CRYSTALLOGRAPHY AND CHEMISTRY OF Li-Rb-Cs BEARING MICAS FROM THE TANCO (CHEMALLOY) PEGMATITE, BERNIC LAKE, MANITOBA

A Thesis

Presented to The Faculty of Graduate Studies University of Manitoba

In Partial Fulfillment of the Requirements for the Degree

of

Master of Science

by

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October, 1970



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ABSTRACT

Twelve Li-Rb-Cs-rich micas from the TANCO pegmatite, Bernic Lake, Manitoba and two from other localities, have been examined in detail by X-ray diffraction, optical and chemical methods. The X-ray study revealed the presence in three of the specimens of the structure type 1M together with the $2M_1$, one is entirely 1M, and all the others are 2M1 only. X-ray powder reflections that distinguish the two structure types are described. The following correlation between structure type and chemical composition was observed: micas with the 2M1 structure were found to contain up to 3.42 wt.% Li20; from 3.5% to 4.28% Li20 both structure types appear with progressively greater amount of 1M; and above about 4.5% Li20 1M alone is likely to occur. The contents of Rb_2^0 (up to 5.1 wt.%) and Cs_2^0 (up to 0.8 wt.%) increase roughly with an increase in Li_2^0 , but they do not seem to affect the change in structure because two of the specimens with highest Rb + Cs have the 2M structure, and the 1M type was found in micas containing lower Rb + Cs but higher Li percentages. Li, Rb and Cs have a little influence on the unit cell dimensions, generally increasing the <u>a</u> and <u>b</u> dimensions and cell volume, and decreasing $\underline{\beta}$ with increasing amounts. The variation

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of the two refractive indices in the plane of the cleavage, derived by the immersion method in monochromatic (Na) light, showed them to decrease with increasing Li_2O . The 2M_1 micas display the highest indices ($\gamma = 1.599 - 1.573$), the IM types show the lowest values ($\gamma' = 1.566 - 1.561$). All the X-ray chemical and optical data indicate that the 2M_1 micas from the TANCO pegmatite belong to muscovite and lithian muscovite, and that the IM structure type is characteristic of lepidolite at this locality.

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CHAPTER I

INTRODUCTION

A. <u>General Geology and Mineralogy of the Tanco Pegmatite</u>, Bernic Lake, Manitoba

The Tanco pegmatite at Bernic Lake is located about 125 miles northeast of Winnipeg in the Lac du Bonnet Mining Division of southeastern Manitoba. Previous works on the same pegmatite may refer to it as the Montgary or Chemalloy pegmatite, according to the names of the companies that in different times were mining the deposit. At present the property is owned by Tanco.

It is a complex zoned pegmatite which contains the western world's largest known reserve of pollucite, the chief ore mineral of cesium, besides several lithiumbearing units. Other minerals of economic importance are Ta oxides, spodumene and beryl, the first ones being the main ore minerals presently extracted. The pegmatite is located near the margin of a granitic intrusive rock, and it is bordered by amphibolite; the earlier rocks in the area and the pegmatite itself are all of Precambrian age.

The pegmatite body has an explored length along the major (east-west) axis of about 2,700 feet, the known

length of the minor (north-south) axis being about 1,600 feet; the body varies in thickness from about 60 to about 270 feet and it is gently dipping ($\sim 15^{\circ}$) northwards. It consists of complex zones, each of which has a more or less distinctive mineral assemblage.

The mineralogy (Nickel, 1961a) is typical of that of cesium-lithium deposits found in various parts of the world, the principal minerals being: quartz, alkali and plagioclase feldspars, lithium micas, spodumene, pollucite, and amblygonite-montebrasite; accessory minerals include beryl, lithiophilite, apatite, tourmaline, wodginite-tantalitepseudoixiolite, tapiolite, cassiterite, microlite, ilmenite, rhodochrosite and some sulphides.

The pegmatite is divided into six zones of primary crystallization and three replacement units by Wright (1963). According to Černý (personal communication, 1970) Wright's division appears to be correct from the descriptive viewpoint; more emphasis on important accessory minerals should be shown in the names of zones, and metasomatic character of aplitic albite and pollucite is rather doubtful.

Wr	ight's zones:	Čei	rný's zones:
1.	quartz-albite border	1.	quartz-albite border
	zone		zone
2.	perthite-quartz-plagio-	2.	perthite-quartz-plagio-
	clace-muscovite wall zone		clase-muscovite wall zone

Wright's zones:

- clase-quartz intermediate zone
- 4. spodumene-quartz intermediate zone with minor perthite
- 5. microcline-quartz-intermediate zone
- 6. quartz core
 - I aplitic albite
 - II lepidolite (replacing microcline of zone 5)
- III pollucite
- The Present Study в.

The chemical and physical full definition of the micas from Bernic Lake was one of two objectives of the present study, and the variation of the physical properties and crystal structure with the chemistry, especially with respect to the Li, Rb and Cs contents, was the other objective. The present work is part of a broader project of investigation in the Mineralogical Laboratory of the University of Manitoba, of the minerals from the Tanco pegmatite which includes: wodginite-tantalite-pseudoixiolite by J.D. Grice and amblygonite-montebrasite by Ivanka Černá, carried out as

Černý's zones:

- 3. spodumene-perthite-plagio- 3. spodumene-perthite-plagioclase-amblygonite-quartzintermediate zone
 - 4. spodumene-amblygonite-quartz (aplitic albite contemporaneous)
 - 5. microcline-quartz-berylwodginite intermediate zone
 - 6. quartz core
 - 7. pollucite
 - I lepidolite

M.Sc. thesis projects as well. Other studies on the alkali feldspar, spodumene, petalite and other minerals from the same pegmatite are being carried out by P. Černý, Postdoctoral Fellow.

All studies should lead to a better understanding of the paragenesis of the different minerals in the pegmatite.

C. Previous Work on Lithium-Micas

An important study on Li-micas and the relationship between polymorphism and composition in the muscovite-lepidolite series, was carried out by Levinson (1953). This study pointed out that the Li content is chiefly responsible for the change from a normal muscovite structure $(2M_1)$ which tolerates up to about 3.3% of Li₂O, to a "transitional structure" from about 3.4% - 4.0% Li₂O, and finally to lepidolite with more than about 4.0% Li₂O. In Levinson's work lepidolites with 4.0% - 5.1% Li₂O would be $2M_2$, whereas those with more than 5.1 % Li₂O would be 1M.

A review of more than 100 analyses of Li-micas from the literature by M.D. Foster (1960) gives the interpretation of these minerals in terms of the chemical composition. The change in structure from muscovite to lepidolite, with an increase of Li content, occurs when the octahedral occupancy is about halfway between 2.00 and 3.00, and the Li occupancy is about 1.00 (equivalent to about 3.75% Li₂0). The results of the present study and the degree of agreement with these generalizations are discussed later (Chapter VI A).

Five samples of Li-micas from the Bernic Lake pegmatite (Tanco) have been studied both chemically and by X-ray diffraction by E.H. Nickel (1961) and two of these samples were restudied in the course of the present work.

D. Experimental Work Carried Out in the Present Study

1. X-ray Diffraction Study:

Powder photographs

Diffractograms

Single-crystal precession photographs

2. Chemical Analysis:

Atomic Absorption Spectrophotometry

X-ray Fluorescence

3. Optical Study:

The two refractive indices in the plane of the cleavage and the approximate 2V.

E. Acknowledgements

The execution of the present work has been made possible through a scholarship offered to the writer by the Canada Council as part of the program of cultural exchanges between the two governments of Italy and Canada.

The writer is grateful to Dr. R.B. Ferguson, Professor of Mineralogy at the Department of Earth Sciences of the University of Manitoba, for help and suggestions as supervisor. Many thanks go to Dr. P. Černý, Postdoctoral Fellow at the same institution for suggesting the research and for useful advice. Mr. K. Ramlal, research chemist, and R.M. Hill, chemistry technician, of the Department of Earth Sciences, carried out the analyses of Si and Al by means of X-ray fluorescence, of Cs by atomic absorption, and of water, and they were very helpful during the execution of the other analyses by the author. C.T. Williams, Mine Manager, and R. Crouse, Mine Geologist, officials of TANCO Ltd. at the Bernic Lake Mine are gratefully acknowledged for the hospitality and the help received during the collecting of the specimens.

Two samples (REN. 1 and REN. 5) were provided by Dr. E.H. Nickel, of the Mines Branch, Department of Mines, Energy and Resources, Ottawa, and two other samples (ROM. 26 and ROM. 28) by Drs.J. Mandarino and R. Gait from the Royal Ontario Museum, Toronto. To them goes the gratitude of the author.

Thanks are also due to Dr. G. Gottardi, Institute of Mineralogy, University of Modena, Italy and Dr. M. Franzini, Institute of Mineralogy, University of Pisa, Italy, for useful communications.

CHAPTER II

DESCRIPTION OF SPECIMENS

A. Specimens from the Tanco Mine, Bernic Lake

The samples are grouped according to the zones of the pegmatite from which they come, according to Černý (personal communication, 1970).

The sequence of the description of the individual zones follows roughly the presumed sequence of crystallization of the pegmatite. In the first three zones the micas described seem to be a normal constituent of the primary assemblage of these individual zones. The last two groups of micas are thought to have formed by replacement of feldspars during a late stage of development of early K-feldspar-rich zones.

Group No. 1

From the coarse-grained K-feldspar-spodumene + quartz-albite-amblygonite zone.

Specimen R.1.	Yellowish-white muscovite in crystals
	5-20mm in size, associated with medium-
	grained K-feldspar, albite and quartz.
Specimen R.2.	Greenish-white muscovite in books of
	crystals about 10mm across, associated

with cleavelandite and quartz.

Specimen R.3.

Violet mica in small (1-3mm) curved crystals developed in columnar aggregates elongated along the [001] direction, in cleavelandite and quartz. This assemblage rims the material of the two preceding specimens R.1. and R.2. against larger concentrations of pure quartz. This mica is associated with curved grey lithian-ferroan muscovite, which is described in Nickel (1961, p. 13, anal. 4).

<u>Specimen R.4.</u> Greenish-white muscovite in large crystals in cleavelandite and quartz, with coatings of yellow-green finegrained muscovite + cookeite. <u>Specimen REN. 1.</u> Curved violet mica in large irregularly columnar aggregates associated with cleavelandite and quartz. This specimen represents the same type of mica as R.3., received from E. H. Nickel, described in Nickel (1961, p. 13, sample No. 1).

Specimen RNB. 330. Curved violet mica in large irregular columnar aggregates in cleavelandite

and quartz, not distinguishable from REN. 1. and again closely related to R.3. It is the same sample used by N. Bristol (1962).

Group No. 2

From the very coarse-grained quartz-spodumene + quartzamblygonite zone, with rather exceptional K-feldspar and pollucite.

<u>Specimen R.15.</u> Green curved muscovite in large columnar aggregates, associated with cleavelandite, wodginite and quartz. The sample comes from the contact between this zone and that described under Group No. 4.

Group No. 3

From the very coarse-grained quartz-spodumene + quartzamblygonite zone, with rather exceptional K-feldspar, as in the previously described Group No. 2, but in immediate contact with the overlying pollucite body.

- Specimen R.12. White muscovite in flakes about 25mm in diameter, breaking down into needleshaped laths.
- <u>Specimen R.13</u>. Green-yellow medium-grained (~ 3mm) muscovite occurring in masses associated with albite, spodumene and quartz.

Group No. 4

From the medium-grained K-feldspar-quartz-berylmuscovite-wodginite zone.

Specimen R.8. Fine-grained green muscovite with quartz and wodginite.

Specimen <u>RBLM. 72.</u> Yellowish-green very fine-grained (massive) muscovite containing relics of K-feldspar and displaying a globular surface against a fissure. A finer grained variety of sample R.8.

Group No. 5

From the coarse-grained K-feldspar + purple mica + quartz ± albite assemblage.

- Specimen R.7. Fine grained (massive) violet lithian muscovite with some quartz and larger amounts of K-feldspar penetrated by the mica.
- <u>Specimen R.9.</u> Fine grained (massive) violet lithian mica with some quartz and larger amounts of K-feldspar penetrated by the mica. In appearance, the same type of mica as R.7.

<u>Specimen</u> <u>REN. 5.</u> Fine grained (flakes up to about lmm) violet lithian muscovite very similar to samples R.7. and R.9., received from E. H. Nickel; described in

Nickel (1961, p. 13, sample no. 5).

The actual locations of the samples collected by the author in the mine are marked on the map of Figure 1.

B. Specimens from other than Bernic Lake

These specimens were received from the Royal Ontario Museum, Toronto, and taken into consideration for correlation with the Bernic Lake specimens. One of the two (ROM. 28) from Bikita, Rhodesia, has a chemical affinity with the specimens from the Tanco Mine in that it is a lithian muscovite with relatively high Rb and Cs contents.

Specimen
ROM.26.868.Red-purple medium-grained ferroan
muscovite from North Bay, Ontario.From the R.O.M. as sample M.26.868;
in the text referred to as ROM.26.Specimen
ROM.28.068.Very fine-grained (massive) purple
muscovite from Bikita, Rhodesia.From the R.O.M. as sample M.28.068;
in the text referred to as ROM.28.



Distinction in zones after Cerná, numbers related to Wright, 1963.

CHAPTER III

X-RAY DIFFRACTION STUDY

A. Powder Photographs

A preliminary powder photograph X-ray diffraction study was carried out for all the samples using standard Philips 114.59mm diameter cameras.

The samples were ground to a fine powder by hand in a mortar and pestle and mounted on fine glass rods with the aid of soft burette grease. Fine collimators were used in order to obtain finer lines and a better resolution of the reflections. The photographs were taken with Ni-filtered Cu radiation.

This investigation revealed that two of the specimens (REN.1 and RNB.330) had patterns that differ from the common $(2M_1)$ muscovite pattern given by all the others. The sample ROM.28 gave a different picture in terms of the intensities, probably due to the extremely fine size of the crystals that prevented almost entirely the preferred orientation which affected, more or less, all the other patterns. The data for the powder patterns are not reported here because an X-ray diffractometer study of all the specimens has also been carried out, and the data collected by this method are more precise and were used for the

determination of accurate cell dimensions.

Figure 2 (a, b, c) shows the three different kinds of patterns obtained from three different structure types: 2M₁, 1M>>2M₁, 1M of micas from the Tanco pegmatite.

B. Powder Diffractograms

A Philips diffractometer was used for this part of the study. The operating conditions were:

Radiation/Filter	Cu/Ni
Voltage	50 kV
Tube current	20 mA
Scanning speed	1/4°20 per minute
Time constant	4 secs.
Range CPS	4×10^2
Zero suppr.	0
Slits	1 [°] , 0.1mm, 1 [°]

Chart speed

10x

The angular range recorded was from 8° 20 to 50° 20; each run would thus take two hours and 48 minutes approximately. The patterns were calibrated by means of synthetic fluorite as an internal standard (Tilling, 1968, after Stewart). Care was taken to avoid preferred orientation, but the intensities of the peaks are affected more or less in all the specimens excluding the one, ROM.28, as already mentioned for the camera work.

The samples were ground to a very fine powder by means of a mechanical mullite mortar, but in one case



- Figure 2. X-ray powder photographs illustrating the three different structure types; Cu/Ni radiation, 114.59mm diameter cameras, contact prints.
 - 2a. Type $2M_1$, specimen REN.5.
 - 2b. Type 1M>>2M₁, specimen REN.1.
 - 2c. Type 1M, specimen RNB.330.

(ROM.26) three hours of grinding destroyed the structure of the mineral, and the grinding was repeated manually.

1. Structure Types

From the diffractograms it emerged that two samples, other than the two (REN.1 and RNB.330) that gave different powder photographs, showed "extra" reflections in addition to those characteristic of the normal 2M₁ muscovite structure. These samples are R.3 and R.9. A study of the diffractograms of one of the first samples (REN.1) revealed that the pattern is mainly due to a 1M structure, and as described later, this was confirmed by a singlecrystal precession study. The "extra" reflections of samples R.3 and R.9 belong to the 1M structure type as well, and this is easily seen from a direct comparison of the diffractograms (Figure 3).

Table 1 compares the powder data for the patterns of the samples R.8, R.3, R.9, REN.1, and RNB.330 with those quoted by Yoder and Eugster (1955) for the 2M₁ and the 1M polytypes.

Table 1 and Figure 3 show clearly that samples R.3, R.9 and REN.1 are mixtures of the two structure types $2M_1$ and 1M in different proportions, whereas R.8 has a true $2M_1$ structure and RNB.330 has a true 1M structure. Some of the reflections are unique for one or the other of the two structure types. The most evident of these are:



Figure 3. X-ray powder diffractograms.

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X-RAY POWDER DIFFRACTOMETER DATA

TABLE 1

										Э.Э			R.3		RI	EN.1		RN	B.#330		· • •		
*2M1 S	Synthet	ic	*1M	Synthe	tic		R.8		0	- K. 9		· . O	-	6	4 0	Ŧ	hkl	A.b	I	hkl	•		
Å.b	I	hkl	a, X	I	hkl	d,A	· 1	hkl	d,Ă	I	hkl	d,A	1	002		40	001	10.037	36	001			
10.014	>100	002	10.077	>100	001	10.060	>100	002	10.094	>100	002	10.031	40	002	5.013	45	002	5.011	60	002			
5.021	55	004	5.036	37	002	5.023	100	004	5.033	100	004	21021			4 500	10	020				• •		
4.478	. 55	110	4.488	90	020			-	•						4.506	10	020						
4.458	65	111	•			4.458	18	111	•												•		
4.391	14	021	4.349	27	111									· ·						.4			
4.296	21	111			0.01																		
4.109	14	022	4.115	10	021				•	1		•											
3.889	37	113				3.880	16	113				3.740	18	023			510	2 6 2 9	16	112	(1M)		
3.735	32	023	3.660	60	ī 12	3./34	10	023	3.648	6	<u>1</u> 12	3.638	24	112	3.640	20	112	3.030	. 10	***	(2M))		
3.500	44	114	5.000	,		3.449	32	114	3.496	24	114	3.493	40	.024	5.450		,003	2 241	>100	003ء	-		
2 251	>100	f024	3 356	>100	1003	3,350	100	{ ⁰²⁴	3.349	>>100	{ ⁰²⁴ 006	3.345	100	{006	3.342	>100	022	3.341	>100	°022	(2)()		
3.331	>100	1006°	3.350	100	022	•••••		-006	2 212	30	114	3.214	54	114	3.215	8	114		•••	110	(21)		
3.208	47	114	2 072	50	112	3.207	40	114	3.083	12	112	3.084	20	112	3.089	40	112	. 3.091	28	114	(1M) (2M,)		
2.999	47	025	- 075 P			2.998	50	025	2.998	20	025	2.996	40	025	2.997	18	113	2.908	16	113	(1M)		
			2.929	6	113	2 868	34	.115	2.872	18	115	2.874	38	115			116		•		(2M.)		
2.8/1	22	115	St. F			2.801	28	116	2.798	18	116				2.685	16	023	2.683	10	023	(1M [†]		
		Ŧ - 1	2.689	[£] ° 1 6	023	X	•									. 10	120		05 2	- 	SBC 1		
2.589	50 45	116	2.582	50	130										2.592	10	130		130	0.6 0.6	2.565	, ¥	
2.562	90	202	2.565	90	131							•			2.566	20	200	2 505	0000	800	2.556 043 545	346	
2.514	20	008	2.500 **2.505	4004	0004	2.510	50	008	2.510	36	008	2.508	60	008	2,506	14	004	. 21 00			CDC 4-5 -	1 T	
2.458	19	13 3					· .				3								÷				
2.446	12	202	2.450	4	131	•	· · ·												·		ti i ca		
2.396	10	204			.	•			•								•				9 - C	•	
2.380	24	133	2.380	- 12	040					2										•	•		
2.236	5	041		-						2. 				,									
2 209	5	221	2.219	1	220						-19-1- 												
2.200			2.191	4	041					~			•					•					
2 1/0	10	222	2.156	20	133											•							
2.132	23	043					·.	•	•														
2 051	6	044	2.109	6	202								= (0010	2 005	60	005	2.004	100	005			
2.010	75	001	0 2.013	32	005	2.008	100	0010	2.008	100	001	0 2.006	20	0010	2.005		•••						N
1.975	14	137	1 900) 4	134	•												•		* 34 (이야 한다. 이야 한다.	Ö Fors	N
1.670	12	201	0 1.668	š 18	116			•						DE 1305	EV.				د. مۇرىيا بۇر	end in 192	M7 Bes -	for 2M	values
* Th	e value	s for	2M, and 1	M synt	hetic s	tructure	types a	are from	m Yoder &	Eugste	r, Geo	ch. Cosm.	A. <u>8</u> 2	72 (TA2					್ಷ ನಿಂದಿ ಕೊಂಡಿದ್ದಾರೆ. ಕಿಂಗ್		an an an ann a' g An an Anna an		
** va	lue no	t quote	ed in Yode	er and	Eugster	•		· · ·				•									•• *		
		-																					

For the 1M structure:

2θ ⁰ (CuKα)	d,A	<u>hkl</u>
24.453	3.640	. <u></u>]12
28.900	3.089	112
30.712	2.911	<u>1</u> 13
33.375	2.685	023

For the 2M₁ structure:

2θ ⁰ (CuKα)	d,A	<u>hkl</u>
25.526	3.490	<u>1</u> 14
27.740	3.215	114
29.825	2,997	025
32.060	2.791	116

2. Cell Dimensions

Every sample was run at least twice on the diffractometer, and the 20 values, after correction using the internal standard, were averaged. These values were used as input data in a least squares computer program for cell dimensions refinement (Appleman, 1963). Approximate values of the cell dimensions to start the refinement were derived from singlecrystal precession photographs which are described later. The Miller indices of the unique reflections, taken from the A.S.T.M. cards, and the extinction conditions for one or the other of the two structure types, were the other input data for the program. Results are given in Table 2.

For the specimens that gave a $2M_1$ pattern with minor

- CELL	DIMENSIONS	FROM THE	POWDER	DIFFRACTOGRAMS	
	and the second	the statement of the second			

TABLE 2

Sample No.	Structure Type	<u>a</u> , A	b, A	<u>c</u> , A	β ^O	Volume A^3	20 Tol.	Cycles
R.1	2м ₁	5.188±.005	9.006±.013	20.144±.008	95 ⁰ 42'±3'	936.53±1.27	.043	3
R.2	2M ₁	5.189±.004	9.000±.010	20.129±.006	95 ⁰ 45'±2'	935.49±0.98	.040	3
R.3	2M ₁ (>>1M)	5.199±.002	9.014±.005	20.157±.002	95 ⁰ 31!±1'	940.36±0.50	.040	4
R.4	^{2M} 1	5.185±.003	9.030±.014	20.143±.009	95 ⁰ 40'±4'	938.57±1.42	.046	3
R.7	2M ₁	5.186±.011	9.017±.017	20.172±.009	95 ⁰ 33'±6'	938.80±2.20	.056	3
R.8	^{2M} 1	5.190±.003	9.006±.007	20.189±.003	95 ⁰ 47'±2'	938.93±0.70	.040	3
R.9	2M ₁ (>1M)	5.194±.009	9.006±.020	20.181±.008	95 ⁰ 36'±4'	939.53±1.96	.057	5
R.12	^{2M} 1	5.183±.003	9.009±.008	20.147±.005	95 ⁰ 45'±3'	935.96±0.84	.040	3
R.13	2M ₁	5.190±.002	8.998±.008	20.183±.005	95 ⁰ 46'±2'	937.74±0.76	.040	4
RBLM.72	^{2M} 1	5.187±.004	9.010±.006	20.179±.004	95 ⁰ 47'±2'	938.28±0.87	.040	3
ROM.26	2M ₁	5.199±.005	9.063±.015	20.076±.005	95 ⁰ 46'±2'	941.17±1.29	.040	4
ROM.28	2M ₁	5.187±.003	9.003±.006	20.232±.006	95 ⁰ 45'±3'	940.04±0.60	.040	3
REN.1	lm(>>2M ₁)	5.224±.001	9.013±.002	10.205±.001;	100 ⁰ 50'±1'	471,90±0.13	.040	4
REN.5	2M ₁	5.199±.005	9.030±.008	20.162±.005	95 ⁰ 30'±2'	942.24±0.92	.040	3
R.15	^{2M} 1	5.188±.003	9.007±.011	20.176±.005	95 ⁰ 46'±3'	938.03±1.07	.040	3
RNB.330	lm	5.220±.004	9.014±.009	10.199±.002	L00 ⁰ 45'±2'	471.49±0.45	.040	3
		+	dogianatog	the standard				

± designates the standard error

IM (R.3 and R.9), the cell dimensions were derived on the basis of only the $2M_1$ reflections. In this case, however, the computer program needed more than the usual 3 cycles of refinement, probably because of the interference of the 1M structure with the reflections that are possible for both the $2M_1$ and the 1M structures. This is also evident from the tolerance in 20 that was allowed by the program in the last cycle for sample R.9 where the amount of 1M is higher. The tolerance is a measure in 20 of the agreement between the observed 20 values and the theoretical ones, once a choice of cell dimensions has been made by the computer. This value is imposed as an input data and in this case it was programmed to go down to 0.04 20.

For the specimen REN.1 that gave a 1M pattern with very minor $2M_1$, the cell dimensions were calculated for the 1M structure, and in this case the computer itself rejected the four reflections that were exclusively due to the $2M_1$ structure type. The same 20 values were used for a $2M_1$ run, naturally with different Miller indices and extinction conditions, but this time most of the 1M reflections were accepted into the $2M_1$ structure being close enough to the theoretical 20 values of that structure. Thus, the cell dimensions derived this way do not have any significance and they are not included in Table 2. Furthermore, the number of cycles required for this run was six and the 20 tolerance went down only to 0.141° .

The structures enclosed in parentheses in Table 2 are present in a lesser amount in the sample, and the cell dimensions were calculated for the more abundant of the two structures.

Table 2 gives the standard errors which were calculated by the computer on the basis of the deviations of the observed 2θ values from the theoretical ones.

C. Single Crystal Precession Investigation

The determination of the unit cell and the space group, and hence of the structure type, was carried out on four of the micas by means of precession photographs. The cell dimensions were used as starting values for the refinement process in the computer program for processing the powder data, as already mentioned.

The method used is fully described in Buerger (1964). The instrument used is a Charles Supper Model 3000 provided with attachment for a Polaroid camera.

1. Sample Preparation and Optic Orientation

A first check of the homogeneity and absence of twinning in the crystal to be used was done on a Zeiss binocular microscope in transmitted light. About half a dozen crystals selected in this way were then observed by means of a Zeiss petrological microscope and a choice was made of the most suitable one. The optical orientation of the crystals was determined by the interference figure. After mounting the crystal on the goniometer head, the orientation was checked again by means of a Donnay optical analyzer (Charles Supper Co. Inc.) and the position of extinction was used to orient the crystal before using the X-rays for orientation precession photographs. In this first stage the [100] axis was chosen as rotation axis, its position being determined by the likely position of the optical plane based on the known Li₂O content.

In the case of muscovite the O.A.P. is at right angles to the crystallographic \underline{x} axis, whereas in the case of lepidolite it is parallel to the \underline{x} direction (Deer et al., 1962). The second orientation was found to occur in sample REN.1 as it has been established by optical study of the crystal that had been used for the precession work.

Another centering operation was performed with the crystal on the precession instrument by means of an autocollimator (Buerger, 1964, p. 51). By this operation the plane of cleavage was brought approximately normal to the X-ray beam, and then by rotation of $90^{\circ}00'$ the X-ray beam would be approximately normal to the (010) plane and \underline{x} would then be very nearly along the rotation axis.

Very small and thin crystal flakes were used (0.3mm x 0.2mm x 0.0015mm) to avoid as much as possible the broadening of the reflections, but this attempt was successful only in part due to the difficulty inherent in these particular minerals.

2. Precession Photographs and their Interpretation

Four samples were analyzed by this method: R.7, R.9, R.13, and REN.1. For samples R.7, R.9 and R.13 both Mo/Zr and Cu/Ni radiations were used, whereas sample REN.1 was X-rayed only by Ni-filtered Cu radiation. Cu radiation has a longer wavelength and thus gives a better resolution, and this proved useful especially for the interpretation of the photographs precessing around [010]. In these photographs the long \underline{c} repeat period caused the reflections along the z^* axis to be too close in the case of Mo radiation and especially for the upper level photographs. On the other hand, the shorter wavelength allows the recording of a greater number of reflecting planes which permits one to attain better accuracy in the measuring of the cell dimensions.

About three orientation photographs taken with the Polaroid camera were generally needed to center the crystal in the required orientation. These were taken with a precession angle $(\overline{\mu})$ of 10° , unfiltered Mo or Cu radiation, and an exposure time of 10 minutes. After one or two orientation photographs, needed to make the plane of the cleavage exactly perpendicular to the X-ray beam, by a rotation of $90^{\circ}00'$ on the dial, the plane (010) was brought normal to the X-ray beam, and another orientation photograph precessing around <u>b</u> was taken. This photograph shows the x^* and z^* axes, and of course the a^{*} and c^{*} repeat periods

and the reciprocal angle β^* which in the case of Figures 4 and 5 is in the upper left quadrant. Subsequently, zeroand first-level photographs were taken in this orientation with a $\overline{\mu} = 25^{\circ}$ (Figures 4 and 5). Operating on the vertical rocker the x^* axis was then made to coincide with the rotation axis, and, after a rotation of $90^{\circ}00'$ on the dial, a zero and first-level photograph precessing around [001] $(\overline{\mu} = 25^{\circ})$ were taken.

A complete set of photographs for each crystal includes a zero and a first-level precessing around <u>b</u>, a zero- and a first-level precessing around <u>c</u>, and the two corresponding cone-axis pictures (Figures 4, 5, 6 and 7).

The cone-axis pictures (Buerger, 1964) are needed to measure the approximate but true repeat periods <u>b</u> and <u>c</u> in order to determine the setting of the instrument for the first-level photographs; therefore, they are often taken just after the zero-level. The cone-axis pictures around <u>b</u> gave satisfactory results (Figure 7), but the ones around <u>c</u> were unusual and difficult to interpret. This difficulty could have been due to the flaky nature of the minerals which caused a diffuseness of the reflections.

The extinction conditions, besides the conventional unit cell dimensions, were derived from the zero-level and first=level photographs precessing around the [010] axis. For samples R.7, R.9 and R.13 the possible space-groups



Figure 4. Sample R.9: zero and first-level precession photographs superimposed, precession axis b [010], $\mu = 25^{\circ}$, Cu/Ni radiation; 2M structure type. Reciprocal parameters a* and c* outlined, z* axis vertical.



Figure 5. Sample REN.1: zero and first-level precession photographs superimposed, precession axis <u>b</u> $\begin{bmatrix} 010 \end{bmatrix}$, $\mu = 25^{\circ}$, Cu/Ni radiation; 1M structure type. Reciprocal parameters a* and c* out-lined, z* axis vertical.



Figure 6. Sample REN.1: zero-level precession photograph precessing around <u>c</u> [001], $\mu = 25^{\circ}$, Cu/Ni radiation. The a* and b* parameters outlined. The pseudo-exagonal symmetry is evident; y* axis vertical.



Figure 7. Sample REN.1: Cone-axis picture, precession axis <u>b</u> [010], $\mu = 10^\circ$; Cu/Ni radiation.

thus derived were C2/c or Cc, whereas for sample REN.1 they were C2/m or C2 or Cm (Nuffield, 1966, p. 372). These results led to the final conclusion that for the first three samples the structure type is the common muscovite $2M_1$, and for sample REN.1 it is 1M.

It should be noted that for sample R.9 it was impossible to recognize the possible presence of some accompanying LM structure because reflections due to this structure would be masked by the ones due to the $2M_1$. In the case of sample REN.1 the little flake used for singlecrystal work was almost certainly entirely constituted by LM structure since it was not possible to recognize any reflections that would have split the <u>c</u>^{*} repeat period revealing a <u>c</u> period of ~ 20 A instead of ~ 10 A.

The cell dimensions were derived measuring the photographs by the method and instrument described in Nuffield (1966, p. 278). Since the values of cell dimensions from these photographs have only a relative importance, no correction for film shrinkage or calibration of the instrument with a standard crystal were made; the errors reported in Table 3 refer only to an uncertainty of measurement. The readings were repeated three times and the deviation from the highest to the lowest was assumed as error. Even though these values are affected by a bigger error, they are perfectly comparable with the more precise values obtained with the diffractometer and in most cases they fall

within the same range (Table 3).

TABLE 3

	CELL	PARAMETERS OBTAINED	FROM PRECESSIO	N PHOTOGRAPHS	1
	COMPA	RED WITH THE ONES OBT	AINED WITH THE	POWDER METHOD	
			•		
Sample No.	Structure Type	a, A	, A	с, А	0 G
·	• •	Prec. 5.195 ± .009	9.030 ± .040	20.310 ± .080	95 ⁰ 351 ± 2.
R.7	$2M_{\rm L}$				
	•	Diff. 5.186 ± .011	9.017 ± .017	20.172 ± .009	95 ⁰ 33' ± 6!
		Prec. 5.191 ± .007	9.015 ± .009	20.141 ± .055	95 ⁰ 20'± 30
R.9	2M ₁				
		Diff. 5.194 ± .009	9.006 ± .020	20.181 ± .008	95 ⁰ 36' ± 4'
		Prec. 5.183 ± .015	8.974 ± .030	20.213 ± .050	95 ⁰ 45' ± 1(
R.13	2M ₁				
		Diff. 5.190 ± .002	8.998 ± .008	20.183 ± .005	95 ⁰ 46' ± 2'
		Prec. 5.193 ± .040	9.003 ± .010	10.203 ± .008	100 ⁰ 40' ± 19
REN.1	TM				
		Diff. 5.224 ± .001	9.013 ± .002	10.205 ± .001	100050' ± 1'

CHAPTER IV

CHEMISTRY

A. Methods

Fourteen of the sixteen specimens examined in this study were chemically analyzed completely or partially, all but two being from the Tanco pegmatite at Bernic Lake, the two exceptions being samples ROM.26 and ROM.28.

An Atomic Absorption Spectrophotometer, Perkin Elmer Model 303, was used for the analysis of Li, Na, K, Rb, Cs, Mg, and Fe on all the fourteen samples. For six of the twelve specimens from Bernic Lake, Si and Al were determined by means of an A.R.L. X-ray fluorescence unit. For these six samples H₂O has also been determined. With the addition of the analysis of F, the analyses of these samples would then be complete, but it was impossible to arrange for the analysis for this element before this thesis was completed. No description of the sample preparation or the handling of the readings from the instruments is given here since they are procedures that are standard in most chemistry laboratories. These analyses were carried out in the chemistry laboratory of the Department of Earth Sciences, University of Manitoba.

B. Results

The results of all the chemical analyses are given in Table 4. The structures revealed by the X-rays are also reported.

A variable amount of Li_2O is contained in the different micas from Bernic Lake from a low value of 0.15% in one of the green muscovites to a high value of 4.28% in the violet mixed muscovite-lepidolite. The content of Rb_2O is relatively high in all the micas from Bernic Lake, the low value being 1.50% and the high 5.10%. The amounts of Cs_2O are less than those of Rb_2O , and they fall between the limits of 0.12% and 0.79%.

The relationships between structure type and chemical compositions are discussed in detail in Chapter VI. However, it can be noted from Table 4 that there is a correlation between the content of Li₂O and the structure type (Levinson, 1953); this is discussed in more detail in Chapter VI. In agreement with Foster (1960) the Si content is higher in the specimens with high Li content. This is due to the necessity of balancing the deficiency of positive charge carried by the replacing of Li for Al in the octahedral sites.

The contents of Rb and Cs show a direct relationship with the Li content. That is, an increase of Li is generally accompanied by an increase in Rb and Cs, (Table 4 and Figures 10a and 10b).

The amount of total Fe, given as ferrous oxide, in

5.68 1.51^{*}101.22 97.29 99.28 98.20 98.82 96.91 Total (Cs) 5.10° 0.55 0.02 0.26 0.50 26.64 44.85 6.44 1.44 (Li, Na, K, Rb, Mg, Fe); K, Ramlal (Al, Si, H₂O) and R.M. Hill n.d. n.d. n.d. n.d. n.d. n.d. n.d. n.d. n.d. n.d n d n.d. n.d 됴 * Values from Nickel (1961) n.d. 0.07 0.37 10.28 0.00 n.d. 0.80 3.92 n.d. n.d. n.d. n.d. n.d. 6.08 н20 0.71 <.01 0.03 n.d. 28.64 47.50 4.59 n.d. n.d. 34.36 43.20 6.80 45.25 7.57 n.d. n.d. 4.28^{*} 0.40^{*} 9.00 4.47^{*} 0.79 0.00 0.06^{*} 0.44^{*} 28.84 45.75 sio₂ n.d. n.d. n.d. 47.80 n.d. n.d. n.d. n.d. 25.90 28.64 MnO AL203 n.d. n.d. n.d. 9.27 2.88 0.33 0.33 0.04 n.d. 0.22 10.12 1.69 0.21 <.01 0.32 n.d. n.d. 2.91 0.50 <.01 0.06 n.d. n.d. 0.21 0.24 11.48 1.56 0.20 <.01 0.31 n.d. n.d. 9.42 1.81 0.12 <.01 0.45 n.d. 9.75 1.50 0.24 <.01 0.41 n.d. 0.51 n.d. 0.07 0.50 2.12 0.21 <.01 0.59 MgO FeO CHEMICAL ANALYSES .37 2.05 0.21 <.01 9.20 2.24 0.12 <.01 Rb_2O Cs_2O 3.46 0.79 9.45 3.59 Values are in wt % 9.12 9.98 3.42 0.17 9.43 00.6 9.39 К₂0 0.27 0.17 0.82 0.85 0.33 0.95 0.19 0.19 0.92 0.41 Li_2O Na₂O 0.15 0.54 3.97 0.56 0.32 0.42 3.12 0.37 3.50 R. Rinaldi Structure lm≫2m₁ Type $2M_{\rm I}^{>>1M}$ $2M_{\rm L}^{>}1M$ 2M₁ $^{2M}_{\rm L}$ 2M 2M₁ 2M1 2M $2M_{1}$ 2M₁ $2M_{1}$ 2M1 $2M_{\rm L}$ Sample R.12 ROM.28 R.13 RBLM.72 **ROM.26** Bγ REN.1 R. 8 R.9 REN.5 К. З R . 4 R.2 R. 7 No. R. 1

TABLE 4

the lepidolite-type and in the violet micas, is about ten times lower than it is for the muscovites-green muscovites.

CHAPTER V

OPTICS

A partial determination of the optical properties was carried out on seventeen of the specimens by measuring the two refractive indices in the plane of the cleavage using the immersion method, and by estimating the 2V values.

The samples were crushed and examined in liquid mounts and the optical reactions tested with the Becke line. A monochromatic source of light (D line of Na light; $\lambda = 589m\mu$) was used in conjunction with a set of refractive indices liquids from 1.520 to 1.592 in steps of 0.002, and from 1.592 to 1.700 in steps of 0.004.

The exact refractive indices of the liquids used were determined by means of a Zeiss refractometer. No correction for temperature variations was made because such variations fell within the limits of the experimental error.

In the case of both lepidolite and muscovite, one of the two principal vibration directions Y and Z is in the basal cleavage plane and the other nearly so, but the case is different in the two minerals.

Figure 8 shows that in muscovite the O.A.P. is normal to (010), and the optical Z coincides with the crystallo-



muscovite

lepidolite

Figure 8.

Optical orientations of muscovite and lepidolite (from Deer et al., 1962, vol. 3). graphic \underline{y} so that Z is in the (001) cleavage plane. Therefore, in muscovite an exact measurement of the refractive index γ can be obtained in the basal cleavage plane. The optical Y is nearly in the cleavage plane (β :x 1^o- 3^o) and therefore an approximate β , namely β ', can be measured in the same orientation. In lepidolite, the situation is reversed, and an exact measurement of the refractive index β may be obtained in the basal cleavage plane (001), with the other refractive index measured in the same plane being an approximate γ , namely γ ' (γ :x 0^o-7^o).

To observe one or the other of the two indices, the crystal was turned to extinction, so that one of the two would be cancelled, and then the same operation was repeated for the other one. Of the two, the higher is γ or γ ', the lower β or β '. In order to make sure that the little flakes used for the determinations were lying flat, only those that showed well centered interference figures were chosen. By observing the interference figures it was also possible to derive an approximate value of 2V by comparing the curvature of the isogyres with the diagram of Wright (Moorhouse, 1959, p. 34).

Table 5 shows clearly that the range of values for the refractive indices of lepidolite is generally lower than for muscovite, which is also true for the samples of the present study.

A sample of lepidolite from the Varuträsk pegmatite

TABLE 5

COMPARATIVE REFRACTIVE INDICES FOR MUSCOVITE

AND LEPIDOLITE (DEER ET AL., 1966)

, 1	8	ୟ	≻	2V
Muscovite 1.552-	:-1.574	1.582-1.610	1.587-1.616	300-47
Lepidolite 1.525-	; - 1.548	1.551-1.585	1.554-1.587	00-58

(Sweden) was also examined for comparison, being a very well studied specimen to which many of the studies on lepidolite and lithian muscovite make reference. This has a 2M₂ structure-type, hence the difference in 2V from the other specimens (Deer et al., 1962, p. 88, anal. 7).

The optic orientation for sample REN.1 (1M structure) was established as being the one of lepidolite (Figure 8b) from the interference figure obtained on the crystal used for the precession photographs.

The refractive indices have proved to be very sensitive to the change in chemical composition; thus, where the cell dimensions would not show any appreciable variation within each type of mica for a change in composition, (Tables 2 and 4), the refractive indices do change. This will be discussed in detail in the next chapter.

In Table 6 are reported the results of the optical study. The uncertainty of measurement is variable from sample to sample and especially for the mixed-layer types it has only an orientative value. The author's estimated limits of error are reported as ± on Table 6.

TABLE 6

OPTICAL STUDY: RESULTS

Sample No.	Structure Type	β or β'		γ or	Ϋ́́		∿2V
R.1	2M1	1.588 ±	.001	1.590	±	.001	40 ⁰
R.2	2M ₁	1.593 ±	.001	1.5954	Ŧ	.0005	40 ⁰
R.3	1 2M,>>1M	1.574 ±	.001	1.575	±	.001	40 [°]
	⊥ 2M₁	1.5893 ±	.0005	1.5912	±	.0005	40 [°] -45 [°]
R. 7	⊥ 2M_	1.576 ±	.001	1.5780	±	.0005	<45 ⁰
R 8	1 2M-	1.5915 ±	.0005	1.5955	Ŧ	.0005	30 ⁰ -35 ⁰
R.0	1 2M_>1M	1.572 ±	.001	1.573	±	.001	>40°
ж. Э в 12	1 2M-	1.5893 ±	.0005	1.593	±	.001	40 ⁰
D 13	1 2M-	1.5893 ±	.0005	1.5912	±	.0005	45 ⁰
DDIM 72	1 2M_	1.5913 ±	.0005	1.597	±	.001	40 [°] -45 [°]
р 15	2M-	1.593 ±	.001	1.595	±	.001	∿40 ⁰
N.13	2111 2м	1.612 ±	.001	1.6160	±	.0005	35 [°] -40 [°]
ROM.20	2 ¹¹ 1 2M	1.575 ±	.001	1.577	±	.001	too fine
ROM.20		1 5600 +	.0005	1.5614	Ŧ	.0005	$40^{\circ} - 45^{\circ}$
REN.1		1 572 +	001	1,573	±	.001	${}^{\sim}40^{\circ}$
REN.5	^{2M} 1.	1 5642 ÷	0005	5 1 5660	+	.0005	5 ∿45 ⁰
RNB.330	LΜ	1.5042 I	.000.	5 1 562		.001	∿28 ⁰
Varuträsk	^{2M} 2	1.5590 ±	.0003	J T. JUZ	÷-		

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CHAPTER VI

DISCUSSION AND COMPARISON OF THE RESULTS

A. Chemical Composition and Structure-type

The previous works on Li-bearing micas mentioned in the introduction (Levinson, 1953; Foster, 1960; etc.) pointed out that there is a relationship between the Li content and the structure, from muscovite (normally $2M_1$) with a maximum of about 3.3% Li₂O, to lepidolite (usually $2M_2$ or IM) with more than about 4.0% Li₂O. Within the values of 3.3% and 4.0% would exist a category of "transitional structure" micas. The term lithian muscovite is used here to define lithium-bearing micas with the muscovite structure (usually $2M_1$) according to Foster (1960); in other words, a muscovite with some Li replacing Al in octahedral sites, but not enough to result in a change in structure.

In the present study, we have noted the presence of more than one structure type in a few of the same samples (R.3, R.9, REN.1, RNB.330). The lithium contents of these samples $(3.5\% - 4.28\% \text{ Li}_2\text{O})$ is such that they would fall, according to Levinson (1953), into a "transitional structure" group. Actually, the appearance of the LM polytype together with the 2M₁ seems to indicate that the amount of Li is not constant throughout the whole sample, and when it is high

enough the mica will assume the 1M lepidolite structure instead of the normal $2M_1$ muscovite structure. A confirmation of this fact is the presence of the three types of mica all in the same hand specimen RNB.330. An X-ray powder diffractogram study of various portions of this specimen revealed the presence in one portion of the $2M_1$ structure type only, in a second portion the $2M_1$ plus minor 1M, and in a third portion, which was examined in detail as one of the standard samples, the 1M polytype alone.

The present figures of Li content corresponding to the change in structure agree more or less with the values of Levinson (1953). They are shown in Figure 9 as a graphical representation analogous to the one of Levinson's paper.

Sample REN.5 with the normal muscovite $2M_1$ structure contains up to 3.42% Li_2 O (Nickel, 1961, p. 13, anal. 5), whereas, according to Levinson, this limit should be at 3.3% Li_2 O. The lowest concentration of Li_2 O corresponding to the first appearance of the 1M lepidolite polytype is 3.5% (Table 4, sample R.9). With 4.28% Li_2 O, the structure type is almost entirely 1M lepidolite (sample REN.1). According to Levinson (1953) the micas with 4.0% - 5.1% Li_2 O should have the $2M_2$ lepidolite structure and the 1M should appear only with more than 5.1% Li_2 O. This has already been proved not the be so (Foster, 1960), and the present results are a further confirmation.





The figures given above for the chemical composition naturally refer to the bulk sample but they are also indicative of the chemical composition of the individual structure types.

The contents of Rb and Cs seem to have no direct influence on the change in structure even though they have been found more concentrated in the samples at high Li content. The plots of Figures 10a and 10b show this tendency of having high Rb and Cs samples with high Li.

Rb and Cs probably do not affect the change in structure because they enter the large interlayer cavities substituting for K^+ , while Li⁺ enters the octahedral cavities substituting for Al³⁺ and thus influences the fundamental framework with its presence. This substitution has also the effect of increasing the Si/Al ratio. This ratio is further increased by the higher amount of Si, generally present in Li-micas in respect with other micas, necessary to balance the charge deficiency due to the Li⁺ - Al³⁺ substitution (Foster, 1960).

B. The Cell Dimensions and the Chemical Compositions with Special Reference to the Li₂O, Rb₂O and Cs₂O Contents

Table 2 shows that the cell dimensions for the samples of muscovites and mixed structures with predominant $2M_1$, from Bernic Lake fall within the following limits:



Figure 10a. Plot of Rb₂O, wt. % against Li₂O, wt. %



Figure 10b. Plot of Cs₂O, wt. % against Li₂O, wt. %

As Table 2 also shows, the two lepidolites REN.1 and RNB.330 have nearly the same cell dimensions as each other; this is also true for the refractive indices as Table 6 shows. Sample REN.1 is referred to as a lepidolite because the LM component greatly exceeds the 2M₁ component.

The variation of cell dimensions is then very small, and for the two dimensions <u>a</u> and <u>b</u> it is absorbed by about one-half by the standard errors. The <u>c</u> dimension is the one that shows the greatest absolute variation, but the percent variation is the same order of magnitude for all <u>a</u>, <u>b</u>, and <u>c</u>.

An attempt to correlate these variations of cell dimensions with chemical composition has been made.

It seems legitimate to suppose that the relatively high content of heavy and large cations such as Rb and Cs should affect the cell dimensions and especially the <u>a</u> and <u>b</u> parameters (M. Franzini, personal communication).

The dimensions <u>a</u> and <u>b</u> versus the Rb_2O contents are plotted in Figures 11a and 11b. It can be noted that there is no great evidence of a regular variation in direct dependence of one or the other of these dimensions with the Rb_2O content, but a slight suggestion in this sense



Figure lla. The cell dimensions a plotted against the Rb₂O contents in wt. %.



can be derived. Analogous plots with Cs₂O show more or less the same picture, and they are therefore not reproduced here. The errors are reported only for the cell dimensions, since no error for the chemical analyses could be computed.

The parameter \underline{c} shows an even greater variation, and in fact the values for the specimens with very high Rb and Cs (R.3, REN.5, R.7, R.9) fall within the values of specimens much poorer in these elements. This plot is not shown.

On the other hand, a plot of the parameter <u>a</u> against <u>b</u> (Figure 12) shows that the samples with high Rb and Cs fall in the peripheral area on the side of the high values even though the variation is very small. This "rule" is followed only in part by sample R.4.

A plot of the cell volume against the sum of Rb₂O and Cs₂O weight percent (Figure 13) shows that there is an increase in the volume for the samples with high Rb and Cs contents. The sample ROM.28 from Bikita, Rhodesia is plotted on Figure 13 together with the samples from Bernic Lake since its Rb and Cs contents are of the same order.

For sample REN.5 the increase of cell dimensions is quite evident. The Rb_2O content in this sample is the highest (5.10%), and it corresponds to about 0.45 atoms per 2 atoms in the potassium sites.

In the normal muscovite (2M1) structure, two-thirds

of the central octahedral layer is occupied by Al, and the remainder is vacant. For the ideal structure, X-ray reflections 06% with 1 odd should be absent, but the fact that some of these reflections for most muscovites are quite strong indicates that the structure is considerably distorteđ. In the case of the present study, no reflections of that type were recorded because the diffractograms were taken for a region of lower angles. In the lithian muscovites where there is partial occupancy of the otherwise vacant octahedral sites, these reflections are weaker, and they are weaker still in patterns from biotite and phlogopite in which octahedral sites are completely filled. Ιt seems therefore, that distortion decreases with increasing tri-octahedral character.

Further evidence of distortion in muscovite is the value of the β angle that in most cases is $95^{\circ}35'$ while for the ideal structure it is $94^{\circ}55'$ (Deer et al., 1962, vol. 3, p. 12).

An attempt has been made to correlate the Li content with the "degree of distortion" for the samples from Bernic Lake by plotting the β angle in increasing order against the Li₂O percent (Figure 14). An increase of the Li content corresponds to a decrease of the β angle (less distortion). The error in the calculation of the β angle has been plotted on the diagram.

C. <u>The Variation of the Refractive Indices in</u> <u>Relation to the Contents of Li₂O, Rb₂O and Cs₂O</u>

The values of the refractive indices from Table 6 are plotted against Li_20 , Rb_20 and Cs_20 contents in Figure 15a, 15b, and 15c.

For the 12 samples from Bernic Lake there is an evident correlation between the contents of Li_20 , Rb_20 and Cs_20 and the values of the refractive indices. An increase in the two refractive indices in the plane of the cleavage corresponds to a decrease in the content in these three elements.

The plot for Cs is in a x10 scale due to the lower concentration of this element.

From these plots it appears that even a small amount of Li_20 lowers the refractive indices of the muscovites whose values are slightly lower than that of the normal muscovites from the literature (Deer et al., 1962, vol. 3).

The iron content of sample ROM.26 clearly increases its refractive indices.

A grouping of the various kinds of micas can be made on the basis of their refractive indices. The lithian muscovites generally have, as already mentioned, refractive indices that are lower than the normal muscovites and in the present study they fall in a group with refractive indices between the values of 1.587 and 1.597. Two samples (REN.5 and R.7) do not fall into this group although they

did not give any indication of the presence of any structure type other than the $2M_1$; for this reason they are classified as lithian muscovites but, due to the high Li_20 content, they fall in the present grouping into the second group of the mixed structures. However, these two samples are differentiated from the mixed structure type in the plot of Cs_20 against the refractive indices (Figure 15c).

The mixed structures (2M₁ and 1M) muscovite-lepidolite type encloses samples R.3 and R.9, but also samples REN.5 and R.7 fall, as already mentioned, in this group whose refractive indices vary from 1.572 to 1.578. The Li₂O content in this group goes up to 3.97 wt.% (sample R.3).

In the third group, the one embracing the true lepidolites, fall the samples REN.1 and RNB.330, but for the latter no chemical data are available so it is not plotted in Figure 15. The refractive indices vary from 1.560 to 1.566. Sample REN.1 is, as a whole, a mixed structure, but the presence of the 2M₁ muscovite structure type is very minor especially in the crystals used for the single-crystal precession study and then for the optical investigation. For this reason it falls into the group of the true lepidolites. The sample of lepidolite from Varuträsk (Sweden) was chosen, as mentioned earlier, for comparison purposes only.

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