STONY-IRON METEORITES (PALLASITES) – A STUDY OF NATURE’S MICROGRAVITY SPECIMENS

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ABSTRACT
The interpretation of metallographic structures is widely used in materials engineering to gain insight into a material’s history. This paper presents Imilac stony-iron meteorite (pallasite) color micrographs that show interrelated regions at low magnification. Logically, stony-iron meteorites such as Imilac formed in a low gravity environment. Color and shape cues can be used to “reconstruct” the last stages of Imilac microstructural evolution before final solidification. The role of gravity as a variable in pallasite microstructural evolution needs study. Micrographs are presented to stimulate interest and gain new insights into pallasite formation conditions as well as microgravity solidification.

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I. INTRODUCTION

The interpretation of metallographic structures is a simple, effective approach, long used in materials engineering to gain insight into conditions experienced by a material during its history. The same approach can be applied to stony-iron (pallasite) meteorites, nature's microgravity solidification specimens, to glean information on conditions in a mushy melt, during the last stages of low gravity solidification.

Micrographs of both typical and anomalous stony-iron (pallasite) and nickel-iron meteorite microstructures are first presented in a visual progression overview (Part II). Next (Part III), a low magnification study of 2 pieces of Imilac pallasite gives insights into microstructural development before the final stages of solidification.

II. A VISUAL OVERVIEW: FROM PALLASITES TO NICKEL-IRON METEORITES

Springwater Pallasite

Initial insights for the concept that stony-iron meteorites are formed by non-equilibrium solidification under microgravity conditions came from the Springwater Pallasite specimen shown in Figure 1 [1, 2, 3, 4]. The yellow-green phase is olivine, a magnesium – iron silicate in the orthorhombic system; it is an isomorphous series with end members Mg$_2$SiO$_4$ (forsterite) and Fe$_2$SiO$_4$ (fayalite). Olivine is set in a matrix of body-centered cubic iron with approximately 7-16 vol% nickel [5]. This combination of low density silicate in a matrix of high density metal does not occur naturally on earth.

Imilac Pallasite

Imilac Pieces A and B, Figure 2, are the subjects of the detailed metallographic study in Part III. Table 1 gives size and mass details for Pieces A and B.
### Table 1 Imilac Pieces A and B

<table>
<thead>
<tr>
<th></th>
<th>Imilac Piece A – ~50-50 Metal/Silicate</th>
<th>Imilac Piece B – ~95-5 Metal Silicate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>21.20 grams</td>
<td>8.28 grams</td>
</tr>
<tr>
<td>Length</td>
<td>4.04 cm</td>
<td>3.58 cm</td>
</tr>
<tr>
<td>Width</td>
<td>2.69 cm</td>
<td>2.46 cm</td>
</tr>
<tr>
<td>Thickness</td>
<td>0.45 – 0.46 cm</td>
<td>0.45 – 0.50 cm</td>
</tr>
</tbody>
</table>

**Brenham Pallasite**

This Brenham image, Figure 3a, is often included in meteorite books for its unusual microstructure, a combination of stony-iron meteorite and characteristic nickel-iron meteorite Widmanstätten structure. Since Figure 3a does not have a scale bar, the Brenham Figures 3b and c are included for scale.

**Agpalilik and Gibeon Nickel-Irons**

Agpalilik and Gibeon show the typical meteoritic Widmanstätten structure (Figure 4a and b). The major microstructural feature is body-centered cubic iron (kamacite) with ~7.5% iron [6].

**Albion Nickel-Iron**

Albion (Figure 5a-c) contains an unusual void within the Widmanstätten structure, a very rare microstructural feature.
Figure 1: Springwater Stony-Iron Meteorite
Figure 2: Imilac Stony-Iron Meteorite – Back lighting highlights translucent regions
Brenham Pallasite with typical Widmanstatten Structure

Figure 3a courtesy of Carleton Moore, Arizona State University, Center for Meteorite Studies
Meteoritic Widmanstatten Structure

**Kamacite** - Body-centered cubic iron - ”Ferrite”
 Ni: 4 - 7.5%  Co: 0.4 - 0.6%

**Taenite** - Face-centered cubic iron - “Austenite”
 Ni: 25 - 50%  Co: .3 - .8%  C: 0.05 - 0.5%  P: 0.05 - 0.1%

Agpalilik  
2.25 cm

**Figure 4a**  
Courtesy of Vagn F. Buchwald

Gibeon

**Figure 4b**  
Courtesy of G. Vander Voort

**Figure 4:** Typical Widmanstatten Structure
Albion Widmanstatten Structure

Figure 5a

From 22 kg mass

Figure 5b

10 mm

Photos Courtesy of Russell W. Kempton
New England Meteoritical Services

Figure 5c

Page 8
III. IMILAC METALLOGRAPHIC STUDY

This section presents a study of both sides of Imilac Pieces A and B; a photo of each side is given first, then a visual map of that same image keyed to the higher magnification images (~18X) that follow. It is common practice for specimen preparers to fill voids created during cutting with epoxy. The epoxy appears as bubble artifacts in olivine regions. These specimens are shown as purchased and have not received metallographic preparation.
IV. CONCLUSIONS

Using color and shape cues and simple digital image tools applied to low magnification micrographs, it is possible to reconstruct the last stages of Imilac microstructural evolution before final solidification. Several pieces of related olivines and the order of their position in the pre-existing “parent” olivine cluster can be determined and the “parent” olivine cluster reconstructed. In Imilac Piece B, a region of liquid metal invasion into the parent olivine cluster can be identified. As more liquid metal invaded the cluster, several olivine pieces separated and were pushed a few millimeters in a gentle movement before final solidification. This same simple reconstruction methodology is possible with Imilac Piece A and the Springwater pallasite piece in Figure 1. It is, thus, a general and powerful technique to visualize the pallasite mushy melt as it freezes in microgravity.

The role of gravity as a variable in pallasite microstructural evolution needs study. These micrographs are presented to stimulate interest and gain new insights into pallasite formation conditions as well as microgravity solidification.

V. REFERENCES

VI. ACKNOWLEDGMENTS

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