muscovite. At the same time, special chromium concentration in the Jacobina fault zone may have been produced by hydrothermal solutions enriched in chromium by leaching of ultramafic wall rocks. Gold and uranium mineralization is doubtless related to the same period of metamorphism and hydrothermal activity, but it is not known whether these elements were actually introduced by hydrothermal solutions, or were already present as a placer deposit that was hydrothermally reworked during this period.

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