Interpretation of the Composition of Lithium Micas

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Interpretation of the Composition of Lithium Micas

By MARGARET D. FOSTER

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

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Relations of lithian muscovites ana
lepidolites, and of siderophyllites,
protolithionites, zinnwaldites, and
lepidolites, based on published analyses

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INTERPRETATION OF THE COMPOSITION OF LITHIUM MICAS

By MARGARET D. FOSTER

ABSTRACT

A study of more than 100 analyses of lithium micas reported in the literature indicates that, compositionally, most of the lithium micas may be interpreted as if derived by isomorphous replacement from muscovite or siderophyllite.

Starting with muscovite, analyses and formulas of aluminum lithium micas, arranged in order of increasing Li content, are characterized by decrease in octahedral Al and in tetrahedral Al and by increase in Si and in octahedral occupancy. These changes can be interpreted as the result of progressive replacement of octahedral Al by Li, in ratios varying between 2 and 3 Li for 1 octahedral Al. The aluminum lithium micas are not, however, members of a continuous isomorphous series. The series is interrupted about halfway between an octahedral occupancy of 2.00 and 3.00 by a change in structure from muscovite to lepidolite. The term "lithian" muscovite is given to aluminum lithium micas having a muscovite structure.

Starting with siderophyllite, or other trioctahedral micas having high Fe^{+2} and very low Mg content, analyses and formulas of ferrous lithium micas, arranged in order of increasing Li content, are characterized by decrease in Fe^{+2}, decrease in tetrahedral Al, increase in Si, and increase in octahedral occupancy. These changes can be interpreted as the result of progressive replacement by Li^{+1} of Fe^{+2}, at an average replacement ratio of 2.0 Li^{+1} for 1.5 Fe^{+2}. As there is less difference between the number of positive charges carried by the replacing cations and the replaced cations than in the aluminum lithium micas, the change in composition and the increase in octahedral occupancy is less in the ferrous lithium micas. The prototype, siderophyllite, is structurally trioctahedral, and, as replacement tends to increase octahedral occupancy, the ferrous lithium micas are also trioctahedral and no structural adjustments are necessary. The ferrous lithium mica series is, therefore, not broken as is the aluminum lithium mica series. Varietal definitions based on octahedral sites occupied by Li^{+1} in the half-cell formula are: lithian siderophylite, having fewer than 0.25 sites occupied by Li^{+1}, protolithionite, having between 0.25 and 0.75 sites occupied by Li^{+1}, zinnwaldite, having between 0.75 and 1.25 sites occupied by Li^{+1}, and lepidolite, having more than 1.25 sites occupied by Li^{+1}.

The high-Li members of both series are lepidolites. Thus lepidolites may be interpreted as if derived from muscovite or from siderophyllite.

INTRODUCTION

This study of the compositional and layer-charge relations of lithium-bearing micas is an extension of similar studies by the writer of the compositional and layer-charge relations of the dioctahedral potassium micas (Foster, 1956) and of the trioctahedral micas (Foster, 1960). In the study of the dioctahedral potassium micas, the effect of octahedral replacement of trivalent by bivalent cations on the charge relation and composition of the constituent layers was studied in detail, and it was shown that these micas can be classified and correlated on the basis of the relation between the charges on their tetrahedral and octahedral layers, and that these micas are members of, and form, a trisilicictetrasilicic series. In the study of the trioctahedral micas, the effect of octahedral replacement of bivalent by trivalent cations on the charge relations and composition of the constituent layers was studied in detail and it was shown that the trioctahedral micas accommodate the additional number of positive charges carried by trivalent cations, compared with bivalent cations, in two quite different ways, and that the phlogopites, biotites, siderophyllites, and lepidomelanes form a complete magnesium-replacement system, in which Mg^{+2} is gradually and completely replaced by bivalent and trivalent cations.

It is the purpose of the present paper to present a similar study of the composition and layer-charge relations of the lithium micas.

CALCULATION OF FORMULAS

For the present study about 80 analyses of aluminum lithium micas and about 45 analyses of ferrous lithium micas were collected from the literature, and formulas were calculated from these analyses by the method devised by Marshall (1949, p. 58) and modified by the author. This method is described in detail in a previous paper of this series (Foster, 1960). Most of the discussion of the compositional characteristics of thes- analyses in the present paper is based on the calculated half-cell formulas.

Attention is directed to the order in which the groups and the cations within the group are written. First the octahedral group, enclosed in parentheses, is written, with the cations in that group noted in order of decreasing valence (except Ti, which is written after Al). Then the tetrahedral group, also enclosed in parentheses, is written, again with the cations noted in order of decreasing valence. Above each group the charge is written. After these two groups, which indicate the cationic composition of the layers, the anionic composition, $O_{10}(OH,F)_2$, is written and the whole is bracketed, thus indicating the composition of the composite layer. After the upper part of the closing bracket, the total negative charge on the composite layer is noted. This is followed by a notation in parentheses of the interlayer cation content, with the positive charge carried by these cations written at the top of the closing parenthesis, and the total number of positions occupied by these cations written at the bottom. The interlayer cations are written last, rather than first, which is the more conventional position, because the amount and charge of the interlayer cations are dependent on and must neutralize the charge on the composite layer.

The negative charge on the composite layer and the positive charge on the interlayer cations should be close to 1.00 in the half-cell formula. In evaluating the dependability of the formulas used in this study a variation of plus or minus 0.10 was permitted in these values. Formulas in which the negative charge on the composite layer and the interlayer cationic charge were greater or less than 1.00 by more than 0.10 were not used in the study unless the number of sites occupied by the interlayer cations was less than 1.10. For example, in a few formulas the negative composite-layer charge and the interlayer cationic charge were greater than 1.10, but because of the presence of bivalent interlayer cations (Ca), the number of interlayer sites occupied was less than 1.10. Such formulas were included in the study. The analyses of aluminum lithium micas that were used in the study and data from which their calculated formulas can be written are given in table 6, in order of increasing lithium content, and analyses of the ferrous lithium micas used in the study, with data for writing their calculated formulas, are given in table 7.

Some analyses of ferrous lithium micas were not used in the study. In most of these analyses, which are given in table 8, the alkali content is high compared with the octahedral and tetrahedral cations; in the rest it is low. These discrepancies may be due to faulty analysis, particularly failure to determine lithium properly, or to nonhomogeneous or contaminated samples.

Any error in the Li determination has a double effect, as Li is an octahedral cation and the other alkalies are interlayer cations. If the Li is not completely separated, the part not separated is reported as Na; thus the Na reported is too high, the alkalies calculated as interlayer cations are also too high, and the octahedral cations are too low. If the determination of Li errs on the high side, the other alkalies reported are too low, and the octahedral cations are too high. If the sample is not homogeneous, it is possible that the part taken for determination of the alkalies might be higher or lower in alkalies than the part taken for determining the other constituents, SiO_2, Al_2O_3, Fe_2O_3, and MgO.

ALUMINUM LITHIUM MICAS

INTERPRETATION OF COMPOSITION OF LEPIDOLITES BASED ON END MEMBERS

In recent years, following Stevens (1938) and Winchell (1942), there has been a strong tendency to interpret lepidolites as isomorphous mixtures of various end members. Stevens found that the composition of the 17 samples upon which he based his study closely approximates that of isomorphous mixtures of polylithionite,

$$(Al_{1.00}Li_{2.00})Si_4O_{10}(OH)_2K_{1.00},$$

with biotite,

$$R^{+2}_{3.00}(Si_{3.00}Al_{1.00})O_{10}(OH)_2K_{1.00},$$

lithium muscovite,

$$(Al_{1.50}Li_{1.50})(Si_{3.00}Al_{1.00})O_{10}(OH)_2K_{1.00},$$

and muscovite,

$$Al_{2.00}(Si_{3.00}Al_{1.00})O_{10}(OH)_2K_{1.00},$$

Stevens considered that in such solid solutions the end members would not be present as individual end-member unit cells, but that the ions of which the end members are composed would be distributed uniformly throughout the structure. The selection of end members to interpret the composition of lepidolites is an arbitrary one. As Stevens (1938, p. 623) remarks:

> Other combinations of four end members which express the compositions equally well are: polylithionite, zinnwaldite (assuming its formula to be $K \cdot LiR''Al \cdot AlSi_3O_{10}F_2$), lithium muscovite, and muscovite; polylithionite, taeniolite ($K \cdot LiR_2'' \cdot Si_4O_{10}F_2$), lithium muscovite, and muscovite. In addition, 5 or 6 of the above end members may be taken, depending on what end members are used to express the bivalent ion content.

Winchell (1942) interpreted lepidolites as isomorphous mixtures of polylithionite, paucilithionite (identical with Stevens' lithium muscovite), and protolithionite ($K_2LiFe_4Al_3Si_6O_{20}F_4$). He calculated 28 lithium micas to these end members and found that Li_2O was deficient in all but 1 and that the average deficiency in Li_2O was almost 1 percent by weight (0.91). However, if some muscovite was assumed to be present also, the deficiency in Li_2O could be eliminated and the composition satisfactorily explained. Winchell considered muscovite to be present, not in solid solution but as a discrete mineral which might be so intimately intergrown or intermixed as to be difficult to detect optically.

Lepidolite and muscovite are, indeed, often intimately associated. In Stevens' study of lepidolites, five samples are discarded because small flakes of lepidolite in them were found to contain minute inclusions of muscovite. Winchell believed that muscovite may coexist with lepidolite in units too small to be detected optically. Ginzburg and Berkhin (1953) believe that considerable lepidolite in pegmatitic rocks has been derived from metasomatic replacement of muscovite and biotite. By incomplete replacement reactions, heterogeneous mixtures of the primary mica with lepidolite have been, they believe, analyzed as one mica type. Pale-violet lepidolites from muscovite in pegmatites from the Kalbinsk Chains, or from Turkestan, often contain relict inclusions of muscovite and intimate graphic intergrowths with this primary muscovite. However, the amount of muscovite that Winchell had to assume to be present to account for the deficiency in lithium content—more than 10 percent in 20 out of 28 samples—is such that its presence could easily be detected by X-rays. For example, Stevens' sample 8 (36, table 6), with an Li_2O content of 5.11 percent, was estimated by Winchell to contain 29.9 percent muscovite. X-ray study by Hendricks and Jefferson (1939) of this sample showed it to have a one-layer lepidolite structure. They did not report the presence of any muscovite in this sample nor in any other of Stevens' samples that had more than 5 percent of Li_2O. They found, however, that Stevens' sample 1 (21, table 6), with a Li_2O content of 2.70, was structurally a muscovite. They found samples 2–5 (22, 23, 24, and 29, table 6), too fine grained for study. Later study of X-ray and Weissenberg photographs by Levinson (1953) confirmed Hendricks and Jefferson's findings with respect to Stevens' samples. In addition Levinson showed that Stevens' samples 2–5 were mixtures of 2-layer muscovite and 6-layer lepidolite. These studies of the crystal structure of lepidolites show that deficiency of Li in them, as compared with end members, cannot always be explained by assumption of admixture with muscovite. It is probable that some materials that have been analyzed as "lepidolites" have contained some occluded or interlayered muscovite, but the work of Hendricks and Jefferson and Levinson demonstrates that lepidolites have characteristic optical properties and structures, and that they are not mixtures of end members as interpreted by Winchell and Stevens.

COMPOSITIONAL CHANGES SHOWN BY THE ANALYSES

The analyses given in table 6 indicate a general increase in SiO_2 content, decrease in Al_2O_3 content, decrease in H_2O+ content, and increase in F content with increase in Li_2O content. Some of the analyses in which Li_2O is very low have only 45 percent or even less of SiO_2, as compared with SiO_2 contents of more than 55 percent in those in which Li_2O is high. On the other hand, analyses which are very low in Li_2O content have the highest amounts of Al, more than 35 percent, whereas those highest in Li_2O content are lowest in Al_2O_3 content, some having only 15 percent or even less. Similarly, analyses very low in Li_2O content have a H_2O+ content of 4 percent or more but a low content of F, less than 0.5 percent, and analyses that contain high amounts of Li_2O are very low in H_2O+, 0.5 percent or less, but have high contents of F, 8 percent or more. These relations are reflected in the data for the calculated formulas which are included in the table. These formulas indicate also that octahedral occupancy increases from about 2 sites in aluminum lithium micas very low in Li_2O to about 3 sites in those containing the highest amounts of Li_2O. These, in general, orderly compositional variations accompanying increase in Li_2O content suggest the sort of isomorphous substitution that characterizes other members of the mica group, such as the substitution of bivalent and other trivalent ions for aluminum in the muscovites (Foster, 1956) and the substitution of trivalent and other bivalent cations for magnesium in the phlogopites and biotites (Foster, 1960, p. 16–32). A similar replacement system among the aluminum lithium micas was suggested by Levinson (1953, p. 88) on the basis of his work on the structure of the micas.

HYPOTHETICAL LI-(OCTAHEDRAL AL) REPLACEMENT RATIOS

Theoretically, Li can be accommodated in muscovite micas in 4 different ways: occupancy of vacant octahedral sites, replacement of 1 ion of Al by 1 ion of Li, replacement of 1 ion of Al by 2 ions of Li, and replacement of 1 ion of Al by 3 ions of Li. The first 3 methods of accommodation necessitate layer-charge readjustments, Li being univalent and Al trivalent; the fourth method does not, as the 3 positive charges carried by 3 Li ions exactly balance the 3 positive charges of the replaced Al ion. However, it does necessitate increase in octahedral occupany, as do also the first and third methods.

In attempting to explain a form of muscovite having as much as 3.3 percent of Li_2O, Levinson (1953, p. 93) speculated as to whether it is possible for such a large amount of Li to replace Al isomorphously in the muscovite structure. He concluded that because of similarity in atomic radii, Al=1.43 A (angstrom units), Li=1.51 A, the substitution is possible but not necessary as Li could occupy vacant octahedral positions. The effect of this sort of accommodation of Li can be illustrated by Stevens' (1938, p. 615) sample 1 (21, table 6), which Levinson found to have a normal muscovite structure and which contains 2.70 percent of Li_2O. This amount of Li_2O is equivalent to 0.73 octahedral positions in the calculated formula. If this number of vacant octahedral positions in the primary muscovite formula

$$[(\underbrace{\overset{-0.15}{\mathrm{Al_{1.84}Fe^{+3}_{0.01}Fe^{+2}_{0.02}Mg_{0.01}Mn^{+2}_{0.12}}}}_{2.00})(\overset{-0.85}{\mathrm{Si_{3.15}Al_{0.85}}})\mathrm{O_{10}(OH,F)_2}]^{-1.00}\,\mathrm{K}^{+1.00}_{1.00},$$

which has the same bivalent-ion content as Stevens' sample, were to be occupied by Li, with no replacement of Al,

$$[(\underbrace{\overset{+0.58}{\mathrm{Al_{1.84}Fe^{+3}_{0.01}Fe^{+2}_{0.02}Mg_{0.01}Mn^{+2}_{0.12}Li_{0.73}}}}_{2.73})(\overset{-1.58}{\mathrm{Si_{2.42}Al_{1.58}}})\mathrm{O_{10}(OH,F)_2}]^{-1.00}\,\mathrm{K}^{+1.00}_{1.00},$$

certain other changes in layer-charge relations and in the composition of the tetrahedral layer necessarily follow. The addition of 0.73 positive charges to the octahedral layer changes the negative charge of 0.15 previously on that layer to a positive charge of 0.58. This positive charge on the octahedral layer requires an increase in the negative tetrahedral charge to 1.58, by increase in Al content and decrease in Si content, in order to preserve the total composite-layer charge at −1.00. Thus a lithium-containing muscovite in which Li merely occupies vacant octahedral positions would, in general, be characterized by a positive octahedral charge and a negative tetrahedral charge in excess of 1.00 by an amount equivalent to the positive octahedral charge, by a decrease in Si equivalent to the increase in negative tetrahedral charge, and by a 1:1 relation between the number of positions occupied by Li and the increase (above 2.00) in occupied octahedral positions. These characteristics are quite different from those shown by the calculated formulas. As illustrated in figures 26 and 28, particularly, the formulas exhibit an increase, not decrease, in Si content with increase in Li content, and an approximate 2:1 ratio between the number of positions occupied by Li and the increase (above 2.00) in the number of octahedral sites occupied. The compositional and charge relations shown in these figures, therefore, indicate that Li is not accommodated in the structure by simple occupancy of vacant octahedral sites by Li. In the actual formula for Stevens' sample 1 (21, table 6)

$$[(\underbrace{\overset{-0.20}{\mathrm{Al_{1.58}Fe^{+3}_{0.01}Fe^{+2}_{0.02}Mg_{0.01}Mn^{+2}_{0.12}Li_{0.73}}}}_{2.47})(\overset{-0.84}{\mathrm{Si_{3.16}Al_{0.84}}})\mathrm{O_{10}(OH,F)_2}]^{-1.04}\mathrm{K(Na,Rb,Cs)}^{+1.01}_{1.01},$$

the octahedral charge is negative, not positive, Si is greater than 3.00, not less, and the ratio of positions occupied by Li to the increase (above 2.00) in the number of octahedral sites occupied is about 5:3, not 1:1. Furthermore, simple occupancy of vacant octahedral sites by Li, with no replacement of Al, cannot explain the amounts of Li found in many aluminum lithium micas. The limit of octahedral occupancy possible, 1.00 octahedral position, is equivalent to only about 3.75 percent of Li_2O, whereas many aluminum lithium micas contain more than 5 percent of Li_2O.

If the Li content of Steven's sample 1 is added to the primary mica above, in the replacement ratio of 1 Li for 1 octahedral Al, the following irrational formula results:

$$[(\underbrace{\overset{-1.61}{\mathrm{Al_{1.11}Fe^{+3}_{0.01}Fe^{+2}_{0.02}Mg_{0.01}Mn^{+2}_{0.12}Li_{0.73}}}}_{2.00})\overset{0.00}{\mathrm{Si_4}}\mathrm{O_{10}(OH,F)_2}]^{-1.61}\mathrm{K}^{+1.61}_{1.61}.$$

The deficiency in positive charges in the octahedral layer is so great that the negative charge on the layer is 1.61, and, even with complete filling of the tetrahedral layer with Si, the charge on the composite layer is also −1.61, instead of −1.00. The greatest amount of Li that can substitute for octahedral Al, ion for ion, in an ideal muscovite, and produce a rational formula, is 0.50:

$$[(\underbrace{\overset{-1.00}{\mathrm{Al_{1.50}Li_{0.50}}}}_{2.00})\overset{0.00}{\mathrm{Si_4}}\mathrm{O_{10}(OH,F)_2}]^{-1.00}\,\mathrm{K}^{+1.00}_{1.00}$$

Any greater degree of substitution at this ratio results in too great a negative octahedral charge and composite-layer charge. This Li limit is too low to account for the composition of many aluminum lithium micas.

A 2:1 Li-(octahedral Al) replacement ratio for the amount of Li present in Stevens' sample 1 in the primary muscovite above results in a formula,

$$[\underbrace{\overset{-0.50}{(Al_{1.48}Fe^{+3}_{0.01}Fe^{+2}_{0.02}Mg_{0.01}Mn^{+2}_{0.12}Li_{0.73})}}_{2.37}\overset{-0.50}{(Si_{3.50}Al_{0.50})}O_{10}(OH,F)_2]^{-1.00}\,K^{+1.00}_{1.00},$$

which resembles more closely the characteristics of the calculated formulas as illustrated in figures 25, 26, and 28; namely, a decrease in Al (IV) content, increase in Si content, and an increase in total octahedral positions occupied which is about one-half the number of lithium positions occupied. The end member for this ratio of replacement would have the formula,

$$[\underbrace{\overset{-1.00}{(Al_{1.00}Li_{2.00})}}_{3.00}\overset{0.00}{Si_4}O_{10}(OH,F)_2]^{-1.00}\,K^{+1.00}_{1.00}.$$

In this formula the ratio of positions occupied by Li to the increase in octahedral positions occupied is 2:1, the increase in Si is also equivalent to half the increase in Li, and the decrease in total Al is equivalent to the increase in Li. These changes can be expressed in the equation

$$n\text{Li}+n\ 0.5\ \text{Si}+0.5\ n\text{Oct.Site}=n\text{Al}. \tag{A}$$

This ratio of replacement permits the admission of enough Li into the structure to account for the composition of the highest amounts of Li that have been reported in lepidolites. This formula represents the composition of polylithionite, one of the Li end members used by both Stevens and Winchell in their interpretation of the composition of lepidolites.

Substitution of 3 Li cations for 1 octahedral Al in the primary muscovite for Stevens' sample 1 produces a formula,

$$[\underbrace{\overset{-0.14}{(Al_{1.60}Fe^{+3}_{0.01}Fe^{+2}_{0.02}Mg_{0.01}Mn^{+2}_{0.12}Li_{0.73})}}_{2.49}\overset{-0.86}{(Si_{3.14}Al_{0.86})}O_{10}(OH,F)_2]^{-1.00}\,K^{+1.00}_{1.00},$$

which is very close to that calculated from the analysis of this sample, suggesting that the Li-(octahedral Al) replacement ratio for this sample is very close to 3:1. The end-member formula for this ratio of replacement,

$$[\underbrace{\overset{0.00}{(Al_{1.50}Li_{1.50})}}_{3.00}\overset{-1.00}{(Si_{3.00}Al_{1.00})}O_{10}(OH,F)_2]^{-1.00}\,K^{+1.00}_{1.00},$$

has the same tetrahedral group as muscovite. As 1.5 cations carrying 1.5 positive charges replace 0.5 cation of Al, which also carries 1.5 positive charges, there is no change in layer-charge relations. The compositional changes involved in this ratio of replacement of Li for octahedral Al may be expressed as

$$1.5n\text{Li}+n\text{Oct.Site}=0.5n\text{Al} \tag{B}$$

Stevens called this hypothetical end member lithium muscovite and Winchell called it paucilithionite. Neither name is satisfactory. Muscovite is a heptaphyllic or dioctahedral mica, whereas the above formula is that of an octaphyllic or trioctahedral mica. Winchell used the prefix pauci because the formula represents the minimum tenor of Li in a lepidolite end member. However, the use of this prefix, which means small or little, for an end member containing more than 5 percent of Li_2O, and in which one-half of the available octahedral sites are occupied by Li, too much minimizes its lithian character. The prefix also exaggerates the difference between this hypothetical end member and polylithionite, which contains about 7.5 percent Li and in which two-thirds of the octahedral sites are occupied by Li. The three Li ions occupying octahedral sites in the unit-cell formula,

$$[\underbrace{\overset{0.00}{(Al_{3.00}Li_{3.00})}}_{6.00}\overset{-2.00}{(Si_{6.00}Al_{2.00})}O_{20}(OH,F)_4]^{-2.00}\,K^{+2.00}_{2.00},$$

suggests the name "trilithionite" as more appropriate for this hypothetical end member. This name also suggests the 3:1 Li-(octahedral Al) replacement ratio of this end member.

This discussion of the possible methods of accommodating Li in the muscovite structure shows that simple occupancy of vacant octahedral sites in muscovite by Li or replacement of 1 octahedral Al by 1 Li either produce irrational formulas for end members or produce end-member formulas whose Li content is too low to be applicable to the interpretation of the composition of some lepidolites. Replacement of octahedral Al by Li in the ratio of 2 or 3 for 1 produces rational end-member formulas capable of interpreting the composition of these micas.

RELATION OF LI TO OTHER CONSTITUENTS IN CALCULATED FORMULAS

RELATION BETWEEN LI AND OCTAHEDRAL AL

The relation between the number of octahedral positions occupied by Li and the number of octahedral positions assumed to have been vacated by Al in formulas of analyzed aluminum lithium micas is shown in figure 25. In a study of the dioctahedral micas (Foster, 1956) it was found that octahedral occupancy in these micas is always close to 2.00 and that replacement of Al by other trivalent and by bivalent cations is ion for ion. Consequently, in calculating the number of octahedral-Al positions replaced by Li it was assumed that 2.00 octahedral sites were occupied in the primary muscovite, and that replacement of octahedral Al by Fe^{+3}, Fe^{+2}, Mg, and Mn was ion for ion—such as 1 ion of Fe^{+3} for 1 of Al, 1 of Fe^{+2} for 1 of Al. The difference, then, between 2.00 and the number of octahedral sites occupied by Al and these other octahedral cations is assumed to represent the number of octahedral-Al cations replaced by the Li present. All but a few of the points fall between line B, which represents the 2:1 Li-(octahedral Al) replacement ratio and leads to the end member polylithionite, and line C, which represents the 3:1 Li-(octahedral Al) replacement ratio and leads to the end member trilithionite.

In the formulas represented by points lying between these 2 lines, therefore, the Li-(octahedral Al) replacement ratio is between 2 and 3. The location of the points indicates that in most of the formulas the ratio is between 2.3 and 2.8. Only 1 of the formulas represented by points that fall outside the area embraced between lines B and C contains more than 2.0 percent Li_2O. This formula, in which the Li-(octahedral Al) replacement ratio is 1.9, is closest in composition to the end member, polylithionite. The other points that fall outside the area between lines B and C fall below line C, indicating that in the formulas that they represent, the Li-(octahedral Al) replacement ratio is greater than 3. In most of these formulas, however, the ratio is quite close to 3, and the discrepancy may be due to slight analytical error, particularly in the determination of Li_2O, to lack of homogeneity in the sample, or to error in assuming that the octahedral occupancy in the primary muscovite was exactly 2.00 in calculating the number of Al sites replaced. The amount of replaced Al in these formulas is so small that an error in octahedral occupancy in the primary muscovite of as little as 0.03 less than 2.00 could account for the high Li-(octahedral Al) ratio in them.

It has been shown that accommodation of Li by replacement of octahedral Al in the ratio of 2 for 1 involves compositional changes in accordance with equation A, $n\text{Li}+0.5n\text{Si}+0.5n\text{Oct.Site}=n\text{Al}$. In other words, for each ion of Li or fraction thereof added, half as many Si ions are added and half as many additional octahedral sites are occupied, but the loss in total Al ions (octahedral and tetrahedral) is the same as the gain in Li ions. It was also shown that in accommodation of Li by replacement of octahedral Al in the ratio of 3.0 for 1.0 involves compositional changes in accordance with equation B, $1.5n\text{Li}+n\text{Oct.Site}=0.5n\text{Al}$. Thus for each 1.5 ion of Li or fraction thereof

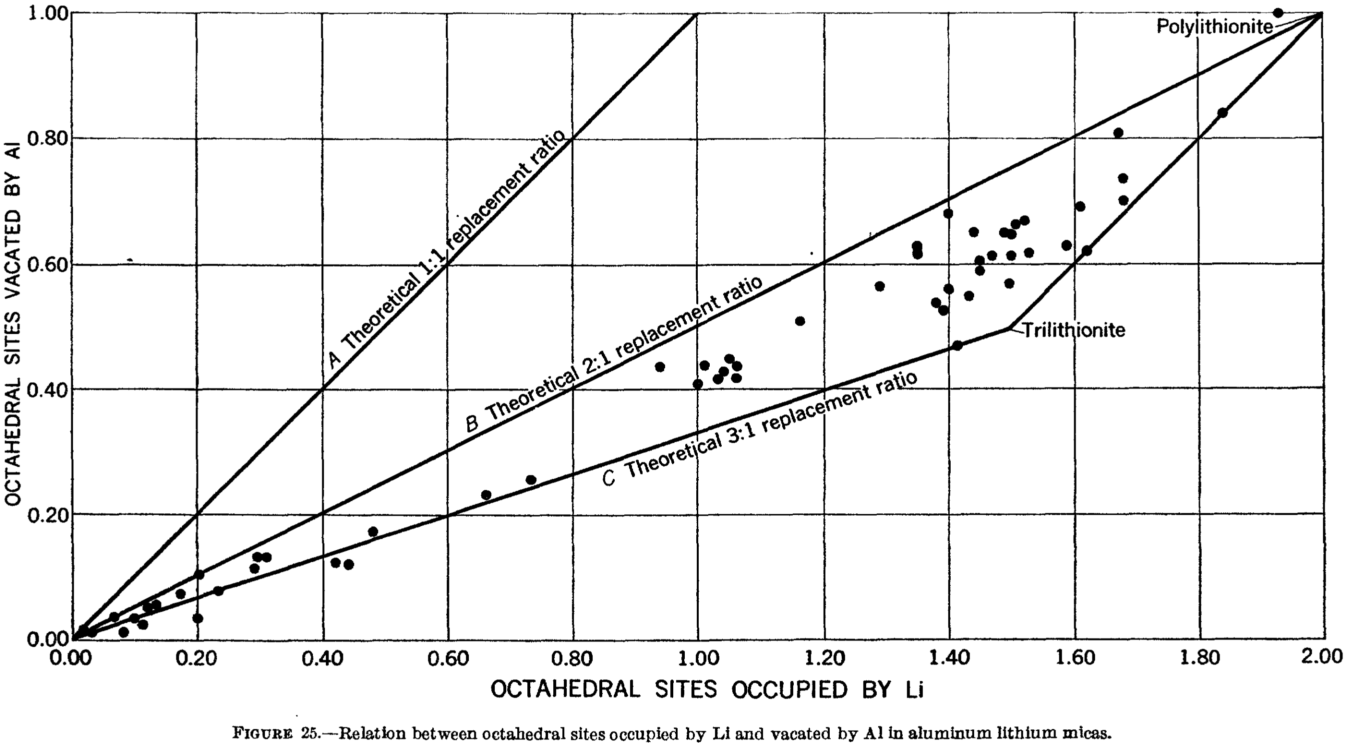

FIGURE 25.—Relation between octahedral sites occupied by Li and vacated by Al in aluminum lithium micas.

added, two-thirds as many octahedral sites are occupied and there is a loss in octahedral Al ions equivalent to one-third the gain in Li ions. This manner of adjustment involves no change in Si content. As the Li-(octahedral Al) replacement ratios in the analyses studied are, for the most part, between 2 and 3, it would be expected that they would show compositional changes between those specified by equations A and B, and that the closer the replacement ratio in any particular formula is to 2 or 3, the closer the compositional changes indicated by that formula will be to equation A or B, respectively.

RELATION BETWEEN (LI—R^{+2}) AND SI

The relation between (Li—R^{+2}) and Si in the aluminum lithium micas studied is shown in figure 26. If, except for Li, the octahedral layer were entirely occupied by trivalent ions, Li in the formulas would have been plotted directly against the increase (above 3.0) in Si. However, the octahedral groups in the formulas are not made up entirely of trivalent ions plus Li, but also contain varying amounts of bivalent ions, and some of the positive charges carried by Li compensate for the deficiency in charge, compared with Al, of these ions. For example, in the formula for analysis 34, table 6,

$$[\underbrace{\overset{-0.41}{(Al_{1.29}Fe^{+2}_{0.01}Mn^{+2}_{0.16}Li_{1.38})}}_{2.84}\overset{-0.62}{(Si_{3.38}Al_{0.62})}O_{10}(OH,F)_2]^{-1.03}K(Na,Rb,Cs)^{+1.03}_{1.03},$$

0.17 of the positive charges carried by Li compensate for the deficiency of the number of positive charges present in the octahedral layer compared with the number carried by the same number of trivalent ions. The effect on the Si content is as though 1.21 and not 1.38 ions of Li were present. In order to eliminate the effect of the variable amounts of R^{+2} ions present in the formulas, Si is plotted against (Li—R^{+2}) in figure 26, not against Li alone. In some of the formulas in which Li is very low, the positive charges added by Li do not entirely compensate for the deficiency in octahedral charge due to the bivalent ions present.

In figure 26 all but a few of the points representing the (Li—R^{+2}):Si relation in the formulas fall between line A, which represents the 2:1—Li:Si relation found in formulas in which the Li-(octahedral Al) replacement ratio is 2, and line B, the baseline, which represents the 1.5:0—Li:Si relation found in formulas in which the Li-(octahedral Al) replacement ratio is 3. Thus the (Li—R^{+2}):Si relation in most of the formulas is consistent with that to be expected in formulas for aluminum lithium micas in which the Li-(octahedral Al) replacement ratio is between 2 and 3.

RELATION BETWEEN LI AND TOTAL AL

The relation between the number of octahedral sites occupied by Li and the total number of formula sites occupied by Al is shown in figure 27. Except for some

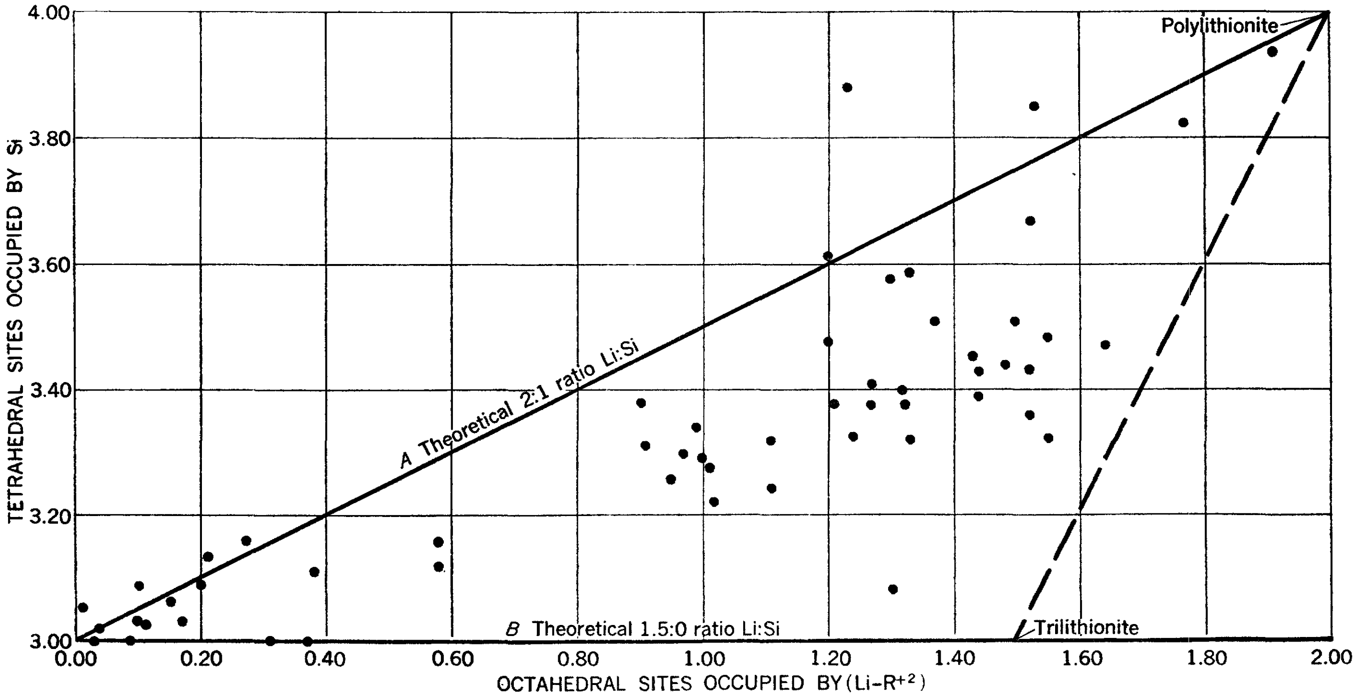

FIGURE 26.—Relation between (Li—R^{+2}) and Si in aluminum lithium micas.

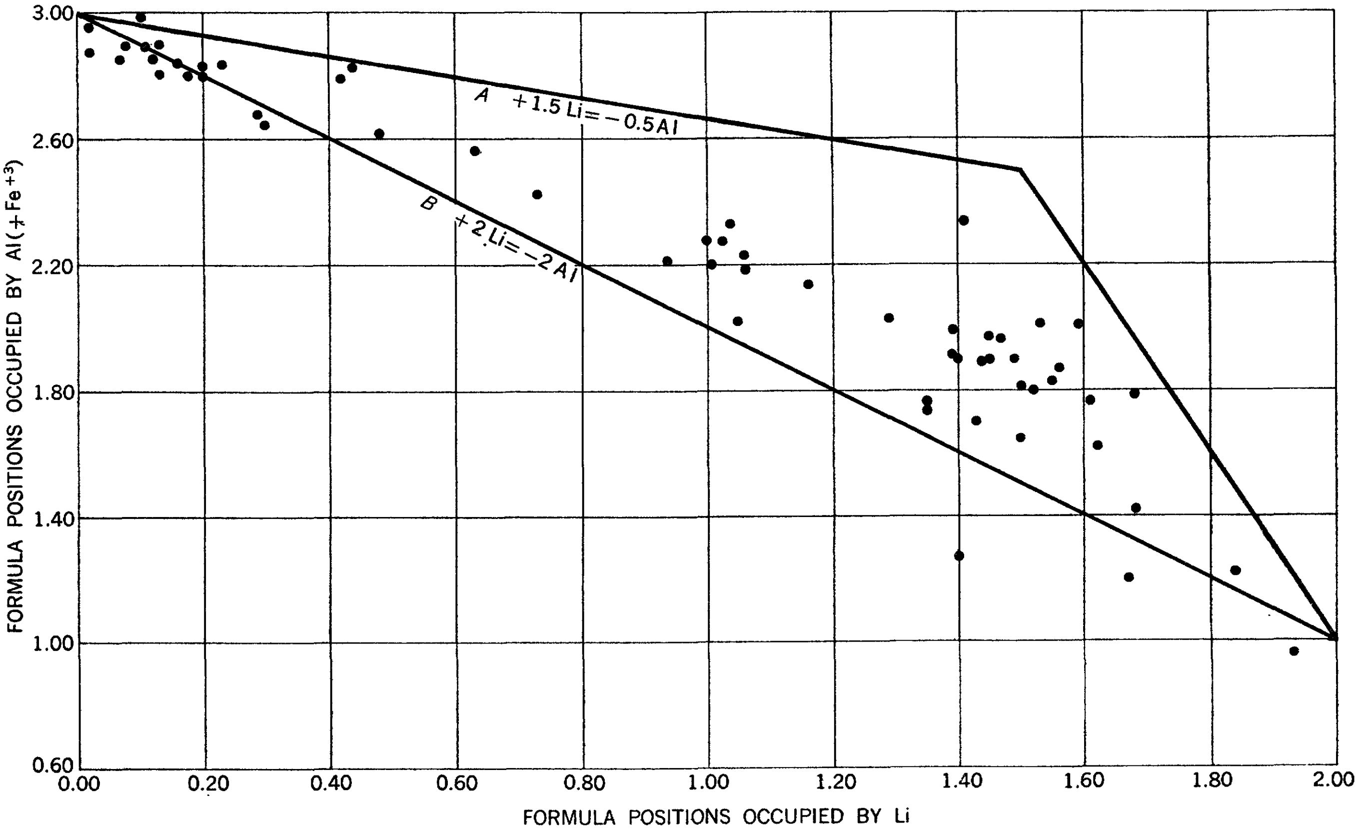

FIGURE 27.—Relation between the number of formula sites occupied by Li and R^{+3} in aluminum lithium micas.

points representing formulas with a low content of Li, almost all the points representing the Li:Al relation in the calculated formulas of the analyses studied fall between lines A and B. Line A represents the Li:Al relation, as compared with muscovite, in formulas in which the Li-Al replacement ratio is 3.0; line B represents the Li:Al relation when the Li-Al replacement ratio is 1.0. The location of most of the points, therefore, indicates a decrease in Al with increase in Li that is in accordance with the Li:Al relation to be expected in formulas in which the Li-Al replacement ratio is between 2 and 3.

RELATION BETWEEN LI AND OCCUPIED OCTAHEDRAL SITES IN EXCESS OF 2.00

The relation between Li and the number of octahedral sites occupied in excess of 2.00 is shown in figure 28. In aluminum lithium micas in which the Li-(octahedral Al) replacement ratio is 2, the number of octahedral positions occupied in excess of 2.00 is theoretically one-half the number of octahedral positions occupied, as represented by line B (fig. 28); in aluminum lithium micas in which the Li-(octahedral Al) replacement ratio is 3, the number of octahedral positions occupied in excess of 2.00 is theoretically in the ratio of 1.5 Li to 1.0 octahedral position, as represented by line A (fig. 28). In accordance with the Li-(octahedral Al) replacement ratios found in the calculated formulas, most of the points representing the relation between the number of octahedral sites occupied by Li and the total number of octahedral sites occupied in excess of 2.00 fall between the two lines.

RELATION BETWEEN Li_2O AND F

A casual inspection of the Li_2O and F values in the analyses in table 6 shows a general increase in F content with increase in Li_2O content. The grouping of the points in figure 29 along the line representing a 1:1 ratio between Li_2O and F indicates a tendency toward a 1:1 relation in these constituents in aluminum lithium micas. Considering the difficulties inherent in the determination of both Li_2O and F, some of the discrepancies shown in figure 29 are probably more to be attributed to error in determination than to other than a 1:1 relation between Li_2O and F. Increase in F content is accompanied by decrease in H_2O+ content (fig. 30).

RELATION BETWEEN LI_2O CONTENT, OCTAHEDRAL OCCUPANCY, AND STRUCTURE

The variations in composition accompanying increase in Li content shown in figures 25, 26, 27, and 28 are those to be expected if Li were substituted for octahedral

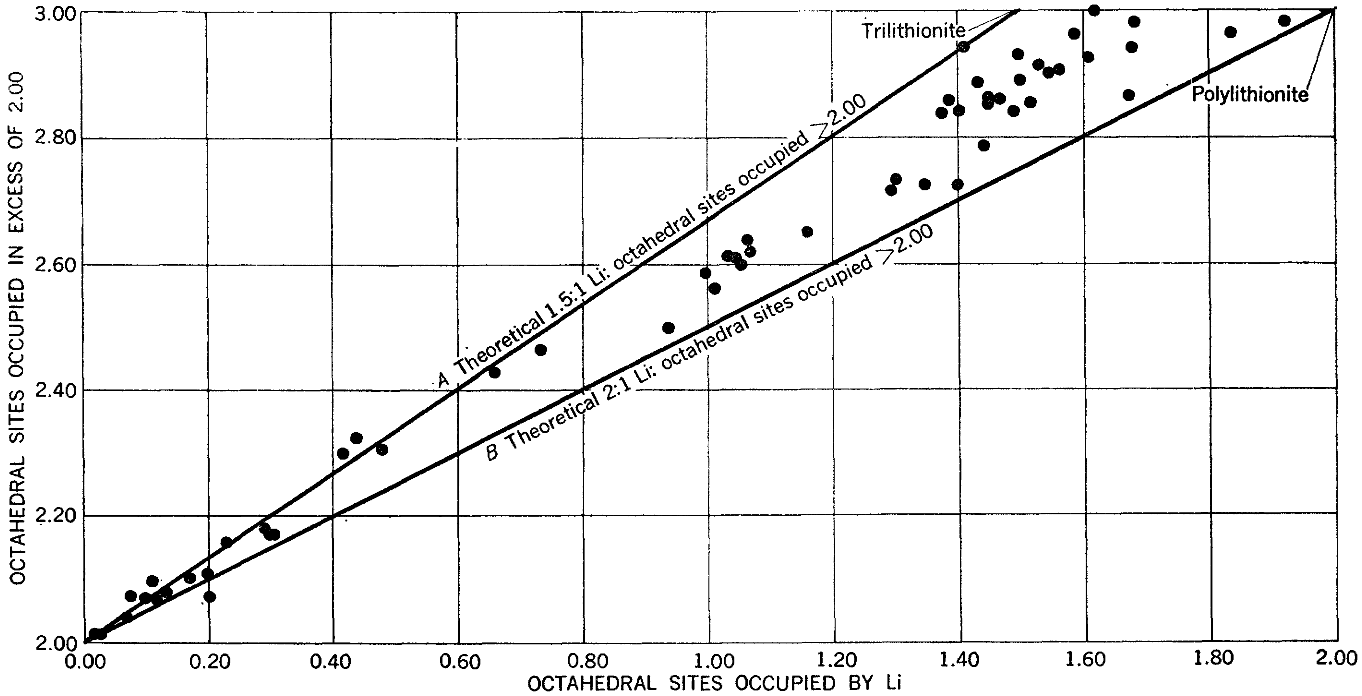

FIGURE 28.—Relation between Li and octahedral occupancy in excess of 2.00 in aluminum lithium micas.

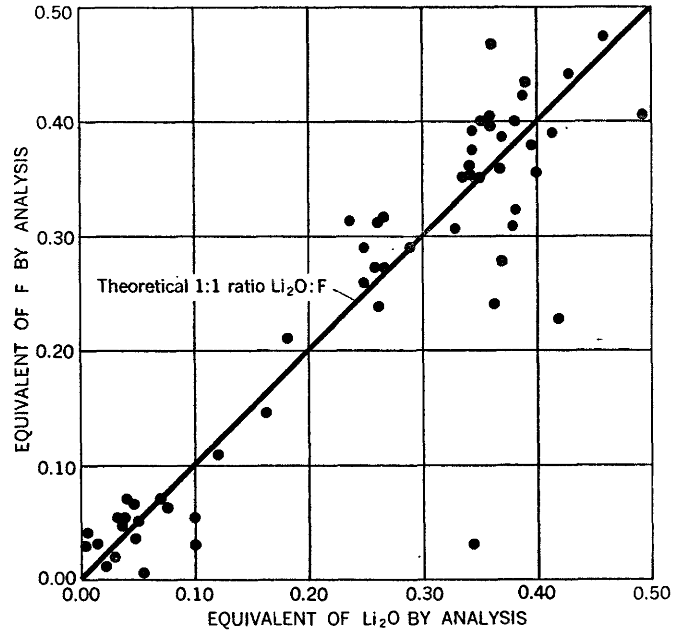

FIGURE 29.—Relation between Li_2O and F in aluminum lithium micas.

Al in muscovite in ratios varying between 2 and 3 Li for 1 octahedral Al. Compositionally, therefore, these micas resemble members of an isomorphous series that starts with muscovite. However, the increase in octahedral occupancy from 2.00 in muscovite to 3.00 in some lepidolites and in the theoretical end members, poly-

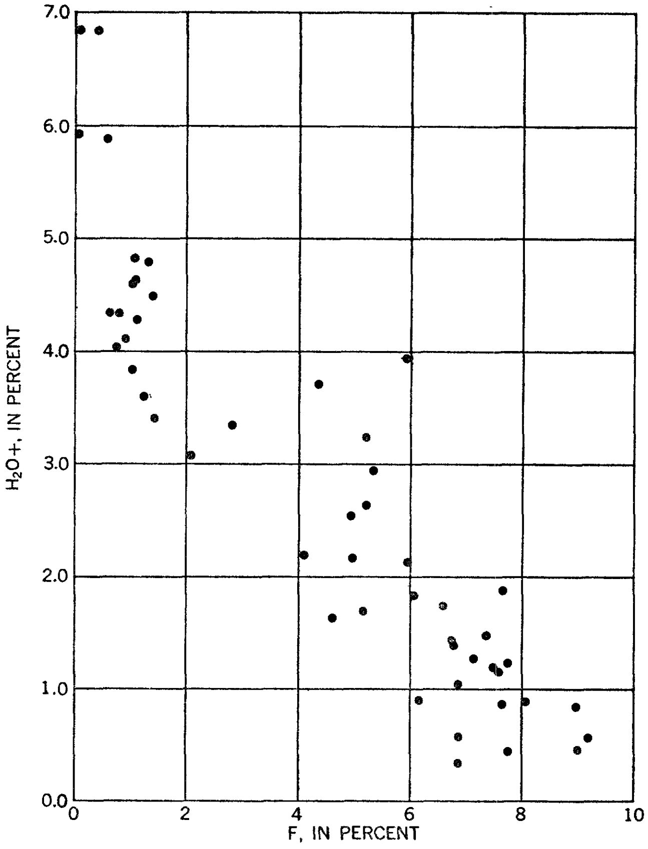

FIGURE 30.—Relation between F and H_2O+ in aluminum lithium micas.

lithionite and trilithionite, raises the problem of structural continuity.

Information as to the structure of aluminum lithium micas is furnished by Hendricks and Jefferson's study of Stevens' lepidolite samples (1939, p. 761), and by Levinson's study of aluminum lithium micas (1953) that varied in Li_2O content from a few tenths of a percent to more than 7 percent. Included among the micas studied by Levinson were most of Stevens' samples. Except for a few samples in a restricted range of Li_2O content, both investigators found that the mica samples studied were not mixtures, as postulated by Stevens (1938) and Winchell (1942), but that each consisted of one structural form. Hendricks and Jefferson found that Stevens' sample 1 (21, table 6), which has an Li_2O content of 2.70 percent, has a muscovite structure, but that his samples 6–10 and 12–17, which contain between 5.04 and 7.26 percent Li_2O, all have lepidolite structures. Also, samples 2–5 of Stevens' suite, which contain between 3.51 and 3.96 percent Li_2O and fall, in Li_2O content, between sample 1, with a muscovite structure, and 6, with a lepidolite structure, were too fine grained for the type of study made by them. Levinson (1953, p. 99) speculated that it seemed likely that "* * * these fine-grained micas owe their macrostructural defects to small-scale variations in their crystal structure which itself probably is assignable to their chemically transitional position in the muscovite-lepidolite series." In order to test this hypothesis, he made detailed powder X-ray studies of these fine-grained micas and found that they all are combinations of 2-layer muscovite and 6-layer lepidolite forms, with the 6-layer[1] lepidolite form predominating over the 2-layer muscovite form in all the samples. As a result of his study of the aluminum lithium micas, Levinson concluded that micas with less than 3.3 percent Li_2O have muscovite structure; those with 3.4 to 4.0 percent Li_2O have mixed structures, and that those with more than 4.0 percent Li_2O have lepidolite structure.

Data for correlation of structure with the number of sites occupied by Li and octahedral cations in Stevens' samples are given in table 1. These data show that in the half-cell formula for Stevens' sample 1, which has a muscovite structure, octahedral occupancy is 2.47; in Stevens' 2, 3, 4, and 5, which are combinations of muscovite and lepidolite forms, octahedral occupancy is 2.50 to 2.62 sites; and in Stevens' other samples, all of which have lepidolite structures, octahedral occupancy is greater than 2.70. Thus the samples that are combinations of forms, giving evidence of transition in structural type, have octahedral occupancies about halfway between 2.00 and 3.00. In these samples, Li occupancy is close to one octahedral site. These relations between Li occupancy, octahedral occupancy, and structural type in Stevens' and Berggren's samples, which were also included in Levinson's study, are shown graphically in figure 31.

TABLE 1.—*Relation between* Li_2O *content, octahedral occupancy, and structure of lithium micas analyzed by Stevens*

Stevens (1938)		Li sites	Octahedral occupancy	Structure	
Specimen	Li_2O (percent)			Hendricks and Jefferson (1939)	Levinson (1953)
1	2.70	0.73	2.47	Muscovite	Normal muscovite.
2	3.51	.94	2.50	Too fine grained for study.	6-layer lepidolite and 2-layer muscovite.
3	3.70	1.00	2.59	do	Do.
4	3.81	1.01	2.57	do	Do.
5	3.96	1.06	2.62	do	Do.
6	5.04	1.35	2.72	6-layer monoclinic	6-layer monoclinic (and lithian muscovite).
7	5.05	1.38	2.84	do	Not available.
8	5.11	1.35	2.73	1-layer	1-layer.
9	5.33	1.44	2.79	do	Not available.
10	5.39	1.50	2.93	do	Do.
11	5.51	1.49	2.84	Not available	Do.
12	5.64	1.52	2.85	6-layer monoclinic	Do.
13	5.78	1.56	2.90	1-layer	1-layer.
14	5.89	1.61	2.92	3-layer hexagonal	3-layer hexagonal.
15	6.18	1.68	2.94	1-layer	1-layer.
16	6.84	1.84	2.96	do	Do.
17	7.26	1.93	2.93	do	Do.

Just as the transitional samples consist of a combination of forms, the values reported for various constituents on analysis are composite values made up of the amounts of these constituents contributed by muscovite and lepidolite forms present. For example, the value for Li_2O found on analysis in these samples is a composite value made up of Li_2O contributed by the muscovite present, in which the Li_2O content may be less than 3.0 percent, and of Li_2O contributed by the lepidolite present, in which the Li_2O content may be more than 4.0 percent. Thus the Li_2O values in the area of mixed forms which suggest a continuity in Li content in figure 31, for example, between aluminian lithium micas of muscovite structure and those of lepidolite structure are deceptive, and there is actually a gap in Li content between these two types of aluminum lithium micas. Similarly, all the other analytical values reported for these mixed-form samples are composite values. Therefore, both the compositional and structural continuity of the aluminum lithium series is broken at the point at which change in structure takes place, and the isomorphous series that starts with muscovite extends only to an octahedral occupancy of about 2.45 sites and an Li occupancy just short of 1.00 octahedral site.

Following Schaller (1930), these aluminum lithium micas having muscovite structures are termed "lithian" muscovites. Levinson applied this term to a new variation of the muscovite polymorph which he observed in muscovite containing at least 3.3 percent

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[1] Smith and Yoder (1956, p. 215) renamed this $2M_1$.

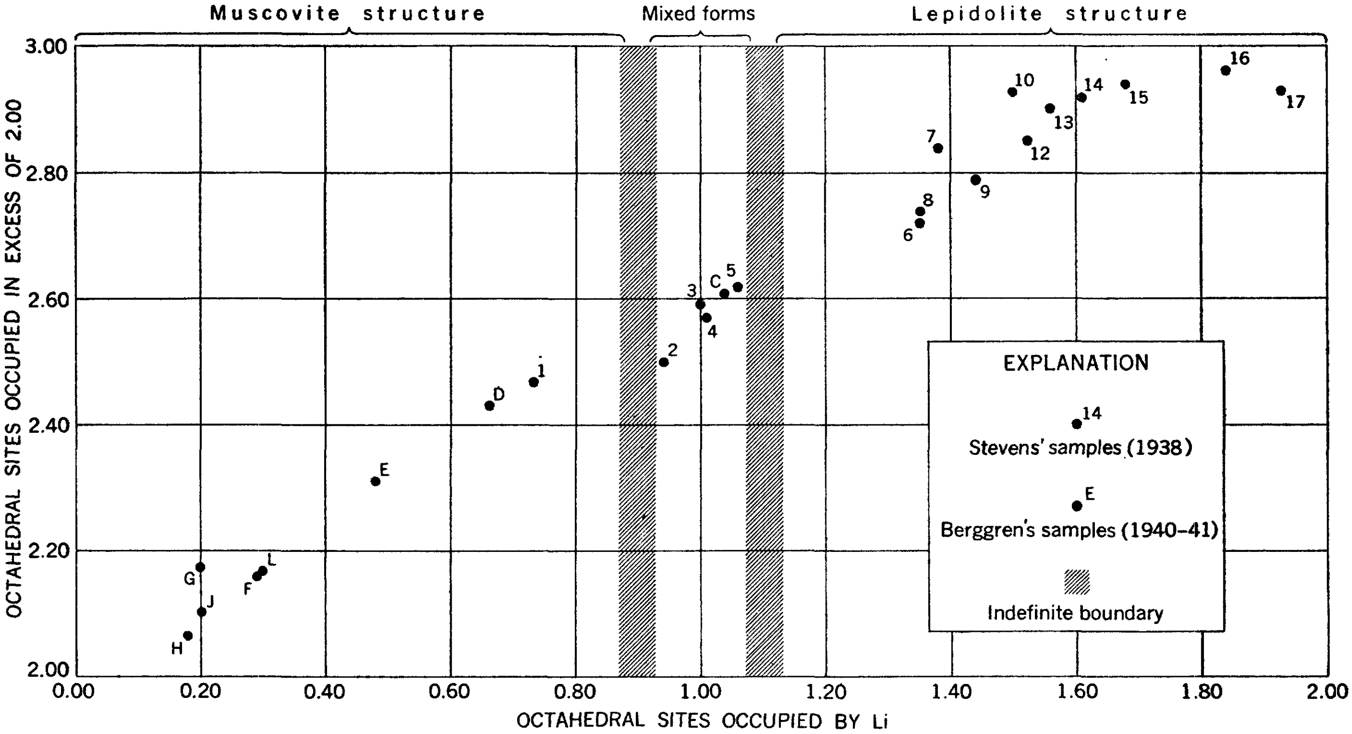

FIGURE 31.—Relation between Li occupancy, octahedral occupancy, and structural type in Stevens' and Berggren's samples. (Numbers refer to samples of Stevens, 1938; letters refer to samples of Berggren, 1940, 1941.)

Li_2O and possibly as much as 4.3 percent Li_2O. In so doing he applied a chemical term to a structural variation, whereas Schaller had proposed the use of the adjectival ending "ian" to names of chemical elements to describe a variety in which there was minor and variable replacement of an essential element by an analogous element, as chromian muscovite, or vanadian muscovite. According to this usage a lithian muscovite is a muscovite containing some Li in place of Al, not a muscovite having a slight structural variation over a limited range of Li_2O content, as used by Levinson.

Because of their different structure, and the break in compositional continuity in the transition area, the lepidolites do not belong to the aluminum lithium isomorphous series that starts with muscovite. However, in composition they can be interpreted as if they were a continuation of this series, that is, on the basis of Li replacement of octahedral Al in muscovite in ratios varying between 2 and 3 Li for 1 octahedral Al. This continuation in type and order of replacement beyond the structural transition zone is illustrated in figures 25 through 31.

Available information on Li content and octahedral occupancy, Li-(octahedral Al) replacement ratios, and structure in Stevens' samples and in Berggren's samples that were studied by Levinson, listed in table 2, shows no consistent correlation between replacement ratio and structure in lithian muscovites and lepidolites. Lithian muscovites have Li-(octahedral Al) replacement ratios ranging from 1.5 to 2.9; lepidolites with 6-layer structures have Li-(octahedral Al) replacement ratios ranging from 2.1 to 2.8, and those with 1-layer structures have Li-(octahedral Al) replacement ratios ranging from 1.9 to 2.6. Apparently, therefore, micas in which the Li-(octahedral Al) replacement ratio is 2 are not distinct structurally from micas in which this replacement ratio is 3.

Three polymorphic variations were found among the lepidolites: the 6-layer monoclinic, the 1-layer, and the 3-layer hexagonal. Levinson correlated the 6-layer monoclinic polymorph with lepidolites containing 4.0 to 5.1 percent Li_2O (equivalent to about 1.05 to 1.40 octahedral sites in half-cell formulas), and the 1-layer polymorph with those having more than 5.1 percent Li_2O. However, Hendricks and Jefferson (1939) concluded that there is no apparent correlation between the different lepidolite polymorphs and composition. Thus Stevens' sample 12 (47, table 6), with 5.64 percent Li_2O, has a 6-layer monoclinic structure whereas others with lower Li_2O content (table 1) have 1-layer lepidolite structures. Nor is there, apparently, any relation among lepidolites, between octahedral occupancy and the different lepidolite polymorphs. As shown in table 2, octahedral occupancy in the 6-layer lepidolites studied ranges between 2.72 and 2.96; that in the 1-layer lepidolites ranges between 2.73 and 2.96. Hendricks and Jefferson also found that the 6-layer and 1-layer polymorphs cannot be distinguished optically.

TABLE 2.—*Comparison of* Li *occupancy,* Li-(*octahedral* Al) *replacement ratio, and structure*

Sample			Li_2O (percent)	Li sites	Octahedral occupancy	Replacement ratio	Structure
Table 6	Other reports						
	Identification	Author					
11	H	Berggren, 1940	0.69	0.18	2.06	1.5	Muscovite.
13	J	Berggren, 1941	.76	.20	2.10	2.0	Do.
15	F	Berggren, 1940	1.10	.29	2.16	2.3	Do.
16	L	Berggren, 1941	1.1	.30	2.17	2.3	Do.
19	E	Berggren, 1940	1.8	.48	2.31	2.8	Do.
20	D	do	2.45	.66	2.43	2.9	Do.
21	1	Stevens, 1938	2.70	.73	2.47	2.8	Do.
33	6	do	5.04	1.35	2.72	2.1	6-layer and muscovite.
34	7	do	5.05	1.38	2.84	2.6	6-layer.
47	12	do	5.64	1.52	2.85	2.3	Do.
53	A	Berggren, 1940	5.95	1.59	2.96	2.5	Do.
36	8	Stevens, 1938	5.11	1.35	2.73	2.2	1-layer.
39	9	do	5.33	1.44	2.79	2.3	Do.
42	10	do	5.39	1.50	2.93	2.6	Do.
50	13	do	5.78	1.56	2.90	2.4	Do.
54	15	do	6.18	1.68	2.94	2.3	Do.
57	16	do	6.84	1.84	2.96	2.1	Do.
58	17	do	7.26	1.93	2.93	1.9	Do.

DISCUSSION

On the basis of chemical evidence alone, the aluminum lithium micas can be considered as if they were members of an isomorphous series, starting with muscovite, in which Li replaces octahedral Al in the ratio of from 2 to 3 Li for 1 octahedral Al. However, structural evidence indicates that the series is not continuous, either structurally or compositionally, but is broken about halfway between muscovite and polylithionite in a zone in which octahedral occupancy is about 2.50 to 2.60 sites and Li occupancy is about 0.95 to 1.05 sites. In this zone the samples are mixed structural forms, muscovite and lepidolite, whereas samples with octahedral occupancy less than 2.50 sites or greater than 2.60 sites are 1 structural form only. As the samples in this zone are mixtures of forms, the analytical values which suggest continuity in composition are composite values and do not actually represent the composition of single-form aluminum lithium micas having an octahedral occupancy of between 2.50 and 2.60 sites. Consequently, the compositional continuity is broken. The aluminum lithium micas, therefore, are members of 2 related series: the lithian muscovite series, which starts with muscovite and extends to micas having an Li occupancy of about 0.85 octahedral sites and an octahedral occupancy of about 2.50 sites, and the lepidolite series, which starts with a lepidolite having an Li occupancy of about 1.10 octahedral sites and an octahedral occupancy of about 2.65 sites and extends to a lepidolite having an Li occupancy of from 1.80 or more octahedral sites and an octahedral occupancy of about 3.00 sites. Selected formulas are given in table 3 that show the relation of lithian muscovites and lepidolites. This relation is shown graphically by histograms in figure 32.

The chemical composition of both the lithian muscovites and lepidolites can be interpreted in the same way; that is, as if they were derived from muscovite by the replacement of octahedral aluminum by lithium in a ratio varying between 2 and 3 Li for 1 octahedral. The other compositional changes that characterize

TABLE 3.—*Selected formulas illustrating relation between lithian muscovites and lepidolites*

	Number in table 6	*Formula*	*Li-(octahedral Al) replacement ratio*
Lithian muscovites	2	$[\underbrace{\overset{-0.04}{(Al_{1.94}Fe^{+3}_{0.02}Fe^{+2}_{0.03}Li_{0.02})}}_{2.01}\overset{-1.00}{(Si_{3.00}Al_{1.00})}O_{10}(OH)_2]^{-1.04}(K,Na,Ca/2)^{+1.05}_{1.03}$	2.0
	16	$[\underbrace{\overset{-0.18}{(Al_{1.71}Fe^{+3}_{0.07}Fe^{+2}_{0.06}Mg_{0.02}Mn^{+2}_{0.01}Li_{0.30})}}_{2.17}\overset{-0.87}{(Si_{3.13}Al_{0.87})}O_{10}(OH)_2]^{-1.05}(K,Na,Rb,Cs,Ca/2)^{+1.06}_{1.05}$	2.3
	21	$[\underbrace{\overset{-0.20}{(Al_{1.58}Fe^{+3}_{0.01}Fe^{+2}_{0.02}Mg_{0.01}Mn^{+2}_{0.12}Li_{0.73})}}_{2.47}\overset{-0.84}{(Si_{3.16}Al_{0.84})}O_{10}(OH)_2]^{-1.04}(K,Na,Rb,Cs)^{+1.01}_{1.01}$	2.8
Mixed structural forms			
Lepidolites	34	$[\underbrace{\overset{-0.41}{(Al_{1.29}Fe^{+2}_{0.01}Mn^{+2}_{0.16}Li_{1.38})}}_{2.84}\overset{-0.62}{(Si_{3.38}Al_{0.62})}O_{10}(OH)_2]^{-1.03}(K,Na,Rb,Cs)^{+1.03}_{1.03}$	2.6
	52	$[\underbrace{\overset{-0.52}{(Al_{1.25}Fe^{+2}_{0.01}Mg_{0.01}Mn^{+2}_{0.04}Li_{1.61})}}_{2.92}\overset{-0.52}{(Si_{3.48}Al_{0.52})}O_{10}(OH)_2]^{-1.04}(K,Na,Rb,Cs)^{+1.02}_{1.02}$	2.3
	57	$[\underbrace{\overset{-0.87}{(Al_{1.05}Fe^{+2}_{0.01}Mg_{0.02}Mn^{+2}_{0.04}Li_{1.84})}}_{2.96}\overset{-0.17}{(Si_{3.83}Al_{0.17})}O_{10}(OH)_2]^{-1.04}(K,Na,Rb,Cs)^{+1.04}_{1.04}$	2.1

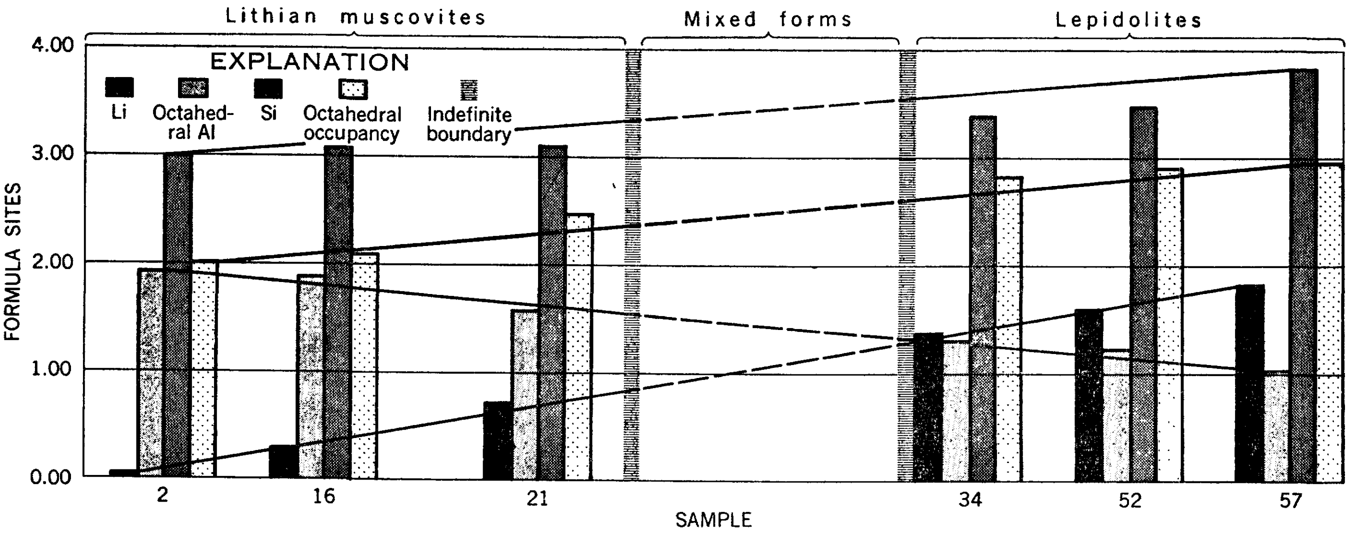

FIGURE 32.—Histograms of selected formulas showing the relation of lithian muscovites and lepidolites. (Numbers below histograms refer to analyses in table 7.)

these micas—increase in silica and decrease in the tetrahedral Al with increase in Li content—are necessitated by the disparity in positive charges carried by the replacing Li and replaced octahedral Al.

The interpretation of the composition of these micas postulated by Stevens (1938) and Winchell (1942), as mixtures of end members, is not borne out by the structural work of Hendricks and Jefferson (1939) and Levinson (1953).

The relation between Li, $R^{+2}(Fe^{+2},Mn^{+2},Mg)$, and octahedral $R^{+3}(Al,Fe^{+3})+Ti^{+4}$ is shown in figure 33, in which the percentages of occupied octahedral sites occupied by Li, $R^{+2}(Fe^{+2},Mn^{+2},Mg)$, and octahedral $R^{+3}(Al,Fe^{+3})+Ti^{+4}$ in each formula are plotted on a triangular diagram. In this diagram ideal muscovite falls at the lower left corner, which represents 100-percent occupancy of the octahedral layer by $Al(+Fe^{+3})$, trilithionite is represented by a point midway along the left side of the triangle, and polylithionite is represented by a point two-thirds of the way up the left side of the triangle. The points representing octahedral occupancy of the calculated formulas of lithian muscovites and lepidolites are distributed along the left side of the triangle from the lower left corner, which represents muscovite, to the point representing polylithionite. Because of the small amounts of FeO, MnO, and (or) MgO found in most lepidolites, few of these points fall on the outside boundary, as do trilithionite and polylithionite. However, all fall between the outside boundary and the line representing 10 percent of bivalent octahedral cations, Fe^{+2}, Mn^{+2}, and Mg.

FERROUS LITHIUM MICAS

PREVIOUS INTERPRETATIONS OF COMPOSITION

Both Kunitz (1924, p. 409) and Winchell (1927, p. 274) regarded lepidolite and protolithionite as end members of a series characterized by decrease in Li content and increase in Fe^{+2}, with protolithionite representing the Fe^{+2}-high, Li-free end of the series. Intermediate members were known as zinnwaldites. Kunitz believed that lepidolite, $KH_2Al_2Le(SiO_4)_3$, contained a special group (2Li,Si), denoted as Le, that was completely replaceable by $3Fe^{+2}$ to form protolithionite. Winchell considered that lepidolite was miscible in all proportions with protolithionite in the crystal state, and that the natural lepidolites, zinnwaldites, and protolithionites were made up of various proportions of the end members. He regarded cryophyllite, a lithium mica described by Cooke (1867) from Cape Ann, Mass., as doubtful. At that time Winchell considered these minerals heptaphyllites, but later (1942, p. 117) he recognized them as octaphyllites and, furthermore, included some lithium in his formula for protolithionite.

Hallimond (1925, p. 311) also believed that lepidolite, zinnwaldite, and protolithionite form a series. However, as indicated by his formulas, $R_2O{\cdot}Li_2O{\cdot}2Al_2O_3{\cdot}6SiO_2{\cdot}2H_2O$, for lepidolite, and $K_2O{\cdot}Li_2O{\cdot}3RO{\cdot}2Al_2O_3{\cdot}6SiO_2{\cdot}2H_2O$, for protolithionite, this series is characterized merely by addition of RO, the Li_2O content remaining constant. Thus Hallimond's series was not a replacement series. The two zinnwaldites reported by Dana, he states, might be regarded as

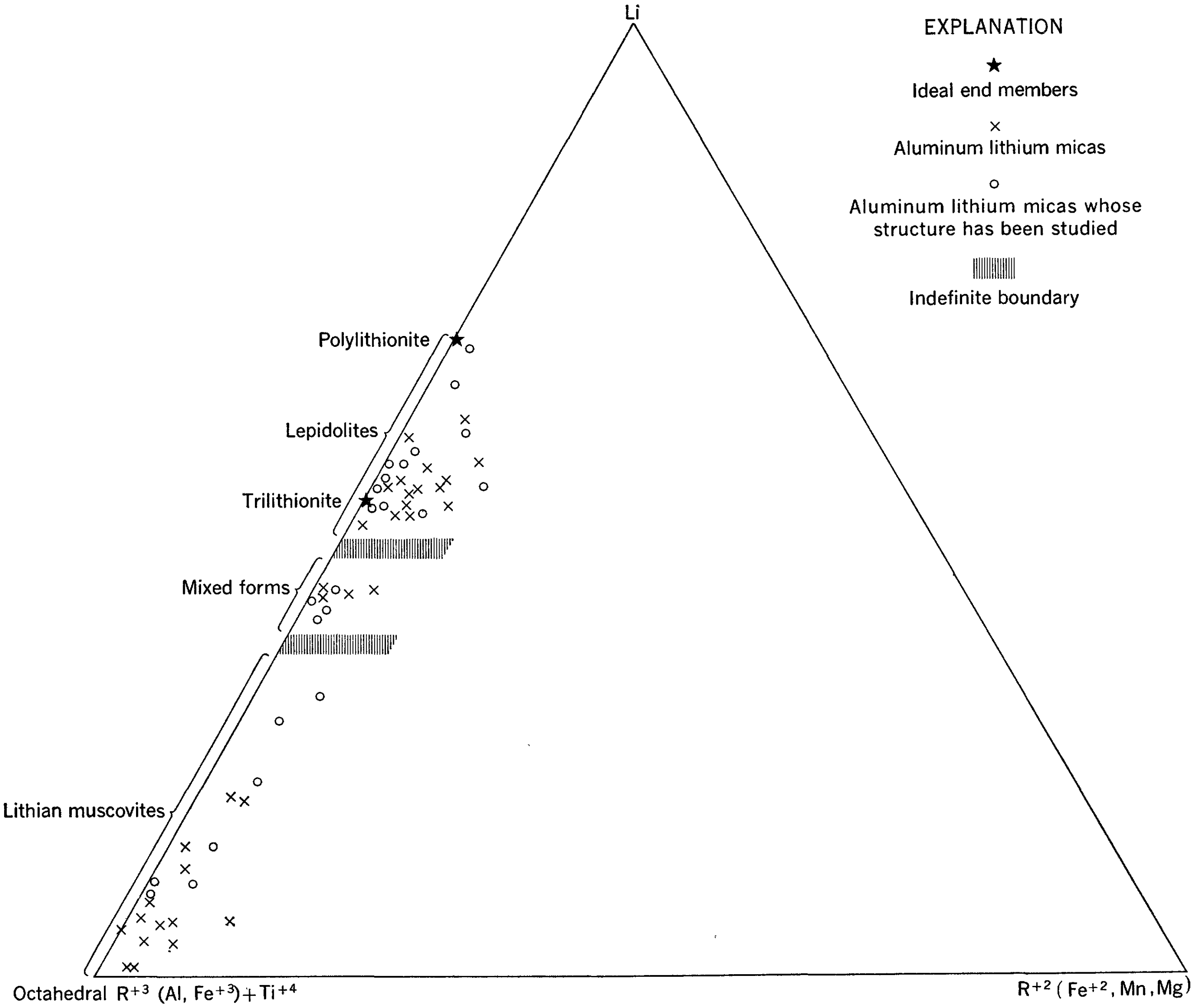

FIGURE 33.—Relation between Li, $R^{+2}(Fe^{+2},Mn^{+2},Mg)$, and octahedral $R^{+3}(Al,Fe^{+3})+Ti^{+4}$ in aluminum lithium micas.

consisting chiefly of the compound $K_2O \cdot Li_2O \cdot RO \cdot 2Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$ or, alternately, as mixtures of lepidolite and protolithionite. He believed that cryophyllite bears the same relation to lepidolite that phengite bears to muscovite.

A classification by Ginzburg and Berkhin (1953) includes the ferrous lithium micas as part of a series of which lepidolite is the high-Li end member and biotite is the Li-free end member. In this series the transition from biotite to lepidolite is supposed to be marked by the replacement of $2Mg^{+2}$ by Li and Al^{+3}.

Thus four kinds of series have been proposed to interpret the composition and relation of the ferrous lithium micas: the lepidolite-protolithionite series of Kunitz (1924, p. 409), in which the Le group (2Li,Si) is completely replaced by $3Fe^{+2}$; the lepidolite-protolithionite series of Winchell, in which the end members are miscible in all proportions and form intermediate members; the lepidolite-protolithionite series of Hallimond, in which Fe^{+2} is additive but Li remains constant; and the biotite-lepidolite series of Ginzburg and Berkhin, in which 2Mg is replaced by (Li+Al). In none of these series are the limits in composition between lepidolite, cryophyllite, zinnwaldite, and protolithionite defined.

The clearest definition of the limits of composition between protolithionite, zinnwaldite, and cryophyllite is that stated in Hey (1955, p. 208). Hey gives the same formula $2[K_2(Li,Fe^{+2},Al)_6(Si,Al)_8O_{20}(F,OH)_4]$ for all three, excepting only that Fe^{+3} is included in the (Li,Fe^{+2},Al) group in his formulas for protolithionite and cryophyllite, but he qualifies the formulas by observations on the amounts of Li, Fe^{+2}, and Si typically present. Thus in protolithionite, zinnwaldite, and cryophyllite, Li occupies 1–2, ≈2, and ≈2½ formula positions, respectively; Fe occupies ≈1½, ≈1½, and ≈1 (including Fe^{+3}) formula positions, respectively; and Si 5½–6, ≈6½, and ≈7 formula positions, respectively. Following Dana (1892, p. 626), Hey gives zinnwaldite species status, with protolithionite and cryophyllite being considered varieties of zinnwaldite.

COMPOSITIONAL CHANGES SHOWN BY ANALYSES

The analyses of ferrous lithium micas vary considerably in SiO_2 and Al_2O_3 content, although there is a general increase in SiO_2 content and decrease in Al_2O_3 content with increase in Li_2O content. However, these relations are not as consistent as in the aluminum lithium micas. The Fe_2O_3 content is quite variable in ferrous lithium micas having less than 3.5 percent of Li_2O; in ferrous lithium micas having more than 3.5 percent of Li_2O, Fe_2O_3 is generally low or absent. FeO is also quite variable, but, in general, decreases with increase in Li_2O content. All but 1 of the ferrous lithium micas included in the study that contained less than 2 percent of Li_2O have more than 15 percent of FeO, those with between 2.0 and 3.0 percent of Li_2O have between 9.0 and 14.0 percent of FeO, and those with more than 3 percent of Li_2O have between 6.0 and 12.6 percent of FeO. MgO is generally low. Many of the analyses contain less than 0.5 percent, and few contain more than 1.0 percent. Only 1 analysis has a significant amount, 5.23 percent.

In most of the formulas calculated from the analyses the number of octahedral sites occupied is greater than 2.60. These micas are, therefore, trioctahedral or octaphyllic micas, not heptaphyllic micas as was formerly assumed by Winchell (1927, p. 274).

RELATION BETWEEN FERROUS LITHIUM MICAS, SIDEROPHYLLITES, AND ALUMINIAN LEPIDOMELANES

In their principal compositional characteristics, their low MgO content with high FeO content, their octahedral occupancy, and their octahedral-tetrahedral charge relations, the ferrous lithium micas with low Li_2O content resemble siderophyllites and lepidomelanes, which are the low-Mg members of the phlogopite-biotite-siderophyllite (or lepidomelane) Mg replacement system (Foster, 1960, p. 30). The similarity in composition is illustrated by the following formulas:

A. Siderophyllites and aluminian lepidomelanes

Number in table 7

1 ------------------------

$$\Big[\overset{-0.06}{\underbrace{(\mathrm{Al}_{0.99}\mathrm{Ti}_{0.01}\mathrm{Fe}^{+3}_{0.05}\mathrm{Fe}^{+2}_{1.32}\mathrm{Mg}_{0.05}\mathrm{Mn}^{+2}_{0.02})}_{2.44}}\overset{-1.03}{(\mathrm{Si}_{2.97}\mathrm{Al}_{1.03})}\mathrm{O}_{10}(\mathrm{OH,F})_2\Big]^{-1.09}\mathrm{K}(\mathrm{Ca}/2)^{+1.10}_{0.98}$$

2 ------------------------

$$\Big[\overset{+0.35}{\underbrace{(\mathrm{Al}_{0.73}\mathrm{Fe}^{+3}_{0.08}\mathrm{Fe}^{+2}_{1.88}\mathrm{Mg}_{0.01}\mathrm{Mn}^{+2}_{0.02}\mathrm{Li}_{0.10})}_{2.82}}\overset{-1.35}{(\mathrm{Si}_{2.65}\mathrm{Al}_{1.35})}\mathrm{O}_{10}(\mathrm{OH,F})_2\Big]^{-1.00}\mathrm{K}(\mathrm{Na,Ca}/2)^{+0.99}_{0.98}$$

4 ------------------------

$$\Big[\overset{+0.24}{\underbrace{(\mathrm{Al}_{0.44}\mathrm{Ti}_{0.09}\mathrm{Fe}^{+3}_{0.49}\mathrm{Fe}^{+2}_{1.38}\mathrm{Mg}_{0.03}\mathrm{Mn}^{+2}_{0.06}\mathrm{Li}_{0.15})}_{2.64}}\overset{-1.19}{(\mathrm{Si}_{2.81}\mathrm{Al}_{1.19})}\mathrm{O}_{10}(\mathrm{OH,F})_2\Big]^{-0.95}\mathrm{K}(\mathrm{Na,Ca}/2)^{+0.96}_{0.87}$$

B. Ferrous lithium micas ($Li_2O<$*1.5 percent*)

9 ------------------------

$$\Big[\overset{+0.06}{\underbrace{({}_{1.06}\mathrm{Ti}_{0.03}\mathrm{Fe}^{+2}_{1.12}\mathrm{Mg}_{0.01}\mathrm{Mn}^{+2}_{0.04}\mathrm{Li}_{0.42})}_{2.68}}\overset{-1.24}{(\mathrm{Si}_{2.76}\mathrm{Al}_{1.24})}\mathrm{O}_{10}(\mathrm{OH,F})_2\Big]^{-1.18}\mathrm{K}(\mathrm{Na,Ca}/2)^{+1.15}_{1.04}$$

10 ------------------------

$$\Big[\overset{+0.01}{\underbrace{(\mathrm{Al}_{0.71}\mathrm{Fe}^{+3}_{0.23}\mathrm{Fe}^{+2}_{1.24}\mathrm{Mg}_{0.03}\mathrm{Mn}^{+2}_{0.10}\mathrm{Li}_{0.45})}_{2.76}}\overset{-1.07}{(\mathrm{Si}_{2.93}\mathrm{Al}_{1.07})}\mathrm{O}_{10}(\mathrm{OH,F})_2\Big]^{-1.06}\mathrm{K}(\mathrm{Na,Ca}/2)^{+1.08}_{1.06}$$

11 ------------------------

$$\Big[\overset{+0.19}{\underbrace{(\mathrm{Al}_{0.57}\mathrm{Ti}_{0.03}\mathrm{Fe}^{+3}_{0.31}\mathrm{Fe}^{+2}_{1.44}\mathrm{Mg}_{0.02}\mathrm{Mn}^{+2}_{0.02}\mathrm{Li}_{0.47})}_{2.86}}\overset{-1.11}{(\mathrm{Si}_{2.89}\mathrm{Al}_{1.11})}\mathrm{O}_{10}(\mathrm{OH,F})_2\Big]^{-0.92}\mathrm{K}(\mathrm{Na,Ca}/2)^{+0.90}_{0.88}$$

In both these groups Mg is insignificant and Fe^{+2} is the dominant octahedral cation, but the amount of Fe^{+2} present varies greatly. In some siderophyllites and in some of the ferrous lithium micas, Al is the principal trivalent octahedral cation, in others in both groups there are significant amounts of trivalent iron. Indeed some low-Mg, high-Fe^{+2} trioctahedral micas, lepidomelanes, contain trivalent iron as the greatly dominant octahedral cation. In formulas calculated from analyses of ferrous lithium micas, the dominant trivalent octahedral cation is usually Al, some contain considerable Fe^{+3}, but Fe^{+3} is not greatly dominant in any of the calculated formulas studied. In the study of the phlogopite-biotite-siderophyllite (or lepidomelane) system (Foster, 1960), it was found that replacements of Mg by bivalent iron (Fe^{+2}), and by the trivalent ions, Al and Fe^{+3}, proceed quite independently; a given degree of replacement by Fe^{+2} has no relation to the degree of replacement by Al or Fe^{+3}, nor has the degree of replacement by Al any relation to the degree of replacement by Fe^{+3}.

The octahedral charge in the siderophyllites and the ferrous lithium micas is usually positive, but it may be about neutral or even slightly negative, depending on how the additional positive charges carried by trivalent octahedral cations (as compared with the number of charges carried by bivalent cations) have been accommodated in the structure (Foster, 1960, p. 16), and the negative tetrahedral charge may be considerably greater than 1.00, close to 1.00, or less than 1.00, depending on the octahedral charge. Octahedral occupancy also varies considerably, depending also on how the additional positive charges of trivalent octahedral cations have been accommodated.

The similarity in characteristics of siderophyllites and ferrous lithium micas suggests that the siderophyllites are the prototypes from which the ferrous lithium micas are derived. It should be noted here that most analyses of siderophyllites and lepidomelanes include small amounts of Li_2O. Some materials that have been called siderophyllite contain as much as 1 percent of Li_2O.

COMPOSITIONAL RELATIONS IN SIDEROPHYLLITES AND FERROUS LITHIUM MICAS

RELATION BETWEEN LI AND TRIVALENT OCTAHEDRAL CATIONS

The relation between the number of formula sites occupied by Li and by trivalent octahedral cations (Al and Fe^{+3}) in siderophyllites and ferrous lithium micas is shown in figure 34. The number of octahedral sites occupied by trivalent cations is more variable, and in general lower, in the siderophyllites and aluminian lepidomelanes and in the ferrous lithium micas having less than 1.5 percent of Li_2O (about 0.5 octahedral sites), than in ferrous lithium micas containing more than 1.5 percent Li_2O. In the latter the octahedral trivalent cationic content is remarkably constant over a range in Li_2O content of from 1.5 to 4.8 percent. This relative constancy in octahedral trivalent cationic content suggests that these cations are not involved in the addition of Li to the structure.

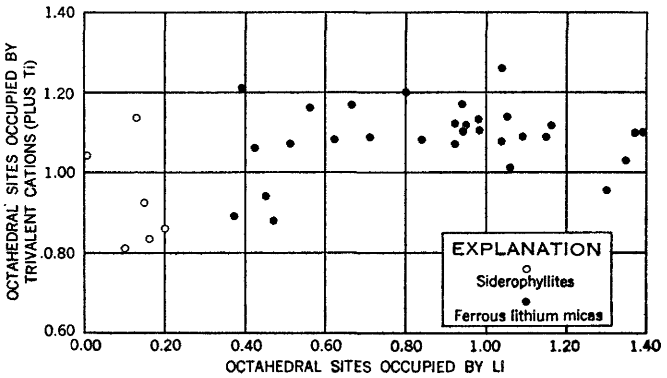

FIGURE 34.—Relation between Li and octahedral R^{+3} cations in siderophyllites and ferrous lithium micas.

RELATION BETWEEN LI AND FE^{+2}

The relation between Li and Fe^{+2} in siderophyllites and ferrous lithium micas is shown in figure 35, in which the number of octahedral sites occupied by Fe^{+2} is plotted against the number of sites occupied by Li. The Fe^{+2} content of siderophyllites (including ferrian siderophyllites and aluminian lepidomelanes) varies greatly, as does also that of the ferrous lithium micas. Even those containing about the same amount of Li vary greatly in Fe^{+2} content. In general, however, there is a sharp downward trend of the points with increase in Li content, which is suggestive of replacement. The ratio of replacement is, however, difficult to determine because of the great variation in Fe^{+2} content in ferrous lithium micas having low Li content, as well as in the siderophyllites from which they are hypothetically assumed to have been derived, as indicated by the great variation in Fe^{+2} content in the siderophyllites at hand. Thus there is no definite point of departure with respect to Fe^{+2} content from which to calculate Fe^{+2} replacement as there was with respect to Al content and Al replacement in the lepidolites.

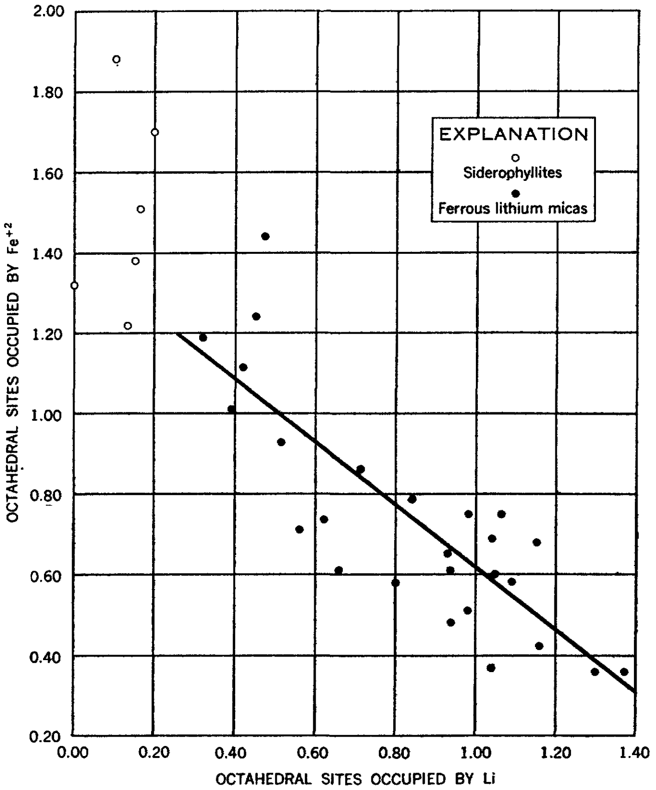

FIGURE 35.—Relation between Li and Fe^{+2} in siderophyllites and ferrous lithium micas.

RELATION BETWEEN LI AND SI

The relation between Li and Si in siderophyllites (including aluminian lepidomelanes) and ferrous lithium micas is shown in figure 36, in which the number of formula sites occupied by Si is plotted against the number of formula sites occupied by Li. As in Fe^{+2} content, the Si content varies greatly, even in micas having about the same Li content. This difference in Si content in samples having about the same Li content is due to the manner in which the additional charges carried by trivalent octahedral cations are accommodated in the structure (Foster, 1960, p. 16). If the additional positive charges are accommodated predominantly as a positive charge on the octahedral layer and neutralized by a negative tetrahedral charge which is greater than 1.00 by an amount about equivalent to the positive octahedral charge, the Si is considerably lower than if the additional positive charges are predominantly neutralized by anions associated with unoccupied octahedral sites. This variation in Si content, owing to differences in the way in which the additional positive charges were accommodated, in ferrous lithium micas with about the same Li content is illustrated in the formulas for analyses 22 and 23, table 7, that follow:

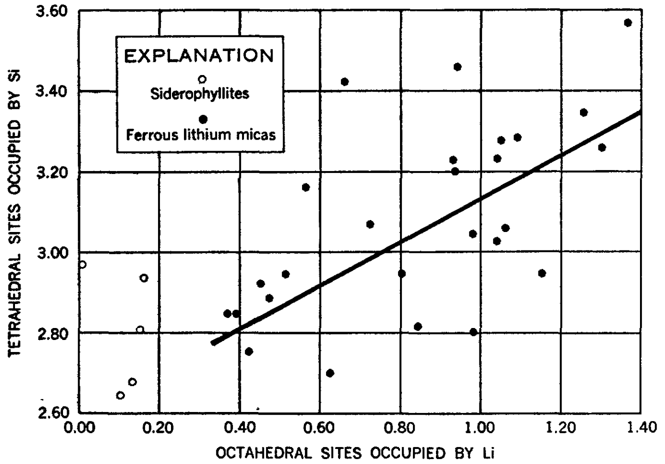

FIGURE 36.—Relation between Li and Si in siderophyllites and ferrous lithium micas.

$$[\overset{+0.19}{\underbrace{(Al_{0.80}Ti_{0.03}Fe^{+3}_{0.33}Fe^{+2}_{0.75}Mg_{0.10}Li_{0.98})}_{2.99}}\overset{-1.20}{(Si_{2.80}Al_{1.20})}O_{10}(OH,F)_2]^{-1.01}K(Na,Ca/2)^{+1.03}_{0.97}$$

$$[\overset{-0.18}{\underbrace{(Al_{1.10}Ti_{0.07}Fe^{+2}_{0.61}Mg_{0.02}Mn^{+2}_{0.02}Li_{0.94})}_{2.76}}\overset{-0.80}{(Si_{3.20}Al_{0.80})}O_{10}(OH,F)_2]^{-0.98}K(Na,Ca/2)^{+1.00}_{0.96}$$

The Li_2O content in the micas represented by these formulas is almost the same, 3.39 and 3.40, respectively. But the SiO^2 content of analysis 22 is only 39.04 percent, as compared with 46.37 percent in 23. In 22, octahedral occupancy is complete. Univalent Li compensates for 0.98 of the additional 1.19 positive charges carried by Al, Fe^{+3}, and Ti^{+4}; the remainder form a positive charge (+0.19) on the octahedral layer that is neutralized by an equivalent increase, above 1.00, in the negative tetrahedral charge. In 23, only 2.76 octahedral sites are occupied. Univalent Li compensates for 0.94 of the 1.24 additional positive charges carried by Al and Ti; the rest are neutralized by negative charges associated with unoccupied octahedral sites. However, the 0.24 unoccupied sites make 0.48 such negative charges available, and as only 0.30 are need to neutralize the uncompensated additional positive charges, the octahedral layer is left with a negative charge of −0.18. In order that the unit layer charge be close to −1.00, the negative tetrahedral charge must be less than 1.00 by the same amount. Because, therefore, of the different ways in which the additional positive charges carried by trivalent cations are accommodated in the structure in such trioctahedral micas as the ferrous lithium micas, there is considerable variation in Si content, even in those in which the Li_2O content is the same. However, despite such differences in SiO_2 content, the upward trend of the points in figure 36 suggests that increase in Li content is accompanied by increase in Si content, although the angle of trend of increase is less than the angle of trend of decrease in Fe^{+2} content.

HYPOTHETICAL FE+2-LI REPLACEMENT RATIOS

If Li replaces Fe^{+2} in the ratio of 2:1, the number of positive charges carried by octahedral cations is not changed, and, consequently, the octahedral and tetrahedral charges and Si are unchanged, but the octahedral occupancy is increased by one-half the number of Li cations added. This is illustrated in the following formulas, in which 1.00 Li is substituted for 0.50 Fe^{+2} in the formula for analysis 4, table 7.

$$[\overset{+0.24}{\underbrace{(Al_{0.44}Ti_{0.09}Fe^{+3}_{0.49}Fe^{+2}_{1.38}Mg_{0.03}Mn^{+2}_{0.06}Li_{0.15})}_{2.64}}\overset{-1.19}{(Si_{2.81}Al_{1.19})}O_{10}(OH,F)_2]^{-0.95}K(Na,Ca/2)^{+0.96}_{0.87},$$

$$[\overset{+0.24}{\underbrace{(Al_{0.44}Ti_{0.09}Fe^{+3}_{0.49}Fe^{+2}_{0.88}Mg_{0.03}Mn^{+2}_{0.06}Li_{1.15})}_{3.14}}\overset{-1.19}{(Si_{2.81}Al_{1.19})}O_{10}(OH,F)_2]^{-0.95}K(Na,Ca/2)^{+0.96}_{0.87}.$$

The octahedral-tetrahedral charge relation and the Si are the same in the second formula as in the first, but octahedral occupancy is increased by 0.5 and is greater than 3.00.

If, on the other hand, Li replaces Fe^{+2} ion for ion in the formula for 4, above,

$$[\overset{-0.76}{\underbrace{(Al_{0.44}Ti_{0.09}Fe^{+3}_{0.49}Fe^{+2}_{0.38}Mg_{0.03}Mn^{+2}_{0.06}Li_{1.15})}_{2.64}}\overset{-0.19}{(Si_{3.81}Al_{0.19})}O_{10}(OH,F)_2]^{-0.95}K(Na,Ca/2)^{+0.96}_{0.87},$$

the octahedral occupancy remains the same, but the layer-charge relation is greatly altered, and there is an increase in Si equivalent to the increase in Li and the decrease in Fe^{+2}. The increase in Si, equivalent to the increase in Li and to the decrease in Fe^{+2}, is greater than indicated by the comparative angles of trend of the points in figures 35 and 36, which indicate that the general increase in Si is generally less than the decrease in Fe^{+2}. The negative octahedral charge is considerably greater, and the negative tetrahedral charge is considerably less, than in any of the calculated formulas of ferrous lithium micas.

Neither of these types of replacement of Fe^{+2} by Li, therefore, correlates well with the characteristics of the ferrous lithium formulas nor with the degree of Si-increase, Fe^{+2}-decrease relation suggested in figures 35 and 36. Substitution of Li for Fe^{+2} in the 2:1 ratio results in no change in Si content; substitution of Li for Fe^{+2} in the 1:1 ratio results in a greater increase in Si than indicated by figure 36. This suggests that the replacement ratio lies between 2:1 and 1:1. In the formula below, a replacement ratio of 2:1.5 (1 Li for 0.75 Fe^{+2}) in the formula for analysis 4, table 7, is assumed.

$$[\overset{-0.26}{\underbrace{(Al_{0.44}Ti_{0.09}Fe^{+3}_{0.49}Fe^{+2}_{0.63}Mg_{0.03}Mn^{+2}_{0.06}Li_{1.15})}_{2.89}}\overset{-0.69}{(Si_{3.31}Al_{0.69})}O_{10}(OH,F)_2]^{-0.95}K(Na,Ca/2)^{+0.96}_{0.87}.$$

In this formula, the increase in Si (+0.5) is equivalent to one-half the increase in Li content (+1.0) and to two-thirds the decrease in Fe^{+2} content (0.75). This relation between Li and Si is about that suggested by the trend of the points in figure 36, and the relation between Si increase and Fe^{+2} decrease is comparable to the relative trend of points in figures 35 and 36. The octahedral-tetrahedral charge relation in this formula and the octahedral occupancy are also comparable with those found in the calculated formula for ferrous lithium micas (the data for writing these calculated formulas are included in table 7). The replacement ratio probably varies considerably, possibly as much as from 2:1 to 1:1 Li for Fe^{+2} in certain specimens of ferrous lithium micas, but a replacement ratio of about 2:1.5 Li for Fe^{+2} best explains in general the amount of decrease in Fe^{+2}, the amount of increase in Si, the octahedral occupancy, and the octahedral-tetrahedral charge relations found in calculated formulas of ferrous lithium micas.

The changes in composition that take place in replacement of Fe^{+2} by Li in this ratio can be expressed briefly as $4n\text{Li}+2n\text{Si}=3n\text{Fe}^{+2}+2n$ tetrahedral Al. Octahedral trivalent cations, Al and Fe^{+3}, are not involved in the replacement, as is indicated in figure 34.

SIDEROPHYLLITE-LEPIDOLITE ISOMORPHOUS SERIES

The relation between Li, $R^{+2}(Fe^{+2},Mn^{+2},Mg)$, and octahedral $R^{+3}(Al,Fe^{+3})+Ti^{+4}$ in siderophyllites and aluminian lepidomelanes and ferrous lithium micas is shown in figure 37, in which the percentages of occupied octahedral sites occupied by Li, $R^{+2}(Fe^{+2},Mn^{+2},Mg)$, and octahedral $R^{+3}(Al,Fe^{+3})+Ti^{+4}$ in each of the calculated formulas used in this study are plotted on a triangular diagram. The points representing siderophyllites and aluminian lepidomelanes occupy an area at the base of the triangle just to the right of the center. Only one point, representing a siderophyllite in which no Li_2O was reported, falls on the baseline. The other five points, which represent siderophyllites and lepidomelanes which contain small amounts of Li_2O, fall a little above the baseline. The points representing the the ferrous lithium micas fall in a band trending diagonally upward from the area occupied by siderophyllites and aluminian lepidomelanes toward the point representing polylithionite. Calculated formulas representing progressive stages of replacement of ferrous iron by Al in the siderophyllite-lepidolite isomorphous series are given in table 4 and are represented graphically in histograms in figure 38. Both the formulas and histograms illustrate the progressive changes in composition that take place with increase in Li content, particularly decrease in Fe^{+2} content and increase in Si content.

The slight hiatus between points (fig. 37)representing siderophyllites and aluminian lepidomelanes and those representing ferrous lithium micas serves to differentiate the former and protolithionite, but differentiation between protolithionites and zinnwaldites must be on an arbitrary basis, as there is no hiatus between points representing these varieties.

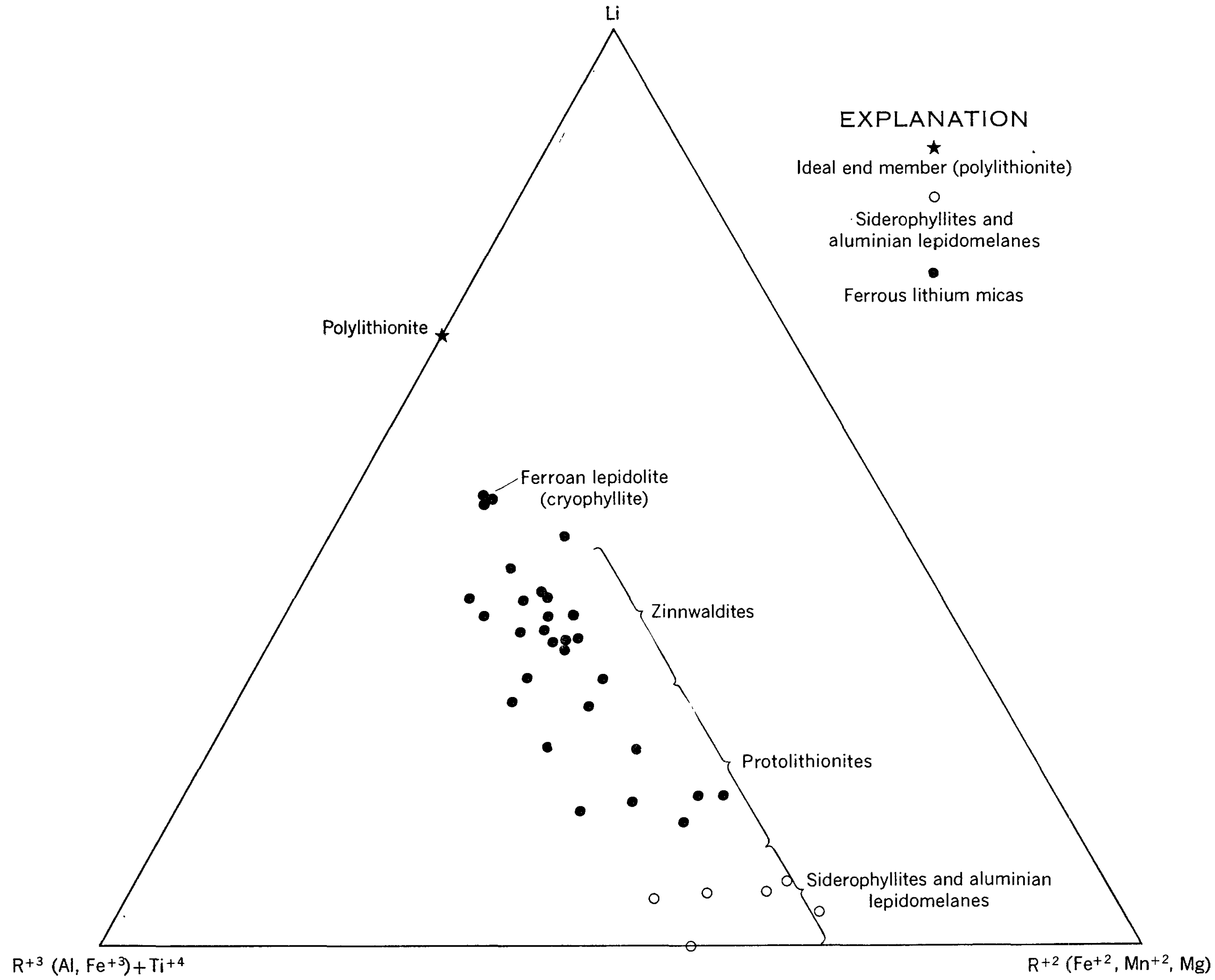

FIGURE 37.—Relation between Li, $R^{+2}(Fe^{+2},Mn^{+2},Mg)$, and octahedral $R^{+3}(Al,Fe^{+3})+Ti^{+4}$ in siderophyllites and ferrous lithium micas.

TABLE 4.—*Selected formulas representing steps in the siderophyllite-lepidolite series*

Number in table 7	*Formula*	*Li_2O (percent)*
3	$[\underbrace{\overset{+0.25}{(\mathrm{Al}_{0.52}\mathrm{Ti}_{0.01}\mathrm{Fe}^{+3}_{0.62}\mathrm{Fe}^{+2}_{1.22}\mathrm{Mg}_{0.09}\mathrm{Mn}^{+2}_{0.02}\mathrm{Li}_{0.13})}}_{2.61}\overset{-1.32}{(\mathrm{Si}_{2.68}\mathrm{Al}_{1.32})}\mathrm{O}_{10}(\mathrm{OH,F})_2]^{-1.07}\ \mathrm{K(Na,Ca/2)}^{+1.06}_{0.99}$	0.39
9	$[\underbrace{\overset{+0.06}{(\mathrm{Al}_{1.06}\mathrm{Ti}_{0.03}\mathrm{Fe}^{+2}_{1.12}\mathrm{Mg}_{0.01}\mathrm{Mn}^{+2}_{0.04}\mathrm{Li}_{0.42})}}_{2.68}\overset{-1.24}{(\mathrm{Si}_{2.76}\mathrm{Al}_{1.24})}\mathrm{O}_{10}(\mathrm{OH,F})_2]^{-1.18}\ \mathrm{K(Na,Ca/2)}^{+1.15}_{1.04}$	1.44
15	$[\underbrace{\overset{-0.16}{(\mathrm{Al}_{1.04}\mathrm{Fe}^{+3}_{0.05}\mathrm{Fe}^{+2}_{0.87}\mathrm{Mg}_{0.06}\mathrm{Li}_{0.71})}}_{2.73}\overset{-0.93}{(\mathrm{Si}_{3.07}\mathrm{Al}_{0.93})}\mathrm{O}_{10}(\mathrm{OH,F})_2]^{-1.09}\ \mathrm{K(Na)}^{+1.08}_{1.08}$	2.42
18	$[\underbrace{\overset{-0.16}{(\mathrm{Al}_{1.08}\mathrm{Fe}^{+3}_{0.04}\mathrm{Fe}^{+2}_{0.68}\mathrm{Mn}^{+2}_{0.10}\mathrm{Li}_{0.92})}}_{2.82}\overset{-0.79}{(\mathrm{Si}_{3.21}\mathrm{Al}_{0.79})}\mathrm{O}_{10}(\mathrm{OH,F})_2]^{-0.95}\ \mathrm{K(Na)}^{+0.94}_{0.94}$	3.28
31	$[\underbrace{\overset{-0.40}{(\mathrm{Al}_{1.11}\mathrm{Fe}^{+3}_{0.01}\mathrm{Fe}^{+2}_{0.42}\mathrm{Mn}^{+2}_{0.12}\mathrm{Li}_{1.16})}}_{2.82}\overset{-0.65}{(\mathrm{Si}_{3.35}\mathrm{Al}_{0.65})}\mathrm{O}_{10}(\mathrm{OH,F})_2]^{-1.05}\ \mathrm{K(Na)}^{+1.07}_{1.07}$	4.18
35	$[\underbrace{\overset{-0.57}{(\mathrm{Al}_{0.90}\mathrm{Fe}^{+3}_{0.21}\mathrm{Fe}^{+2}_{0.34}\mathrm{Mn}_{0.02}\mathrm{Li}_{1.38})}}_{2.85}\overset{-0.42}{(\mathrm{Si}_{3.58}\mathrm{Al}_{0.42})}\mathrm{O}_{10}(\mathrm{OH,F})_2]^{-0.99}\ \mathrm{K(Na)}^{+1.00}_{1.00}$	4.99

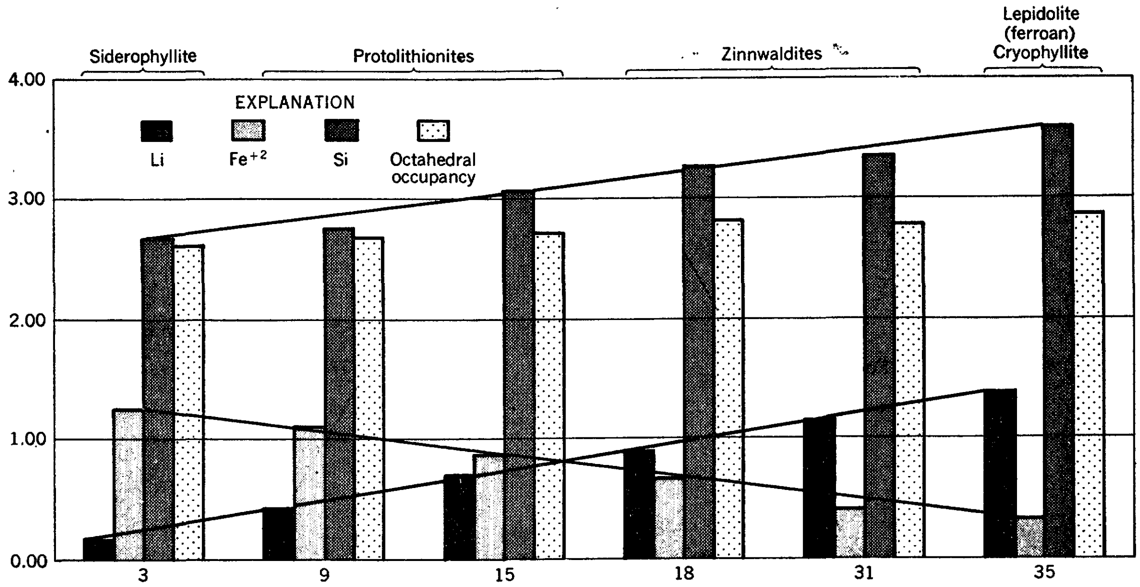

FIGURE 38.—Histograms of selected formulas representing steps in the siderophyllites-lepidolite series. (Numbers below histograms refer to analyses in table 7.)

SIDEROPHYLLITES AND LEPIDOMELANES

Siderophyllites and lepidomelanes are the high-Fe^{+2}, low-Mg members of the trioctahedral Mg replacement system of which phlogopite, $Mg_{3.0}(Si_{3.0}Al_{1.0})O_{10}(OH,F)_2K_{1.0}$, is the high-Mg, low-$Fe^{+2}$ member (Foster, 1960, p. 24). Heretofore it has been assumed that the high-Fe^{+2} end member of a Mg-Fe^{+2} replacement series is annite, $Fe^{+2}_{3.0}(Si_{3.0}Al_{1.0})O_{10}(OH,F)_2K_{1.0}$, the Fe^{+2} analog of phlogopite, but a study of analyses of natural trioctahedral micas showed that no natural representative of such a mica has been recorded in the literature, that replacement of Mg by Fe^{+2} is also always accompanied by more or less replacement by Al and Fe^{+3}, and, consequently, that the low-Mg, high-Fe^{+2} end of the system is represented not by annite but by siderophyllite, in which the principal octahedral trivalent cation is dominantly Al, and lepidomelane, in which it is Fe^{+3}. High-Fe^{+2}, low-Mg trioctahedral micas that contain both octahedral Al and Fe^{+3} are termed ferrian siderophyllites, or aluminian lepidomelanes, depending on whether octahedral Al or Fe^{+3} is dominant. In some formulas the amounts of octahedral Al and of Fe^{+3} present are about equal.

In most of the formulas calculated from analyses of ferrous lithium micas, Al is the predominent trivalent octahedral cation, although in a few formulas Fe^{+3} is equal to, or slightly greater than, the octahedral Al. However, in none is Fe^3 greatly dominant over trioctahedral Al. This suggests that the siderophyllites, ferrian siderophyllites, and aluminian lepidomelanes are prototypes of these minerals, but not lepidomelanes, in which Fe^{+3} is greatly predominant.

The available calculated formulas of these prototypes vary considerably in content of Fe^{+2}, Fe^{+3}, and octahedral Al. In the analyses at hand, Fe^{+2} ranges from 1.22 to 1.88 occupied sites and averages 1.50, Fe^{+3} ranges from 0.05 to 0.62 and averages 0.36, and octahedral Al ranges from 0.44 to 0.99 and averages 0.57. Total trivalent octahedral cations (R^{+3}) range from 0.81 to 1.14 occupied octahedral sites and average 0.93. The reciprocal extremes in R^{+3} and Fe^{+2} content are illustrated in the following formulas for analyses 2 and 3, table 7,

$$[\overset{+0.35}{\underbrace{(Al_{0.73}Fe^{+3}_{0.08}Fe^{+2}_{1.88}Mg_{0.01}Mn^{+2}_{0.02}Li_{0.10})}_{2.82}}\overset{-1.35}{(Si_{2.65}Al_{1.35})}O_{10}(OH,F)_2]^{-1.00}K(Na,Ca/2)^{+0.99}_{0.98},$$

$$[\overset{+0.25}{\underbrace{(Al_{0.52}Ti_{0.01}Fe^{+3}_{0.62}Fe^{+2}_{1.22}Mg_{0.09}Mn^{+2}_{0.02}Li_{0.13})}_{2.61}}\overset{-1.32}{(Si_{2.68}Al_{1.32})}O_{10}(OH,F)_2]^{-1.07}K(Na,Ca/2)^{+1.06}_{0.99}.$$

The first formula, calculated from analysis 2, table 7, has the highest Fe^{+2} content and the lowest octahedral-R^{+3} content of the available analysis of siderophyllites and aluminian lepidomelanes; the second formula, calculated from analysis 3, table 7, has the lowest Fe^{+2} and the highest octahedral R^{+3}. Thus siderophyllite, the prototype of the ferrous lithium micas, varies greatly in Fe^{+2}, Fe^{+3}, and Al content, just as ferrous lithium micas that contain about equal amounts of Li may vary widely in these constituents.

In all but one of the analyses of siderophyllite the presence of a small amount of Li is reported.

PROTOLITHIONITES

Kunitz (1924, p. 409) considered protolithionite the lithium-free member of a ferrous lithium mica series of which lepidolite was the high-Li end member, with a formula, $KH_2AlFe_3^{+2}Si_3O_{12}$, that is identical with Winchell's formula for annite. At this time Winchell (1927, p. 274) also considered protolithionite Li free, but heptaphyllic (or dioctahedral), with the formula $H_4K_2Fe_3^{+2}Al_4Si_5O_{22}$. Later Winchell (1942, p. 117) recognized it as octaphyllic (or trioctahedral) and used is as an end member, representing the maximum tenor of bivalent cations together with a minimum tenor of Li, in interpreting the composition of lepidolites. In the formula which he then assigned to protolithionite, $K_2LiFe_4^{+2}Al_3Si_6O_{20}F_4$, Li occupies 1 unit-cell formula site. Hey (1955, p. 208) observes that Li occupies between 1 and 2 sites in the unit-cell formula.

Perhaps because of these considerable differences in the Li content in published formulas for protolithionite, published analyses for materials called protolithionite also vary considerably in Li content. No analyses purported to be those of protolithionite were discovered in which no Li_2O was reported, but one published as that of a protolithionite contained only 0.32 percent of Li_2O ($\approx$0.10 octahedral site in the half-cell formula), and another contained only 0.39 percent of Li_2O. On the other hand, another analysis reporting 4.57 percent of Li_2O ($\approx$1.30 octahedral sites in the half-cell formula) was also called that of a protolithionite. The literature indicates, therefore, a state of considerable confusion as to the Li_2O content of protolithionite.

In the present study the Li content of protolithionite is defined as 0.5±0.25 octahedral sites in the half-cell formula, or 1.00±0.50 sites in the unit-cell formula. This Li content is based on the Li content in the formula used by Winchell in 1942 and on Hey's statement as to the Li content of protolithionite. A range is given for Li because these micas are interpreted as belonging to an isomorphous series, the members of which contain varying amounts of Li. This is the range bracketed opposite protolithionite in figure 37. The permissible site occupancy given is equivalent to a range of from about 0.75 to about 2.50 percent in Li_2O content. Ferrous lithium micas containing a little Li_2O but less than 0.75 percent, like those represented by points near the baseline in figure 37, are considered lithian siderophyllites, or lepidomelanes, depending on the Al and Fe^{+3} content. Those containing more than 2.50 percent of Li_2O are considered zinnwaldites or ferroan lepidolites.

In the protolithionite analyses 7–15, table 7, Li varies from 1.19 to 2.42 percent Li_2O, equivalent to a variation in octahedral sites of from 0.37 to 0.71 in the half-cell formula. FeO, as in the siderophyllites, is quite variable, ranging from 10.20 to 21.97 percent (0.61 to 1.44 octahedral sites in the half-cell formula). The octahedral content of trivalent cations, Al and Fe^{+3}, with Al usually dominant, is considerably more constant, varying only between 0.91 and 1.21 octahedral sites. These ranges in content of the principal octahedral cations can be expressed as follows:

$$(R^{+3}_{1.10\pm0.20},Fe^{+2}_{1.00\pm0.40},Li_{0.50\pm0.25}).$$

Winchell assumes full octahedral occupancy in the formula for protolithionite that he used in 1942 in his interpretation of the composition of lepidolites. In this formula, recast in the half-cell notation used herein,

$$[\underbrace{\overset{0.00}{(Al_{0.5}Fe^{+2}_{2.0}Li_{0.5})}}_{3.00}\overset{-1.00}{(Si_{3.0}Al_{1.0})}O_{10}(OH)_2]^{-1.00}\,K^{+1.00}_{1.00},$$

the excess in positive charges carried by Al (as compared with the number of positive charges carried by bivalent cations) is exactly compensated by the deficiency in positive charges carried by Li, and the octahedral layer is neutral. All the charge on the unit composite layer is on the tetrahedral layers owing to the substitution of Al for one Si cation. However, in all the formulas calculated from analyses of natural protolithionites, the octahedral trivalent cations, Al and Fe^{+3}, with usually a little Ti, are considerably in excess of Li, so that there are extra positive octahedral charges to be accommodated in the structure. In most of the calculated formulas the greater part of the additional positive charges are neutralized by negative charges associated with unoccupied octahedral sites, and there is only a slight positive charge on the octahedral layer to be neutralized by an equivalent negative charge in excess of 1.00 on the tetrahedral layers. In these formulas, octahedral occupancy ranges between 2.63 and 2.88, and Si is less than 3.00, and ranges between 2.72 and 2.95. However, in three of the calculated formulas for protolithionites the octahedral layer has a negative charge, and Si is greater than 3.00. Exclusive of one formula in which Si is exceptionally high (3.43 tetrahedral sites), the range in the number of tetrahedral sites occupied by Si in the calculated formulas for protolithionite is from 2.72 to 3.17, approximately 2.95±0.25.

The number of octahedral sites occupied by Fe^{+2} in the formulas calculated from analyses of protolithionite, as here defined, is generally higher than that specified by Hey (1955, p. 208). Hey's value for Fe^{+2}, 0.75 sites in terms of the half-cell formula, corresponds with only the lower part of the range for Fe^{+2} found in the calculated formulas, 0.60 to 1.40. On the other hand, Hey's value for Si, 2.75 to 3.00 in terms of a half-cell formula, agrees fairly well with the Si content of the calculated formulas, 2.70 to 3.20. Hey indicates that protolithionites contain little Fe^{+3}, but more than half of the analyses had more than 2.5 percent of Fe_2O_3 and one had as much as 7.81 percent of Fe_2O_3.

ZINNWALDITES

Zinnwaldite was considered an intermediate member of the lepidolite-protolithionite system by Kunitz (1924, p. 409), Winchell (1927, p. 274), and Hallimond (1925, p. 311), and was not assigned a definite formula. Hey (1955, p. 208) gives the formula 2 $[K_2(Li,Fe,^{+2}Al)_6(Si,Al)_8O_{20}(F,OH)_4]$ for zinnwaldite, with the observation that there is often considerable deficiency in the (Li,Fe^{+2},Al) group, and that typically $Li \approx 2$, $Fe^{+2} \approx 1½$, and $Si \approx 6½$. On the basis of the Li content in this formula, the Li content of zinnwaldite is herein defined as 1.0 ± 0.25 octahedral sites in the half-cell formula, or 2.00 ± 0.50 octahedral sites in the unit-cell formula. Again a range is given because these micas, as members of an isomorphous series, contain varying amounts of Li, as well as of the other constituents. This is the range bracketed opposite zinnwaldite in figure 37. The defined range in octahedral-site occupancy is equivalent to a Li_2O content of from about 2.50 to about 4.50 percent.

In the zinnwaldite analyses 16–31, table 7, Li_2O varies from 2.62 to 4.18 percent, equivalent to octahedral-site occupancies of 0.80 to 1.16 in the half-cell formulas. FeO is generally lower than in the protolithionites and not quite so variable, ranging from 6.35 to 12.22 percent (0.37 to 0.79 octahedral sites in the half-cell formulas). In general, the contents of Li_2O and FeO in these analyses bear a reciprocal relation to each other: the lower contents of Li_2O are associated with the higher contents of FeO, and vice versa. The octahedral content of the trivalent cations Al and Fe^{+3} in the half-cell formulas for zinnwaldites is quite constant, varying only between an occupancy of 1.07 and 1.26 sites, with no apparent relation between octahedral R^{+3} and Li content. In most of the analyses of zinnwaldite the amount of Fe_2O_3 present is very small, and octahedral Al is the greatly dominant R^{+3} cation in the formulas calculated from these analyses, but several analyses contain significant amounts of Fe_2O_3, and in the formulas calculated from these analyses Fe^{+3} may occupy about as many or even more octahedral sites than Al. The ranges in octahedral content of the principal cations in half-cell formulas for zinnwaldites are summarized in the following expression:

$$(R^{+3}_{1.15\pm0.10}, Fe^{+2}_{0.55\pm0.20}, Li_{1.00\pm.25}).$$

Octahedral occupancy in the zinnwaldites is generally between 2.75 and 3.00. Only 1 calculated formula for a zinnwaldite (21, table 7) had an octahedral occupancy significantly lower than 2.75. This formula has an octahedral occupancy of only 2.62. In most of the calculated formulas the octahedral charge is negative. Consequently, Si in these formulas is generally in excess of 3.00 and ranges from 3.03 to 3.46. However, in 3 calculated formulas (17, 22, and 25, table 7) the octahedral group had a positive charge, and Si was less than 3.00—2.82, 2.80, and 2.95. Thus the range in the number of tetrahedral sites occupied by Si in the calculated formulas for zinnwaldites is quite wide, 2.80–3.46, or 3.15 ± 0.35.

The amounts of Fe^{+2} and Si in the calculated formulas herein defined as those of zinnwaldite differ somewhat from the amounts indicated by Hey (1955, p. 208) as present in zinnwaldite. Hey's value for Fe^{+2}, about 1½ sites in the unit-cell formula, represents the high end of the range of Fe^{+2} present in the calculated formulas. The median value for Fe^{+2} present, in terms of the unit-cell formula, is much closer to 1.00 (1.10) than to 1.5 octahedral sites. Hey's value for Si, about 6½ sites in the unit-cell formula, is somewhat higher than the median and average value for Si found in the calculated formulas, which is 6.3. Hey's formula for zinnwaldite includes no Fe^{+3}, although his formulas for protolithionite and cryophyllite both include Fe^{+3}. As pointed out above, some of the calculated formulas containing the amounts of Li to be found in zinnwaldite, as defined by Hey, contain appreciable amounts of Fe^{+3}.

FERROAN LEPIDOLITE (CRYOPHYLLITE)

The name cryophyllite was given by Cooke (1867, p. 217) to a micaceous mineral found in the granite ledges that form the extremity of Cape Ann, Mass. Cooke's analyses of two types of this material showed them to have virtually the same chemical composition. Later, in 1886, three different types of cryophyllite from Cape Ann were analyzed by R. B. Riggs (Clarke, 1886, p. 358). These three types were also virtually identical in chemical composition and were similar to those analyzed by Cooke, except that Riggs obtained somewhat higher values for Li_2O—4.81, 4.87, and 4.99 percent, compared with Cooke's 4.05 and 4.06 percent. No other occurrence of a ferrous lithium mica having a comparable Li_2O content has been reported in the literature. On the basis of these analyses, particularly those of Riggs, cryophyllite has been considered a variety of zinnwaldite (Dana, 1892, p. 626, and Hey, 1955, p. 208) with a somewhat higher Li and lower Fe^{+}_{2} content. The relation between cryophyllite and zinnwaldites is shown in figure 37.

The formula calculated from the average of Riggs' 3 analyses (33, 34, and 35, table 7),

$$[\underbrace{\overset{-0.60}{(Al_{0.92}Fe^{+3}_{0.16}Fe^{+2}_{0.38}Mg_{0.02}Li_{1.36})}}_{2.84}\overset{-0.42}{(Si_{3.58}Al_{0.42})}O_{10}(F,OH)_2]^{-1.02}K(Na)^{+1.05}_{1.05},$$

has a Li content similar to that of Stevens' sample 7 (34, table 6), a 6-layer lepidolite,

$$[\underbrace{\overset{-0.41}{(Al_{1.29}Fe^{+2}_{0.01}Mn^{+2}_{0.16}Li_{1.38})}}_{2.84}\overset{-0.62}{(Si_{3.38}Al_{0.62})}O_{10}(F,OH)_2]^{-1.03}K(Na,Rb,Cs)^{+1.03}_{1.03},$$

and does not greatly exceed Stevens' sample 10 (42, table 6), a 1-layer lepidolite,

$$[\underbrace{\overset{-0.50}{(Al_{1.10}Ti_{0.01}Fe^{+3}_{0.02}Fe^{+2}_{0.15}Mn^{+2}_{0.15}Li_{1.50})}}_{2.93}\overset{-0.52}{(Si_{3.48}Al_{0.52})}O_{10}(F,OH)_2]^{-1.02}K(Na,Rb,Cs)^{+0.99}_{0.99},$$

in content of R^{+2} cations. In the formula for cryophyllite, R^{+2} is made up almost entirely of Fe^{+2}; in the formula for Stevens' sample 10, R^{+2} is made up equally of Fe^{+2} and Mn^{+2}. These two formulas also have about the same ocatahedral-R^{+3} content, although in the cryophyllite formula Fe^{+3} occupies 0.16 octahedral sites and in Stevens' sample 10 only 0.03 octahedral sites. Thus Li_2O content and the relation between Li, Fe^{+2}(Mg, Mn^{+2}), and R^{+3}(Al, Fe^{+3}) in the material called cryophyllite are comparable with that in some lepidolites. It is, therefore, recommended that the material known as cryophyllite be considered a ferroan variety of lepidolite, and that the name cryophyllite be discarded.

RELATION BETWEEN ALUMINUM LITHIUM MICAS AND FERROUS LITHIUM MICAS

The relation between the aluminum lithium micas and the ferrous lithium micas is illustrated in figure 39 (which combines fig. 33), which shows the Li, R^{+2}(Fe^{+2}, Mn^{+2}, Mg), and octahedral R^{+3}(Al, Fe^{+3})+Ti^{+4} relation in aluminum lithium micas, and figure 37, which shows the same relation in ferrous lithium micas. Lepidolites are aluminum lithium micas and, as such, were discussed with other aluminum lithium micas, and their composition was interpreted as if derived from muscovite by replacement of octahedral Al by Li. However, figure 39 shows that complete, or almost complete, replacement of Fe^{+2} in siderophyllite also produces lepidolites. Thus the lepidolite composition can be interpreted as the result of two different series of replacements.

The following equations show the general course of evolution of lepidolite from muscovite and from siderophyllite, using the average Li-(octahedral Al) and Li-Fe^{+2} replacement ratios found in the natural micas:

Muscovite to lepidolite

Muscovite-- $[\overset{0.00}{Al_{2.00}}\overset{-1.00}{(Si_{3.00}Al_{1.00})}O_{10}(OH)_2]^{-1.00}\ K^{+1.00}_{1.00}$

Lithian
muscovite-- $[\underbrace{\overset{-0.10}{(Al_{1.80}Li_{0.50})}}_{2.30}\overset{-0.90}{(Si_{3.10}Al_{0.90})}O_{10}(OH,F)_2]^{-1.00}K^{+1.00}_{1.00}$

Mixed structures

Lepidolite-- $[\underbrace{\overset{-0.30}{(Al_{1.40}Li_{1.50})}}_{2.90}\overset{-0.70}{(Si_{3.30}Al_{0.70})}O_{10}(F,OH)_2]^{-1.00}K^{+1.00}_{1.00}$

Siderophyllite to lepidolite

Siderophyllite------------------------ $[\underbrace{\overset{+0.15}{(R^{+3}_{1.05}Fe^{+2}_{1.50})}}_{2.55}\overset{-1.15}{(Si_{2.85}Al_{1.15})}O_{10}(OH)_2]^{-1.00}\ K^{+1.00}_{1.00}$

Protolithionite--------------- $[\underbrace{\overset{-0.19}{(R^{+3}_{1.05}Fe^{+2}_{1.12}Li_{0.50})}}_{2.67}\overset{-0.81}{(Si_{3.19}Al_{0.81})}O_{10}(OH,F)_2]^{-1.00}\ K^{+1.00}_{1.00}$

Zinnwaldite--------------------- $[\underbrace{\overset{-0\ 35}{(R^{+3}_{1.05}Fe^{+2}_{0.75}Li_{1.00})}}_{2.80}\overset{-0.65}{(Si_{3.35}Al_{0.65})}O_{10}(OH,F)_2]^{-1.00}\ K^{+1.00}_{1.00}$

Lepidolite
(ferroan)----------------------- $[\underbrace{\overset{-0.61}{(R^{+3}_{1.05}Fe^{+2}_{0.37}Li_{1.50})}}_{2.92}\overset{-0.39}{(Si_{3.61}Al_{0.39})}O_{10}(F,OH)_2]^{-1.00}\ K^{+1.00}_{1.00}$

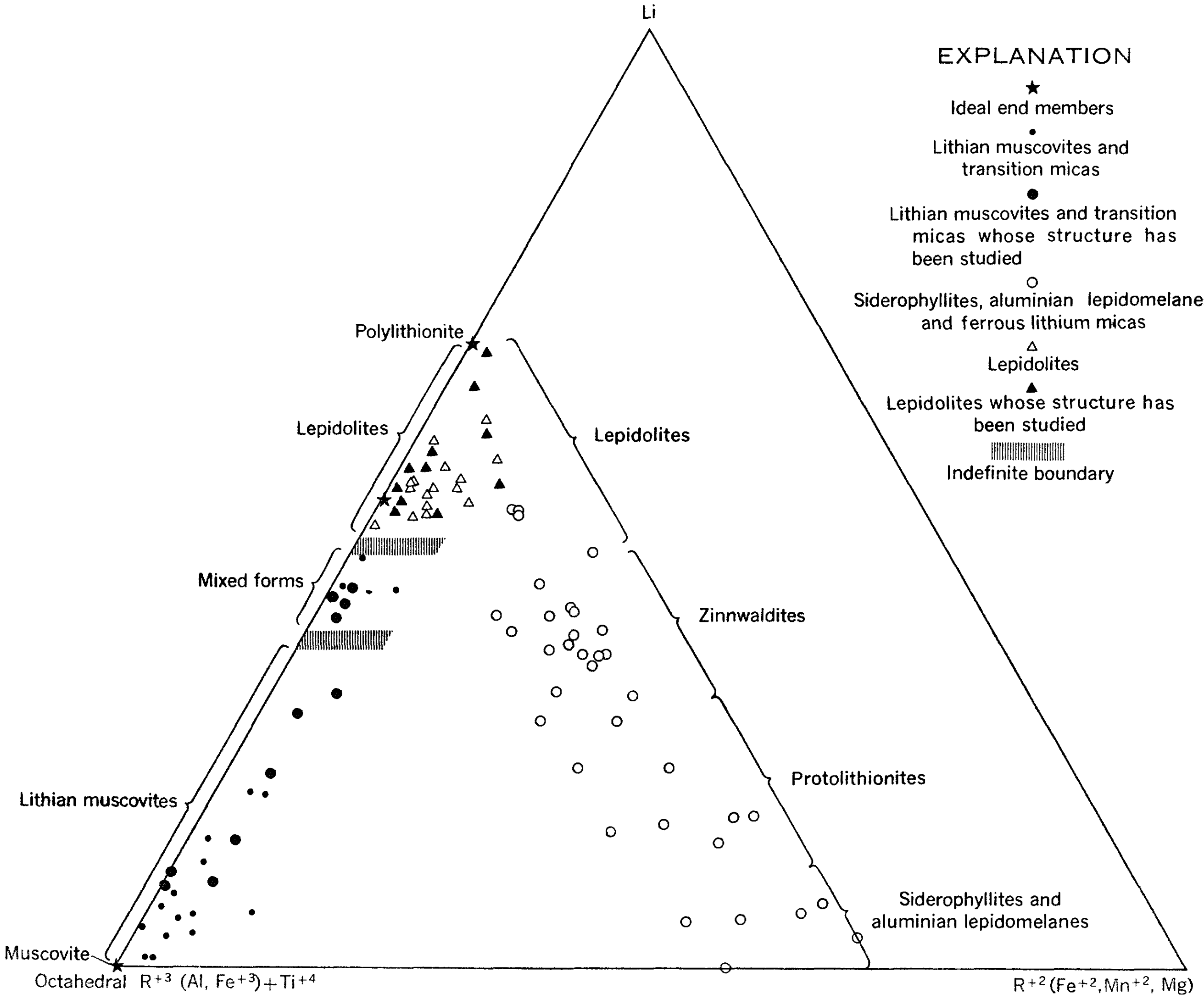

FIGURE 39.—Relation between Li, R^{+2} (Fe^{+2}, Mn^{+2}, Mg), and octahedral R^{+3}(Al, Fe^{+3})+Ti^{+4}, in lithium micas.

Replacement of octahedral Al in muscovite by Li in the ratio of 2 Li for 1 octahedral Al leads to polylithionite,

$$[\overset{-1.00}{\underbrace{(Al_{1.00}Li_{2.00})}_{3.00}}\overset{0.00}{Si_{4.00}}O_{10}F_2]^{-1.00}\ K^{+1.00}_{1.00},$$

as the high-Li end of the series, but in the natural aluminum lithium micas studied the replacement ratio varied between 2 and 3 Li for 1 octahedral Al. In the series above, therefore, the replacement ratio used is 2.5 Li for 1.0 octahedral Al. At this replacement ratio the greatest number of octahedral sites that Li can occupy is 1.68, with Al occupying 1.33 sites. Among the formulas for lepidolite, only 2 (57 and 58, table 6) had a higher Li occupancy, 1.84 and 1.93 sites, respectively. In these 2 formulas the Li-(octahedral Al) replacement ratio is 2.0, and they are close to polylithionite. Aside from these 2 formulas, the lepidolite formula having the highest Li occupancy is 56, table 6, in which Li occupies 1.68 sites and Al(+Mn^{+2}) occupies 1.30 sites, and the Li-(octahedral Al) replacement ratio is 2.4. This formula, therefore, is almost identical with that of the high-Li end of the series shown above, in which the Li-(octahedral Al) replacement ratio is 2.5.

The series of formulas shown for the evolution of lepidolite from siderophyllite is based on the averages of the formulas at hand for siderophyllite, protolithionite, and zinnwaldite. The generalized formulas for these averages show an average replacement ratio of 2.0 Li for 1.5 Fe^{+2}. Extension of this series of formulas at the same replacement ratio to the highest Li occupancy produces a formula,

$$[\overset{-0.78}{\underbrace{(R^{+3}_{1.05}Fe^{42}_{0.11}Li_{.185})}_{3.01}}\overset{-0.22}{(Si_{3.78}Al_{0.22})}O_{10}(F,OH)_2]^{-1.00}\ K^{+1.00}_{1.00},$$

which is close to polylithionite and very like the formula for 57, table 6,

$$\big[\underbrace{(\mathrm{Al}_{1.05}\overset{-0.87}{\mathrm{R}^{+2}_{0.07}}\mathrm{Li}_{1.84})}_{2.96}(\mathrm{Si}_{3.83}\overset{-0.17}{\mathrm{Al}_{0.17}})\mathrm{O}_{10}(\mathrm{F,OH})_2\big]^{-1.00}\mathrm{K}(\mathrm{Na,Rb,Cs})^{+1.00}_{1.00}$$

These two series of formulas, one starting with muscovite, the other with siderophyllite, produce formulas for lepidolite that have the same Li occupancy but which differ considerably in octahedral-R^{+3} occupancy. They also differ in Fe^{+2} content, but this is not so significant as the difference in octahedral-R^{+3} content, because the ferrous lithium micas themselves differ considerably in Fe^{+2} content and could produce a lepidolite containing little or no Fe^{+3}. On the other hand, the octahedral-R^{+3} content in the lepidolite formulas and the range of octahedral-R^{+3} occupancy found in ferrous lithium micas may serve to suggest the source of certain lepidolites.

In some of the calculated formulas of lepidolites in which Li occupies fewer than 1.60 sites, octahedral Al is higher than that found in any of the calculated formulas for siderophyllite, protolithionite, or zinnwaldite. Such lepidolites may be interpreted as derivations of muscovite. In other lepidolite formulas having fewer than 1.60 sites occupied by Li, octahedral Al occupancy is comparable with that in calculated formulas for siderophyllites and ferrous lithium micas in which octahedral R^{+3} is made up almost entirely of Al. Such lepidolites can be interpreted as possibly derived from siderophyllite. The very low Fe^{+3} content of these lepidolites indicates, however, a highly aluminian siderophyllite as the possible source. None could have been derived from siderophyllite containing significant amounts of Fe^{+3}, or from aluminian lepidomelane, as can some of the protolithionites and zinnwaldites.

In the two lepidolite formulas in which Li occupancy is greater than 1.70 sites (57 and 58, table 6), the lepidolites they represent can be interpreted as having been derived either from muscovite, at a Li-(octahedral Al) replacement ratio of 2:1, or from siderophyllite.

UNUSUAL LITHIUM MICAS

Four analyses of lithium micas can not be interpreted as if derived by replacement from either muscovite or siderophyllite. One of these is the analysis of the rare mica, taeniolite, made by Stevens (Miser and Stevens, 1938, p. 106) from Magnet Cove, Ark. (1, table 5). The formula calculated from this analysis,

$$\big[\underbrace{(\mathrm{Al}_{0.08}\mathrm{Ti}_{0.01}\overset{-0.98}{\mathrm{Fe}^{+3}_{0.02}}\mathrm{Fe}^{+2}_{0.01}\mathrm{Mg}_{1.93}\mathrm{Li}_{0.84})}_{2.89}(\mathrm{Si}_{3.97}\overset{-0.03}{\mathrm{Al}_{0.03}})\mathrm{O}_{10}(\mathrm{F,OH})_2\big]^{-1.01}(\mathrm{K}_{0.90},\mathrm{Na}_{0.08})^{+0.99}_{0.99},$$

resembles that of a phlogopite in which about 0.84 Mg had been replaced by 0.84 Li,

$$\big[\underbrace{(\mathrm{Al}_{0.08}\mathrm{Ti}_{0.01}\overset{-0.10}{\mathrm{Fe}^{+3}_{0.02}}\mathrm{Fe}^{+2}_{0.01}\mathrm{Mg}_{2.77})}_{2.89}(\mathrm{Si}_{3.13}\overset{-0.87}{\mathrm{Al}_{0.87}})\mathrm{O}_{10}(\mathrm{OH})_2\big]^{-0.97}(\mathrm{K}_{0.90},\mathrm{Na}_{0.08})^{+0.98}_{0.98}.$$

The deficiency in the amount of positive charge carried by the Li cations results in a negative charge on the octahedral layer, which necessitates an equivalent decrease in the negative charge on the tetrahedral layers. The sample is very low in both octahedral and tetrahedral Al, and Si, which occupies almost all the tetrahedral sites, is quite high. This specimen is very close to the ideal high-Li end member of a hypothetical phlogopite-taeniolite series,

$$\begin{gathered}
\big[\overset{0.00}{\mathrm{Mg}_{3.00}}(\mathrm{Si}_{3.00}\overset{-1.00}{\mathrm{Al}_{1.00}})\mathrm{O}_{10}(\mathrm{OH})_2\big]^{-1.00}\ \mathrm{K}^{+1.00}_{1.00}\\
\downarrow\\
\big[\underbrace{(\overset{-0.50}{\mathrm{Mg}_{2.50}\mathrm{Li}_{0.50}})}_{3.00}(\mathrm{Si}_{3.50}\overset{-0.50}{\mathrm{Al}_{0.50}})\mathrm{O}_{10}(\mathrm{OH})_2\big]^{-1.00}\ \mathrm{K}^{+1.00}_{1.00}\\
\downarrow\\
\big[\underbrace{(\overset{-1.00}{\mathrm{Mg}_{2.00}\mathrm{Li}_{1.00}})}_{3.00}\mathrm{Si}_4\mathrm{O}_{10}(\mathrm{OH})_2\big]^{-1.00}\ \mathrm{K}^{+1.00}_{1.00}
\end{gathered}$$

This specimen has a 1-layer structure (monoclinic hemihedral), as determined by Hendricks and Jefferson (1939, p. 758).

TABLE 5.—*Analyses of lithian micas that do not fit in the aluminum lithium or ferrous lithium series*

	1	2	3	4
SiO_2	58.82	42.02	35.61	36.97
TiO_2	.11	1.35	1.46	2.64
Al_2O_3	1.29	18.75	20.03	17.51
Fe_2O_3	.40	.66	.13	2.26
FeO	.24	8.29	21.85	14.81
MnO	----------	.27	1.19	.22
MgO	19.18	9.55	5.23	8.45
CaO	----------	.93	----------	None
Li_2O	3.10	1.20	.93	.65
Na_2O	.64	.73	.52	.45
K_2O	10.44	8.54	9.69	8.48
Rb_2O	----------	1.85	----------	1.48
Cs_2O	----------	.47	----------	1.12
H_2O-	.09	.16	1.87	.32
H_2O+	.59	2.44		2.48
F	8.56	4.34	.76	3.17
Total	103.46	101.55	99.27	101.01
(O=F)	−3.60	−1.83	−.32	−1.33
Total	99.86	99.72	98.95	99.68

1. Magnet Cove, Ark. (Miser and Stevens, 1938, p. 106). Associated with clay and novaculite.
2. Kings Mountain, N.C. (Hess and Stevens, 1937, p. 1044, analysis 1). From mica schist at contact with spodumene pegmatite.
3. Middletown, Conn. (Dana, 1892, p. 630, analysis 29).
4. Tin Mountain, S. Dak. (Hess and Stevens, 1937, p. 1044, analysis 2).

The formulas calculated from analyses 2, 3, and 4, table 5,

$$[\overset{-0.20}{\underbrace{(Al_{0.65}Ti_{0.07}Fe^{+3}_{0.04}Fe^{+2}_{0.50}Mg_{1.03}Mn^{+2}_{0.02}Li_{0.35})}_{2.66}}\overset{-0.95}{(Si_{3.05}Al_{0.95})}O_{10}(OH,F)_2]^{-1.15}K(Na,Rb,Cs,Ca/2)^{+1.14}_{1.06},$$

$$[\overset{+0.28}{\underbrace{(Al_{0.51}Ti_{0.08}Fe^{+3}_{0.01}Fe^{+2}_{1.39}Mg_{0.59}Mn^{+2}_{0.08}Li_{0.28})}_{2.94}}\overset{-1.29}{(Si_{2.71}Al_{1.29})}O_{10}(OH,F)_2]^{-1.01}K(Na)^{+1.02}_{1.02},\text{ and}$$

$$[\overset{+0.18}{\underbrace{(Al_{0.39}Ti_{0.15}Fe^{+3}_{0.13}Fe^{+2}_{0.94}Mg_{0.96}Mn^{+2}_{0.01}Li_{0.20})}_{2.78}}\overset{-1.18}{(Si_{2.82}Al_{1.18})}O_{10}(OH,F)_2]^{-1.00}K(Na,Rb,Cs)^{+1.00}_{1.00},$$

respectively, resemble biotites in which some Fe^{+2}, or Mg, has been replaced by Li.

SUMMARY

The composition of most lithium micas can be interpreted as if derived from muscovite, by the replacement of octahedral Al by Li, or from siderophyllite, by the replacement of Fe^{+2} by Li. In the aluminum lithium micas Li replaces octahedral Al in ratios varying between 2 and 3 Li for 1 octahedral Al, with an average replacement ratio of about 2.5. Increasing Li content is, therefore, accompanied by increasing octahedral occupancy, from 2.00 in muscovite to about 3.00 in some lepidolites. Correlation of calculated formulas with the structural work of Hendricks and Jefferson and of Levinson indicates that a change in structure to the lepidolite structure takes place when the octahedral occupancy is about half way between 2.00 and 3.00 and Li occupancy is about 1.00 (equivalent to about 3.75 percent Li_2O). Because of the disparity between the amount of positive charge carried by the replacing Li cations and the replaced Al cations, increase in Li content is also accompanied by increase in the amount of negative charge on the octahedral layer and by decrease in tetrahedral Al and increase in Si, with consequent decrease in the negative charge on the tetrahedral layers. Thus the chemical characteristics of the aluminum lithium micas with increase in Li are: decrease in both octahedral Al and tetrahedral Al, increase in Si, and increase in octahedral occupancy. However, the aluminum lithium micas are not members of a continuous series; the series is broken at about the halfway point by the structural change necessitated by increase in octahedral occupancy.

Starting with siderophyllite (ferrian siderophyllite, or aluminian lepidomelane), the ferrous lithium micas form a series in which Li progressively replaces Fe^{+2} in an approximate ratio of 2.0 Li for 1.5 Fe^{+2}. Ferrous lithium micas in which Li occupies fewer than 0.25 octahedral sites are termed lithian siderophyllites, lithian ferrian siderophyllites, or lithian aluminian lepidomelanes, depending on the Fe^{+3} content; those in which Li occupies between 0.25 and 0.75 sites are defined as protolithionites; those in which Li occupies between 0.75 and 1.25 sites are defined as zinnwaldites; and those in which Li occupies more than 1.25 sites are considered lepidolites. Thus the high-lithium mica described by Cooke, and named cryophyllite, is considered a ferroan lepidolite. The greatest number of octahedral sites that can be occupied by Li, at the approximate Li-Fe^{+2} replacement ratio and at the average octahedral R^{+3} content found in these micas, is 1.85,

$$[\overset{-0.78}{\underbrace{(R^{+3}_{1.05}Fe^{+2}_{0.11}Li_{1.85})}_{3.01}}\overset{-0.22}{(Si_{3.78}Al_{0.22})}O_{10}(F,OH)_2]^{-1.00}\ K^{+1.00}_{1.00}.$$

In siderophyllites and protolithionites, R^{+3} may consist entirely of Al or may contain significant amounts of Fe^{+3}, but in most zinnwaldites R^{+3} is made up predominantly of Al. Fe^{+3} is low in all the lepidolites. In this series, as in the aluminum lithium mica series, increasing Li content is accompanied by increasing octahedral occupancy, but the increase is not as great, and the ferrous lithium micas are trioctahedral throughout, except perhaps for some siderophyllites and protolithionites in which octahedral occupancy is less than 2.50. Increase in octahedral negative charge and decrease in tetrahedral negative charge also accompany increase in Li content. Thus the compositional characteristics of the series are increase in Li content, decrease in Fe^{+2} content, decrease in octahedral Al content, and increase in Si content.

The two series join in lepidolite. Lepidolites derived from siderophyllite would be expected to be lower in octahedral and tetrahedral Al, for the same Li content, than lepidolites derived from muscovite; they would also be higher in Fe^{+2}, although not necessarily, as the ferrous lithium micas vary considerably in Fe^{+2} content. The ideal end member of both series is polylithionite,

$$[\overset{-1.00}{\underbrace{(Al_{1.00}Li_{2.00})}_{3.00}}\overset{0.00}{Si_{4.00}}O_{10}F_2]^{-1.00}\ K^{+1.00}_{1.00}.$$

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TABLE 6.—*Analyses, with data for writing formulas, of aluminum lithium micas used in interpretation of composition*

[In order of increasing Li_2O content]

Analysis [1]	Percent														
	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MgO	MnO	Li_2O	CaO	Na_2O	K_2O	Rb_2O	Cs_2O	H_2O+	H_2O-	F
1	45.54	36.36	0.07	0.25	0.02	0.07	0.80	0.06	0.09	0.57	10.76	-----	-----	4.35	0.55	0.62
2	44.85	37.20	.04	.40	.45	Tr.	.02	.07	.22	1.10	10.20	-----	-----	4.36	.60	.79
3	44.10	33.04	.14	2.95	.50	.33	.03	.24	.36	.78	9.73	-----	-----	5.90	1.64	.56
4	45.22	37.46	-----	Tr.	.56	.38	.71	.32	.10	1.19	10.71	-----	-----	3.68		.73
5	44.80	37.72	-----	.67	-----	-----	-----	.38	-----	.91	10.07	0.82	0.09	4.52		.20
6	42.30	33.50	.05	.97	1.20	.16	.01	.40	.94	.96	9.31	-----	-----	6.85	4.09	.37
7	45.03	36.33	.02	.14	.02	.05	.41	.41	.09	.69	10.50	.79	.06	4.56	.79	1.01
8	43.65	32.54	.14	2.62	1.63	1.06	-----	.46	-----	1.05	8.92	.53	<.20	3.85	2.48	1.00
9	45.24	36.85	.01	.09	.02	.08	.12	.49	.00	.64	10.08	.93	.20	4.12	.46	.91
10	45.60	35.96	.03	.10	.02	.05	.37	.63	.08	.59	10.52	-----	-----	4.81	.44	1.31
11	46.01	35.64	.00	.13	.00	.04	.09	.69	1.12	1.88	8.19	1.20	.20	4.65	.08	.54
12	45.18	35.76	.15	.00	1.52	.07	.11	.73	.00	.88	9.95	.57	Tr.	4.48	.38	.88
13	46.17	35.57	.00	.15	.08	.00	.04	.76	.00	.56	10.37	1.1	.3	4.06	.12	.76
14	42.90	31.00	.46	4.79	.70	.22	.00	.80	.60	.51	8.90	-----	-----	6.84	3.06	.07
15	47.64	34.22	.00	.10	-----	.28	.05	1.10	.00	.47	10.40	.35	.75	3.62	.10	1.21
16	46.24	32.37	.10	1.34	1.14	.19	.09	1.1	.10	.79	10.16	1.3	.2	3.41	.69	1.41
17	41.52	32.58	.28	.88	.94	.10	.00	1.51	.68	.30	9.60	-----	-----	6.50	4.86	1.02
18	43.24	33.90	.24	.55	1.38	.26	.01	1.53	.90	.12	10.21	-----	-----	5.96	2.36	.05
19	46.30	33.08	.00	.00	1.20	.14	.28	1.80	.00	.63	10.09	1.37	.41	3.06	.34	2.06
20	46.34	32.47	.06	.00	1.06	.00	.35	2.45	.36	.5	9.46	1.5	.2	3.32	.32	2.82
21	47.00	30.60	Tr.	.26	.41	.13	2.04	2.70	Tr.	.77	9.52	1.93	.18	2.18	.25	4.09
22	49.50	28.06	Tr.	-----	[3].11	.00	.54	3.51	.00	1.27	10.32	1.11	.13	2.15	.27	5.98
23	48.58	28.93	Tr.	-----	[3].04	.00	.92	3.70	Tr.	.87	10.02	.91	.16	2.56	.54	4.93
24	50.20	28.18	Tr.	-----	[3].04	.00	.28	3.81	Tr.	.64	9.91	1.55	.11	2.18	.18	4.97
25	49.52	28.80	-----	.40	.24	.02	.07	3.87	.13	.13	8.82	3.73	.08	1.72		5.18
26	48.68	29.62	.00	.10	.00	.00	.28	3.9	.00	1.3	10.06	1.5	.2	1.64	.14	4.60
27	50.30	25.49	Tr.	.05	1.30	.38	.53	3.90	.24	.95	10.13	1.39	.17	1.84	.08	6.03
28	49.14	27.66	.00	-----	[3].43	.05	1.22	3.95	Tr.	.40	10.13	1.17	.62	2.64		5.21
29	49.29	28.40	Tr.	-----	[3].05	.12	.65	3.96	Tr.	.77	9.93	1.56	.12	1.76	.14	6.52
30	49.62	27.30	-----	.31	.07	-----	.55	4.34	-----	2.17	8.03	2.44	.72	1.52		5.45
31	51.52	25.96	-----	.31	-----	.02	.20	4.90	.16	1.06	11.01	-----	-----	.95		5.80
32	48.94	22.21	.00	1.55	1.52	.03	.75	4.99	.10	.53	8.62	3.8	1.08	1.46	0.88	6.69
33	53.45	22.15	Tr.	-----	[3].16	.14	.52	5.04	.00	.74	9.58	1.56	.48	1.28	.46	7.22
34	49.58	23.87	.06	-----	[3].21	.00	2.78	5.05	.00	.57	10.14	1.62	.09	1.22	.51	7.49
35	49.19	24.81	.08	-----	[3].24	.05	2.51	5.10	Tr.	.52	10.25	1.78	.19	1.21		6.89
36	54.69	22.83	Tr.	-----	[3].11	.00	.14	5.11	.00	.57	9.53	1.64	.17	1.02	.31	6.86
37	57.44	15.50	-----	.50	-----	1.70	Tr.	5.16	.64	.64	8.69	-----	-----	4.28	3.68	1.04
38	51.88	20.65	.21	.79	1.99	.00	2.01	5.26	.00	.51	10.55	-----	-----	1.89		7.65
39	51.70	23.97	Tr.	-----	[3].04	.00	.17	5.33	Tr.	.89	10.79	.42	.41	1.24	.26	7.76
40	50.16	23.54	.00	.46	1.27	.06	.79	5.34	.04	1.10	10.97	-----	-----	1.39	.78	6.75
41	49.28	24.36	-----	.63	-----	.73	.87	5.36	.26	.66	11.24	.32	-----	.87		8.92
42	50.31	19.95	.22	.49	2.55	.02	2.63	5.39	Tr.	.59	10.14	.97	.06	.88	.66	7.65
43	49.14	21.90	.08	.44	.24	.88	1.41	5.41	.96	.52	9.82	-----	-----	3.25	3.51	4.61
44	50.92	25.12	.00	.06	.00	.06	.52	5.5	.00	.56	9.75	2.0	.66	.57	.06	6.86
45	51.10	23.98	Tr.	-----	Tr.	.00	.13	5.51	Tr.	.63	10.25	1.38	.48	1.50	.56	7.36
46	48.96	20.12	.13	.40	.18	.32	1.32	5.57	.67	.72	10.18	-----	.05	2.96	3.68	5.28
47	52.58	22.82	Tr.	-----	.01	.00	.28	5.64	Tr.	.59	10.11	1.04	.67	1.35	.30	7.56
48	49.18	18.85	.12	.42	.16	1.24	1.77	5.67	.26	.06	10.37	-----	-----	3.94	3.86	5.93
49	50.60	25.42	.00	.28	.02	.00	.15	5.7	.00	.35	9.08	3.2	.93	.79	.09	6.15
50	51.25	23.71	.01	-----	[3].07	.08	.61	5.78	Tr.	.65	9.90	2.00	.08	.90	.34	8.08
51	51.67	23.22	.06	-----	[6].04	.30	1.37	5.83	.00	1.03	11.18	-----	-----	.44		8.22
52	51.07	22.05	.06	-----	[3].23	.09	.76	5.89	Tr.	.82	9.70	1.38	.09	.96		7.13
53	49.80	25.56	.00	.08	.00	.22	.38	5.95	.00	.4	9.67	1.97	1.2	.38	.50	6.85
54	54.40	17.95	.02	-----	[3].21	.30	2.06	6.18	Tr.	.72	10.28	1.22	.24	.58	.81	9.19
55	58.56	14.97	.36	.43	-----	1.30	.14	6.31	.22	.84	10.63	-----	-----	3.72	.88	4.34
56	52.57	23.01	.04	.08	-----	-----	.63	6.37	-----	.90	11.10	-----	-----	.59		8.26
57	57.03	15.55	.03	-----	[3].12	.22	.72	6.84	Tr.	.44	10.65	1.35	.40	.49	.74	9.00
58	59.56	12.04	.48	.13	.42	.34	.03	7.26	Tr.	.53	11.05	1.14	None	.47	.73	7.73

Note and footnotes at end of table.

TABLE 6.—*Analyses, with data for writing formulas, of aluminum lithium micas used in interpretation of composition*—Continued

[In order of increasing Li_2O content]

Analysis[1]	Percent			Octahedral positions occupied by—								Octahedral charge	Tetrahedral charge	Composite layer charge	Interlayer cations	
	Total	$O=F_2$	Adjusted total	Al	Ti	Fe^{+3}	Fe^{+2}	Mg	Mn^{+2}	Li	Total				Charge	Positions
1	100.11	−0.26	99.85	1.92	0.00	0.01	0.00	0.01	0.05	0.02	2.01	−0.07	−0.95	−1.02	+1.00	1.00
2	100.30	−.33	99.97	1.94	.00	.02	.03	.00	.00	.02	2.01	−.04	−1.00	−1.04	+1.05	1.03
3	100.30	−.24	100.06	1.75	.01	.15	.03	.03	.00	.07	2.04	−.07	−.95	−1.02	+1.02	.99
4	101.06	−.31	100.75	1.88	--------	.00	.03	.04	.04	.08	2.07	−.06	−1.02	−1.08	+1.06	1.06
5	[3] 100.39	−.08	100.31	1.93	--------	.03	--------	--------	--------	.10	[2] 2.07	+.01	−1.02	−1.01	+1.00	1.00
6	101.11	−.16	100.95	1.81	.00	.05	.07	.02	--------	.12	2.07	−.12	−1.00	−1.12	+1.12	1.05
7	100.90	−.42	100.48	1.90	.00	.01	.00	.05	.02	.11	2.09	−.02	−.98	−1.00	+1.00	.99
8	100.13	−.42	99.71	1.68	.01	.14	.09	.11	--------	.13	2.16	+.03	−.98	−.95	+.95	.95
9	100.24	−.38	99.86	1.93	.00	.00	.00	.01	.01	.13	2.08	−.04	−.97	−1.01	+.99	.99
10	100.51	−.55	99.96	1.90	.00	.01	.00	.00	.02	.17	2.10	−.06	−.94	−1.00	+.99	.98
11	100.46	−.23	100.23	1.86	.00	.01	.00	.00	.01	.18	2.06	−.19	−.94	−1.13	+1.15	1.07
12	100.66	−.37	100.29	1.86	.01	.00	.08	.01	.01	.20	2.17	+.02	−.97	−.95	+.99	.99
13	100.04	−.32	99.72	1.89	.00	.01	.00	.00	.00	.20	2.10	−.10	−.91	−1.01	+1.01	1.01
14	100.85	−.03	100.82	1.60	.02	.25	.04	.02	.00	.23	2.16	−.02	−.97	−.99	+.96	.91
15	100.29	−.51	99.78	1.84	.00	.00	--------	.03	.00	.29	2.16	−.13	−.84	−.97	+.98	.98
16	100.63	−.59	100.04	1.71	.00	.07	.06	.02	.01	.30	2.17	−.18	−.87	−1.05	+1.06	1.05
17	100.77	−.43	100.34	1.74	.02	.05	.06	.01	.00	.44	2.32	+.03	−1.02	−.99	+1.03	.98
18	100.71	−.02	100.69	1.73	.01	.03	.08	.03	.00	.42	2.30	−.04	−1.02	−1.06	+1.05	.98
19	100.76	−.87	99.89	1.73	.00	.00	.07	.01	.02	.48	2.31	−.13	−.89	−1.02	+1.02	1.02
20	101.21	−1.19	100.02	1.69	.00	.00	.06	.00	.02	.66	2.43	−.11	−.88	−.99	+1.03	1.01
21	102.06	−1.72	100.34	1.58	.00	.01	.02	.01	.12	.73	2.47	−.20	−.84	−1.04	+1.01	1.01
22	102.95	−2.52	100.43	1.52	.00	--------	.01	.00	.03	.94	2.50	−.42	−.69	−1.11	+1.10	1.10
23	102.16	−2.08	100.08	1.54	.00	--------	.00	.00	.05	1.00	2.59	−.28	−.74	−1.02	+1.01	1.01
24	102.05	−2.09	99.96	1.54	.00	--------	.00	.00	.02	1.01	2.57	−.33	−.66	−.99	+.99	.99
25	102.71	−2.18	100.53	1.55	--------	.02	.01	.00	.00	1.03	2.61	−.20	−.71	−.91	+.94	.93
26	102.02	−1.94	100.08	1.54	.00	.01	.00	.00	.02	1.04	2.61	−.27	−.78	−1.05	+1.08	1.08
27	102.78	−2.54	100.24	1.40	.00	.00	.08	.04	.03	1.05	2.60	−.45	−.62	−1.07	+1.09	1.08
28	102.62	−2.19	100.43	1.49	.00	--------	.02	.00	.07	1.06	2.64	−.29	−.70	−.99	+.98	.98
29	103.27	−2.75	100.52	1.51	.00	--------	.00	.01	.04	1.06	2.62	−.31	−.72	−1.03	+1.02	1.02
30	102.52	−2.29	100.23	1.44	--------	.02.	.00	--------	.03	1.16	2.65	−.40	−.68	−1.08	+1.09	1.09
31	101.89	−2.44	99.45	1.39	--------	.02	--------	.00	.02	1.29	2.72	−.44	−.62	−1.06	+1.08	1.07
32	103.15	−2.82	100.33	1.21	.00	.08	.09	.00	.04	1.39	2.81	−.48	−.60	−1.08	+1.06	1.05
33	102.78	−3.04	99.74	1.32	.00	--------	.01	.01	.03	1.35	2.72	−.59	−.42	−1.01	+.99	.99
34	103.19	−3.15	100.04	1.29	.00	--------	.01	.00	.16	1.38	2.84	−.41	−.62	−1.03	+1.03	1.03
35	102.82	−2.90	99.92	1.32	.00	--------	.01	.00	.14	1.39	2.86	−.35	−.67	−1.02	+1.03	1.03
36	102.98	−2.89	100.09	1.36	.00	--------	.01	.00	.01	1.35	2.73	−.53	−.41	−.94	+.94	.94
37	[4] 99.70	−.43	99.27	1.12	--------	.03	--------	.17	.00	1.40	2.72	−.81	−.12	−.93	+.93	.88
38	103.39	−3.22	100.17	1.16	.01	.04	.11	.00	.12	1.43	2.87	−.47	−.49	−.96	+.98	.98
39	102.98	−3.27	99.71	1.34	.00	--------	.00	.00	.01	1.44	2.79	−.52	−.55	−1.07	+1.06	1.06
40	[5] 102.70	−2.85	99.85	1.26	.00	.02	.07	.01	.04	1.45	2.85	−.47	−.62	−1.09	+1.09	1.09
41	103.50	−3.76	99.74	1.26	--------	.03	--------	.07	.05	1.45	2.86	−.44	−.68	−1.12	+1.10	1.08
42	102.51	−3.22	99.29	1.10	.01	.02	.15	.00	.15	1.50	2.93	−.50	−.52	−1.02	+.99	.99
43	102.17	−2.16	100.01	1.19	.00	.02	.01	.09	.08	1.50	2.89	−.51	−.60	−1.11	+1.08	1.01
44	102.64	−2.89	99.75	1.36	.00	.00	.00	.00	.03	1.47	2.86	−.39	−.61	−1.00	+1.00	1.00
45	102.88	−3.10	99.78	1.34	.00	--------	.00	.00	.01	1.49	2.84	−.47	−.56	−1.03	+1.03	1.03
46	100.54	−2.22	98.32	1.40	.01	.02	.01	.03	.07	1.41	2.95	−.07	−.92	−.99	+1.00	.95
47	102.95	−3.18	99.77	1.31	.00	--------	.00	.00	.02	1.52	2.85	−.51	−.49	−1.00	+1.00	1.00
48	101.83	−2.50	99.33	1.10	.01	.02	.01	.13	.11	1.62	3.00	−.48	−.49	−.97	+.99	.97
49	102.76	−2.59	100.17	1.36	.00	.01	.00	.00	.01	1.53	2.91	−.34	−.64	−.98	+.98	.98
50	103.46	−3.40	100.06	1.30	.00	--------	.00	.01	.03	1.56	2.90	−.46	−.57	−1.03	+1.02	1.02
51	103.36	−3.46	99.90	1.24	.00	--------	.00	.03	.08	1.55	2.90	−.51	−.57	−1.08	+1.08	1.08
52	100.23	−3.00	97.23	1.25	.00	--------	.01	.01	.04	1.61	2.92	−.52	−.52	−1.04	+1.02	1.02
53	102.96	−2.89	100.07	1.33	.00	.00	.00	.02	.02	1.59	2.96	−.34	−.68	−1.02	+.99	.99
54	104.16	−3.87	100.29	1.10	.00	--------	.01	.03	.12	1.68	2.94	−.70	−.33	−1.03	+1.04	1.04
55	[7] 103.10	−1.83	101.27	1.01	.02	.02	--------	.13	.01	1.67	2.86	−.88	−.15	−1.03	+1.03	1.02
56	103.55	−3.48	100.07	1.26	.00	.00	--------	--------	.04	1.68	2.98	−.46	−.53	−.99	+1.05	1.05
57	[8] 103.72	−3.79	99.93	1.05	.00	--------	.01	.02	.04	1.84	2.96	−.87	−.17	−1.04	+1.04	1.04
58	[9] 103.43	−3.26	100.17	.88	.02	.01	.02	.03	.00	1.93	[9] 2.93	−1.02	−.06	−1.08	+1.05	1.05

The numbers in the footnotes below are in percent.

[1] See descriptions on page 144 for origin of samples and source of analyses.

[2] Includes 0.21 Mn_2O_3, ⇔0.01 octahedral position.

[3] Total Fe reported as FeO.

[4] Includes 0.09 P_2O_5 and 0.34 SO_3.

[5] Includes 0.05 Cl.

[6] May be present as Fe_2O_3.

[7] Includes 0.04 P_2O_5, 0.34 SO_3, and 0.02 Cl.

[8] Includes 0.14 Nb_2O_5, ⇔0.00 octahedral position.

[9] Includes 1.52 Nb_2O_5, ⇔0.04 octahedral position.

(Notes to table 6 are on page 144)

NOTES TO TABLE 6

1. Apache, Petaca, N. Mex. (Heinrich and Levinson, 1953, p. 43, no. 4).
2. Russia, locality not given (Ginzburg and Berhkin, 1953, p. 95).
3. Yamanoo, Tsukuba, Japan (Shibata, 1952b, p. 163, no. 12).
4. Londonderry, Western Australia (Simpson, 1927, p. 46).
5. Harding mine, 9½ miles east of Embudo, N. Mex. (Wells, 1937), p. 108, B. Corrections of percentages of alkalies by Stevens and Schaller, 1942, p. 527.
6. Yamanoo, Tsukuba, Japan (Shibata, 1952b, p. 163, no. 11).
7. White Spar mine No. 1, Gunnison County, Colo. (Heinrich and Levinson, 1953, p. 43, no. 2).
8. Kimito, southwest Finland (Pehrman, 1945, p. 56).
9. Pittlite, Rociada, N. Mex. (Heinrich and Levinson, 1953, p. 43, no. 5).
10. Brown Derby No. 1 mine, Gunnison County, Colo. (Heinrich and Levinson, 1953, p. 43, no. 3).
11. Varuträsk, Sweden (Berggren, 1940, p. 183, H.). Normal muscovite structure.
12. Varuträsk, Sweden (Berggren, 1940, p. 183, G). Normal muscovite structure.
13. Varuträsk, Sweden (Berggren, 1941, p. 264, J). Normal muscovite structure.
14. Nagatare, Fukuoka Pref., Japan (Shibata, 1952b, p. 164, no. 19).
15. Varuträsk, Sweden (Berggren, 1940, p. 185, F).
16. Varuträsk, Sweden (Berggren, 1941, p. 264, L). Normal muscovite structure.
17. Bunsen mine, South Kankyō-nandō, Korea (Shibata, 1952b, p. 164, no. 21).
18. Bunsen mine, South Kankyō-nandō, Korea (Shibata, 1952b, p. 164, no. 22).
19. Varuträsk, Sweden (Berggren, 1940, p. 185, E). Normal muscovite structure.
20. Varaträsk, Sweden (Berggren, 1940, p. 185, D). Normal muscovite structure.
21. Manitoba, Canada (Stevens, 1938, p. 615, no. 1, U.S. Natl. Mus. No. 97635). Normal muscovite structure.
22. Katerina mine, Pala, San Diego County, Calif. (Stevens, 1938, p. 615, no. 2). Transitional structure (combination of forms).
23. Stewart mine, "40 acres," Pala, San Diego County, Calif. (Stevens, 1938, p. 615, no. 3). Transitional structure (combination of forms).
24. Panama-Pacific-Exposition mine, Chihuahua Valley, east of Oak Grove, San Diego County, Calif. (Stevens, 1938, p. 615, no. 4). Transitional structure (combination of forms).
25. Norway, Maine (Clarke, 1910, p. 287, F).
26. Varuträsk, Sweden (Berggren, 1940, p. 185. C). Normal muscovite structure.
27. Rozna, Moravia, Czechoslovakia (R. E. Stevens written communication, 1938, U.S. Geol. Survey Lab. Record No. D-789).
28. Mt. Apatite, Auburn, Maine (Winchell, 1942, p. 115, no. 17, U.S. Natl. Mus. No. 80230).
29. Stewart mine, San Diego County, Calif. (Stevens, 1938, p. 615, no. 5). Transitional structure (combination of forms).
30. Auburn, Maine (Clarke, 1910, p. 287, D).
31. Black Mountain, Rumford, Maine (Clarke, 1910, p. 287, A).
32. Kimito, southwest Finland (Pehrman, 1945, p. 59).
33. Stewart mine, Pala, San Diego County, Calif. (Stevens, 1938, p. 615, no. 6). Structure, 6-layer lepidolite.
34. Ohio City, Colo. (Stevens, 1938, p. 615, no. 7. U.S. Natl. Mus. No. 97893). Structure, 6-layer lepidolite.
35. Ohio City, Colo. (Winchell, 1942, p. 115, no. 10).
36. Himalaya mine, Mesa Grande, San Diego County, Calif. (Stevens, 1938, p. 615, no. 8). Structure, 1-layer lepidolite.
37. Locality not given (Shilin, 1953. p. 155).
38. Wakefield, Quebec, Canada (Winchell, 1942, p. 115, no. 26).
39. San Diego mine, Mesa Grande, San Diego County, Calif. (Stevens, 1938, p. 615, no. 9). Structure, 1-layer lepidolite.
40. Alabaschta, Urals (Winchell, 1942, p. 115, no. 18).
41. New Ross, Nova Scotia (Walker and Parsons, 1924, p. 49).
42. Wakefield, Quebec, Canada (Stevens, 1938, p. 615, no. 10). Structure, 1-layer lepidolite.
43. Uruchin, Kōgen-dō, Korea (Shibata, 1952b, p. 165, no. 25).
44. Roezna, Moravia (Berggren, 1941, p. 271, no. 1).
45. Stewart mine, Pala, San Diego County, Calif. (Stevens, 1938, p. 615, no. 11). Structure not determined.
46. Yagatare, Fukuoka Pref., Japan (Shibata, 1952b, p. 164, no. 20).
47. Stewart mine, Pala, San Diego County, Calif. (Stevens, 1938, p. 615, no. 12). Structure, 6-layer lepidolite.
48. Bunsen mine, South Kankyō-nandō, Korea (Shibata, 1952a, p. 150).
49. Utō, Sweden (Berggren, 1941, p. 269).
50. Himalaya mine, Mesa Grande, San Diego County, Calif. (Stevens, 1938, p. 615, no. 13). Structure, 1-layer lepidolite.
51. Londonderry, Western Australia (Simpson, 1927, p. 46).
52. Calgoorie, Western Australia (Stevens, 1938, p. 615, no. 14). Structure, 3-layer hexagonal lepidolite.
53. Varuträsk, Sweden (Berggren, 1940, p. 185, A). Structure, 6-layer lepidolite.
54. Little Three mine, Ramona, San Diego County, Calif. (Stevens, 1938, p. 615, no. 15). Structure, 1-layer lepidolite.
55. Locality not given (Shilin, 1953, p. 155, no. 2).
56. Londonderry, Western Australia (Simpson, 1927, p. 46, no. III).
57. Antsongombato, Madagascar (Stevens, 1938, p. 615, no. 16). Structure, 1-layer lepidolite.
58. Kangerdluarsuk, Julianehaab district, Greenland (Stevens, 1938, p. 615, no. 17, U.S. Natl. Mus. No. 94314). Structure, 1-layer lepidolite.

TABLE 7.—*Analyses, with data for writing formulas, of siderophyllites and ferrous lithium micas used in interpretation of composition*

[In order of increasing Li^2O content]

Analysis[1]	Percent													
	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MgO	MnO	Li_2O	CaO	Na_2O	K_2O	H_2O+	H_2O-	F	Total
1	39.60	22.80	0.21	0.79	20.98	0.46	0.29	--------	1.52	Tr.	8.95	2.93	0.24	2.03	100.80
2	33.60	22.36	.06	1.44	28.54	.10	.33	0.32	.14	0.46	8.90	1.66	.08	.89	[2] 98.91
3	32.52	19.07	.21	10.08	17.83	.70	.21	.39	.73	.21	8.53	3.17	3.21	2.36	99.22
4	35.25	17.24	1.51	8.15	20.61	.28	.89	.48	1.10	.27	7.21	2.99	2.78	1.67	100.43
5	36.52	14.99	.76	7.73	22.41	.62	.74	.50	.35	.44	7.68	3.62	2.20	1.97	100.53
6	31.96	17.06	.08	7.44	24.12	.29	.71	.59	.48	.51	7.41	5.66	2.94	1.59	100.84
7	37.29	20.96	1.62	2.87	18.69	1.19	--------	1.19	.48	1.01	8.64	3.31		--------	[3] 98.17
8	38.00	23.63	--------	4.84	16.17	--------	.24	1.29	--------	1.08	9.40	.98	.54	3.80	[4] 100.72
9	38.00	27.00	.64	--------	18.50	.12	.64	1.44	1.30	1.37	8.15	3.00	.04	1.66	101.86
10	38.64	19.91	--------	3.98	19.33	.27	1.59	1.47	.28	.68	9.68	1.59		5.76	103.38
11	36.91	18.20	.55	5.18	21.97	.20	.29	1.48	.23	.28	8.22	4.51		3.15	101.17
12	43.70	22.96	.32	.59	11.67	--------	1.96	1.92	--------	.74	9.58	1.35	.08	5.52	[5] 101.53
13	37.12	22.37	Tr.	7.81	12.03	2.20	3.21	2.10	1.05	.81	8.60	2.13		.21	99.64
14	48.26	20.73	--------	.21	10.20	--------	.68	2.31	--------	1.10	10.47	.60	.40	5.40	[6] 101.04
15	41.78	22.76	--------	.98	14.24	.55	--------	2.42	--------	.67	10.51	1.41		6.48	101.80
16	38.83	22.27	.12	4.40	9.07	.38	1.66	2.62	1.14	.48	9.53	H_2O-	H_2O+	3.82	100.99
17	36.51	18.37	.14	10.06	12.22	.63	1.97	2.70	.99	.18	8.99	2.93	3.74	4.79	104.22
18	45.87	22.50	--------	.66	11.66	--------	1.75	3.28	--------	.42	10.46	0.91		7.94	[7] 105.53
19	45.23	21.78	--------	.47	11.25	.23	1.73	3.23	--------	.78	9.98	.97	--------	7.98	103.63
20	46.44	21.84	--------	1.41	10.06	--------	1.89	3.36	--------	.54	10.58	--------	--------	7.62	103.74
21	48.42	20.02	.16	.32	7.98	--------	.37	3.27	.97	2.45	6.35	2.27	.54	6.12	99.24
22	39.04	23.56	.57	6.10	12.42	.97	--------	3.39	.78	.71	8.51	3.25		--------	99.30
23	46.37	23.45	1.30	--------	10.06	.21	.35	3.40	.50	1.27	8.57	3.60	.27	2.55	102.44
24	42.62	23.61	Tr.	1.05	8.58	.99	4.02	3.41	.32	.82	9.41	1.96	.76	2.78	100.33
25	43.50	25.00	1.35	--------	11.80	.14	.73	3.70	.42	1.20	7.73	4.05	.55	1.28	101.45
26	43.20	23.34	1.33	--------	12.60	.20	.73	3.70	.45	1.38	7.66	4.60	1.29	1.28	101.76
27	46.80	24.50	--------	.50	6.35	--------	1.38	3.73	.24	1.73	9.20	.88		8.63	103.94
28	46.74	21.78	--------	1.19	10.22	.00	.37	3.72	.00	.54	10.37	.89		7.54	103.36
29	45.88	20.80	--------	.97	9.65	.13	1.74	3.78	--------	.96	9.11	1.42	--------	5.12	99.56
30	41.60	25.70	.76	--------	11.45	.12	.22	4.03	.30	2.20	8.03	4.40	.86	1.58	101.25
31	48.40	21.62	--------	.24	7.19	--------	1.97	4.18	.06	1.12	10.45	.64	.24	2.24	[8] 100.83
32	45.98	18.04	.22	3.56	6.00	1.50	2.46	4.57	1.80	.25	9.91	.86	1.14	5.66	101.95
33	51.46	16.22	--------	2.21	7.63	.17	.06	4.81	Tr.	.89	10.65	1.12		7.44	102.66
34	51.96	16.89	--------	2.63	6.32	.03	.24	4.87	.12	.87	10.70	1.31		6.78	102.72
35	52.17	16.39	--------	4.11	5.99	Tr.	.32	4.99	Tr.	.63	10.48	1.46		7.02	103.56

Note and footnotes at end of table.

TABLE 7.—*Analysis, with data for writing formulas, of siderophyllites and ferrous lithium micas used in interpretation of composition*—Continued

[In order of increasing Li_2O content]

Analysis [1]	Percent		Octahedral positions occupied by—								Octahedral charge	Tetrahedral charge	Composite-layer charge	Interlayer cations	
	$O=F_2$	Adjusted total	Al	Ti	Fe^{+3}	Fe^{+2}	Mg	Mn^{+2}	Li	Total				Charge	Positions
1	−0.85	99.95	0.99	0.01	0.05	1.32	0.05	0.02	--------	2.44	−0.06	−1.03	−1.09	+1.10	0.98
2	−.37	98.54	.73	.00	.08	1.88	.01	.02	0.10	2.82	+.35	−1.35	−1.00	+.99	.98
3	−.99	98.23	.52	.01	.62	1.22	.09	.02	.13	2.61	+.25	−1.32	−1.07	+1.06	.99
4	−.70	99.73	.44	.09	.49	1.38	.03	.06	.15	2.64	+.24	−1.19	−.95	+.96	.87
5	−.84	99.69	.36	.05	.47	1.51	.08	.05	.16	2.68	+.13	−1.06	−.93	+.92	.89
6	−.67	100.17	.39	.00	.47	1.70	.04	.05	.20	2.85	+.36	−1.31	−.95	+.96	.92
7	--------	--------	.72	.09	.16	1.19	.14	--------	.37	[3] 2.68	+.05	−1.16	−1.11	+1.07	1.03
8	−1.60	99.12	.94	--------	.27	1.01	--------	.02	.39	2.63	+.08	−1.15	−1.07	+1.06	1.06
9	−.70	101.16	1.06	.03	--------	1.12	.01	.04	.42	2.68	+.06	−1.24	−1.18	+1.15	1.04
10	−2.42	100.96	.71	--------	.23	1.24	.03	.10	.45	2.76	+.01	−1.06	−1.08	+1.08	1.06
11	−1.33	99.84	.57	.03	.31	1.44	.02	.02	.47	2.86	+.19	−1.11	−.92	+.90	.89
12	−2.32	99.21	1.13	.02	.03	.71	--------	.12	.56	2.57	−.22	−.83	−1.05	+1.04	1.04
13	−.09	99.55	.65	.00	.43	.74	.24	.20	.62	2.88	+.22	−1.28	−1.06	+1.08	1.00
14	−2.27	98.77	1.16	--------	.01	.61	--------	.04	.66	2.48	−.53	−.57	−1.10	+1.07	1.07
15	−2.72	99.08	1.04	--------	.05	.87	.06	--------	.71	2.73	−.16	−.93	−1.09	+1.08	1.08
16	−1.61	99.38	.95	.01	.25	.58	.04	.11	.80	2.74	−.10	−1.05	−1.15	+1.19	1.08
17	−2.02	102.20	.50	.01	.58	.79	.07	.13	.84	2.92	+.10	−1.18	−1.08	−1.08	1.00
18	−3.34	102.19	1.08	--------	.04	.68	--------	.10	.92	2.82	−.16	−.79	−.95	+.94	.94
19	−3.36	100.27	1.05	--------	.02	.68	.02	.10	.92	2.79	−.27	−.78	−1.05	+1.01	1.01
20	−3.21	100.53	1.05	--------	.07	.59	--------	.11	.95	2.77	−.29	−.75	−1.04	+1.02	1.02
21	−2.58	96.66	1.15	.01	.02	.48	--------	.02	.94	2.62	−.51	−.54	−1.05	+1.07	.99
22	--------	--------	.80	.03	.33	.75	.10	--------	.98	2.99	+.19	−1.20	−1.01	+1.03	.97
23	−1.07	101.37	1.10	.07	--------	.61	.02	.02	.94	2.76	−.18	−.80	−.98	+1.00	.96
24	−1.17	99.16	1.04	.00	.06	.51	.10	.24	.98	2.93	−.02	−.95	−.97	+1.02	.99
25	−.54	100.91	1.08	.07	--------	.69	.01	.04	1.04	2.93	+.04	−.97	−.93	+.91	.88
26	−.54	101.22	1.01	.07	--------	.75	.02	.04	1.06	2.95	−.01	−.94	−.95	+.95	.91
27	−3.63	100.31	1.23	--------	.03	.37	--------	.08	1.04	2.75	−.28	−.77	−1.05	+1.08	1.08
28	−3.17	100.19	1.08	--------	.06	.60	--------	.02	1.05	2.81	−.29	−.72	−1.01	+1.00	1.00
29	−2.16	97.40	1.04	--------	.05	.58	.01	.10	1.09	2.87	−.26	−.72	−.98	+.96	.96
30	−.67	100.58	1.09	.04	--------	.68	.01	.01	1.15	2.98	−.02	−1.05	−1.07	+1.07	1.05
31	−1.04	99.79	1.11	--------	.01	.42	--------	.12	1.16	2.82	−.40	−.65	−1.05	+1.07	1.07
32	−2.38	99.57	.77	.01	.19	.36	.16	.14	1.30	2.93	−.46	−.74	−1.20	+1.20	1.07
33	−3.13	99.53	.91	--------	.12	.44	.02	.00	1.35	2.84	−.64	−.42	−1.06	+1.07	1.07
34	−2.85	99.87	.94	--------	.14	.36	.00	.01	1.36	2.81	−.66	−.42	−1.08	+1.07	1.06
35	−2.96	100.60	.90	--------	.21	.34	.00	.02	1.38	2.85	−.57	−.42	−.99	+1.00	1.00

The numbers in the footnotes below are in percent.

[1] See descriptions below for origin of samples and source of analyses.

[2] Contains 0.03 P_2O_5.

[3] Contains 0.32 SnO_2 (<>0.01 octahedral position), and 0.60 undissolved residue.

[4] Contains 0.75 B_2O_3.

[5] Contains 1.04 Rb_2O and 0.10 Cs_2O.

[6] Contains 0.68 B_2O_3.

[7] Contains 0.08 P_2O_5.

[8] Contains 2.48 B_2O_3.

NOTES TO TABLE 7

1. New Castle, Ireland (Nockolds and Richey, 1939, p. 39). In greisen veins cutting aplite veins in granite.
2. Yagenyama, Japan (Shibata, 1952b, p. 162, no. 7). In topaz vein in granite pegmatite.
3. Ebisu mine, Naegi District, Japan (Shibata, 1952b, p. 162, no. 6). In greisen.
4. Hachiman, Naegi District, Japan (Shibata, 1952b, p. 161, no. 1). In granite pegmatite.
5. Hachiman, Naegi District, Japan (Shibata, 1952b, p. 161, no. 2). In pegmatite.
6. Hachiman, Naegi District, Japan (Shibata, 1952b, p. 161, no. 3). In pegmatite.
7. Wilzschhaus, Germany (Stelzner, 1896, p. 391). From granite.
8. Lingwu, Hunan, China (Meng and Chang, 1935, p. 57). In pneumatolytic-metamorphosed rocks (greisen).
9. Volhynia, Russia (Tsyganov, 1954, p. 386, no. 9). From topaz pegmatite.
10. Zinnwald, Erzegebirge, Bohemia (Kunitz, 1924, p. 413).
11. Volhynia, Russia (Buryanova, 1940, p. 532–533). From granite pegmatite.
12. Morefield mine, Amelia, Va. (Wells, 1937, p. 113).
13. Near Jundai, northwest of São Paulo, Brazil (Saldanha, 1946, p. 49). In quartz veins in gneiss, microgranitic quartz-porphyry, and greisen.
14. Lingwn, Hunan, China (Meng and Chang, 1935, p. 57). In pneumatolytic-metamorphosed rock (greisen).
15. Altenburg, Saxony, Germany (Kunitz, 1924, p. 413, no. 7).
16. Yamanota, Naegi District, Japan (Shibata, 1952b, p. 162, no. 5). In pegmatite.
17. Hachiman, Naegi District, Japan (Shibata, 1952b, p. 161, no. 4). In pegmatite.
18. Zinnwald, Erzegebirge, Bohemia (Dana, 1892, p. 626, no. 1).
19. Zinnwald, Erzegebirge, Bohemia (Kunitz, 1924, p. 413).
20. Zinnwald, Erzegebirge, Bohemia (Dana, 1892, p. 626, no. 2).
21. Volhynia, Russia (Litvin, 1956, p. 120, no. 15). From pegmatite.
22. Eibenstock, Erzegebirge, Bohemia (Stelzner, 1896, p. 391).
23. Volhynia, Russia (Tsyganov, 1954, p. 386, no. 1). From pegmatite.
24. Locality not given (Ginzburg and Berhkin, 1953, p. 105).
25. Volhynia, Russia (Litvin, 1956, p. 120, no. 10). From pegmatite.
26. Volhynia, Russia (Litvin, 1956, p. 120, no. 9). From pegmatite.
27. Cassiterite Creek, Cape York, Alaska (Clarke, 1910, p. 287, no. M). W. T. Schaller, analyst.
28. Zinnwald, Erzegebirge, Bohemia (Winchell, 1942, p. 115, no. 24).
29. Anataboko, Madagascar (Duparc, Wunder, and Sabot, 1910, p. 369). From pegmatite.
30. Volhynia, Russia (Tsyganov, 1954, p. 386, no. 2). From pegmatite.
31. Lingwu, Hunan, China (Meng and Chang, 1935, p. 56). In pneumatolytic-metamorphosed rock (greisen).
32. Sakihama, Okirai, Iwate Pref., Japan (Shibata, 1952b, p. 162, no. 17).
33. Cape Ann, Rockport, Mass. (Clarke, 1886, p. 358, no. B). R. B. Riggs, analyst.
34. Cape Ann, Rockport, Mass. (Clarke, 1886, p. 358, no. A). R. B. Riggs, analyst.
35. Cape Ann, Rockport, Mass.(Clarke, 1886, p. 358, no. C). R. B. Riggs, analyst.

TABLE 8.—*Analyses, with data for writing formulas, of ferrous lithium micas not used in interpretation of composition*

[In order of increasing Li_2O content]

Analysis [1]	Percent														
	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MgO	MnO	Li_2O	CaO	Na_2O	K_2O	H_2O+	H_2O-	F	Total
1	32.53	17.90	0.88	4.45	30.93	0.13	0.49	0.77	0.20	0.10	7.19	3.57	--------	1.21	100.35
2	37.65	16.80	1.10	.32	22.26	2.91	.39	1.21	1.36	3.57	6.54	2.17	0.28	4.28	100.84
3	37.83	24.35	.30	7.59	11.78	.44	.27	1.73	.20	2.24	10.03	1.23		4.28	102.27
4	47.00	25.75	1.40	--------	11.50	.21	.64	1.85	.24	1.77	5.35	4.20	.41	3.09	103.41
5	35.20	20.30	1.60	--------	26.50	.16	.53	2.01	.17	2.30	8.70	2.80	.28	1.66	102.21
6	35.80	19.80	1.64	--------	27.80	.30	--------	2.02	1.75	2.28	5.85	3.00	.30	1.66	102.20
7	47.10	24.80	.80	--------	12.30	.15	--------	2.30	.22	1.60	6.26	4.47	.23	3.33	103.56
8	41.78	21.46	.57	.26	15.36	.47	.38	2.45	2.71	2.64	6.12	1.91	.24	5.95	102.30
9	45.80	21.21	Tr.	2.78	6.18	.57	4.80	2.59	.72	1.29	8.89	.44	.38	5.78	[2] 103.47
10	41.10	25.22	.80	--------	14.10	.05	.75	2.74	.20	1.86	9.80	4.05	.09	2.95	103.71
11	43.00	24.65	.71	--------	11.60	.05	--------	2.86	1.18	2.28	9.01	3.90	.15	2.58	101.97
12	45.24	18.40	.19	1.06	9.95	.28	.63	3.51	1.25	2.78	7.63	2.09	.36	6.32	99.69
13	46.58	24.10	--------	.69	4.28	.49	1.34	3.56	.68	.84	10.81	1.59		7.90	102.77
14	43.50	25.00	1.35	--------	11.80	.14	.73	3.70	.42	1.20	7.73	4.05	.55	1.28	101.45

Analysis [1]	Percent		Octahedral positions occupied by—								Octahedral charge	Tetrahedral charge	Composite layer charge	Interlayer cations	
	O=F_2	Adjusted total	Al	Ti	Fe^{+3}	Fe^{+2}	Mg	Mn^{+2}	Li	Total				Charge	Positions
1	−0.51	99.84	0.49	0.06	0.03	2.16	0.01	0.03	0.26	3.04	+0.46	−1.28	−0.82	+0.82	0.80
2	−1.80	99.04	.46	.06	.02	1.44	.34	.02	.38	2.72	−.34	−1.08	−1.42	+1.41	1.30
3	−1.80	100.47	.86	.02	.42	.72	.05	.02	.51	2.60	+.01	−1.24	−1.23	+1.28	1.26
4	−1.30	102.11	1.28	.07	--------	.66	.02	.04	.51	2.58	+.07	−.79	−.72	+.74	.72
5	−.70	101.51	.53	.09	--------	1.70	.02	.03	.62	2.99	+.07	−1.30	−1.23	+1.22	1.19
6	−.70	101.50	.50	.09	--------	1.77	.03	--------	.62	3.01	+.08	−1.28	−1.20	+1.19	1.05
7	−1.40	102.16	1.24	.04	--------	.71	.01	--------	.64	2.64	−.04	−.76	−.80	+.80	.78
8	−2.50	99.80	.90	.03	.01	.94	.02	.05	.72	2.67	−.41	−.95	−1.36	+1.37	1.16
9	−2.43	101.04	1.00	.00	.15	.36	.06	.29	.73	2.59	−.40	−.77	−1.17	+1.18	1.12
10	−1.24	102.47	1.06	.04	--------	.84	.00	.04	.78	2.77	−.12	−1.07	−1.19	+1.18	1.15
11	−1.09	100.88	1.11	.04	--------	.69	.00	--------	.81	2.65	−.32	−.95	−1.27	+1.31	1.22
12	−2.66	97.03	.92	.01	.06	.61	.03	.04	1.04	2.71	−.62	−.68	−1.30	+1.31	1.21
13	−3.33	99.44	1.24	--------	.04	.25	.05	.08	1.00	2.66	−.40	−.75	−1.15	+1.17	1.12
14	−.54	100.91	1.08	.07	--------	.69	.01	.04	1.04	2.93	+.04	−.97	−.93	+.91	.88

[1] See descriptions below for origin of samples and source of analyses.
[2] Contains 2.04 percent $(Rb,Cs)_2O$.

NOTES TO TABLE 8

1. Volhynia, Russia (Buryanova, 1940, p. 522–523).
2. Volhynia, Russia (Litvin, 1956, p. 120, no. 5). From pegmatite.
3. Gayer, Saxony, Germany (Dana, 1892, p. 627, no. 2).
4. Volhynia, Russia (Tsyganov, 1954, p. 386, no. 3). From pegmatite.
5. Volhynia, Russia (Tsyganov, 1954, p. 386, no. 10). From pegmatite.
6. Volhynia, Russia (Tsyganov, 1954, p. 386, no. 11). From pegmatite.
7. Volhynia, Russia (Tsyganov, 1954, p. 386, no. 6). From pegmatite.
8. Volhynia, Russia (Litvin, 1956, p. 120, no. 7). From pegmatite.
9. Minagi, Okayama Pref., Japan (Ukai, Nishimura, and Hashimoto, 1956, p. 32 no. 2).
10. Volhynia, Russia (Tsyganov, 1954, p. 386, no. 8). From pegmatite.
11. Volhynia, Russia (Tsyganov, 1954, p. 386, no. 4). From pegmatite.
12. Volhynia, Russia (Litvin, 1956, p. 120, no. 14). From pegmatite.
13. New Ross, Nova Scotia (Walker and Parsons, 1924, p. 49). From pegmatite.
14. Volhynia, Russia (Tsyganov, 1954, p. 386, no. 5). From pegmatite.

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