SCHILLER STRUCTURE

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Oriented, rod-like, needle-like, tabular or platy, granular and "dust" inclusions, distributed along two or more intersecting planes, are common in certain minerals of the plutonic rocks such as gabbros and related deep-seated types. The structures formed by such oriented inclusions have been called "schiller structures" by various observers, including the writer (7), regardless of the mineral species containing them. In many cases, however, these inclusions do not impart that peculiar chatoyance, or sheen, to the crystals which act as host for them, which the writer considers essential for a true schiller effect, so that it seems pertinent to inquire into the usage of the term "schiller" in connection with some of these occurrences.

The expression originated with the old German miners, who called certain minerals "schiller-spath" that were iridescent when light was reflected from them at certain angles.

Werner (1749–1817) used the term, according to Karl von Raumer (30),[1] who mentions the "schiller-spar of Werner" and who selected, himself, the name "schillerfels" as a designation for a rock-group composed of "early greenstone" and gabbro because ". . . it is composed of those rocks which have an iridescence, and also because Werner's schiller-spar is an oryktognostic (sic) constituent" (p. 40; translation).

Haüy (12) employed the term "schillerspath" as a mineral name for those minerals exhibiting iridescence, and "schillerstein" as the rock-name for rocks containing "schillerspath." Scheerer (23), Streng (25), Des Cloiseau (8) and Hagge (10) used such terms as "schillerfels" and "schillerspath" in about the same sense as the words were employed by Haüy, applying the expressions to certain types of pyroxene; but none of these writers used the word "schiller" as an expression descriptive of inclusion-structures.

Iridescence displayed by various feldspars has been studied by numerous investigators, some of whom used the term "schiller" in connection with the phenomenon, whereas others did not use the word. Von Bonsdorf (28), Scheerer (23), Vogelsang (27),[2] and

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[1] Numerals refer to titles listed in alphabetical order at the end of this paper.

[2] Vogelsang referred the golden and reddish colors to reflections from included mineral microlites, but the blue color was considered to be a polarization phenomenon produced by light reflected from planes.

Andersen (2) ascribe the chatoyance of certain feldspars to reflection of light from inclusions, whereas Brewster (5) thought that the iridescence might be due to

... crystallized laminae disseminated through the felspar, and giving the colors of thin plates; or they may be slender crystals, which, like the veins of calcareous-spar, develop the tints of polarized light; or they may be crystallized cavities, either entirely empty, or containing solid, fluid, or gaseous substances (p. 324).

Von Hessel (29), Senff (24), Nordenskjöld (17), Zirkel (32), Reusch (19), Bøggild (4),[3] and Parsons (18) believed that the color phenomena are due to reflection of light from planes, of one sort or another, within the crystals, with consequent polarization.

Cathrein (6), Williams (31), Hobbs (13), Tertsch (26), Rogers (20) and Rosenbusch (22)[4] describe oriented inclusions in hornblende in considerable detail, but none of these authors referred to such structures, in hornblende, as "schiller structures." Other writers, however, among whom are Haidinger (11), Rose (21), Kosmann (16), Zirkel (32), Judd (15), and Williams (31) refer to "schiller" or "schillerization" in their descriptions of pyroxene; and Hutton (14), Bancroft (3), Agar (1) and the writer (7) describe oriented inclusions in hornblende, allude to the structures formed by the inclusions as "schiller" structures, or refer to "schillerization" as a phenomenon caused by the inclusions described.

The concept of "schillerization" as a *process* that might affect minerals of different species was first set forth by Judd (15), who considered the phenomenon to be due to a deep-seated secondary alteration of pyroxene and allied minerals along "solution-planes" with the production of solution-cavities within the crystals, commonly filled with the products of alteration; thus:

... these enclosures are of the nature of *negative crystals* which are more or less completely filled with products of decomposition of the mineral. When these negative crystals are completely filled with foreign substances, the enclosures assume the outlines of true crystals, though they do not, of course, exhibit their optical properties (p. 384).

The chatoyance displayed by crystals so affected was ascribed to the polarization of light reflected from these minute, filled,

[3] Bøggild coined the term "labradorization" as a substitute for "schiller" in connection with his study of iridescence in feldspars.

[4] In an earlier edition of Rosenbusch's work (1907) the term "schiller" was, however, used in connection with the description of inclusions in hornblende; and he does use the term in connection with pyroxene.

secondary "negative" cavities. Judd believed that the filling consisted of "hydrated oxides like chalcedony, opal, göthite and limonite" (p. 387).

Thus there seems to have been no very consistent usage of the term "schiller," for the expression, in one form or another, has been employed in the description of iridescent effects displayed by different minerals, for microstructures produced by oriented inclusions in minerals which commonly exhibit no iridescence at all, and as both mineral and rock names; and the phenomenon of
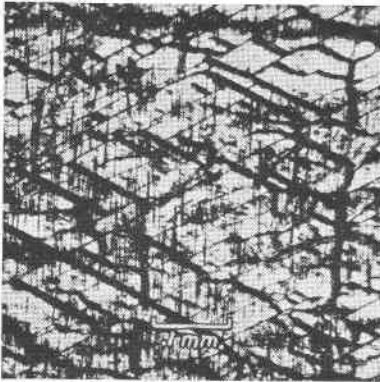

FIG. 1. Hornblende in hornblendic pyroxenite, near Humacao, Puerto Rico, ordinary light; the scale is 0.10 mm. Showing magnetite plates or rods oriented parallel to (010) and bisecting the prismatic cleavages. Magnetite is distributed along cleavage planes also. No iridescence is displayed by the hornblende in this rock, so that for the term "schiller" the writer proposes to substitute the term "endoblastic" in the description of such structure.
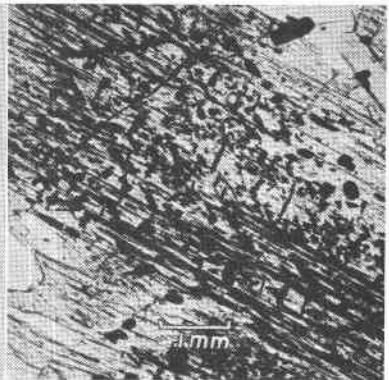
FIG. 2. Oriented magnetite inclusions in the hornblende of a diorite that occurs about one mile west of West Torrington, Conn., ordinary light; the scale is 0.10 mm. This structure was called "schiller structure" by Agar (1), but no iridescence is displayed. Another example of "endoblastic" structure.

iridescence has been variously ascribed to reflection of light, with consequent polarization, from planes within the crystals, from crystal inclusions, and from filled negative cavities.

The writer has observed oriented crystal inclusions of magnetite or ilmenite in the hornblende of various rocks to which he has referred as "schiller structure" or "schillerization effects"; incor-

rectly, as he now believes. Figures 1 to 3 illustrate such inclusions. Figure 1 shows plates or rods of magnetite in hornblende, oriented parallel to (010), bisecting the angles made by the prismatic cleavages and intersecting another set of the same kind of inclusions distributed along the cleavage directions. The rock is a hornblendic pyroxenite from Puerto Rico (7). Not one of the thin sections examined contained hornblende that was even slightly iridescent in incident light, although a few crystals returned a very weak white-light reflection from some of the inclusions; no real chatoyance was
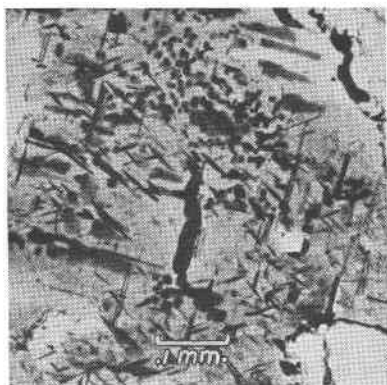

FIG. 3. Oriented inclusions of magnetite and biotite in the hornblende of a norite from the Cortlandt series, ordinary light; the scale is 0.10 mm. The hornblende in this rock displays no iridescence whatever, although the hyperthene (Fig. 6) exhibits very spectacular schiller effects. These are merely oriented inclusions in the hornblende, to which the term "schiller" should not be applied. Typical "endoblastic" structure.
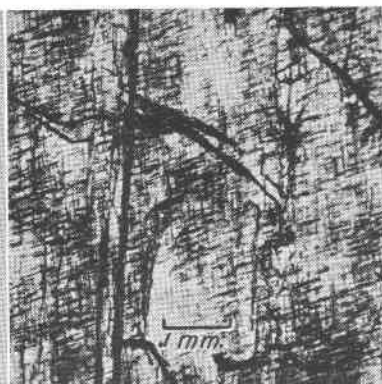
FIG. 4. Pyroxene in magnetiferous pyroxenite, near Humacao, Puerto Rico, ordinary light; the scale is 0.10 mm. Brownish films distributed along parting or "solution" planes. These planes are slightly oblique to the thin section, so that the traces of them shown in the photomicrograph appear wider than is actually the case. Incident light is reflected from such areas in this rock with faint iridescence. A schiller *effect* is produced, but the writer would call the *structure* "endoblastic."

observed, however. Figure 2 shows oriented magnetite inclusions in the hornblende of a diorite from Connecticut described by Agar (1). None of the hornblende in the section examined by the writer[5] displayed iridescence in incident light. Nor does any of the

[5] Through the courtesy of Dr. Agar.

hornblende, illustrated in Figure 3, in a norite from the Cortlandt Series, show iridescence, although fifteen thin sections of the rock were examined. In the same thin sections, however, beautifully pleochroic hypersthene displays spectacular iridescence, which is connected with extremely thin, reddish-brown "films" or scales, distributed along so-called "solution-planes" or parting planes, illustrated in Figure 6. The iridescence may be best observed under the microscope, using strong oblique illumination directed downward on the surface of the thin-section. The intensity and bril-
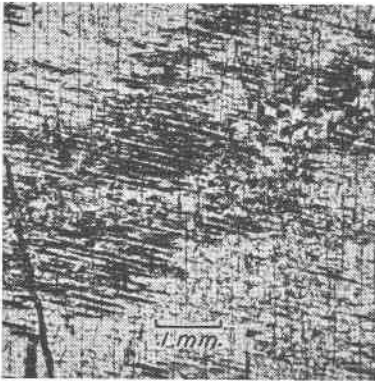

FIG. 5. Diallage in an olivine gabbro from Minnesota, ordinary light; the scale is 0.10 mm.

Showing thin films along parting planes. These are not magnetite inclusions. Such inclusions in the pyroxene of this rock exhibit faint to more or less pronounced iridescence in grains which are favorably oriented. An "endoblastic" *structure* productive of schiller *effects*.
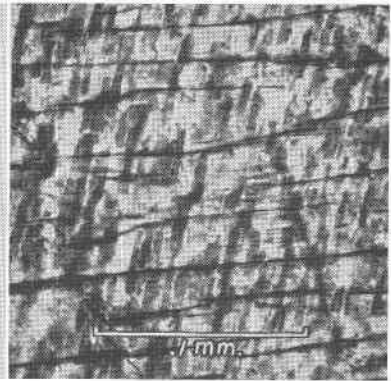
FIG. 6. Hypersthene in the same norite which contains the hornblende shown in Fig. 3, ordinary light; the scale is 0.10 mm. This crystal exhibits very spectacular and striking iridescence in incident light. The chatoyance is directly connected with the thin films seen in the photomicrograph. These films are not crystal inclusions. Typical schiller *effects* produced from a striking "endoblastic" *structure*.

liance of the phenomenon is dependent in part on the orientation of the hypersthene in the section, in part on the inclination of the "films" with respect to the surface of the mineral grain and in part on the level within the thin section at which the "films" may happen to lie; for many grains of hypersthene in the same sections, and containing the same sets of "films," display no iridescence at all under the same condition of illumination.

Both the pyroxene, Figure 4, in the pyroxenite from Puerto Rico, previously referred to, and the pyroxene, Figure 5, in an olivine gabbro from Minnesota, contain small irregular areas exhibiting films along parting planes which appear black in the photomicrographs and thicker than they really are, because the sections are somewhat oblique to the planes along which the "films" are distributed. These are not magnetite inclusions; they are thin brownish films, which give distinct, though feeble, color reflections in incident light from properly oriented grains in the sections.
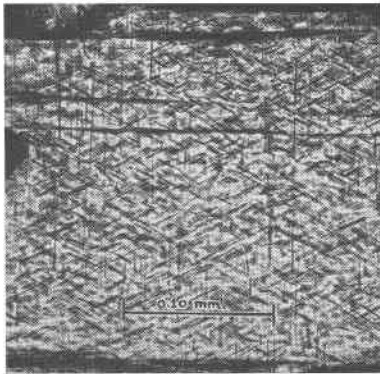

FIG. 7. Hypersthene in the complex emery rock of the Cortlandt Series, ordinary light; the scale is 0.10 mm. The inclusions are extremely minute crystal needles oriented in three directions, and brilliantly iridescent in reflected light, giving a typical schiller *effect*. The rock is metamorphic, and so far as the writer is aware this, and the biotite illustrated in Fig. 8, are the only recorded examples of schiller effects in minerals of metamorphic rocks. The *structure* in the hypersthene is "endoblastic."
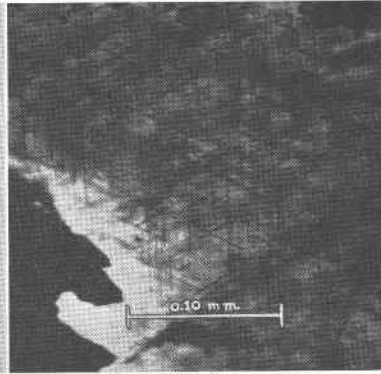
FIG. 8. Biotite in the same complex emery rock in which the hypersthene, illustrated in Fig. 7 occurs, ordinary light; the scale is 0.10 mm. The crystal lies with the base parallel to the surface of the section; it is dark colored and shows strong absorption, hence difficult to photograph. The thin needles, oriented in three directions, exhibit brilliant iridescence in reflected light. This structure in biotite has been called "sagenite structure," but the term "endoblastic" is also appropriate.

According to Judd (15), schillerization in pyroxenes is due to alteration along solution planes with the production of negative cavities filled with the products of decomposition. Neither the hypersthene nor the pyroxene in the rocks mentioned above are in the least altered. Some of the pyroxene in the pyroxenite from Puerto Rico has been converted into hornblende, but the hornblende de-

rived from the pyroxene is not iridescent; whereas the grains of unaltered pyroxene that contain "films" along parting planes exhibit some chatoyance, even if slight, provided they are favorably oriented in the sections. Alteration, therefore, does not seem to be a necessary factor.

The phenomenon is not confined to minerals of the igneous rocks, for some of the hypersthene, and even an occasional biotite flake, in the complex emery rock of the Cortlandt Series, react in the same way under appropriate conditions of illumination. According to Rogers (20) the emery rock is a product formed by the assimilation of blocks of Manhattan schist in the invading norite of the Cortlandt Series; Gillson and Kania (9), however, concluded that the emery deposits are

... contact metamorphic in origin, and were formed by either gaseous or liquid emanations from the magma reservoir, which passed upward through the already solid border of the igneous mass, ("melanorite" according to the authors) and into the schists (Manhattan schist), depositing the ore minerals in both the endomorphic and exomorphic zones.

Whether the emery rock is a syntectic product, as postulated by Rogers, or a hydrothermal contact metamorphic product, as assumed by Gillson and Kania, the mineral ensemble in it is characteristically metamorphic; the hypersthene is intimately associated with sillimanite, spinel, corundum, magnetite, quartz, cordierite, garnet, enstatite, andesine, calcite, biotite, and other related, but less abundant components. The hypersthene carries inclusions of both intersecting needles (see Figure 7) with a three-way orientation, and dark, wine-red, rectangular scales or "films," so thin that they are superposed in two or more layers within the thin section. Both needles and "films" are iridescent in oblique incident light in favorably oriented grains. The needles are crystal inclusions, but the nature of the "films" is not determinable in thin section.

In another section[6] of the same material occasional reddish-brown flakes of biotite lying in the section with their bases parallel to the surface of it contain three sets of intersecting, hair-like inclusions, presumably rutile, illustrated in Figure 8, which are brilliantly iridescent in incident light. This is the only example of the schiller effect in biotite that has come to the attention of the writer.

In all of the examples observed iridescence is confined strictly

[6] The sections were cut from the lighter fractions obtained during a mill-run of the emery rock.

to the inclusions, whether they be needles, rods, plates or "films." Those portions of the host mineral free of inclusions are not iridescent at all; at least under the conditions of illumination previously mentioned. Iridescence seems to be independent of the *kind* of inclusions; that is, there is no single, specific sort of inclusion that alone displays the phenomenon to the exclusion of all other kinds. Consequently the writer believes that the term "schiller *structure*" is a misnomer, for there is no single specific structure responsible for the effect, which seems to be dependent rather on the minute size and thinness of the included matter than on the substance of it. If the inclusions are too large or too thick, it apparently matters not at all what their orientation may be; they are then not iridescent. Moreover, it seems certain, from the work of previous investigators, that some minerals, notably certain of the feldspars, display iridescence although there are no inclusions in them; the color effect in such cases being due to reflection of light from sub-microscopic planes. The tentative suggestion is made, therefore, that the term "schiller" be restricted to the iridescence displayed by minerals, whether the sheen or chatoyance is caused by reflection of light from either inclusions or planes. For minute *inclusion structures*, especially those structures formed by the separation of substances from solid solution in rock forming minerals, no matter whether iridescence is produced by them or not, the writer ventures to suggest the term "endoblastic"; from "endon," within, and "blastos," a sprout or shoot. "Blast" has long been used both as a suffix and prefix in metamorphic terminology, but the usage intended here refers to the microcrystallization or growth *within* a solid crystal.

Endoblastic structures, used in this sense, are those minute structures produced in individual host crystals, either by the separation from solid solution of oriented and usually intersecting sets of crystal needles, plates or rods, or oriented "films" and roughly euhedral "negative" cavities, filled or empty. The term does not apply to larger inclusions in crystals, for which the expression poikilitic has long been used and which may have been formed in other ways.

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