Stepping Back in Time #2

Digital Reconstruction of the Gibeon Widmanstätten Structure

by Phyllis Z. Budka

A digital reconstruction technique that provides insights into the final solidification stage of the Imilac pallasite was presented in the November 2003 issue of *Meteorite.* This same technique can be applied to the Gibeon Widmanstätten structure (Fig. 1a) with equally unexpected results. The visual evidence presented here requires that currently accepted theories of meteoritic Widmanstätten structure formation, going back 100 years, must be re-examined.

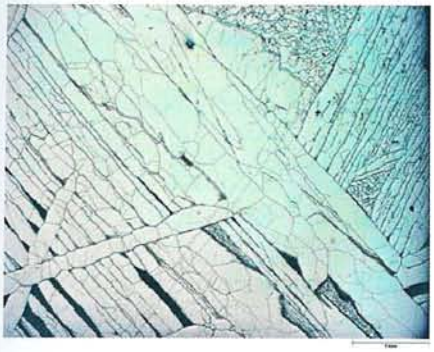

Fig. 1a Gibeon meteorite Widmanstätten structure. 2% Nital etch. Scale bar is 1 mm.

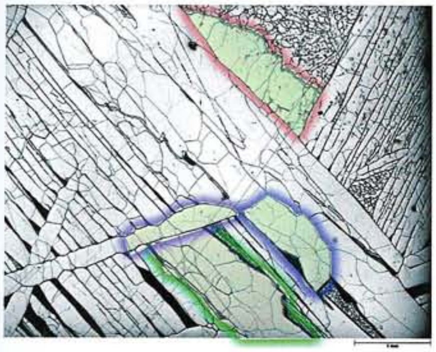

Fig. 1b Kamacite areas of interest outlined in color. Scale bar is 1 mm.

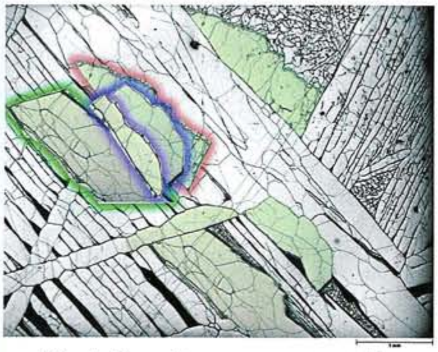

Fig. 1c Kamacite areas reconstructed by matching interfaces and subgrain boundaries to show prior attachment positions in the image plane. Scale bar is 1 mm.

Fig. 1a shows the Widmanstätten structure of the Gibeon nickel-iron fine octahedrite meteorite, with a 2% Nital etch. Digital image tools were used to first highlight kamacite areas of interest (Fig. 1b) and then "reconstruct" prior attachment positions by matching interfaces and subgrain boundaries (Fig. 1c) in the plane of the image. Reconstructed paths of kamacite areas shown by the arrows (Fig. 1d) indicate that both translation and rotation can occur. Fig. 1e shows detail of areas of interface match.

The digital reconstruction technique illustrates that relatively large crystal pieces had some freedom to move a distance and even rotate from their prior attachment positions. The reconstruction is facilitated by some well-preserved matching crystal interfaces. Such crystal mobility implies that the system was not completely solidified (i.e., in a mushy state) when this movement occurred. Therefore, the macro-meteoritic Widmanstätten structure is a solidification fabric, a dendritic structure, not produced by the solid state Widmanstätten transformation mechanism under equilibrium conditions, as originally proposed by Osmond and Cartaud in 1904 (1) and still commonly interpreted as such today.

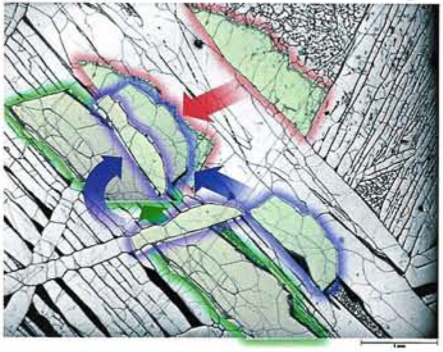

Fig. 1d Potential paths of kamacite areas shown by arrows. Scale bar is 1 mm.

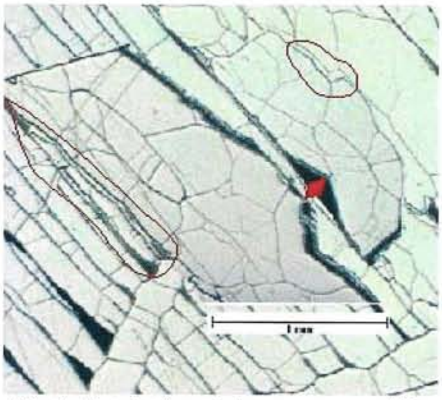

Fig. 1e Detail of match between green and blue pieces (See Fig. 1b) are outlined in red. Matching areas are slightly displaced to show match; arrow indicates region of "puzzle piece" match. Scale bar is 1 mm.

This 1904 work serves as the foundation for the meteoritic "Metallographic Cooling Rate" thermal history theory and its application to the Fe-Ni phase diagram. In addition, it is the basis for models of meteorite parent body formation (2). In view of the period of the original investigation and the name tie to central west Africa, it is logical that "Tombouctou" is part of the Gibeon fall. Therefore, it is necessary to investigate if insights can be gained by applying the digital reconstruction technique to evidence presented by Osmond and Cartaud.

Micrographs of the Tombouctou meteorite from the 1904 Osmond and Cartaud paper are shown in Figs. 2a and 3a. Although the fields of view in these figures are limited, the features of interest are the relatively long, prominent, irregularly-shaped back regions bordering some kamacite lamellae. These features are shown within the triangular regions of Figs. 2b and 3b. Using shape clues, some black features with contiguous kamacite can be matched to other sets of black features. Each triangular area match indicates a position where the kamacite lamellae were once attached. Here, the visual information indicates that the regions labeled "A" in Figs. 2b and 3b were probably once contiguous with the regions marked "B." The

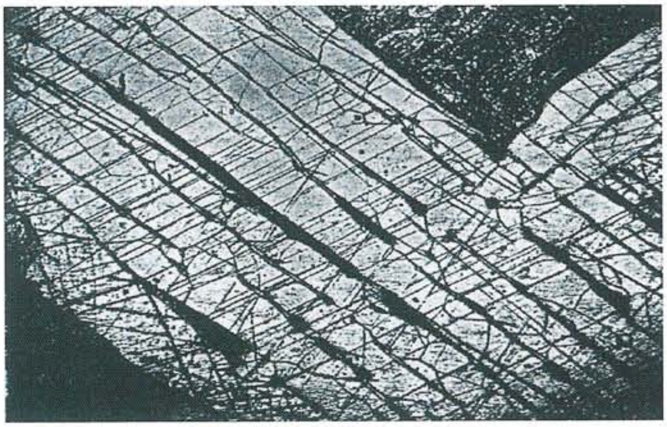

Fig. 2a Tombouctou nickel-iron meteorite Widmanstätten structure at 25 diameters. Etchant 4:1 water/picric acid.

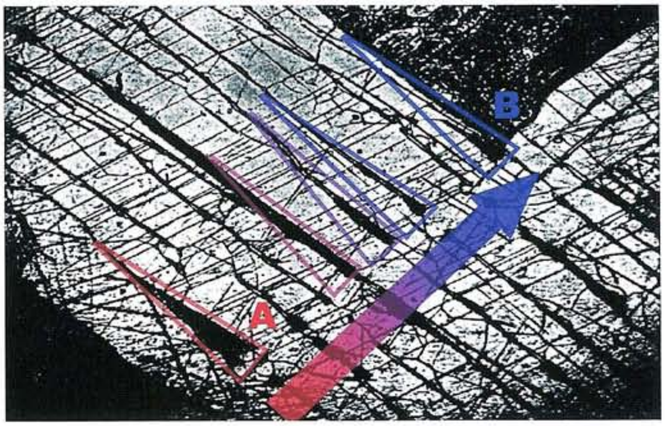

Fig. 2b Arrow shows path of lamella A to matching position at lamella B (in this image); colored triangles outline intermediate matching interfaces.

arrows indicate the direction of the "reconstruction" step back in time.

The macro-meteoritic Widmanstätten structure typically includes small amounts of C, S, P, Co and have never been reproduced in a laboratory. The cubic symmetry of the Fe-Ni system, its complex interactions with alloying elements, responses to unknown heating and cooling conditions (i.e. phase transformations) and responses to solidification stresses (i.e. slip) all contribute complexity. These factors, coupled with Osmond and Cartaud's 1904 connection with Earth alloys, have all served to mask a fundamental, logical problem by assuming the conclusion that the microstructures seen in Figs. 1-3 are the result of a solid-state phase transformation. From this assumption, researchers have deduced that the meteoritic Widmanstätten structure formed in the core of meteorite parent bodies, calculated metallographic cooling rates and determined meteorite parent body sizes. This is circular reasoning.

Analysis of these structures shows that the Gibeon and Tombouctou meteoritic Widmanstätten structures are characteristic of final stage solidification of a complex mushy melt for which, logically, gravitational body force and thermal history are unknowns. The meteoritic Widmanstätten structure has been misinterpreted as a solid-state phase transformation for nearly 100 years. The reconstruction technique shows that it is time to take another look.

Phyllis Z. Budka, 2135 Morrow Avenue, Niskayuna, NY 12309; e-mail: abudka@nycap.rr.com

Acknowledgments

The author is grateful to Dr. Thomas P. Budka for the Osmond and Cartaud translation and to Ms. Tymm Schumaker for the Gibeon photography.

References

1. F. Osmond & G. Cartaud, "Sur Les Fers Meteoritques," *Revue de Metallurgie*, pp. 69-79, 1904.

2. P.Z. Budka, "Meteorites as Specimens for Microgravity Research," *Metallurgical Transactions* A, Vol. 19A, pp. 1919-1923, Aug. 1988.

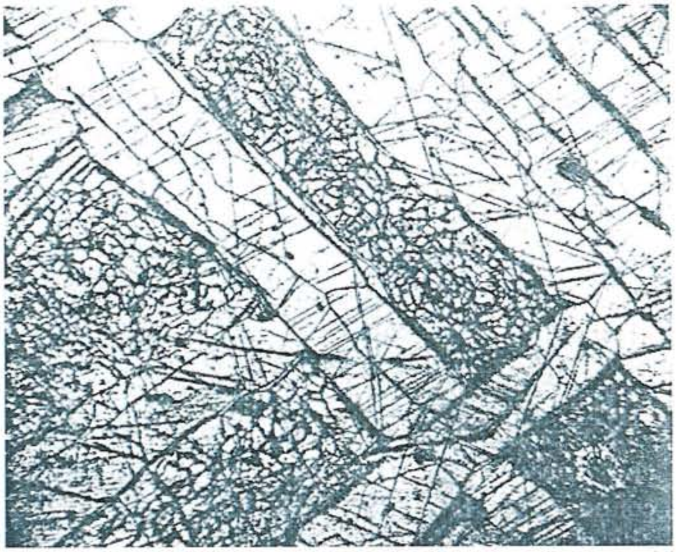

Fig. 3a Tombouctou nickel-iron meteorite Widmanstätten structure at 25 diameters. Etchant 4:1 water/picric acid.

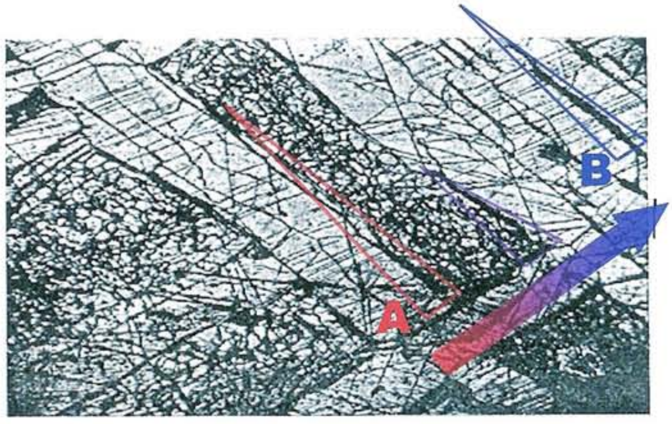

Fig. 3b Arrow shows path of lamella A to matching position at lamella B (in this image); colored triangle outlines intermediate matching interface.