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A REVISED SHOCK HISTORY FOR THE YOUNGEST UNBRECCIATED LUNAR BASALT– NORTHWEST AFRICA 032.

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Summary

Northwest Africa (NWA) 032 is considered to be the youngest radiometrically-dated mare basalt, with concordant Rb-Sr and Sm-Nd ages of 2.947 ± 0.016 Ga and 2.931 ± 0.092, respectively [1]. These ages are ~175 Ma older than those from ^{40}Ar-^{39}Ar (2.779 ± 0.014 Ga) [2]. NWA 032 contains a high modal abundance of pyroxene (50.7 vol%), plagioclase (29.4 vol%), and olivine (11.3 vol%) [3]. The texture is that of an unbrecciated olivine-pyroxene phyric basalt. Olivine phenocrysts are zoned with Mg rich cores (Fo_{34-50}) and thin, discontinuous Fe-rich rims (Fo_{30}). Fine grained (≤ 1µm) elongated, tapered plagioclase crystals (An_{80-90}) are present within the groundmass, interspersed with pyroxene ($En_{1-25}Wo_{15-25}$) of similar shape and size. These two minerals occur in a plumose texture, radiating from a common nucleation point. Pyroxene may be categorized based on grain size as either groundmass (<1 µm), intermediate crystals (~50 µm) or larger phenocrysts (~100 µm) [3]. The mineralogy of NWA 032 makes it ideal for the study and classification of shock features based on the updated shock classification scheme [4], which relies on petrographic observations of deformation and transformation in olivine, pyroxene and plagioclase – the three most abundant minerals in NWA 032. A previous description of shock effects in NWA 032 allowed for a shock pressure estimate of ~40-60 GPa [3]; however, the shock state of plagioclase feldspar (shock-amorphized vs crystalline) was inconclusive, owing to the fine grain size of this mineral (≤1µm). The purpose of our study is to characterize the shock deformation and transformation effects in NWA 032 using a combination of field emission scanning electron microscopy (FESEM) and Raman spectroscopy, focusing on the shock state of feldspar, as well as characterizing the crystallization products of shock melting. The latter have been demonstrated as useful criteria to evaluate shock conditions [5]. Our results more tightly constrain the shock history experienced by NWA 032.

Samples and Methods

One polished thin section of lunar meteorite NWA 032 was made available to this study through loan from the University of Alberta Meteorite Collection. Shock deformation effects such as mosaicism were assessed using a petrographic microscope where the optical properties of igneous minerals could be observed in reflected, transmitted polarized and crossed polarized illumination. Areas of interest were further characterized using high resolution back-scattered electron (BSE) imaging. BSE images were collected with a 20 kV accelerating voltage using a ZEISS Sigma 300 FESEM at the University of Alberta. Mineral identification and composition were aided by acquisition of spot analyses using a Bruker energy-dispersive X-ray (EDX) spectrometer that is fitted on the FESEM. The structural state of phases (i.e., crystalline versus amorphous) was assessed using a Bruker SENTERRA Raman spectrometer at MacEwan University. Spectral backgrounds were graphically reduced using commercial spectroscopy software. The RRUFF Raman online database and published spectra of pyroxene, olivine, plagioclase and maskelynite [6] were used to determine the expected vibrational modes for the phases analyzed.

Results, Observations, Conclusions

Elongated pyroxene crystals displayed thin, parallel bands spaced ~15 µm apart, identified as mechanical twins. Thin, parallel sets of open fissures with 3-5 µm spacing, are found heterogeneously distributed throughout phenocryst pyroxene grains. Both the intermediate elongate and the phenocryst pyroxene display undulatory extinction to weak mosaicism. Olivine contains planar fractures, which appear as open fissures spaced ~10 µm apart, and weak to moderate mosaicism. Groundmass plagioclase grains displayed optical properties characteristic of isotropic materials (i.e., extinction under crossed polarized illumination). The Raman spectrum acquired from individual plagioclase grains contained none of expected peaks – a high intensity triplet between 484 cm^{-1} and 560 cm^{-1} and a distinct peak between 980 cm^{-1} and 1000 cm^{-1} [6] – expected of well crystalline Ca-rich plagioclase. Instead, acquired spectra contain broad features characteristic of an amorphous structure [6]. Textures indicating melting, such as flow lines or vesicles, were not observed in BSE images of the groundmass plagioclase.

Shock veins in NWA 032 occur as an anastomosing network of black, glassy veins cutting across the basaltic host rock. Offsets and displacement of igneous minerals are observed along vein margins. Shock vein width ranges from ~1 µm up to 100 µm. BSE imaging reveal internal textures that are dominantly glassy and schlieren-rich. Major element composition from EDX spectra suggest both micrometer sized Mg-Fe-rich and Mg-Ca-Fe-rich silicates nucleate off the entrained mineral fragments along shock vein margins. Raman spectra acquired from these aphanitic minerals may be divided into two distinct spectral signatures in terms of their peak positions and intensities. One spectrum displays sharp, intense peaks at ~318 cm^{-1}, 384 cm^{-1}, 658 cm^{-1}, and 994 cm^{-1}, characteristic of clino- and orthopyroxene. The other spectrum showed a doublet at 810 cm^{-1} and 841cm^{-1}, characteristic of olivine. Regions of shock melting also include isolated, irregularly shaped pockets, heterogeneously distributed throughout the host rock. Like shock veins, internal textures of shock melt pockets are dominantly glassy and schlieren rich with nucleation of crystals restricted to the margins of entrained igneous minerals. EDX and Raman spectra from these crystals are consistent with pyroxene and olivine. No high pressure compositional equivalents such as ringwoodite have been documented.

Constraining the temperature-pressure-time conditions of the impact that ejected NWA 032 from the moon is largely predicated on the shock state of plagioclase feldspar. The presence of maskelynite, constrains the shock pressures experienced by NWA 032 to ~28-35 GPa, corresponding to a post shock temperature of 200-250 °C.

References

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