SHOCK EFFECTS AND MINERALOGY IN EUCRITES: EXPANDING OUR KNOWLEDGE OF THE IMPACT HISTORY OF VESTOIDS

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Introduction: Shock effects in meteorites can be used to elucidate impact processes on planetary surfaces. So far, shock effects in L chondrites and martian meteorites have been well documented. In general, these shock effects reflect late solar system impacts <500 Ma and <20 Ma, respectively [1-2]. It is important to investigate shock effects in other meteorite groups which reflect ancient solar system impacts. Recently, investigations of high pressure assemblages in shocked eucrites have been used to infer the shock history of the ~530 km diameter asteroid, Vesta [3-6].

The majority of eucrites are thought to originate from Vesta, though some studies have shown that petrologically similar meteorites, with different O-isotope compositions that may reflect origins other parent bodies. The dates from impact resetting of eucrites and eucrite clasts in howardites indicate early impacts, with ages clustering between ~3.4 – 4.1 Ga, and around ~4.5 Ga [7-8]. If these meteorites originate from Vesta, they provide a means to study impact processing on a differentiated, Earth-like planetary embryo through a high impact flux, i.e. the lunar cataclysm. In this study, we describe shock effects in a suite of eucrites to explore impact processes that affected Vesta and V-type asteroids.

Samples and Methods: Doubly polished thin sections of eucrites Northwest Africa (NWA) 7643, 8120, and 8677 were studied with polarized and reflected light microscopy to document host rock shock effects and shock-melt. A JEOL 8530F electron microprobe, equipped with a field-emission gun, was used to document the texture and chemistry of transformed and recrystallized regions, using a beam energy and current of 15 keV, 15 nA, respectively. Mineral polymorphs were determined using Raman spectroscopy with a 532-nm (green) laser operating at 6 mW.

Results:

Northwest Africa 7643

NWA 7643 consists of subophitic intergrowths of anorthite and pigeonite with augite exsolution lamellae and accessory SiO_2, ilmenite, and troilite. The feldspars located along shock melt have been partially converted to maskelynite. Feldspars within shock melt exhibit spherulitic textures that suggest recrystallization. Much of the sample is transected by shock-melt-rich breccia containing subrounded host rock clasts and monomineralic fragments. A large, ~4 mm wide shock vein exhibits distinct textural zones that transition from 5 µm acicular crystals in an aphanitic matrix at the margins into agglomerations of granular plagioclase and pyroxene towards the vein interior. The center of the quenched melt vein is comprised of ~10 µm euhedral pyroxenes that are compositionally zoned.

The fragments entrained in this melt exhibit evidence for deformation, melting, and/or transformation. Plagioclase clasts exhibit schlieren textures resembling isoclinal folds. Backscatter electron (BSE) images of maskelynites in the melt show high-contrast domains that appear as aggregates radiating from grain boundaries. While these textures suggest transformation, Raman spectra indicate anorthite. SiO_2 grains in the shock melt exhibit smooth homogenous cores with high contrast and a rim of low contrast material. Raman spectroscopy reveals that the high contrast cores consist of quartz and coesite, that are rimmed with quartz.

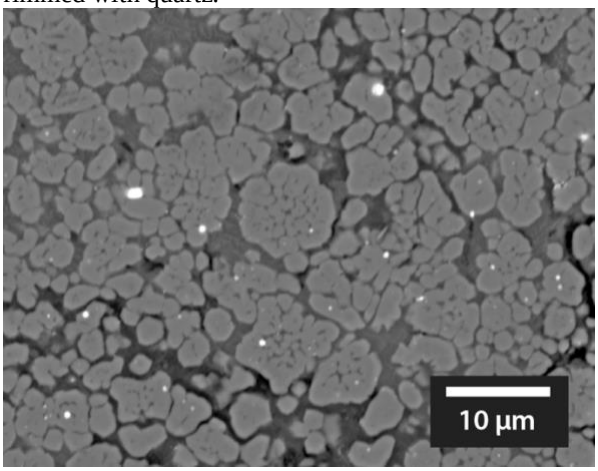

Figure 1: BSE image of poikilitic garnets that quenched from shock melt in NWA 8120.

Northwest Africa 8120

NWA 8120 is a monomict breccia composed of subophitic to ophitic intergrowths of anorthite and exsolved pigeonite with accessory SiO_2, ilmenite, and chromite. The section is transected by a ~1-mm shock vein. Host-rock plagioclase is predominantly anisotropic, while those associated with the shock vein are partially isotropic. BSE images of grains entrained in or associated with shock melt reveal dendritic textures akin to those described in the eucrite NWA 10658 [5-6]. Raman spectra from this material indicate the presence of garnet + tissintite. In addition,

plagioclase pseudomorphs occur with radial, cellular-type textures, like those described above in NWA 7643. Raman specrtra indicate the presence of tissintite and possible coesite.

The shock-vein crystallization assemblage contains predominantly Ca-rich, poikilitic garnets that are similar to Ca-rich majorites observed in the NWA 8159 martian meteorite (Figure 1) [9]. While these melt garnets represent the dominant liquidus phase, the central region of the thickest portion of the vein exhibits smooth, homogenous texture with round troilite blebs. Raman spectra from this zone are consistent with a glass.

Northwest Africa 8677

The NWA 8677 genomict breccia consists of predominantly recrystallized, granulitic clasts with minor gabbroic fragments entrained in finer breccia with shock melt. The two lithologies contain compositionally similar anorthitic plagioclase and exsolved pigeonites, with minor ilmenite and SiO_2. Feldspars associated with shock melt are partially to completely amorphous, and many are riddled with rounded pyroxene inclusions. Recrystallized feldspars exhibit spherulitic textures similar to those in NWA 7643.

BSE images of large shock-melted zones exhibit well-developed crystalline quench textures, with elongate lathes of plagioclase and pyroxene. SiO_2 fragments entrained in this region are generally ~50-100 µm and exhibit polycrystalline domains. Raman spectra from these areas indicate quartz + cristobalite. A large ~600 µm silica fragment is rimmed with texturally similar, quartz + cristobalite, with a homogenous, high-contrast core. Raman spectra from the core are consistent with coesite.

Discussion:

Interpretation of shock effects and mineralogy.

The polymorphic mineralogy in NWA 8120 is similar to that documented in other eucrites and martian meteorites [3-6, 9]. Based on their similarity to the Ca-rich majorites in NWA 10658 and NWA 8159, we infer that the garnets in NWA 8120 have a majorite component. The presence of distinct zones of garnet and amorphous material in the shock vein indicates quench during compression. Quench started with crystallization of the poikilitic garnets along the shock-vein margins and ended with the quench of glass in the vein center. The preservation of the shock melt assemblage and associated high-pressure pseudomorphs in NWA 8120 implies a rapid quench.

Although much of the mineralogy associated with melt in NWA 7643 and 8677 is dominated by low pressure assemblages, the survival of the coesite provides evidence of strong shock. The apparent low pressure signature retained in these eucrites is due to the abundance of melt formed during the shock loading. The cooling rate of shock melt is strongly dependent on the melt volume and the temperature of the surrounding host rock [10-11]. The temperature of the incipient shock melt and the melt rich zones likely remained quite high after pressure release. Other high-pressure assemblages that may have formed during shock, would have back transformed and/or recrystallized to low-pressure phases. This is consistent with the observation of quartz-cristobalite rims on coesite and the recrystallized, spherulitic feldspars associated with the melt. In the case of NWA 8120, the smaller amount of melt resulted in the preservation of high-pressure garnets and plagioclase pseudomorphs.

Insights into impacts on Vesta & V-type asteroids.

The overall shock effects and mineral assemblages preserved in these three eucrites reflect high-pressure shock conditions, with contrasting post-shock thermal histories. The melt crystallization assemblages suggest relatively short pressure pulse durations, similar to what has been documented in martian meteorites. This is in contrast with highly shocked L-chondrites, which record a long shock pulse duration from the parent body break up event. The formation and preservation of high-pressure assemblages in these samples requires that the target material was relatively cool prior to impact. Age dating from these samples is needed to determine the timing of the shock, but based on available age data, these samples were likely affected by ancient impacts on Vesta and V-type asteroids.

Future Work: Forthcoming TEM analytical work will be done to characterize compositions and confirm the structure of mineral polymorphs. The combination of shock effects and assemblages will be used to discuss shock conditions.

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