Characterization of the Textures and Compositions of Zircon in the Eucrite Northwest Africa (NWA) 8677: Implications for Future Age Dating Interpretations.

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Introduction: Eucrites are among the most abundant achondritic material that comes from the differentiated asteroid 4 Vesta. These basaltic rocks can serve as a record for the history of this body and are integral for interpreting the impacts that the asteroid experienced. A previous characterization of the petrography and shock effects in the eucrite NWA 8677 was presented at the 2019 LPSC [1]. That study analyzed the mineral compositions and shock effects in gabbroic and basaltic lithologies to confirm the genomict nature of the breccia and determine degree of shock in the lithologies. The gabbro clasts are highly shocked whereas the basalt is only weakly shocked [1]. With a conclusion that determines the lithologies exhibit different shock stages, further study into the timing of the impact history could begin.

During the petrographic characterization of the sample, 17 zircon grains between 15-40 μm were found throughout the thin section. Zircon is not common in eucrites as these are mafic rocks with relatively low Zr abundances which therefore does not allow for the saturation of zircon [2]. These 17 grains will allow for multiple geochemical tools to be utilized, specifically for this study we will the U-Pb isotope system, which is the most reliable chronometer available.

The purpose of this study is to first characterize the textures and compositions of the zircons present. This data will be invaluable when the $^{207}Pb/^{206}Pb$ ages are acquired to better understand what events these zircons have recorded, be it initial crystallization and/or a record of the impacts the meteorite experienced. With these ages, we can then combine all geochemical tools available to better understand the timing of differentiation, igneous and metamorphic conditions and how these chemical processes were altered by impacts on planetesimals, such as Vesta.

Sample and Methods: A polished thin section of the genomict eucrite, NWA 8677 was analyzed petrographically to document shock effects and map the location of zircon grains. The chemistry and textures of the sample were documented using the Jeol JXA-8530F electron microprobe, equipped with a field-emission electron source, in the Eyring Materials Center at ASU. Analyses were performed with a beam energy of 15 kV and a beam current of 15 nA. Semi-quantitative compositional data were collected using Energy Dispersive Spectroscopy (EDS) and the quantitative compositional data were collected using Wavelength Dispersive Spectroscopy (WDS) to document the compositions of minerals. Textures were characterized with back scattered electron (BSE) images and zircon zoning patterns were imaged with cathodoluminescence (CL).

Results: There is a distinct difference in shock effects documented between the gabbro/breccia and basalt. The breccia is host to a preserved grain of the high-pressure phase of quartz, coesite. Feldspar grains within the gabbro exhibit mosaicism as well as recrystallized domains. The basalt conversely still retains crystalline plagioclase as well as other low shock features such as undulose extinction in plagioclase and pyroxene. The presence of PDFs in silica within the basalt is also evidence for a low shock stage. With evidence of two different shock stages between the lithologies, it is interpreted that this rock would have experienced at least two impacts.

With this interpretation in mind, it is now of interest to return to the 17 zircons that were found previously and do a thorough and complete compositional and textural characterization to support a two-impact history. Among the 17 grains, there are some in all three lithologies of the sample: the breccia, gabbro and basalt. As discussed in the interpretation of the impact history of this sample, each lithology experienced impact, but to varying degrees. This is evident in the textures present in the grains.

The zircons in the gabbro and breccia no longer have the primary igneous zoning, but instead show a complex metamorphosed texture in CL (Fig. 1). Additionally, these grains show evidence for fractures that have been filled with melt, which have been confirmed to be melt inclusions by EDS that record the presence of Fe, Mg, Ca, Na, Al, and Si.

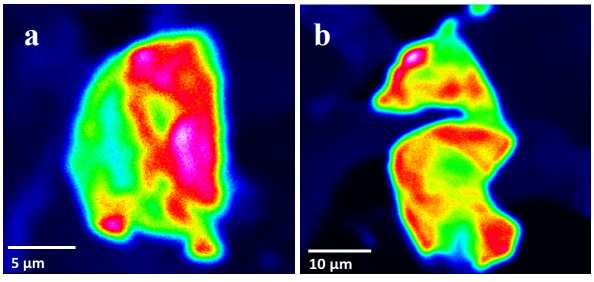

Fig 1: Cathodoluminescence (CL) images of zircon grains lacking primary magmatic texture in the gabbro and breccia lithologies of NWA 8677. Warm coolers represent high count areas, cool colors represent low count areas

One zircon in particular in the gabbro has a tail-shaped feature extending along a grain boundary between two ilmenite crystals (Fig. 2). This grain-boundary zircon formed by some degree of melting the zircon crystal and jetting of liquid into the grain boundary. Evidence for this melting is also apparent from the multitude of melt inclusions along this tail feature. The zircons in the basalt do not show any of the complex textures of those in the breccia and gabbro and appear relatively untouched by deformation.

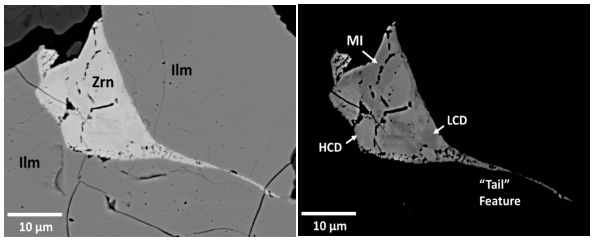

Figure 2: BSE image of a zircon (Zrn) grain formed between ilmenite (Ilm) (a), High-contrast BSE image of the same grain to bring out the high and low contrast domains (HCD and LCD, respectively) as well as the melt inclusions (MI) that have formed within the crystal and the "tail" feature discussed.

The Ti content of the zircon shown in Figure 2 was analyzed to provide the apparent crystallization temperature [4]. Assuming the activity of silica is 1 and with the presence of ilmenite adjacent to the grain, we assume an activity of TiO_2 of 0.5. Three spots in the above-mentioned grain were analyzed to determine the TiO_2 content: near center, bottom boundary and right boundary. These spots yielded TiO_2 content of 0.37, 0.49 and 0.62 wt.% respective to the spots listed previously. Using the equation from Watson and Harrison 2005, and using the aforementioned activities of SiO_2 and TiO_2, the apparent temperature is between 1500 and 1680ºC for the different spots. Relatively similar TiO_2 contents were measured in one other grain adjacent to ilmenite.

Discussion: The fractured and melted zircon grains in the breccia and gabbro have undergone a relatively high degree of shock metamorphism from impact on the parent body. This is consistent with what has been previously observed throughout these two lithologies, where the high-pressure phase coesite is preserved within gabbroic fragments [1]. However, no evidence for phase transformation of zircon to reidite or baddeleyite is observed in the BSE images. The tail-shaped feature in the zircon mentioned above is indicative of melting and recrystallization between the ilmenite. The apparent crystallization temperature calculated is consistent as it indicates high temperatures that would be present locally in highly shocked material. Melt inclusions within host zircon in other areas of the breccia provide additional evidence for some degree of melting.

None of the fracturing or shock-melting effects are present in the zircon in the basalt, which suggests that the basalt-hosted zircons may preserve primary magmatic growth. This is consistent with previous observations of weak shock effects in basaltic pyroxene and feldspar grains. As was previously documented [1], crystalline plagioclase is present within the basalt, which indicates a maximum shock stage of S3 [3]. This suggests that the basalt experienced comparatively low shock metamorphism than the gabbro. The most likely shock history of this sample is that the gabbro was initially highly shocked and brecciated, with a second impact incorporating the basalt with the gabbro and breccia. This second impact would then crush out the pore spaces between the breccia fragments and generate the abundance of shock melt present. Therefore, it is likely that the zircons in the breccia and gabbro have recorded the initial, high shock stage impact event. Future use of SIMS will obtain U-Pb ages on these zircons that will help determine the timing of impact and if the zircon in the basalt still record the initial crystallization age.

References: [1] Marquardt, M. et al. (2019) 50th *LPSC,* 2184.pdf [2] Misawa, K., et al. (2005) *Geochim et Cosmochim* 69, 5847-5861. [3] Watson, E. B., and Harrison, T. M., (2005) *Science* 308, 841-844 [4] Stöffler, D., et al. 2017 *Meteoritics & Planetary Science* 1, 5-49.

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