# STUDIES IN THE MICA GROUP; MINERALOGY OF THE ROSE MUSCOVITES*

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ABSTRACT

Rose muscovite is a variety of muscovite with distinctive paragenetic, optical, and chemical characteristics. It occurs in replacement units of complex pegmatites with a hydrothermal Na-Li phase and is the youngest mica to form, even following lepidolite. Indices of refraction are lower than those of normal muscovite, with average values: $\alpha=1.555$, $\beta=1.586$, $\gamma=1.592$. Chemically the rose muscovites are characterized by the consistent presence of small amounts of $Fe_2O_3$, MnO, $Li_2O$, $Rb_2O$ and F. The unusual color is not related to the $Li_2O$ content but depends upon the essential absence of $Fe^2$ and the dominance of Mn over $Fe^3$.

## INTRODUCTION

This paper purposes to describe the mineralogy and paragenesis of the unusual rose or pink pegmatitic muscovites and to discuss the interrelation of their chemical composition and color. The field work was done by the senior author in New Mexico and Colorado at various times during the summers of 1948, 1949, 1951, and 1952, and in Finland, Sweden, and Norway during the summer of 1950. Laboratory investigations were conducted jointly in 1951–1952.

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## Occurrences

### *United States*

#### New England

*Goshen, Massachusetts:* The occurrence of rose mica at Goshen was recorded by Hitchcock (1841, p. 701). Apparently the first reference to the possibility that this rose mica was not lepidolite was given by Dana (1850), who states (p. 361), ". . . a rose mica is obtained at the albite vein in Chesterfield, Mass., and at Goshen in the same State. . . . The Goshen mineral is of difficult fusibility and slight lithia reaction, and may not be of this species." Mallet (1857) analyzed the Goshen mica and confirmed its very low lithia content, concluding it was muscovite.

The Goshen pegmatites have been described by Julien (1879*A*, 1879*B*), Emerson (1898, 1917), Browne (1933), and Hess and Ralston (1938). The mineral assemblage includes albite, spodumene, blue, green, and pink tourmaline, colorless and light yellow beryl (goshenite), columbite, and cassiterite. The rose mica is associated with the pink tourmaline. Because of its reported large 2E, it is possible that the rose mica from nearby Chesterfield also may be muscovite, but specimens were not available for examination.

*Bolton, Massachusetts:* The Bolton marble quarry, famous for lilac scapolite, has been described by Palache and Pinger (1923) who state (p. 154), "There is an abundance of coarse granite pegmatite boulders in the immediate neighborhood of the quarry but the rock could not be discovered in place . . . the formation of scapolite on the unusually large scale . . . is due to the action of pegmatite intrusions upon the materials of the gneiss limestone contact zone."

Specimens of rose mica-bearing pegmatite from Bolton show the following megascopic zonal arrangement:

(*a*) Wall rock, a ¼-inch remnant of finely granular quartzose schist.
(*b*) Border zone, ½-inch thick, fine-grained white feldspar-quartz rock with minor specks of schorl. The gray quartz rods tend to be normal to the wall.
(*c*) Coarse-grained cleavelandite-smoky quartz-muscovite pegmatite, with mica books as large as two inches across and a few schorl crystals.

A thin section of the border zone shows a fine-grained intergrowth of orthoclase with poikilitic quartz, oligoclase with a narrow sodic selvage, quartz, and rounded deep blue tourmaline grains.

In a thin section of unit *c*, cleavelandite blades can be seen to replace orthoclase of an anhedral equigranular quartz-orthoclase intergrowth. Both the earlier minerals are minutely fractured and locally show marked wavy extinction, neither of which characterizes the albite. Some of the cleavelandite is veined by later quartz and is associated with ragged crystals of irregularly mottled blue tourmaline. Nearly all the mica books have combined wedge and fishtail structure, but some books include flattened euhedral schorl crystals. Some of the smaller books are entirely rose colored, but most are mainly pale yellowish green with rims of pink along one side (Fig. 1). The colors intergrade. Several larger wedged books vary in the proportions of the two colors in different sheets, with green predominating at one end of the book and rose at the other.

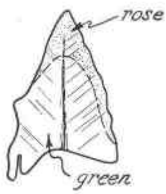


FIG. 1. Zoned rose and green muscovite from Bolton, Massachusetts. $\times\frac{1}{2}$.

*Haddam Neck, Connecticut:* The pegmatite at Haddam Neck contains zoned mica crystals, quartz, albite, and microcline together with green and red tourmaline, green and red apatite, green and brown fluorite, colorless to pink beryl, cookeite, lepidolite, columbite, and microlite (Bowman, 1902, 1903). The columnar mica crystals, as much as 3 inches across and about 2 inches long, are composed of a core of green-white muscovite and a rim of lepidolite, which is in turn coated by fibrous rose muscovite. This fibrous overgrowth consists of parallel *c*-axis needles of rose muscovite. The cleavage plates are made up of minute rhombic units intergrown in a 60°–120° mosaic. The lepidolite-rose muscovite contact is sharp and straight, and the rhombs are either in parallel position or in twin position (Fig. 2). Bowman (1902, p. 120) states, "Among (the micas) themselves they never show any deviation from the order, greenish-white muscovite—lepidolite—fibrous muscovite." Bowman notes the occurrence of similar material at Auburn, Maine, which could not be verified by the writers.

*Lord Hill pegmatite, Rumford, Maine:* According to Woodard (1951) the Lord Hill pegmatite contains an aplitic border zone of oligoclase, myrmekite, microcline, biotite, and muscovite, a wall-zone of albite, quartz, microcline-perthite, and muscovite and a quartz-perthitic microcline core. Aggregates of cleavelandite, fluorite, spessartite, topaz, and muscovite form replacement bodies in the core. Light pink muscovite is interstitial to the cleavelandite blades.

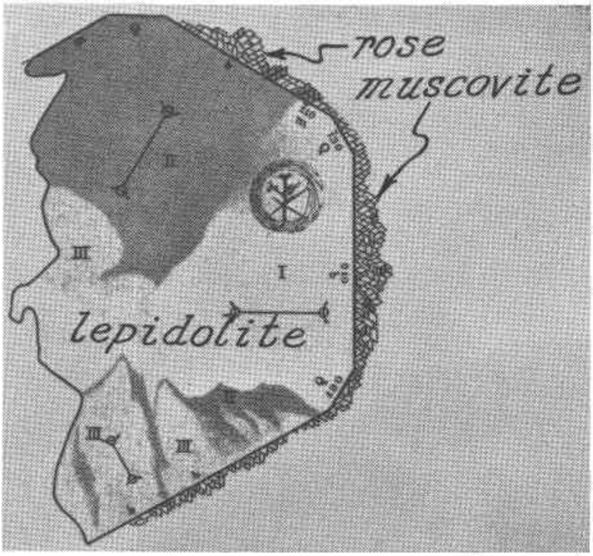


FIG. 2. Oriented overgrowth of fine-grained rose muscovite on lepidolite, after Bowman (1902A). ×5.

## Virginia

*Rutherford pegmatite, Amelia Court House:* Glass (1935) describes a shell-pink variety of muscovite that occurs as tiny fan-shaped plates in the angular cavities between interlocking platy cleavelandite blades. Of five varieties of sericite studied by her, two (varieties 3 and 4) vary in color from aniline lilac to grayish lavender. These (p. 755) ". . . occur in two forms—waxy, talc-like masses, which under high magnification, appear to be aggregates of minute scales or fibers. . . . Varieties 3 and 4 are optically identical. These varieties of muscovite are found intimately associated with the bluish colored cleavelandite albite, in some places filling interstices between the albite plates." Glass also notes that a green sericite (Variety 1) ". . . is penetrated by veinlets of the lilac-colored variety with cleancut contacts."

## New Mexico

*Harding pegmatite, Taos County:* The Harding pegmatite has been known as a source of fine and unusual pegmatitic mineral specimens for several decades, and commercial quantities of lepidolite, spodumene, beryl, tantalite, and microlite have been produced from it. Schaller and Henderson (1926), Hirschi (1928), Hess (1933), Just (1937), Northrop (1942), Jahns and Wright (1944), Montgomery (1950) and Jahns (1951) have described its mineralogy and geology, and Roos (1926), Soulé


PLATE I. Rose muscovite pseudomorphous after spodumene, Harding pegmatite, New Mexico.

(1946) and Berliner (1949) have emphasized the economic aspects of the deposit.

The Harding pegmatite is a nearly horizontal lens-like dike, 50–60 feet in average thickness, which has been traced southwestward down-dip for 1,000 feet. It is known to contain concentrations of beryl, lithium and tantalum minerals for distances of 350 feet along the strike and 650 feet down-dip. The dike is markedly layered:

(0) Hanging-wall amphibolite.
(1) Quartz-muscovite-albitized microcline with minor apatite, columbite, lepidolite; white to rose beryl very abundant locally; 6 inches to 5 feet thick. A similar zone lies locally above the footwall.
(2) Massive quartz, 6 feet thick.
(3) Quartz with long slender spodumene laths; some microcline and beryl near the base; 20 feet thick.
(4) Coarse-grained spodumene-microcline-quartz ("spotted rock"); variable amounts of albite, muscovite, lepidolite, tantalite, and brown microlite; 30 feet thick.
(5) A series of discontinuous lepidolite pods containing spodumene, smoky quartz and yellow microlite.
(6) Cleavelandite-rose muscovite; 20–30 feet thick.
(7) Quartz-cleavelandite; as much as 15 feet thick.
(8) Sugary albite rock; 10 feet thick.

This complete sequence is not present in all parts of the dike, for some units are lensoid and discontinuous. Most of the rose muscovite is concentrated in the cleavelandite-rich replacement unit (6) below the "spotted rock" central unit (4), but some pods of cleavelandite-rose muscovite rock also have been localized along the contact between the quartz-lath spodumene zone (3) and the overlying massive quartz zone (2).

The cleavelandite-rose muscovite rock shows spectacular color contrasts (Plate I). Much of the rose mica occurs as aggregates of fine-grained flakes ($\frac{1}{4}$-inch or less in diameter) that form thin tablets 1–2 inches wide and 5–6 inches long, pseudomorphous after spodumene crystals. All stages of replacement are present, from spodumene laths coated by rose mica films or encroached by a network of ramifying mica veinlets, through composite laths of ragged spodumene relicts and rose mica in varying proportions, to rose mica-granular quartz laths containing only a few rounded blebs of spodumene or none at all (Fig. 3). A few small flakes of yellow microlite and greenish-blue apatite also occur in some of the pseudomorphs. The muscovite flakes are generally rudely oriented with (001) parallel with the flat direction of the lath (100) of the spodumene. Rose muscovite also occurs as elongated to rounded pods, several inches across, of randomly oriented flakes filling interstices between the cleavelandite blades and rosettes (Fig. 4). A few similar mica pods occur in smoky quartz. Much rarer are fist-sized, curved masses of rose mica in which the grain size ranges from cryptocrystalline to coarse-grained.

Locally rose muscovite is associated with anhedral to platy white beryl. Through the kindness of Dr. W. T. Schaller the senior writer was able to examine an apparently unique specimen, collected by Professor Richard H. Jahns, which consists of very fine-grained scaly, rose mica pseudomorphous after a single stubby crystal, $1\frac{1}{4}$ inches on edge and ex-

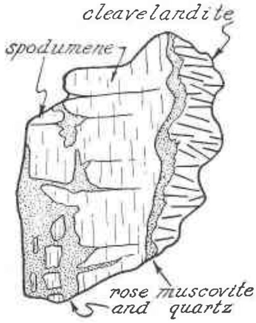


Fig. 3. Rose muscovite replacing spodumene, Harding pegmatite, New Mexico, $\times\frac{1}{2}$.

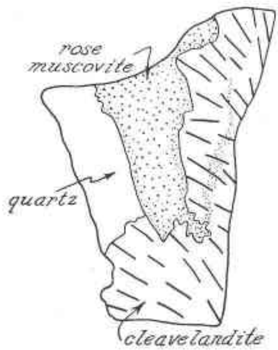


Fig. 4. Rose muscovite pod along quartz-cleavelandite contact, with minor replacement of cleavelandite, Harding pegmatite, New Mexico. $\times\frac{1}{2}$.

posed for three inches along the *c*-axis direction enclosed in massive pink beryl. The crystal is orthorhombic with prisms, basal pinacoid and modifying dome faces and could have been either topaz or andalusite from the habit; from the association topaz seems more probable.

Studies of thin sections of the cleavelandite-rose mica rock support the megascopic paragenetic interpretations. Spodumene blades are invaded by rose muscovite and quartz. Veinlets of mica flakes also follow along contacts between cleavelandite blades or between cleavelandite and quartz, corroding the albite, and bisect masses of anhedral beryl. Many of the muscovite flakes are zoned with a very thin rim that displays a lower birefringence than that of the main central part of the crystal.

Jahns (written communication) states, ". . . the several specimens that I do have and the several other observations that I made in the field all indicate that the pink muscovite is later than the gray and purple lepidolite. In all these places the lepidolite is veined by the muscovite—the pink muscovite, that is. There also is a little fine-grained gray to greenish gray muscovite in the Harding pegmatite that is later even than the pink muscovite."

These combined observations indicate that the rose muscovite is one of the very latest minerals to form. It followed spodumene, cleavelandite, alkali beryl and lepidolite. The lepidolite itself is younger than microcline and the coarse silvery-green book muscovite.

*Pilar pegmatites, Taos County:* The Pilar purple muscovite, described by Schaller and Henderson (1926), differs markedly from the Harding rose muscovite, and all other muscovites, in composition, optical properties, and paragenesis. It occurs in simple, small quartz-microcline pegmatite dikes, and none of the minerals typical of other rose muscovite occurrences are found with it.

*Pittlite pegmatites, Mora County:* Several lithium-tantalum pegmatites on the eastern side of the Sangre de Christo Range near Rociada were examined during June 1951. Brief descriptions of these by Jahns (1946*B*) and Page (1950) do not specifically mention the rose muscovite that is relatively abundant in one of the dikes. Two elongated pegmatite pods, cutting the foliation of fine-grained amphibole schist, strike slightly east of north and are exposed over a distance of about 100 feet. The northern body is 50 feet long, 16 feet wide and is exposed to a depth of 40 feet. Its western contact dips steeply west-northwest, whereas the eastern wall dips about 60° east-southeast. The other dike, a few feet to the south, is 10 feet wide and is exposed for 45 feet.

The northern pegmatite is zoned with:

(1) Wall zone of quartz-sodic plagioclase-muscovite.
(2) Core of quartz with some microcline.
(3) A unit along the western margin of the core consisting mainly of quartz, cleavelandite and lepidolite, with a maximum thickness of about 10 feet, tapering southward.

The southern dike contains similar units, except that the quartz-cleavelandite-lepidolite rock occurs as two irregular central pods. Rarer minerals occurring in the cleavelandite unit are tourmaline, beryl, topaz, spodumene, amblygonite, apatite, monazite, microlite, betafite, tantalite, fluorite, and bismutite.

As in the Harding dike, the rose mica is associated closely with cleavelandite, which at the Pittlite deposit is mottled white to blue-gray. Much of it is interstitial to the blades as elongated or irregular pods, usually one inch or less across. The microscope shows veinlets of muscovite across cleavelandite blades or along blade contacts. Many mica flakes have a thin rim with slightly lower birefringence. Anhedral white beryl also is cut and dactylicly penetrated by mica veins. Many mica flakes are bent or crenulated, with undulatory extinction. Some are peripherally replaced by an aggregate of exceedingly fine-grained sericite of slightly lower refractive index than the rose muscovite. Associated are grains of deep brown microlite and coarser flakes of purple lepidolite. Fist-sized masses of milky topaz are enclosed in a jacket of very fine-grained waxy to coarser flaky rose muscovite. The rose muscovite is younger than cleavelandite, beryl, topaz, and probably lepidolite, though for the latter the relations are not clear-cut.

*Petaca District, Rio Arriba County:* Rose muscovite has been found in pegmatites of the Petaca district, whose geology and mineralogy have been studied by Just (1937), Northrop (1942), Heinrich and Jahns (1946), Jahns (1946*A*) and Wright (1948). A complete bibliography of the literature on these deposits has been compiled by Jahns (1946*A*, pp. 15–16). Most of the pegmatites of economic importance are well zoned and also commonly contain superimposed hydrothermal replacement units of cleavelandite and muscovite. The chief accessory minerals of these replacement bodies are fluorite, columbite, monazite, samarskite, bismutite, and copper sulfides. Pink muscovite was observed in eight deposits, or 12% of the 69 deposits studied by Jahns. The main occurrences are in the Apache and Globe pegmatites, others are in the Kiawa, Canary Bird, Cribbenville, Conquistador and Fridlund deposits. In none, however, is the rose mica abundant. It appears typically as small irregular pods, six inches or less long, in cleavelandite or sugary albite or in quartz pods within cleavelandite units. Flakes are rarely larger than ¼-inch. Columbite and small flakes of pale apple-green muscovite are associates, and in one pod from the Apache mine, pink muscovite grades into green muscovite. Wright's conclusion (1948, p. 688) appears to apply generally to the district, ". . . the pink muscovite is also one of the latest minerals in the Globe pegmatite."

## Colorado

*Quartz Creek District, Gunnison County:* The complex pegmatites near Ohio City resemble the Harding and Pittlite dikes, chemically and mineralogically. Eckel (1933), Landes (1935), Fairchild et al. (1935), Hanley (1947), Hanley, Heinrich and Page (1950) and Staatz and Trites (1950) have presented descriptions of the geology and mineralogy of these pegmatites. At the Brown Derby mine are exposed three parallel dikes that strike N. 56° E. and dip 30–35° SE. The Brown Derby No. 1 dike, the largest and mineralogically most complex, is just over 900 feet long, as much as 40 feet wide at the surface and has been explored down dip for 65 feet.

The lithium-rich part of the dike is strikingly layered:

(0) Footwall, hornblende schist.
(1) Fine-grained albite-quartz unit, with local cleavelandite and accessory schorl, beryl, and lepidolite; average thickness 1.5 feet.
(2) Cleavelandite-quartz-lepidolite-topaz unit with accessory beryl and alkali tourmaline; books of deep lavender lepidolite as much as 10 inches across form a distinct band at the top of the unit; average thickness 2 feet.
(3) Lepidolite-quartz-cleavelandite-microlite unit. The lepidolite is generally fine-grained; alkali tourmaline is an accessory mineral; maximum thickness 8 feet.
(4) Cleavelandite-quartz-curved lepidolite unit with local concentrations of alkali tourmaline; maximum thickness a little less than 2 feet.
(5) Quartz-cleavelandite unit. Mainly massive quartz with veins and replacement masses of cleavelandite; 4 feet thick.
(6) Hanging-wall, hornblende schist.

North of the lithium-rich part the dike consists mainly of quartz-microcline-albite-muscovite rock with minor schorl and beryl. South of the lithium-rich part the dike forks into an eastern limb consisting of quartz-microcline-albite-muscovite pegmatite and a western branch made up mainly of cleavelandite-quartz rock with some lepidolite and alkali tourmaline. In one pit in the western limb there is exposed on the hanging-wall contact a pod of fine-grained albite-quartz-zinnwaldite pegmatite with considerable columbite, monazite, schorl, garnet, and minor gahnite and fluorite.

Most of the rose muscovite appears in unit 2 and is closely associated with the topaz, which occurs in milky, rounded or rudely-faced crystals, as much as four feet long and one foot in diameter. The rose mica, which forms a jacket around the topaz crystals, coating and corroding them, varies from microscopically felted aggregates to coarse flakes $\frac{1}{2}$ inch across. From many of the coatings veinlets of coarse flakes extend into and through the topaz crystals (Fig. 5). Some of the topaz crystals are light pink in color but show no megascopic mica. Under the microscope, these are seen to be strongly brecciated in diverse directions on a small scale. Veinlets of very fine-grained pink mica follow the brecciated zones, surrounding and replacing randomly oriented topaz fragments.

The White Spar No. 1 and No. 2 pegmatites (Hanley, Heinrich and Page, 1950, pp. 77–80) are about 0.8 mile northeast of the Brown Derby group. The White Spar No. 1, which is about 200 feet long and as much as 85 feet wide, trends N. 20° E. and dips 30–35° SE. A wall zone of medium-grained quartz-microcline-muscovite pegmatite surrounds a quartz core four feet thick. A core margin replacement unit of cleavelandite-lepidolite rock, six feet thick, has been developed along the wall zone-core contact, together with a small pod of lepidolite-microlite pegmatite on the hanging wall side of the core. In the core margin unit also occur beryl, topaz, alkali tourmaline, microlite, columbite and rose muscovite. The rose mica occurs in several ways:

(1) As fine to coarse-grained veinlets in and peripheral replacements of topaz.
(2) As veinlets in cleavelandite, with flakes as much as one inch across.
(3) As fine-grained aggregates interstitial to wedge-shaped cleavelandite clusters.
(4) As minute aggregates of flakes in quartz-microcline-oligoclase pegmatite along the outer edge of the core-margin unit. Here coarser flakes occur in quartz, whereas very fine-grained vermicular patches replace microcline.

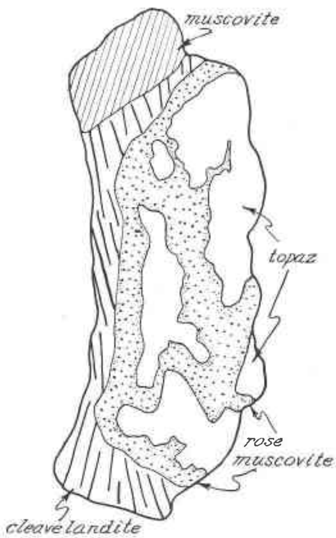


FIG. 5. Rose muscovite coating and veining topaz crystal. Brown Derby No. 1 pegmatite, Colorado. $\times\frac{1}{2}$.

## California

*Mesa Grande:* An analysis is recorded of a pink muscovite from Mesa Grande (Clarke, 1915, p. 330). Other minerals present in this deposit include alkali tourmalines, alkali beryl, bavenite, apatite, pollucite, cleavelandite, and lepidolite.

## *Canada*

### Manitoba

*Pointe du Bois:* Rose muscovites occur in several deposits in the Pointe du Bois area, particularly in the Bear and Annie pegmatites (Ellsworth, 1932; Stockwell, 1933*A*, 1933*B*). The Bear pegmatite contains three well-defined units:

(1) Lower: Medium-grained albite-quartz-microcline-pegmatite, overlain by aplitic scallopy-banded albite-quartz-garnet rock ("line-rock") and above that a 3–6-inch cleavelandite band. Small amounts of lepidolite, zinnwaldite, and spodumene occur in the "line-rock."
(2) Middle: Lower and upper bands, containing large microcline crystals and quartz-spodumene crystals with interstitial quartz, cleavelandite, and lepidolite occur around an inner layer of lepidolite-cleavelandite-quartz rock with local beryl, spodumene, and rose or purple muscovite.
(3) Upper: Quartz-muscovite pegmatite with minor microcline separated from unit 2 by a one-foot cleavelandite band.

Light lilac muscovite forms a massive rock of very fine scales, 1 mm. or less in diameter, in the inner layer of unit 2. It was found exposed in an area 5–10 feet across, together with quartz, cleavelandite and smaller amounts of spodumene, topaz, white to pink beryl, montebrasite, and lithiophilite. Lilac curved muscovite, with 1.80% $Li_2O$, is associated with gray curved muscovite locally in the same unit.

### Quebec

*Fiedmont area, Abitibi County:* Tremblay (1950) has described pegmatites in the Fiedmont area that have quartz cores enclosed in spodumene-rich units also containing quartz, microcline, cleavelandite, lepidolite, and accessory sugary albite, beryl, spessartite, columbite-tantalite, microlite, betafite, bismuthinite, molybdenite, and powellite. Both green and buff spodumene may be partly or completely altered to a lithium-bearing mica. The relpacement begins from the margin or from fractures. According to Tremblay (private communication) this mica is pink in color, and the lithium content was assumed from the color and the association. It has the optical properties of muscovite and forms rosettes or platy aggregates.

## *Europe*

### Norway

*Iveland-Evje District, Setesdal:* The pegmatites of the Iveland-Evje district have been investigated by Björlykke (1935*A*, 1935*B*, 1936, 1937, 1939) and by Barth (1928, 1931). Deposits from which rose muscovite has been recorded are Skripeland No. 1, Birkeland No. 2 and 3 and Landsverk. These are pegmatites in which occur a strongly developed cleavelandite phase and various combinations of accessory spessartite, topaz, beryl, schorl, microlite, tantalite, zircon, gadolinite, monazite, xenotime, thorite, uranothorite, betafite, allanite, fergusonite, euxenite, and bismuthinite. The rose muscovite is closely associated with a green muscovite and with cleavelandite, occurring as:

(1) A thin layer between topaz and cleavelandite, with the cleavage normal to the topaz surface.
(2) Interstitial to cleavelandite blades.
(3) In vugs in cleavelandite with small albite crystals.

Flakes as large as one-half inch in diameter occur, but most are smaller.

*Höydalen, Tördal, Telemark:* A cleavelandite-rich pegmatite at Höydalen contains an albite-quartz-spessartite outer zone around an amazonite core largely replaced by cleavelandite and quartz with accessory gadolinite, alvite, yttrotantalite, cassiterite, topaz, fluorite, lepidolite, lithium muscovite, and both bladed and massive pink muscovite (Oftedal, 1944). Assuming that the Sc content of micas decreases with the temperature (and thus time) of their formation, Oftedal (1943) has determined the rose muscovite to be the youngest of the three micas:

| | g./ton Sc | % $Li_2O$ |
|---|---|---|
| (1) Gray lithium-rich muscovite | 700 | 1.5 |
| (2) Red violet lepidolite | 5 | 5.0 |
| (3) Pink muscovite | <3 | <0.1–0.3 |

The rose muscovite accompanies cleavelandite, with relicts of gray albitized microcline appearing in some specimens. In thin section the gray lithium-rich muscovite, which also is mainly interstitial to cleavelandite, replaces the feldspar marginally and not uncommonly is separated from the plagioclase by a narrow reaction rim of fine-grained quartz and sillimanite needles. Small anhedral specks of fluorite also occur in the albite.

## Sweden

*Varuträsk:* The minerals of the complex pegmatite at Varuträsk have been described in numerous papers by Quensel and his students. Quensel (1952), in his description of the paragenesis, lists a complete bibliography. Berggren (1940, 1941) has analyzed the micas, and Lundblad (1942) has studied them optically. Berggren (1940) states that the very fine-grained rose mica occurs in the eastern wing of the pegmatite, which is a trough-shaped body whose axis trends north-northwest. The zones of the pegmatite include (Quensel, 1952):

(1) Fine-grained quartz-muscovite border zone.
(2) Wall zone of coarse-grained quartz, muscovite, and schorl.
(3) Outer intermediate zone of albite, microcline, quartz, and beryl.
(4) Inner intermediate zone of microcline, quartz, muscovite, spodumene, and amblygonite.
(5) Massive quartz core.

Upon these zones several hydrothermal replacement units have been developed:

(6) A high-temperature lithium unit with lepidolite, spodumene, quartz, petalite, and alkali tourmaline.
(7) A high-temperature cesium unit of pollucite and quartz.
(8) An intermediate- to low-temperature unit of cleavelandite, quartz, lepidolite, blue tourmaline, Mn-Fe phosphates, Cb-Ta minerals, uraninite, and cassiterite.
(9) Veins of fluorite.

The detailed paragenesis of the rose muscovite is not fully known, but it occurs in the cleavelandite replacement unit (8). Another rose muscovite, described as a purple oncosine with 1.10% $Li_2O$ is found in veinlets in the eastern limb of the deposit.

### Finland

*Kimito District:* According to Pehrman (1945), the large muscovite books of the Kimito pegmatites are yellow or gray in color, whereas the muscovite that occurs in fine scaly masses is violet or green. He lists the optical constants of violet muscovite from the Lemnäs pegmatite.

## *Africa*

### Nigeria

*Ejiba:* Jacobson and Webb (1946, p. 20) state, "An unusual type of muscovite was collected from an intensely albitized microcline-quartz-muscovite pegmatite near Ejiba. The muscovite occurs in crystals elongated along the *c*-axis. The books are about half an inch in diameter and up to three inches long. At one end they are apple-green in colour and at the other lilac. The colours grade into one another along the length of the crystal."

The color arrangement, variation and intergradation in this mica are very similar to those in material from Bolton, Massachusetts. The albitized pegmatites contain the accessory suite: cleavelandite, sugary albite, lepidolite, alkali tourmaline, apatite, monazite, triphylite, amblygonite, beryl, cassiterite, columbite-tantalite, tapiolite, and microlite.

## *Australia and Asia*

### Western Australia

*Pilbara, North-West Division:* The Strelley pegmatite (Ellis, 1950) contains scattered masses of pale violet to purplish muscovite, cryptocrystalline to massive and translucent. The mica replaces (potash?) feldspar along with pale purple chalcedony. In the Pilgangorra deposits occur numerous small lenses and bunches of scaly pink muscovite, associated with albitized parts of the pegmatite. Spodumene in these pegmatites shows varying degrees of alteration to purplish pseudomorphs composed mainly of fine-grained muscovite. Partial analyses of these and numerous other rose muscovites from Wodgina and West Wodgina have been made by Rowledge (1945). Simpson (1927) also reports a rose muscovite from Londonderry. It varies from colorless to pale mauve, lilac or sea green and occurs in association with lepidolite. Spodumene in pegmatites in the McPhees Range (Simpson, 1938) has been replaced similarly by gray to nearly purple muscovite.

### Japan

*Suizawa, Ishigura, Mi-e Prefecture:* A rose muscovite from Suizawa has been analyzed by Iimori and Yoshimura (1929).

## General Paragenesis

Although the data are incomplete for some of the deposits, the previous descriptions are sufficient to establish several generalizations regarding the paragenesis of the rose muscovites:

(1) Rose muscovites apparently are restricted to replacement units in zoned pegmatites.
(2) The replacement units are of the Na-Li type, commonly containing cleavelandite, lepidolite, spodumene, topaz, beryl, and tantalum minerals.
(3) Rose muscovite forms partial or complete pseudomorphs after spodumene and topaz, also replaces cleavelandite and beryl and occurs as overgrowths on lepidolite or normal muscovite. Thus, in general, rose muscovites are among the very youngest of the minerals of the replacement unit, and the sequence of mica formation is: muscovite, lepidolite, rose muscovite.

This conclusion opposes that of Stevens and Schaller (1942, p. 533) who state, "In the full development of the lithium stage, the mica formed is essentially lepidolite. No new muscovite is formed at this stage. The muscovite now present in specimens from the lithium phase is residual muscovite from the preceding sodium phase, as evidenced by the many examples of muscovite completely or partially changed to lepidolite, by the pink color of this muscovite with percentages of $Li_2O$ intermediate between those of the greenish muscovites of the albite phase and those of lepidolite, and by the border of lepidolite formed around the muscovite, which is often colored pink adjacent to the lepidolite border."

It appears that once the peak of lithium replacement has passed, muscovite of the rose type is formed, either by direct precipitation along fractures and in cavities or through replacement of a lithium mineral such as spodumene and of non-lithium minerals such as topaz and cleavelandite.

## Physical Properties

### *Color*

Exact color determinations of rose muscovites are considerably hampered by the physical nature of most of the specimens. Because of the general fine grain and the very pale colors, color determinations on single sheets of standard thickness are not possible. Color can only be determined for aggregates, which under standard illumination show some variations in their tints owing to:

(1) Variations in grain size.
(2) Variations in thickness of specimens.
(3) Variations in amount and type of admixed material or in underlying matrix material.

However, despite these variables, reproducible determinations were obtained by rectangularly masking the specimens and correlating the exposed areas in juxtaposition with units of the Ridgway (1912) tables.

Except for determinations by Schaller and Henderson (1926), color designations of rose muscovite have been entirely qualitative, employing such terms as pink, rose, magenta, lilac, lavender, purplish, purple, and violet. Our color designations are listed in Table 1. In thin section the rose muscovites are colorless. Schaller and Henderson (1926, p. 10) note very weak pleochroism in thick scales of the Harding mica. There is normally no difficulty in distinguishing, colorimetrically, between the rose muscovites and the so-called "ruby" muscovites. As has been pointed out by Jahns and Lancaster (1950, p. 43), most "ruby" micas are buff, drab, and cinnamon brown. However, because of their color, the rose muscovites have been confused repeatedly with lepidolites. Wherever the two similarly colored micas are closely associated, the lepidolite generally is characterized by a more bluish or purplish tint (Schaller and Henderson 1926, p. 9), but in some cases color alone does not suffice and an $Li_2O$ determination or an $x$-ray photograph is required. Because of this color similarity probably many rose muscovites have remained unrecognized, and the variety may well be more common than the published record indicates.

## *Optical Constants*

In Table 1 also are listed the optical constants of representative rose muscovites studied as well as some scattered data from the literature. The ranges in values are remarkably narrow in our measurements:

| | Average values |
|---|---|
| $\alpha=1.553$–$1.556$ | $\alpha=1.555$ |
| $\beta=1.584$–$1.595$ | $\beta=1.586$ |
| $\gamma=1.587$–$1.599$ | $\gamma=1.592$ |
| $2V=42$–$46\frac{1}{2}°$, $r>v$ weak | $2V=45°$ |

All three indices were measured on an Abbé refractometer, and $\beta$ and $\gamma$ also were checked by means of the immersion method. 2E was determined by means of the Mallard equation, and 2V was calculated.

TABLE 1. OPTICAL PROPERTIES OF REPRESENTATIVE ROSE MUSCOVITES

| Locality | Ridgway Plate No. and Color | $\alpha$ | $\beta$ | $\gamma$ | Axial Angle | Reference |
|---|---|---|---|---|---|---|
| Goshen, Mass. | — | — | — | — | 2E=74–76° | Mallet, 1857 |
| Bolton, Mass. | XXVI, cameo pink | 1.556 | 1.590 | 1.595 | 2V=45° | This paper |
| Haddam Neck, Conn. | — | — | — | — | 2E=75½° | Bowman, 1903 |
| Amelia, Va. | — | 1.553 | 1.582 | 1.588 | calc. 2V=48° | Glass, 1935 |
| Amelia, Va. | — | 1.552 | 1.583 | 1.590 | 2V=45° | Glass, 1935 |
| Harding, N. M. | XXVI, rosalane purple<br>rosalane pink<br>XXXVII, eupatorium purple<br>daphne pink | 1.558 | 1.587 | 1.591 | 2E=69°<br>calc. 2V=42° | Schaller and Henderson, 1926 |
| Harding, N. M. | XII, deep rose pink | 1.555 | 1.587 | 1.592 | 2V=45° | This paper |
| Harding, N. M. | XXXVIII, pale Persian lilac | 1.555 | 1.587 | 1.592 | 2V=46½° | This paper |
| Pittlite, N. M. | XXVI, cameo pink | — | 1.586 | 1.589 | 2V=46° | This paper |
| Apache, N. M. | XII, rose pink | 1.555 | 1.586 | 1.592 | 2V=43½° | This paper |
| Globe, N. M. | XXVI, cameo pink | — | 1.588 | 1.592 | 2V=44° | This paper |
| Brown Derby, Colo. | XXVII, pale vinaceous | 1.553 | 1.584 | 1.587 | 2V=45° | This paper |
| Brown Derby, Colo. | XXVII, pale vinaceous | 1.555 | 1.588 | 1.591 | 2V=45° | This paper |
| White Spar No. 1, Colo. | XXVII, pinkish vinaceous | 1.553 | 1.586 | 1.590 | 2V=45–46½° | This paper |
| Iveland, Norway | XXVI, cameo pink | 1.554 | 1.586 | 1.590 | 2V=45° | This paper |
| Höydalen, Norway | XXXVIII, pale rhodonite pink | 1.553 | 1.585 | 1.590 | 2V=45° | This paper |
| Höydalen, Norway | XXVII, livid pink | 1.555 | 1.586 | 1.592 | 2V=46½° | This paper |
| Lemnäs, Finland | — | — | 1.589 | 1.594 | 2V=44°56′ | Pehrman, 1945 |
| Ejiba, Nigeria | XXXIX, pale brownish vinaceous | — | 1.587 | 1.592 | 2V=42° | This paper |
| Pilgangoora, North-West Terr., Australia | XXV, mauvette | — | 1.595 | 1.599 | 2V=44½° | This paper |

The refractive indices of rose muscovites are consistently lower, by 0.01–0.02, than the average values for 250 specimens of other pegmatitic muscovites, and the 2V values for rose muscovite are higher than those of the other pegmatitic muscovites. The purple muscovite from Pilar, N.M. (Schaller and Henderson, 1926) is optically not a rose muscovite, as here defined. Its color is much deeper, with strong pleochroism, the indices of refraction are unusually high: $\alpha = 1.565$, $\beta = 1.597$, $\gamma = 1.602$, $2E = 77°$. Jakob (1925) also has described an allegedly pale rose muscovite, but examination of a specimen of his analyzed material shows it to be a typical "ruby" muscovite, both in color and indices.

### *Structure*

As demonstrated by Levinson (1952) there is a strong correlation in the muscovite-lepidolite series between $Li_2O$ content and structure. Muscovite (0–3.3% $Li_2O$) is invariably two-layered monoclinic; lithian muscovite is two-layered monoclinic with consistent, small-scale departures from the normal muscovite structure; most micas of this series with 3.4–4.0% $Li_2O$ are structurally transitional, consisting of both 2-layered and 6-layered polymorphs; lepidolites are 6-layered (4.0–5.1% $Li_2O$) or 1-layered monoclinic (>5.1% $Li_2O$). All of the rose muscovites studied have the two-layered monoclinic normal muscovite structure and normal cell dimensions.

### *Chemistry*

Selected previously published analyses of rose muscovites are collected in Table 2. They show little variation in $SiO_2$ or $Al_2O_3$. Total iron is very low, normally less than 1%, and, where determined, MnO or $Mn_2O_3$ is present in small amounts. $Li_2O$ is very low, usually less than 0.5%.

Five new analyses of rose muscovites are presented in Table 3. Again variations in $SiO_2$ and $Al_2O_3$ are not significant; $Li_2O$ contents are similarly very low; total iron is very low, and MnO exceeds total iron in all but No. 1. Fluorine averages a little less than 1%. The formulae, which show the close relation to other muscovites, are:

1. $(K_{1.7}Na)_{1.9}(Mn_{0.02}, Mg, Fe^{2})_{0.03}(Al_{3.8}, Li_{0.02}Fe^{3}_{0.02}Ti)_{3.8}(Si_6, Al_2)_8O_{19.7}OH_4F_{0.3}$.
2. $(K_{1.7}, Na, Rb, Ca)_{2.0}Mn_{0.06}(Al_{3.6}, Li_{0.2}, Fe^{3})_{3.8}(Si_{5.9}, Al_{2.1})_8O_{19.6}OH_4F_{0.4}$.
3. $(K_{1.7}, Na, Ca)_{1.9}Mn_{0.04}(Al_{3.3}, Li_{0.3})_{3.6}(Si_{5.9}, Al_{2.1})_8O_{19.4}OH_{4.1}F_{0.5}$.
4. $(K_{1.8}, Na, Ca)_{2.2}Mn_{0.1}(Al_{3.4}, Li_{0.1})_{3.5}(Si_{5.9}, Al_{2.1})_8O_{19.9}OH_{3.1}F_{0.3}$.
5. $(K_{1.7}, Na, Rb, Cs)_{2.0}(Mn_{.02}, Mg_{.02})_{.04}(Al_{3.8}, Li_{0.3})_{4.1}(Si_6, Al_2)_8O_{19.9}OH_{3.7}F_{0.4}$.

The rose muscovites are low Fe, low Mn, normal Si muscovites, with consistent minor Li, F, Rb, and Cs. The rose muscovites, despite their color, cannot be grouped with alurgite, which is characterized by high $SiO_2$ content and is best classed as ferrian phengite. They also differ chemically from the red mica from Cajon Pass, Calif., so-called "alurgite,"

TABLE 2. SELECTED OLDER ANALYSES OF ROSE MUSCOVITES

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 47.02 | — | 46.28 | 46.81 | 46.80 | 44.80 | — | 45.63 | 45.58 | 45.56 | 46.01 | 47.64 | 45.77 | 45.22 |
| $TiO_2$ | — | — | — | 0.01 | 0.01 | — | — | tr. | 0.00 | 0.00 | — | 0.00 | 0.10 | n.d. |
| $Al_2O_3$ | 36.83 | — | 36.86 | 36.09 | 35.84 | 37.72 | — | 37.42 | 37.45 | 29.53 | 35.64 | 34.22 | 37.02 | 37.46 |
| $Fe_2O_3$ | 0.51 | — | 0.97 | 0.25 | 0.24 | 0.67 | — | tr. | 0.16 | 0.12 | 0.13 | 0.10 | 0.75 | tr. |
| FeO | | | | | | n.d. | — | — | — | 0.10 | — | — | — | 0.56 |
| MnO | 1.05 | — | tr. | n.d. | — | — | — | .06 | 0.15 | 2.32 | 0.09 | 0.05 | — | 0.71 |
| $Mn_2O_3$ | — | — | — | — | — | 0.21 | — | — | — | — | — | — | — | — |
| MgO | 0.26 | — | — | 0.62 | 0.56 | — | — | 0.00 | 0.13 | 0.29 | 0.04 | 0.28 | 0.34 | 0.38 |
| CaO | — | — | — | 0.29 | 0.29 | — | — | 0.00 | 0.28 | 0.15 | 1.12 | 0.00 | 0.12 | 0.10 |
| $Li_2O$ | 0.30 | 0.64 | 0.26 | n.d. | — | tr. | 0.38 | 0.20 | 0.13 | 1.80 | 0.69 | 1.10 | 0.26 | 0.32 |
| $Na_2O$ | — | 0.99 | 1.41 | 0.68 | 0.60 | — | 0.91 | 1.43 | 0.93 | 2.65 | 1.88 | 0.47 | 1.17 | 1.19 |
| $K_2O$ | 9.80 | 9.08 | 10.63 | 10.24 | 10.08 | 10.66 | 10.07 | 9.95 | 10.90 | 11.01 | 8.19 | 10.40 | 9.28 | 10.71 |
| $Rb_2O$ | — | — | — | n.d. | — | — | 0.82 | — | — | tr. | 1.20 | 0.35 | — | — |
| $Cs_2O$ | — | — | — | n.d. | — | — | 0.09 | — | — | 0.33 | 0.20 | 0.75 | — | — |
| $H_2O-$ | — | — | — | 0.42 | 0.64 | 4.52 | — | — | — | 3.12 | 0.08 | 0.10 | 0.86 | — |
| $H_2O+$ | 3.90 | — | 4.83 | 5.00 | 5.05 | | — | 4.43 | 3.16 | | 4.65 | 3.62 | 1.39 | 3.68 |
| F | 0.52 | 1.89 | 0.377 | n.d. | — | 0.20 | — | 0.77 | 0.97 | 3.45 | 0.54 | 1.21 | 0.44 | 0.73 |
| | 100.19 | — | 101.257 | 100.41 | 100.11 | 100.18 | — | 99.89 | 99.84 | 101.43 | 100.46 | 100.29 | 99.18 | 101.06 |
| O=F | 0.22 | — | 0.158 | — | — | .08 | — | 0.32 | 0.41 | 1.45 | 0.23 | 0.51 | 0.18 | .31 |
| Total | 99.97 | — | 101.099 | 100.41 | 100.11 | 100.10 | — | 99.57 | 99.43 | 99.98 | 100.23 | 99.78 | 99.00 | 100.75 |

1. Goshen, Mass. Rammelsberg, 1875.
2. Goshen, Mass. Mallet, 1857.
3. Haddam Neck, Conn. Bowman, 1903. $P_2O_5$—0.09. "The MnO is sufficient to give the fused carbonates a pale bluish-green tinge, . . ." Bowman, 1902.
4., 5. Rutherford, Va. Glass, 1935. Iron determined as $Fe_2O_3$ and recalculated as FeO.
6. Harding, N. M. Schaller and Henderson, 1926.
7. Harding, N. M. Stevens and Schaller, 1942. Another determination by Ahrens (1948) gave $Rb_2O$—0.17, $Tl_2O$—0.015.
8. Mesa Grande, Calif. Clarke, 1915.
9., 10. Pointe du Bois, Manitoba. Ellsworth, 1932.
11., 12. Varuträsk, Sweden, Berggren, 1940.
13. Suizawa, Japan. Iimori and Yoshimura, 1929. (Cu, Pb)O—1.65, rare earths—0.03. Note low $H_2O+$.
14. Londonderry, Western Australia. Simpson, 1927.

TABLE 3. NEW ANALYSES OF ROSE MUSCOVITE

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ | 45.00 | 45.03 | 45.60 | 45.54 | 45.24 |
| $TiO_2$ | 0.02 | 0.02 | 0.03 | 0.07 | 0.01 |
| $Al_2O_3$ | 37.41 | 36.33 | 35.96 | 36.36 | 36.85 |
| $Fe_2O_3$ | 0.12 | 0.14 | 0.10 | 0.25 | 0.09 |
| FeO | 0.05 | 0.02 | 0.02 | 0.02 | 0.02 |
| MnO | 0.15 | 0.41 | 0.37 | 0.80 | 0.12 |
| MgO | 0.06 | 0.05 | 0.05 | 0.07 | 0.08 |
| $Li_2O$ | 0.02 | 0.41 | 0.63 | 0.06 | 0.49 |
| CaO | 0.03 | 0.09 | 0.08 | 0.09 | 0.00 |
| $Na_2O$ | 0.63 | 0.69 | 0.59 | 0.57 | 0.64 |
| $K_2O$ | 10.50 | 10.50 | 10.52 | 10.76 | 10.08 |
| $Cs_2O$ | n.d.* | 0.06 | n.d.* | n.d.* | 0.20 |
| $Rb_2O$ | n.d.* | 0.79 | n.d.* | n.d.* | 0.93 |
| $H_2O+$ | 4.48 | 4.56 | 4.81 | 4.35 | 4.12 |
| $H_2O-$ | 0.68 | 0.79 | 0.44 | 0.55 | 0.46 |
| F | 0.78 | 1.01 | 1.31 | 0.62 | 0.91 |
| | 99.93 | 100.45 | 100.51 | 100.11 | 100.24 |
| 0=F | 0.33 | 0.42 | 0.55 | 0.26 | 0.38 |
| Total | 99.60 | 100.03 | 99.96 | 99.85 | 99.86 |

*Analyst:* Eileen H. Oslund, Univ. Minnesota, Rock Anal. Lab.
* n.d., not determined: Cs and Rb weighed and calculated as K.
$Li_2O$, $Cs_2O$, $Rb_2O$ by flame spectrophotometer, R. B. Ellestad, *analyst.*
1. Birkeland 2, Iveland, Norway.
2. White Spar No. 1, Gunnison Co., Colo.
3. Brown Derby No. 1, Gunnison Co., Colo.
4. Apache, Petaca, N. M.
5. Pittlite, Rociada, N. M.

of Webb (1939) and the reddish mica from Pilar, N. M., of Schaller and Henderson (1926), which are ferrian muscovites. Neither alurgite nor ferrian muscovite contain lithium, whereas the rose muscovites always contain small amounts of that element.

## *Minor Elements*

The various minor elements recorded spectrographically in rose muscovites are listed in Table 4. Included also are the contents of $Fe_2O_3$ and MnO, which are in general agreement with the results of wet chemical analysis on other samples from the same localities. Ahrens (1948) has demonstrated that the Harding mica is unique in its very low Rb-Tl ratio, $Rb_2O/Tl_2O=12$. His muscovite with the next lowest ratio has $Rb_2O/Tl_2O=30$. Glass (1935) for No. 2, Table 2 determined the absence of BeO and the presence of B and Sn. Table 4 shows that the rose muscovites consistently contain significant quantities of Rb, and most of them also have small amounts of Cs. Ga and Sn are usually present, as is Ba in very minute amounts. Cr, V, Sr, Si and Co are very rarely present or are absent entirely. The absence of Sc is in general accord with the results of Oftedal (1943).

TABLE 4. MINOR ELEMENTS IN ROSE MUSCOVITES

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| $Fe_2O_3$ | 0.12 | 0.12 | 0.15 | 0.08 | 0.19 | 0.04 | 0.09 | 0.12 |
| MnO | 0.17 | 0.38 | 0.25 | 0.45 | 0.95 | 0.10 | 0.22 | 0.15 |
| $Cr_2O_3$ | — | 0.0001 | 0.0001 | 0.0001 | — | — | — | — |
| BaO | 0.0003 | 0.0004 | 0.0003 | 0.0005 | 0.002 | — | 0.0003 | 0.001 |
| $Rb_2O$ | 0.29 | 0.41 | 1.0 | 1.8 | 0.26 | 0.17 | 0.62 | 0.46 |
| $Cs_2O$ | — | 0.17 | 0.08 | 0.17 | 0.12 | — | 0.28 | 0.07 |
| SrO | — | — | — | 0.003 | — | — | — | — |
| $SnO_2$ | 0.002 | 0.04 | 0.03 | 0.07 | 0.004 | 0.005 | — | 0.05 |
| $Ga_2O_3$ | 0.008 | 0.019 | 0.037 | 0.05 | 0.035 | 0.009 | 0.014 | 0.021 |
| $Sc_2O_3$ | — | — | — | — | — | — | — | — |
| $V_2O_5$ | — | — | — | — | — | — | 0.0004 | — |
| $Co_2O_3$ | — | — | — | — | — | — | — | — |

Spectrochemical determinations by Charles E. Harvey.
1. Birkeland 2, Iveland, Norway.
2. Höydalen, Telemark, Norway.
3. White Spar No. 2, Colorado.
4. Brown Derby No. 1, Colorado.
5. Apache, Petaca, New Mexico.
6. Pittlite, Rociada, New Mexico.
7. Harding, New Mexico.
8. Bolton, Massachusetts.

## CAUSE OF COLOR

Several suggestions have been advanced in previous studies regarding the cause of color of rose muscovites. Iimori and Yoshimura (1929), who report 1.65% of (Cu, Pb)O in their analysis, believed that the color results from the presence of the Cu in the colloidal state. Spectroscopically they also detected Sc, Y, La, Eu, Gd, Dy, and Er, but regarded the quantity of Er and Eu too low to cause the pigmentation. Micke (1950) postulates a rhythmic variation in F to account for pale violet zones in muscovite, but offers no supporting evidence. Webb (1939) thought Ti caused the red color of the California "alurgite," but Meixner (1939) pointed out that other micas of similar general composition and of similar Ti contents are not red. Co was suggested as a possible coloring agent, but Table 4 shows that the Co content of rose muscovites is nil.

Because of the color similarity to some lepidolites, a few investigations have attempted to relate the rose color of these muscovites with Li content. Ellis (1950) for example, in describing the replacement of feldspar in the Main Tantalite Dike at Strelley by fine-grained pale purple chalcedony that grades into cryptocrystalline rose muscovite suggests that the color of both is due to Li. There is, however, no correlation even in lepidolites between color and Li content. High-lithium lepidolites may be purple, gray, or even white.

That the rose muscovite color depends on the presence of Mn was advanced early and has since been reemphasized by several workers. Mallet (1857) stated with regard to the Goshen mica, ". . . and there can I think be little doubt that both are essentially potash-micas of the species muscovite, the rose-colored being probably tinged by oxyd of manganese." Likewise Bowman (1902) reiterated that, "The MnO . . . is probably the cause of the pink colour of the mineral, but it does not appear to be present in weighable amounts." Schaller and Henderson (1926, p. 11) state, "In chemical composition there is very little variation in these micas from that of normal muscovite. Small quantities of iron and manganese are present as inherent parts of the mineral, probably replacing alumina (sic), and their combined color effect produces the abnormal color and pleochroism of the mineral." There exist today numerous analyses of non-rose or non-purple muscovites that contain small amounts of MnO as well as amounts of $Fe_2O_3$ considerably above that reported by Schaller and Henderson (1926) in the Harding mica, which has $Fe_2O_3 = 0.67\%$. It seems unlikely, therefore, that the combined effect of small amounts of these ions brings about an abnormal coloration that cannot be produced by larger quantities of the same elements.

As has been pointed out by Shibata (1952) the pigmenting agents in muscovite are $Fe^2$, $Fe^3$ and Mn; Ti is normally negligible in muscovites. In an ordinary mica analysis the valence of Mn cannot readily be determined, and any Mn present is usually reported as MnO. If FeO is present in the muscovite it is to be presumed that Mn is present only as $Mn^2$, for Fe is more easily oxidized than Mn:

| | $E_0$ (in volts) |
|---|---|
| $Fe^{2+} \rightarrow Fe^{3+} + e$ | 0.77 |
| $Mn^{2+} \rightarrow Mn^{3} + e$ | 1.51 |

In most muscovites FeO, or $FeO + Fe_2O_3$, is greatly in excess of MnO, and any coloration effect that $Mn^2$ could contribute is masked by the effects of the $Fe^2$ or $Fe^3$ ions, for compounds of bivalent Mn are only faintly colored. However in muscovite in which $Fe^2$ is negligible and only small amounts of $Fe^3$ are present, the Mn can and may well exist as $Mn^3$, which is a strong chromophore. In the newly analyzed rose muscovites of Tables 3 and 4, FeO is nearly absent and $MnO > Fe_2O_3 + FeO$ in all micas but No. 1, in which $FeO+Fe_2O_3:MnO$ is$\cong$1:1. Micas 2–5 are distinctly rose colored, but No. 1, from Iveland, Norway, is of an exceedingly pale rose tint, and flakes in some parts of the aggregate are completely colorless or even a very faint green. The rose muscovites owe their delicate and unusual color, therefore, not to the mere presence of either Fe or Mn, nor even to their combined presence, but to the essential absence of $Fe^2$ and the equality or predominance of $Mn^3$ with respect to $Fe^3$.

This conclusion is substantiated by Jacobson and Webb (1946) who found that in their zoned mica books the green part had a higher Fe/Mn ratio than the rose part. Further support is offered, for example, by two analyses of muscovites by Ellsworth (1932, pp. 266–267). The two curved micas occur together in the Annie pegmatite. The lilac (No. 10, Table 2) contrasts with the gray:

| | *Lilac* | *Gray* |
|---|---|---|
| $Fe_2O_3$ | 0.12 | 2.20 |
| $FeO$ | 0.10 | 2.57 |
| $MnO$ | 2.32 | 0.90 |
| $Li_2O$ | 1.80 | 0.90 |

In lepidolites, the color variations also are related to fluctuations in the Fe/Mn ratio. The role of Mn in the coloration of lepidolite has been stressed, for example, by Hintze, 1897 and by Doelter, 1917. As stated by Shibata (1952 p. 160), "Lepidolite is pink or violet, which is due to the color of manganese. Lepidolite is sometimes colorless when it is poor in MnO. Lithium is not a color agent. . . ." Those lepidolites that are colorless or of very pale colors usually have Fe:Mn$\cong$1:1; those that are gray normally have Fe>Mn, whereas the purple lepidolites contain more Mn than Fe.

## References

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