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NATURAL MICA STUDIES

By

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INTRODUCTION

Mineralogical and structural studies of natural micas was initiated with financial support from the U. S. Army Signal Corps on September 1, 1951. The work completed during the first quarter period represents an extension and an expansion of studies of this group of minerals that had been in progress in the Department of Mineralogy, University of Michigan since June, 1950. Early work (i.e., prior to September 1, 1951) involved collection and cataloging of samples and measurements of optical constants. X-ray studies which were begun in October, 1950, were directed particularly to the muscovite-lepidolite series. Beginning in September, 1951, the investigation has been expanded along several lines, but initial studies have been concentrated especially on deciphering the relationship between polymorphism and chemical variation.

The following pieces of equipment have been purchased and installed during the first quarter:

1. A North American Phillips x-ray diffraction unit ($3,970).
2. An Otto von der Heyde Weissenberg camera ($1,200).
3. A track for mounting a powder camera ($185).

The following equipment has been ordered:

1. A mechanical grinding mill.
2. A mechanical mortar grinder.

The project is under the supervision of E. Wm. Heinrich, Associate Professor of Mineralogy, and employs the following personnel:

1. Alfred A. Levinson, B.S., M.S., University of Michigan, 1949, 1/2 time.
2. Donald W. Levandowski, B.S., Montana School of Mines, 1950, 1/2 time.
3. Charles H. Hewitt, B.S., Montana School of Mines, 1951, 1/2 time.
4. Mrs. Eleanor G. Smith, B.A., Hunter College, 1947, M.A., Columbia University, 1949, part time.

OPTICAL STUDIES

The three indices of refraction of approximately 250 muscovites have been measured on an Abbé refractometer, and the 2E value of these micas, as well as those of 100 other muscovites from central Colorado, were determined by means of the Fuess axial angle apparatus. Most of these micas were collected by Heinrich during several field seasons and stem from the following districts: the Franklin-Sylva, Shelby and Spruce Pine Districts of North Carolina, the Thomaston-Barnesville district of Georgia, the Petaca District of New Mexico, and various other localities in Alabama, South Dakota, Idaho and Montana. Other micas from the Eight Mile Park and Micanite Districts of Fremont and Park Counties, Colorado, were collected by Levinson during the summer of 1950. The geological occurrences of all these samples are known accurately, and in most cases the deposits from which they were secured have been studied in detail in the field.

The values of 2E, the optical constant showing the largest and most easily determinable variation, as measured on the Fuess axial angle apparatus, can usually be duplicated to within ± 0.5°. However, some of the micas, particularly those from New Mexico and South Dakota, were either heavily stained, bent, or reeved, which resulted in unreliable readings with this method. The indices of refraction were determined on the same specimen of mica for which 2E had been measured. The values of the three indices, which can be obtained with one mounting on the Abbé refractometer, are reproducible to within ± .001.

The data obtained from these measurements support the theory that the variation in geological occurrence, which is a function of the origin of the micas, is reflected in significant variations in the optical properties. Preliminary correlations may be expressed as follows:

1. There appears to be no systematic variation in color of micas from districts in all parts of the United States.

2. There may be a general quantitative relationship between structural defects and certain districts.

3. There is a variation in optical constants with staining (iron oxide inclusions) but the results cannot as yet be expressed in a systematic manner.

In about half of the stained sheets tested, the stained part has indices slightly higher than the clear part, but in the remainder of the specimens, the reverse is true. In most cases 2E is about the same in both parts of the crystal.

4. Within a pegmatite that contains both green and brown muscovite, the green variety will consistently show the larger 2E.

5. Those muscovites with a relatively large 2E, whether green or brown, generally have lower indices than muscovites with a relatively small or moderate-sized 2E.

6. The value of the partial birefringence, $\gamma - \beta$, is greater in green muscovites than in brown ones from the same pegmatite.

The variations in optical and other physical properties are undoubtedly related to variations in the chemistry of the micas, but no adequate studies have been completed to correlate chemistry with color or chemistry with refractive indices in the muscovites or in the lepidolites.

The relationship between color and chemical composition in the biotites has been studied by Hall (1941), who indicates that iron causes a green color and titanium produces brown and red, whereas magnesium dilutes or masks the effects of titanium. Scattered references indicate that variations in iron content with muscovites are accompanied by appreciable color variations. Hall (1941) also has investigated the influence of chemical composition on refractive indices in the biotites and a similar study has been conducted by Heinrich (1947). Further optical studies must await the securance of a relatively large number of chemical analyses.

By combining what is known at the present time with respect to paragenesis, physical properties and optical properties, it is possible to establish a tentative subdivision of pegmatitic muscovites into genetic groups:

1. Magmatic (?) muscovites of wall zones.

2. Early hydrothermal (?) muscovites of core-margin units.

3. Late hydrothermal, fine-grained muscovite (sericite) of replacement units.

4. Late hydrothermal rose or lilac muscovite of replacement units in pegmatites; these usually contain a hydrothermal lithium phase.

The mineralogy of the rose-colored muscovites also has been studied and results may be expected upon completion of five new chemical analyses, financed by the Faculty Research Fund of the University of Michigan.

It is noteworthy that although the measurement of 2E can be duplicated to within 0.5° in most muscovites, there appear in some single specimens variations that cannot be dismissed as being due to a physical macrodefect, such as warping. In several specimens variations from 2 to 5.5° were noted. These variations occur within a relatively small area and are difficult to explain. Possibly local chemical variations must be postulated.

X-RAY STUDIES OF MUSCOVITE

The structures of about 85 muscovites, chiefly of pegmatite origin, have been determined by the Weissenberg X-ray method. Included are "normal" muscovites, rose muscovites and sericites. Without exception all have the two-layered monoclinic structure (monoclinic space group C 2/c) described in detail by Jackson and West (1930, 1933) and Hendricks and Jefferson (1939). These results confirm those of Hendricks and Jefferson (1939), Winchell (1925, 1932, 1935), and others who report polymorphism in all micas except muscovite.

The distinguishing feature of muscovite is that it shows distortion from the ideal structure (Fig. 1). This is deduced from the presence of certain reflections (06l with l odd), which should normally be absent in the ideal arrangement on the basis of the structure-factor calculations of Jackson and West (1930, 1933). This distortion results from an incomplete filling of the octahedral positions and is considered by Hendricks (1939) to be the factor permitting only the two-layered structure for muscovite.

However, in a recent paper, Axelrod and Grimaldi (1949) have reported a new polymorph of muscovite which contains three layers in the monoclinic unit cell and has a very small, variable 2V of from 3° to 15° (Fig. 4). A portion of this analyzed material has been secured and a preliminary study of it substantiates the existence of the new polymorph.

However, there is a striking similarity between the "three-layered monoclinic muscovite" (space group C2 determined by Axelrod and Grimaldi (1949)) Weissenberg photographs and those of the three-layered rhombohedral mica polymorph (space group $C3_112$ or $C3_212$ determined by Hendricks (1939)), recorded for biotite, alurgite, phlogopite, zinnwaldite and lepidolite. There is apparently room for a difference of opinion in the interpretation of the x-ray photographs of this muscovite. Axelrod and Grimaldi (1949) chose the former space group owing to the presence of diffuse scattering in the (h_ak_al) zone lines of one of the pseudo a and pseudo b axes. They state (p. 569),

> "The x-ray symmetry, based on the symmetry of the individual Weissenberg patterns, was C_2h or D_{3d}. If the differences in diffuseness between Weissenberg patterns are neglected, a three-fold axis is demonstrated and the Laue symmetry is D_{3d}. If, as we prefer, the optical axial angle of 12° is not ascribed to strain and the differences in diffuseness are not neglected, the Laue symmetry must be taken as C_{2h} with the structure very close to trigonal."

Not until additional Weissenberg photographs can be studied will it be possible to assign definitely the space group of this polymorph. The cause of the polymorphism in this lone variant of muscovite remains to be explained.

The diffuse scattering mentioned above has been reported by Hendricks (1939) in all micas except muscovite and is observed along those reciprocal lattice lines in which h and k are constant, but in which k is not divisible by three ($h_ak_bl, k_b \neq 3n$). Laue photographs taken perpendicular to the cleavage demonstrate scattering in the form of asterism or radial streaks. Mauguin (1927) first noticed this effect and its significant absence in muscovite, and theorized it was the result of some randomness in the positions of the heavy ions. Hendricks (1939) explained this phenomenon in terms of constant h and k indices with an apparently continuous variation of the l index. This results from a variable periodicity in the stacking of mica layers in such a manner that those planes with the k index a multiple of three are undisturbed. He further states that if one-half a mica layer is translated by nb/3 with respect to the other half, it leaves the layer unchanged but results in a change of the successive layers. This then is the factor which permits polymorphism in the micas. Distortion in the muscovite structure prohibits translation. Continuous scattering, then, arises from destruction of the lattice periodicity perpendicular to the cleavage, resulting from a translation of some layers along the b axis, parallel to the cleavage, by nb/3. Scattering has also been reported in other layered silicate minerals such as stilpnomelane, vermiculite, cronstedite and the chlorites. Essentially the same explanation is given for the phenomenon in these minerals.

In addition to the muscovite described by Axelrod and Grimaldi (1949), Postel and Adelhelm (1944) have described a white muscovite of late hydrothermal origin from the Wissachickon complex in which 2V varied from 22° to 50°. The explanation advanced is that random shift in the structure planes of the mica may have some bearing on the low and variable 2V. In their paper they illustrate a Laue photograph showing asterism which, if not due to some physical defect, may indicate the existence of another muscovite whose structure is aberrant.

Several muscovites have been found which showed scattering (Fig. 2). The scattering, however, was observed only along the (021) reciprocal lattice line (only o-level a-axes photographs have been taken of most muscovites). The exact significance of this scattering has as yet not been determined.

X-RAY STUDIES OF LEPIDOLITE

Because muscovites apparently form continuous chemical and paragenetic series with the lithium-bearing micas, attention also has necessarily been directed to the structure of the lithium micas and lepidolites. About 100 samples of lepidolites have been x-rayed and their symmetry determined. All the polymorphs reported by Hendricks (1939) have been recorded, and in general the results agree favorably with his. One anomaly discovered is a lepidolite whose structure is that of the normal one-layer monoclinic polymorph (space group Cm) but which has its optic plane normal to the side pinacoid instead of parallel with it.

A systematic study has been made of one book of lepidolite for the purpose of determining the extent of polymorphic variations within a single book. The sheets in the book consist of many different crystals, often similarly oriented. Between many of these crystal units are fine-grained aggregates of lepidolite crystal with irregular form and anomalous extinction. The optic planes of the various crystal units in a single sheet are at 30°, or some multiple thereof, to each other.

Below are listed the various polymorphs found in the one book. Samples M29 (A) through M29 (M) are from a sheet near the top of the book. Those numbered M29 (1) through M29 (14) are from a sheet near the center of the book.

M29(a)	6-layer monoclinic
(b)	6-layer monoclinic + 2-layer muscovite type
(c)	6-layer monoclinic + 2-layer muscovite type (faint)

M29(d)	6-layer monoclinic + 2-layer muscovite type
(e)	6-layer monoclinic + 2-layer muscovite type (faint)
(f)	1-layer monoclinic
(g)	6-layer monoclinic + 2-layer muscovite type
(h)	6-layer monoclinic
(i)	6-layer monoclinic + 2-layer muscovite type (very faint)
(j)	6-layer monoclinic + 2-layer muscovite type (very faint)
(k)	1-layer monoclinic
(l)	6-layer monoclinic + 2-layer muscovite type
(m)	6-layer monoclinic
M29(1)	6-layer monoclinic
(2)	6-layer monoclinic
(3)	6-layer monoclinic
(4)	6-layer monoclinic
(5)	6-layer monoclinic
(6)	6-layer monoclinic
(7)	6-layer monoclinic
(8)	6-layer monoclinic + 2-layer muscovite type (faint)
(9)	6-layer monoclinic
(10)	6-layer monoclinic
(11)	6-layer monoclinic
(12)	6-layer monoclinic
(13)	1-layer monoclinic
(14)	6-layer monoclinic

Diffuse scattering is observed in:

M29(a)
(b)
(e)
(g)
(h)
(i)
(j)

M29(1)
(6)
(7)
(8)
(10)

2V on all sections of the sheet, regardless of polymorph, remains invariant.

This list demonstrates that the predominant type is the 6-layer monoclinic. The 6-layer pattern alone or in combination with the 2-layer pattern was obtained in 24 of the 27 attempts. The presence of the 1-layer and 2-layer polymorphs probably must be explained on the basis of chemical variation. If this is the case, chemical variation in lepidolites is possible not only by sheets but within individual sheets.

In this connection the work done on the lepidolites analyzed by Stevens (1938) is of interest. These samples have been studied by Hendricks (1939) and many were also made available for our use by the U. S. National Museum. The following table illustrates the high correlation between Hendricks' (1939) and our data.

Stevens No.	% Li$_2$O	Hendricks-structure	Project M978
1	2.70	Muscovite	Not available
2	3.51	Too fine grained for study	Too fine grained for study
3	3.70		6-layer monoclinic
4	3.81		Too fine grained for study
5	3.96		
6	5.04	6-layer monoclinic	6-layer monoclinic and muscovite
7	5.05	6-layer monoclinic	Not available
8	5.11	Single layer	Single layer
9	5.33	Single layer	Single layer
10	5.39	Single layer	Not available
11	5.51	Not available	Not available
12	5.64	6-layer monoclinic	Not available
13	5.78	Single layer	Single layer
14	5.89	3-layer	3-layer hexagonal
15	6.18	Single layer	Single layer
16	6.84	Single layer	Single layer
17	7.26	Single layer	Not available

On the basis of the preceding results it is suggested that that type of polymorph occurring in lepidolites may be related to the Li$_2$O content. Hendricks, however, states (p. 763),

> "Samples 6 to 17 show three different structures without evident correlation with composition."

Further work along this line is justified before any final decision can be arrived at. It is noteworthy that Stevens No. 8 through No. 17 with the exceptions of No. 12 and No. 14 are all one-layer forms. The percentage of Li$_2$O ranges from 5.11 to 7.26. The content of Li$_2$O in No. 12 probably should be redetermined. Stevens No. 14 is of the three-layer hexagonal type, which is difficult to explain. However, Hendricks (1939) notes (p. 764):

> "While the 6-layer and single-layer lepidolites cannot be distinguished optically, the 3-layer hexagonal structure is immediately evident. This particular sample (Stevens No. 14, U.S.N.M. R4365) is a very large sheet from Londonderry in

> Western Australia. The sheet is predominantly uniaxial, but in a few parts the optic axes (2V) open up to 20-40°. These parts upon examination by x-ray diffraction are found to have the single-layer structure. If the change is to be accounted for by composition, then it is varying on a small scale and the composite nature of the analyzed material would obscure any correlation between structure and composition."

Under these circumstances it would seem best to eliminate this sample from consideration.

Stevens No. 1 is classified as having the muscovite type of structure. The optic plane is normal to (010) as in other muscovites whereas true lepidolites have optic planes parallel with the side pinacoid. It is readily distinguished from normal muscovite by the conspicuous absence of the (020) reflection (Fig. 3). A mica with these characteristics is best referred to as a lithium muscovite.

Between the 2-layer muscovite type and the 6-layer lepidolite type considerable crystallographic "confusion" may be expected as changes such as the rotation of optic plane occur. Hendricks (1939) notes that Stevens' (1938) Nos. 2, 3, 4, and 5, (which are in the above-mentioned interval) are too fine-grained for study, and speculates (p. 763),

> "It is tantalizing to think that samples 2 to 5 owe their poor crystal development to their close approach to the limit of the lepidolite solid solution in muscovite."

It seems very likely that these lepidolites or lithium muscovites owe their defective macrostructural features to small-scale variations in their crystal structure which itself probably is assignable to their transitional position in the muscovite-lepidolite series. If this is the case, it may be that in muscovite itself, chemical composition may be at least partly correlative with structural defects.

In order to study these intermediate micas (Stevens 2 to 5) the powder x-ray method must be employed. Good powder photographs have been obtained of several of the varieties. Results on specimens already studied by the Weissenberg method indicate that the various polymorphs may be recognized by means of powder photographs. The differences are small but distinct. This allows the investigation of very-fine-grained micas.

Further work along this line of investigation requires obtaining more samples of analyzed micas. Letters have been sent to a relatively large number of investigators who have published mica analyses within the last decade and some samples already have arrived.

SUMMARY

The following lines of work have been pursued during the first quarter.

1. Optical distinctions between micas of different districts, occurrences and colors.
2. Chemistry and mineralogy of the rose muscovites.
3. Polymorphism of muscovites.
4. Polymorphism of micas transitional in the muscovite-lepidolite series.

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____________ The Biotite system: Am. Mineral., 20, pp. 773-779 (1935).

APPENDIX

MUSCOVITES X-RAYED

M 1-69	Big Ridge, N. C.
M 2-69	Big Ridge, N. C.
M 3-29	Arrowwood Mine, Macon Co., N. C.
M 4-75	Big Ridge, N. C.
M 5-322	Meyers Quarry, Eight Mile Park, Colo.
M 6-184	Tin Mtn. Pegmatite, Black Hills, S. D.
M 7-29	Arrowwood Mine, Macon Co., N. C.
M 8-72	Big Ridge, N. C.
M 9-185	Bentz Mine, Latah Co., Idaho
M 10-214	La Paloma Mine, Petaca, New Mexico
M 11-299	School Section Pegmatite, Eight Mile Park, Colo.
M 12-297	School Section Pegmatite, Eight Mile Park, Colo.
M 13-129	Zeph Young, Spruce Pine, N. C.
M 14-78	Big Ridge, N. C.
M 15-55	Poll Miller, Macon Co., N. C.
M 16-6	Jasper, Jackson Co., N. C.
M 17-5 (Clear)	Gregory Mine, Jackson Co., N. C.
M 18-5 (Spotted)	Gregory Mine, Jackson Co., N. C.
M 20-123	Meadow Mica Mine, Spruce Pine, N. C.
M 21-97	Alexander Co., N. C.
M 22-338	Suzana No. 1, Eight Mile Park, Colo.
M 23-NH1	Grafton, N. H.
M 24-NH2	East Alstead, N. H.
M 25-149	Upson Co., Ga.
M 26-6P-102a	Brown Derby Peg. Gunnison Co., Colo.
M 30-6P-43	Brown Derby Peg. Gunnison Co., Colo.
M 37-6P-50	Brown Derby Peg. Gunnison Co., Colo.
M 38-6P-101	Brown Derby Peg. Gunnison Co., Colo.
M 36-EWH-MQ	Meyers Quarry, Eight Mile Park, Colo.
M 41-4P-5	Black Hills, S. D.
M 44 X-1	Kimito, Finland
M 45 C21-7	Craigmont Mine Corundum Deposits, Bancroft, Ontario
M 46 X-2	Kimito, Finland
M 47 X-3	Madison, Conn.
M 48 X-4	Varutrask, Sweden
M 49 X-5	Hebron, Maine
M 50 X-6	Karlshus Moss, Norway
M 76 (a)-9037A	Keystone, S. D.
M 76 (b)-9037A	Keystone, S. D.
M 76 (c)-9037A	Keystone, S. D.
M 82 (a) Var-4	Varutrask, Sweden

M 83 (a) Var-5	Varutrask, Sweden
M 83 (b) Var-5	Varutrask, Sweden
M 84 (a) Var-6	Varutrask, Sweden
M 84 (b) Var-6	Varutrask, Sweden
M 85 (a) Heb-1	Hebron, Maine
M 85 (b) Heb-1	Hebron, Maine
M 88 (c) Aub-2	Auburn, Maine
M 94 (c) Top?-1	Topsham, Maine
M 95 (e) Top-2	Topsham, Maine
M 101 (a) Sch-1	Schwarzenberg, Saxony
M 101 (b) Sch-1	Schwarzenberg, Saxony
M 101 (c) Sch-1	Schwarzenberg, Saxony
EWH M-74	Corundum Peg. Gallatin Co., Mont.

Pink Muscovites

M 19	Colo.?
M 52 (a) X-8	Bolton, Mass.
M 52 (b) X-8	Bolton, Mass.
M 60 PM-1	**Iveland**, Norway
M 61 (a) PM-2	Hoeydalen Seter, Norway
M 61 (b) PM-2	Hoeydalen Seter, Norway
M 61 (c) PM-2	Hoeydalen Seter, Norway
M 63 PM-4	Setersdal, Norway
M 64 PM-5	Apache
M 65 PM-6	Newry, Maine
M 66 PM-7	Globe
M 67 PM-38	White Spar No. 1, Colo.
M 75 (a) 6P-90	White Spar No. 1, Colo.
M 75 (b) 6P-90	White Spar No. 1, Colo.

Sericite - Pinite - Margarodite

EWH M-42 (1)	Mica Lode - Eight Mile Park, Colo.
EWH M-42 (2) (repeat)	Mica Lode - Eight Mile Park, Colo.
EWH M-5	Mica Lode - Eight Mile Park, Colo.
M-46 EWH	Mica Lode - Eight Mile Park, Colo.
EWH Pinite	Micanite Ridge, Micanite, Colo.
M 42 C19-7	Lyndoch Peg. No. 1, Bancroft, Ontario
M 43 Meyers Ranch	Meyers Ranch Peg., Colo.
M 53 - 113	Harris Quarry, Rhode Island
M 51 X-7 Margarodite (musc)	Uterdrauberg, Carinthia

Lithium Muscovites (two-layer muscovite type)

M 62 (a) PM-2	Hoeydalen Seter, Norway
(b)	Hoeydalen Seter, Norway
(c)	Hoeydalen Seter, Norway
(d)	Hoeydalen Seter, Norway
M 33 6P-2	Brown Derby, Colorado
M 58 (a) Stevens No. 6	Stewart Mine, Pala, California
M 78 4P-10	Black Hills, S. D.
M 81 (a) Var-3	Varutrask, Sweden
(b)	Varutrask, Sweden
M 82 (b) Var-4	Varutrask, Sweden
M 92 New-3	Newry, Me.
M 95 (b) Top-2	Topsham, Me.
M 98 (a) S.P.-1	South Portland, Me.
(c)	South Portland, Me.

Lepidolites

M 27 6P-21	Brown Derby Peg., Colo.	6-layer Mono. Lepid.
M 28 6P-27	Brown Derby Peg., Colo.	6-layer
M 29 6P-83	Opportunity Peg., Colo.	6-layer
M 29 (a) 6P-83	Opportunity Peg., Colo.	6-layer
(b)	Opportunity Peg., Colo.	6-layer (2-layer)
(c)	Opportunity Peg., Colo.	6-layer (2-layer)
(d)	Opportunity Peg., Colo.	6-layer (2-layer)
(e)	Opportunity Peg., Colo.	6-layer (2-layer)
(f)	Opportunity Peg., Colo.	1-layer
(g)	Opportunity Peg., Colo.	6-layer (2-layer)
(h)	Opportunity Peg., Colo.	6-layer (2-layer)
(i)	Opportunity Peg., Colo.	6-layer
(j)	Opportunity Peg., Colo.	6-layer
(k)	Opportunity Peg., Colo.	1-layer
(l)	Opportunity Peg., Colo.	6-layer (2-layer)
(m)	Opportunity Peg., Colo.	6-layer
M 29 6P-83 (1)	Opportunity Peg., Colo.	6-layer
(2)	Opportunity Peg., Colo.	6-layer
(3)	Opportunity Peg., Colo.	6-layer
(4)	Opportunity Peg., Colo.	6-layer
(5)	Opportunity Peg., Colo.	6-layer
(6)	Opportunity Peg., Colo.	6-layer
(7)	Opportunity Peg., Colo.	6-layer
(8)	Opportunity Peg., Colo.	6-layer (2-layer)
(9)	Opportunity Peg., Colo.	6-layer
(10)	Opportunity Peg., Colo.	6-layer
(12)	Opportunity Peg., Colo.	6-layer

M 29 6P-83 (13)	Opportunity Peg., Colo.	1-layer
(14)	Opportunity Peg., Colo.	6-layer
M 31 (a) 6P-66	Brown Derby Peg., Colo.	6-layer
(b)	Brown Derby Peg., Colo.	6-layer
(c)	Brown Derby Peg., Colo.	6-layer
M 32 6P-2	Brown Derby Peg., Colo.	1-layer
M 34 (a) 6P-3	Brown Derby Peg., Colo.	?
(b)	Brown Derby Peg., Colo.	6-layer (and ?)
(c)	Brown Derby Peg., Colo.	6-layer
M 35 6P-16	Brown Derby Peg., Colo.	6-layer
M 39 (a) 6P-8	Brown Derby Peg., Colo.	6-layer (and ?)
(b)	Brown Derby Peg., Colo.	1-layer
M 40 (a) 6P-117	Brown Derby Peg., Colo.	6-layer (and ?)
(b)	Brown Derby Peg., Colo.	1-layer
M 54 -- 93924 Stevens	15 Ramona, Calif.	1-layer
M 55 (a) Stevens No. 3	Pala, Calif.	6-layer
(b) Stevens No. 3	Pala, Calif.	6-layer
M 56 (a) 86872	Pala, Calif.	1-layer
(b) 86872	Pala, Calif.	1-layer
M 57 (a) Stevens No. 16	Antsongombato, Madagascar	1-layer
(b) Stevens No. 16	Antsongombato, Madagascar	1-layer
M 58 (b) Stevens No. 6	Stewart Mine, Pala, Calif.	6-layer
M 59 (a) Stevens No. 8	Mesa Grande, Calif.	1-layer
(b) Stevens No. 8	Mesa Grande, Calif.	1-layer
M 68 (a) Stevens No. 9	Mesa Grande, Calif.	1-layer
(b) Stevens No. 9	Mesa Grande, Calif.	1-layer
M 69 (a) Stevens No. 13	Mesa Grande, Calif.	1-layer
(b) Stevens No. 13	Mesa Grande, Calif.	1-layer
M 70 (a) Stevens No. 13	Mesa Grande, Calif.	1-layer
(b) Stevens No. 13	Mesa Grande, Calif.	1-layer
M 71 Stevens No. 5	Stewart Mine, Pala, Calif.	6-layer
M 72 Stevens No. 2	Katerina Mine, Pala, Calif.	?
M 73 Stevens No. 4	Chihuahua Valley, Calif.	?
M 74 (a) Stevens No. 14	Calgoorie, W. Australia	3-layer
(b) Stevens No. 14	Calgoorie, W. Australia	3-layer
M 77 -- 903?	Keystone, S. D.	?
M 79 (a) Var-1	Varutrask, Sweden	6-layer
(b) Var-1	Varutrask, Sweden	6-layer
M 80 (a) Var-2	Varutrask, Sweden	6-layer
(b) Var-2	Varutrask, Sweden	6-layer
M 86 (a) Heb-2	Hebron, Maine	?
(b) Heb-2	Hebron, Maine	6-layer
M 87 (a) Aub-1	Auburn, Maine	1-layer
(b) Aub-1	Auburn, Maine	1-layer
M 88 (a) Aub-2	Auburn, Maine	1-layer
(b) Aub-2	Auburn, Maine	1-layer

M 89 (a) Aub-3A	Auburn, Maine	6-layer
(b) Aub-3D	Auburn, Maine	6-layer
(c) Aub-3E	Auburn, Maine	6-layer
(d) Aub-3H	Auburn, Maine	1-layer
M 90 (a) New-1	Newry, Maine	6-layer
(b) New-1	Newry, Maine	6-layer
M 91 (a) New-2	Newry, Maine	6-layer
(b) New-2	Newry, Maine	1-layer
(c) New-2	Newry, Maine	6-layer
(d) New-2	Newry, Maine	1-layer
M 93 Rum-1	Rumford, Maine	?
M 94 (a) Top?-1	Topsham, Maine	1-layer
(b) Top?-1	Topsham, Maine	1-layer
M 95 (a) Top-2	Topsham, Maine	1-layer
(c) Top-2	Topsham, Maine	1-layer
(d) Top-2	Topsham, Maine	1-layer
M 96 (a) Top?-3	Topsham, Maine	1-layer
(b) Top?-3	Topsham, Maine	1-layer
M 97 (a) Top-4	Topsham, Maine	1-layer
(b) Top-4	Topsham, Maine	1-layer
M 98 (b) S.P.-1	South Portland, Maine	1-layer
(d) S.P.-1	South Portland, Maine	1-layer
M 99 Zinn-1	Zinnwald, Bohemia	?
M 100 Zinn-2	Zinnwald, Bohemia	?
M 102 (a) Sk-2	Skuleboda, Sweden	1-layer
(b) Sk-2	Skuleboda, Sweden	1-layer
(c) Sk-2	Skuleboda, Sweden	1-layer
M 103 (a) Sk-1	Skuleboda, Sweden	?
(b) Sk-1	Skuleboda, Sweden	1-layer
(c) Sk-1	Skuleboda, Sweden	1-layer

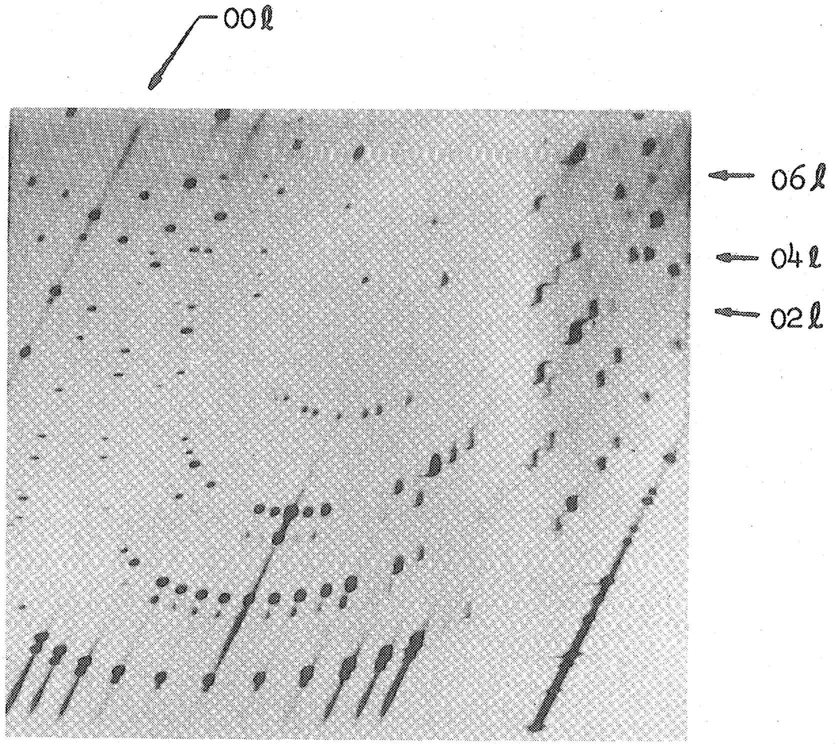

Fig. 1. Muscovite (normal form). 0 level <u>a</u> axis. Specimen M2-69.

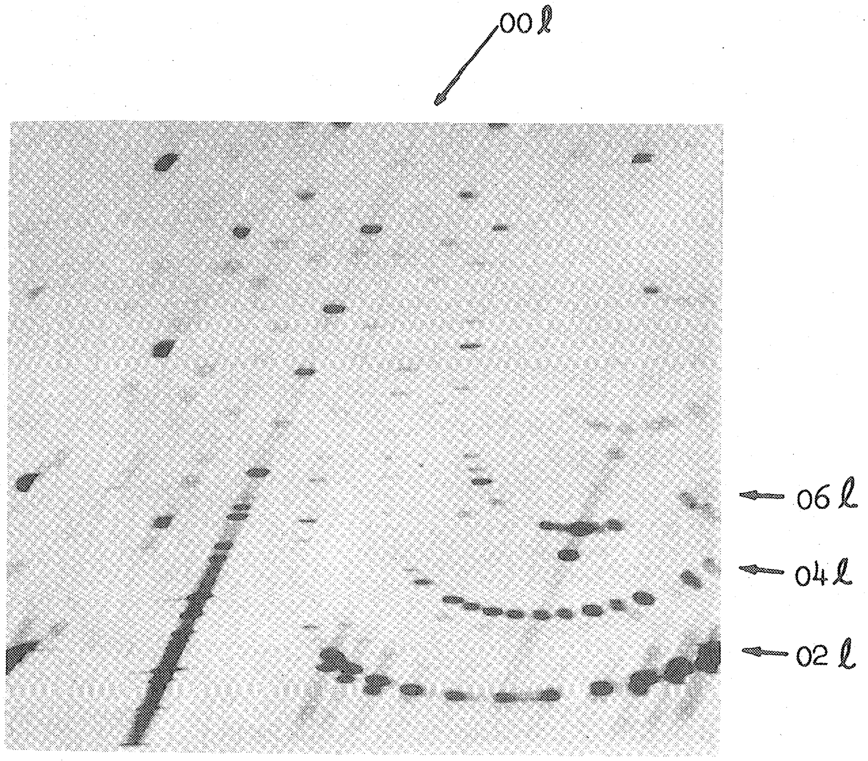

Fig. 2(a). Muscovite showing moderate diffuse scattering along 02ℓ reciprocal lattice line. 0 level a axis. Specimen M16-6.

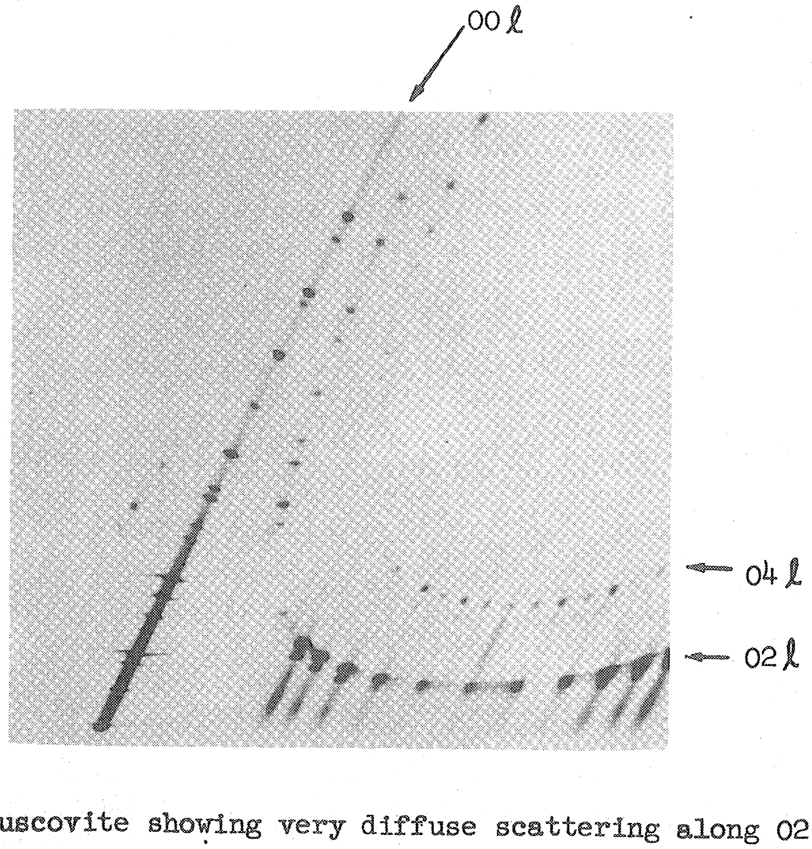

Fig. 2(b). Muscovite showing very diffuse scattering along 02ℓ reciprocal lattice line. 0 level a axis. Another photograph of same specimen (M16-6) as Fig. 2(a).

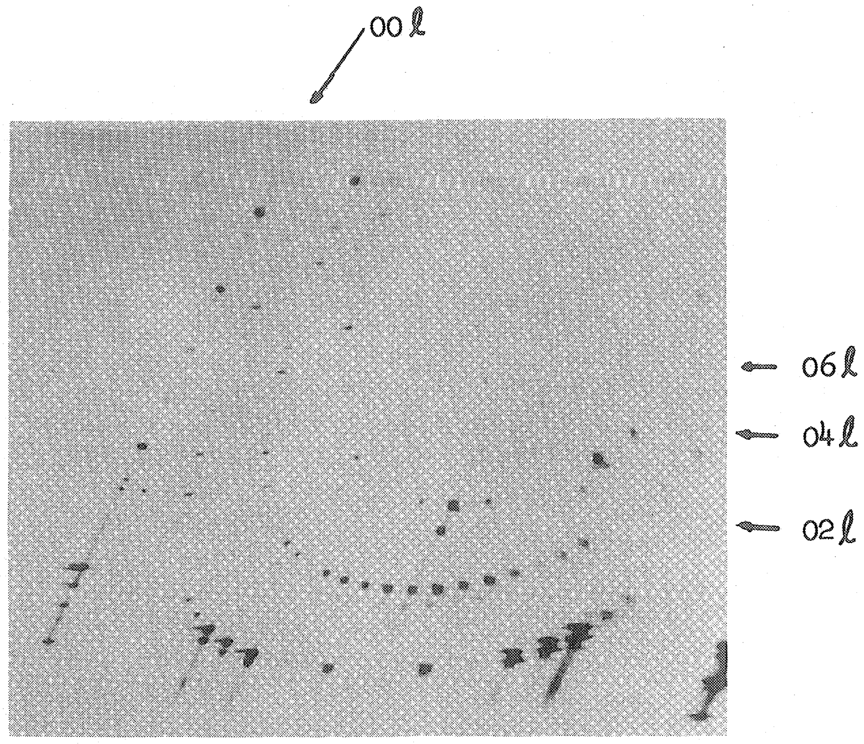

Fig. 3. Lithium muscovite. O level *a* axis. Note absence of 020. (Compare with Fig. 1.) Specimen M58(a) Stevens No. 6.

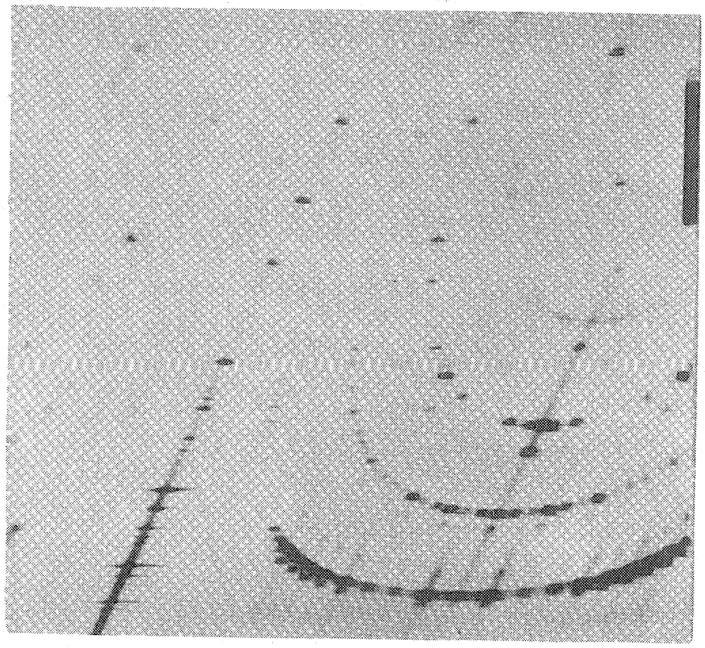

Fig. 4. Three-layered muscovite described by Axelrod and Grimaldi (1949). 0 level a axis.