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Study of minerals from the pegmatites of the Nellore mica-belt, Andhra Pradesh, India
Part II. Muscovite

V. R. R. M. BABU
Department of Geology, Andhra University, Waltair

SUMMARY. The muscovites are $2M_1$ polymorph type; minimum temperature of crystallization of 435 °C is obtained from the molecular percentage of paragonite in muscovite.

THE Nellore pegmatites are mined mainly for muscovite. Generally, pegmatites rich in microcline perthite are uneconomical for muscovite mining. Though the muscovite is not an important mineral of the wall zone, in some of the pegmatites muscovite lodes are observed in the wall zone; it is an essential mineral constituent of intermediate zone, is observed in the quartz core margin, and occurs as fracture fillings. Concentration of muscovite around xenoliths of country rock in the pegmatites is common.

Muscovite occurs in shades of green and ruby. Swaminathan (1930), who gave analyses, reported books of mica measuring as much as '10 feet along the basal planes, and 15 feet along the folia'. But usually all gradations of size from a few square feet of area down to scales of microscopic dimensions are observed. Sp. gr. $2{\cdot}90 \pm 0{\cdot}05$; $2V_\alpha$ 38–44°; β varies from 1·580 to 1·590.

The *inclusions* in muscovite are divided into primary inclusions (those formed during or shortly after crystallization of the mica) and secondary inclusions (those formed between the cleavage planes, chiefly through the action of circulating ground water). Some primary inclusions, when removed, leave a hole in the main sheet, interrupting the continuity of the cleavage planes. But secondary inclusions and a few primary inclusions are confined to the space between the sheets.

The primary inclusions in the muscovite under study are garnet, quartz, and magnetite. The secondary inclusions are limonite and hematite. Garnet occurs as small subhedral crystals, quartz as thin layers between the cleavage planes. Magnetite is observed as small crystals, needles, dendrites, and stripes (fig. 1). The magnetite is black and opaque when it is sufficiently thick; it is light smoky grey and isotropic in the thinner aggregates. The length of the stripes, needles, and dendrites vary from a few mm to 100 mm. Some of the inclusions are parallel to rays of the percussion figure. A close similarity of atomic arrangement and spacing in (111) planes of magnetite with that of the (001) plane of muscovite is reported (Frondel and Ashby, 1937). The black magnetite inclusions are altered to yellow and red inclusions. The magnetite

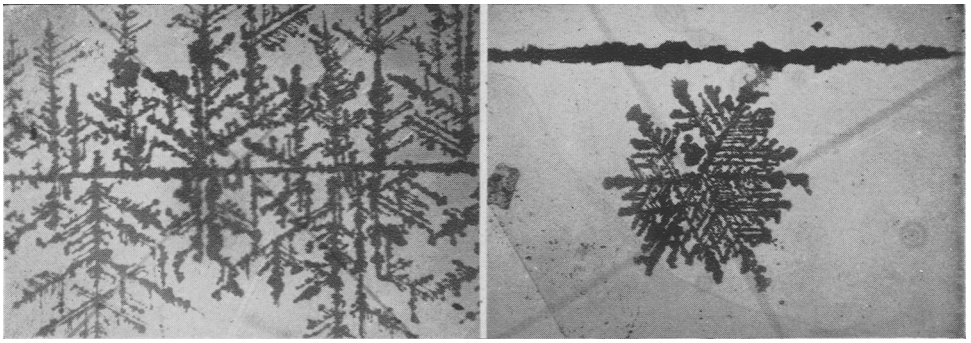

FIG. 1. Dendritic magnetite inclusions in muscovite. Polarized light, ×70.

TABLE I. *Chemical analyses of muscovites*

	1	2	8	9
SiO_2	42·22	42·32	46·42	46·28
Al_2O_3	38·64	38·32	36·77	36·02
Fe_2O_3	0·27	0·10	0·21	0·32
FeO	1·47	1·26	1·64	1·58
MgO	1·31	1·33	0·72	0·84
CaO	0·90	0·92	1·28	1·32
Na_2O	0·72	0·83	0·72	0·82
K_2O	8·84	9·01	8·94	9·10
H_2O	5·42	5·20	3·24	3·32
F	0·10	0·11	—	Trace

	Number of ions on the basis of 12 (O, OH, F)		Number of ions on the basis of 11 oxygens	
	1	2	1	2
Si	2·788 } 4	2·813 } 4	2·840 } 4	2·855 } 4
Al^{iv}	1·212 }	1·187 }	1·160 }	1·145 }
Al^{vi}	1·784	1·814	1·903	1·901
Fe^{+3}	0·013	0·005	0·014	0·005
Fe^{+2}	0·081 } 2·007	0·070 } 2·021	0·083 } 2·131	0·071 } 2·111
Mg	0·129	0·132	0·131	0·134
Ca	0·064	0·065	0·065	0·066
K	0·744 } 0·900	0·764 } 0·936	0·758 } 0·917	0·775 } 0·949
Na	0·092	0·107	0·094	0·108
F	0·021	0·023	0·021	0·023
OH	2·386 } 12	2·304 } 12	If OH 1·979	If OH 1·977
O	9·593	9·673	H_2O 4·11%	H_2O 4·40%
a	5·213 Å	5·228 Å		
b	9·016	9·044		
c	20·03	20·11		
β	95° 20′	95° 44′		

1. Ruby muscovite, Madiga Inam Mine, Kalichedu. Anal. V. R. R. M. Babu.
2. Green muscovite, Bhavani Sankar Mine, Tummalatalupur. Anal. V. R. R. M. Babu.
8. Green muscovite, Palamani Mine, Chaganam. Anal. Swaminathan, 1930.
9. Green muscovite, Inukurti Mine, Inukurti. Anal. Swaminathan, 1930.

and yellow limonitic inclusions when heated directly on a Bunsen flame to a temperature of about 170±20 °C in contact with air turned red, became translucent and showed anisotropy. The yellow and red inclusions are feebly magnetic.

The chemical analyses, structural formulae, and unit cell dimensions of the muscovites under study are given in table I. The H_2O content in both samples is more than the theoretical 4·5 %. The unit cell dimensions of the analysed muscovites are similar

TABLE II. *Minimum temperature of crystallization of muscovite from the pegmatites determined from the muscovite–paragonite proportions*

1 to 7. Anal. V. R. R. M. Babu. 8 and 9. Anal. Swaminathan, 1930

No.	Na_2O (wt %)	K_2O (wt %)	Paragonite (mol %)	Minimum temperature of crystallization (°C)
1	0·72	8·84	10·48	450
2	0·83	9·01	11·93	490
3	0·95	11·20	11·85	485
4	0·75	10·60	9·60	435
5	0·95	12·50	11·51	480
6	0·88	10·30	9·60	435
7	1·00	10·30	12·70	500
8	0·72	8·94	10·38	450
9	0·82	9·10	10·00	440

1. Ruby muscovite from the non-zoned pegmatite of Madiga Inam Mine, Kalichedu.
2. Green muscovite from the intermediate zone of the pegmatite of Bhavanisankar Mine, Tummalatalupur.
3. Ruby muscovite from the non-zoned pegmatite of Meenakshisundaram Mine, Vutukuru.
4. Green muscovite from pegmatite of Anantamadugu Mine, Anantamadugu.
5. Ruby muscovite from the non-zoned pegmatite of Kalyanarama Mine, Kalichedu.
6. Green muscovite from the intermediate zone of the pegmatite of Rajeswari Mine, Tummalatalupur.
7. Honey muscovite from the non-zoned pegmatite of Ramanamahavilas Mine, Vutukuru.
8. Green muscovite from the non-zoned pegmatite of Palamani Mine, Chaganam.
9. Green muscovite from pegmatite of Inukurti Mine, Inukurti.

to those of the most common polymorph, $2M_1$ muscovite. The $2M_1$ polymorph indicates that in muscovite the distortion is large, which may be due to the partial filling of the octahedral sites (Deer *et al.*, 1963).

Temperature of crystallization of muscovite. $2M_1$ muscovite, which is the only stable form of muscovite, is usually assumed to have crystallized between 420 and 650 °C (Velde, 1965). But, based on the studies of Yoder and Eugster (1955), Segnit and Kennedy (1961), and Evans (1965), it is concluded that the muscovite that is associated with quartz in the pegmatites crystallized well below 650 °C. As the pegmatite magma contains high concentration of K and Al and is acidic in nature, the muscovite under study might have crystallized below 500 °C (Gruner, 1939; Folk, 1947). This deduction is supported by the theoretical study of Brotzen (1959), that 'muscovite started to form at about 500 °C (core margin?)' and continued to form until about

300 °C. The association with albite gives it a temperature of crystallization of about 450 °C (Babu, 1966). These theoretical deductions are supported by the chemical analyses. The molecular percentage of paragonite in muscovites was calculated from the chemical analyses and the temperature of crystallization (table II) read from the phase diagram for the subsolidus region of the muscovite–paragonite join of Eugster and Yoder (1955). From the above theoretical deductions and experimental conclusions, a minimum temperature of crystallization for muscovite may be given at about 435 °C.

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