EUCRITE IMPACT MELT NWA 5218 – EVIDENCE FOR A LARGE CRATER ON VESTA.
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Introduction: Northwest Africa (NWA) 5218 is a 76 g achondrite that is classified as a eucrite [1]. However, an initial classification [2] describes it as a "eucrite shock-melt breccia…(*in which*) large, partially melted cumulate basalt clasts are set in a shock melt flow...". We explore the petrology of this clast-bearing impact melt rock (Fig. 1), which could be a characteristic lithology at large impact craters on asteroid Vesta [3].

Methods: Optical microscopy, scanning electron-microscopy, and Raman spectroscopy were used on a thin section (Fig. 1) for petrographic characterization. The impact melt composition was determined by 20 µm diameter defocused-beam analyses with a Cameca SX-100 electron microprobe. The data from 97 spots were corrected for mineral density effects [4]. Constituent mineral phases were analyzed with a focused-beam. Bidirectonal visible and near-infrared (VNIR) and biconical FT-IR reflectance spectra were measured on the surface of a sample slab on its central melt area and on an eucrite clast, and from 125-500 µm and <125µm powders of melt.

Results: *General petrography:* The sample specimen is a coherent, medium dark-grey (N4), melt rock. The thin section captures a central, subophitic-textured melt that contains ~1 cm to tens of µm-size sub-angular to rounded, variably-shocked eucrite clasts. Clasts >100 µm are coarse-grained with equigranular ~1 mm size plagioclase, quartz, and clinopyroxene (Fig. 1). Single crystals of chromite, ilmenite, zircon, Ca-Mg phosphate, Fe-metal, and troilite are embedded in the melt. Polymineralic clasts are mostly compositionally similar to the above mentioned larger clasts but scarce granulitic fragments are observed as well.

The eucrite clasts are composed of plagioclase ($An_{89-92}Ab_{8-11}Or_{0.2-0.6}$, n=18), pyroxene ($En_{30-45.3}Fs_{22.7-62.6}Wo_{1.5-44.7}$, n=67), quartz (as indicated by Raman-spectroscopy) with variable FeO concentrations between 0.1 and 2 wt% (n=4), variably Ti-rich chromite ($Cr_{15.6}Fe^{2+}_{7.5}Fe^{3+}_{3.7}Al_{3.8}Ti_{1}Mg_{0.3}Mn_{0.2}$ and $Cr_{9.6}Fe^{2+}_{7.1}Fe^{3+}_{8.1}Al_{1.7}Ti_{4.8}Mg_{0.9}Mn_{0.2}$, n=3), accessory Fe-metal (Ni and P <0.1 wt%, $Co_{0.1-1.5}$), troilite, and zircon. Also, anhedral, ~15 µm Ca-Mg-phosphate crystals (whitlockite?) occur within target rock clasts. Two phosphate grains that are bordering impact melt are surrounded by ~10 µm-wide voids that may be degassing vesicles from decomposing phosphate.

The target rock clasts are embedded in a dark-brown matrix of impact melt (Fig. 1) that contains vesicles with sizes up to ~1 mm in diameter. The melt exhibits a sub-ophitic texture in the central part of ~10 to 30 µm acicular to platy plagioclase ($An_{87-90}Ab_{10-13}Or_{0.1-0.4}$; n=8) in a matrix of zoned pyroxene ($En_{4-57}Fs_{27-75}Wo_{7-43}$; n=13). Close to entrained lithic clasts, the impact melt is usually darker and finer grained. Trachytic-textured melts of ~100 µm size, skeletal plagioclase with interstitial Fe-rich augite (Fs_{57-63}; n=3) occur as well as intrusions in eucrite clasts, and as a 0.5 mm wide zonea round a eucrite clast (Fig. 1).

Minor secondary alteration products are rare <5 micron euhedral laths of barite.

Figure 1. Thin section scan of NWA 5218. Black bar is 1 cm long. C - clast, M - melt; arrows indicate trachytic-textured melts.

Shock petrography: Lithic clasts frequently exhibit rounding due to advanced digestion in the melt and a wide variety of shock metamorphic effects. Plagioclase and clinopyroxene show brittle and crystal-plastic deformation effects such as fracturing, planar fractures, and undulous extinction. Clinopyroxene frequently exhibits reduced birefringence, mechanical twinning, and intense mosaicism. Some plagioclase displays annealed planar deformation features and a few feldspar grains appear to be recrystallized maskelynite with a checkerboard texture [5]. Quartz clasts were not found to have planar deformation features or ballen textures. However, quartz and clinopyroxene ubiquitously display blackening from finely dispersed, sub-µm-size, Fe-rich inclusions. A clast of chromite in the melt shows a characteristic decomposition corona, indicating temperatures >1635 °C [6,7]. Also, two zircon clasts in the melt show a possible granular recrystallization texture, which would indicate decomposition at temperatures >1676 °C [8].

Modal Composition: Point counting of 694 points of a central melt domain yield an abundance of 59 vol% zoned pyroxene, 37.9 vol% plagioclase, 0.6 vol% opaques (chromite, ilmenite, troilite, Fe-metal), 3.6 vol% holes, and 8.9 vol% clastic debris.

Chemical composition: The bulk impact melt has a Mg# and TiO_2 concentration that is typical for main group basaltic eucrites [9]. Also, plagioclase and Fe-rich clinopyroxene compositions in eucrite clasts are typical for basaltic eucrites, not cumulate eucrites [9].

Metal phases in NWA 5218 are almost pure Fe-iron, suggesting they are the products of indigenous igneous processing. A formation due to reduction-degassing of troilite as previously implied for the Camel Donga basaltic eucrite [10] seems plausible. In contrast to metal grains in many lunar impact melts (e.g., [11]), these metal grains do not record a chondritic or iron meteoritic projectile contamination.

Laser ablation inductively coupled plasma mass spectrometry data for metal particles and the bulk melt of NWA 5218 will also be reported.

Reflectance spectra: VNIR spectra of the melt area shows much darker reflectance of about 9 % at 0.55 µm than that of the eucrite clast of about 35 %, which is comparable to Vesta's albedo. Both spectra show the presence of both low-Ca and high-Ca pyroxenes as spectrally dominant phases and a blue continuum that is typical of slab spectra. Their FT-IR spectra show a strong 3-µm water absorption band, most of which is likely due to terrestrial weathering.

Oxygen isotope analysis, now underway, will test NWA 5218's link to the HEDs and Vesta or identify a different achondrite parentage [12].

Discussion & Summary: Temperatures of magmatic eucrite melts are experimentally constrained to <1200 °C [13]. In contrast, the decomposed chromite and granular textured zircon indicate superheating of the impact melt prior to equilibration with lithic debris. This equilibration stage of NWA 5218 is constrained by the absence of olivine in the crystallized impact melt, which is suggestive of a maximum temperature < ~1150 °C [13]. The two-pyroxene thermometer of [14] yields a best fit for a low-Ca-pyroxene-pigeonite pair from the sub-ophitic melt at ~838 °C; in contrast, Pyroxene in two eucrite clasts show an excellent fit for a low-Ca-pyroxene – augite pair at 684 °C, and for a pigeonite–augite pair in another clast at 1028 °C. Composition and textures of these clasts are characteristic for metamorphic type 5 and 6 eucrite pyroxenes [15]. If their thermal metamorphism has been caused by progressive burial in a basalt pile, burial depths for type 5 and 6 eucrites deeper than ~5 to 7 km can be assumed [16]. It follows that in contrast to the howardite impact melt NWA 5415 [17], NWA 5218 suggests formation in a deeper seated setting on the HED parent asteroid that mostly affected highly metamorphosed basaltic eucrite lithologies. A first-order estimate for its geological setting could indicate a cratering event on Vesta that produced a melting zone at a depth of at least ~5 km [17]. The prolonged cooling that allowed complete crystallization of NWA 5218 furthermore suggests a setting as part of a larger volume of impact melt. This implies NWA 5218 remained part of a crater fill during a larger-scale cratering event instead of being ejected and rapidly cooled.

Several very large impact craters on Vesta [18] may contain appreciable volumes of similar impact melt. Our reflectance spectra of NWA 5218 provide a comparison with data that is going to be produced by the DAWN-mission, and may be used to identify impact melt deposits that have escaped space weathering, e.g., at a crater wall or central uplift. Because the reflectance spectrum of the melt is much darker than those of HED clasts, any rocky surface area of Vesta having melt should show significantly lower reflectance. However, ground into a fine powder, melt may show similar spectral shape and brightness as average HEDs, which complicates quantification of melt in remote-sensing studies like the DAWN-mission.

Acknowledgments: D. Mittlefehldt, G. A. Robinson, A. Peslier, L. Le (NASA-JSC) for analytical support.

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