Water Content of Micas and Chlorites

GEOLOGICAL SURVEY PROFESSIONAL PAPER 474-F

Water Content of Micas and Chlorites

By MARGARET D. FOSTER

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 474-F

A study of the (OH,F)/O *relation in micas and of the* OH/O *relation in chlorites*

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1964

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402

CONTENTS

ILLUSTRATIONS

TABLES

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

WATER CONTENT OF MICAS AND CHLORITES

By Margaret D. Foster

ABSTRACT

Atomic ratios were calculated, on the basis of the determined H_2O and F, for 72 analyses of aluminum potassium dioctahedral micas and lithian muscovites, 65 analyses of trioctahedral micas, and 110 analyses of chlorites that had been carefully selected, particularly with respect to summation and completeness with which H_2O and F were reported. The atomic ratios indicate that in most (about 90 percent) aluminum potassium dioctahedral micas and lithian muscovites (OH,F) is close to, or higher than, the theoretical 2.00, but that in many (about 45 percent) trioctahedral micas and chlorites (OH,F) or (OH), respectively, is less than 2.00 or 8.00, respectively, with reciprocally higher O. In this connection it is interesting to note that trioctahedral micas and chlorites have the trioctahedral mica unit in common. Many of the analyses that yield deficient (OH,F) or (OH) also yield octahedral occupancies in excess of 3.00 if micas, or 6.00 if chlorites. Analyses that yield abnormal values for octahedral occupancy were considered faulty or of impure material and were discarded.

Slight vacancy of anion sites, as assumed by Brindley and Youell (1953) to enable them to write a structural formula for ferric chamosite, could produce conversion factors that would increase the atomic ratios for (OH,F) or (OH) and decrease abnormal values for octahedral occupancies. Although it is not positively known that all anion sites are occupied, it is generally assumed so. Present methods do not furnish precise data on anion-site occupancy, but techniques involving neutron activation or oxygen isotope dilution may soon be available that will yield more reliable information as to anion-site occupancy.

Internal oxidation and dehydration as suggested by Eugster and Wones (1962) can explain (OH,F) or (OH) deficiency in some Fe^{2+} dominant trioctahedral micas and chlorites, but not in all; it cannot explain (OH,F) or (OH) deficiency in micas and chlorites that contain little or no iron, or any other oxidizable ion like Mn or Ti.

The determining factor in (OH,F) or (OH) content in micas or chlorites may be the oxygen fugacity of the environment in which the mica of chlorite crystallizes.

INTRODUCTION

A recent paper by Foster, Wones, and Eugster (1963) has pointed out some of the problems and difficulties connected with calculation of atomic ratios from analyses of micaceous minerals when the calculation is based on the (OH) and F values reported, rather than on the theoretical O(OH,F) content of micas. Mineralogical literature contains references to the low values reported for water in some analyses of micas, but no previous workers have attempted to test this deficiency and to pose the problem of a restudy of the accurate determination of the anionic constituents of micaceous minerals.

Atomic ratios for micas are commonly calculated on the basis of the theoretical $O_{10}(OH,F)_2$ content of micas, rather than on the basis of the H_2O and F values reported in the analyses. There is considerable justification for this practice, as many analyses do not report F, or do not differentiate H_2O+ and H_2O-, reporting only total H_2O, or even "loss on ignition." Even in analyses in which H_2O+ and H_2O- are differentiated, there is the probability that the H_2O+ reported includes some H_2O-, as at the temperatures at which H_2O- is determined, 100°C or 110°C, all H_2O- may not have been driven off. Because of this, the atomic ratios used in several recent studies of the chemical composition of micas and chlorites (Foster, 1956, 1960a, 1960b, and 1962) were calculated on the basis of the theoretical $O_{10}(OH,F)_2$ content of micas and on the basis of the theoretical $O_{10}(OH)_8$ content of chlorites, respectively. This method of calculation was criticized by Eugster and Wones (1962) as disregarding possible hydrogen deficiency, particularly in micas high in Fe^{2+}, as a result of the oxidation of some Fe^{2+} in accordance with the equation,

$$\underset{\text{annite}}{KFe^{2+}_{3.0}(Si_{3.0}Al_{1.0})O_{10.0}(OH)_{2.0}} \rightleftharpoons \underset{\text{'oxyannite'}}{K(Fe^{2+}_{1.0}Fe^{3+}_{2.0})(Si_{3.0}Al_{1.0})O_{12.0}} + \underset{\text{gas}}{H_2},$$

which they postulate as operative in the formation of "oxyannite" from annite.

The calculation of atomic ratios of micas and the difference between the values based on the determined H_2O and F and those based on the theoretical O(OH,F) content was discussed by Foster, Wones, and Eugster (1963). They found that in a group of 13 analyses of highly ferruginous trioctahedral micas selected from

Foster s compilation (1960a) the atomic ratio for (OH,F), calculated on the basis of the determined H_2O and F, varied from 1.13 to 3.38 with only 4 having an atomic ratio for (OH,F) close to the theoretical 2.00; but that even in the analyses that represented the extremes of (OH,F) content, the atomic ratios obtained for Fe^{2+}, Si, Al, and the other cationic constituents are not enough different to alter the essential character of the mica, as indicated by atomic ratios calculated on the basis of the theoretical O(OH,F) content, as in Foster's previous studies.

However, the great variability in the (OH,F) content of these micas, and the relation between Fe^{3+} and deficient (OH,F) contents in micas, postulated by Eugster and Wones, suggested the desirability of examining the (OH,F)/O and the (OH,F)/Fe^{3+} relations in micas, particularly in Mg-dominant as compared with Fe^{2+}-dominant trioctahedral micas, and dioctahedral as compared with trioctahedral micas. As chlorites, which contain a mica unit similar to that in trioctahedral micas, could possibly undergo the same type of oxidation of Fe^{2+} and depreciation in (OH) content, the (OH)/O and (OH)/Fe^{3+} relations in chlorites were also included in the study.

SELECTION OF MICA ANALYSES

Ideally for a study of this kind only post-1900 analyses of micas that report H_2O-, H_2O+, and F, and whose summation is between 99.75 and 100.50 should be considered. However, such rigid standards would eliminate many good analyses, and would greatly reduce the number of analyses available for the study. Even after extending the acceptable summation low to 99.5 and high to 100.6, only 62, or about one-third, of the 166 mica analyses that eventually were included in this study reported H_2O-, H_2O+, and F. Such a small number of analyses, 12 dioctahedral micas, 31 trioctahedral micas, and 19 lithium micas, lepidolites and zinnwaldites, does not provide a large enough sampling to permit valid conclusions as to the (OH,F)/O and (OH,F)/Fe^{3+} relations of these micas to be drawn. Consequently, the standards were relaxed somewhat to enlarge the number of analyses of each type of mica studied. The number of analyses used of different degrees of completion with respect to H_2O and F are shown in table 1. In all these analyses the summation was greater than 99.50 and less than 100.60.

Relatively few analyses of muscovite report F, and many do not differentiate H_2O- and H_2O+. Of 60 analyses of muscovite, sericite, damourite, and chrome mica reported by Dana (1892), F is reported in 17, less than one-third; H_2O- and H_2O+ are not differentiated in any, H_2O only being reported. Of 16 analyses of muscovite listed by Clarke (1910), F is reported in 7, and H_2O- and H_2O+ are differentiated in only 5. The 25 more recent analyses of muscovite by Volk (1939) report only "loss on ignition"—no F values are given. Among the 73 post-1900 analyses of muscovites, sericites, and phengites whose summation fell within the limits set for analyses to be used in this study, F is reported in 36, or one-half of the total number, and H_2O- and H_2O+ are differentiated in only 26. F seldom exceeds 1.00 percent in aluminum dioctahedral micas. The 17 F values reported by Dana average 0.65 percent, and the 7 reported by Clarke average 0.53 percent. With the exception of 14 lithiam-containing muscovites, the other 22 analyses of aluminum potassium dioctahedral micas used in this study that reported F, reported an average of 0.33 percent, with only 4 higher than 0.70 percent. As 0.33 percent F is about equivalent to an atomic ratio of only 0.08; whether or not F is reported in analyses of aluminum potassium dioctahedral micas—excepting lithian muscovites—is, therefore, usually relatively unimportant. It is because of this relative unimportance of F in these dioctahedral micas that 36 analyses that did not report F, but whose summation fell between 99.5 and 100.6 percent, were considered acceptable for this study.

TABLE 1.—*Degree of completeness, with respect to* H_2O *and* F, *of mica analyses used in study of* (OH,F)/O *relations*

Type of mica	Number of analyses reporting—				
	H_2O-, H_2O+, and F	Total H_2O and F	H_2O-, and H_2O+	Total H_2O	Totals
Aluminum dioctohedral (and lithian muscovite)	12	24	14	22	72
Trioctahedral (phlogopite, biotite)	31	20	8	6	65
Lepidolite and zinnwaldite	19	10	0	0	29
Total	62	54	22	28	166

Fluorine is of considerably more importance in the trioctahedral micas, and, consequently, is more often reported in analyses of these micas. Many analyses in which F is not reported are low in summation, which suggests that F may be present. Thus, in a compilation of 138 analyses (Foster, 1960a), 30 of the 60 in which F is not reported have a summation of less than 99.50. Of the 65 analyses used in the present study, F is reported in 51. Of the other 14, H_2O is adequate to produce a normal (OH) content in all but 5, and in 4 of these H_2O is so deficient that the amount of F that could be accommodated within the summation limits is much too small to raise (OH,F) to normal. In only one analysis could the amount of F that could be accommodated within the summation limits raise (OH,F) to $(OH,F)_{2.0}$.

The average F content reported in these analyses is 1.21 percent, with the Mg-dominant analyses averaging

1.15, and the Fe^{2+}-dominant analyses averaging 1.25 percent. The highest F value reported in the Mg-dominant and Fe^{2+}-dominant analyses is 3.67 percent and 3.88 percent, respectively.

All the 29 analyses of lepidolites, protolithionites, and zinnwaldites used included F, with H_2O- and H_2O+ differentiated in about two-thirds of them.

In this report, reference to H_2O unspecified as to (+) or (−) indicates that the analyst reported only total H_2O and did not differentiate between H_2O- and H_2O+.

RELATION BETWEEN (OH,F) AND O IN ALUMINUM POTASSIUM DIOCTAHEDRAL MICAS AND LITHIAN MUSCOVITES[1]

The theoretical $(OH)_2$ content of muscovite is equivalent to about 4.5 percent H_2O+. Of the 72 analyses of muscovites, sericites, phengites, chromian micas, and lithian muscovites collected from the literature that were used in this study (shown in table 3) the H_2O+, or the total H_2O reported, exceeded 4.5 percent in 43, or in about 60 percent, and was between 4.0 and 4.5 percent in 17 others, in most of which some F was also reported. In the other 13 analyses H_2O is greater than 3.00 percent except in one, a lithian muscovite, which contains only 2.18 percent H_2O+, but which also contains 4.09 percent F. About half of the analyses in this low H_2O group are those of lithian muscovites, and they contain enough F to bring the calculated (OH,F) up to the normal value. In the rest of this low H_2O group F is very low, or not reported, and the calculated (OH,F) is deficient.

Atomic ratios are given in table 4 for some of the analyses of aluminum potassium dioctahedral micas and lithian muscovites in table 3.

The relation between (OH,F) and O in 55 of the analyses of dioctahedral micas and lithian muscovites used in this study, in terms of atomic ratios calculated on the basis of determined H_2O+ (or total H_2O) and F values, is shown in plate 1*A*. The relation between (OH,F) and O in the other 17 analyses in this group are not plotted because the water values reported are considerably greater than 4.5 percent and are undifferentiated. Among the dioctahedral micas and lithian muscovites (OH,F) is usually close to the theoretical 2.00, or higher; only 7 of the 72 in the group are significantly deficient in (OH,F). It should be borne in mind, however, that some of those plotted as close to normal, 2.00 ± 0.15, may be slightly deficient even though the atomic-ratio calculation is based on a determined H_2O+ value, because at the temperature at which H_2O- is determined all the H_2O- may not have been driven off, and thus the H_2O+ value may be high. Similarly, some of the (OH,F) values plotted as high may actually be normal.

[1] Lithian muscovites are herein distinguished from dioctahedral micas because their octahedral occupancy may be as high as 2.40, although they have muscovite structures.

RELATION BETWEEN (OH,F) AND O IN TRIOCTAHEDRAL MICAS

A casual comparison of groups or compilations of analyses of aluminum potassium dioctahedral micas and of trioctahedral micas, such as those given in Clarke (1910) and Dana (1892), is sufficient to make apparent the great differences in the amounts of water and fluorine reported in analyses of these two types of micas. Whereas H_2O in aluminum potassium dioctahedral micas (table 3) usually amounts to more than 4 percent, with F low and often not reported, H_2O in trioctahedral micas is often less than 4 percent, and F is higher and more frequently reported, as is shown in table 5. The 65 analyses of trioctahedral micas used in this study were selected from an earlier compilation (Foster, 1960a), although many analyses included in that compilation were not used in this study, particularly those that had low summation with F not reported. In only 12 of these analyses is more than 4 percent of H_2O+ or total H_2O reported, and in only 1 is more than 5 percent reported. In all the others H_2O, or H_2O+ is less than 4 percent. In some, sufficient F is present to raise the atomic ratio for (OH,F) to, or even above, normal (2.00), when the atomic ratio is calculated on the basis of the determined H_2O (H_2O+) and F, but in many others the atomic ratio for (OH,F) is deficient.

Atomic ratios for analyses of trioctahedral micas selected from Foster (1960a, table 11, p. 41–42) are given in table 5.

The relation between (OH,F) and O in these analyses, calculated on the basis of the determined H_2O+ (or H_2O) and F, is shown on plate 1*B*. Particularly to be noted is the large proportion of the analyses that are deficient in (OH,F), 44.6 per cent, as compared with only about 10 per cent that are deficient among the aluminum dioctahedral micas and lithian muscovites. Deficiency in (OH,F) is not restricted to the Fe^{2+}-dominant biotites; about one-half of the analyses that are deficient in (OH,F) are those of Mg-dominant biotites.

RELATION BETWEEN (OH,F) AND O IN LITHIUM MICAS

The study of the relation between (OH,F) and O in lithium micas is based on analyses of 23 lepidolites, 1 prolithionite, and 5 zinnwaldites selected from tables 6 and 7 of Foster (1960b). Atomic ratios calculated on the basis of the reported H_2O and F values are given in tables 6 and 7, and the (OH,F)/O relation in these micas is shown in figure 1. Five of the 23 lepidolite analyses were deficient, 7 were high, and 11 were close to the theoretical in (OH,F) content. However, for several of those that were high in (OH,F), the atomic ratios were calculated on the basis of the figure reported for total H_2O. As this figure probably includes some H_2O-, some of these micas whose analyses yield a high atomic ratio for (OH,F), may actually have a normal (OH,F) content. The data on the ferrous lithium micas are too scanty to permit the drawing of valid conclusions as to the (OH,F) content in them. However, in two of the 5 analyses (OH,F) was very deficient, and the F reported is much lower than would be expected with the amount of Li_2O reported. Gottesman (1962) noted that three of the four prolithionites that he studied were low in (OH,F) content, with the deficiency amounting to 0.34 to 0.43 sites.

In the lithium micas—lepidolites, protolithionites, and zinnwaldites—F plays a much larger role than in the aluminum potassium dioctahedral micas and the trioctahedral micas, phlogopites, biotites, siderophyllites, and lepidomelanes. In the lepidolites, particularly, (OH,F) consists predominantly of F, with a general increase in F with increase in Li content. This relation between Li and F—in terms of atomic ratios—in the lepidolites included in this study is shown in figure 2. The different symbols indicative of (OH,F) content show that in all the analyses that are high or

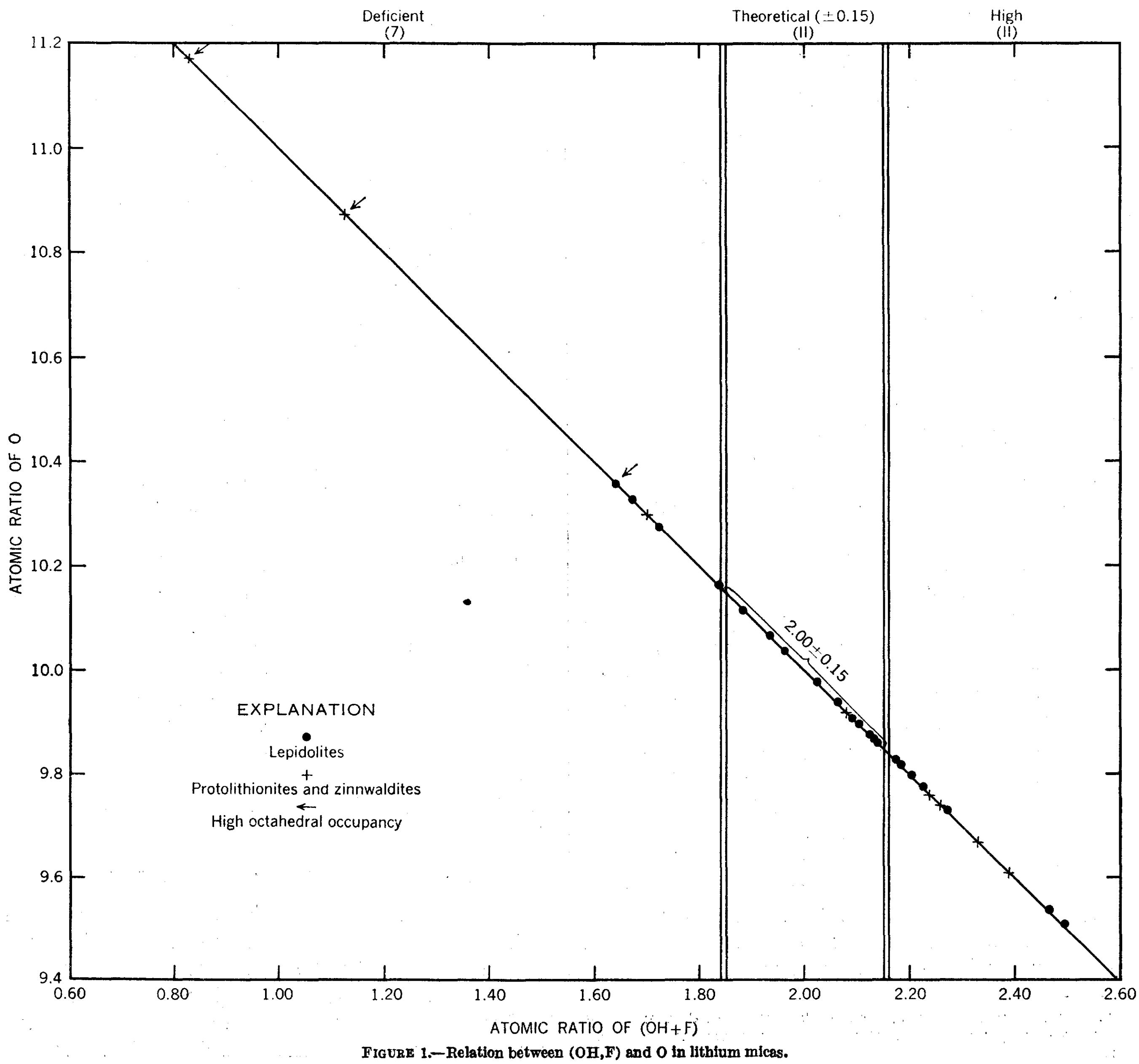

FIGURE 1.—Relation between (OH,F) and O in lithium micas.

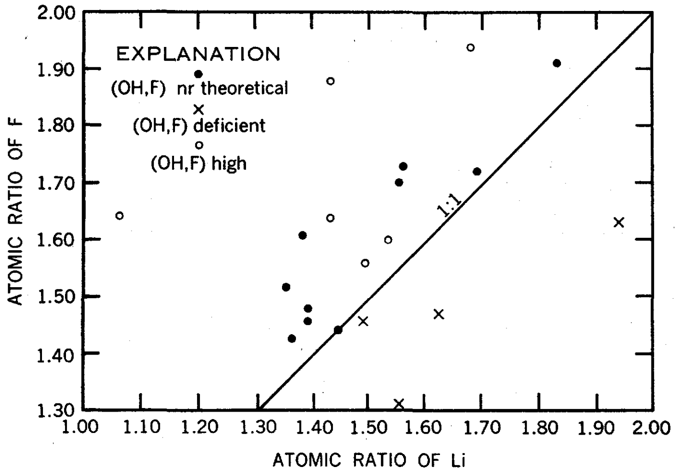

FIGURE 2.—Relation between Li and F, in terms of atomic ratios, in lepidolites.

normal in (OH,F), F was also higher than, or fairly closely, equivalent to Li; in 3 of the 4 analyses that were low in (OH,F), F was lower than Li. The two samples most deficient in (OH,F) had very low F content with respect to Li.

RELATION BETWEEN (OH) AND O IN CHLORITES

The 110 analyses of chlorites used in this study were selected from the compilation of chlorite analyses in Foster (1962). Many analyses included in that compilation were rejected for use in this study, either because of low or high summation, <99.5 or >100.6, or because the H_2O reported was obviously too high. Atomic ratios based on the H_2O reported in the selected analyses are shown in table 8.

The percentage of H_2O equivalent to the theoretical $(OH)_8$ of chlorite varies with the character of the chlorite. The 31 chlorite analyses with $Fe^{2+}:R^{2+}<0.25$ that gave atomic ratios for (OH) of 8 ± 0.20 reported H_2O contents between 12.21 and 13.30 percent and averaged 12.75 percent. In 7 analyses having $Fe^{2+}:R^{2+}$ of 0.25 to 0.50 that gave atomic ratios of 8.0 ± 0.20, H_2O ranged from 11.25 to 11.79 percent and averaged 11.57 percent, and 2 analyses having $Fe^{2+}:R^{2+}$ of 0.50 to 0.75 that gave near theoretical atomic ratios for (OH) contained slightly less H_2O, 11.06 and 11.12 percent. Seven analyses with $Fe^{2+}:R^{2+}>0.75$ that gave atomic ratios of 8.0 ± 0.20 reported from 10.10 to 10.72 percent H_2O. This decrease in H_2O content with decrease in MgO content and increase in FeO content is shown graphically in figure 3. A similar decrease in H_2O (plus F) content with decrease in MgO and increase in FeO characterizes the trioctahedral micas, but as in these micas H_2O and F must both be taken into account, the relation is not so obvious as in the chlorites.

The relation between (OH) and O in these chlorite analyses is shown in plate 1*C*. The distribution of points is very similar to that in the trioctahedral micas, shown in plate 1*B*, with respect to the proportion that are deficient, near theoretical, and high in (OH). For example, the percentage of chlorite analyses that gives deficient atomic ratios of (OH) is 44.4, and the percentage of trioctahedral analyses that give deficient (OH,F) atomic ratios is 44.6. Forty-two percent of the chlorite analyses give near theoretical (OH) atomic ratios as compared with 40 percent of the trioctahedral analyses. This distribution is quite different from that in the aluminum dioctahedral micas and lithian muscovites, most of the analyses of which give normal or high atomic ratios for (OH,F), with only 11 percent giving deficient atomic ratios.

The number of chlorite analyses that give high, normal, or deficient atomic ratios for (OH) differs with the character of the chlorite, as shown in table 8. In the high-magnesium chlorites, with $Fe^{2+}:R^{2+}<0.25$, almost 56 percent of the analyses gave normal atomic ratios for (OH), and only about one-third gave low atomic ratios for (OH), whereas two-thirds of the analyses with $Fe^{2+}:R^{2+}$ 0.25–0.75 gave low atomic ratios for (OH) with only one-third giving normal or

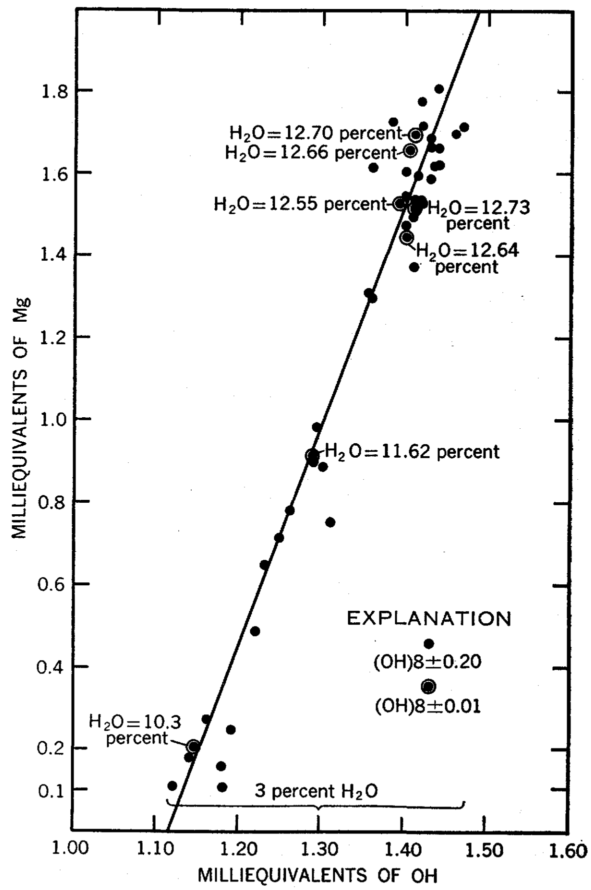

FIGURE 3.—Relation between Mg and (OH), in terms of milliequivalents, in chlorites having $(OH)_{8\pm0.20}$ content.

TABLE 2.—*Distribution of chlorite analyses with respect to* OH *content and* $Fe^{2+}:R^{2+}$ *ratio*

$Fe^{2+}:R^{2+}$	Number of analyses for indicated OH content			
	Low <7.80	Normal 7.80–8.20	High >8.20	Total
<0.25	16	31	7	54
0.25–0.75	26	9	5	40
>0.75	6	7	3	16
Total	48	47	15	110

high atomic ratios for (OH). Of analyses with $Fe^{2+}:R^{2+}$ >0.75, one-third give deficient OH atomic ratios and the others give normal or high (OH) atomic ratios.

ABNORMAL OCTAHEDRAL OCCUPANCY

Some of the analyses that yield deficient (OH,F) atomic ratios for micas or deficients (OH) ratios for chlorites yield normal values for octahedral occupancy, but others yield abnormally high values for octahedral occupancy. These high values for octahedral occupancy suggest that the conversion factors used in calculating these atomic ratios are too low. As the factors are based on the reported values for H_2O and F, then these values must also be too low, even though the summations of the analyses fall within the limits set for acceptance. In most of the analyses that yield both deficient (OH,F) or (OH) ratios and abnormal octahedral occupancies, the summations are too high to permit accommodation of sufficient H_2O or F to increase the conversion factors enough to yield normal values for octahedral occupancy. Consequently the low values reported for H_2O or F cannot be attributed simply to erroneous determination of these constituents. Whatever the cause of the low values reported for H_2O or F, analyses that yield abnormally high values for octahedral occupancy are not acceptable, and were discarded.

This necessitates discarding 5 of the 7 (OH,F) deficient analyses of aluminum potassium dioctahedral micas and lithian muscovites, 11 of the 29 (OH,F) deficient analyses of trioctahedral micas, and 19 of the 48 (OH) deficient analyses of chlorite. The symbols representing these analyses that were discarded because of abnormal octahedral occupancy are distinguished by arrows in plate 1.

After discarding the analyses that yielded abnormal octahedral occupancies, the number of the remaining analyses that yield deficient (OH,F) ratios for micas and (OH) ratios for chlorites are, 2 of 67 analyses of aluminum potassium dioctahedral micas and lithian muscovites, 18 of 54 analyses of trioctahedral micas, and 29 of 89 analyses of chlorites. In other words, about 33 percent of the remaining analyses of trioctahedral micas and of chlorites yield deficient ratios for (OH,F) or (OH), respectively, but only 3 percent of the remaining analyses of aluminium potassium dioctahedral micas and lithian muscovites yield deficient ratios for (OH,F).

It is difficult to deduce whether or not a calculated octahedral occupancy for a lepidolite is abnormal, as octahedral occupancy for lepidolites is rather indefinite, ranging from about 2.5 to 3, depending on the Li content. However, only 1 of the 4 analyses of lepidolite that yielded deficient ratios for (OH,F) also yielded an atomic ratio for octahedral occupancy greater than 3.0. Of 8 analyses of zinnwaldite and protolithionite 3 yielded deficient (OH,F) ratios, and 2 of these also yielded abnormally high values for octahedral occupancy, 3.16, and 3.17, respectively. The symbols for the 3 analyses of lithium micas that yielded abnormal values for octahedral occupancy are indicated by arrows in figure 1.

RELATION BETWEEN Fe^{3+} AND EXCESS O

Eugster and Wones (1962) suggest that highly ferruginous trioctahedral micas may be deficient in (OH,F) because of some internal oxidation and dehydration in accordance with the equation they postulate for the development of "oxyannite" from annite. If (OH,F) deficiency in Fe^{2+}-dominant trioctahedral micas were due to this cause, the Fe^{3+} present should be at least equivalent to the deficiency in (OH,F), or, reciprocally, to the amount of O in excess of 10.00. The relation between Fe^{3+} and O in excess of 10.00 in the 10 Fe^{2+}-dominant, (OH,F)-deficient trioctahedral micas that were included in this study after discarding the analyses that gave abnormal octahedral occupancies is shown in figure 4. The location of the points with respect to the diagonal line, which represents the 1:1 relation between Fe^{3+} and excess O, shows that Fe^{3+} is equivalent to, or in excess of, O in about one-half of the Fe^{2+}-dominant (OH,F)-deficient trioctahedral micas; in the other 5 of these analyses Fe^{3+} is considerably lower than the excess oxygen. The relation between Fe^{3+} and excess oxygen in the remaining 11 Fe^{2+}-dominant (OH)-deficient chlorites, which is also shown in figure 4, is similar to that in the trioctahedral micas. In about one-half of the analyses Fe^{3+} is equivalent to, or greater than, excess O; in the other 6, Fe^{3+} is lower than excess O. In two of the chlorites in which Fe^{3+} is greater than the excess O, some octahedral Fe^{3+} is necessary for charge balance because of low octahedral Al and is, consequently, an essential constituent of the structure. If the amount of Fe^{3+} that is essential is subtracted from the total Fe^{3+}, the amount of Fe^{3+} that is left in one sample is somewhat higher than the excess O, in the other it is lower. These re-

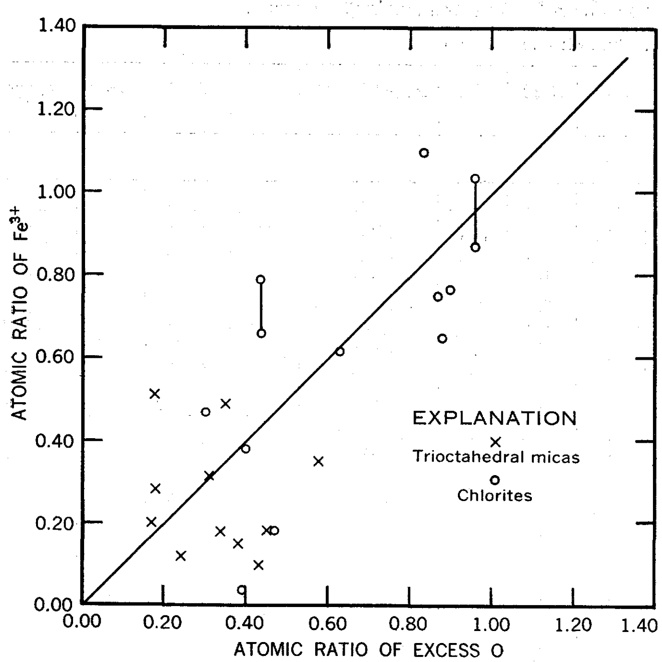

FIGURE 4.—Relation between Fe^{3+} and excess O in Fe^{2+}-dominant trioctahedral micas and chlorites.

lations in the two analyses are indicated in the figure by two pairs of connected symbols for chlorites.

The relatively low degree of correlation between Fe^{3+} and excess O in these analyses suggests that although internal oxidation and dehydration may explain (OH) deficiency in some Fe^{2+}-dominant trioctahedral micas and chlorites, such oxidation of Fe^{2+} cannot explain it in others, nor can this mechanism explain such deficiency in trioctahedral micas and chlorites that contain little or no iron, and of which there are a considerable number, as indicated in plate 1.

DISCUSSION

Brindley and Youell (1953) assumed the vacancy of some anion sites to explain the very low H_2O (one-fourth the original) found in chamosite that had been heated in air to 400°C for 2 hours, as to calculate a formula on the basis of the full anionic content would have yielded an unconvincing result. As they had a structural formula for the unheated chamosite, in which iron was present predominantly as Fe^{2+}, they assumed the heated material to be the ferric form, and to have the same tetrahedral and octahedral composition, except that iron, as shown by analysis, was present predominantly as Fe^{3+}. As the H_2O present in the heated material was equivalent to only one-fourth of the OH present in the unheated material, it was necessary to reduce the number of anion sites to achieve structural neutrality. They assigned the one (OH) remaining to the middle layer, and stated that "the oxygens atoms in excess of five in ferric chamosite, namely 2.3, must presumably replace the 3(OH) layer in ferrous chamosite." Thus, Brindley and Youell assume 7.4 percent of the anion sites to be vacant in order to explain a low H_2O content that would have produced an irrational formula if all the anion sites had been assumed to be occupied.

A similar assumption could be made with respect to the micas and chlorites whose analyses yield deficient values for (OH,F) or (OH), respectively, particularly those that also yield abnormal octahedral occupancies. If it is postulated, for example, that a small percentage, 3 to 5 percent, of the anion sites in such (OH,F)-deficient high-octahedral micas are vacant, a larger conversion factor would be obtained that would produce higher atomic ratios for (OH,F) and lower octahedral occupancies.

Although such an assumption would be very useful in explaining the abnormal octahedral occupancies sometimes obtained when the calculation of atomic ratios is based on an atomic valence content of 48, it is highly speculative. Full anionic occupancy is usually taken for granted, and many mineralogists believe that even a very slight degree of anion-site vacancy would result in collapse of the structure. On the other hand, Hatten S. Yoder, Jr. (written communication, 1963) thinks that it is possible that there can be some anion-site vacancy; that O+F does not necessarily have to equal 24 in the unit cell. It is not positively known that all anion sites are occupied. An accurate method for total-oxygen analyses of minerals is needed. By the present methods the accuracy is poor, but methods involving neutron activation or oxygen-isotope dilution may soon be available that will produce more accurate results than are possible at present, and that will give more definite information about the occupancy of anionic sites.

The atomic ratios based on determined H_2O and F indicate that in almost all micas having a muscovite structure (OH,F) is equal to or higher than the theoretical 2.00, but that in micas having a trioctahedral structure (OH,F) is equal to, or often, less than 2.00, but seldom higher than 2.00. Reciprocally, O is 10.0, or less than 10.0 in micas having a muscovite structure and 10.0 or more in micas having a trioctahedral structure. Chlorites are like trioctahedral micas in that many are deficient in (OH) content and, like them, have the trioctahedral mica unit.

Internal oxidation and dehydration can explain low (OH,F) or low (OH) in some trioctahedral micas and chlorites that contain Fe^{3+}, but not in others, nor can it explain low (OH,F) or low (OH) in micas and chlorites that contain few, if any oxidizable ions. The determining factor may be the oxygen fugacity of the environment in which the mica or chlorite crystallizes.

Table 3.—*Analyses of aluminum potassium dioctahedral micas and lithian muscovites*

[In order of increasing SiO_2 content. Symbol: nf, not found]

Analysis	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MnO	MgO	Li_2O	CaO	Na_2O	K_2O	$H_2O(-)$	$H_2O(+)$	F	Total	O=F	Adjusted total
Si<3.10, tetrahedral sites																	
1	42.60	33.60	0.89	0.70	1.46		1.57		0.80	1.59	9.28	[1]7.82			100.31		
2	42.90	33.21	.58	.00	1.45		1.37		.00	1.70	9.65	[1]9.73			100.59		
3	43.37	33.19	.33	1.95	1.00		1.36		.00	1.03	10.17	[1]7.74			100.14		
4	43.43	33.92	Trace	.00	4.47		.75		.00	.54	10.90	[1]5.48			99.49		
5	43.50	35.41	.00	.84	.89		.80		.31	1.28	10.04	[1]6.74			99.81		
6	43.64	36.24	.98	.84			1.88			2.56	8.83	0.44	5.12		100.53		
7	43.65	32.54	.14	2.62	1.63		1.06	0.46		1.05	8.92	2.48	3.85	1.00	[2]99.93	0.42	99.51
8	43.67	29.76	.72	4.36		0.59	1.19		.06	.54	10.00	2.24	6.28	.95	[3]100.41	.40	100.01
9	44.15	34.96	.11	.00	1.32		1.00		.14	1.21	9.81	[1]7.53			100.23		
10	44.28	35.64	.14	2.56		None	.28		.28	.36	10.34	4.92		nf	[4]99.96		
11	44.40	37.83	.09	.49			.44		.62	.86	8.30	5.79			[5]99.90		
12	44.58	38.03		1.37	.43		.12		.17	1.48	9.78	4.11		.85	100.92	.36	100.56
13	44.61	38.62	.02	.98	.24		.11		.71	.69	9.54	.13	4.47		100.12		
14	44.65	36.63	.00	.00	.85		.61		.20	.90	10.30	[1]5.92			100.06		
15	44.68	31.80	.70	4.49	.84	.04	1.30		.52	.79	10.48	.28	3.50	.11	[6]99.81	.05	99.76
16	44.73	30.67	.34	3.42	1.42	.02	1.56		.00	.53	10.18	1.43	5.17	.02	[7]100.23	.01	100.22
17	44.77	33.26	.18	1.82	1.34		1.21		.26	.78	10.58	[1]6.02			100.22		
18	44.77	35.36	.00	.28	2.13	.15	.87		.00	.95	10.81	4.54		.15	100.01	.06	99.95
19	44.78	33.80	.30	1.80	.75		1.10		.34	1.58	9.29	[1]6.20			99.94		
20	44.80	34.50	.73	.64	.65		2.40		.00	1.47	9.48	[1]5.53			100.20		
21	44.80	37.72		.67						1.40	10.66	4.52		.20	[8]100.18	.08	100.10
22	44.85	37.20	.04	.40	.45	.02	Trace	.07	.22	1.10	10.20	.60	4.36	.79	100.30	.33	99.97
23	44.87	37.72	.02	.54	.00	Trace	.32	Trace	.36	1.04	9.83	.38	4.72	None	[9]100.24		
24	44.95	39.48		Trace			.32		None	.98	9.22	.47	4.92		100.34		
25	45.03	36.33	.02	.14	.02	.41	.05	.41	.09	.69	10.50	.79	4.56	1.01	[10]100.90	.42	100.48
26	45.37	36.77		1.82	.41		.39			1.54	10.18	3.29		1.12	100.89	.46	100.43
27	45.41	31.23	.72	4.76	1.64		.68			1.37	10.29	4.48			100.58		
28	45.1	35.1	.4	2.3			1.4			1.0	9.8	4.6			99.7		
29	45.12	34.19	.51	.85	.64	.02	.92	Trace	.25	.71	10.33	1.57	5.05	.05	[11]100.32		
30	45.13	37.50	.00	1.25	.10	.02	.06	None	None	1.21	10.54	.00	4.36		100.17		
31	45.16	35.61		2.95						1.03	10.32	4.36		.05	[12]100.18	.02	100.16
32	45.18	35.76	.15	.00	1.52	.11	.07	.73	.00	.88	9.95	.38	4.48	.88	[13]100.66	.37	100.29
33	45.24	36.85	.01	.09	.02	.12	.08	.49	.00	.64	10.08	.46	4.12	.91	[14]100.24	.38	99.86
34	45.31	32.73	.22	3.43	.96		1.18			1.21	10.44	4.09		.68	100.25	.29	99.96
35	45.42	33.52	.39	1.47	1.11	None	1.22		1.12	1.34	8.06	5.89			99.54		
36	45.45	34.41	.31	.12	.40		3.11		.17	1.40	10.44	[1]4.77			100.58		
37	45.54	36.36	.07	.25	.02	.80	.07	.06	.09	.57	10.76	.55	4.35	.62	100.11	.26	99.85
38	45.60	35.96	.03	.10	.02	.37	.05	.63	.08	.59	10.52	.44	4.81	1.31	100.51	.55	99.96
39	45.63	37.42	Trace	Trace		.06	None	.20	None	1.43	9.95	4.43		.77	99.89	.32	99.57
40	45.64	35.67		2.62	.47		.18		.12	1.37	9.88	4.30		.18	100.43	.08	100.35
41	46.01	35.64	.00	.13	.00	.09	.04	.69	1.12	1.88	8.19	.08	4.65	.54	[15]100.46	.23	100.23
42	46.01	37.08	.00	.18	.16	.05	.16		.22	.54	10.79	.12	4.58		99.89		
43	46.10	34.28	.29	.51	1.57		1.25	.00	.18	.19	9.98	1.32	4.58	.00	100.25		
44	46.17	35.57	.00	.15	.08	.04	.00	.76	.00	.56	10.37	.12	4.06	.76	[16]100.04	.32	99.72
45	46.42	34.85		1.95			.27	Trace		1.31	10.03	5.09			99.92		
46	46.55	36.97	.36	.74	.10	.00	.15		.00	1.90	8.33	.06	4.28	.06	[17]99.79	.03	99.76
47	46.81	36.09	.01		.25		.62		.29	.68	10.24	.42	5.00		100.41		
Si>3.10, tetrahedral sites																	
48	45.34	31.36	0.19	0.46	1.57	0.09	2.74		0.36	1.06	9.12	1.13	6.12		99.54		
49	45.50	33.20	.20	1.03	1.41	.04	.96		Trace	.52	10.49	1.10	5.37	.18	[18]100.12		
50	45.66	31.80	.31	2.69	1.53		.92		.09	.60	10.34	.36	5.32	.37	99.99	.16	99.83
51	45.97	31.67		2.56	.53		.31		.15	1.03	9.07	.51	3.48		[19]100.09		
52	46.10	30.54	2.04	3.43	1.96	.00	1.71		.07	3.82	6.54	3.83		.05	100.09	.02	100.07
53	46.24	32.37	.10	1.34	1.14	.09	.19	1.1	.10	.79	10.16	.69	3.41	1.41	[20]100.63	.59	100.04
54	46.25	31.89		1.52	2.08	.15	1.00		.29	1.15	10.18	.12	4.93	1.39	100.95	.58	100.37
55	46.30	33.08	.00	.00	1.20	.28	.14	1.80	.00	.63	10.09	.34	3.06	2.06	[21]100.76	.87	99.89
56	46.34	32.47	.06	.00	1.06	.35	.00	2.45	.36	.5	9.46	.32	3.32	2.82	[22]101.21	1.19	100.02
57	46.35	29.69	.28	.23	.85	.01	1.93		Trace	.78	10.53	.12	4.69	.04	[23]100.31	.02	100.29
58	46.77	34.75	.21	.71	.77		.92		.13	.47	10.61	4.48		.16	[24]100.11	.07	100.04
59	46.80	35.84	.01		.24		.56		.29	.60	10.08	.64	5.05		100.11		
60	47.00	30.60	Trace	.26	.41	2.04	.13	2.70	Trace	.77	9.52	.25	2.18	4.09	[25]102.06	1.72	100.34
61	47.15	33.57	1.31	1.35	.32	None	.45		.14	1.04	9.27	.48	5.20	.05	100.33	.02	100.31
62	47.24	31.86			.56		2.91	.14	.58	.16	10.72	5.37			[26]100.41		
63	47.29	30.65	.79	4.45			1.02		.11	.13	10.36	.06	5.03		99.89		
64	47.62	24.74		8.11	2.55	.08	1.88			.11	10.72	4.05		.14	100.00	.06	99.94
65	47.64	34.22	.00	.10		.05	.28	1.10	.00	.47	10.40	.10	3.62	1.21	[27]100.29	.51	99.78
66	48.70	21.08	.58	9.10	1.96	.33	2.87		<.1	.37	9.85	.27	4.89		100.00		
67	48.91	26.30	.36	5.61	.89	.18	3.22		Trace	.58	9.31	.34	4.37		100.07		
68	49.01	29.01	.74	2.25	.77	.06	3.91			1.87	8.86	3.77			100.25		
69	49.16	30.81	.04		1.43		2.22		.15	.48	10.90	.15	4.73		100.07		
70	49.43	22.60	.71	7.43	.82	.15	3.52		.04	.41	10.53	.25	4.56		[28]100.48		
71	53.22	21.19		1.22		.18	6.02			.34	11.20	5.75			[29]99.99		
72	56.00	23.52		3.30	.51		2.12		.37	2.72	7.03	3.52			[30]99.87		

See footnotes on opposite page.

TABLE 3.—*Analyses of aluminum potassium dioctahedral micas and lithian muscovites*—Continued

[1] Loss on ignition.
[2-30] Values given in percent. Analyses include—
[2] 0.53 Rb_2O.
[3] 0.05 BaO.
[4] 1.16 BaO.
[5] 1.08 V_2O_3.
[6] 0.23 BaO, 0.04 SrO, and 0.01 P_2O_5.
[7] 0.66 BaO, 0.02 V_2O_3, 0.03 P_2O_5, and 0.03 SO_3.
[8] 0.21 Mn_2O_3.
[9] 0.27 Cr_2O_3, 0.09 V_2O_3, and 0.08 P_2O_5.
[10] 0.79 Rb_2O, and 0.06 Cs_2O.
[11] 0.01 V_2O_3, and 0.10 P_2O_5.
[12] 0.70 Mn_2O_3.
[13] 0.57 Rb_2O.
[14] 0.93 Rb_2O, and 0.20 Cs_2O.
[15] 1.20 Rb_2O, and 0.20 Cs_2O.

[2-30] Values given in percent—Continued
[16] 1.1 Rb_2O, and 0.30 Cs_2O.
[17] 0.19 BaO, 0.04 CO_2, and 0.06 P_2O_5.
[18] 0.04 BaO, 0.05 P_2O_5, and 0.03 S.
[19] 4.81 Cr_2O_3.
[20] 1.3 Rb_2O, and 0.2 Cs_2O.
[21] 1.37 Rb_2O, and 0.41 Cs_2O.
[22] 1.5 Rb_2O, and 0.2 Cs_2O.
[23] 4.60 Cr_2O_3, 0.15 BaO, 0.01 P_2O_5, and 0.05 S.
[24] 0.13 BaO.
[25] 1.93 Rb_2O, and 0.18 Cs_2O.
[26] 0.87 Cr_2O_3.
[27] 0.35 Rb_2O, and 0.75 Cs_2O.
[28] 0.03 P_2O_5.
[29] 0.87 Mn_2O_3.
[30] 0.78 Cr_2O_3.

LOCALITY AND REFERENCE FOR ANALYSES IN TABLE 3

Si<3.10, tetrahedral sites

1. Haywood, N.C., Volk, G. W., 1939, Am. Mineralogist, v. 24, p. 259, no. 7, G. W. Volk, analyst.
2. Mitchell County, N.C., Volk, G. W., 1939, Am. Mineralogist, v. 24, p. 259, no. 8, G. W. Volk, analyst.
3. Bamle, Norway, Volk, G. W., 1939, Am. Mineralogist, v. 24, p. 259, no. 18, G. W. Volk, analyst.
4. Branchville, Conn., Volk, G. W., 1939, Am. Mineralogist, v. 24, p. 259, no. 16, G. W. Volk, analyst.
5. Montville, N.J., Volk, G. W., 1939, Am. Mineralogist, v. 24, p. 259, no. 12, G. W. Volk, analyst.
6. Val Antrona (Ossola), Italy, Pagliani, G., and Martinengh, M., 1914, Periodica Mineralog, Roma, v. 12, p. 56, muscovite.
7. Kimito, Finland, Pehrman, Gunnar, 1945, Acad. Aboensis, math. et phys., Acta 15, p. 56, R. Birch and S. Hendriksson, analysts, muscovite.
8. Ultevis district, Jokkmokk, Sweden, Ödman, O. H., 1950, Sveriges Geol. Undersökning Årsbok 44, p. 18, G. Assarsson and A. Balder, analysts, alurgite.
9. Keystone, S. Dak., Volk, G. W., 1939, Am. Mineralogist, v. 24, p. 259, no. 25, G. W. Volk, analyst.
10. Lower Chittering, S.W. Australia, Simpson, E. S., 1932, Royal Soc. Western Australia Jour., v. 18, p. 67, D. G. Murray, analyst, muscovite.
11. Schmiedefeld, Thüringia, Germany, Jung, Hermann, 1937, Chemie der Erde, v. 11, p. 39, muscovite.
12. Chandlers-Holler, Hampshire, Kunitz, Wilhelm, 1924, Neues Jahrb. Mineralogie, Geologie u. Paläontologie Beilage Band 50, p. 412, no. 1, table 1, W. Kunitz, analyst, muscovite.
13. Williamtown, South Australia, Alderman, A. R., 1942, Royal Soc. South Australia Trans., v. 66, p. 7, A. R. Alderman, analyst, damourite.
14. Haddam Neck, Conn., Volk, G. W., 1939, Am. Mineralogist, v. 24, p. 259, no. 15, G. W. Volk, analyst.
15. Tollgate Quarry, Malvern, England, Tha Hla, 1945, Mineralog. Mag., v. 27, p. 139, A. W. Groves, analyst, muscovite.
16. Henry Pass, George Sound, New Zealand, Hutton, C. O., and Seelye, F. T., 1945, Royal Soc. New Zealand Trans., v. 75, p. 161, A, F. T. Seelye, analyst, muscovite.
17. Burke Falls, Ontario, Canada, Volk, G. W., 1939, Am. Mineralogist, v. 24, p. 259, no. 19, G. W. Volk, analyst.
18. Finnbo, Dalecarlia, Sweden, Eckermann, Harry von, 1927, Geol. Fören. Stockholm Förh., v. 49, p. 231, H. V. Eckermann, analyst, muscovite.
19. Kokomo, Colo., Volk, G. W., 1939, Am. Mineralogist, v. 24, p. 259, no. 5, G. W. Volk, analyst.
20. Haywood, N.C., Volk, G. W., 1939, Am. Mineralogist, v. 24, p. 259, no. 2, G. W. Volk, analyst.
21. Taos, N. Mex., Schaller, W. T., and Henderson, E. P., 1926, Am. Mineralogist, v. 11, p. 12, E. P. Henderson, analyst, muscovite.
22. Russia, locality not give, Ginzburg, A. I., and Berkhin, S. I., 1953, Mineralog. Muzeya. Akad. Nauk SSSR Trudy, v. 5, p. 95, K. P. Sokovoy and L. Bitumilevich, analysts, muscovite.
23. Westland, South Island, New Zealand, Hutton, C. O., 1940, New Zealand Jour. Sci. and Technology, v. 21, sec. 6B., p. 330B, F. T. Seelye, analyst, muscovite.
24. Williamtown, South Australia, Alderman, A. R., 1942, Royal Soc. South Australia Trans., v. 66, p. 7, T. W. Dalwood, analyst, damourite.
25. White spar mine, no. 1. Gunnison County, Colo., Heinrich, E. W., and Levinson, A. A., 1953, Am. Mineralogist, v. 38, p. 43, no. 2, E. H. Oslund, analyst, muscovite.
26. Utö, Sweden, Kunitz, Wilhelm, 1924, Neues Jahrb. Mineralogie, Geologie u. Paläontologie Beilage Band 50, p. 412, no. 2, table 1, W. Kunitz, analyst, muscovite.
27. Dewalla, India, Kunitz, Wilhelm, 1924, Neues Jahrb. Mineralogie, Geologie u. Paläontologie Beilage Band 50, p. 412, no. 9, table 1, W. Kunitz, analyst, muscovite.
28. Rubatab area, northern Sudan. Kabesh, M. L., 1960, Sudan Geol. Survey Dept., Bull. no. 7, p. 29, muscovite.
29. Westland, South Island, New Zealand, Hutton, C. O., 1940, New Zealand Jour. Sci. and Technology, v. 21, sec. 6B., p. 330B, F. T. Seelye, analyst.
30. Gojas (Lalin), Pontevedra, Spain?, Parga-Pondal, I, and Fraga-Padin, M. de la E., 1934, Soc. Española Fis. Quím. Anal., v. 32, p. 1015, muscovite.
31. Pilar, N. Mex., Schaller, W. T., and Henderson, E. P., 1926, Am. Mineralogist v. 11, p. 12, E. P. Henderson, analyst, muscovite.
32. Varuträsk, Sweden, Berggren, Thelma, 1940, Geol. Fören Stockholm Förh., v. 62, p. 185, G, T. Berggren, analyst, muscovite.
33. Pittlite, Rociada, N. Mex., Heinrich, E. W., and Levinson, A. A., 1953, Am. Mineralogist, v. 38, p. 43, no. 5, E. H. Oslund, analyst, muscovite.
34. Mount Crawford, Australia, Kunitz, Wilhelm, 1924, Neues Jahrb. Mineralogie, Geologie u. Paläontologie Beilage Band 50, p. 412, no. 6, W. Kunitz, analyst, muscovite.
35. Battle Branch Mine, Auraria, Ga., Wells, R. C., 1937, U.S. Geol. Survey Bull. 878, p. 108, F, R. E. Stevens, analyst, muscovite.
36. Dobrova, Carinthia, Volk, G. W., 1939, Am. Mineralogist, v. 24, p. 529, no. 21, G. W. Volk, analyst, muscovite.
37. Apache, Petaca, N. Mex., Heinrich, E. W., and Levinson, A. A., 1953, Am. Mineralogist, v. 38, p. 43, no. 4, E. H. Oslund, analyst, muscovite.
38. Brown Derby No. 1 mine, Gunnison County, Colo., Heinrich, E. W., and Levinson, A. A., 1953, Am. Mineralogist, v. 38, p. 43, no. 3, E. H. Oslund, analyst, muscovite.
39. Mesa Grande, San Diego County, Calif., Clarke, F. W., 1910, U.S. Geol. Survey Bull. 419, p. 286, H, W. T. Schaller, analyst, muscovite.
40. Madagascar, Kunitz, Wilhelm, 1924, Neues Jahrb. Mineralogie, Geologie, u Paläontologie Beilage-Band 50, p. 412, no. 4, table 1, W. Kunitz, analyst, muscovite.
41. Varuträsk, Sweden, Berggren, Thelma, 1940, Geol. Fören. Stockholm Förh., v. 62, p. 185, H. T. Berggren, analyst, muscovite.
42. Wodgina, Northwest Division, Western Australia, Simpson, E. S., 1936, Royal Soc. Western Australia Jour., v. 22, p. 10, D. G. Murray, analyst, muscovite.
43. Caruso mine, Harts Range, central Australia, Joklik, G. F., 1955, Econ. Geology, v. 50, p. 645, Avery and Anderson, analysts, muscovite.
44. Varuträsk, Sweden, Berggren, Thelma, 1941, Geol. Fören. Stockholm Förh., v. 63, p. 264, J. T. Berggren, analyst, oncosine.
45. Ollierques, Puy-de-Dôme, France, Barbier, Ph, and Gonnard, Ferd., 1910, Soc. française Minéralogie Bull., v. 33, p. 78, muscovite.
46. Hagers Mountain, Person County, N. C., Espenshade, G. H., and Potter, D. B., 1960, U.S. Geol. Survey Prof. Paper 336, p. 13, L. M. Kehl, analyst, muscovite.
47. Amelia, Va., Glass, J. J., 1935, Am. Mineralogist v. 20, p. 756, no. 3, R. E. Stevens, analyst, sericite.

Si>3.10, tetrahedral sites

48. Unan mine, Shimane Pref., Japan, Minato, H., and Takano, Y., 1952, Tokyo Univ. Coll. Gen. Education Sci. Papers, v. 2, p. 196, H. Minato, analyst, sericite.
49. Mariner's Peak, S. Westland, New Zealand, Hutton, C. O., and Seelye, F. T., 1945, Royal Soc. New Zealand Trans., v. 75, p. 161, B, F. T. Seelye, analyst, muscovite.
50. Mattawan Township, Nipissing district, Ontario, Canada, Ferguson, R. B., 1943, Toronto Univ. Studies, Geol. Ser., no. 48, p. 40, no. 1, R. B. Ferguson, analyst, muscovite.
51. Pointe du Bois, Manitoba, Canada, Whitmore, D. R. E., Berry, L. G., and Hawley, J. E., 1946, Am. Mineralogist, v. 31, p. 8, D. R. E. Whitmore, analyst, chrome mica.
52. Wissahickon Valley, Pa., Postel, A. W., and Adelhelm, William, 1944, Am. Mineralogist, v. 29, p. 285, F. A. Gonyer, analyst, white mica.
53. Varuträsk, Sweden, Berggren, Thelma, 1941, Geol. Fören Stockholm Förh. v. 63, p. 264, L, T. Berggren, analyst, muscovite.
54. Chacaltaya, Bolivia, Thugutt, St. J., 1936, Arch. Mineralog. Tow, Nauk, Warsaw, v. 12, p. 59.
55. Varuträsk, Sweden, Berggren, Thelma, 1940, Geol. Fören. Stockholm Förh., v. 62, p. 185, E, T. Berggren, analyst, lepidolite.
56. Varuträsk, Sweden, Berggren, Thelma, 1940, Geol. Fören. Stockholm Förh., v. 62, p. 185, D, T. Berggren, analyst, lepidolite.
57. W. Otago, New Zealand, Hutton, C. O., 1942, Royal Soc. New Zealand Trans. v. 72, p. 54A, F. T. Seelye, analyst, fuchsite.
58. Sultan Basin, Washington, Milton, Charles, 1949, Am. Mineralogist, v. 34, p. 567, F. S. Grimaldi, analyst, muscovite.
59. Amelia, Va., Glass, J. J., 1935, Am. Mineralogist, v. 20, p. 756, no. 4, R. E. Stevens, analyst, sericite.
60. Manitoba, Canada, Stevens, R. E., 1938, Am. M ineralogist, v. 23, p. 615 no. 1, R. E. Stevens, analyst, lepidolite.
61. Mozambique, Holmes, Arthur, 1917, Geol. Soc. London Quart. Jour., v. 74, p. 74, D. F. Harwood, analyst, muscovite.
62. Binnenthal, Switzerland, Whitmore, D. R. E., Berry, L. G., and Hawley, J. E., 1946, Am. Mineralogist, v. 31, p. 9, no. 4, G. T. Prior, analyst, fuchsite.
63. Coeur d'Alene district, Idaho, Milton, Charles, analyst, 1938, Unpublished analysis.
64. Grandfather Mountain, N. C., Foster, M. D., Bryant, Bruce, and Hathaway, John, 1960, Am. Mineralogist, v. 45, p. 845, M. D. Foster, analyst.
65. Varuträsk, Sweden, Berggren, Thelma, 1940, Geol. Fören. Stockholm Förh., v. 62, p. 185, F, T. Berggren, analyst, oncosine.
66. Imori dist., Kii peninsula, Japan, Kanchira, Keüchiro, and Banno, Shohei, 1960, Geol. Soc. Japan Jour., v. 66, p. 658, H. Haramura, analyst, ferriphengite.
67. Oyahana, Saitana Pref., Japan, Miyashiro, Akiho, 1962, Geol. Soc. Japan Jour. v. 68, p. 234, no. 1, table 2, H. Haramura, analyst, muscovite.
68. Soazza, Passo di Genano, Graubunden, Switzerland, Smulikowski, K., 1954, Polska Akad. Nauk, Kom. Geolog., Arch. Mineralog. v. 18, p. 60, J. Jakob, analyst, muscovite.
69. Amelia, Va., Glass, J. J., 1935, Am. Mineralogist, v. 20, p. 756, no. 5, R. E. Stevens, analyst, sericite.
70. Tokusima, Japan, Miyashiro, Akiho, 1962, Geol. Soc. Japan Jour. v. 68, p. 234, no. 2, table 1, H. Haramura, analyst, muscovite.
71. Piedmont, Italy, Penfield, S. L., 1893, Am. Jour. Sci., 3d Ser., v. 46, p. 290, S. L. Penfield, analyst, alurgite.
72. Ross Mine, Hislop Township, Ontario, Whitmore, D. R. E., Berry, L. G., and Hawley, J. E., 1946, Am. Mineralogist, v. 31, p. 11, no. 3.

TABLE 4.—*Atomic ratios for some of the analyses of aluminum potassium dioctahedral micas and lithian muscovites given in table 3*

Analysis (See table 3)	Si	Al(IV)	Al(VI)	Ti	Fe^{3+}	Fe^{2+}	Mn^{2+}	Mg	Octahedral cations	Li	Ca	Na	K	Interlayer cations	OH	F	(OH+F)	O
Si<3.10, tetrahedral sites																		
6	2.88	1.12	1.70	0.05	0.04	--------	--------	0.18	1.97	--------	--------	0.33	0.74	1.07	2.25	--------	2.25	9.75
7	3.03	.97	1.68	.01	.14	0.09	--------	.11	2.16	0.13	--------	.14	.79	[1] .95	1.78	0.22	2.00	10.00
8	2.95	1.05	1.32	.04	.22	--------	0.03	.12	1.73	--------	--------	.07	.86	[2] .95	2.85	.20	3.05	8.95
10	2.97	1.03	1.78	.01	.13	--------	--------	.03	1.95	--------	0.02	.05	.85	[3] .95	2.20	--------	2.20	9.80
12	2.95	1.05	1.92	--------	.07	.02	--------	.01	2.02	--------	.01	.19	.83	1.03	1.81	.18	1.99	10.01
13	2.95	1.05	1.96	--------	.05	.01	--------	.01	2.03	--------	.05	.08	.81	.94	1.97	--------	1.97	10.03
15	3.08	.92	1.66	.04	.23	.05	.00	.13	2.11	--------	.04	.10	.92	[4] 1.07	1.61	.02	1.63	10.37
16	3.10	.90	1.60	.02	.18	.08	--------	.16	2.04	--------	.00	.07	.90	[5] .99	2.35	.00	2.35	9.65
18	3.01	.99	1.80	--------	.01	.12	.01	.09	2.03	--------	--------	.12	.93	1.05	2.03	.03	2.06	9.94
21	2.97	1.03	1.92	--------	.03	--------	--------	--------	[6] 1.97	--------	--------	.18	.90	1.08	2.00	.04	2.04	9.96
22	2.99	1.01	1.91	.00	.02	.03	.00	.00	1.98	.02	.02	.14	.87	1.03	1.94	.17	2.11	9.89
23	2.97	1.03	1.91	.00	.03	.00	.00	.03	[7] 2.00	.00	.03	.14	.83	1.00	2.08	.00	2.08	9.92
24	2.94	1.06	1.99	--------	.00	--------	--------	.03	2.02	--------	--------	.13	.77	.90	2.15	--------	2.15	9.85
25	3.03	.97	1.92	--------	.01	.00	.02	.00	2.06	.11	.06	.09	.90	[8] 1.08	2.03	.21	2.24	9.76
26	3.03	.97	1.93	--------	.09	.02	--------	.04	2.08	--------	--------	.20	.87	1.07	1.47	.24	1.71	10.29
27	3.07	.93	1.55	.04	.24	.09	--------	.07	1.99	--------	--------	.18	.88	1.06	2.02	--------	2.02	9.98
28	3.01	.99	1.76	.02	.12	--------	--------	.14	2.04	--------	--------	.13	.83	.96	2.05	--------	2.05	9.95
29	3.07	.93	1.80	.03	.04	.04	.00	.09	2.00	.00	.02	.09	.89	1.00	2.26	.00	2.26	9.74
30	3.00	1.00	1.93	--------	.06	.01	--------	.01	2.01	--------	--------	.16	.89	1.05	1.93	--------	1.93	10.07
31	3.02	.98	1.87	--------	.15	--------	--------	--------	[9] 2.06	--------	--------	.13	.88	1.01	1.94	.01	1.95	10.05
32	3.03	.97	1.85	.01	--------	.08	.01	.01	2.16	.20	.00	.11	.85	[10] .98	1.99	.18	2.17	9.83
33	3.02	.98	1.93	.00	.00	.00	.01	.01	2.08	.13	.00	.08	.86	[11] .98	1.84	.19	2.03	9.97
34	3.06	.94	1.65	.01	.17	.05	--------	.12	2.00	--------	--------	.16	.90	1.06	1.84	.15	1.99	10.01
36	3.00	1.00	1.69	.02	.01	.02	--------	.31	2.05	--------	.01	.18	.88	1.07	2.10	--------	2.10	9.90
37	3.04	.96	1.91	.00	.01	.00	.05	.01	2.00	.02	.01	.07	.92	1.00	1.94	.13	2.07	9.93
38	3.06	.94	1.91	.00	.01	.00	.02	.00	2.11	.17	.06	.08	.90	1.04	2.12	.27	2.39	9.61
39	3.02	.98	1.93	.00	.00	--------	.00	.00	1.98	.05	.00	.18	.84	1.02	1.95	.16	2.11	9.89
40	3.04	.96	1.83	--------	.13	.03	--------	.02	2.01	--------	.01	.18	.84	1.03	1.91	.04	1.95	10.05
41	3.06	.94	1.86	.00	.01	.00	.01	.00	2.07	.19	.08	.24	.70	[12] 1.07	2.05	.11	2.16	9.84
42	3.04	.96	1.94	--------	.01	.01	.00	.02	1.98	--------	.02	.07	.91	1.00	2.02	--------	2.02	9.98
43	3.09	.91	1.80	.01	.03	.09	--------	.12	2.05	.00	.01	.02	.85	.88	2.05	.00	2.05	9.95
44	3.09	.91	1.90	.00	.01	.00	.00	.00	2.11	.20	.00	.07	.89	[13] 1.01	1.81	.16	1.97	10.03
46	3.08	.92	1.95	.02	.04	.01	.00	.01	2.03	--------	.00	.24	.70	.94	1.88	.01	1.89	10.11
Si>3.10, tetrahedral sites																		
51	3.14	0.86	1.68	--------	0.13	0.03	--------	0.03	[14] 2.13	--------	0.01	0.14	0.79	0.94	1.58	--------	1.58	10.42
52	3.11	.89	1.52	0.10	.17	.11	0.00	.17	2.07	--------	.00	.50	.56	1.06	1.72	0.02	1.74	10.26
53	3.15	.85	1.74	.00	.07	.07	.01	.02	2.21	0.30	.08	.10	.88	1.06	1.55	.30	1.85	10.15
55	3.14	.86	1.78	--------	--------	.07	.02	.01	2.37	.49	--------	.08	.87	[15] 1.02	1.38	.44	1.82	10.18
56	3.11	.89	1.67	.06	.00	.06	.02	.00	2.41	.66	.03	.06	.81	[16] .96	1.48	.60	2.08	9.92
57	3.12	.88	1.48	.01	.01	.05	.00	.19	[17] 1.99	--------	.00	.10	.91	1.01	2.11	.00	2.11	9.89
58	3.11	.89	1.83	.01	.04	.04	.00	.09	2.01	--------	.01	.06	.90	.97	1.98	.03	2.01	9.99
60	3.18	.82	1.62	.00	.01	.02	.12	.01	2.52	.74	.00	.10	.82	[18] 1.01	.98	.87	1.85	2.13
61	3.14	.86	1.77	.07	.07	.02	.00	.04	1.97	--------	.01	.14	.79	.94	2.28	--------	2.28	9.72
63	3.19	.81	1.62	.04	.22	--------	--------	.10	1.98	--------	.01	.02	.89	.92	2.25	--------	2.25	9.75
64	3.28	.72	1.29	--------	.44	.15	--------	.19	2.07	--------	--------	.02	.94	.96	1.86	.03	1.89	10.11
65	3.18	.82	1.87	.00	.01	--------	.00	.03	2.21	.30	.00	.06	.89	[19] .99	1.61	.26	1.87	10.13
66	3.38	.62	1.10	.03	.48	.11	.02	.30	2.04	--------	.00	.05	.87	.92	2.24	--------	2.24	9.76
67	3.30	.70	1.39	.02	.28	.05	.01	.32	2.07	--------	.00	.08	.80	.88	1.96	--------	1.96	10.04
68	3.28	.72	1.56	.04	.11	.04	--------	.39	2.14	.00	--------	.24	.76	1.00	1.68	--------	1.68	10.32
69	3.27	.73	1.68	.00	--------	.08	--------	.22	1.98	--------	.01	.06	.92	.99	2.09	--------	2.09	9.91
70	3.36	.64	1.17	.04	.38	.05	.01	.36	2.01	--------	.00	.05	.91	96.	2.06	--------	2.06	9.94
72	3.71	.29	1.55	--------	.16	.03	--------	.21	[20] 1.99	--------	.03	.35	.59	.97	1.56	--------	1.56	10.44

[1-20] Values include—
[1] 0.02 Rb.
[2] 0.02 Ba.
[3] 0.03 Ba.
[4] 0.01 Ba.
[5] 0.02 Ba.
[6] 0.02 Mn^{3+}
[7] 0.01 Cr^{3+}, and 0.01 V^{3+}.
[8] 0.03 Rb.
[9] 0.04 Mn^{3+}.
[10] 0.02 Rb.
[11] 0.04 Rb.
[12] 0.05 Rb.
[13] 0.05 Rb.
[14] 0.26 Cr^{3+}.
[15] 0.06 Rb, and 0.01 Cs.
[16] 0.06 Rb.
[17] 0.25 Cr^{3+}.
[18] 0.09 Rb.
[19] 0.02 Rb, and 0.02 Cs.
[20] 0.04 Cr^{3+}.

TABLE 5.—*Atomic ratios for analyses of selected trioctahedral micas*

[From Foster (1960a, table 11, p. 41–42). Symbols for (OH+F): T, theoretical, 2.00 ± 0.15; H, high, >2.15; D, deficient, <1.85]

Analysis	Si	Al (IV)	Al (VI)	Ti	Fe^{3+}	Fe^{2+}	Mn^{2+}	Mg	Octahedral cations	Ca	Na	K	Interlayer cations	OH	F	(OH+F)	O	Relation of (OH+F) to theoretical
Phlogopites and magnesium biotites																		
2	2.91	1.09	0.01	------	0.04	0.10	------	2.96	3.11	0.03	0.13	0.93	1.09	0.98	0.71	1.69	10.31	D
6	2.82	1.18	.04	0.02	.04	.05	0.00	2.87	3.02	.03	.10	.76	.89	1.88	.26	2.14	9.86	T
7	2.99	[1] .96	.00	------	[1] .06	.04	------	2.91	2.96	------	.18	.91	1.09	1.93	.83	2.76	9.24	H
7a	2.85	1.15	.06	.01	.06	.02	.00	2.86	3.01	.00	.03	.96	.99	2.18	.00	2.18	9.82	H
9a	2.87	[2] 1.09	.00	.00	[2] .10	.13	------	2.80	2.99	.03	.33	.71	1.07	1.38	.64	2.02	9.98	T
14	2.61	1.39	.15	.03	.04	.08	.00	2.66	2.96	.02	.08	.85	[3] .97	2.25	------	2.25	9.75	H
18	2.72	1.28	.15	.03	.05	.25	.00	2.45	2.93	------	.06	.87	[4] .95	1.78	.50	2.28	9.72	H
19	2.86	1.14	.28	.04	.02	.14	------	2.39	2.87	------	.02	.87	.89	1 97	.14	2.11	9.89	T
20	3.08	.92	.50	.02	.12	.34	.00	2.55	3.53	.00	.22	.85	[5] 1.11	.30	.18	.48	11.52	D
25	3.15	.85	.32	.05	.02	.32	------	2.39	[6] 3.25	------	.12	1.00	1.12	.74	.07	.81	11.19	D
33	2.69	[7] 1.29	.00	.15	[7] .23	.31	.02	2.14	2.83	.03	.03	.89	[8] .99	2.01	.09	2.10	9.90	T
35	2.87	1.13	.26	.02	.15	.70	.01	2.06	3.20	.07	.04	.89	1.00	1.11	.06	1.17	10.83	D
36	2.88	1.12	.24	.06	.18	.54	.02	1.74	[9] 2.81	.12	.12	.75	.99	1.55	.32	1.87	10.13	T
37	2.65	1.35	.87	.02	.00	.43	.01	1.52	[10] 2.92	.01	.11	.79	.91	1.26	.53	1.79	10.21	D
38	2.91	1.09	.16	.28	.31	.52	.02	1.75	3.04	.09	.14	.83	[11] 1.07	.52	.30	.82	11.18	D
39	2.68	1.32	.05	.42	.16	.65	------	1.72	3.00	.05	.16	.84	1.05	1.20	------	1.20	10.80	D
40	2.67	1.33	.39	.07	.10	.72	.01	1.68	[12] 3.04	.08	.15	.77	[13] 1.02	1.45	.11	1.56	10.44	D
41	2.78	1.22	.40	.18	.02	.85	.01	1.68	3.14	.02	.14	.93	1.09	.95	.10	1.05	10.95	D
42	2.87	1.13	.27	.16	.10	.95	.01	1.69	3.18	.01	.15	.97	1.13	.82	.11	.93	11.07	D
43	2.73	1.27	.38	.09	.12	.59	.02	1.53	2.73	.00	.19	.86	1.05	2.07	------	2.07	9.93	T
46	2.88	1.12	.61	.12	.17	.66	.02	1.49	3.07	.00	.21	.96	1.17	.79	------	.79	11.21	D
47	2.67	1.33	.23	.20	.20	.80	.02	1.45	2.90	.03	.10	.90	1.03	1.37	.25	1.62	10.38	D
52	2.78	1.22	.27	.11	.17	.98	.01	1.36	2.90	.00	.03	.91	.94	1.91	------	1.91	10.09	T
56	2.74	1.26	.20	.17	.22	.91	.01	1.25	2.76	------	.05	.86	[14] .93	2.01	.02	2.03	9.97	T
59	2.67	1.33	.05	.23	.17	1.17	.02	1.19	[15] 2.93	.09	.06	.78	.93	1.57	.28	1.85	10.15	T
61	2.76	1.24	.45	.06	.32	.94	.05	1.12	2.94	.05	.06	.91	1.02	1.31	.06	1.37	10.63	D
62	2.76	1.24	.51	.14	.12	.88	------	1.08	2.73	.04	.12	.81	.97	1.50	.37	1.87	10.13	T
Ferrous biotites, siderophyllites, lepidomelanes																		
58	2.74	1.26	0.45	0.16	0.02	1.30	0.02	1.22	3.17	0.02	0.07	0.94	1.03	1.08	0.02	1.10	10.90	D
60	2.85	1.15	.25	.25	.14	1.38	.01	1.19	3.22	.01	.06	.93	1.00	.42	.40	.82	11.18	D
70	2.87	1.13	.25	.20	.18	1.56	------	1.11	3.30	.10	.08	.83	1.01	.55	.04	.59	11.41	D
73	2.59	1.41	.35	.14	.19	1.05	.02	1.03	2.78	.01	.19	.77	.97	2.04	------	2.04	9.96	T
75	2.60	1.40	.05	.20	.41	1.00	.03	1.00	2.69	.03	.27	.73	1.03	2.10	------	2.10	9.90	T
81	2.81	1.19	.38	.15	.13	.94	.01	.96	[16] 2.77	.00	.07	.82	[17] 1.00	1.21	.76	1.97	10.03	T
83	2.67	1.33	.15	.20	.19	1.28	.02	.94	[18] 2.86	.09	.12	.78	.99	1.48	.41	1.89	10.11	T
84	2.95	1.05	.13	.04	.28	1.37	.06	.95	2.83	------	.23	.86	1.09	1.82	------	1.82	10.18	D
85	2.69	1.31	.11	.16	.38	1.14	.02	.93	2.74	------	.23	.77	1.00	2.03	------	2.03	9.97	T
88	2.64	1.36	.32	.16	.12	1.40	------	.93	2.93	.04	.05	.88	.97	1.70	.06	1.76	10.24	D
93	2.86	1.14	.18	.10	.32	1.21	.06	.90	2.77	------	.18	.84	1.02	1.90	------	1.90	10.10	T
95	2.79	1.21	.18	.31	.17	.99	.02	.86	[19] 2.57	.05	.10	.82	.97	2.07	.11	2.18	9.82	H
96	2.76	1.24	.24	.09	.26	1.60	.07	.90	3.16	------	.14	.92	1.06	.68	.52	1.20	10.80	D
97	2.66	1.34	.45	.29	.10	1.14	.00	.84	2.82	.04	.10	.80	.94	1.47	.10	1.57	10.43	D
98	2.76	1.24	.29	.16	.20	1.30	.03	.82	2.80	.08	.06	.83	.97	1.83	------	1.83	10.17	D
99	2.84	[20] .75	.00	.22	[20] .60	1.34	.08	.84	2.67	.00	.08	.92	1.00	1.96	.23	2.19	9.81	H
102	2.89	[21] 1.05	.00	.14	[21] .37	1.49	.17	.79	2.90	.00	.16	.88	1.04	1.30	.39	1.69	10.31	D
105	2.56	1.44	.30	.06	.27	1.32	.16	.74	2.85	.04	.08	.93	1.05	1.93	.04	1.97	10.03	T
107	2.72	1.28	.13	.16	.18	1.74	.06	.72	2.99	.03	.08	.85	.96	1.66	------	1.66	10.34	D
108	2.70	1.30	.31	.21	.15	1.42	.03	.69	[22] 2.85	.10	.09	.88	1.07	1.34	.28	1.62	10.38	D
109	2.58	1.42	.08	.22	.35	1.46	------	.68	2.79	.02	.13	.79	.94	2.01	------	2.01	9.99	T
110	2.63	1.37	.51	.08	.23	1.22	.03	.65	[23] 2.78	.03	.06	.89	.98	1.76	.22	1.98	10.02	T
112	2.58	1.42	.04	.12	.51	1.47	.14	.63	2.91	.03	.07	.83	.93	1.79	.03	1.82	10.18	D
113	2.62	1.38	.43	.10	.20	1.17	.03	.59	[24] 2.62	.06	.08	.80	.94	2.27	.16	2.43	9.57	H
117	2.70	[25] 1.29	.00	.18	[25] .49	1.58	.07	.60	2.91	.05	.08	.80	.93	1.41	.24	1.65	10.35	D
118	2.80	1.20	.68	.18	.18	1.05	.02	.53	2.64	.10	.20	.75	1.05	1.02	.53	1.55	10.45	D
119	2.89	1.11	.40	.15	.30	1.15	.03	.52	[26] 2.66	.05	.10	.75	.90	1.58	.36	1.94	10.06	T
120	2.68	1.32	.28	.14	.14	1.70	.11	.53	2.90	.07	.07	.74	.88	1.86	------	1.86	10.14	T
121	2.66	1.34	.44	.12	.25	1.24	.03	.51	[27] 2.65	.07	.06	.79	.92	1.98	.17	2.15	9.85	T
122	2.88	[28] 1.09	.00	.23	[28] .38	2.01	.03	.30	2.92	.07	.08	.80	.95	1.35	.07	1.42	10.58	D
123	2.63	1.37	.16	.05	.79	1.36	.07	.15	[29] 2.74	.09	.00	.78	.87	1.80	.23	2.03	9.97	T
124	2.68	1.32	.22	.02	.54	2.26	.02	.12	3.18	.00	.11	1.06	1.17	1.09	.04	1.13	10.87	D
128	2.89	1.11	.29	.05	.46	1.48	.05	.07	[30] 2.56	.03	.07	.78	.88	1.91	.50	2.41	9.59	H
129	2.98	1.02	1.00	.01	.04	1.32	.02	.05	2.44	.12	.00	.86	.98	1.47	.48	1.95	10.05	T
130	2.52	1.48	.11	.00	.44	1.59	.04	.03	[31] 2.39	.04	.08	.74	.86	2.98	.40	3.38	8.62	H
131	2.81	1.19	.43	.09	.49	1.37	.06	.03	[32] 2.62	.09	.04	.73	.86	1.59	.42	2.01	9.99	T
132	2.97	1.03	.47	.00	.00	2.02	.07	.03	[33] 2.92	.01	.09	.92	[34] 1.03	1.02	.98	[35] 2.03	9.97	T
133	2.76	1.24	.37	.03	.29	1.38	.01	.01	[36] 2.53	.02	.04	.78	.84	2.25	.74	2.99	9.01	H

[1] 0.05 Fe^{3+} in tetrahedral layer.
[2] 0.04 Fe^{3+} in tetrahedral layer.
[3, 4] Values contain—
[3] 0.02 Ba.
[4] 0.02 Ba.
[5, 6] Values include—
[5] 0.04 Ba.
[6] 0.04 Cr^{3+}, 0.03 Ni, and 0.08 Li.
[7] 0.02 Fe^{3+} in tetrahedral layer.
[8–19] Values include—
[8] 0.04 Ba.
[9] 0.03 Li.
[10] 0.07 Li.
[11] 0.01 Ba.
[12] 0.07 Li.
[13] 0.02 Ba.
[14] 0.02 Ba.
[15] 0.10 Li.
[16] 0.20 Li.
[17] 0.07 Rb, and 0.04 Cs.
[18] 0.08 Li.
[19] 0.04 Li.
[20] 0.41 Fe^{3+} in tetrahedral layer.
[21] 0.06 Fe^{3+} in tetrahedral layer.
[22–24] Values include—
[22] 0.04 Li.
[23] 0.06 Li.
[24] 0.10 Li.
[25] 0.01 Fe^{3+} in tetrahedral layer.
[26, 27] Values include—
[26] 0.11 Li.
[27] 0.06 Li.
[28] 0.03 Fe^{3+} in tetrahedral layer.
[29–36] Values include—
[29] 0.16 Li.
[30] 0.16 Li.
[31] 0.18 Li.
[32] 0.15 Li.
[33] 0.33 Li.
[34] 0.01 Rb.
[35] 0.03 Cl.
[36] 0.44 Li.

TABLE 6.—*Atomic ratios for analyses of selected lepidolites*

[From Foster (1960b table 6, p. 142–143). Symbols for (OH+F): T, theoretical, 2.00—0.15; H, high, >2.15; D, deficient, <1.85]

Analysis	Si	Al(IV)	Al(VI)	Ti	Fe^{3+}	Fe^{2+}	Mn^{2+}	Mg	Li	Octahedral cations	Ca	Na	K	Rb	Cs	Interlayer cations	OH	F	(OH+F)	O	Relation of (OH+F) to theoretical
32	3.38	0.62	1.19	0.00	0.08	0.09	0.04	0.00	1.39	2.79	0.01	0.07	0.76	0.17	0.03	1.04	0.67	1.46	2.13	9.87	T
33	3.56	.44	1.30	.00	--------	.01	.03	.01	1.35	2.70	.00	.10	.81	.07	.01	.99	.57	1.52	2.09	9.91	T
34	3.38	.62	1.29	.00	--------	.01	.16	.00	1.38	2.84	.00	.07	.88	.07	.00	1.02	.37	1.61	1.98	10.02	T
35	3.33	.67	1.31	.00	--------	.01	.14	.00	1.39	2.85	.00	.07	.89	.08	.00	1.04	.54	1.48	2.02	9.98	T
36	3.61	.39	1.39	.00	--------	.01	.01	.00	1.36	2.77	.00	.07	.80	.07	.00	.94	.45	1.43	1.88	10.12	T
38	3.49	.51	1.13	.01	.04	.11	.12	.00	1.06	2.47	.00	.06	.91	------	------	.97	.85	1.64	2.49	9.51	H
39	3.45	.55	1.34	.00	.00	.00	.01	.00	1.43	2.78	.00	12	.92	.02	.01	1.07	.37	1.64	2.01	9.99	T
40	3.38	.62	1.25	.00	.02	.07	.04	.00	1.44	2.82	.00	.14	.94	------	------	1.08	.62	1.44	2.06	9.94	T
41	3.28	.72	1.20	------	.03	--------	.05	.07	1.43	2.78	.02	.08	.96	.01	------	1.07	.39	1.88	2.27	9.73	H
43	3.33	.67	1.08	.00	.02	.01	.08	.08	1.47	2.74	.07	.07	.85	------	------	.99	1.47	.99	2.46	9.54	H
44	3.43	.57	1.43	.00	--------	.00	.03	.00	1.49	2.95	.00	.07	.84	.08	.02	1.01	.26	1.46	1.72	10.28	D
45	3.41	.59	1.29	.00	--------	.00	.01	.00	1.48	2.78	.00	.08	.87	.06	.01	1.03	.67	1.55	2.22	9.78	H
47	3.48	.52	1.27	.00	--------	.00	.02	.00	1.50	2.79	.00	.08	.86	.04	.02	1.00	.60	1.58	2.18	9.82	H
49	3.42	.58	1.44	.00	.01	.00	.01	.00	1.55	3.01	.00	.04	.78	.14	.03	.99	.36	1.31	1.67	10.33	D
50	3.42	.58	1.28	.00	--------	.00	.03	.01	1.55	2.87	.00	.08	.84	.08	.00	1.00	.40	1.70	2.10	9.90	T
51	3.44	.56	1.26	.00	--------	.00	.08	.03	1.56	2.93	.00	.13	.95	------	------	1.08	.20	1.73	1.93	10.07	T
53	3.38	.62	1.42	.00	.00	.00	.02	.02	1.62	3.08	.00	.05	.83	.09	.00	.97	.17	1.47	1.64	10.36	D
54	3.68	.32	1.11	.00	--------	.01	.12	.03	1.68	2.95	.00	.09	.89	.05	.00	1.03	.26	1.94	2.20	9.80	H
56	3.47	.53	1.26	.00	.00	--------	.04	------	1.69	2.99	------	.01	.94	------	------	.95	.24	1.72	1.96	10.04	T
57	3.80	.20	1.02	.00	--------	.01	.04	.02	1.83	2.92	.00	.06	.90	.06	.01	.97	.22	1.91	2.13	9.87	T
58	3.97	.03	.91	.02	.01	.02	.00	.03	1.94	[1] 2.98	.00	.07	.94	.05	.00	1.06	.21	1.63	1.84	10.16	D

[1] Includes 0.05 Nb.

TABLE 7.—*Atomic ratios for analyses of selected ferrous lithian micas*

[From Foster (1960b, table 7, p. 144–145). Symbols for (OH+F): T, theoretical, 2.00±0.15; H, high, >2.15; D, deficient, <1.85]

Analysis	Si	Al(IV)	Al(VI)	Ti	Fe^{3+}	Fe^{2+}	Mn^{2+}	Mg	Li	Octahedral cations	Ca	Na	K	Rb	Cs	Interlayer cations	OH	F	(OH+F)	O	Relation of (OH+F) to theoretical
13	2.82	1.18	0.84	0.00	0.45	0.77	0.21	0.25	0.64	3.16	0.08	0.12	0.84	------	------	1.04	1.08	0.05	1.13	10.87	D
19	3.19	.81	1.01	------	.03	.66	.10	.02	.92	2.74	------	.11	.90	------	------	1.01	.46	1.78	2.24	9.76	H
27	3.25	.75	1.25	------	.03	.37	.08	------	1.04	2.77	.02	.23	.81	------	------	1.06	.40	1.86	2.26	9.74	H
28	3.27	.73	1.06	------	.06	.60	.02	.00	1.05	2.79	.00	.07	.92	------	------	.99	.42	1.67	2.09	9.91	T
30	2.90	1.10	1.00	.04	--------	.67	.01	.01	1.13	2.86	.02	.30	.71	------	------	1.03	2.04	.35	2.39	9.61	H
31	3.52	.48	1.38	------	.01	.44	.12	------	1.22	3.17	.00	.16	.97	------	------	1.13	.31	.52	.83	11.17	D
32	3.30	.70	.83	.01	.14	.36	.15	.16	1.32	2.97	.14	.03	.91	------	------	1.08	.41	1.29	1.70	10.30	D
33–35 [1]	3.55	.45	.82	.01	.12	.43	.01	.00	1.44	[2] 2.85	.00	.01	.87	0.03	------	.91	.63	1.70	2.33	9.67	H

[1] Mean of two new analyses of cryophyllite, Cape Ann, Mass., from Foster, M. D., and Evans, H. T., Jr., 1962, Am. Mineralogist, v. 47, p. 346, M. D. Foster, B. Ingram, J. J. Warr, and S. M. Berthold, analysts.

[2] Includes 0.02 Zn.

TABLE 8.—*Atomic ratios, based on determined H_2O content, for analyses of selected chlorites*

[From Foster (1962, table 2, p. A27–A29)]

Analysis	Si	Al(IV)	Al(VI)	Ti	Fe^{3+}	Fe^{2+}	Mn^{2+}	Mg	Octahedral cations	O	OH	Relation of (OH) to theoretical
						Fe^{2+} : R^{2+}=0.00–0.25						
1	2.50	1.50	1.56	0.01	0.26	0.61	0.01	3.91	6.36	11.03	6.97	Deficient.
3	2.52	1.48	1.54	.01	.02	.10	04	4.28	5.99	10.07	7.93	Near theoretical.
4	2.60	1.40	1.41	------	.51	.84	------	3.15	5.91	10.38	7.62	Deficient.
5	2.60	1.40	1.44	.00	.04	.41	.00	4.24	6.13	10.31	7.69	Do.
6	2.61	1.39	1.50	------	.00	.71	------	3.92	6.13	10.39	7.61	Do.
7	2.59	1.41	1.30	.00	.13	.41	.00	4.14	5.98	9.99	8.01	Near theoretical.
9	2.60	1.40	1.28	------	.10	.03	.00	4.56	5.97	9.89	8.11	Do.
11	2.61	1.39	1.21	------	.12	.24	------	4.34	5.91	9.78	8.22	High.
13	2.66	1.34	1.32	------	.22	.51	------	3.97	6.02	10.25	7.75	Deficient.
14	2.64	1.36	1.32	------	.05	.33	.00	4.30	6.00	10.00	8.00	Theoretical.
15	2.62	1.38	1.14	.01	.13	.64	.03	3.99	5.94	9.83	8.17	Near theoretical.
16	2.66	1.34	1.40	.01	.04	.76	.01	3.77	5.99	10.08	7.92	Do.
17	2.68	1.32	1.58	------	.02	.03	.00	4.33	5.96	10.16	7.84	Do.
18	2.72	1.28	1.16	.08	.16	1.15	------	3.68	6.23	10.65	7.35	Deficient.
20	2.69	1.31	1.37	------	.29	.42	------	3.81	5.89	10.13	7.87	Near theoretical.
22	2.73	1.27	1.58	------	.29	.87	.15	3.07	5.96	10.51	7.49	Deficient.
23	2.65	1.35	1.20	------	.02	.24	.02	4.52	6.00	9.87	8.13	Near theoretical.
25	2.72	1.28	1.13	------	.07	.00	.05	4.72	5.97	9.88	8.12	Do.
26	2.77	1.23	1.42	.02	.00	1.01	.00	3.62	6.07	10.36	7.64	Deficient.
27	2.78	1.22	1.28	------	.04	.02	------	4.66	6.00	10.10	7.90	Near theoretical.
29	2.77	1.23	1.13	------	.06	.14	------	4.63	5.96	9.96	8.04	Do.
30	2.80	1.20	1.12	.03	.20	.50	.02	4.23	6.10	10.39	7.61	Deficient.
34	2.78	1.22	1.10	.01	.12	.34	.00	4.37	5.94	9.88	8.12	Near theoretical.
35	2.83	1.17	1.05	------	.30	.10	------	4.62	6.07	10.38	7.62	Deficient.
36	2.79	1.21	1.15	------	.00	.04	.00	4.75	5.94	9.84	8.16	Near theoretical.
37	2.80	1.20	1.04	------	.12	.01	------	4.76	5.93	9.80	8.20	Do.
38	2.84	1.16	1.06	------	.02	.53	.02	4.39	6.02	9.99	8.01	Do.
42	2.83	1.17	.84	.00	.13	.13	.00	4.71	[1] 5.90	9.64	8.36	High.
43	2.89	1.11	.99	------	.19	.32	------	4.64	6.14	10.20	7.80	Near theoretical.
44	2.87	1.13	1.07	.00	.02	.15	.00	4.72	5.96	9.99	8.01	Do.
45	2.88	1.12	.89	------	.24	.05	.00	4.82	6.00	10.00	8.00	Theoretical.
46	2.92	1.08	1.27	------	.02	.24	------	4.50	6.03	10.22	7.78	Deficient.
48	3.03	.97	1.19	------	.04	.29	------	4.98	6.50	11.23	6.77	Very deficient.
49	2.88	1.12	.89	------	.14	.08	------	4.78	5.89	9.70	8.30	High.
50	2.91	1.09	.97	.00	.12	.11	.00	4.73	5.93	9.86	8.14	Near theoretical.
51	2.93	1.07	.82	------	.16	.40	------	4.59	5.97	9.86	8.14	Do.
53	2.94	1.06	.91	------	.14	.29	.03	4.62	5.99	9.93	8.07	Do.
54	2.94	1.06	.85	------	.21	.05	.00	4.87	5.98	9.92	8.08	Do.
55	2.95	1.05	1.03	------	.11	.49	.00	4.29	5.92	9.92	8.08	Do.
56	2.96	1.04	1.00	.01	.14	.38	.00	4.39	5.92	9.95	8.05	Do.
57	2.96	1.04	.90	.00	.14	.14	.00	4.61	[2] 5.88	9.82	8.18	Do.
58	3.00	1.00	.70	------	.03	.09	.00	4.91	[3] 6.04	10.14	7.86	Do.
59	2.98	1.02	.94	.00	.00	.73	.01	4.29	5.97	9.88	8.12	Do.
60	2.97	1.03	.87	.00	.14	.12	.00	4.69	5.82	9.62	8.38	High.
61	3.02	.98	.87	.00	.04	.08	.00	4.97	[4] 6.02	10.07	7.93	Near theoretical.
62	3.05	.95	.99	.00	.04	.29	.01	4.76	6.09	10.24	7.76	Deficient.
64	3.07	.93	.73	.01	.20	.46	.02	4.72	6.14	10.29	7.71	Do.
66	3.07	.93	.82	.00	.04	.06	.00	5.06	5.98	9.92	8.08	Near theoretical.
67	3.04	.96	.68	.01	.13	.28	.00	4.66	[5] 5.86	9.69	8.31	High.
69	3.12	.88	1.30	.01	.17	.32	.00	3.96	5.76	10.16	7.84	Near theoretical.
72	3.13	.87	.76	.00	.17	.27	.00	4.62	[6] 5.83	9.68	8.32	High.
76	3.24	.76	.39	.01	.61	.19	.02	4.21	5.43	9.14	8.86	Do.
77	3.41	.59	.59	------	.07	.14	.00	5.43	6.23	10.50	7.50	Deficient.
78	3.53	.47	.93	.00	.07	.56	.01	4.47	6.04	10.61	7.39	Do.
						Fe^{2+} : R^{2+}=0.25–0.75						
79	2.50	1.50	1.20	------	1.40	1.37	------	1.93	5.90	10.93	7.07	Very deficient.
80	2.42	1.58	1.41	------	.33	2.64	------	1.58	5.96	10.06	7.94	Near theoretical.
83	2.56	1.44	1.31	------	1.10	2.40	------	1.13	5.94	10.84	7.16	Deficient.
84	2.50	1.50	1.09	------	.41	1.70	------	2.77	5.97	9.95	8.05	Near theoretical.
85	2.59	1.41	1.74	.01	.77	2.34	.02	1.01	5.89	10.90	7.10	Deficient.
86	2.50	1.50	1.20	.01	.39	2.40	------	1.75	5.75	9.66	8.34	High.
89	2.65	1.35	1.50	.00	.50	1.90	------	2.23	6.13	10.90	7.10	Very deficient.
90	2.60	1.40	1.35	------	.22	1.52	.02	2.91	6.02	10.21	7.79	Deficient.
91	2.63	1.37	1.24	.00	.68	1.75	------	2.30	5.97	10.49	7.51	Do.
92	2.63	1.37	1.59	------	.38	2.03	.02	1.90	5.92	10.40	7.60	Do.
94	2.67	1.33	1.39	.01	.27	2.20	.04	2.31	6.22	10.77	7.23	Do.
95	2.61	1.39	1.40	.01	.22	2.44	.03	2.09	6.19	10.66	7.34	Do.
96	2.67	1.33	1.50	.10	.62	1.95	.03	1.62	5.82	10.63	7.37	Do.
97	2.65	1.35	1.39	.00	.27	1.82	.06	2.42	5.96	10.24	7.76	Do.
101	2.65	1.35	1.90	.01	.04	2.74	.05	1.14	5.88	10.39	7.61	Do.
102	2.70	1.30	1.49	------	.23	1.64	------	2.80	6.16	10.73	7.27	Do.
103	2.68	1.32	1.35	------	.36	2.06	.04	2.30	6.11	10.59	7.41	Do.
104	2.66	1.34	1.24	.00	.39	2.16	.05	2.08	5.92	10.11	7.89	Near theoretical.
105	2.67	1.33	1.21	.00	.32	1.94	.02	2.46	5.95	10.11	9.89	Do.
106	2.70	1.30	1.34	.07	.22	1.90	.03	2.40	5.96	10.35	7.65	Deficient.

See footnotes at end of table.

TABLE 8.—*Atomic ratios, based on determined H_2O content, for analyses of selected chlorites*—Continued

Analysis	Si	Al(IV)	Al(VI)	Ti	Fe^{3+}	Fe^{2+}	Mn^{2+}	Mg	Octahedral cations	O	OH	Relation of (OH) to theoretical
						$Fe^{2+} : R^{2+}$=0.25–0.75—Continued						
107	2.67	1.33	1.12	----------	.25	2.64	.00	2.12	6.13	10.32	7.68	Deficient.
108	2.73	1.27	1.61	.02	.26	1.75	.02	2.31	5.97	10.58	7.42	Do.
109	2.79	1.21	1.75	----------	.02	1.71	.02	2.87	6.37	11.30	6.70	Very deficient.
110	2.70	1.30	1.21	.00	.14	1.60	.05	3.02	6.02	10.08	7.92	Near theoretical.
111	2.69	1.31	1.12	----------	.14	1.84	.04	2.86	6.00	9.99	8.01	Do.
112	2.68	1.32	1.41	----------	.26	1.72	.05	2.35	5.79	9.95	8.05	Do.
113	2.73	1.27	1.17	.00	.79	2.34	.00	1.59	5.89	10.44	7.56	Deficient.
115	2.80	1.20	1.03	.00	1.04	2.78	.27	.93	6.05	10.96	7.04	Very deficient.
117	2.69	1.31	1.03	.01	.09	1.38	.03	3.39	5.93	9.72	8.28	High.
119	2.76	1.24	1.26	.00	.15	1.74	.02	2.77	5.94	10.06	7.94	Near theoretical.
120	2.79	1.21	1.20	.02	.27	1.90	.02	2.52	[7] 5.94	10.21	7.79	Deficient.
123	2.88	1.12	1.22	----------	.47	2.36	.00	1.84	5.89	10.30	7.70	Do.
126	2.96	1.04	1.61	----------	.66	1.70	----------	1.96	5.93	11.10	6.90	Very deficient.
127	2.82	1.18	.90	----------	.55	1.93	.00	2.30	[8] 5.73	9.69	8.31	High.
129	2.89	1.11	.81	.01	1.00	1.54	.00	2.11	5.47	9.68	8.32	Do.
130	3.02	.98	.96	----------	.31	2.26	.02	2.32	5.87	9.96	8.04	Near theoretical.
131	3.12	.88	1.64	.03	.18	2.61	.12	1.15	5.73	10.47	7.53	Deficient.
132	3.01	.99	1.02	----------	.14	2.88	.05	1.53	5.62	9.38	8.62	Very high.
133	3.28	.72	1.40	.02	.23	2.42	.00	2.10	6.17	11.28	6.72	Very deficient.
134	3.37	.63	.93	----------	.75	2.08	.12	2.02	5.90	10.87	7.13	Do.
						$Fe^{2+} : R^{2+}$=>0.75						
135	2.36	1.64	1.05	----------	.88	3.31	.08	.61	5.93	10.14	7.86	Near theoretical.
136	2.42	1.58	.83	.00	.76	3.69	----------	.72	6.00	10.01	7.99	Do.
137	2.42	1.58	1.12	.00	.85	3.20	.04	.53	5.74	9.88	8.12	Do.
139	2.52	1.48	1.43	.00	.07	4.17	.00	.40	6.07	10.19	7.81	Do.
140	2.50	1.50	1.02	.02	.79	3.56	.01	.37	5.77	9.84	8.16	Do.
141	2.60	1.40	1.37	.00	.65	3.45	.00	.66	6.13	10.88	7.12	Very deficient
142	2.56	1.44	1.56	.01	.39	3.81	.02	.20	5.99	10.47	7.53	Deficient.
144	2.64	1.36	.62	.02	1.06	3.70	.00	.60	6.00	10.38	7.62	Do.
147	2.57	1.43	.92	----------	.37	3.33	.00	.88	5.50	8.85	9.15	Very high.
148	2.74	1.26	1.64	----------	.62	2.92	.00	.59	5.77	10.56	7.44	Deficient.
149	2.66	1.34	1.01	.00	.35	3.71	.00	.77	5.84	9.71	8.29	High.
150	2.73	1.27	1.40	.00	.18	3.40	.05	.93	5.96	10.19	7.81	Near theoretical.
151	2.74	1.26	1.34	.03	.50	2.93	.08	.82	5.70	10.08	7.92	Do.
152	2.99	1.01	1.66	.02	.11	3.43	.20	.45	5.87	10.57	7.43	Deficient.
153	2.95	1.05	1.05	.00	.56	3.18	----------	.74	5.53	9.58	8.42	High.
154	3.34	.66	1.66	.02	.20	3.19	.12	.44	5.63	10.49	7.51	Deficient.

Footnotes 1–4 include—
[1] 0.07 Cr^{3+}, and 0.02 Ni.
[2] 0.09 Cr^{3+}.
[3] 0.31 Cr^{3+}.
[4] .06 Cr^{3+}.

Footnotes 5–8 include—
[5] 0.08 Cr^{3+}, and 0.02 Ni.
[6] 0.01 Cr^{3+}.
[7] 0.01 Ni.
[8] 0.05 Cr^{3+}

REFERENCES

Brindley, G. W., and Youell, R. F., 1953, Ferrous chamosite and ferric chamosite: Mineralog. Mag., v. 30, p. 57–70.

Clarke, F. W., 1910, Analyses of rocks and minerals from the laboratory of the United States Geological Survey, 1880–1908: U.S. Geol. Survey Bull. 419, p. 285–289.

Dana, E. S., 1892, A system of mineralogy, 6th ed: New York, John Wiley and Sons, p. 617–619, 630–633.

Eugster, H. P., and Wones, D. R., 1962, Stability relations of the ferruginous biotite, annite: Jour. Petrology, v. 3, p. 82–125.

Foster, M. D., 1956, Correlation of dioctahedral potassium micas on the basis of their charge relations: U.S. Geol. Survey Bull. 1036–D, p. 57–67.

Foster, M. D., 1960a, Interpretation of the composition of trioctahedral micas: U.S. Geol. Survey Prof. Paper 354–B, p. 24–49.

——— 1960b, Interpretation of the composition of lithium micas: U.S. Geol. Survey Prof. Paper 354–E, p. 115–147.

——— 1962, Interpretation of the composition of chlorites: U.S. Geol. Survey Prof. Paper 414–A, p. A1–A33.

Foster, M. D., Wones, D. R., and Eugster, H. P., 1963, The atomic ratios of natural ferruginous biotites, with reference to the Stability relations of the ferruginous biotite, annite: Jour. Petrology, v. 4, no. 2, p. 302–306.

Gottesmann, Bärbel, 1962, Über einige Lithium-Glimmer aus Zinnwald und Altenberg in Sachsen: Geologie, v. 11, no. 10, p. 1164–1176.

Volk, G. W., 1939, Optical and chemical studies of muscovite: Am. Mineralogist, v. 24, p. 255–266.