SEPARATION PLANES IN MAGNETITE

J. W. Greig, H. E. Merwin, and E. Posnjak,
Geophysical Laboratory, Washington, D.C.

During the course of an investigation of the equilibrium relationships of Fe_3O_4, Fe_2O_3, and oxygen we had occasion to use some of the very pure magnetite from the Lovers' Pit at Mineville, N.Y. This material occurs as granular magnetite and faceted crystals. It is remarkable for the size of the masses with uniform orientation, and for the perfection of a system of intersecting planes parallel to the octahedral directions of the magnetite, along which it separates when broken. The faces of the crystals are marked by striae where these separation planes outcrop. A close inspection shows that there are other separation planes and striae in addition to the octahedral ones.

Following Cathrein[1] and Mügge[2] such separations, parallel to the octahedron, in magnetite, are usually attributed to polysynthetic spinel twinning, the planes along which the separation takes place being then composition planes or planes common to two individuals, and therefore parting planes. However, Kemp[3] in describing magnetite crystals from this locality expressed a doubt that the separation planes in them were due to polysynthetic twinning. He said: "The beds that contain them have been subjected to great dynamic movements and these partings are very probably due to pressure—which has developed the fine pseudo-cleavage planes in the massive mineral. If it were allowable to conceive of a chief parting[4] along 0, and a rarer one along ∞0, occasioned by such pressure, without any accompanying twinning, I should think it more likely to be the true cause of the phenomena." Professor Kemp's drawing of one of these crystals showing the striae on its faces gives an excellent idea of their appearance. This drawing will be familiar to most readers for it has been reproduced in Dana's System and in the Textbook to illustrate notes on polysynthetic twinning.

A preliminary examination of our Mineville material disclosed no sign of twinning so we obtained some other specimens together with a number of magnetites from other localities and studied them[5] (see Table 1). These specimens included a number of good crystals showing striations on their faces, and a number of pieces showing well developed planes, often with striations on them.

[1] Cathrein, A., *Zeit. f. Kryst.*, vol. **12**, pp. 47–49, 1886.

[2] Mügge, O., *Neues Jahrbuch f. Min.*, vol. **1**, pp. 244–246, 1889.

[3] Kemp, J. F., *Am. Jour. Sci.*, vol. **40**, pp. 63–64, 1890.

[4] The term "parting" is evidently not used here in the same sense in which it is used in the first sentence of this paragraph.

[5] We are indebted to Drs. William F. Foshag and E. P. Henderson for their kindness in supplying these specimens from the collections of the U. S. National Museum.

TABLE 1. LIST OF MAGNETITES EXAMINED

The numbers are the U. S. National Museum numbers of the specimens. All were examined in polished section after partial oxidation, (g) indicates that an examination was made with the goniometer. The form symbols indicate separation planes in the cases in which they were found. Transparent filling was found in some of the separation planes in each specimen that showed these planes.

Mineville, N.Y. Crystals and fragments. Several samples including 47725 and 47830. (g), (111), (110), (831).
Pt. Henry, N.Y. 79343. Fragments. (g), (111), (110), (100).
Nigger Hill Mine, Warren Co., N.Y. 11603. Fragments. (g), (111), (110), (100).
Nordst jernegrafvan Westaufors, Sweden. 48972. Fragments. (g), (111), (100).
Texas, Lancaster Co., Pa. 83432. Octahedra in schist. (111) not very common.
Cedar City, Utah. 99484. Lodestone. Rather earthy looking on fractured surface. No sign of separation planes. Partial oxidation shows that it is made up of small differently oriented units.
Magnet Cove, Ark. 83701. No sign of separation planes. Partial oxidation results in extremely minute hematite lamellae distributed through the material.
Brewster, N.Y. R 1972. Dodecahedra. No indication of separation planes.
Tilley Foster Mine, N.Y. R 1974. Dodecahedra. No indication of separation planes.
French Creek, Chester Co., Pa. 48534. Crystal faces stepped, resulting in curved appearance. No indication of separation planes. Only a very slight tendency for the hematite formed by partial oxidation to form lamellae parallel to the (111) planes of the magnetite.

Several of these crystals and a number of fragments were examined on the goniometer. No signals from faces in the twinned position were obtainable from any of the striations on crystal faces. The fragments likewise, with one exception, gave no indication of twinning. In the single exception, the planes giving signals belonged to two individuals with the angular relationship of spinel twins.

An examination of each of these magnetites was also made by partially oxidizing the material, then examining polished sections under the microscope. The hematite that is formed when the magnetite is heated in air at an appropriate temperature is usually[6] arranged in thin lamellae lying parallel to the octahedral planes of the magnetite. The sizes of the lamellae vary greatly from one specimen to another. From the angles between the outcrops of the lamellae on the polished surface it is a simple matter to determine the orientation of the magnetite[7] (see Figs. 1, 2, and 3). Since, in most cases, when small pieces of magnetite are partially oxidized in this way, the hematite lamellae are not confined to a narrow

[6] Magnetite from French Creek, Chester Co., Pa., U. S. Nat. Museum No. 48534 is exceptional. The hematite formed when the material is heated in air at 1000° shows scarcely any tendency to the usual arrangement.

[7] *Am. Jour. Sci.*, vol. **30**, p. 311, 1935.

zone surrounding the specimen, but also appear scattered throughout the interior, partial oxidization usually provides us with a means of determining the orientation of the magnetite in any desired part of the polished surface.

Fig. 1. Polished section of a fragment of magnetite from Pt. Henry, N.Y., U. S. Nat. Museum No. 79343. ×375. Partially oxidized by being heated in air at 950°–1000°. The bright portions are hematite, the ground is magnetite. The parallel continuous lines of hematite running NE–SW mark separation planes parallel to one octahedral plane. The surface of the fragment that was exposed to the air during oxidation is shown on both sides in the upper part of the photograph. Note that the short lamellae of hematite are distributed throughout, as is also the case in the other two figures.

In contrast to these short, widely distributed lamellae the separation planes in the partially oxidized magnetites are represented by fairly continuous sheets of hematite (see Figs. 1, 2, and 3). A thin sheet of hematite usually develops along these planes before much appears in the main body of the magnetite, and from it short lamellae extend into the magnetite on each side, and thus show its orientation. In no case did we

FIG. 2. Polished section of magnetite from the Nigger Hill Mine, U. S. Nat. Museum No. 11603, partially oxidized in air at 950°–1000°. ×740. The bright portions are hematite, the ground is magnetite. The continuous narrow line of hematite running NE–SW marks an octahedral separation plane. The two parallel zones of more numerous short hematite lamellae, crossing the middle of the photograph nearly horizontally, mark the outcrops of two separation planes or potential separation planes parallel to the dodecahedron.

find any change in the orientation of the magnetite along one of these planes. There is always, of course, a layer converted to hematite, whose orientation cannot be found, but by controlling the oxidation this layer may usually be kept very thin. In the more favorable cases it was quite evident that if there had been any layer of magnetite, with an orientation different from that of the main body, the width of its outcrop must have been less than 0.001 mm. Yet in this work, as in the goniometric work, no evidence of polysynthetic twinning was found.

It was stated above that one example of individuals with the angular relationship of spinel twins was found with the goniometer. The piece showing it was partially oxidized, sectioned, and examined with the microscope. The polished surface showed two good-sized areas of uni-

Fig. 3. Another polished surface of a partially oxidized fragment from the Nigger Hill Mine. ×740. One octahedral separation plane crosses the photograph running NE–SW. Above it a curved fracture shows. In this as in the other photographs it can be seen that the short lamellae of hematite produced by the oxidation provide a key to the orientation of the magnetite, and permit one to place an upper limit to the width of the outcrop of any possible twin lamella lying along a separation plane.

form orientation, and the angles of the outcrops of the hematite lamellae on this surface showed again that the two individuals were related to each other according to the spinel law. But, although each individual showed also a number of separation planes, there was no indication of polysynthetic twinning, and, since the surface separating the two individuals was not a plane, it was evident that this relationship was not secondary.

Besides the octahedral separation planes, which in some specimens are so closely spaced and brilliant as to appear like a perfect cleavage, several other much poorer separation planes have been observed in these magnetites. Kemp noted that planes parallel to the dodecahedron occurred in the Mineville material, and we found that pieces from several localities when mounted on the goniometer showed dodecahedral or cubic separation planes or both.

In the case of some very good octahedra from Mineville there are striae that can be traced half-way around the crystals. The planes, of which these are the outcrops, represent the form (831). This is rather surprising for this form is not mentioned in Dana or in the Winkeltabellen as having been observed on magnetite.

Thus we find no evidence of polysynthetic twinning as a cause of the octahedral separation planes in these magnetites. Moreover we find separation planes with an orientation—(831)—that is extremely improbable as a composition plane, and still others with orientations—(110) and (100)—that preclude twinning as the cause.

As a rule these other planes are much less conspicuous on the polished surface of the partially oxidized magnetite than are the octahedral separation planes. In some cases they are indicated by a somewhat discontinuous line of small, irregularly shaped areas of hematite. In other cases they appear as zones of more or less closely spaced small hematite lamellae lying parallel to the octahedral planes (see Fig. 2).

Openings along many of these planes have been filled with silicates. This transparent material is sometimes visible under the Greenough binocular as an iridescent film on exposed surfaces. In some cases it shows up when a polished section is examined under the microscope, and it is probable that it is also present in many cases when it is too thin to be seen in this way.

It is evident that the separation planes are the result of some special conditions to which these magnetites were subjected while still in the earth.[8] Their development is considered to be analogous to the develop-

[8] We have made some observations that suggest that the development of small lamellae of hematite throughout the interior of a grain of magnetite while it is being heated in air is, like the development of the separation planes, a consequence of the forces to which it was subjected while in the earth. Among the magnetites that we examined there were some from three different sources in which the oxidation—while resulting in the typical lamellae lying parallel to the octahedral planes of the magnetite—was confined pretty well to the outer layer, or to zones along irregular fractures, and only slowly advanced into the interior. None of these showed any development of the separation planes. They are: synthetic magnetite, crystals from Brewster, N.Y., U.S. Nat. Museum No. R 1972, crystals from the Tilley Foster mine, U. S. Nat. Museum No. R 1974. All the magnetites that showed a good development of separation planes showed also a good development of small hematite lamellae in the interior, but so did several that did not show separation planes. Usually the hematite lamellae are distributed more or less uniformly between all four octahedral planes. However, the partial oxidation of some magnetite from Port Henry resulted in a striking exception. There was a pronouncedly preferential development of the lamellae parallel to one octahedral plane. This difference in directions, that in a normal isometric crystal are equivalent, must be the result of outside forces.

ment of jointing in rocks, but with the crystal structure of the magnetite as well as the differential pressure exercising control. This conclusion is obviously in harmony with Kemp's idea quoted above. It does not, of course, deny the occurrence of polysynthetic twinning as a cause of parting in some magnetites.

Magnetite is described as a mineral without a distinct cleavage, and our observations are in agreement with this description. We have examined a great number of polished surfaces of synthetic magnetite. Although the material spalls readily and the polished surface pits on standing we saw no indication of cleavage. When the magnetites described above, that show such a pronounced development of separation planes, are crushed, much of the breaking is along these planes at first, but, as crushing is continued, more and more conchoidal fractures develop, as if the plane surfaces were formed only where pre-arranged or pre-existing. With other magnetites all surfaces formed by crushing appear conchoidal or at most to have only steplike modifications of the conchoidal surface.

Summary

A number of magnetites showing separation planes were examined to see whether or not they offered any support for the customary explanation of this pseudo-cleavage, i.e., that it is parting along the composition planes between twins. No evidence of this could be found. Although the octahedral separation planes are much the most common and best developed, separation planes were also found parallel to some faces of three other forms, (831), (110), and (100). The orientation of the first of these makes twinning extremely improbable and the orientations of the other two make it impossible as a cause of the separation planes. Silicate has been deposited in openings along many of these planes. It is believed that the separation planes in these magnetites were developed without twinning by differential pressure, much as joints are produced in rocks, but with the crystal structure as well as the differential pressure exercising control.