ORIENTED INCLUSIONS OF STAUROLITE, ZIRCON AND GARNET IN MUSCOVITE. SKATING CRYSTALS AND THEIR SIGNIFICANCE

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CONTENTS

ABSTRACT

Microscopic crystals of staurolite, zircon and garnet included in muscovite are described. Statistical study proves that the inclusions are distributed in preferred orientations relative to the muscovite. In general, preferred orientations occur at crystallographic positions in which directions of relatively low index in the planes of contact of the inclusions and the muscovite coincide.

The included crystals are shown to have deposited from suspension upon the {001} face of the muscovite and to have moved about thereon before their burial by continued growth of the mica. The skating impetus is ascribed to the variation of interfacial surface energy with the relative orientation of the crystal faces in contact. The spontaneous, non-vectorial, movement of camphor crystals upon a water surface is analogous. The preferred orientations in the present instances express the vectorial character of crystal-surface forces, as contrasted to liquid surfaces, and mark final resting positions of relatively low interfacial energy. Experimental observations relevant to this effect are described.

INTRODUCTION

Statistical Basis of Orientation

The relative crystallographic position of two adjoining crystals is uniquely described by stating (1) a parallel pair of planes in the two crystals, and (2) the angular relation between a crystallographic direction in each of these planes. An oriented overgrowth, or oriented intergrowth, may be defined as a position of crystallographic coincidence between crystals of unlike species with which is associated a degree of frequency greater than that of chance. The recognition, in this sense, of orientation and of randomness requires the application of a statistical method.

A statistical study is here described of the crystallographic relations of flattened staurolite, garnet and zircon crystals enclosed between the {001} cleavages of muscovite crystals. The writer is indebted to Mr. George E. Ashby of Brooklyn, New York, for opportunity to examine the specimens.

The method of study involved (1) the identification of the plane of contact of the enclosed crystals with {001} of the muscovite, and (2) the angular relation between some identifiable direction in the plane of contact and [100] in {001} of the muscovite. The latter direction was established from an interference figure in the measurement of each inclusion. The angular positions thus determined were graphed against the frequency of occurrence and the presence or absence of orientations recognized thereby.

Description of Inclusions

Staurolite

Golden-brown staurolite crystals averaging about 0.5 mm. in length were found in abundance embedded in muscovite from a pegmatitic zone in the Manhattan schist at 107–108th Street and Broadway, Manhattan Island, New York City. The crystals ordinarily have a lath-like habit, with the forms {010}, {110} and {101} (Figs. 1, 3). Crystals of rhomboidal habit, caused by the near suppression of {110} were noted, and long prismatic crystals extended parallel to [001] with {010} almost or entirely suppressed were not uncommon (Figs. 4, 8). Interpenetration twins on {232} were abundant. The cell dimensions of the staurolite, determined by x-ray rotation photographs, are as follows:

$$a_0 = 7.84,\ b_0 = 16.56,\ c_0 = 5.64\ \text{Å}.$$

The position relative to the muscovite of 528 staurolite crystals was measured. Three different planes of attachment to {001} of the muscovite were found:

(1) 400, or 75.7 per cent, of the total number of inclusions were arranged with {010} parallel to {001} of the muscovite. The angle made by [001] of these crystals with [100] of the muscovite was measured. The statement of this angle and of the planes of attachment mentioned uniquely defines the relative crystallographic position of the two

minerals. The results of the measurements for this particular plane of attachment are represented graphically in Fig. 12. The measurements, which are accurate to 30′, are restricted by symmetry to an angular range of 90° between the [100] and [001] directions of the muscovite and staurolite, respectively. The positions of orientation to be recognized from this and accompanying graphs are discussed in a following section.

FIG. 1. Staurolite, with *b*{010}, *m*{110} and *r*{101}.

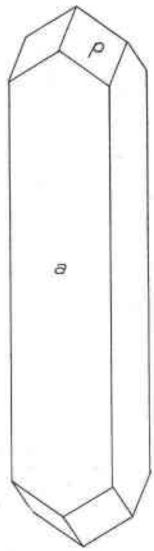

FIG. 2. Zircon, with *a*{100} and *p*{111}.

(2) 128, or 24.3 per cent, of the total inclusions were arranged with {110} parallel to {001} of the muscovite (Figs. 4, 8). The angle made by [001] of the inclusions with [100] of the muscovite was measured. The measurements are graphically represented in Fig. 13.

(3) A few staurolite crystals were also noted which were attached by {101} to {001} of the muscovite. These crystals were not measured.

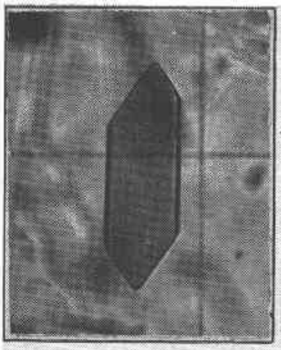
Fig. 3

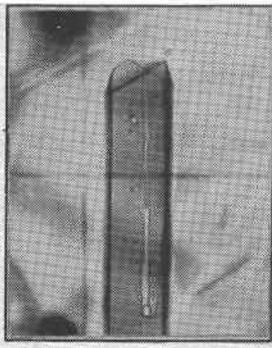
Fig. 4

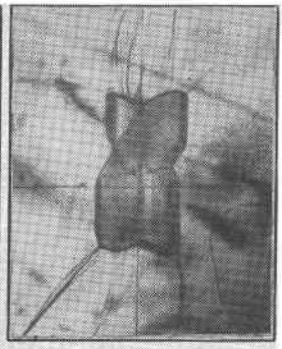
Fig. 5

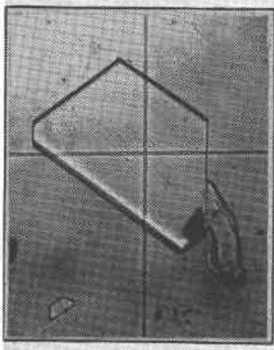
Fig. 6

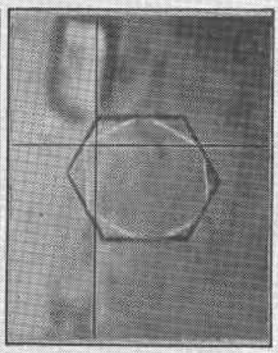
Fig. 7

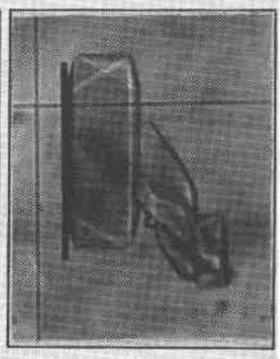
Fig. 8

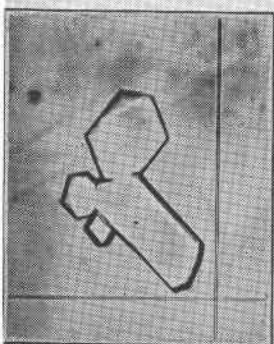
Fig. 9

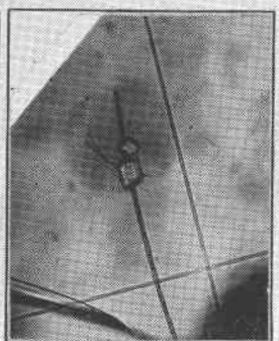
Fig. 10

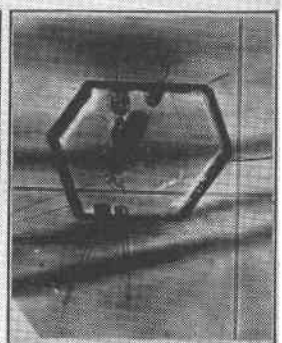
Fig. 11

(See opposite page for description to figures)

FIG. 3. Staurolite crystal flattened on {010}, with {101} and {110}.

FIG. 4. Staurolite crystal resting upon {110}, with {101} and narrow {010}.

FIG. 5. Staurolite interpenetration twin on {232}.

FIG. 6. Flattened and distorted garnet dodecahedron, with attachment of ferrous sulphate.

FIG. 7. Garnet flattened on {111} and bounded laterally by {110}.

FIG. 8. Group composed of a staurolite crystal resting on {110}, a penetration twin of staurolite tilted on side, and a narrow black prismatic crystal of unknown species.

FIG. 9. Planar group of four garnet crystals, two flattened on {110} and two flattened on {111}.

FIG. 10. Two garnet crystals impaled on a zircon prism.

FIG. 11. Garnet crystal penetrated by two zircon crystals.

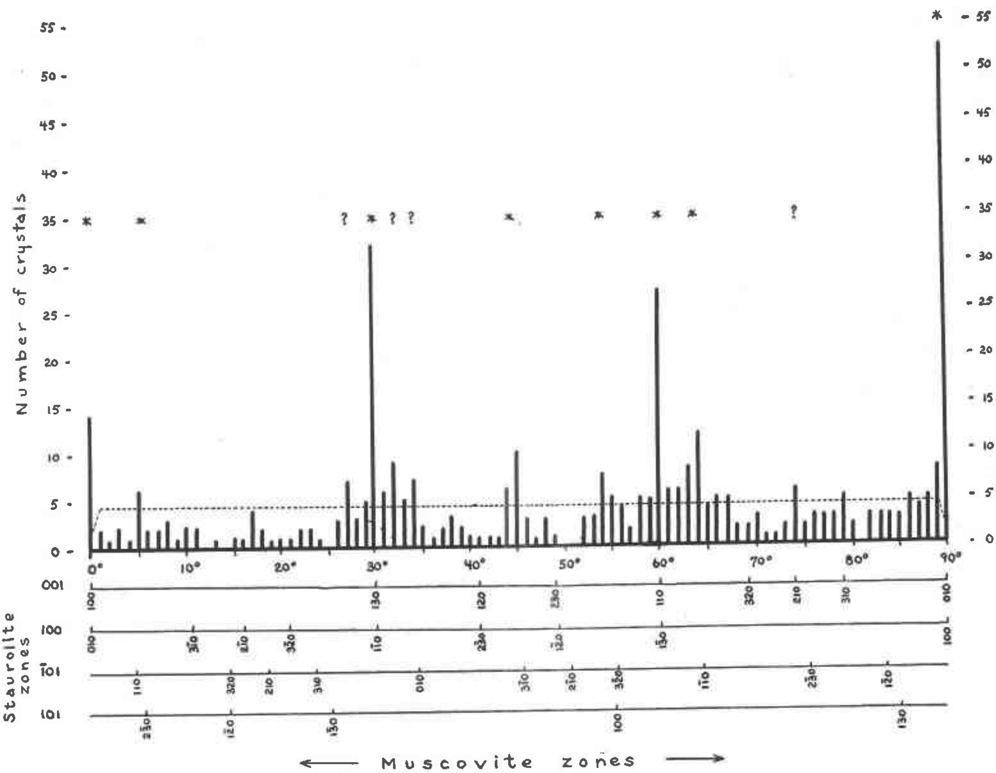

FIG. 12. Staurolite {010} upon muscovite {001}. Observed angles between staurolite [001] and muscovite [100] plotted for 400 crystals. Dotted line indicates average (theoretically random) population of graph.

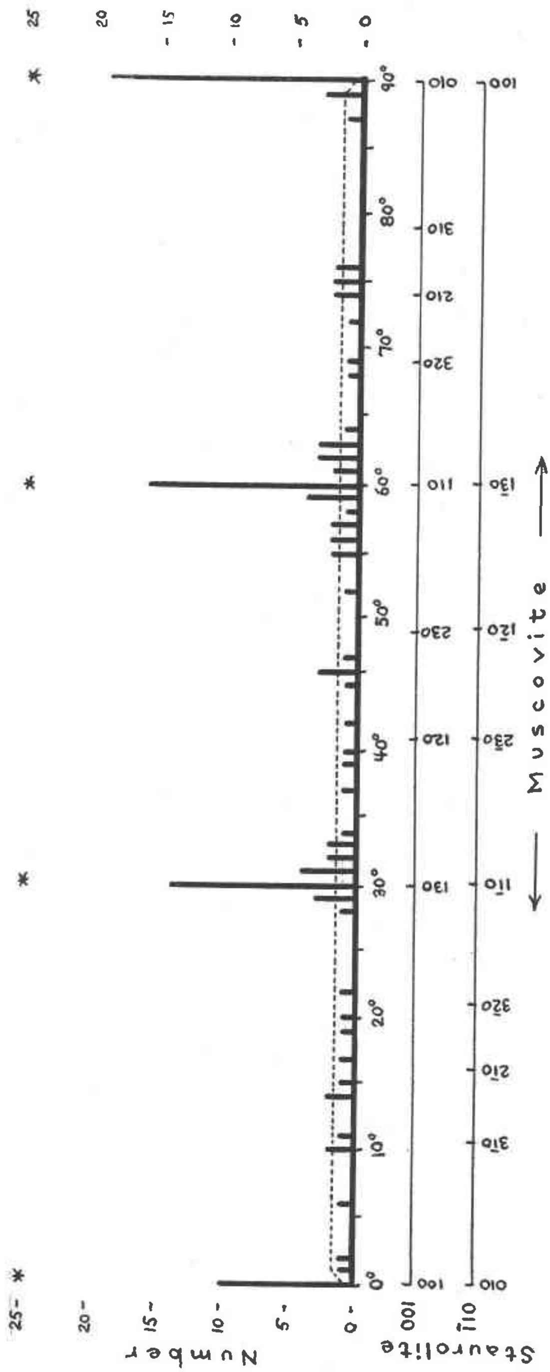

FIG. 13. Staurolite {110} upon muscovite {001}. Observed angles between staurolite [001] and muscovite [100] plotted for 128 crystals. Dotted line indicates average (theoretically random) population of graph.

Zircon

Zircon inclusions were identified in a pale greenish muscovite from a pegmatitic zone in the Manhattan schist at 176th Street between Audubon and St. Nicholas' Avenues, Manhattan Island, New York City. The crystals are long prismatic, averaging about 0.5 mm. in length, and are bounded by a prism and pyramid of different orders. The pyramid faces, which are somewhat pitted and rounded, gave interfacial angles, measured on the microscope stage, ranging between 54° and 60°. The form may be taken as $p\{111\}$, with $pp' = 56°40'$, making the prism $a\{100\}$. This is a common habit for the species (Fig. 2). A few knee-shaped twins on {101} were noted. In color the crystals are deep brown, sometimes with a deeper, hour-glass type of coloration beneath the faces of {111}. The cell dimensions of the zircon were not determined, since there is evidence that the crystals are altered.

All of the zircon crystals are surrounded by diffuse brown pleochroic haloes. The halo is particularly intense about minute black specks on the surface of the zircon, presumably attached crystals of a more radioactive mineral. Small, thread-like zircon prisms were often separated into a row of dash or dot-like rounded fragments. This feature, and the rough, pitted surface characteristic of the larger crystals, is doubtlessly the result of alteration.

The zircon crystals rest by a {100} face upon {001} of the muscovite. The angle between [001] of the zircon and [100] of the muscovite was measured for 92 crystals. The measurements are represented graphically in Fig. 14.

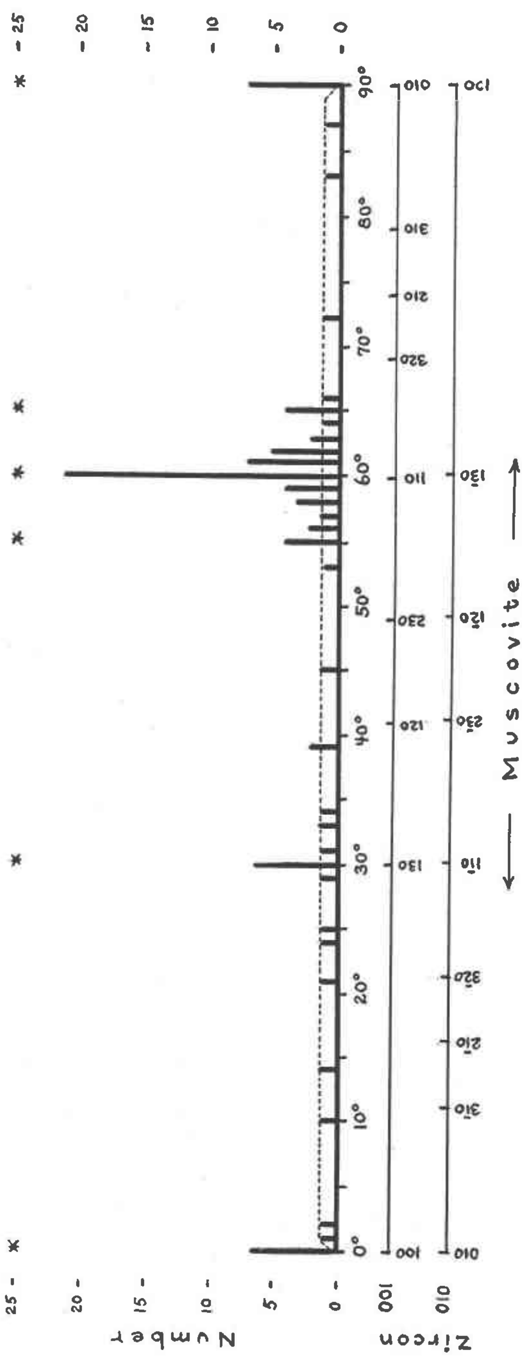

FIG. 14. Zircon {100} upon muscovite {001}. Observed angles between zircon [001] and muscovite [100] plotted for 92 crystals. Dotted line indicates average (theoretically random) population of graph.

Garnet

Flattened garnet crystals were found associated with the zircon inclusions previously described. The crystals range up to 0.5 mm. in size and are colorless, grading to pale rose in thicker individuals. Many of the garnets had a peculiar wavy appendage springing from a black spot (yellow in reflected light) on their surface (Fig. 6). The appendage has a pale green tint and is probably an iron sulphate mineral arising from the alteration of pyrite or pyrrhotite. Other garnet crystals had inclusions of zircon within them or were penetrated by needle-like zircon prisms (Figs. 10, 11). The garnet was usually radially cracked about the inclusions. The cell dimension of the garnet was determined from an x-ray rotation photograph as:

$$a_0 = 11.585 \pm 0.01 \text{ Å}.$$

The position relative to the muscovite of 607 garnet crystals was measured. Two different planes of attachment to $\{001\}$ of the muscovite were found, as follows:

(1) 514, or 84.7 per cent, of the total number of the crystals were dodecahedra flattened on $\{110\}$ and were attached to $\{001\}$ of the muscovite by this plane (Fig. 6). The crystals were occasionally modified by $\{111\}$ or, more rarely, by an $\{hll\}$ form. Many crystals were slightly distorted by elongation on [001], [111] or otherwise. The angle between [001] of the garnet and [100] of the muscovite was measured. The measurements are represented graphically in Fig. 15.

(2) 93, or 15.4 per cent, of the crystals were flattened on $\{111\}$ and were bounded laterally by $\{110\}$, giving the crystals a hexagonal shape (Fig. 7). The reference direction used in the measurement of these crystals was a side of the hexagon, or $[\bar{1}\bar{1}2]$. The angle between this direction and [100] of the muscovite was measured and the results are represented graphically in Fig. 16. The symmetry restricts the range of plotting to 30°.

Inclusions of garnet in muscovite have been reported by many previous observers,[1] but none have demonstrated a tendency for the garnet crystals to orient relative to the mica. It must be stressed that only rarely can the fact of orientation be recognized by ordinary visual inspection, as in the special case of parallelism between a number of immediately adjacent crystals. The fact of orientation or of randomness must, in general, be established by statistical investigation.

[1] For instance see Mountain, E. D., and Kent, L. E.: *Min. Mag.*, **25**, 125 (1938) and Hall, G. M.: *Am. Mineral.*, **19**, 79 (1934).

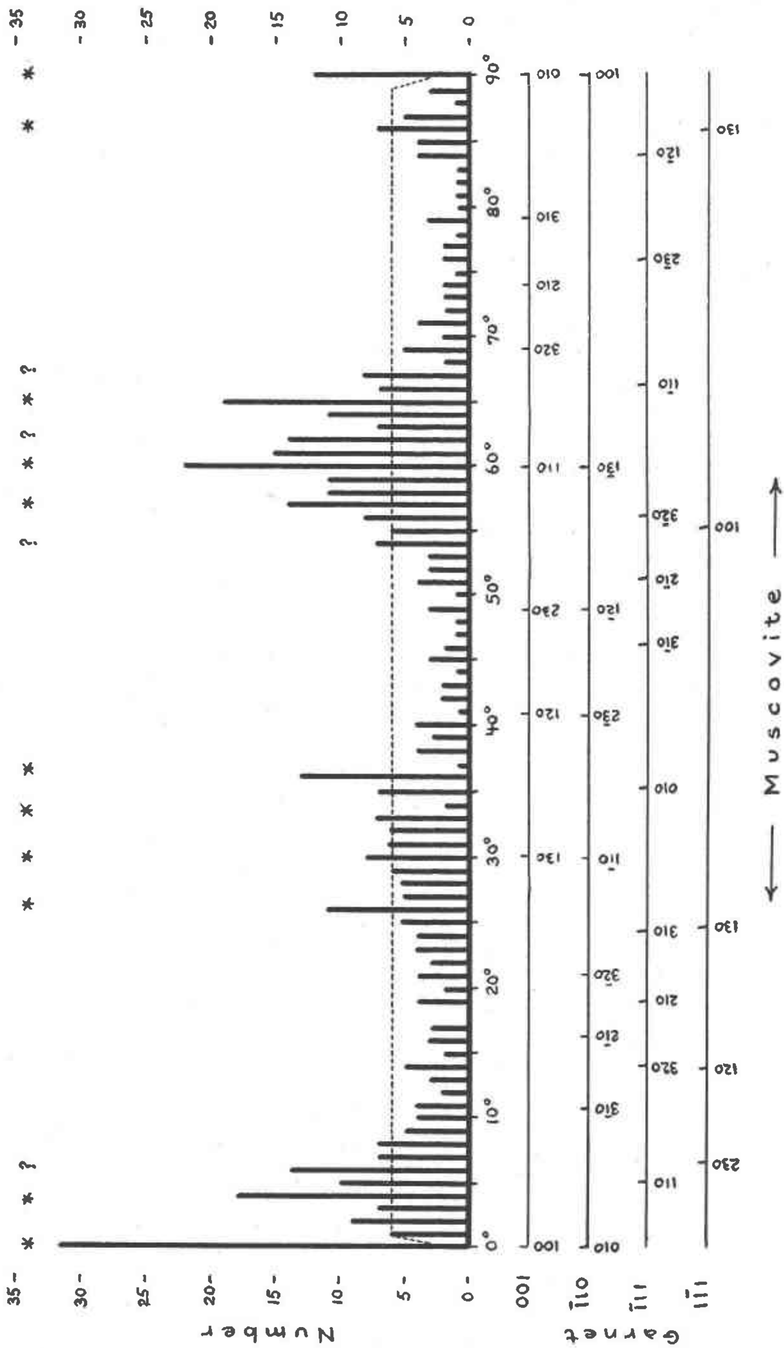

FIG. 15. Garnet {110} upon muscovite {001}. Observed angles between garnet [001] and muscovite [100] plotted for 514 crystals. Dotted line indicates average (theoretically random) population of graph.

RECOGNITION OF ORIENTATIONS. SUMMARY OF OBSERVATIONS

The measurements graphically represented in Figs. 12 to 16 state uniquely the crystallographic positions of the inclusions relative to the

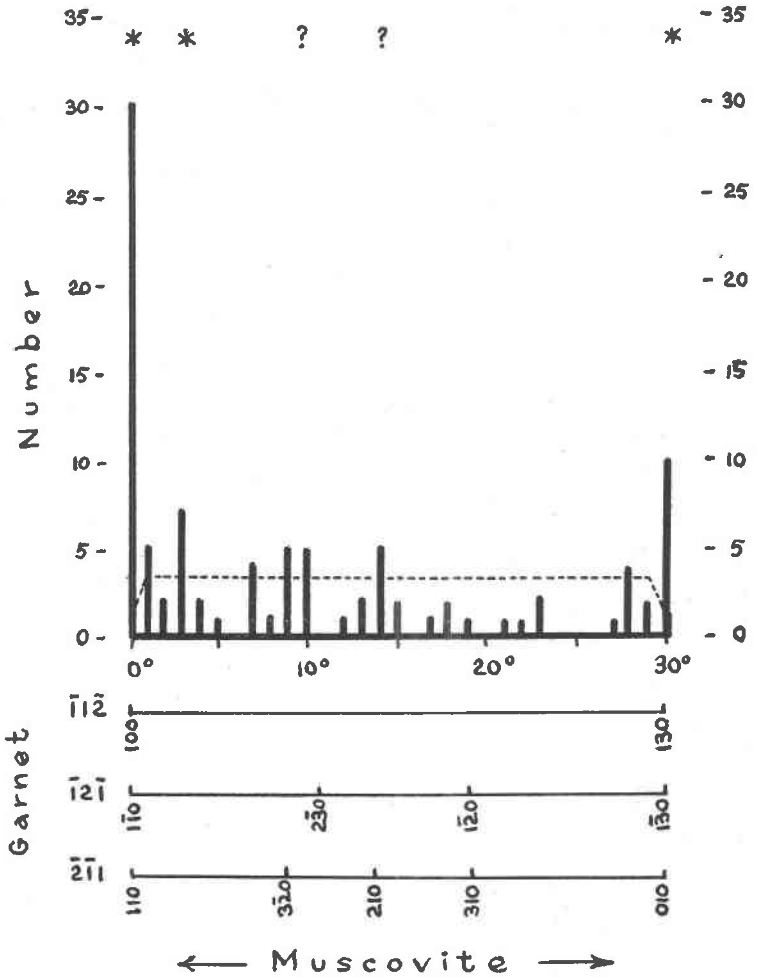

FIG. 16. Garnet {111} upon muscovite {001}. Observed angles between garnet [$\bar{1}\bar{1}2$] and muscovite [100] plotted for 93 crystals. Dotted line indicates average (theoretically random) population of graph.

muscovite. In general, an orientation is defined in these graphs by any position in which the statistical population is significantly greater than that expected from random distribution. The population expected from purely random distribution is indicated in the graphs by a broken line.

The recognition of orientations is, however, a matter of considerable difficulty, and is not subject to any generality of treatment. It may be noted that the actual position of an orientation may fall between the arbitrary reference divisions on the graphs, causing a distribution of observations about that position with consequent loss of definition. Closely spaced orientations also suffer loss of definition. Such positions can not be located more precisely by any statistical test, and their definition can be increased only by increased refinement of measurement and plotting. Also it is questionable whether orientations can be recognized with any certainty in regions of the graphs in which the population of sequential positions of reference is less than 3 or 4, regardless of the total number of observations. The low population (group number) prohibits an estimation of the validity of such orientations by statistical methods, such as the χ^2 "goodness-of-fit" test applied by H. Winchell[2] to the analysis of petrofabric diagrams. Uncertainty also arises as to the significance of positions of relatively high population that occur adjacent to major orientations. Positions of this nature doubtlessly contain a proportion, at least, of observations distributed through error of measurement about the major orientation.

The positions on the graphs whose population is considered to be significantly greater than that of chance distribution are summarized in Table 1. A few orientations of doubtful validity are included. Both the doubtful and the certain orientations are also indicated in the graphs, by question marks or asterisks.

Correlation Between Orientations and Coincidence of Directions of Low Index

The successive coincidences between directions of relatively low index in the contact planes of the inclusions and the muscovite, as the former are rotated upon the latter, are represented in the several graphs. In illustration, the direction [001] in {010} of staurolite coincides with [130] in {001} of muscovite, when the reference directions used in the measurement of the two minerals, staurolite [001] and muscovite [100], make an angle of 30°. It should be noted, however, that at any angular position of the reference directions an infinite number of directions in the contact planes of the two minerals coincide. Only a small selection of coincidences of relatively low index are here given.

Major orientations are found to occur at angular positions in which directions of relatively low index in the planes of contact of the two minerals coincide. This significant circumstance was first noted in a study of tourmaline inclusions in muscovite.[3]

[2] Winchell, H.: *Am. Mineral.*, **22**, 15 (1937).
[3] Frondel, C.: *Am. Mineral.*, **21**, 777 (1936).

A position of orientation and the frequency thereof, however, can not be quantitatively connected with some particular coincidence of this kind. It is obvious that the graphs are ambiguous in that many coincidences of different directions overlap at any angular position of

TABLE 1. SUMMARY OF OBSERVED ORIENTATIONS

Mineral	Contact plane with {001} of muscovite	Observed angle between stated direction and [100] of muscovite	Per cent of total number of crystals attached by stated contact plane
Staurolite	{010}	[001] 0°	3.5
		5°	1.5
		27°?	1.7
		30°	8.0
		32°?	2.2
		34°?	1.7
		45°	4.0
		54°	3.0
		60°	6.7
		64°	3.7
		74°?	1.5
		90°	13.75
Staurolite	{110}	[001] 0°	7.8
		30°	10.9
		60°	12.5
		90°	14.8
Zircon	{100}	[001] 0°	6.5
		30°	6.5
		55°	4.3
		60°	22.3
		65°	4.3
		90°	7.6

Mineral	Contact plane with {001} of muscovite	Observed angle between stated direction and [100] of muscovite	Per cent of total number of crystals attached by stated contact plane
Garnet	{110}	[001] 0°	6.2
		4°	3.5
		6°?	2.7
		26°	2.1
		30°	1.5
		33°	1.4
		36°	2.5
		54°?	1.4
		57°	2.7
		60°	4.3
		62°?	2.7
		65°	3.7
		67°?	1.5
		86°?	1.5
		90°	2.3
Garnet	{111}	$[\bar{1}12]$ 0°	32.3
		3°	7.5
		10°	5.4
		14°	5.4
		30°	10.8

orientation, and the contribution of each of these to the orientation is not apparent. Evidence of this ambiguity is found in that the equivalent + and − positions of some particular coincidence which occur at different angular positions in the graphs have not equal frequency. Thus in Fig. 12, it is seen that at an angular position of 15° that staurolite $[\bar{1}01]$ is parallel to muscovite [320] with a population of 1, while at an angular position of 56° the equivalent directions of opposite sign, staurolite $[\bar{1}01]$ and muscovite $[3\bar{2}0]$, are again parallel, but with a population of

4. The identification of an orientation-frequency with a particular coincidence requires a knowledge of the general relation between the two crystals which finds expression in the orientation phenomenon itself. This situation and its implications are outlined more fully in a later section.

It is considered that all of the graphs would define additional orientations if the number of observations was increased. In their present stage of development there is no conclusive evidence that the occurrences at any position are entirely of chance distribution.

Mode of Emplacement of the Inclusions

Two theories of origin of the inclusions may be suggested. The crystals now present as inclusions originally may have been freely suspended in a solution that was in contact with growing crystals of muscovite. The suspended crystals came into contact with the {001} faces of the muscovite, through gravitational settling or current action, became attached thereto, and were then buried by the continued growth of the mica. On the other hand, the garnet, staruolite and zircon crystals may have nucleated and crystallized directly upon the surface of the mica and were then buried. The characters of the inclusions which bear on their origin are discussed below:

(1) Edge and Corner Attachment. The penetration twins of staurolite, and groups of two or more intersecting garnet, zircon or staurolite crystals rest upon {001} of the mica by the touching of corners and edges of the aggregate and not by plane faces (Figs. 5, 8). Attachment in this way suggests attachment by mechanical settling-out. Direct crystallization of the crystals upon the surface of the mica would result in attachment by a plane face.

(2) Impaled Crystals. Conclusive evidence of the prior existence in the solution of suspended crystals is found in the occurrence of garnets impaled on needle-like prisms of zircon (Fig. 10). Other garnets had small inclusions of zircon, or had broken stubs of zircon prisms extending from their surface (Fig. 11). These intergrowths must have been preformed.

(3) Damaged Crystals. Staurolite and garnet crystals with their edges chipped or nicked were occasionally noted, as were broken zircon crystals. While the damage may have been inflicted through the contact of some body with the crystals while they were attached to and exposed on the surface of the mica, it seems more likely that chipping would result from jostling about in suspension or by impact with the mica surface.

(4). Bunched Crystals. Aggregates of 2, 3 or more staurolite or garnet crystals were noted which were attached to the mica by a face and touched laterally but did not interpenetrate (Figs. 8, 9). Also, the grouped crystals often were not all attached to the muscovite by the same plane (Fig. 9). These occurrences are inconsistent with an origin by direct crystallization upon the mica. Surface crystallization would favor scattered, isolated crystals, since the inception and growth of a crystal impoverishes the solution in its neighborhood and thereby acts against the formation of immediately adjoining nuclei. On the other hand, the bunches themselves can not have been preformed, since they lack cohesion as a unit and, also, are arranged in a common plane. These planar aggregates seem best explained by the assumption that the individuals composing them had slid about on the surface of the mica until their movement was stopped by contact with another crystal, or otherwise, with the building up of a log-jam.

(5). Restrictions in Kind of Contact Surfaces. Only those planes which are present as bounding faces on the crystals occur as contact surfaces with {001} on the mica. This is evidence for mechanical settling-out, insofar that direct crystallization upon the mica surface would not be limited in this way.

(6). Variation in Plane of Flattening. The plane of flattening varies somewhat according to the plane of attachment to the mica (compare Figs. 6 and 7 of garnet). This variation, and the occurrence of flattening itself, would not be expected if the crystals had been entirely preformed, by free growth during suspension in a solution. Crystallization directly upon the surface of the mica would satisfy the observations, since artificially overgrown crystals tend to become flattened parallel to the plane of attachment. However, the flattening can also be explained on the assumption that the crystals fell with a particular face upon the mica and still continued to grow, becoming flattened thereby.

It is considered that the observations described above force the conclusion that the crystals were preformed and had been mechanically attached to and then enclosed by the muscovite. The growth of the crystals probably continued after their attachment to the mica and up to the time of their burial by the simultaneously growing mica.

The manner in which the various orientations were impressed on the crystals now remains to be explained. Since the circumstances of incidence of the suspended crystals were without directional qualities, the observed orientations must have been assumed after the attachment of the crystals through some control exerted or participated in by the muscovite.

Factors Controlling Orientation. Skating Crystals

If ether vapor is brought into contact with a smooth surface of water, vigorous movements and currents are spontaneously set up in the latter. Ether markedly lowers the surface tension of water but the lowering does not take place uniformly over the water surface, so that liquid is drawn surficially from places of low surface tension to those of a higher one until equilibrium is reached. Similarly, camphor lowers the surface tension of water from approximately 70 to 21 dynes. If a small piece of solid camphor is dropped upon a clean surface of water it slowly dissolves and, at the same time, rapidly moves about under the impetus of local inequalities in surface tension. This movement is, of course, non-vectorial.

A plane crystalline surface that has come into contact with another crystalline surface is subject to similar influences. An essential difference from liquid surfaces exists, however, in that crystals are vectorial structures and the properties of their surfaces vary with direction therein.

Accordingly, at the contact of two plane crystalline surfaces, the interfacial surface energy must vary with the relative position of orientation of the two crystals. Only one position of orientation, together with any equivalent positions fixed by symmetry, is that of minimum interfacial energy. This particular position, for reasons pointed out elsewhere by the writer,[4] is that of most stable mutual coincidence of the two crystals. Crystals in contact, if given freedom of choice, would assume this special orientation. However, under certain circumstances described below, an infinite range of orientations must be expected.

It is assumed that a crystal freely suspended in a medium is brought randomly upon a plane crystalline surface and can move thereon in rotatory fashion under an original impetus. During the rotation of the crystal the interfacial surface energy will continuously increase and decrease in value, according to the relative crystallographic position of the two individuals. As the original impetus decreases, a point will be reached in which the kinetic energy is insufficient to push the crystal over some position of relatively high interfacial energy. The movements of the skating crystal would then be constrained to a particular range of interfacial energies, or orientations, and become more and more vectorial. The final position of rest will be that of minimum interfacial energy within this range. This position of orientation is seen to be not necessarily that of least interfacial energy between the contact planes of the two species of crystals. The various positions of orientation thus fixed express a frequency analysis of the relation between interfacial surface energy and orientation. The orientations observed between the garnet and other inclusions in the muscovite are believed to be of this origin. While an original impetus is assumed, the crystals probably move about at least in part under the impetus of the surface forces, as with camphor.

Some Relevant Observations

The reality of the orienting mechanism described above has been demonstrated experimentally. If small octahedra of alum are suspended by agitation in a saturated solution of alum and are allowed to come into contact with a large octahedral surface of alum exposed in the solution, it is found that the small crystals become attached to the larger surface. This attachment is not at random positions. The measurements of Schaskolsky and Schubnikov,[5] who devised the experiments to test the earlier observations of Gaubert[6] on lead nitrate, and of Laemmlein[7] on

[4] Frondel, C.: *Am. Jour. Sci.*, **30**, 51 (1935).
[5] Schaskolsky, M., and Schubnikov, A.: *Zeits. Krist.*, **85**, 1 (1933).
[6] Gaubert, P.: *Bull. Soc. Min.*, **19**, 431 (1896).
[7] Laemmlein, G. G.: *C. R. Acad. Sc. U.S.S.R.*, 709 (1930).

quartz, proved that the superposed alum crystals are distributed among definite positions of orientation. These authors also express the view that the small alum crystals after falling randomly upon the larger alum surface spontaneously rotated to the observed positions of orientation.

The effects described above are a direct extension of the well established fact that large crystals may grow by the direct attachment of crystals of colloidal size to their surface. The observations of Walmsley[8] on the direct linking together of ultra-microscopic dodecahedra of cadmium oxide dispersed in air to form large aggregate single crystals afford a particularly convincing illustration. In general, the orienting effect is enhanced among crystals in the colloidal range of sizes because the mass of the crystals is small relative to the surface forces which control the process.

A Structure-Analysis Implication of Orientation

An interesting implication may be remarked. Inasmuch as the orienting tendency is an expression of the arrangement, spacing and bonding of the structure-units which compose the contact surfaces, then the orientation-frequencies, which express the variation of some structure-determined factor, presumably surface energy, with direction, should lead to the analysis of the crystal structures.

The periodicities in the contact surface of the randomly impinging crystals analyze the periodicities in the supporting crystal surface in the same sense that the periodicities in an impinging heterogeneous beam of x-rays analyze the periodicities of a crystal. The orientation graphs may be likened to powder diffraction patterns, in which the positions and intensities of reflection are represented by the positions and frequencies of orientation.

The indexing of an orientation graph could proceed by means of coincidence tables, such as are graphically represented in the figures. Assuming that the structure of one of the minerals is known, then the relative position and importance (in some structural regard) of crystallographic directions in the contact surface or surfaces of the unknown crystal may be found in a cut and try way similar in principle to the indexing of an x-ray powder photograph. It is necessary in this, however, to first know the general relation obtaining between structure and position-frequency which finds expression in the orientation itself, that is, some equivalent of the Bragg equation. Efforts to find such a relation by comparing packing densities along assumed shared directions in the inclusions and in the muscovite were unsuccessful.

[8] Walmsley, H. P.: *Proc. Phys. Soc. London,* **40,** 7 (1928).

Experimental Investigation of Skating Crystals

Two experimental techniques were devised to investigate the control exerted by a plane crystalline surface on the orientation of mechanically superdeposited crystals.

Adherence Angle Technique

This technique is based on the von Buzagh method of measuring the adherence angle of solid particles resting upon a plane surface in a solution.[9] A von Buzagh apparatus was obtained[10] and was modified by the writer by the addition of a graduated rotating stage to the tilting stage. The device as modified permitted the measurement, by rotation of the stage in successive experiments, of the angle of slip along various directions in a supporting plane crystalline surface. A cleavage sheet of muscovite was used for the supporting surface. The idea was that the angle of slip would vary with the orientation of the muscovite, and that this angle would be related to the structural make-up of the mica along the direction of slip.

Experiments were made using fine powders of glass, staurolite and quartz. The angle of slip, however, was found to vary erratically, and duplicable measurements could not be obtained at any fixed orientation. The principal difficulty was in obtaining particles of the proper size. Control of this factor, for reasons described by von Buzagh, is essential to the application of the adherence angle method. Spherical glass or metal beads of the proper size would probably afford a fair test of the idea.

Sedimentation Technique

A plane crystalline surface was placed in a saturated solution of a given salt, and minute crystals of that salt were allowed to settle out thereon. The crystallographic positions of the superposed crystals relative to the supporting crystal were then measured and graphed.

An extensive series of experiments were undertaken in which minute octahedra of alum were allowed to settle out upon a cleavage sheet of muscovite immersed in a saturated solution of alum. The results of the best of these experiments are shown in Fig. 17. It is considered that the graph does not define any well-marked tendency for orientation.

[9] von Buzagh, A.: *Kolloid Zeits.*, **47**, 370 (1929); **51**, 230 (1930); **52**, 46 (1930).

[10] Through the courtesy of Prof. Ernst H. Hauser, Department of Colloid Chemistry, Massachusetts Institute of Technology.

Experiments were also made in which $KClO_3$ crystals were deposited upon muscovite, and in which minute cleavage cubes of galena were settled out from water upon muscovite and upon gypsum. The measurements made with these substances did not prove any undoubted

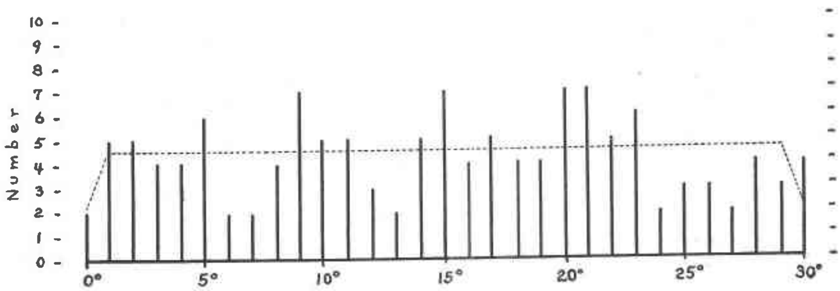

FIG. 17. Alum {111} upon muscovite {001}. Observed angles between alum [110] and muscovite [100] plotted for 131 crystals. Dotted line indicates average (theoretically random) population of graph.

tendency for orientation. It is felt, however, that these experiments and those with alum mentioned above may have been largely prejudiced by errors introduced during the manipulation of the supporting crystal and by errors of measurement.