ORIENTED INCLUSIONS OF MAGNETITE AND HEMATITE IN MUSCOVITE

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CONTENTS

INTRODUCTION

Extremely thin, oriented, black or smoky brown inclusions of iron oxide frequently occur between the basal cleavages of muscovite, and have been briefly described by a number of writers (1–16). The presence of such inclusions in mica may affect the value for commercial purposes by impairing the splitting qualities and transparency, and by decreasing the dielectric strength.

The included mineral has generally been called magnetite. However, it is found that two contrasting types of inclusions can be distinguished. One type, of relatively rare occurrence and hitherto little known, is definitely magnetite. The second type of inclusion, of which the lattice- and dendrite-like growths in the Pennsbury, Pennsylvania, muscovite are typical, and comprising most of the so-called magnetite inclusions mentioned in the literature, probably consists of hematite.

The material investigated in the present study included a collection of approximately 500 specimens of muscovite containing inclusions collected by one of the authors (G. E. A.) from 26 localities on Manhattan Island, New York City; similar specimens from the collection of the New York Mineralogical Club; and a suite of mica sheets and other specimens from the collection of the American Museum of Natural History.

The writers are indebted to Mr. Herbert P. Whitlock for opportunity to examine the material from the Museum, and to Dr. Frederick H. Pough for a critical reading of the manuscript.

DESCRIPTION OF SPECIMENS*

MAGNETITE INCLUSIONS

Magnetite inclusions are readily distinguished by their color, habit, and the presence of parting cracks. The inclusions are frequently so thin

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* The following description of the inclusions refers generally to specimens from all of the observed localities.

as to be translucent, and are then pure gray, iron-gray or lavender gray in color. Smoke-gray and light drab tints of color are frequently seen in the thinnest crystals. Opaque crystals are iron-black in color and fairly lustrous.

Parting Cracks. Octahedral parting cracks, arranged in three sets intersecting at 60°, are almost invariably present in the crystals (Figs. 1, 2, 6, 7). The arrangement of the cracks in a 60° pattern identifies the inclusions as plates flattened on (111).

The cracks are open, but as a rule draw together at the margin of the crystal. The development is not always uniform. In some instances, a crystal may be blocked out into relatively large hexagonal segments by a strongly developed series of wide cracks, with the interior of each segment fissured on a smaller scale. The interior cracks are then relatively narrow and fade out at the margins of the larger segments. Sometimes the crystal is blocked out into a net-like pattern of small rhombic segments by the development of but two of the sets of cracks. Several instances were noted in which the cracks outlined a single hexagon inscribed in the hexagonal outline of the crystal. Again, three small cracks only may radiate from the center of the crystal. Fishbone patterns were also seen. The cracks can be discerned in all but the thinnest, pure gray or smoke-gray and nearly transparent, inclusions.

A few crystals, in muscovite from 176th Street, between Audubon and St. Nicholas' Avenues, New York City, were found to be peculiar in that they showed a second series of cracks at right angles to the ordinary series (Fig. 6). Cracks in this orientation could be caused only by a parting parallel to the dodecahedron or to a trapezohedron. It was not possible, however, to determine to which of these forms the parting cracks belonged. A minor dodecahedral parting in magnetite has been observed by Kemp (17).

The characteristics of the cracks suggest that they have been formed by the contraction of the crystals. Twinning has obviously played no part in their formation. Although evidence of secondary mechanical working is usually visible in the muscovite crystals, the cracks appear to bear no relation to such disturbances. Efforts to obtain parting cracks experimentally by flexing or shearing foils of mica containing inclusions were unsuccessful.

Habit; Size. The magnetite inclusions generally have a hexagonal outline, with the parting cracks perpendicular to the sides (Figs. 1, 5, 7). This position of the cracks identifies the laterally bounding faces as those of the dodecahedron. Although several thousand crystals were noted, from twenty-two localities, all were bounded laterally by dodecahedral faces, at least in part. This fact is remarkable, since the form of most

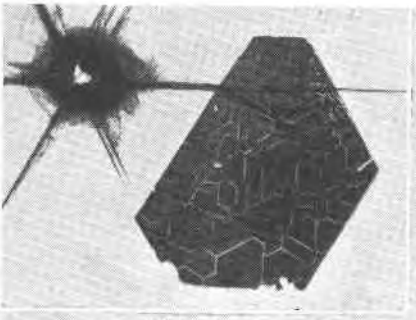

FIG. 1

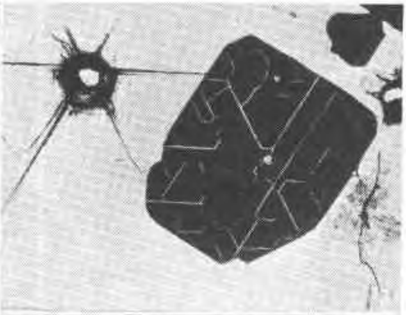

FIG. 2

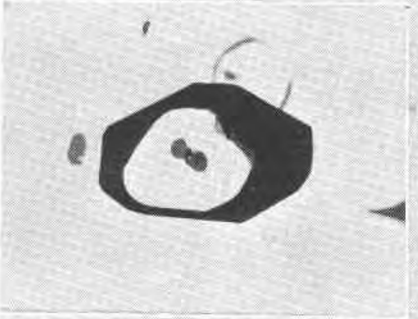

FIG. 3

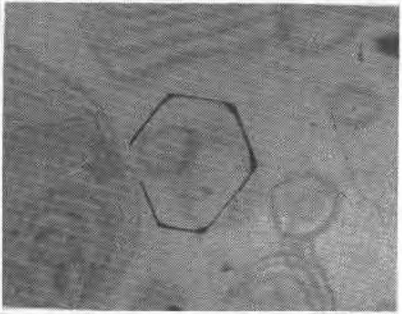

FIG. 4

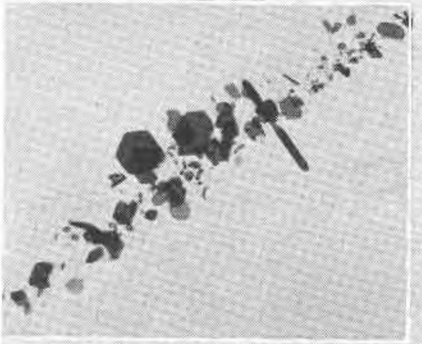

FIG. 5

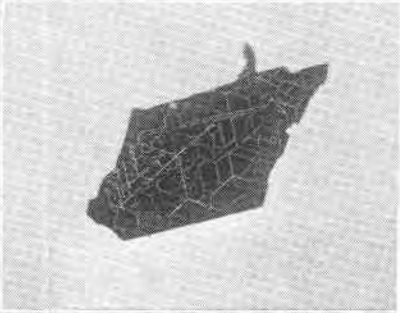

FIG. 6

PLATE 1

FIG. 1. Magnetite inclusion of typical habit. The crystal is oriented with the parting cracks perpendicular to the rays of the percussion figure (i.e., parallel to the pressure figure). N. Y. C. ×24.

FIG. 2. Inclusion of unusual cubic habit, caused by the unequal development of truncating modifying faces. The crystal is oriented with the parting cracks parallel to the rays of the percussion figure. N. Y. C. ×24.

frequent occurrence on magnetite is the octahedron.[1] The crystals, as a whole, are combinations of (110) and (111), since the surface forming the contact with (001) of the mica, and on which the crystals are flattened, is an octahedral face, as has been noted. Modifying faces, truncating the angles of the dodecahedral outline, are occasionally present. The faces of the modifying forms are often unequally developed, and one or more of them may be entirely suppressed (Figs. 2, 3).

The unmodified dodecahedral crystals are frequently distorted by the complete or partial suppression of faces, and may then present triangular, trapezoidal or rhombic outlines. The outline is sometimes slightly rounded, more frequently in the thinner crystals, and in some instances the entire outline may be a smooth curve. Rarely the outline is partially or completely jagged.

Lath- and needle-like magnetite inclusions were abundant in muscovite from Gilsum, N. H. (Fig. 9), and were occasionally noted in specimens from other localities (Fig. 5). The needles show a single set of parting cracks, which are perpendicular to the direction of elongation. The lath-like inclusions, and locally enlarged portions of the needles, however, present all three sets of cracks. The terminations of the laths and needles are usually rounded, but may be rectangular, through the suppression of two adjoining dodecahedral faces in combination with a truncating face (Fig. 8). Rarely the terminations are formed by the ordinary dodecahedral faces, or by combinations of this form with modifying faces. In one instance, the lath-like crystals were observed to radiate from a common center (Fig. 8). A few bent needles were also seen.

Skeletal crystals are not uncommon, and present a variety of shapes. Several perfectly formed skeletal hexagons with reinforced corners were noted (Fig. 4). Other related crystals had a narrow, opaque border and a thin, translucent interior (Fig. 3). In phlogopite crystals from North Burgess, Ontario, translucent magnetite laths were marked by opaque

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[1] The persistence-values for the commoner forms of magnetite are (Chudoba, K., and Schilly, W., *Neues Jahrb., Beil.-Bd.* **68A,** pp. 241–267, 1934):

Form—	111	110	100	331	511	531	211	510	331	432	773
p.v. —	*89*	*79*	*69.5*	*54*	*21*	*17*	*16*	*14.5*	*14.5*	*6*	*6*

FIG. 3. Modified and distorted magnetite inclusion with a dark, thick, border zone and a thin, nearly transparent, interior. The "islands" are separate inclusions at different levels in the mica. N. Y. C. ×24.

FIG. 4. Hexagonal, rim-like, skeletal magnetite crystal with reinforced corners. ×24.

FIG. 5. Linear arrangement of magnetite inclusions. A lath-like crystal and two needle-like crystals can be seen. N. Y. C. ×24.

FIG. 6. Magnetite crystal with dodecahedral (?) parting. This parting is seen as two closely parallel cracks and a single inclined crack near the top of the photograph. N. Y. C. ×24.

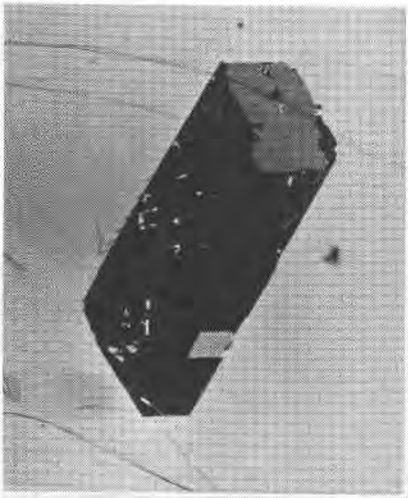

FIG. 7

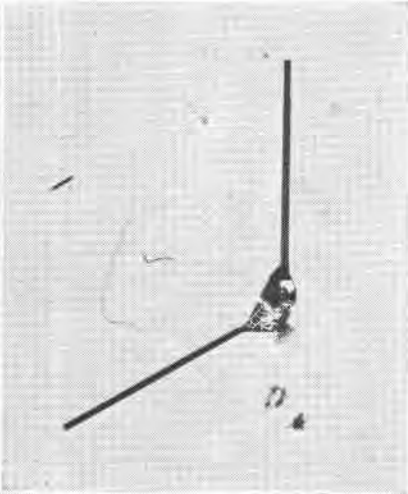

FIG. 8

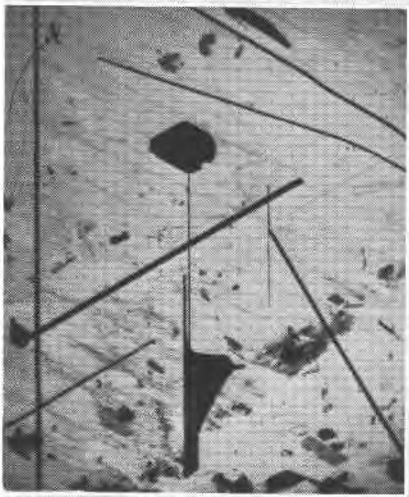

FIG. 9

FIG. 10

PLATE 2

FIG. 7. Inclusion of typical habit, exhibiting layer growth. The thinnest layer, indistinct in the photograph, is found in the rhombic inserted area and in the small interior openings. The uncracked, opaque, irregular areas are pyrite. N. Y. C. ×28.

FIG. 8. Lath-like inclusions diverging at 120° from a common center. The terminations of the laths are rectangular. N. Y. C. ×28.

FIG. 9. Elongated lath- and needle-like magnetite inclusions. One lath is enlarged laterally. Six different orientations can be seen. Gilsum, N. H. ×18.

FIG. 10. Magnetite octahedron with pronounced growth terraces on the octahedral faces. Nordmark, Sweden. ×3.

lines along their margins while their interiors contained rounded openings, resembling bubbles in a tube. Three-dimensional skeletal magnetite crystals have been described from igneous rocks (18), glass (19) and sintered iron ores (20).

The magnetite inclusions are quite small, averaging 1 mm. or less in diameter. The largest equant crystal noted measured only 4 mm. in diameter. The small size and sporadic occurrence of the crystals makes them inconspicuous. The elongated crystals usually range between 0.05–0.1 mm. in width and 1–10 mm. in length. The average length of 766 such crystals was 5.3 mm. (Table 1). A few needles, although invisible or nearly so to the unaided eye, were found to range between 5 and 10 cms. in length.

Layer Growth; Interference Effects; Thickness. The thickening, or growth perpendicular to the plane of flattening, of the magnetite crystals is frequently seen to have taken place discontinuously by the deposition of successive layers of uniform thickness (Figs. 3, 5, 7). A single crystal may show three or four such layers. The boundary of each deposit may be irregular or straight, but is marked by an abrupt change in color. The layers do not spread out from a point in the interior of the underlying layer, but appear to grow inward from the sides of the crystal, as is suggested by the bordered and skeletal crystals previously described. Opaque areas of pyrite, free from parting cracks, may be present in the inclusions and be confused with the growth layers.

The layer growth may be related to the relatively thick growth terraces, built up parallel to (111) on macroscopic magnetite crystals (Fig. 10). Layer growth, similar to that of the inclusions, has been described for various organic and metallic crystals.

Small areas adjacent to the boundary of overlapping layers are sometimes brightly colored in shades of blue or blue-green in ordinary transmitted light. This interference phenomenon is possibly caused by extremely thin laminae of mica partially intercalated between the magnetite layers. No interference colors were observed from the inclusions themselves. Brilliant interference colors were observed over an area of overlap of separate, translucent magnetite crystals lying at slightly different levels in the mica.

The opaque inclusions transect the mica laminae, and range in thickness up to 0.5 mm. Crystals thicker than 0.05 mm. are rare, and usually form striated, lens-like bodies. The translucent inclusions are too thin and adherent to be mechanically separated from the mica. The limit of opacity could not be determined exactly, but is at a thickness of less than 0.003 mm., since mica sheets that thick containing opaque inclusions were prepared by cleavage. Cleavage sheets 0.001 mm. thick containing translucent, but relatively dark colored, needles were also prepared.

Orientation. The orientation of the inclusions to the mica can be defined by stating the position of a direction in the plane of flattening—(111)—of the magnetite relative to the direction 010 (or any other direction) in (001) of the muscovite.

It is necessary that the identity of a single, fixed, direction in the magnetite be known, in order that the full range of possible orientations on (001) may be traversed. In inclusions of equant habit, however, the only directions whose positions are known are those of the octahedral parting cracks, and the hexagonal symmetry of the cracks restricts the range of measurement to 30°. On this basis, the inclusions were found, almost without exception, to occur in two orientations: the parting cracks falling parallel either to the rays of the percussion figure (i.e., to 010, 110, and $1\bar{1}0$), or to the rays of the pressure figure (i.e., to 100, 130, and $1\bar{3}0$) of the mica (Figs. 1, 2). These orientations are ambiguous, inasmuch as (001) of muscovite actually possesses binary symmetry and is only pseudo-hexagonal, and hence the inclusions may be individually oriented to particular rays of one or the other of the figures. The percussion figure orientation is, on the whole, more frequent than the pressure figure orientation. There is a variation in this respect in specimens from different localities, and in different specimens from the same locality.

In the case of elongated inclusions, the entire range of possible orientations can be traversed by investigating the inclination of the direction of elongation to 010 of the muscovite, and the exact positions of orientation can be determined. The elongation, as has been noted, is parallel to a (110)–(111) edge, and is at right angles to the parting cracks. Measurements of 780 elongated inclusions in muscovite from Gilsum, N. H., established four different orientations, the direction of elongation coinciding with 010; 100; 110 and $1\bar{1}0$; and 130 and $1\bar{3}0$ of the muscovite (Table 1). Both the relative frequency of orientation and the relative elongation of the inclusions varies with these positions, and the elongation increases with the frequency of orientation. The percussion and pressure figure positions of the equant inclusions represent these four orientations.

Origin. The magnetite inclusions may be observed, when sufficiently abundant, to be arranged in successive, concentric zones outlining the growth stages of the mica. A partial, chevron-like, zonal arrangement or a simple alignment of the inclusions may also be noted (Fig. 5). Flattened inclusions of garnet and tourmaline are often associated with the magnetite inclusions and may then occur within and, when sufficiently abundant, be aligned within the magnetite zones. This mode of arrangement of the magnetite inclusions indicates that they have crystallized simultaneously with the mica.

TABLE 1. ORIENTATION OF ELONGATED MAGNETITE INCLUSIONS TO MUSCOVITE. GILSUM, N. H.

(The inclusions are flattened on (111), upon muscovite (001), and are elongated parallel to a (110)-(111) edge.)

Observed Inclinations to Muscovite 010.	0°	30°	60°	90°	Other
Corresponding Directions of Orientation.	010	130 $1\bar{3}0$	110 $1\bar{1}0$	100	
Number of Inclusions Observed.	23	507	29	207	14
Average Length in mm.	2.5	6.0	3.1	4.3	

The occurrence of thick, transecting, magnetite crystals also suggests a primary origin. Such inclusions could not have been formed by infiltration between the laminae, or by crystallization from solid solution. Furthermore, the inclusions do not appear to have originated by the chemical alteration of the muscovite, since they occur typically as widely separated individuals or, less often, in crowded aggregates in obviously unaltered, frequently colorless and transparent, mica books.

Localities. Magnitite inclusions were identified in muscovite from the following localities: Tuckahoe, Westchester County, New York; Gilsum, New Hamphsire; Gilletts' Quarry, Haddam Neck, Connecticut; New Fane, Vermont; Spruce Pine, North Carolina; Fremont County, Colorado; Macon County, North Carolina; Standish, Maine; and 11 localities on Manhattan Island, New York City. Magnetite inclusions were also identified in phlogopite from North Burgess, Ontario, and New Connecticut, Jefferson County, New York, and in clinochlore from Tilly Foster, Putnam County, New York. Of the iron oxide inclusions in mica cited in the literature, only the instances described by Bowman ((1); Haddam, Conn.); Mügge ((12); India), G. M. Hall ((7); Spruce Pine, N. C.), and Lacroix ((9); France) definitely appear to be magnetite.

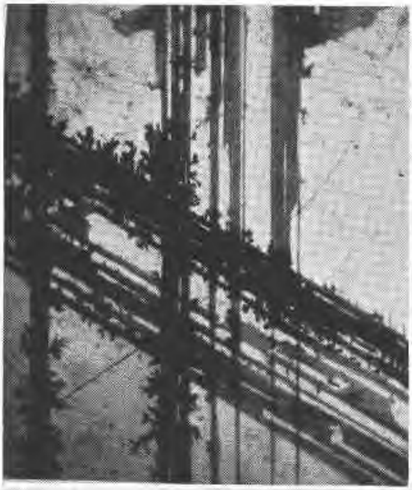

FIG. 11

FIG. 12

FIG. 13

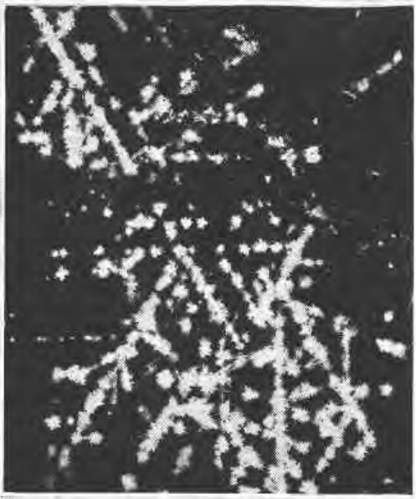

FIG 14

PLATE 3

FIG. 11. Lattice-like growths of hematite, showing minor dendrites springing from the sides of the laths. The two sets of laths are at different levels in the mica and are parts of separate crystals. Pennsbury, Pennsylvania. ×24.

FIG. 12. Extended dendritic growths of hematite. Three separate, overlapping, dendrites are present but cannot be distinguished in the photograph. The dendrites spring from long, narrow lattice rays, and their branches are severally oriented to the pressure and percussion figures. N. Y. C. ×10.

HEMATITE INCLUSIONS

A second type of iron oxide inclusion in muscovite appears as complex dendritic or lattice-like growths of relatively large size. Growths of this type are of wide-spread occurrence, and comprise most of the instances mentioned in the literature. Although the included mineral has generally been called magnetite, the growths differ markedly from the magnetite inclusions described on the preceding pages and undoubtedly represent some other mineral.

The color of the inclusions in transmitted light varies with their thickness from reddish brown and deep brown to pale brown and smoky tints. Opaque crystals are relatively rare, and are dull in luster and brownish black, reddish brown or deep brown in color. The translucent crystals are isotropic and non-pleochroic. Most of the inclusions that appear opaque to the unaided eye are subtranslucent when strongly illuminated under the microscope. Bright shades of yellow and red are seen in inclusions that have undergone alteration, presumably to hydrous iron oxides.

Habit; Size. The growths appear as an arrangement of laths or stripes intersecting in a lattice pattern at angles of 60° (Figs. 11, 13, 17, 18), or as dendrites with the arms branching at 60° (Figs. 12, 14, 15, 16, 18). All gradations occur between the lattice and dendritic varieties. The growths are usually extremely complex, and present a fascinating variety of patterns.

Sometimes one or two of the three sets of laths in the lattice growths are subordinate in development, or are suppressed altogether. Minute dendrites frequently spring from the major laths of the pattern (Fig. 11). Linear arrangements of seemingly isolated dendrites are found to be connected by extremely narrow rays usually visible only under magnification (Fig. 14). The marginal and aligned dendrites are apparently of later formation than the lattice rays from which they spring. Isolated dendritic cyrstals are also common, and a mica sheet may be closely speckled with small growths of this kind (Fig. 15). Single dendrites are frequently very complex, but may be simple star-like crystals.

The continued growth and filling-in of dendritic crystals eventually results in the formation of small, complete crystals with a hexagonal outline. Such crystals typically have a perforate or sieve-like appearance.

FIG. 13. Photogram of lattice-like growths of hematite. The inclusions are absent from a pressure zone that traverses the mica. A number of separate, overlapping crystals are present. Delaware. Natural size.

FIG. 14. Photogram of dendritic hematite growths aligned along indistinct, thread-like, lattice rays. The inclusion is almost entirely composed of a single, highly skeletonized crystal. Colorado. Natural size.

The rays of the lattice growths may also be bounded by hexagonal faces; however, the terminations of the laths are rarely well developed, and generally fray out into parallel needles. The sides of the dendrites are usually irregular. Occasionally the inclusions are neither dendritic nor lattice-like, but form broad equant crystals, 1 cm. or more in diameter, with a more or less perfect hexagonal outline. Such crystals grade by elongation into lath-like crystals. Small dendrites may spring from the corners of the hexagons.

Even the most extended and open lattice growths consist of a single highly skeletonized crystal. This fact is more apparent in the dendritic variety of inclusion. Ordinarily a number—sometimes hundreds—of such crystals occur at different levels within the mica sheet, and careful examination is necessary to trace out the extent of a single individual. Some of the instances of extended two-dimensional skeletal growth and distortion seen in the inclusions are remarkable. In muscovite from Fremont County, Colorado, very thin lattice rays had a width of 0.05 mm. or so and lengths up to 13 cms. These rays branched at one or both terminations into radiating rays of comparable dimensions, the whole assemblage representing a single continuous crystal. The stripes in the Pennsbury, Pennsylvania, muscovite occasionally measure 30 cms. or more in length. Lattice growths covering an area of 100 sq. cms. or more are very common, and the average size is, at least, several square centimeters. The dendritic growths are much smaller in area, and run on the average between 0.25 and 1 sq. mm., although they occasionally reach an area of 1 sq. cm. or more.

Parting cracks were not observed in any of the inclusions. In specimens from several localities, the growths were noted to contain minute dash-like inclusions, oriented in a 60° pattern, of a pink or colorless, birefringent mineral, probably rutile (Fig. 16).

Interference Effects; Thickness. Both the opaque and the translucent inclusions may be outlined on the surface of cleavage sheets by interference colors. The order of the color is not related to the thickness of the inclusions, and in very thin cleavage sheets the color may be seen to be different on opposite sides of an inclusion. The colors are not complementary. The effect is apparently caused by interference from a mica film above inclusions that are immediately adjacent to the surface of the sheet.

Interference colors may also be shown by relatively light colored inclusions not adjacent to the surface of the sheet, and are evidently produced by the inclusions themselves. The thickness of such crystals can be estimated from the color exhibited, and was found to range between

150 and 400$\mu\mu$. At greater thicknesses the interference colors are obscured by the absorption color. The thickness of the non-interfering, darker colored inclusions was estimated by measuring the thickness of the enclosing mica laminae, and was found to range below 0.006 mm. for even the thickest opaque crystals. The degree of transparency is greater than in the magnetite inclusions. The inclusions cannot be mechanically separated from the mica.

Identity of the Included Mineral. The lattice-like and dendritic growths from Pennsbury, which are characteristic of the type, were originally referred by J. D. Dana (3) to magnetite, but were later considered by Rose (14) to be hematite; Dana and Brush (4) later re-affirmed the view that the mineral was magnetite, and the growths have since been generally ascribed to that species. However, the inclusions contrast with the hitherto little known type of inclusion identified in the present study as magnetite, and undoubtedly represent some other species. The principal points of difference may be summed up as follows:

MAGNETITE	HEMATITE (?)
Color: in transmitted light typically lavender gray or pure gray; opaque crystals lustrous and iron-black.	*Color:* in transmitted light typically brown or smoky; opaque crystals dull and brownish black, reddish brown or deep brown.
Parting cracks, arranged in a 60° pattern.	No parting cracks.
Habit: equant hexagonal crystals; occasionally lath or needle-like crystals.	*Habit:* extended highly skeletonized dendritic and lattice-like growths, with hexagonal symmetry.
Size: equant crystals average 1 mm. or less in diameter; elongated crystals average 5 mm. in length.	*Size:* the lattice growths frequently are 100 sq. cms. or more in area, and average at least several square centimeters. The dendrites average about 0.25–1 sq. mm. in area but reach 1 sq. cm. or more, and are usually interconnected.
Opaque inclusions common; very thick (0.01–0.1 mm. or more) inclusions observed and transect mica laminae.	Opaque inclusions rare. All range in thickness below 0.006 mm. The degree of transparency is greater than in the magnetite inclusions.
Layer growth.	No layer growth.
Isotropic.	Isotropic; but, if hematite, the crystals are flattened on (0001) perpendicular to the optic axis.

Relatively rare; usually isolated, inconspicuous crystals.	Very common; usually densely aggregated, conspicuous crystals.
Origin: enclosed during the primary growth of the mica.	*Origin:* secondary, and apparently exsolution growths.

It is also significant that both the magnetite and the lattice and dendritic type of inclusion frequently occur together in the same mica sheet.

The absorption colors of the lattice and dendritic growths are charteristic of hematite, and it seems probable, since the mineral is known to be an anhydrous oxide of iron, that the growths represent this species.

Orientation. If the mineral of the inclusions is hematite, considerations of crystallographic coincidence with the muscovite, to be described, identify the plane of flattening as (0001). The isotropism and the hexagonal outline of the inclusions agree with this orientation.

The laterally bounding faces of the inclusions are not determinable. For instance, there are no means of determining whether the faces are of first or second order forms. However, certain features of orientation and coincidence with the mica, and the arrangement of the rutile (?) inclusions,[2] indicate that the laterally bounding faces are those of a first order form.

Lewis (10) was first to recognize that the inclusions stand in crystallographic relation to the muscovite. The symmetrical 60° pattern of the dendritic growths had earlier been ascribed by J. D. Dana (3) to repeated twinning.

Two general types of orientation can be recognized. The inclusions are commonly arranged with the directions of elongation parallel to the rays of the percussion figure. Rarely are the inclusions oriented to the pressure figure. As was noted for the equant magnetite inclusions, the orientations as stated in this manner are ambiguous.

Single crystal lattices and dendrites oriented to one of the figures usually have minor extensions, at right angles to the major system, oriented parallel to the other figure (Fig. 17). Small dendrites springing from the major laths of a lattice are commonly oriented in such fashion. In some case, a rectangular, grid-iron, pattern is formed by the equal development of rays of both orientations in a single growth. Occasionally elongated thread- or lath-like extensions from the growths traverse the mica at an angle to the pressure and percussion figure positions.

Origin. The origin of the inclusions is uncertain. However, certain features indicate that the hematite was not included during the primary

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[2] In the oriented overgrowths of rutile upon (0001) of hematite (11), the rutile is flattened on (100) and is arranged with c perpendicular to the $(10\bar{1}0)$–(0001) edges. If this orientation holds true of the rutile needles in the hematite inclusions, the bounding faces are those of a first order form, since the needles are arranged perpendicular to the outline.

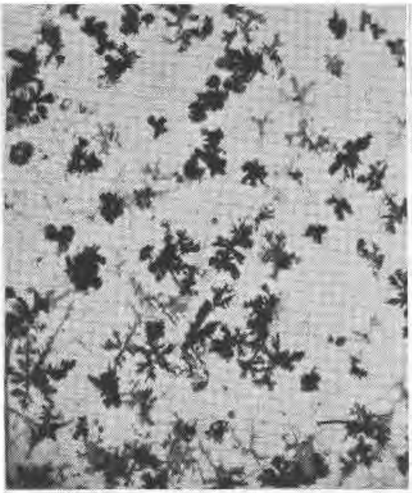

FIG. 15

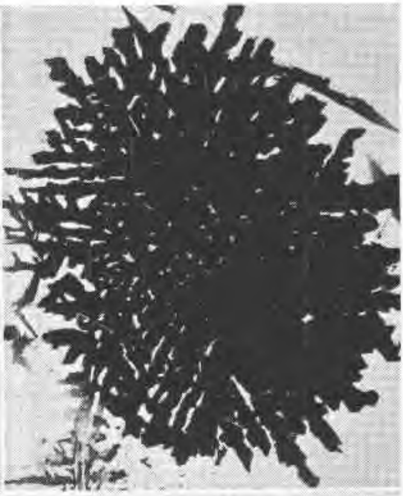

FIG. 16

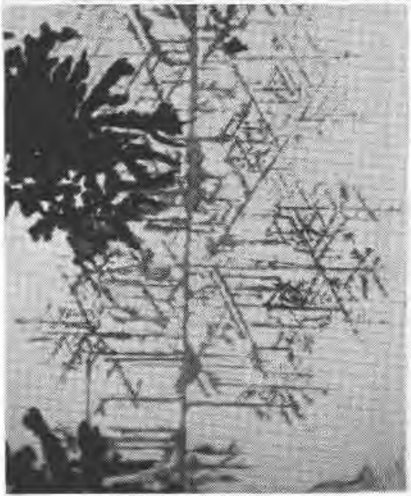

FIG. 17

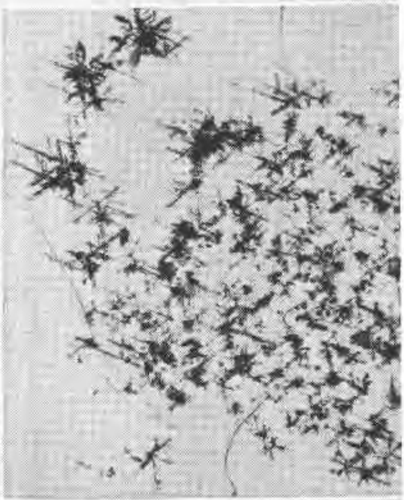

FIG. 18

PLATE 4

FIG. 15. Isolated dendrites of hematite. A portion of a large evenly spotted mica sheet. Colorado. ×14.

FIG. 16. A partially "filled-in" dendritic growth of hematite. Minute dash-like inclusions of rutile (*), oriented in a 60° pattern at right angles to the bounding faces, can be seen. N. Y. C. ×10.

growth of the muscovite. In wrinkled and sheared mica, for instance, the inclusions frequently occur in densely aggregated zones parallel to the wrinkling or ruling, and may be more or less confined to the disturbed areas of the books. Conversely, instances were observed in which the inclusions were absent from a pressure zone that traversed an otherwise undisturbed sheet of mica (Fig. 13).

In muscovite from Bedford, N. Y., the wrinkled and ruled portions of the sheets contained densely aggregated minute dendrites, interconnected by nearly invisible thread-like rays, while the undisturbed portions of the sheets contained scattered, broad, and more or less perfect hexagonal crystals 1 cm. or so in diameter. In many specimens from this occurrence the dendrites were aligned along parallel rulings in the mica. When the rulings were curved or slightly divergent, the hematite zones followed the curvature but the inclusions within the zones maintained their parallel orientation. The rulings were not open cracks, but sharp folds.

Inasmuch as the distribution and habit of the inclusions is influenced by secondary structures in the mica, the hematite must have originated subsequently to the crystallization of the muscovite. Other observers have also held the growths to be secondary. Nevertheless, the inclusions do not appear to have been formed by the chemical decomposition of the muscovite, as has been often suggested, or to have been emplaced by infiltration between the mica laminae.

The marginal portions of the sheets are characteristically quite free from inclusions, and the inclusions neither extend out from open, secondary cracks in the mica, nor occur within such cracks. Further, the inclusions are not more abundant in dark-colored, iron-rich, varieties of muscovite, as would be expected if formed by alteration, and commonly occur in colorless and unquestionably fresh and unaltered mica. The growths were found on a cursory examination to be rare in biotite and phlogopite. A few specimens of lepidolite and of chlorites and hydrous micas were also examined but no inclusions were observed. The widespread occurrence of the inclusions, the chemical stability of muscovite, and the occurrence of hundreds of closely interleaved inclusions in a single mica book also weigh against an origin by infiltration or by decomposition of the muscovite.

FIG. 17. A complicated single crystal lattice-work springing at right angles from a long lath-like ray. The two dark dendrites are separate crystals at different levels in the mica. N. Y. C. ×28.

FIG. 18. Hematite growth resembling both the dendritic and lattice varieties. N. Y. C. ×24.

Alternatively, the hematite may have crystallized from solid solution in the muscovite. This origin seems most in accord with the feature of variation in distribution and habit with respect to mechanical effects in the mica. Hexagonal, basally flattened exsolution growths of hematite are well known in aventurine feldspar, magnetite, carnallite and other species. The formation of exsolution growths of hematite in magnetite is facilitated by relief of strain (19).

Localities. Hematite growths of the nature described were examined in muscovite from Chandler's Hollow, Delaware; Darlington, Delaware County, Pennsylvania; Branchville, Connecticut; "Maine"; Pennsbury, Chester County, Pennsylvania; Fremont County, Colorado; Bedford, Westchester County, New York; "Quebec"; "North Carolina"; "India"; "Siberia"; and from 19 localities on Manhattan Island, New York City (Ashby collection). Many further localities are cited in references 1–16. The inclusions are very much more common than the magnetite inclusions described in the preceding section.

STRUCTURAL RELATIONS OF MAGNETITE, HEMATITE, AND MUSCOVITE

Comparison of the crystal structure of magnetite[3] with that of (001) planes of muscovite reveals a close similarity of atomic arrangement and spacing in (111) planes and a general dissimilarity in other planes. In Figs. 19*a* and 19*b* (111) oxygen planes of magnetite are shown superposed on a (001) oxygen plane of muscovite with the parting cracks in the percussion and pressure figure orientations. A close correspondence also occurs between (111) Fe″ and Fe‴ planes of magnetite and (001) Si (=3 Si+Al) planes of muscovite, but the overall coincidence is less than in oxygen planes.

With hematite, a close similarity of structure with (001) of muscovite occurs in (0001) planes. Lacroix (9) observed specularite crystals overgrowing muscovite in oriented position by sharing of these planes. In Figs. 19*c* and 19*d*, (0001) oxygen planes of hematite are shown superposed on a (001) oxygen plane of muscovite. The crystal outline is chosen as a first order form, and is drawn in the percussion and pressure figure orientations. On this basis, the greatest coincidence occurs in the percussion figure orientation, which is the most common position of the natural growths. A second order outline would place the greatest coincidence in the pressure figure orientation. The assumption as to habit, supported as it is by the arrangement of the rutile (?) inclusions, there-

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[3] Magnetite, $a_0=8.37$; hematite, $a_0=5.42$, $\alpha=55° 17'$; muscovite, $a_0=5.18$, $b_0=9.02$.

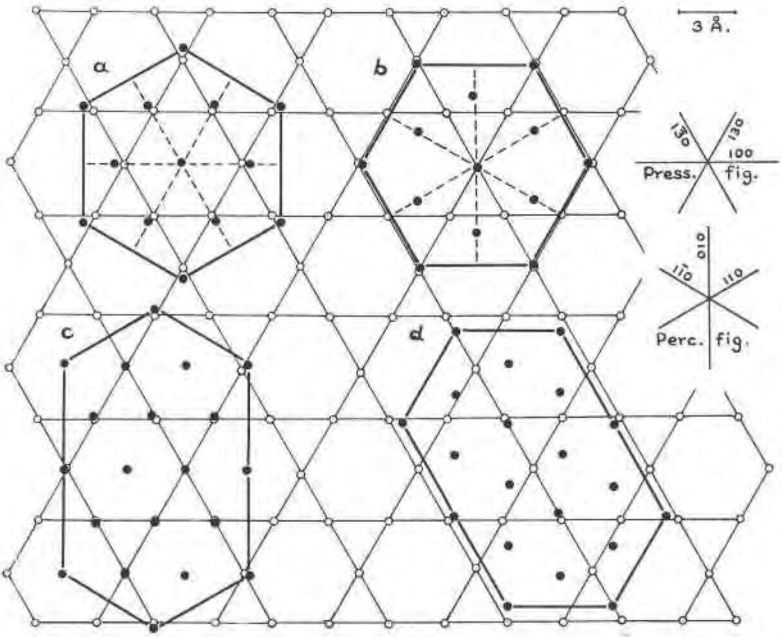

FIG. 19

Figs. 19*a* and 19*b* represent (111) oxygen planes of magnetite superposed on a (001) oxygen plane of muscovite. The crystal outline is dodecahedral, with the parting cracks (indicated by broken lines) parallel to the pressure figure in *a* and to the percussion figure in *b*.

Figs. 19*c* and 19*d* represent (0001) oxygen planes of hematite. The crystal outline is taken as a first order form, and is parallel to the percussion figure in *c* and to the pressure figure in *d*.

fore seems to be justified. In Fe''' (0001) planes of hematite, the overall coincidence with (001) Si planes of muscovite is less in either orientation than in oxygen planes, and the greatest coincidence, under the assumption made as to habit, is in the pressure figure orientation.

It is interesting to note that hematite and magnetite reciprocally form oriented over- and inter-growths by the sharing of (001) and (111) planes, and that they are analogously oriented upon (001) of muscovite. In terms of crystal growth, the structurally similar planes afford a ready-made foundation layer for the deposition of succeeding planes of the over- or inter-growing crystal, and determine positions of orientation of high frequency.

Oriented growths of muscovite upon magnetite or hematite have not been described. However, chlorite has been described overgrowing the

(111) faces of magnetite in oriented position (21). Al-spinel has also been observed (22) to be penetrated by plates of mica disposed parallel to the octahedral faces of the crystal.

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