SHOCK INDUCED FELDSPAR AND SILICA TRANSFORMATION IN POLYMICT EUCRITE NORTHWEST AFRICA 10658.

C. Fudge[1], J. Hu[2], C. Ma[2], A. Wittmann[3] and T. G. Sharp[1], [1]School of Earth and Space Exploration, Arizona State University, Tempe AZ, USA 85287-1404. cfudge@asu.edu [2]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena CA, USA 91125. [3]LeRoy Eyring Center for Solid State Science, Arizona State University, Tempe AZ, USA 85287-1704.

Introduction: Howardite-eucrite-diogenite (HED) meteorites belong to the largest group of achondrites and originate from protoplanet 4 Vesta. The surface of Vesta has been extensively affected by impacts which brecciated and mixed eucrite and diogenite material to produce a regolith and formed large basins in the south pole region [1]. Shock features preserved in meteorites due to high-velocity impacts include deformation and fracturing, local to complete melting, and high-pressure minerals. These effects can yield constraints on the pressure-temperature-time history of impact on the parent body.

Previous studies have reported variable shock features preserved in eucrites, including brecciation, mechanical twinning, transformation of feldspar to maskelynite or glass, and the local formation of melt pockets or veins cross-cutting the stone [2]. Coesite and stishovite, high-pressure polymorphs of silica, have been reported to coexist with silica glass in Béréba [3] and NWA 8003 [4]. These authors estimated a shock pressure of ~8-13 GPa and ~8-10 GPa, respectively. The purpose of this study is to explore shock metamorphic features preserved in NWA 10658 and to constrain the pressure-temperature impact conditions recorded in this sample.

Sample and Methods: Regions of interest were identified in a thin section of NWA 10658 with a petrographic microscope. Back-scattered electron (BSE) images of transformation textures and mineral chemistry were acquired with a JXA-8530F electron microprobe. Wavelength-dispersive spectroscopy (WDS) analyses were performed with a 15 kV, 15 nA beam. The beam was defocused to 5-10 µm on alkali-bearing phases. High-pressure minerals were identified with Raman spectroscopy and electron backscatter diffraction (EBSD) analysis.

Results: NWA 10658 is a polymict breccia composed of two populations of $\leq$ 4 mm clasts embedded in a fine-grained matrix. The predominant clast assemblage consists of orthopyroxenes up to 3 mm ($Fs_{29-48}Wo_{2-4}$) with >10 µm exsolution lamellae of augite ($Fs_{10-18}Wo_{43-45}$) intergrown with plagioclase ($Ab_{7-12}An_{91-92}Or_{0.1-0.6}$). The other clast assemblage is texturally subophitic and consists of 400 µm intergrowths of pigeonite ($Fs_{59}Wo_{5-6}$), augite ($Fs_{28-29}Wo_{4-42}$) and plagioclase ($Ab_{12-16}An_{82-87}Or_{0.7-2.6}$) [5].

The texture of the brecciated matrix exhibits evidence of brittle-ductile deformation and local melting, including crushed and compacted fragments. Some regions have been sheared, producing glassy zones. Shock-induced melt pockets approach 700 µm and contain rounded troilite droplets and silicate fragments. Preliminary Raman data of the melt assemblage suggests the presence of pyroxene and garnet.

Radial expansion cracks surround plagioclase and SiO_2 fragments, crosscutting the melt and propagating into the surrounding host rock. Transformed SiO_2 grains contain high contrast domains with polycrystalline texture in a glassy matrix. Raman spectra collected from the polycrystalline and homogenous regions of SiO_2 confirm the presence of coesite in silica glass.

Feldspars up to 4 mm have been partially to completely converted to glass. Crystalline remnants in partially maskelynitized grains exhibit mosaicism and/or planar deformation features. Plagioclases entrained in the shock-induced melt have been transformed to tissinite, the high-pressure polymorph of clinopyroxene [6]. In addition, some plagioclase has been pseudomorphically replaced by a material exhibiting a dendritic texture in BSE images (Figure 1). Raman spectra collected from this dendritic material are consistent with grossular garnet (Figure 1, inset).
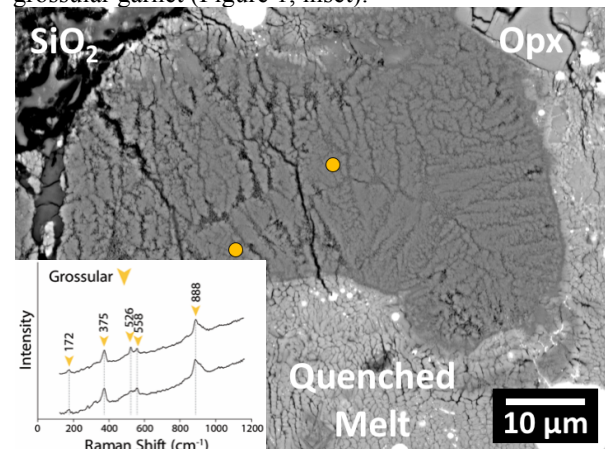

Figure 1: BSE image of dendritic texture in feldspar clast entrained in a shock melt pocket in NWA 10658. The locations of Raman analyses are illustrated by gold circles. Representative Raman spectra are given in the inset panel. Peak positions for grossular garnet are indicated by gold arrows.

We tested for the presence of garnet with EBSD (Figure 2). Preliminary EBSD phase mapping shows that the adjacent quenched melt and the dendritic pseudomorph after plagioclase are garnets. Orientation mapping suggests that the quenched melt garnet and the adjacent garnet pseudomorph have the same crystallographic orientation, consistent with an overgrowth relationship. Additional EBSD data is needed to confirm these results. A comparison of the composition of plagioclase clasts as well as the garnet pseudomorph was conducted with EPMA (Table 1).
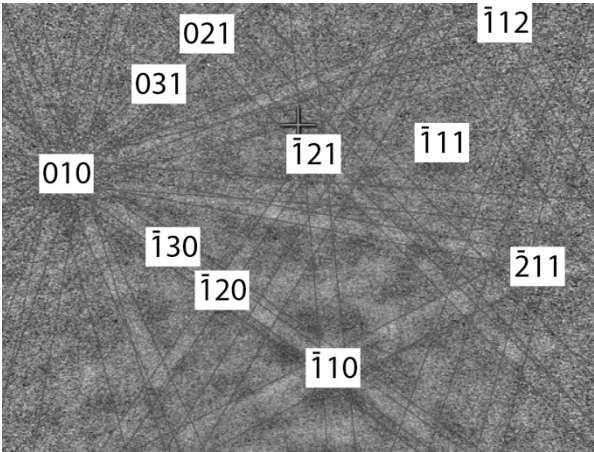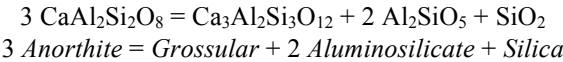

Figure 2: Indexed EBSD pattern of grossular garnet with Ia 3d cubic structure shown in Fig. 1.

Oxides (wt%)	Grossular (n=4)	Plagioclase (n=7)
K_2O	0.09	0.07
Al_2O_3	34.8	34.9
Na_2O	1.12	0.91
MnO	0.03	0.02
CaO	18.3	18.7
SiO_2	45.8	45.2
MgO	0.02	0.02
FeO	0.42	0.34
Total	100.5	100.2

Table 1: Chemical compositions of grossular garnet after plagioclase and maskelynite clasts entrained in the shock melt (Cr_2O_3 and TiO_2 abundances were below the detection limit).

Discussion: Although majoritic garnets are common in highly-shocked meteorites, grossular garnets are not. Grossular-bearing majorites have been reported in the shergottite NWA 8159, where they crystallized from shock melt at high pressure [7]. The grossular garnet in NWA 10658 represents the transformation from anorthitic plagioclase, which has not been previously reported in eucrites or other shocked meteorites. The reaction of pure anorthite to pure grossular may occur by the following reaction:

$$3\ CaAl_2Si_2O_8 = Ca_3Al_2Si_3O_{12} + 2\ Al_2SiO_5 + SiO_2$$
$$3\ \textit{Anorthite} = \textit{Grossular} + 2\ \textit{Aluminosilicate} + \textit{Silica}$$

However, our Raman data to date for the transformed plagioclase have no peaks affiliated with aluminosilicates or silica polymorphs. This suggests that the grossular-bearing garnet observed here is non-stoichiometric and likely contains excess aluminum. Further EBSD and TEM work is needed to confirm these results and identify any additional phases.

We identified abundant coesite in transformed silica grains, however, we found no evidence for stishovite or the post-stishovite polymorph seifertite in our Raman data. Although coesite is stable at pressures up to ~10 GPa, it is likely to have formed metastably along with other SiO_2 phases at higher pressure. The formation of maskelynite and planar deformation features in anorthitic plagioclase suggest a pressure up to ~24 GPa based on shock-recovery experiments [8]. Forthcoming EBSD and transmission electron microscope investigations on the shock melt are expected to provide further insight into pressure and temperature conditions and will be presented at the meeting.

References: [1] McSween H. et al. (2013) *Meteoritics & Planet. Sci. 48,* 2090-2104. [2] Yamaguchi A. et al. (1997) *Antarct. Meteorite Res. 10,* 415-436. [3] Miyahara M. et al. (2014) *Proc. Natl. Acad. Sci. 111*, 10939-10942. [4] Pang R.-L. et al. (2016) *Sci. Rep. 6*, 26063. [5] Fudge C. et al. (2016) *79th Ann. Meet. Met. Soc.,* Abstract #6480. [6] Ma C. et al. (2015) *EPSL 422*, 194-205. [7] Sharp et al (2015) *LPSC XLVI*, Abstract #1939 [8] Fritz et al. (2011) *LPSC XLII,* Abstract #1196.