Some Mineral Inclusions in Mica of Manhattan Island

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SOME MINERAL INCLUSIONS IN MICA OF MANHATTAN ISLAND

A MICROSCOPICAL STUDY

BY

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The Minerals occurring as Inclusions in the Muscovite of Manhattan Island fall into three general groups:

A. Primary or Original Minerals, which were formed and deposited simultaneously with the Mica.

B. Secondary Minerals, introduced through heated solutions during periods of strain by external pressure.

C. Minerals which have resulted through the decomposition of either the primary or secondary minerals.

They are enclosed between the lamina of the meta-morphosed Granitic rocks of Manhattan Island and are abnormal in their crystallization, in that they are mainly two-dimensional, their thickness being limited by the available space between the mica lamina.

The minerals to be described were collected chiefly between 1900 and 1925, during excavations for the subways and other building operations.
While the prominent basal cleavage of muscovite permits the easy separation of the lamina under strain and the penetration of mineral-bearing solutions, there are other cleavage phenomena which determine the orientation of the minerals so deposited.

These lesser cleavages in mica are indicated by the P E R C U S S I O N and P R E S S U R E F I G U R E S. (Fig. 1)

The Percussion Figure is developed when a sharp pointed punch is struck a sharp blow on a cleavage plate of mica, when a six-rayed cleavage star is produced, one of the three lines of which is parallel to the clinopinacoid, thus fixing the crystallographic orientation of the mica plate when the crystalline faces are wanting.

When a dull pointed instrument is firmly pressed upon a mica plate a six-rayed star is likewise formed, whose rays however are at right angles to those of the percussion star.

These so-called Percussion and Pressure Figures, representing directions of fracture and hence a minimum of cohesion along these lines means that certain molecular forces within the mica have dictated this condition.
Fig. 1.

Percussion Figure

Pressure Figure

Clinoptyidal Plane of Symmetry

One line of the percussion star is parallel to the plane of symmetry. The other two lines are parallel to the prismatic edges of the six-sided fragment of mica.

India Muscovite Mica, with percussion figures.
Even a very cursory examination of any Manhattan Island mica will show that the movement of the rock masses has left its record in the production of lines of strain. Upon applying the test of the strike figure it will be noted that these strain lines form at right angles to the strike figure and correspond in direction to the pressure figure.

Strain lines are very common in mica and in many instances the infiltration of iron and manganese oxides have resulted in more strongly outlining these rhombic fractures. (Fig. 2 & 3)

Strain lines have developed, singly in some cases, while in others where the straining has been more severe, strain bands have been formed extending across the entire crystal in one or more directions.

The pressure caused by the growth of included crystals has also produced fractures or lines of strain in the muscovite which radiate from the angles of the enclosed crystals and follow the direction of the lines of the pressure figure. (Fig. 4 and Fig. 5)

In some instances, where the straining has not been severe enough to actually produce fracturing of the mica, strain areas surrounding the included crystals are demonstrable by polarized light.

Natural percussion stars are rare and when produced have probably resulted from a sudden thrust of the strata which has caused the sharp point of an included crystal or mineral fragment to penetrate the lamina in contact with it.

Rock movements have in some cases been so exerted that a slight faulting has taken place and the edges of the mica plates have been sheared into long ribbons. In other instances the straining has caused a fine wrinkling over the entire crystal. Where the pressure has been exerted strongly and somewhat evenly in all directions, rhombic and hexagonal cleavages have been formed. (Fig. 6)

Phantoms caused by pressure were observed in material collected at 166th Street and Fort Washington Avenue.
Fig. 4.

Spinel

172nd St. & Fort Washington Av.

Fig. 5.

Tourmaline xl.

Strain fractures radiate from the angles of crystal, following the direction of the pressure figure.

171st St. & Fort Washington Av.

Fig. 6.

Strain cleavages

17th Street & 20th Ave.
MAGNETITE

Magnetite crystals occurring between the mica sheets do not penetrate the lamina but lie superficially between the plates and these crystals more than any others have been influenced in their deposition, which has been mainly along the direction of the strain lines, although in some instances they conform to the direction of the percussion figure.

This condition holds good not only regarding the linear arrangement of the crystals (Fig. 21) but also the orientation of the crystals themselves. (Fig. 7, 8 & 9)

Magnetite is very common in the muscovite of Manhattan Island, occurring in irregular patches, in crystals of hexagonal outline and in fine hair-like prismatic crystals, some of which are excessively elongated. Measurement of some of these crystals proved them to be more than eight hundred times longer than their width.

In many cases the magnetite has assumed a rhombic form and conforms in outline to the direction of the rays of either the percussion or the pressure figure. (Fig. 24)

In many magnetite crystals hexagonal parting cracks occur which in some instances are parallel to the pressure figure and in others agree with the percussion figure. (Compare Fig. 7 & 8 with 10 to 13.)

In rare instances there have been developed parting cracks in the same crystal which conform to both the percussion and pressure figures. (Fig. 14)

There are exceptions to all rules and I have observed, in a few cases, that neither the outline of the crystal nor its parting cracks exactly agree with either the percussion or pressure figure. Such crystals, probably, have either been loosened and shifted from their original position by subsequent straining of the mica sheet or they may represent a deposition as the resultant of these two forces.

Magnetite crystals from a pegmatite dike at 176th Street between St Nicholas and Audubon Avenues are of extreme tenuity and of a habit not noted elsewhere. These crystals are in some cases so thin as to be transparent and many of them have geometrically divided segments, some of a buff color while others are a distinct blue. (Fig. 15 - 16)

In some instances the overlapping portion of two extremely thin crystals is of a distinct color, in one case a bright green. This color effect can undoubtedly be referred to interference of light due to thin films, as the color by reflected light is complementary to that by transmitted light.

Another curious example of interference colors is referred to on page 21.
MAGNETITE

Interference colors of thin films is a phenomena very common in mica and illustrates the variation in separation of the lamina, demonstrating by the Newton rings produced and by the irregular areas of color films which shift with every flexion, the air filled spaces existing between the mica sheets. With large flattened crystal inclusions these interference colors appear over the surface of the included crystal but do not spread to the surrounding area.

It would seem evident that the muscovite from this locality (176th St. and St Nicholas Avenue) not only had allowed extremely small separation between the lamina for the reception of mineral bearing solutions but that there was also an insufficient quantity of crystallizable material for the completion of the work of crystal building. This condition is shown not alone from the extreme tenuity of the magnetite crystals but also from the deposition of magnetite in very irregular patches without definite outline as well as from the unsuccessful effort implied in the production of incomplete and skeleton crystals. (Fig. 17-18-19 & 23.)

In Figure 19 will be seen the nearly perfect outline of a magnetite crystal whose last expiring efforts to form a perfect crystal from the available material only resulted in reinforcing the internal angles of the crystal skeleton.

Dana reports the cubic form in magnetite as rare, yet we have many examples in these microscopic crystals of both the cubic and prismatic habit, which latter represents the over-development of the cube in one direction. Figure 20 is a striking illustration of this habit. It may also be noted that the prismatic arms of this magnetite aggregation are arranged at 120 degrees to each other. In direction they are parallel to the corresponding rays of the percussion star.

This development of the cube in one dimension and the projection of the resulting prismatic crystals in a definite direction is a further proof of the intimate molecular relation between the host and the parasitic mineral and of the molecular forces exerted by the mica impelling the deposition of the mineral along lines of cohesive minima.

What might be called skeleton crystals of magnetite are made up of a reticulation of fine prismatic crystals set at approximatively sixty degrees to each other.

Very minute magnetite crystals of prismatic habit also occurred at this locality implanted upon the larger magnetite crystals. (Fig. 15 & 25)
Examples of interrupted growth or multiple phantoms occur in the Muscovite from 173rd Street and Broadway, the inclusions forming phantom bands being composed of Manganese Dendrites associated with Magnetite groups of many small similarly oriented crystals joined together.

At 176th Street between St Nicholas and Audubon Avenues phantoms outlined by magnetite crystals occurred in the muscovite. These crystals are set at right angles to the direction of the face of the phantom. (Fig. 21)

Mr. James G. Manchester (1) has recorded the occurrence of magnetite in large masses at several localities on Manhattan Island.

During the summer of 1915 I collected muscovite crystals at 168th Street and Fort Washington Avenue containing small stout octahedrons of magnetite.

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Magnetite X.L.S. with Percussion Star.


1454 Street & Broadway.

Magnetite X.L.S. are at different levels in the mica plate.

Outline of some X.L.S. agree with Percussion Star, while others are at right angles to it.

Likewise in some the parting cracks agree with the Percussion Star, while others are at right angles.
MAGNETITE

171st Street & Fort Washington Ave.

Fig. 10

Fig. 11

Fig. 12

Fig. 13

x11.

x15

x18

Parting cracks agree with percussion star.
Magnetite

Fig. 1

176 1/4 St., between St Nicholas & Audubon Aves.

A Magnetite xl. in which the Parting cracks agree with both the Percussion and Pressure figures in the same crystal.

Fig. 15.

Magnetite with light segment and implanted prismatic crystals.

176 1/4 St., bet. St. Nicholas & Audubon Aves.

Magnetite xl., outline parallel to Percussion parting cracks parallel to Pressure Star.

176 1/4 St., bet. St. Nicholas & Audubon Aves.
**MAGNETITE**

**Fig. 17**

Incomplete XL.

**Fig. 19**

Skeleton crystal.

**Fig. 21**

Magnetite XLS. Outlining phantom parallel to pressure figure. Crystals are set at right angles to arrangement direction.
Fig. 22.

MAGNETITE

176 4th St. & St. Nicholas Ave.

MAGNETITE

Roughly torn in 3 directions approximating 120° to each other.

Prismatic with light portions.

Fig. 23.

MAGNETITE

With hexagonal opening.

176th Street and St. Nicholas Ave.

Fig. 25.

MAGNETITE

Implanted crystal.

176 4th St., St. Nicholas & Audubon Aves.
PYRITE

Pyrite as a coating on muscovite crystals is frequently observed. This enveloping pyrite will be found on splitting the mica apart to have forced its way between the lamina and been intruded from the outer edge of the mica crystal in fan-shaped groups with crystalline terminations.

Flattened cubes of pyrite in single crystals and in groups are quite common (Fig. 26, 30, 31 & 32) also flattened octahedral forms or cubes with the corners truncated. (Fig. 27)

Prismatic forms, representing the excessive development of the cube in one dimension occurred at 144th-145th Street and 147th Street and Broadway and were, I believe, first observed from these localities by Mr. Frederick Braun. (Fig. 28)

It will be noted that these prismatic crystals are arranged at approximately sixty degrees to each other, forming rhombic figures.

I have collected examples of this habit at 168th Street and Fort Washington Avenue and in this instance the prismatic pyrite in rhombic arrangement overlies thin sheets of calcite.

In some instances there occur cubic depressions in the mica sheet, probably resulting from the decomposition and complete removal of the original pyrite cube which in their growth had exerted sufficient pressure to force a depression in the mica sheet in much the same way a die would do when pressed into some plastic substance. Further reference to this phenomenon is made on page 17.

Phantoms, outlined by pyrite crystals, were observed at several localities, notably at 180th Street and Broadway and at 86th Street and the Hudson River.

A unique occurrence of tapering acicular pyrite crystals in radiating groups was observed at 145th Street and Broadway. (Fig. 29 & 34)

Flattened nodules and disks of pyrite occurred at several localities. (Fig. 33)

Pseudomorphs of pyrite, after what was in all probability magnetite, judging from the characteristic parting cracks in the original mineral, were observed in mica from the Subway excavations at 144th-145th Streets and Broadway by Mr. Frekerick Braun. (Fig. 34 - 35)

Partial decomposition has taken place along the edges of the parting cracks.
Fig. 26.
GROUP PYRITE CUBES.
1/2" ST. & FORT WASHINGTON AVE.

Fig. 27.
PYRITE, CUBE TRUNCATED.
172° ST. AND HAVEN AVENUE.

Fig. 28.
CUBIC & D PRISMATIC PYRITE XLS.
IN RHOMBOID ARRANGEMENT.
144-145° ST. & BROADWAY.

Fig. 29.
CURIOUS ACICULAR PYRITE XLS.
154-155° ST. & BROADWAY.
Fig. 30

Pyrite x15.

Cube.

Elongated Cube.

165th St., 1st Hudson River.

Fig. 31

Pyrite group.

1/2 2nd St., 3rd Fort Washington Av.
Fig. 34.

Pyrite pseudomorph after Magnetite with parting cracks, filled with decomposition product. Associated with Abicular Pyrite crystals.

x 28.

Fig. 35.

Pyrite pseudomorph after Magnetite. Partial decomposition has taken place along the edges of the parting cracks.

x 14.
The DECOMPOSITION of
PYRITE

By the action of circulating waters pyrite may become oxidized and hydrated and gradually pass into the hydrated sesquioxide state most commonly recognized as Limonite.

This decomposition of pyrite which has taken place within the walls of the mica crystal may show many of the delicate series of changes in the mineral on account of the infinitely slow progress of the oxidation.

Of the very long series of oxides and hydrates of iron known to the chemist, barely a half dozen or so have been recognized by the mineralogist in nature, so it is not at all impossible that among these mica inclusions some of these unrecognized ones may be awaiting identification.

F.W. Clarke (1) gives a list of the several hydroxides of iron which have been given definite rank as mineral species

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>TURGITE</td>
<td>2 Fe₂O₃ plus 1 H₂O</td>
</tr>
<tr>
<td>GOETHITE</td>
<td>&quot; 2 &quot;</td>
</tr>
<tr>
<td>LIMONITE</td>
<td>&quot; 3 &quot;</td>
</tr>
<tr>
<td>XANTHOSIDERITE</td>
<td>&quot; 4 &quot;</td>
</tr>
<tr>
<td>LIMNITE</td>
<td>&quot; 5 &quot;</td>
</tr>
</tbody>
</table>

Clarke also observes that of these minerals only Goethite is crystalline, the others being amorphous and that all sorts of mixtures between them are likely to occur.

According to P. Nicolardot (2) ferric hydroxide exists in at least six modifications, all of which are polymers of the simplest hydroxide.

The hydroxides of iron resulting from the decomposition of pyrite are evidently complex and not very definite compounds and their identification as microscopic particles between the lamina of the mica cannot be very certainly determined. Their transformation within the confines of the microscopic laboratory in the mica may have resulted in the preservation of many steps in the process otherwise not observable, for here we have presented the various stages representing the changes which have taken place in single crystals, from the incipient stages of decay, only indicated by a slight tarnish, to the final and complete stage in which there is an elimination of all mineral matter and in which there is only a remnant left as a faint outline bordering the original crystal.

It is not improbable that the changes observed do not entirely correspond with those taking place under ordinary atmospheric attack and that we may as a result, have a series of dirivative substances, some of which at least may have no counterparts as mineral species.

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Groups of pyrite crystals so slightly altered as to present no further
evidence of change than some loss of surface brightness are bordered by an
alteration product (Fig. 36-37) which fills the spaces between the crystals
with mineral matter which is strongly birefringent.
Single crystals are bordered by limonitic matter. (Fig. 38 )

Where the decomposition has proceeded much further the crystal will be
found to have lost its opacity and become translucent, with the crystals
assuming a bright red color (Fig. 46 ) which in some cases is retained
throughout while in others the color gradually changes through an orange
to a brownish yellow at the edges.
Other crystals in the orange stage are surrounded by a border with long
streamers of limonitic-like matter. (Fig. 45 )
There also occur, in some cases, short straight projections of a light
yellow color protruding everywhere at right angles to the face of the
crystal. (Fig. 44 ) These straight projections seem to differ entirely
from the streamers (Fig. 45-46 ) and have the appearance of crystallites
in structure, but are not birefringent.
Some crystals are surrounded by a cloud of birefringent material which
is made up of crystalline circular radiating groups of crystals, possibly
Goethite.

At 191st Street and Wadsworth Avenue I found crystals of decomposed
pyrite of a rich red color, which still retained a core of the original
pyrite. (Fig. 39 )

In many instances the solution of the pyrite has been so gradual that
it might be described as an etching process, which has been exerted along
the cleavage planes and developed the octahedral axes of the flattened
cubic crystals. (Fig. 42-43-49-50) In other cases the cubic structure
has been developed. (Fig. 40-41)

Further decomposition has resulted in a portion of the crystal being
dissolved, with the resulting limonitic-like matter deposited as a border.
(Fig. 47-48)

In some cases the elimination of the pyrite has left hollow squares
or skeleton crystals of limonitic-like matter. (Fig. 51-52-53)
In other cases there is only a faint outline of the pyrite cube left
and where the leaching out has been still more complete the only evidence
remaining is a faint border to what might be termed shadow crystals.(Fig.56)

Clear spaces surrounded by a deep bordering, with streamers of limon-
itic matter represent the complete leaching out of the original pyrite.
(Fig. 57-58)

Another form is represented by large patches of limonite, within which
are clear cubic spaces. (Fig. 59 )
The DECOMPOSITION of PYRITE

It will be noted that the resulting limonite extends far beyond the confines of the space originally filled by the pyrite. (Fig. 43-45-46)

Van Hise (1) states that in the change from a crystalline to an amorphous form the volume of the resulting limonite is greater than the pyrite from which it was derived.

This observation of Van Hise made on large ore bodies is strikingly confirmed and illustrated in the case of the decomposition of single crystals of pyrite in the Manhattan Island Mica.

Dots and concretions of a blood red color occurring in the mica have been referred to Hematite. At first, from the examination of a few isolated specimens, I was inclined to coincide with this view, but on further examination extending to many hundreds of specimens and observing its varied appearance and associations I was led to the belief that the mineral is not Hematite but a transition stage of the passage of pyrite into the hydrated sesquioxides. Moreover, Hematite is an an-hydrous ferric oxide, free of combined water, and as observed by Eckel (2) is not likely to result from the same processes which produced the brown ores, Turgite, Limonite and the other hydrous sesquioxides.

This mineral, whatever it may prove to be is always found closely associated with other decomposition products of the pyrite and occurs in concentric and radiating dots and larger aggregations, while in some cases the dots are strung along in rows, forming rods. (Fig. 60)

At 176th Street and St Nicholas Avenue, where this mineral was of very common occurrence I also observed pyrite crystals which were undergoing decomposition to be of the same rich blood-red color, while surrounding these crystals was the usual limonitic-like decomposition product streaming off from the crystals, (Fig. 46 & 48) Again, some of these crystals were red only in part, the color merging from red into orange and toward the edges to a brownish yellow.

Another formation of the alteration product is represented in Fig. 51; a radiating concentric aggregation of matter streaming off from the center in straight lines, like a disintegrating or exploding star.

Still another form (Fig. 52) is without any radiating lines but the central body is surrounded by a halo of the same material separated by a clear space.

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The DECOMPOSITION of PYRITE

**Fig. 36.**

Group of Pyrite X15, slightly altered.
Alteration product fills the spaces between the crystals.
165th Street & Broadway.

**Fig. 37.**

Pyrite, slightly altered, with border of alteration product.
NOTE: Some pyrite fragments were removed to show border more plainly.
172nd St. & Fort Washington Ave.

**Fig. 38.**

Pyrite X15, slightly decomposed with border of limonitic matter.
172nd St. & Fort Washington Ave.
The Decomposition of Pyrite

Fig. 39.

Pyrite altering, with core of unaltered pyrite in the lower portion; the upper portion being translucent and of a bright red color.
191st Street and Wadsworth Ave.

Fig. 40.

Pyrite altering with some of original pyrite remaining.
166th St. and Fort Washington Avenue.

Fig. 41.

Pyrite altering with cubic parting cracks.
172nd St. & Fort Washington Av
Pyrite Altering
Bordering limonitic matter with streamers.
176th St., 62nd St., Nicholas & Audubon Aves.
The decomposition of pyrite

Fig. 47.
Pyrite decomposing
172nd St. and Haven Ave.
The border of decomposition product is separated by a clear space.

Fig. 48.
Pyrite after decomposing
176th St., between St. Nicholas & Audubon Aves.

Fig. 49.
Limonite pseudo after pyrite
with development of octahedral axes.
176th St., 642 St. Nicholas & Audubon Aves.

Fig. 50.
Limonite pseudo after pyrite
with development of octahedral axes.
176th St., 642 St. Nicholas & Audubon Aves.
**The Decomposition of Pyrite**

**Fig. 51.**

Limonite Pseudomorph After Pyrite - Skeleton Crystals.

144-145th St. and Broadway.

**Fig. 52.**

Limonite After Pyrite, Leaving Skeleton Crystals.

172nd St. & Fort Washington Av.

**Fig. 53.**

Pyrite Xl. Nearly Leached Out.

172nd St. & Fort Washington Av.
The DECOMPOSITION of PYRITE

**Fig. 54.**
Pyrite, leached out center nearly clear. 172nd St. & Haven Ave.

**Fig. 55.**
The limonitic skeleton bordered by the decomposition product is separated by a clear space. Pyrite altering. 172nd St. & Fort Washington Ave.

**Fig. 56.**
Pyrite xls. altering. Limonite skeleton. 144th-145th St. and Broadway.
The Decomposition of Pyrite

Fig. 57

Faint outline of original Pyrite X4. With slight coloring in center showing leaching out almost complete. Surrounded by a cloud of limonitic matter.

170th St, bet. St Nicholas & Audubon Aves.

Fig. 58

Pyrite entirely leached out leaving original space clear.

172nd Street and Ft. Washington Ave.

Fig. 59

Limonitic deposit surrounding clear spaces originally Pyrite.

165th-168th St, & Ft. Washington Ave.
The DECOMPOSITION of PYRITE

Fig. 60

176th STREET BETWEEN ST. NICHOLAS & AUDUBON AVE.

Fig. 61

Limonitic Matter in concentric aggregation. Either forming or disintegrating.

165 1/2 - 168 1/2 STREET & FORT WASHINGTON AVENUE.
AMPHIBOLE

In a belt running in an easterly and westerly direction between 171st Street and 176th Street and from Audubon on the east to Fort Washington Avenue on the west, Amphibole occurs in the muscovite in radiating crystals in comparatively large fan-shaped groups.

These groups always project inwardly from the edge of the mica crystal and are never observed wholly isolated within the mica.

Very fine rod-like crystals of what are probably Amphibole were observed in the muscovite at 176th Street and St Nicholas Avenue. (Fig. 63.)

These crystals are in some instances surrounded by very pronounced pleochroic halos. (Fig. 63.)

Amphibole, variety Byssolite, in fine hair-like crystals penetrating the muscovite at various angles to its cleavage occurs at several localities, but notably at 172nd Street and Fort Washington Avenue.

APATITE

Very friable glassy light green crystals and masses of Apatite associated with muscovite were collected at 168th Street and Fort Washington Avenue.

Stout hexagonal prisms, a quarter inch in diameter and penetrating the mica crystals at right angles to the cleavage plane were also collected at the same locality; while small hexagonal prisms and irregular prismatic crystals, lying between the laminae, were observed in material from 171st Street and Fort Washington Avenue and 176th Street and St Nicholas Avenue.

At the latter locality flattened hexagonal dark green crystals occurred in the mica. (Fig. 64.)
Fig. 63.

AMPHIBOLE.

WITH HALOS.

176th St., 64th St., Nicholas & Audubon Aves.

Fig. 64.

APATITE xls.

176th St., 64th St., Nicholas & Audubon Aves.
BIOTITE

Biotite, as an intergrowth with muscovite occurs in brown and
greenish flakes, irregular patches and minute crystals of rhombic
form, from many localities. (Fig. 65.)

In addition to the macroscopic intergrowths of Biotite and Muscovite
there are Biotite crystals which are imbedded in the muscovite and penetrate
it diagonally to the cleavage laminae.

This habit was also observed with muscovite and examples of plates of
muscovite interpenetrating other plates of muscovite diagonally were
observed in material collected at 172nd Street and Fort Washington Avenue.

CALCITE

Calcite has been deposited between the mica lamina in sheets and
 lenses and shows its characteristic rhombic cleavage.
(Fig. 66, 67, and 68.)
Its occurrence is not confined to any particular area of the Island.

Some of the Calcite sheets have transparent rhombic spaces within
them. (Fig. 69.)

Plates of Calcite, roughly hexagonal in outline, and surrounding
decomposed remains of rhombs of Siderite, occurred at several localities.
(Fig. 70.)
In some cases the enclosed Siderite rhomb was in evidence only as a
faint shadow in the middle of the Calcite plates; while in others, it had
entirely disappeared and the calcite plates partly extended over its former
place, the only evidence remaining of the original Siderite being the staining
of the calcite by the limonitic product of its decomposition.

As to the probable origin of the calcite surrounding these pseudomorphs
after siderite crystals, I am of the opinion that the siderite antedated the
introduction of the waters bearing the carbonate of lime and acted as centers
of deposition and growth for the resulting calcite.
Fig. 65

BIOTITE IN RHOMBIC INCLUSIONS, WITH THE LINEAR ARRANGEMENT PARALLEL TO THE PERCUSSION FIGUR
171 ST. & FORT WASHINGTON AVE.

Fig. 66

Calcite. x 18.

Fig. 67

Calcite. x 18.
Fig. 68.

Calcite
145th St. & Broadway.
R.T.T.

Calcite
X/10.

Fig. 69.

Calcite with transparent rhombs.
172nd St. & Audubon Ave.

Fig. 70.

Hexagonal plates of Calcite, surrounding decomposed remains of rhombs of siderite.
54th St. & Broadway.
R.T.T.
DUMORTIERITE.

Dumortierite, in purple blue crystals, up to several inches in length, enclosed between the mica lamina, was collected by Mr. James Walker at 171st Street and Fort Washington Avenue.

Mr. Frederick Braun also reported finding a single crystal in mica at 171st Street and Boulevard. (now Broadway)

GARNET.

Garnet is a very common accessory mineral in the gneiss of Manhattan Island and occurs quite frequently in the dikes of pegmatite.

Garnet is associated with and included in the mica in very perfect crystals, as well as imperfectly formed crystals strongly ribbed and stepped by the edges of the enclosing mica.

Garnet in the form of thin flattened crystals also occurs between the mica lamina and very thin crystalline plates of garnet so enclosed were obtained at 176th Street and St Nicholas Avenue.

At this locality the muscovite crystals showed interruption of growth, the phantoms being outlined by thin flattened crystals of Garnet.

HEMATITE.

Dendritic or lattice-like growths, which have generally been referred to as Magnetite, have been identified by Mr. Clifford Frondell as Hematite. (1) (Fig. 71, 72 and 73.)

**HEMATITE**

**Fig. 71**

*Hematite in Dendritic Arrangement parallel to Percussion Figure.*

144-145 St. & Broadway.

**X/10.**

**Fig. 72**

*Hematite Stellate Arrangement at Right Angles to Percussion Figure.*

171 1/2 St. & Fort Washington Ave.

**X 12.**

**Fig. 73**

*Dendritic Hematite in Stellate Arrangement parallel to Percussion Figure.*

171 1/2 St. & Fort Washington Ave.
Manganese oxide, a decomposition product, is always more or less mixed with iron sesquioxide.

It occurs as Wad, filling irregular and crystalline cavities and has been introduced along strain cracks in the muscovite.

It also occurs in irregular spots, moss-like aggregations and in the well known dendritic forms which are the most prominent of all the intruded minerals. Their geometrical arrangement, either parallel the strain lines, as is most common, or to the lines of the percussion figure, are among the earliest observations of every collector.

Dendrites in stellate form and following the direction of the percussion stars is shown in Figure 74, from 93rd Street and Riverside Drive.

In some material collected at 90th Street and Broadway these dendrites were so regularly and closely arranged at 60 degrees to each other as to produce asterism when a source of light was viewed through the mica sheet.

The visual star thus formed is similar to that observed in PHLOGOPITE, in which case however it is said to be due to included crystals of RUTILE. Figure 75 is a photomicrograph of a sheet of Phlogopite showing the minute Rutile crystals with a percussion star. Figure 76 is visual star which appears when, as in this instance, a candle flame is viewed through the sheet of Phlogopite.
Dendritic Manganese.

**Fig. 74**

Dendritic Deposit of Manganese, Parallel to the Percussion Figure.

93rd Street and Riverside Drive.

**Fig. 75**

Phlogopite with inclusions of Rutile crystals arranged at right angles to the percussion figure.

**Fig. 76**

Visual Star in Phlogopite.
LIMONITE.

When not occurring as a pseudomorph Limonite is found as an infiltration which has penetrated the lamina of the mica and been deposited along strain lines and as a filling in rhombic spaces in the muscovite.

It also occurs in dark brown radiating patches.

As noted elsewhere, Calcite as well as Agate and Quartz inclusions are stained by Limonite.

PYRRHOTITE.

Thin tabular crystals of Pyrrhotite are reported, included in Muscovite from 215th Street and Broadway. 1.

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Quartz occurs in hexagonal crystals which penetrate the mica at high angles to the basal cleavage; also in masses associated with the muscovite which penetrate the lamina. While some of the Quartz is of irregular outline, other occurrences are of a regular geometric figure, usually a low triangular pyramid and resemble Babel Quartz in having the sides of the pyramid bounded by a series of steps or benches from the top to the bottom, the result of the imprint of the edges of the mica sheets.

Both smoky and milky varieties of quartz occur filling spaces and fissures caused by growth as well as strain. (Fig. 77)

In specimens from 169th Street and Fort Washington Avenue this intruded quartz was crowded with crystals of Tourmaline.

Smoky quartz in thin flattened sheets consisting of aggregations of circular crystallizations, filling triangular and rhombic spaces between the mica sheet were found in several localities. (Fig. 78)

Sheets of Quartz, some very thin and colored by iron oxide were found lying between the lamina. (Fig. 78 and 81)

The structure is from granular to coarsely crystalline. In some instances it has developed aggregations of spherical structure. Some of these spherical crystallizations show interruption of growth, the concentric rings being outlined by opaque particles.

Associated with the quartz sheets are flattened single and doubly terminated crystals, also thin plates bordered by crystals, (Fig. 82) as well as what might be termed sections of quartz geodes, with crystals of quartz projecting into and lining the central cavity.

Agate also occurs intimately associated with the crystalline quartz and often exhibiting the well known fortification structure. The Agate is quite generally stained by iron oxide and encloses spaces of hexagonal outline, either clear or filled with quartz. (Fig. 80)

At 161st Street and Fort Washington Avenue and also at 176th Street and St Nicholas Avenue some of the quartz was observed to have a cubic outline, while some of the radiating crystallizations surrounded cubic centers.

Mention has already been made (Page 8) of impressions made in the muscovite during the formation of Pyrite crystals. These cubic centers are evidently these spaces left in the mica upon removal of the pyrite, which have subsequently been filled by the quartz infiltration. Some of these cubic spaces are strongly outlined by iron oxide, which has probably resulted from the decomposition of the pyrite which formerly occupied the spaces. (Fig. 83)
Deposit of Quartz in Rhombohedrons parallel to the percussion figure.

171st St. & Fort Washington Ave.

Smoky Quartz, triangular form.

147th St. & Broadway.

176th St. & St. Nicholas & Audubon Ave.

Sheet of Quartz & Agate colored by iron oxide.

Agate, colored by iron oxide, encloses clear spaces of rhombic form.

x15

x14

x30
Fig. 51

Quartz Plates, bordered by Quartz crystals, with groups of Rutile crystals.

176 1/2 St. Nicholas & Audubon Aves.

Quartz in cubic form outlined by Iron Oxide.

Fig. 52

176 1/2 Street between St. Nicholas & Audubon Aves.
RUTILE.

Clusters of Rutile crystals in rhombic grouping were collected by Mr. Frederick Braun during the excavations for the Subway, at 54 - 55th Street and Broadway. (Fig. 84)

Radiating groups of acicular crystals and small bunches of needles of Rutile were found at several localities. (Fig. 85 & 86)

Hematite crystallizations cut by minute pink dash-like inclusions, presumably Rutile (1) oriented in a sixty degree pattern to each other, occurred at 93rd Street and Riverside Drive. (Fig. 87 & 88)

I also collected rutile crystals of this habit at 191st Street and Wadsworth Avenue and 168th Street and Fort Washington Avenue.

Mr. James G. Manchester (2) describes and illustrates a fine group of two terminated Rutile crystals penetrating a terminated Quartz crystal, collected at 207th Street and Broadway.

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RUTILE

**Fig. 84**
Rutile crystals grouped in rhombic formation.
54-55 45th St, 6 Broadway. (R.T.T.)

**Fig. 85**
Rutile group.
171st Street & Fort Washington Ave.

**Fig. 86**
Radiating group of rutile.
Needles of pink Rutile embedded in Hematite. Arranged at 60° to each other and parallel to the percussion figure.

9328 Street, Riverside Drive.
SIDERITE

I have not observed Siderite as an inclusion in the Muscovite of Manhattan Island except as a pseudomorph, having been replaced by Limonite. This may be accounted for by the fact that ferrous carbonate is an unstable compound and quite readily oxidizes to Limonite.

Its decomposition has been complete, no trace of the original mineral being left.

Mention has already been made under Calcite (Page 13) of borders of this mineral surrounding centers of limonite pseudomorph after rhombs of Siderite. (Fig. 70)

In other cases these pseudomorphs occur without the calcite borders, the rhombs of limonite often being surrounded by a framing rhomb of the same mineral, while in other cases the rhomb borders a clear space within. (Fig. 89 and 90)

These limonite pseudomorphs after siderite appear coarsely granular and porous.

T. Sterry Hunt (1) states that "when a crystal of ferrous carbonate loses its carbon dioxide and absorbs oxygen and water and passes into hydrous ferric oxide (Limonite) the resulting pseudomorph is found to be porous", (2) the contraction in volume being 19.5% when the densities are the same, while with Siderite of Sp. Gr. 3.6 its conversion into Limonite of Sp. Gr. 4.0 would result in a contraction of 27.5%.

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Fig. 89

Limonite Pseudomorph after Siderite

x14

Fig. 90

Limonite Pseudomorph after Siderite

x14

176th St, between St Nicholas & Audubon Aves.
SPINEL.

At 171-172nd Streets and Fort Washington Avenue I found spinel crystals in flattened and much modified octahedrons.

These crystals varied in color from light green to a dark greenish blue, in some cases showing zonal structure and twinning lines.

They are frequently associated with Tourmaline crystals, being included in groups of the latter and one specimen was noted penetrated by a crystal of Tourmaline.   (Fig. 91.)
This mineral is quite an accessory in the mica of Manhattan Island.

Stout black tourmaline crystals penetrate the mica sheets in all directions and while they are rather friable, are often to be found with perfect terminations.

Between the mica lamina however are flattened but beautifully perfect transparent crystals. These flattened tourmalines range from rather stout brown prisms to extremely thin colorless ones. Quite frequently they show phantoms, single and multiple, from interruption of growth.

As already mentioned (Page 3) strain lines in the muscovite have resulted through the pressure exerted during the growth of crystals and this is notably so in the case of tourmaline. (Fig. 5)

Mr. James G. Manchester collected at 168th Street and Broadway a very interesting piece of muscovite containing small transparent tourmaline crystals, the colors of which changed with the angle at which they were viewed. Upon examination it was seen that the tourmaline crystals overlay thin plates of the same mineral. The colors observed were the interference colors of thin plates. They very strikingly illustrated the phenomenon, first observed I believe, by Sir Isaac Newton, that when light is transmitted obliquely the same color requires a greater thickness of film to produce it, and that, therefore, the color of any film will descend in the color scale if it is viewed obliquely.
Fig. 92

Tourmaline

Spinell

172nd St. & Fort Washington Ave.

Fig. 93

Tourmaline xl.

172nd St. & Fort Washington Ave.

Tourmaline xl. with Cavities

176th St. & Fort Washington Ave.
XENOTIME and MONAZITE

These rare earth minerals have been found sparingly on Manhattan Island. At the time the Speedway way under construction crystals of both these minerals were obtained and in some instances were enclosed within the mica.

ZIRCON

Zircon in flattened crystals were observed in mica at 107th Street and Broadway and at 176th Street between St Nicholas and Audubon Avenues. (Fig. 95)
Fig. 96.

Awaiting Identification.

Twin xls.

144th - 145th St., and Broadway.

165th - 168th St., and Fort Washington Ave.

176th St., between St. Nicholas & Audubon Aves.
In conclusion I would point out to the reader that the identification of many of the minerals described was a difficult matter, not alone on account of their abnormal crystallization, due to their formation under conditions of pressure and strain, but also because of the difficult application of optical tests owing to their enclosure within the mica.

In this connection I might mention that a further study of the, as yet, unidentified minerals observed (Fig. 96) is to be undertaken by the Mineralogical Museum of Harvard University, they having accepted my entire collection, consisting of upwards of two hundred and fifty microscopical preparations together with all the duplicate material of the study.

Geo. E. Atchby.