nearly equal to the amount of the structural hydroxyl ions in an ideal muscovite layer, suggesting that the weight-loss above 400° C. involves the liberation of both the interlayer ammonium ions and the structural water.

Discussion

In sericites or so-called illites, the presence of hydronium ions (H_3O^+) has been frequently suggested. These suggestions are based mainly on either weight-loss studies which seem to suggest a presence of strongly chemisorped interlayer water, or on charge balance requirements throughout the crystal, but no direct evidence has yet been obtained. At an early stage of the present investigation, the presence of hydronium ions was assumed in order to interpret the excess decrease of alkali ions over the increase of the ratio, Si/Al, in the tetrahedral layers, and also the abnormal weight-loss characteristics of the disordered sericites (Fig. 2). As described above, however, the interlayer ammonium ions can account for these abnormalities without assuming the presence of hydronium ions, except that the specimen 302 still retains a little excess of the ignition loss (about 0.7%) after the subtraction of ammonium ions, which may indicate the presence of H_3O^+. Without direct evidence, however, presence of the hydronium ion is still open to question. Details of the present investigation will be reported in the near future.

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VARIATIONS OF THE BASAL SPACINGS OF MUSCOVITE IN SILLIMANITE-BEARING PELITIC SCHISTS OF NORTHWESTERN MAINE

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Introduction

During a detailed petrologic study of the pelitic schists of N.W. Maine (for location see Fig. 1, Guidotti, 1963) it became apparent that the basal spacings of muscovite in sillimanite-bearing rocks fall into distinct ranges corresponding to the metamorphic grade, Guidotti (1963), (1965A) and Evans and Guidotti (1966). This note is primarily concerned with the data on basal spacings which indicates that muscovite is very sensitive to changes in metamorphic conditions. It is suggested that other workers might find this easily measured parameter useful in studying pelitic schists.

Since the basal spacings of muscovite vary with their K/Na ratio, Yoder and Eugster (1955), it is apparent that the K/Na ratio of the muscovite in these sillimanite-bearing rocks is related to the metamorphic grade. The work of Evans and Guidotti (1966) indicates a straight-line

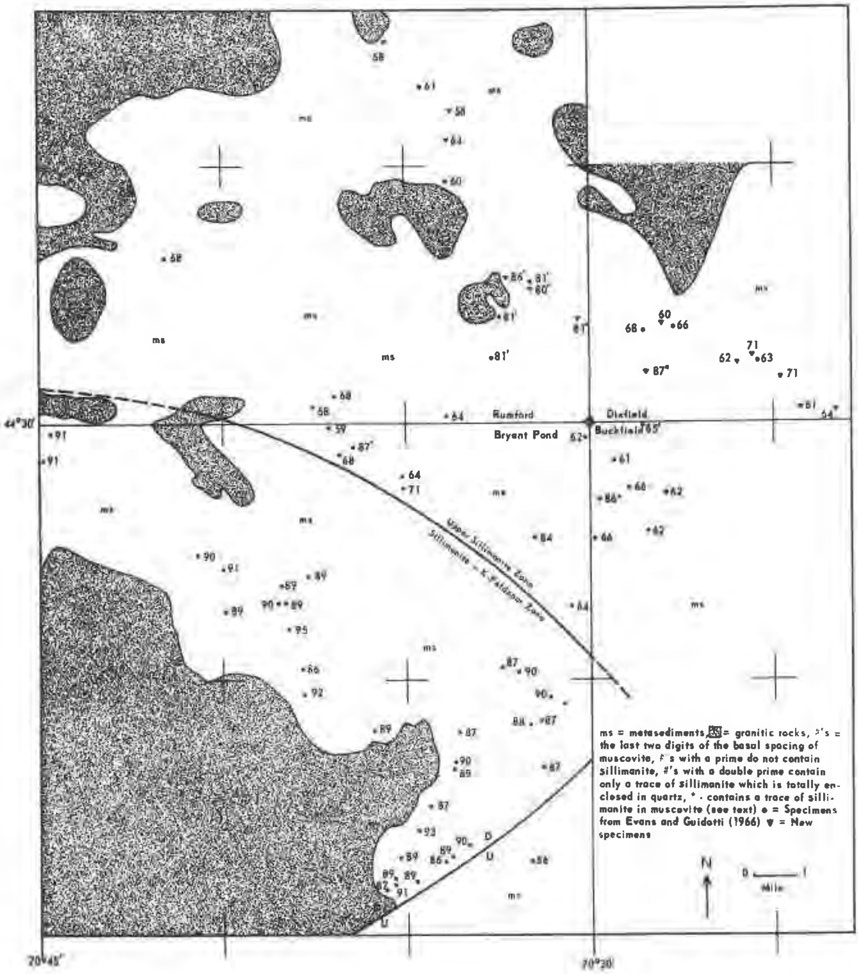
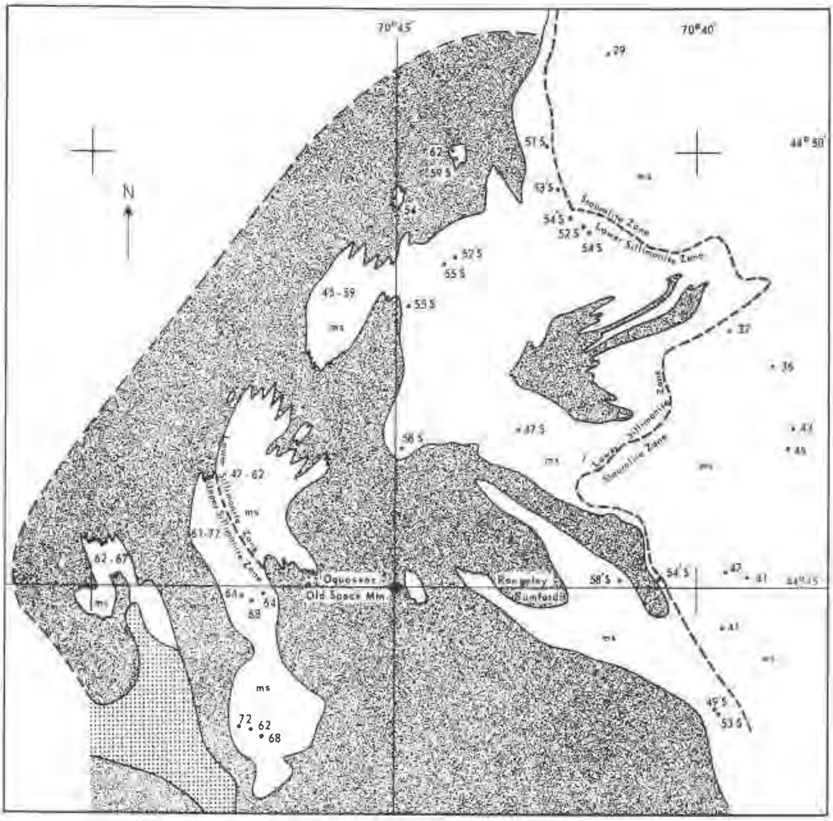


FIG. 1. Locations of Specimens



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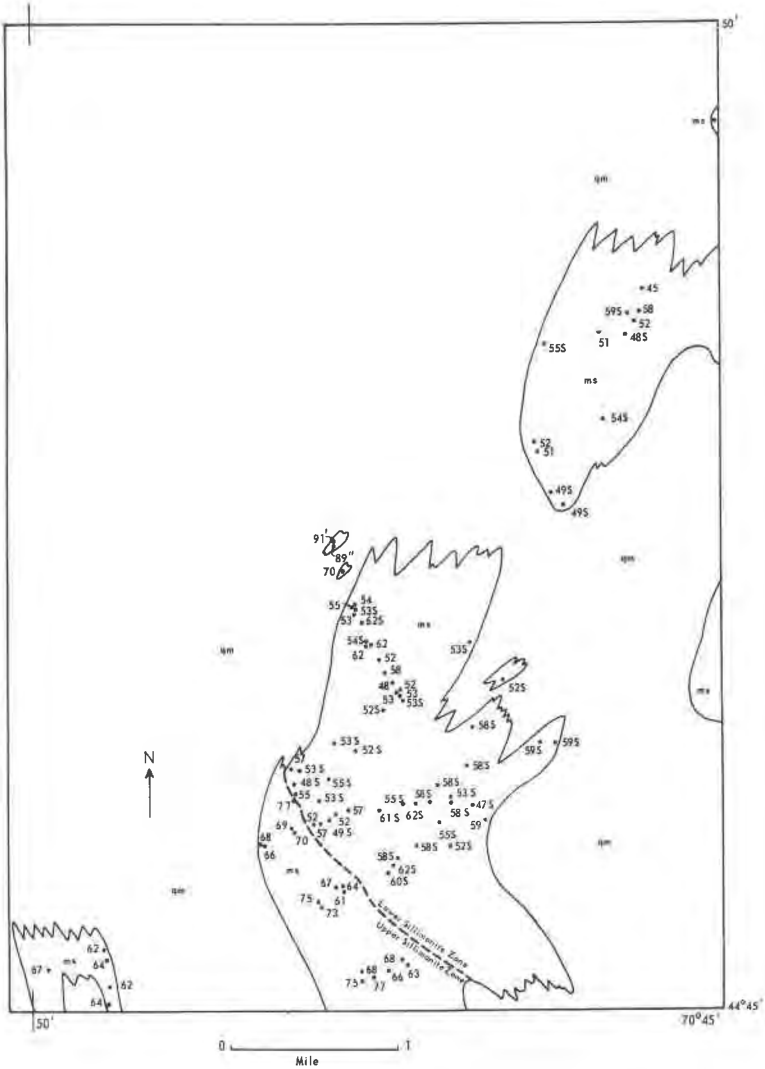
ms = metasediment, [symbol]= Quartz monzonite, [symbol]= Umbagog granodiorite, •'s = the last two digits of the basal spacing of muscovite, S = Staurolite present, •'s with a prime do not contain sillimanite Specimens in the staurolite zone contain staurolite + primary chlorite

FIG. 2. Geologic Map of Portions of the Oquossoc, Old Speck Mtn., Rumford, and Rangeley Quadrangles, Maine

relationship between the basal spacings and K/Na ratio for much of the range of muscovite compositions under consideration.

Figures 1, 2 and 3 show the distribution of specimens in the two regions studied (Fig. 3 is an enlargement of part of Fig. 2) and also indicate the different grades of metamorphism—*i.e.*, lower sillimanite zone (Thompson, 1957, p. 851), upper sillimanite zone, and the K-feldspar-sillimanite zone. Only a few specimens from the staurolite zone in the Rangeley quadrangle have been included because work there has just begun. The transition between the lower and upper sillimanite zone is based upon the disappearance of staurolite.



ms = Metasediments, qm = Quartz Monzonite, #'s = the last two digits of the basal spacing of muscovite, #'s with a prime, do not contain sillimanite, #'s with a double prime contain sillimanite totally enclosed in quartz S = Staurolite present

FIG. 3. Geologic Map of the S.E. 1/9 of the Oquossoc Quadrangle

METHODS OF STUDY

The assemblage in each specimen was determined in thin section. Muscovite for x-ray determination was obtained by grinding a small chip of each specimen and separating the muscovite by means of a

Frantz magnetic separator and heavy liquids. Slide amounts of muscovite (at least 80% pure) were then prepared for diffractometer scans.

All runs were made on a General Electric XRD-6 diffractometer using CuKα radiation with a Ni filter. Instrumental settings include: 0.1° slit, scanning speed of 0.4° of 2θ/min., chart speed of 1 inch/min., time constant of 4, and range of 1000. Each sample was scanned at least twice, backward and forward, from 48° to 45° with reagent grade CaF_2 as an internal standard. In most cases the (0010) peak of muscovite (2m polymorph) and (220) peak of the fluorite were about the same height. Measurements of d for (002) of muscovite are accurate to ± 0.002 Å. Only the last two digits from each basal spacing value have been plotted on Figs. 1, 2, and 3. For example, the number 58 is taken from 9.958 Å.

Descriptions of Individual Areas

Figure 1 shows the location of specimens above and below the K-feldspar-sillimanite isograd in the Bryant Pond region. The distribution of granitic bodies in the Rumford quadrangle is from Forsythe (1955), in the Dixfield quadrangle from Pankiwskyj (1964), in the Buckfield quadrangle from Warner (unpublished), and in the Bryant Pond quadrangle from Guidotti (1965B). Below the isograd the sillimanite-bearing rocks all contain the assemblage qtz+plag+sill+musc+bio+ilm$\pm$pyrrho$\pm$garn. With few exceptions all rocks contain 5% or more of sillimanite, and in all specimens the sillimanite occurs as swirls and stringers of fibrolite in the micas (especially biotite) which extends out into the surrounding quartz and feldspar grains. The basal spacings of the muscovite fall within the range 9.958 to 9.971 Å, with one exception at 9.984 Å.

Also shown are specimens with the same assemblage as above except that sillimanite is absent or is present only in trace amounts as trains of needles which are totally enclosed in quartz (especially in those quartz grains which occur as abundant inclusions in poikiloblasts of muscovite). In both cases the rocks are highly micaceous and can be termed pelitic schist. The basal spacings of muscovite in these rocks lie between 9.980 and 9.987 Å. Presumably the rocks with sillimanite totally enclosed in quartz indicate only approximate equilibrium or else represent an example of very local equilibrium with the sillimanite in equilibrium with the quartz but not with the micas. If only very local equilibrium has been attained, then for some petrologic purposes (such as a consideration of the muscovite composition) it may be valid to ignore the sillimanite inclusions within the quartz. It seems likely that sillimanite was once present also in the micas but disappeared by reaction leaving only the needles now preserved in the quartz. This is supported by the almost universal observation that the first sillimanite to form during prograde metamorphism is in the micas (especially biotite). The exact manner of disappearance of sillimanite by reaction is unknown but may involve a mechanism such as a back-reaction or readjustment to equilibrium following an initial metastable formation of the sillimanite. Nonetheless it would seem likely that these rocks, as well as those devoid of sillimanite, formed at about the same time and in approximate equilibrium with the rocks containing abundant sillimanite within the micas. This is supported by the following: (1) There is little or no evidence in rocks throughout the region that indicates later retrograding. (2) On an A-K-Na projection, Thompson (1961), it can be seen that the muscovite in sillimanite-free rocks should be consistently more K-rich (larger basal spacings) than in rocks with sillimanite. This is certainly true for the rocks under consideration, especially if we disregard the sillimanite which is present only as inclusions in quartz.

One mica-rich specimen (with an asterisk in Fig. 1), in which the muscovite has a basal spacing of 9.986 Å, has a trace of sillimanite, most of which is in quartz, but one large muscovite flake contains in its central portion a patch of stubby fibrolite needles. Along some edges of the fibrolite patch the sillimanite needles have been replaced by a cloudy substance and in places by an opaque material. From these textural relations and the basal spacing of the muscovite it seems clear that this rock has not attained equilibrium, not even on a very local scale. Nonetheless, the clear textural evidence that the sillimanite is reacting out of the muscovite lends support to the earlier suggestion that the rocks containing only sillimanite which is fully enclosed in quartz originally had sillimanite in the micas.

Above the K-feldspar-sillimanite isograd rocks that contain both sillimanite and orthoclase have sillimanite in the micas.[1] The basal spacings of the muscovites are within the rather narrow range of 9.986 to 9.995 Å which indicates that the muscovite is more K-rich above the K-feldspar-sillimanite isograd than below it. The chemical data of Evans and Guidotti (1966) shows that this is the case as the muscovite specimens from the sillimanite zone have approximately 14 mole % of the paragonite end member whereas those from the K-feldspar-sillimanite zone have about 6½ mole % paragonite.

Figure 2 shows the location of specimens and the last two digits of the basal spacings of muscovite in the vicinity of the mutual corner of the Oquossoc, Rangeley, Old Speck Mtn., and Rumford quadrangles (see Fig. 1, Guidotti, 1963). The locations of the granitic rocks in the Range-

[1] Also present in this grade, but not considered here, are sillimanite-bearing rocks without orthoclase in which the muscovite has basal spacings intermediate between those of the two grades considered above (see Group III of Evans and Guidotti, 1966).

ley quadrangle are taken from Moench (in press), in the Old Speck Mtn. quadrangle from Milton (1961), in the Rumford quadrangle from Forsythe (1955), and in the Oquossoc quadrangle from Guidotti (unpubl. map, Maine Geol. Survey). The location of the staurolite grade—lower sillimanite grade boundary is, as yet, highly tentative, and is based mainly upon the work of R. Moench (personal communication) with some modification by the writer.

The assemblage in the upper sillimanite zone of Figs. 2 and 3 is qtz +plag+musc+bio+sill+ilm±pyrrho±garn. In addition, one specimen plotted is without sillimanite and one has sillimanite only as inclusions within the quartz.

Five specimens in the lower sillimanite zone, near its lower boundary, do not contain sillimanite. However, the presence of the highly aluminous mineral staurolite suggests that these five specimens would have a bulk composition (in an A-K-Na projection) close to that of the sill +musc+plag field. Thus they would have a muscovite with a K/Na ratio near that of a sillimanite-bearing rock. As indicated by the letter S, many specimens in the lower sillimanite grade do contain staurolite which is commonly enclosed in an aggregate of coarse muscovite flakes that form pseudomorphs. Some rocks near the upper limit of the grade contain only a trace of staurolite in the cores. Guidotti (1965A) and Pankiwskyj (1964) have presented evidence that these pseudomorphs are the result of a prograde reaction; hence the total assemblage in most of these rocks is qtz+plag+sill+musc+bio+ilm±staur±pyrrho ±garn. In addition, four specimens contain relics of andalusite, commonly enclosed by coarse muscovite flakes.

The seven specimens from the staurolite grade contain the assemblage qtz+plag+staur+musc+bio+Mg-chlorite+garn+ilm+pyrrho. A magnesian composition for the chlorite is suggested by its anomalous brown interference color, negative elongation, and (+) optic sign (Albee 1962). Because it occurs as perfectly fresh, independent plates, there is no reason to ascribe a retrograde origin to it.

Here also it is apparent that the basal spacings of the muscovite in the sillimanite-bearing rocks are closely related to the grade of metamorphism. Additional details on the locations of specimens in the SE. $\frac{1}{9}$ of the Oquossoc quadrangle are shown in Fig. 3.

In the upper sillimanite grade (Figs. 2 and 3) we see that:

(1) The muscovite basal spacings are similar to those in the same grade shown in Fig. 1, located about 20 miles to the SE.

(2) The basal spacings of muscovite in the rocks just above the isograd between the lower and upper sillimanite zone indicate a somewhat more K-rich muscovite than that in the rocks well above the isograd.

(3) The basal spacings of the muscovite in the rocks just above the aforementioned isograd show an abrupt increase when compared with those immediately below the isograd.

In the lower sillimanite zone (Figs. 2 and 3) the basal spacings of muscovite range from 9.945 to 9.962 and average near 9.954. A few values overlap those in the upper sillimanite zone, but nearly all of them are considerably smaller—and when compared to those from just above the transition to the upper sillimanite zone, there is virtually no overlap.

By means of Fig. 4 in Evans and Guidotti (1966) it can be estimated that the mole % of paragonite in a muscovite with a basal spacing of 9.954 Å (the average value in the lower sillimanite zone) is about 20%.

Basal spacings of muscovite in the lower sillimanite grade rise only slightly as the upper sillimanite isograd is approached, and one of the lowest values in the group (9.948 Å) is found just below the isograd (Fig. 3).

The basal spacings of the muscovite in the seven specimens from the staurolite grade are in the range 9.947° to 9.929 Å, values that are considerably less than those in the lower sillimanite grade although there is a minor overlap. However, from an A-K-Na projection, such as that given by Thompson (1961, Fig. 6d), it is apparent that a somewhat more sodic muscovite (lower basal spacing) would be expected in this grade for rocks containing an aluminum silicate such as andalusite. The work of Evans and Guidotti (1966, Fig. 4) indicates that the muscovite with a basal spacing of 9.929 has approximately 30 mole % of paragonite.

Discussion

Some of the factors which might reasonably be expected to affect the K/Na ratio of muscovite (and thus the basal spacing) in sillimanite-bearing rocks are temperature, total pressure, P_{H_2O}, and, in rocks *without* K-feldspar, the An-content of the coexisting plagioclase. Present (but incomplete) data seems to indicate a wide and unsystematic range of An-contents ($An_{15}An_{30}$) for the plagioclase in the staurolite, lower sillimanite, and upper sillimanite grade rocks. Hence it would seem that the other three variables may be the more important ones. Certainly there seems to be a relationship between the values of the muscovite basal spacings and the metamorphic grade. In the study of Evans and Guidotti (1966) on the K-feldspar-sillimanite isograd it is suggested that T and P_{H_2O} were especially important and that above the isograd the P_{H_2O} were especially important and that above the isograd the P_{H_2O} was internally controlled or buffered by the mineral assemblage. It is hoped that work in progress will shed light on the relative importance of these variables for the transition from the staurolite grade to the upper sillimanite grade. It will be of interest to see if the distribution of basal spacing values for the various grades and assemblages considered above will be maintained as work is extended to the surrounding regions.

Detailed observations on the manner in which solid solution phases (such as muscovite) change composition over a range of metamorphic conditions may be a good key to deciphering the relative importance of the pertinent variables and may (if the solid solution phase is a hydrous one) shed some light on whether a variable such as P_{H_2O} can vary abruptly (possibly controlled by changes in the assemblage present) or whether it is externally controlled along smooth gradients (a boundary value component of Zen, 1963) such as is commonly assumed for temperature.

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