**TOMOGRAPHY OF THE BRENHAM PALLASITE** Jacob Spinsby[1], Heiner Friedrich[2], and Peter R. Buseck[1,3], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ; jspinsby@mchsi.com, [2]Inorganic Chemistry and Catalysis, Utrecht University, The Netherlands; H.Friedrich@uu.nl, [3]Dept. of Chemistry & Biochemistry, Arizona State University, Tempe, AZ,; pbuseck@asu.edu.

**Introduction:** Pallasites are the coarsest-grained, silicate-bearing meteorites. Their textures indicate they were at least partially molten, and their mineralogy shows they are the products of differentiation processes. However, little is known about the details of how they formed. Their major constituents have strikingly different densities (olivine ~3.3 g/cm^3, Fe/Ni ~7.9 g/cm^3) and melting temperatures (olivine ~2000K, Fe/Ni ~1600K), and it is thus surprising to find them physically intergrown. Because the metal is opaque, it is difficult to look into or through these meteorites and it is thus challenging to determine the 3-dimensional details of the intergrowths.

In 1969, as part of an undergraduate work-study program and an ongoing study into these meteorites [1], a series of serial sections of the Brenham pallasite were prepared. The products lay dormant for several decades, but here we report on the results of a tomographic reconstruction and analysis of these sections. In a companion study, we report on oriented, linear inclusions in the olivine of another pallasite [2].

**Experimental:** A brick-shaped piece of Brenham, ~20 mm on a side, was used. Readily distinguishable phases were olivine, Fe/Ni metal, troilite, and schreibersite. The surface was polished, etched, photographed. Then roughly 0.5 mm of meteorite was removed by grinding, after which the procedure was repeated. The result was a series of 41 photographs (Figure 1). These were archived until we developed procedures for electron tomography [3], at which time we applied the algorithms to the Brenham sections.

After the photographs were scanned and digitized, we used two programs created at ASU, called ETSAV (for Electron Tomography Segmentation, surface Area, and Volume and ETCut (for Electron Tomography CUTter), to produce the results in Table 1. Although created for electron microscope images, they can be used for a wide range of tomographic applications [3]. Details of the procedures are given in [4]. Figure 2 is a tomogram of the reconstructed meteorite.

ETSAV separates objects, and returns volume and surface area for each object. It can be adjusted to return surface areas of one object against another object, which was done.

**Results:** Olivine is the primary constituent of our sample, making up approximately 67.2% of the volume. Next in abundance is FeNi metal with 23.1%, troilite: 4.4%, and schreibersite: 3.4%. The remaining 1.9% was likely left out during the manual segmentation of the images. Table 1 shows the volume percentages and weight percentages derived from them. Table 2 provides information about which phases are in contact with which other phases.

Relative uncertainties in the volumes and surface areas can be as high as 3% and 12% respectively, but decrease for larger objects. These errors arise from modeling curved objects using many small cubes (voxels). The larger the object, and thus the more cubes used to model it, the smaller the error.

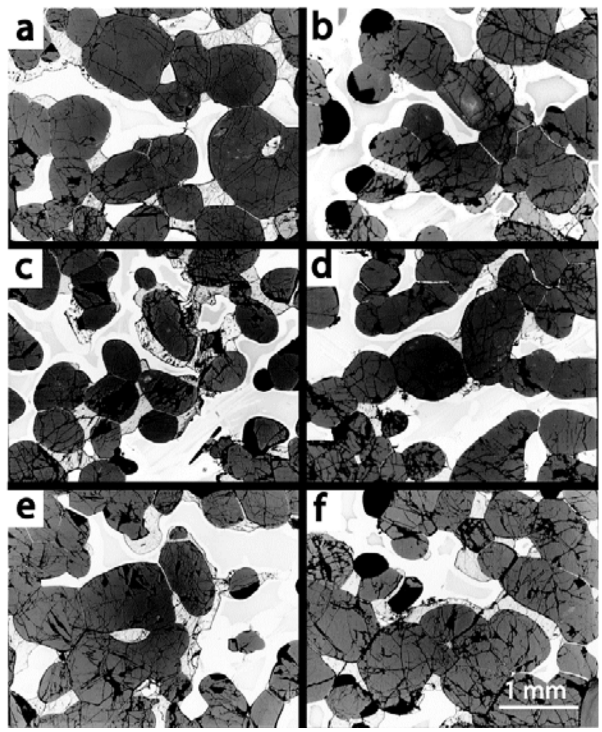


**Figure 1**. Six of the 41 polished surfaces of the Brenham pallasite that were used for the 3-dimensional reconstruction. Successive sections are 3.5 mm apart. The dark gray material is olivine (black where plucked during polishing), the white is metal (kamacite near the olivine and taenite in the metal centers), and the light gray material bordering the olivine is troilite and schreibersite. The schreibersite is whiter and contains numerous fractures.

We used ETSAV to determine whether specific phases occur as large, continuous objects or as many small, isolated ones. All the olivine in our sample is interconnected, as is almost all the FeNi metal, with 95% of the volume contained in a single object.

Schreibersite and troilite consist of several disconnected units. 40% of the schreibersite volume is connected as a single object, 11.5% is in a second object, and the remainder is in smaller units. 32.5% of the troilite is in its largest object, with 17.1%, 9.6% and 4.3% in unconnected objects. The remainder is in smaller isolated pockets.

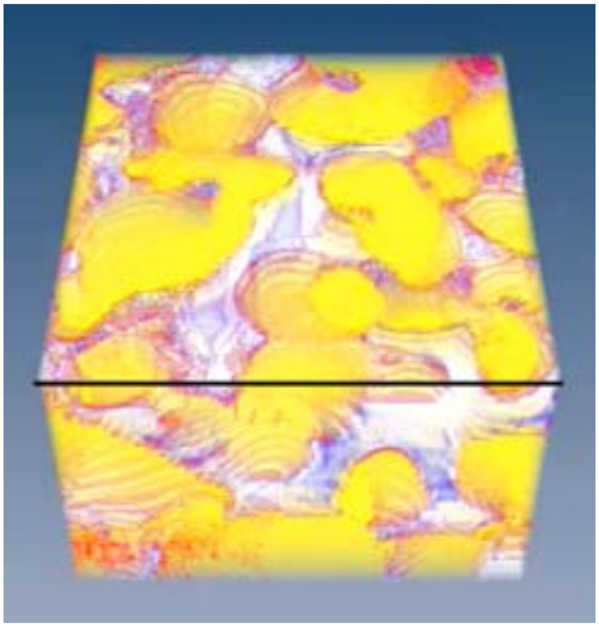

**Figure 2**. Tomogram of the sample of Brenham pallasite. The olivine is yellow, FeNi is white and light blue, troilite is purple, and schreibersite is red.

**Discussion:** Pallasite meteorites can be markedly heterogeneous in composition and textures, with some parts consisting of essentially pure metal and others containing the characteristic olivine-metal intergrowths. Here we restrict ourselves to the latter since that is the part that was sampled.

Wager and Brown [5] pointed out that if roughly equidimensional olivine crystals are allowed to accumulate by settling in a pre-existing layer, roughly 60-65% of the volume would consist of olivine. Randomly closest-packed spheres occupy approximately 64% of a given volume. Olivine in our sample is rounded but not spherical and occupies 67% of the volume. Approximate close packing is a plausible assumption. Since essentially all olivine is contained within a single object, the suggestion [1] that the crystals crystallized and grew in contact with one another seems reasonable.

Buseck [1] proposed that troilite and schreibersite crystallized out of a late liquid, adhering to the olivine before solidification of the pallasite was complete. This suggested wetting effect is supported by the results of the surface-area measurements since troilite and schreibersite combine to cover almost 50% of the surface area of the olivine.

Holzheid et al. [6] demonstrated that when a silicate liquid forms an interconnected melt network within a solid olivine matrix, sulfide adheres to olivine surfaces and does not form a continuous network. Our surface-area measurements are consistent with such a conclusion, as troilite and schreibersite are made up of many separate objects. These observations are consistent with a model where the sulphide and phosphide were part of a melt that existed after olivine solidification and that adhered to the olivine grains and moved diffusively along their surfaces.

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**References:** [1] Buseck P.R. (1977) *GCA*, *41*, 711–740. [2] Stevens M. and Buseck P.R. (2008) *LPS XXXIX, Abstract xxxx.* [3] Spinsby J., Friedrich H., and Buseck P.R. (2008) *Computers & Geosciences 34*, 1-7. [4] Spinsby J. (2005) *ASU M.S. thesis*. [5] Wager L.R. and Brown G.M. (1968) *Layered Igneous Rocks, 588p.*, Oliver and Boyd. [6] Holzheid A., Schmitz M.D., and Grove T.L. (2000) *JGR 105*, 13555-13567.

**Table 1**. Volume and weight percentages in the sectioned piece of Brenham.

| | Vol. % | Weight % |
|---|---|---|
| Olivine | 67.2 | 50.4 |
| FeNi metal | 23.1 | 39.3 |
| Troilite | 4.4 | 4.8 |
| Schreibersite | 3.4 | 5.5 |

**Table 2**. Surface contact areas of the Brenham constituents. The percentages of surface area of the phases in the left column that border the specified phases in the top row are indicated. The (rounded) sums of the rows total 100%.

| | Olivine | FeNi metal | Troilite | Schreibersite |
|---|---|---|---|---|
| Olivine | **X** | 53.9% | 26.5% | 19.7% |
| Fe/Ni metal | 70.7% | **X** | 12.3% | 17.0% |
| Troilite | 56.1% | 19.8% | **X** | 24.1% |
| Schreibersite | 44.7% | 29.4% | 25.9% | **X** |