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THE RARE ALKALIES IN MICAS*

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Contents

Abstract

Determinations are given of all of the alkalies (lithium, sodium, potassium, rubidium, and cesium) in 43 samples of micas, including paragonite, muscovite, biotite, phlogopite, vermiculite, zinnwaldite, taeniolite, lepidolite, and polylithionite.

The geologic occurrence of the rare alkalies in micas is discussed. Increase in rare alkalies in micas from successive stages of hydrothermal replacement in pegmatites is shown. Lithium was found to be present in all the micas analyzed, but rubidium and cesium were found only in micas from the later stages of magmatic differentiation.

Introduction

This study is the first of a projected series on the geologic occurrence of the rare alkalies—lithium, rubidium, and cesium. Some micas, particularly those in pegmatites, are known to contain the rare alkalies and further analyses of micas will give additional information of the way the rare alkalies are concentrated in nature. The three rare alkalies are very seldom determined in the analyses of rocks or minerals and hence very little is known about their distribution. As a preliminary step in the analysis of some micas containing rare alkalies, the methods of separating and determining all five alkalies were studied by Wells and Stevens and a satisfactory procedure was developed.[1] On the basis of these improved

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[1] Wells, Roger C., and Stevens, Rollin E., Determination of the common and rare alkalies in mineral analysis: *Ind. & Eng. Chem.*, Anal. Ed., **6,** 439 (1934).

methods, it is planned to make analyses of various mineral groups, such as the micas, the feldspars, the beryls, and others. As a first contribution, the five alkalies have been determined in a suite of micas and the results obtained are here presented. It is realized fully that the series is incomplete and it is hoped that further determinations will help to complete the picture.

The data here presented were determined for 3 paragonites, 12 muscovites, 6 biotites, one phlogopite, one taeniolite, one zinnwaldite, one vermiculite and 18 lepidolites (including polylithionite). The results for the paragonites, lepidolites, two biotites, and for taeniolite and zinnwaldite have already been published in the descriptions of these minerals. The analyses are listed under each mineral name in the order of increasing percentages of Li_2O. The analyses were made by Stevens and the collection and preparation of most of the samples and discussion of the geochemical relations is by Schaller.

Paragonite

The alkalies in three paragonites[2] are shown in Table 1.

Table 1. Alkalies in Paragonite

	1. Switzerland	2. Italy	3. Euphyllite, Pennsylvania
Li_2O	0.08	0.13	0.73
Na_2O	6.28	7.26	5.64
K_2O	2.17	1.01	1.71
Rb_2O	0.12	None	0.11
Cs_2O	None	None	None

1. Monte Campione, Switzerland.
2. Fenestrella, near Borgofranco, Valle del Chisone, Piedmont, Italy.
3. Corundum Hill, Pa.

All three samples contain lithium; rubidium is present in very small quantities in two samples and absent in one, and cesium is absent in all three samples.

Muscovite

Eleven of the twelve muscovites are from pegmatites, nine from San Diego County, California.

[2] Schaller, W. T., and Stevens, R. E., The validity of paragonite as a mineral species: *Am. Mineral.*, **26**, 541–545 (1941).

TABLE 2. ALKALIES IN MUSCOVITE

	1. N.C.	2. Calif.	3. Tyrol	4. Calif.	5. Calif.	6. Calif.
Li_2O	0.04	0.05	0.07	0.07	0.19	0.28
Na_2O	0.72	0.83	1.81	0.92	0.78	0.81
K_2O	10.59	10.21	8.89	9.90	10.26	10.05
Rb_2O	None	0.12	None	None	0.08	0.17
Cs_2O	None	0.11	None	None	0.03	0.12
	7. Calif.	8. Calif.	9. Calif.	10. N.M.	11. Calif.	12. Calif.
Li_2O	0.31	0.33	0.36	0.38	0.47	0.55
Na_2O	0.86	1.06	0.85	0.91	0.76	0.45
K_2O	10.13	9.97	10.27	10.07	10.30	11.06
Rb_2O	None	0.25	0.12	0.82	None	0.08
Cs_2O	None	0.17	0.08	0.09	None	0.14

1. Ordinary commercial sheet mica, pale olive in color. From Spruce Pine area, N. C. Sent in by B. C. Burgess of Spruce Pine. Relatively high in iron. Material analyzed, carefully separated from included visible iron oxides, contains 1.42 per cent FeO and 4.38 per cent Fe_2O_3, as determined by J. G. Fairchild.

2. Granular mass of greenish mica associated with abundant almandine garnet. A.B.C. gem mine, Ramona, San Diego County, Calif.

3. Medium grained, resembling coarse sericite schist. Pregratten, Pusterthal, Tyrol. Labeled paragonite, var. pragrattite. U. S. Nat. Mus. Coll. No. R4415.

4. Parallel blades of muscovite intergrown with albitized pegmatite. Victor gem mine, Rincon, San Diego County, Calif.

5. Plumose muscovite in microcline graphic granite at edge of albitized area. North end of Douglas dike (below the Stewart mine), at east base of Stewart Hill, Pala, San Diego County, Calif. Although occurring in microcline graphic granite, adjacent to albitized pegmatite, the muscovite definitely belongs to the sodium phase of replacement, the development of the muscovite and associated black tourmaline advancing slightly beyond the zone of formation of abundant albite. The non-albitized microcline and microcline graphic granite of the pegmatites not adjacent to an albitized zone are essentially free from any muscovite.

6. Small sheets of greenish muscovite, 2 to 3 inches across, with narrow border of lepidolite. The lepidolite and half inch of adjoining muscovite removed. Ed. Fletcher gem mine, north side of Stewart Hill, Pala, San Diego County, Calif.

7. Sheets of muscovite in pegmatite, largely albitized. Mission gem mine, near southern base of Stewart Hill, Pala, San Diego County, Calif.

8. Small sheets of muscovite, intergrown with crystals of albite, Pala View gem mine, on southeastern slope of Stewart Hill (above the Stewart mine), Pala, San Diego County, Calif. U. S. Nat. Mus. Coll. No. 89,190. The muscovite shows poorly developed crystal faces and the specimen evidently came from a cavity.

9. Small sheets of greenish muscovite, 2 inches long and 1 to $1\frac{1}{2}$ inches wide, with narrow border of lepidolite. The lepidolite border and quarter inch of adjoining muscovite removed. Hiriart gem mine, Hiriart Hill, Pala, San Diego County, Calif.

10. Purple muscovite from Harding mine, about 10 miles east of Embudo, Taos County, New Mexico. Description of purple muscovite published by Schaller, W. T., and Henderson, E. P., Purple muscovite from New Mexico: *Am. Mineral.*, **11**, 5–16 (1926).

11. Sheets of muscovite, about one half inch wide, in albitized pegmatite. From south end of Douglas dike (below Stewart mine) on southeastern base of Stewart Hill, Pala, San Diego County, Calif.

12. Compact, fine-grained sericite. In pegmatite of Labat's gem mine, N.E. of Warner Hot Springs, San Diego County, Calif.

The purple muscovite from the Harding mine, New Mexico, is considerably richer in the rare alkalies than any sample of muscovite from San Diego County, Calif. The compact sericite (no. 12) from Labat's gem mine contains more rare alkalies than any of the sheet muscovites, even those (nos. 6 and 9) with a border of lepidolite.

Lithium is present in every muscovite analyzed. Both rubidium and cesium are present in seven of the twelve samples. Their quantity, however, is small in the samples from California. There seems to be no obvious relation between the quantity of lithium and the combined quantities of rubidium and cesium.

Biotite

Six biotites were analyzed for rare alkalies, five from pegmatites and one from the Alberene quarry, Virginia. In these biotites, the percentage of FeO, MnO, and MgO, where determined, are added to help characterize the biotites.

Table 3. Alkalies in Biotite

	1. Va.	2. Va.	3. S.D.	4. Calif.	5. Calif.	6. N.C.
Li_2O	0.09	0.11	0.65	1.05	1.17	1.20
Na_2O	0.22	0.86	0.45	0.22	0.19	0.73
K_2O	9.54	8.08	8.48	8.47	8.80	8.54
Rb_2O	None	None	1.48	0.10	0.08	1.85
Cs_2O	None	None	1.12	0.08	0.14	0.47
FeO	N.d.	8.96	14.81	13.89	24.21	8.29
MnO	N.d.	0.24	0.22	N.d.	N.d.	0.27
MgO	N.d.	16.15	8.45	N.d.	N.d.	9.55

1. Black mica from the Alberene Quarry, Alberene, Albermarle County, Virginia. Sample furnished by C. S. Ross.

2. Black mica from the contact of simple pegmatite (free from lithium minerals) and schist. The pegmatite was formerly mined for commercial sheet muscovite. Ridgway, Virginia. Collected by W. T. Schaller. Mica completely analysed by R. E. Stevens.

3. Brown mica from pegmatite on property of Maywood Chemical Co., 8 miles N.W. of Custer, South Dakota. Described by Hess, F. L., and Fahey, J. J., Cesium biotite from Custer County, South Dakota: *Am. Mineral.*, **17,** 173–176 (1932), with corrections of percentages of potassium, rubidium, and cesium, by Hess, F. L., and Stevens, R. E., A rare-alkali biotite from Kings Mountain, North Carolina: *Am. Mineral.*, **22,** 1044 (1937).

4. Black mica from top of upper part of pegmatite at S.W. end of Tourmaline Queen gem mine, eastern side of Stewart Hill, Pala, San Diego County, Calif. Iron determination by J. J. Fahey.

5. Greenish mica from Panama Pacific Exposition gem mine, Chihuahua Valley, San Diego County, California. Iron determinations by J. J. Fahey.

6. Brown mica from spodumene carrying pegmatite at Kings Mountain, North Carolina. Described by Hess, F. L., and Stevens, R. E., A rare-alkali biotite from Kings Mountain, North Carolina: *Am. Mineral.*, **22**, 1040 (1937).

All six biotites contain lithium in greater quantity than the muscovites. Four of the biotites contain more lithium than the lithium richest muscovite; three of the biotites have twice as much as the lithium richest muscovite. The average of the six biotites (0.71 per cent Li_2O) is nearly three times as much as the average of the 12 muscovites (0.26 per cent Li_2O). Rubidium and cesium, as in the muscovites, are present in some and absent in others. Their quantity in samples nos. 3 and 6, from pegmatites containing abundant lithium minerals, equals the quantity in the lepidolites. The percentage of Rb_2O+Cs_2O in either of these two biotites exceeds that of any of the 18 lepidolites listed and the average (2.46 per cent) exceeds considerably the average (1.57) of the 18 lepidolites. The average of the five biotites from pegmatites (1.06 per cent) is five times that of the average (0.20 per cent) of the 12 muscovites. As was to be expected, the biotite (no. 1) from the soapstone quarry at Alberene, Va., contained neither rubidium nor cesium. Their absence in the biotite (no. 2) from Ridgeway, Va., however, was unexpected, as the zinnwaldite from Amelia, Va., contains appreciable rubidium and some cesium, although other lithium minerals are not known to be present in either pegmatite.

The average per cent of Na_2O (0.45) in the biotites is only half as great (0.90) as that in the muscovites.

Phlogopite, Vermiculite, Zinnwaldite and Taeniolite

The rare alkalies were determined in only one sample of each of these micas.

Table 4. Alkalies in Phlogopite, Vermiculite, Zinnwaldite, and Taeniolite

	Phlogopite	Vermiculite	Zinnwaldite	Taeniolite
Li_2O	0.05	0.04	1.92	3.10
Na_2O	0.35	0.20	0.74	0.64
K_2O	10.14	2.66	9.56	10.44
Rb_2O	None	None	1.04	None
Cs_2O	None	0.02	0.10	None

Phlogopite. From Cockeysville marble, north of Baltimore, Md. Sample furnished by C. S. Ross.

Vermiculite. Yellow Mt., Macon County, Georgia. Alkalies by Wells and Stevens.

Zinnwaldite. Morefield mine, Amelia, Amelia County, Virginia. Analysis of mica by J. J. Fahey, cesium by Stevens, and other alkalies by Wells. Described by Glass, J. J., The pegmatite minerals from near Amelia, Virginia: *Am. Mineral.*, **20**, 756 (1935).

Taeniolite. Magnet Cove, Arkansas. Described by Miser, H. D., and Stevens, R. E., Taeniolite from Magnet Cove, Arkansas: *Am. Mineral.*, **23**, 104–110 (1938).

Lepidolite, Including Polylithionite

Samples nos. 1 to 4 and 5 to 17, and the localities are described by Stevens.[3] No. 4*a*, fine-grained lepidolite appearing pale greenish in the matrix, was furnished by Prof. H. Mohr of the Deutsche Technische Hochschule at Brno, Czechoslovakia. This greenish lepidolite, much less abundant at Rožna than the more common lilac colored variety, was stated[4] to contain only 1.78 per cent Li_2O, but Stevens found 3.90 per cent. No. 17 is polylithionite from Greenland and nos. 15 (from Ramona, Calif.) and 16 (from Madagascar) approach polylithionite.

Lepidolite no. 1 from Manitoba, Canada, and the relatively low lithium samples from the Stewart mine, Pala, California, have the muscovite type of structure, according to Hendricks,[5] and should probably be called muscovite rather than lepidolite.

All of these lepidolites, except no. 17 (polylithionite from Greenland), are from typical granitic pegmatites and show no relation between the quantity of rubidium and cesium, and their geographic distribution. Rubidium exceeds cesium in every analysis though the two alkalies are present in nearly equal quantities in sample no. 9 from the San Diego mine at Mesa Grande, but in the two samples (nos. 8 and 13) from the adjoining Himalaya mine, on the northward extension of the same pegmatite dike, rubidum greatly exceeds cesium. Neither is there any relation between lithium as compared with rubidium and cesium, either for all the lepidolites or for those from different parts of a single dike. Compare, for example, nos. 3, 5, 6, 11, and 12 from the Stewart mine at Pala and nos. 8, 9, and 13 from Mesa Grande. Neither polylithionite from Greenland (no. 17) nor taeniolite from Arkansas contain any cesium although rubidium is present in polylithionite and absent in taeniolite. Neither of these two minerals are from typical granitic pegmatites, and although the taeniolite occurs in chert (novaculite), it is on the border of the nepheline rich rocks of Magnet Cove from which the lithium, fluorine, potassium, and magnesium apparently were derived.

[3] Stevens, R. E., New analyses of lepidolites and their interpretation: *Am. Mineral.*, **23**, 615 (1938).

[4] Mohr, H., Das Lepidolitvorkommen "Rožna" in Mähren als Lithiumerz-Lagerstätte: *Berg.- und Hüttenmännisches Jahrb.*, **82**, Heft 2, 48 (1934).

[5] Hendricks, S. B., Polymorphism of the micas: *Am. Mineral.*, **24**, 759–761, (1939), and personal communication.

TABLE 5. ALKALIES IN LEPIDOLITE, INCLUDING POLYLITHIONITE

	1	2	3	4	4a	5	6	7	8
Li_2O	2.70	3.51	3.70	3.81	3.90	3.96	5.04	5.05	5.11
Na_2O	0.77	1.27	0.87	0.64	0.95	0.77	0.74	0.57	0.57
K_2O	9.52	10.32	10.02	9.91	10.13	9.93	9.58	10.14	9.53
Rb_2O	1.93	1.11	0.91	1.55	1.39	1.56	1.56	1.62	1.64
Cs_2O	0.18	0.13	0.16	0.11	0.17	0.12	0.48	0.09	0.17
	9	10	11	12	13	14	15	16	17
Li_2O	5.33	5.39	5.51	5.64	5.78	5.89	6.18	6.84	7.26
Na_2O	0.89	0.59	0.63	0.59	0.65	0.82	0.72	0.44	0.53
K_2O	10.79	10.14	10.25	10.11	9.90	9.70	10.28	10.65	11.05
Rb_2O	0.42	0.97	1.38	1.04	2.00	1.38	1.22	1.35	1.14
Cs_2O	0.41	0.06	0.48	0.67	0.08	0.09	0.24	0.40	None

1. Manitoba, Canada.
2, 3, 5, 6, 11, 12. Pala, Calif.
4. Chihuahua Valley, San Diego County, Calif.
4a. Mt. Hradiska, Rožna, Moravia, Czechoslovakia.
7. Ohio City, Colorado.
8, 9, 13. Mesa Grande, Calif.
10. Wakefield, Canada.
14. W. Australia.
15. Ramona, Calif.
16. Madagascar.
17. Greenland.

DISTRIBUTION OF RARE ALKALIES IN DIFFERENT MICAS

The distribution of the rare alkalies in the different micas analyzed may be shown by the average values for the four named micas, paragonite, muscovite, biotite, and lepidolite.

TABLE 6. AVERAGE PERCENTAGE OF RARE ALKALIES IN PARAGONITE, MUSCOVITE, BIOTITE AND LEPIDOLITE

	Paragonite	Muscovite	Biotite	Lepidolite
Li_2O	0.31	0.26	0.71	4.90
Rb_2O	0.08	0.14	0.59	1.35
Cs_2O	0.00	0.06	0.30	0.24
Total	0.39	0.46	1.60	6.49

These average values must be considered as applying only to the samples analyzed and possibly not to these four micas in general, for which data on the content of rare alkalies are woefully lacking. Furthermore, the micas analyzed were largely pegmatitic micas, namely, one of the three paragonites, eleven of the twelve muscovites, five of the six biotites, and all of the eighteen lepidolites.

Average values may also be given on the basis of type of occurrence, as non-pegmatitic and pegmatitic.

TABLE 7. AVERAGE PERCENTAGE OF RARE ALKALIES IN NON-PEGMATITIC MICAS AND PEGMATITIC MICAS

	7 Non-pegmatitic micas		18 Pegmatitic micas, excluding lepidolites	35 Pegmatitic micas, including lepidolites
	Excluding taeniolite	Including taeniolite		
Li_2O	0.08	0.51	0.55	2.66
Rb_2O	0.02	0.02	0.35	0.84
Cs_2O	0.00	0.00	0.15	0.19
Total	0.10	0.53	1.05	3.69

The seven non-pegmatitic micas include the two paragonites (nos. 1 and 2) from Switzerland and Italy, one muscovite (no. 3) from the Tyrol, one biotite (no. 1) from Alberene, Virginia, phlogopite, vermiculite, and taeniolite. The average values for the non-pegmatitic micas are given with taeniolite excluded and included, as the 3.10 per cent of Li_2O in taeniolite raises the average per cent considerably. Only one of these non-pegmatitic micas (paragonite no. 1) contains rubidium (0.12 per cent Rb_2O) and only one (vermiculite, with 0.02 per cent Cs_2O) contains any cesium. Of the eighteen pegmatitic micas, excluding lepidolite, only five contain no rubidium and only six contain no cesium. All the seventeen lepidolites (not including the polylithionite from Greenland, which contains rubidium but no cesium) contain both rubidium and cesium.

INCREASE IN PERCENTAGES OF RARE ALKALIES IN PEGMATITES WITH SUCCESSIVE STAGES OF HYDROTHERMAL REPLACEMENT

Muscovite is the only one of these micas for which a small suite of samples from known stages of successive hydrothermal replacement in pegmatites could be obtained. These samples were prepared from specimens from the southern California field of lithium-bearing pegmatites. If the theory[6] is correct that these pegmatites originally consisted only

[6] Schaller, W. T., The genesis of lithium pegmatites: *Am. Jour. Sci.*, ser. 5, **10**, 269–279 (1925).

of feldspars with possibly some quartz, then all micas now present are later and have been introduced in successive stages of hydrothermal replacements. Accumulating evidence shows the general soundness of the replacement theory. In general, two main successive stages of hydrothermal replacement may be defined, for the present purpose, as follows:

(1) Sodium stage, A. Albitization. Development of large quantities of albite with minor associated muscovite, garnet and black tourmaline, by replacement of the primary microcline and microcline graphic granite. The resulting albitized pegmatite is solid rock, almost free from any cavities lined with terminated crystals. Where such small cavities exist in the albitized rock, as they do very occasionally, it is believed that the rock has been subjected to the beginning of the second stage.

(2) Lithium stage, B. Development of large quantities of lepidolite and green and pink lithium tourmaline. At some places, lithium minerals have developed extensively without the formation of any cavities, as for example the large lenses containing thousands of tons of massive lepidolite at the Stewart mine at Pala. At other places, cavities have developed to a considerable extent, with well crystallized terminated minerals, as at Mesa Grande.

Five (nos. 2, 4, 5, 7, and 11) of the muscovites from the California pegmatites, for which the percentages of alkalies present have been determined, are from the sodium or albitization stage. The content of rare alkalies in these muscovites is shown in Table 8 under A. Three (nos. 6, 8, and 9) of the muscovites from the California pegmatites are from the beginning of the lithium stage, as shown by the presence of the lepidolite borders (nos. 6 and 9) or by cavities (no. 8).

In the full development of the lithium stage, the mica formed is essentially lepidolite. No new muscovite is formed in this stage. The muscovite now present in specimens from the lithium phase is residual muscovite from the preceding sodium phase, as evidenced by the many examples of muscovite completely or partially changed to lepidolite, by the pink color of this muscovite with percentages of Li_2O intermediate between those of the greenish muscovites of the albite phase and those of lepidolite,[7] and by the border of lepidolite formed around the muscovite, which is often colored pink adjacent to the lepidolite border. The content

[7] The pink muscovite from pegmatites from various localities in the world are similar examples, such as the purple muscovite from New Mexico (muscovite no. 10), the rose-colcred mica from Goshen, Mass., with 0.64 percent Li_2O, the several lilac or gray muscovites from Manitoba, described by Ellsworth, H. V. (Rare-element minerals from Canada, Geol. Survey, *Econ. Geol.* Ser., no. **11**, 264–266, 1932), with from 0.90 to 1.80 per cent Li_2O, and the rose-colored muscovites from Sweden (Berggren, Thelma, Minerals of the Varuträsk pegmatite. XV. Analyses of mica minerals and their interpretation: *Geol. Fören. Stockholm Föhr.*, **62**, heft 2, 185, 1940), with from 0.69 to 1.10 per cent Li_2O.

of rare alkalies in these muscovites of the beginning of the lithium stage is shown in Table 8 under B.

TABLE 8. RARE ALKALIES IN MUSCOVITES FROM CALIFORNIA PEGMATITES ARRANGED IN TWO STAGES OF HYDROTHERMAL REPLACEMENTS

	Sodium stage, A						Beginning of lithium stage, B			
	In microcline graphic granite	In albitized pegmatite					With border of lepidolite		Cavity	
	5	2	4	7	11	Av.	6	9	8	Av.
Li_2O	0.19	0.05	0.07	0.31	0.47	0.22	0.28	0.36	0.33	0.32
Rb_2O	0.08	0.12	0.00	0.00	0.00	0.04	0.17	0.12	0.25	0.18
Cs_2O	0.03	0.11	0.00	0.00	0.00	0.03	0.12	0.08	0.17	0.12
Total	0.30	0.28	0.07	0.31	0.47	0.29	0.57	0.56	0.75	0.62

The position of the compact sericite (muscovite no. 12) from Labat's gem mine, California, in the hydrothermal replacement series, is unknown. From its location in the pegmatite it was thought to be related to the early sodium or albitization stage (A), but its relatively high content of rare alkalies suggests that it is related to the beginning of the lithium stage (B). Similarly, the oncosine (crypto-crystalline muscovite or sericite) from Varuträsk[8] contains more lithium and cesium than do the three muscovites for which analyses are given, though it is lower in rubidium.

The increase of rare alkalies in progressive stages of hydrothermal replacements in pegmatites is further shown in Table 9 by a comparison of certain average values. In column 1 are given the average percentages of the rare alkalies in eight micas,[9] chiefly from non-pegmatitic sources, or from pegmatites where hydrothermal replacements have played only a very minor part. Six of these eight samples contain neither rudibium nor cesium. The average percentages of the rare alkalies in the sodium phase (A) of the early hydrothermal replacement (chiefly albitization with accompaniment of minor quantities of muscovite, black tourmaline, and reddish-brown garnet), are shown in column 2, those in the begin-

[8] Berggren, *op. cit.*, p. 185, Analysis F.

[9] The two non-pegmatitic paragonites, the commercial sheet muscovite (no. 1) from a pegmatite at Spruce Pine, N. C., the non-pegmatitic muscovite (no. 3) from the Tyrol, biotite (no. 1) from Alberene, Va., biotite (no. 2) from a non-lithium pegmatite at Ridgeway, Va., phlogopite, and vermiculite.

ning of the lithium phase in column 3, and those in the full development of the lithium phase, culminating in lepidolite, in column 4. The increase in lithium and rubidium, although progressively irregular, is much greater than that of cesium.

TABLE 9. INCREASE IN PERCENTAGES OF RARE ALKALIES IN MICAS FROM VARIOUS STAGES OF REPLACEMENT

	1	2	3	4
	Chiefly non-pegmatitic	Sodium phase, A, albitization	Beginning of lithium phase	Lithium phase, B
Li_2O	0.08	0.22	0.32	4.90
Rb_2O	0.01	0.04	0.18	1.35
Cs_2O	0.00	0.03	0.12	0.24
Total	0.09	0.29	0.62	6.49

The pegmatitic muscovite from North Carolina (no. 1, Table 2) and that from the Tyrol (no. 3) are free from[10] both rubidium and cesium, as are also three of the five muscovites from the first stage of albitization, suggesting that muscovites not from a later replacement stage contain neither rubidium nor cesium.

The average total rare alkali content, chiefly lithium, of the eight micas largely of non-pegmatitic sources, as given in column 1 of Table 9, is 0.09 per cent. That of the five muscovites (nos. 2, 4, 5, 7, 11) from the cavity free albitization stage of pegmatites, given in column 2, is 0.29 per cent, about three times as great as that for largely non-pegmatitic micas. This total quantity of rare alkalies, however, is still small. That is, the first stage of the albitization of the microcline and of microcline graphic granite in pegmatites, with its concomitant development of muscovite, garnet, and black tourmaline, was not accompanied by any noteworthy increase of the rare alkalies. The absence of any rubidium and cesium in three out of the five muscovites from albitized pegmatites of the sodium stage (A) is striking. Whether the quantities of the rare alkalies in the muscovites of stage A of the replacement series are about the same as, or greater than, the rare alkali content of the original replaced microcline, cannot be told until the analyses of such microclines are completed.

With the beginning of the lithium stage, the percentage of rare alkalies (av. = 0.62) is doubled over that of the sodium stage (av. = 0.29). The increase in rubidium and cesium however is much greater than that of

[10] That is "free from" in the sense that they could not be determined analytically.

lithium, which shows only a fifty per cent increase, whereas both rubidium and cesium increase about fourfold. The single sample of muscovite (no. 8) from a cavity and hence late, contains more of the rare alkalies than either of the two muscovites (nos. 6 and 9) with a border of lepidolite.

The later lithium stage of replacement with the development of much lepidolite is distinguished by considerable quantities of the rare alkalies, as evidenced by the analyses of the lepidolites. As shown by column 4, the quantity of Li_2O, in micas of the lithium phase (B) is 22 times that in the sodium phase (A), Rb_2O is 34 times, and Cs_2O is 8 times as much.

General Conclusions

It is realized fully that a consideration of the distribution of the rare alkalies lithium, rubidium, and cesium in micas, though based on analyses of 43 samples, is necessarily incomplete, and further investigations may not support some of the general tentative conclusions here expressed. The common micas (muscovite and biotite) in granitic rocks, in mica schists, in volcanic rocks, etc., have not been analyzed for their content of rare alkalies and the micas in metamorphic limestones are represented by only one sample.

Based only on the determinations here presented lithium seems to be present in every mica; at least it is found to be present in every mica for which a careful determination of lithium is made. If a "trace" be defined as not greater than 0.01 per cent in careful analytical work, the smallest quantities of Li_2O found (0.04 per cent in muscovite no. 1 and in vermiculite, 0.05 per cent in muscovite no. 2 and in phlogopite) are greater than "traces." Many mineral analyses report traces of lithium (in beryls for example) where the quantity may be much greater and as much as several tenths of a per cent. There is more lithium in pegmatitic biotites than in pegmatitic muscovites though the biotites have only half as much soda. The three analyses of the sodium mica paragonite show widely varying quantities of lithium. The element lithium is by no means restricted to minerals from pegmatites and if looked for will probably be found in many minerals not occurring in pegmatites. The magnesium clay from Hector, Calif., contains it as do several (if not all) margarites. The lithium-bearing taeniolite from Arkansas occurs in chert, and some manganese minerals contain lithium. Rubidium and cesium, on the other hand, seem to be restricted to pegmatitic minerals, judging from the very meager results available.

Rubidium is not known to occur as an essential constituent of any mineral. It is found in pegmatite minerals containing potassium such as the micas. However, not all pegmatite micas contain rubidium. It is absent in the one sample of commercial sheet muscovite from North Carolina, in three muscovites (nos. 4, 7, and 11) from the gem pegmatites of San Diego County, Calif., and in the biotite from Ridgeway, Va. It occurs in the greatest quantity in those micas from the complex pegmatites which contain an abundance of lithium minerals although there is no relation as to its quantity as compared with the quantity of lithium in any single mineral. In general, it seems to be absent in non-pegmatitic micas. Thus the biotite from the soapstone area at Alberene, Va., and the phlogopite from the Cockeysville marble near Baltimore, Md., are free from rubidium yet the paragonite schist with kyanite from Monte Campino, Switzerland, has 0.12 per cent Rb_2O. It occurs most abundantly in the lepidolites, reaching a maximum of two per cent Rb_2O in lepidolite no. 13.

Cesium generally accompanies rubidium in the micas though generally in much smaller amounts. Only in muscovite no. 12 and in biotite no. 5, both from California, does the percentage of Cs_2O exceed that of Rb_2O. Cesium is absent in all three paragonites, in five muscovites, which are also free from rubidium, in two biotites, and in phlogopite and taeniolite, likewise free from rubidium. The small quantity of 0.02 per cent Cs_2O, with no rubidium, in the vermiculite from Georgia, is unusual. Cesium is absent in polylithionite but present in all the lepidolites. Its occurrence in micas seems to bear no relation to the quantity of either lithium or rubidium present.

One can only conclude from these results that the distribution of the rare alkalies lithium, rubidium, and cesium is very erratic in any single pegmatite, and in pegmatites in general, as illustrated by the development of the only cesium mineral, pollucite, with relatively very little lithium and rubidium in pegmatites from Elba, Maine, South Dakota, and Sweden. The three rare alkalies are just as erratic in any given mica but their total quantity increases with the successive stages of hydrothermal replacement.