

IMPACT METAMORPHISM OF DIOGENITE NORTHWEST AFRICA 10268: HIGH-PRESSURE MINERALS AND IDENTIFICATION OF POTENTIAL DATING TARGETS. E. L. Walton, MacEwan University, Department of Physical Sciences, 10700 104 Ave NW, Edmonton AB, Canada (waltone5@macewan.ca).

Introduction: Howardite-Eucrite-Diogenite (HED) meteorites are a clan of mafic and ultramafic rocks that are widely, though not universally, accepted to originate from the asteroid 4 Vesta [1]. The surface of Vesta is marked by two impact basins and hundreds of smaller impact craters [2]. Vestan rocks are therefore expected to have been affected by multiple impact events. Indeed, a large portion of this achondrite clan are impact-derived breccias [1]. The timing of impact metamorphism in HEDs can help to unravel the bombardment history of the inner solar system. Recently, attention has focused on dating of accessory phases—apatite, zircon, baddeleyite—to shed light on the complex thermal history of the HED parent body [4,5].

Despite the prevalence of impact processes affecting the HED clan, this important aspect of their history, compared to lunar and martian meteorites, has been little studied [6]. Here, shock effects in noritic diogenite Northwest Africa (NWA) 10268 are reported. These data fill a gap in the literature surrounding shock recorded in diogenites and identify targets for *in situ* dating, which may help to unravel the impact history of our early solar system.

Samples and Methods: Two samples, one polished thin section and one polished probe mount of NWA 10268 were available to this study. Mafic minerals and plagioclase were observed with an optical microscope. Areas of interest were characterized at higher resolution using a ZEISS Sigma 300 FESEM. BSE images were acquired with a 15-20 kV accelerating voltage. Mineral identification was aided by a Bruker EDX spectrometer. Mineral structures were analyzed using a Horiba Scientific XPLORA-PLUS Raman spectrometer, fitted with a four-grating turret. Sample were viewed using a petrographic microscope integrated with the Raman system. The Raman spectrum was collected in confocal mode using a 532 nm laser, with the real volume resolution assessed to be better than 1.5 μm laterally and 2-3 μm in depth. The spectrum for each phase was collected in the Raman shift range of 100-1550 cm^{-1} using the 1800 grooves / millimeter grating, to achieve a spectral resolution of 1.4 cm^{-1} at FWHM.

The major and minor element composition of minerals and glasses were quantified using a Cameca SX100 EMPA, equipped with five WDS. Spot analyses were acquired using an accelerating voltage of 15 kV, and a beam current of 15 nA. Most minerals were analyzed using a focused beam (1 μm); a defocused (10 μm) beam was employed to analyze feldspar to reduce

alkali mobility. Natural and synthetic minerals were used as element standards. The distribution of Si, Na, S, Ti, Fe, Al, Mg, Ca, R and Cr was mapped using the same Cameca EMPA instrument. The WDS X-ray elemental maps were acquired using a $\sim 1 \mu\text{m}$ electron beam, an accelerating voltage of 20 kV, and a beam current of 100 nA. The map pixel size is 20 x 20 micrometers with a 30 ms dwell time per pixel.

Results and Discussion: NWA 10268 has a largely unbrecciated texture, consisting mainly of interlocking grains of orthopyroxene (0.5-6 mm size) and plagioclase (20 μm size to ~ 2 mm). Minor minerals include chromite, clinopyroxene, silica and phosphates, with accessory troilite, ilmenite and zircon. Abundances of pyroxene, plagioclase, and chromite vary slightly between samples: 78-79 vol% (pyroxene), 17-20 vol% (plagioclase), 1-3 vol% (chromite), 1 vol% (silica) and 1 vol% (phosphates). A portion of the thin section exhibits a comminuted texture.

Petrography of Host Rock Minerals. Optically, orthopyroxene exhibits weak to moderate mosaicism, well-developed cleavage, a high density of fractures and first order interference colours ($\delta_{\text{max}} = 0.010$). Orthopyroxene grains are typically untwinned, however, a few examples of grains with lamellar twins are observed. Plagioclase is likewise heavily fractured, exhibits mosaicism, first order interference colours ($\delta_{\text{max}} = 0.010$) and polysynthetic twinning. Fractures within orthopyroxene and plagioclase are healed by the fusion crust. The Raman spectrum from orthopyroxene, plagioclase and clinopyroxene exhibit sharp, well-defined peaks characteristic of crystalline minerals. A single grain of zircon is documented from the thin section. This 21 x 24 μm size euhedral zircon is associated with ilmenite, enclosed by clinopyroxene, and contains Ti (0.21 wt% TiO_2), Ni (0.02 wt% NiO) and Ca (0.05 wt% CaO) from WDS spot analysis. The Raman spectrum shows sharp peaks at 202 cm^{-1} , 344 cm^{-1} , 428 cm^{-1} and 980 cm^{-1} , characteristic of crystalline zircon. Phosphates are typically apatite, found as individual equant grains ranging from 5-20 μm , as larger $\sim 300 \mu\text{m}$ size grains and as rounded inclusions in ilmenite. The Raman spectrum exhibits a strong peak at 964 cm^{-1} , typical of crystalline apatite.

Localized Shock Effects. Plagioclase adjacent to large chromite grains are internally smooth (unfractured), optically isotropic, and exhibit broadened peaks centered over ~ 503 and 1008 cm^{-1} in the Raman spectrum. The composition of both plagioclase varieties (fractured / unfractured) overlaps and spans anorthite-

bytownite ($\text{Ab}_{8.9-19.8}\text{An}_{78.9-90.9}\text{Or}_{0.3-1.3}$). Several small ($10\text{--}40\text{ }\mu\text{m}$), isolated pockets of quenched glass are found throughout the host rock. These pockets are restricted to the grain boundaries between oxide and silicate minerals. The matrix is schlieren rich and easily damaged by electron and laser beams. EMPA WDS spot analysis of one pocket, located at the interface between clinopyroxene and ilmenite, are consistent with a mixture of these two phases, with a chemical composition enriched in Ti ($17.4\text{--}22.1\text{ wt\% TiO}_2$), Fe ($16.6\text{--}20.1\text{ wt\% FeO}$), Si ($29.9\text{--}33.2\text{ wt\% SiO}_2$) and Ca ($11.8\text{--}13.1\text{ wt\% CaO}$).

Black to dark brown veins form an anastomosing network that cuts across the host rock and ranges in width from $10\text{ s of micrometers}$ up to $\sim 530\text{ }\mu\text{m}$. Offset and displacement of igneous minerals are observed along vein margins. With proximity to these veins, host rock minerals are transformed. The most obvious, texturally, is a transition from highly fractured to smooth, unfractured plagioclase in the vicinity of veins. These smooth grains are optically isotropic, have a composition that overlaps with fractured plagioclase, exhibit broadened peaks in the Raman spectrum and are surrounded by irregular fractures radiating from grain margins into neighboring pyroxene. These characteristics are consistent with the shock-produced, amorphous form of plagioclase, maskelynite [7]. Portions of amorphous plagioclase in direct contact with the vein matrix exhibit a subtle change in greyscale in BSE images and contain fractures. EMPA WDS spot analyses demonstrate a slight increase in Fe (0.54 wt\% FeO versus $0.26\text{--}0.27\text{ wt\% FeO}$) and decrease in Na ($0.91\text{ wt\% Na}_2\text{O}$ versus $1.07\text{--}1.10\text{ wt\% Na}_2\text{O}$). Peaks in the Raman spectrum at 980 cm^{-1} and 1000 cm^{-1} are consistent with tissantite, the vacancy-rich, high-pressure clinopyroxene with anorthite composition. Apatite in contact with the vein matrix is polycrystalline with peaks in the Raman spectrum at 413 , 578 , 977 and 1005 cm^{-1} . These peak positions are distinct from apatite in the host rock (964 cm^{-1}) and are characteristic of tuite—a high-pressure phosphate polymorph [8]. The margins of silica grains in contact with the veins are bright in BSE images, with a peak at 755 cm^{-1} in the Raman spectrum diagnostic of stishovite. The association of high-pressure phases (maskelynite, tuite, tissantite and stishovite) and these veins are consistent with a shock origin, and they are hereafter referred to as shock veins.

The shock vein matrix comprises small crystals embedded in glass, as well as entrained grains of rounded plagioclase and pyroxene. The degree of crystallinity varies with vein width; thinner veins ($\sim 10\text{--}20\text{ }\mu\text{m}$) are wholly crystalline, in contrast to wider, zoned veins. The margins of these wide veins is completely crystalline, grading into a zone of glass + crystals. The approximate center of the vein is

dominantly glassy. Crystals in the shock vein matrix are fine-grained, ranging from ($\leq 1\text{ }\mu\text{m}$ size up to $3\text{ }\mu\text{m}$), equant and compositionally zoned. The small size of these crystals precluded quantification of zoning; EMPA WDS spot analyses were taken from the core of the crystals to limit contamination from surrounding glass. The composition and peaks in the Raman spectrum are consistent with pyroxene as the main mineral to have crystallized in the shock vein, with a composition ($\text{En}_{46.8-52.5}\text{Fs}_{28.5-38.4}\text{Wo}_{19.8-29.4}$, $\text{FeO/MnO} = 29\text{--}34$, $\text{mg\# } 63\text{--}70$) distinct from that of host rock pyroxene. Low cations totals ($= 3.887\text{--}3.924$ atoms per formula unit), calculated from WDS spot analyses based on 6-oxygen, suggest that these pyroxenes contain vacancies. The Raman spectrum is characterized by peaks at 667 cm^{-1} and 1010 cm^{-1} . Portions of the shock vein matrix contain schlieren of anorthite composition. Peaks in the Raman spectrum acquired from these schlieren at 365 cm^{-1} , 565 cm^{-1} , 642 cm^{-1} and 916 cm^{-1} and composition are consistent with Ca-rich garnet.

Conclusion. This study documents shock deformation in host rock pyroxene and plagioclase (mosaicism / fracturing), as well as localized shock effects including the formation shock melt pockets, shock veins and plagioclase amorphization, in noritic diogenite NWA 10268. Crystalline plagioclase and maskelynite formation in NWA 10268 constrain the minimum shock pressure to have been $\sim 22\text{ GPa}$ but less than 25 GPa [9]. This shock pressure range agrees with pressures constrained by mosaicism in orthopyroxene [10]. Shock veins are associated with solid state transformation of plagioclase to maskelynite and tissantite, apatite to tuite and silica to stishovite. Vacancy-rich pyroxene and garnet have crystallized from shock melt. Accessory phases apatite and zircon may be targeted by future studies aimed at unraveling the timing of igneous crystallization and impact metamorphism of constituent minerals. The abundance of $\geq 100\text{ }\mu\text{m}$ size apatite grains in NWA 10268 ($\sim 1\text{ vol\%}$) and the observation of polycrystalline apatite associated with quenched products of shock melting make this mineral a particularly attractive phase for geochronology. Targeting polycrystalline grains associated with shock melt would petrographically tie resultant ages to an impact event.

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