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Introduction: Asteroid 4 Vesta has an extensively brecciated surface of howardite-eucrite-diogenite (HED) material [1]. Howardites are the most abundant polymict breccias associated with Vesta [2] and have previously been shown to incorporate exogenic material including clasts of chondrites and other achondrite groups [3,4]. Here, we present a petrographic thin section of howardite Dhofar 018 containing a single intact radial pyroxene chondrule, analyzed through combined techniques to investigate this novel observation.

Methods: Initial analysis of the thin section of Dhofar 018 was undertaken through optical microscopy. The X-Ray Fluorescence Microscopy Beamline (XFM, Australian Synchrotron) was utilized to collect elemental data of one third of the sample with incident energy 18.5 keV, pixel size 2 μm, dwell time per pixel 6.67 milliseconds. Scanning electron microscopy (SEM, MCEM) imaging of the chondrule was carried out using a JEOL JSM-7001F FE SEM at 15 keV, probe current 0.8 nA, working distance 10 mm. Electron probe microanalysis (EPMA, CSIRO) using a JEOL JXA-8530 FE EPMA with Bruker XFlash 6 silicon drift detectors collected line-scans across the chondrule at 12 keV, 20 nA, 1 μm beam defocus and step size 3 μm, and high resolution element mapping of the chondrule at 15 keV, 40 nA, 1 μm beam defocus, 40 millisecond dwell time and 1 μm resolution.

Results: Optical Microscopy. Optical analysis in both plain-polarized and cross-polarized of the sample used in this study finds that the howardite contains numerous brown glasses and small clasts of eucrite and diogenite material. The entrained radial pyroxene chondrule was identified at this stage.

XFM. Large area imaging finds that Dhofar 018 is an unsorted matrix-supported breccia composed predominantly of both eucritic and diogenitic low-Ca pyroxene (47.2 vol%), high-Ca pyroxene (15.2 vol%), and plagioclase (31.1 vol%), with accessory chromite, troilite, ilmenite, and Fe-metal.

SEM. Imaging of the whole chondrule (Fig.1) shows it has a sharp contact with the surrounding howardite matrix. High magnification imaging finds no textural changes across the chondrule but minor diffusive equilibration between the skeletal pyroxene and neighboring mesostasis. Small “faults” offset these features.

Figure 1. Backscatter electron (BSE) image of the chondrule entrained in howardite Dhofar 018.

EPMA. Elemental analysis of the chondrule gives a mean composition of Fe_{52.9}WO_{8.1} (n = 110) and finds no major compositional variation across the chondrule, nor the presence of albite in the mesostasis. This composition is distinct from HED meteorites [5].

Summary: Chondrites are typically assigned a petrologic type based on observations of the whole rock whereas here we are restricted to a single chondrule. Our data suggests that this chondrule is most suited to a Type IIB [6], petrologic type 3.0-3.1 classification [7] on the basis of composition, the lack of significant thermal metamorphism, and the lack of albite in the chondrule mesostasis. The chondrule has undergone minimal thermal and mechanical alteration once entrained in the Dhofar 018 source. This suggests that Vesta’s regolith was able to be lithified through cool compaction from slow impacts. The presence of eucrite and diogenite material also observed in the sample implies that free-floating primordial chondrules were (and maybe still are) available in the Solar System after Vesta’s accretion and differentiation.