Oriented lamellae in the Gibeon meteorite

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Summary. A re-examination of twelve specimens of the Gibeon meteorite has established that the meteorite is basically an octahedrite but has, in several irons of the meteorite, lamellae of kamacite of early origin parallel to the cube. Lamellae containing daubréelite, predating twinning and kamacite exsolution, are common parallel to the cube and rare parallel to the octahedron. A survey of other features failed to suggest any definitely correlated with the anomalous kamacite lamellae.

IN 1910 Rinne described a meteoritic iron from Goamus Farm, near Gibeon in South-west Africa, that showed kamacite lamellae parallel to the cube as well as the octahedron. For meteorites with this structure he suggested the term *tesseraoktaedrit*. Since then the following names have been suggested for the meteorite having this structure: tesselated octahedrite, tessellated octahedrite, tesseraloctahedrite, cubo-octahedrite, and dodecahedrite.

Since 1910 similar textures have been reported from other irons of the Gibeon meteorite (Spencer, 1941; this paper) and from the La Porte iron (Roy and Wyant, 1950). It has also been suggested that the kamacite lamellae are parallel not to the cube and the octahedron but to the rhombic dodecahedron (hence the term dodecahedrite).

An examination of a small specimen of the La Porte meteorite (B.M. 1959, 952), showing a Widmanstätten figure similar to that figured by Roy and Wyant (1950) and upon which they based their interpretation of the structure of the meteorite, revealed no evidence of lamellae parallel to the cube. Stereographic plots of measurements on three surfaces nearly at 90° to each other indicated that the four traces of the figure were all due to lamellae at least roughly parallel to the octahedron. Gibeon is thus apparently unique.

Gibeon must, on falling, have weighed more than the over 15 000 Kg recovered and have had a volume equivalent to a sphere of at least $1\frac{1}{2}$ m in diameter. It fell as a shower of irons, the largest recorded weighing 650 Kg. The original relative positions of these is unknown. It is a fine octahedrite, with about 8 % nickel, belonging to Ga–Ge class IVa of

Wasson (1967). It has a number of unusual features among which are the presence in some specimens of kamacite lamellae parallel to the cube, of large-scale twins and grain contacts in the metal phase, and of daubréelite in lamellae and in nodules. Also present in some specimens is granulation of the kamacite due to heat and distortion of the Widmanstätten figure. The distribution of the first three features between some of the specimens examined is as follows (the name of the iron is followed by the British Museum (Natural History) number of the specimen:

Kamacite lamellae parallel to the cube: Goamus (B.M. 1910, 753) common and up to 50 mm long, Great Namaqualand (B.M. 54729) rare and up to 7 mm long, Kameelhaar (B.M. 1941, 1) moderately common and up to 40 mm long, and Mukerop (B.M. 85891) rare and up to 3 mm long.

Twinning: Mukerop (B.M. 85891) and Great Namaqualand (B.M. 54729).

Large-scale grain contacts: Mukerop (B.M. 1921, 190) and Kameelhaar (B.M. 1941, 1).

It will be noted that none of these features are specific to a single iron nor does the presence of any one necessarily exclude the presence of any other.

Kamacite lamellae. Since it has been found that lamellae parallel to the cube can only be recognized on large surfaces roughly parallel to the cube face it can seldom be said with certainty that they do not occur in any given specimen. Of the three specimens in which they were found Goamus (B.M. 1910, 753) showed them best and was studied in detail.

An examination of three etched non-parallel surfaces of this specimen showed conclusively both that the dominant structure is of lamellae parallel to the octahedron and that the other kamacite lamellae are parallel to the cube but elongated in the tetrad-axis directions. Over areas many centimetres in diameter single skeletal crystals may occur composed of lamellae in both directions, those parallel to the cube obviously having formed first and extended later along planes parallel to the octahedron.

In Goamus (B.M. 1910, 753), which is a slab about 800 cm^2, the distribution of the kamacite lamellae parallel to the cube is not uniform, varying in 10 cm^2 areas from nil to about 20 % of the total kamacite. These lamellae are about twice the thickness of those parallel to the octahedron, having a true thickness[1] of $0{\cdot}39 \pm 0{\cdot}015$ (18) mm as opposed

[1] Mean, standard error of the mean, and number of measurements.

to $0{\cdot}20 \pm 0{\cdot}008$ (42) mm. Some have central narrow (*circa* 0·08 mm) lamellae containing daubréelite, similar to those occurring as larger independent lamellae.

Rough X-ray back-reflection Laue photographs showed strong asterism but indicated that all the kamacite was oriented in directions consistent with previous determinations (see Hey, 1942). Electron-probe microanalysis indicated that the kamacite in both orientations had similar nickel content.

Bright and dull kamacite. The Widmanstätten figure produced by etching Goamus (B.M. 1910, 753) with 5 % nital is unusual in showing two distinct types of kamacite. One has the normal matt surface and shows oriented sheen due to reflection from etch-pits. The other, forming about 12 % of the kamacite, has a slightly undulating but highly reflective surface with only a few scattered etch-pits and shows no sheen. A single crystal of kamacite is either of one type or the other regardless of whether individual lamellae are parallel to the cube or octahedron. X-ray back-reflection Laue photographs and electron-microprobe microanalysis showed no consistent differences in the orientation, degree of strain, or chemistry between the two types. A similar effect may be seen in Lion River (B.M. 32048).

'Bright' kamacite was also noted in Kameelhaar (B.M. 1941, 1) in which it surrounds nodules containing daubréelite. This material is not swathing kamacite in the normal sense since it shows a continuation of the normal Widmanstätten figure within it. It may be suggested that in this specimen the bright kamacite may have changed composition due to its proximity to the shock heated nodule although it is hard to visualize a similar mechanism for the production of the 'bright' kamacite in Goamus.

Reichenbach lamellae. The phrase Reichenbach lamellae is used in the sense of Spencer (1951) to mean regularly oriented lamellae of minerals other than iron-alloys in meteoric irons.

In Gibeon there are at least three types of inclusions: microscopic rhabdites, Reichenbach lamellae, and nodules up to 30 mm in diameter. The latter, which have been described by El Goresy (1965), often seem to be similar in composition to the Reichenbach lamellae and may grade into them. In those specimens where Reichenbach lamellae have been observed they are in general parallel to the cube, with two exceptions, Goamus and Mukerop.

In Goamus (B.M. 1910, 753) two types of lamellae, similar in appearance but differing in size and orientation, occur. One type, parallel to the cube, varies in cross-section length from extremely short to 20 mm with frequency peaks at 5 and 10 mm; their true thickness is about 1·5 mm. The other type, parallel to the octahedron, is rarer, forming about 20 % of the lamellae exceeding one millimetre, and having a symmetrical unimodal size distribution with a range from 1 to 5 mm and a peak at 3 mm. They have about the same true thickness but on a surface parallel to the cube appear thicker due to the angle of intersection and their shorter cross-section length. Unlike the Reichenbach lamellae parallel to the cube they do not form the cores of any kamacite lamellae.

In Mukerop (B.M. 85891) the Reichenbach lamellae are both shorter and wider in section, reaching a length of only 10 mm but a true thickness of 2 mm. They are of interest in that their orientation is independent of changes in the Widmanstätten figure due to twinning. It can be shown that these Reichenbach lamellae are parallel to the face of a cube; the crystallographic axes of this cube are not parallel to the axes of any of the twinned subindividuals of the iron as a whole, they are however related according to the spinel twin law to the axes of the sub-individual at the bottom right of fig. 1 where the relationship between the various sub-individuals is shown. Since this sub-individual, labelled B, is related to that labelled C by spinel twinning on a second and different axis, which is in turn related to D by twinning on a third axis, the Reichenbach lamellae show no simple relationship to sub-individuals C and D. The only simple hypothesis is that the Reichenbach lamellae indicate an early orientation, which gave rise to orientation B, which in turn twinned to give C, which gave D. It is also important that the kamacite lamellae parallel to the cube in this specimen are not parallel to the Reichenbach lamellae, which excludes any causal relationship between the two. The surface shown in fig. 1 is apparently that which faces the surface figured by Berwerth (1902, fig. 1 (II)).

A similar hypothesis simplifies the orientation of the Reichenbach lamellae (up to 3×1 mm in section) in Great Namaqualand (B.M. 54729), which is also twinned. In others such as Kameelhaar (B.M. 1941, 1) and Amalia-Goamus (B.M. 1959, 159) the Reichenbach lamellae are of similar size and parallel to the cube.

Examination of one of the Reichenbach lamellae in Goamus (B.M. 1910, 753) by reflected light and with the electron-probe microanalyser reveals grains of daubréelite veined by kamacite (with about 1·9 % nickel) in daubréelite veined with taenite (with about 56 % nickel). The daubréelite contains about 20 % iron and negligible nickel, which is in agreement with previous determinations. El Goresy (1965) figures

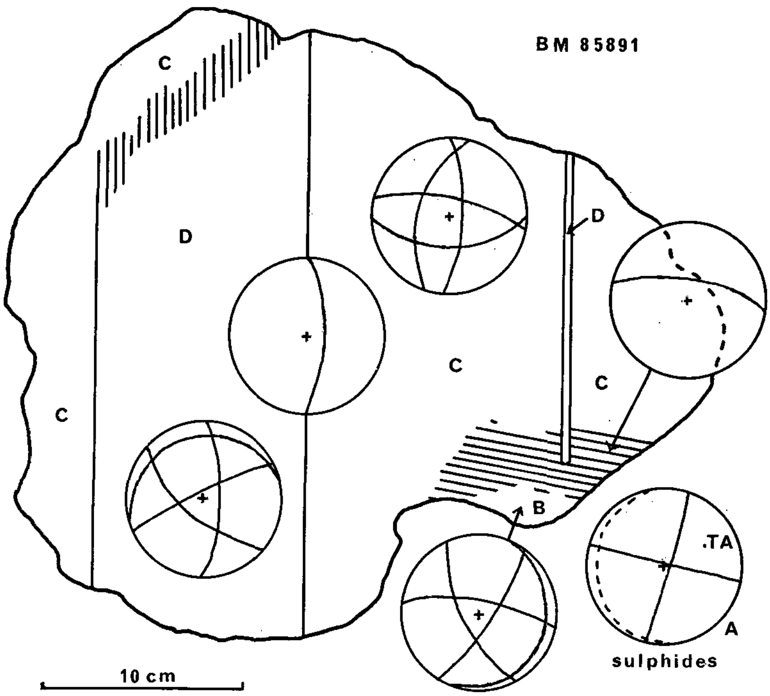

FIG. 1. Sketch of a slab of Mukerop (B.M. 85891) with stereograms (upper hemisphere projection) showing orientation of octahedral kamacite lamellae, twin planes and Reichenbach lamellae. TA = twin axis relating orientation of Reichenbach lamellae and orientation of kamacite lamellae of subindividual B. Cubic as well as octahedral kamacite lamellae are visible in the central sub-individual C but are obscured elsewhere by unsuitable orientation or granulation of the kamacite; Reichenbach lamellae are present in all sub-individuals except the two smallest and follow a single orientation pattern; on the top left and bottom right of the slab as figured the composition place is replaced by a transition zone in which a common direction, parallel to the twin plane, predominates; corrosion penetration into the slab occurs along one boundary of the narrow twin D and along the central C–D composition plane as well as to a lesser extent parallel to kamacite directions elsewhere. In the half of the meteorite that remains unsliced in Vienna this corrosion penetration shows up the outcrop of the narrow twin on the weathered surface, presumably explaining why the specimen was sectioned at approximately 90° to the twin composition planes (pers. comm. H. J. Axon).

a similar lamella and refers to it as a sieve-like daubréelite crystal in which troilite is completely reabsorbed and replaced by kamacite.

Thermal history. In an effort to compare the thermal history of Gibeon with that of other octahedrites a modal analysis and electron-probe studies were made on a 2 cm^2 mount of Goamus (B.M. 1910, 753).

Modal analysis of the metallic phases indicated: kamacite 88·5 % (including 4·5 % coarse kamacite in plessite), dark plessite 6 %, and taenite 5·5 %. Assuming a nickel content of 8 % the method of Massalski and Park (1962) gives a lowest temperature of equilibrium of 515° C. Although this figure may have little significance it does indicate a similar cooling history to the two similar but normal octahedrites that have been studied.

Electron probe microanalysis indicated that the kamacite had about 7·5 % nickel and the taenite at the interface with kamacite reached about 40 % nickel without allowance for probe resolution. One measurement on fine plessite gave 12·7 % nickel. These results are within the range given by other meteorites of similar type and group (Reed, 1965).

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