**Petrologic Characterization and U-Th-Pb Chronology of Ca-Phosphate in Noritic Diogenite Northwest Africa 10666.** C. Martinez¹, T. J. Lapen⁴, M. Righter¹, A.J. Irving²

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**Introduction:** Howardites, eucrites, and diogenites (HEDs) are a clan of meteorites believed to be derived from asteroid 4 Vesta located in the asteroid belt between Mars and Jupiter [1]. The HED clan make up the largest suite of achondrite meteorites available for study from any solar system body, excluding the Moon [2]. Being so abundant, they provide clues of early planetary processes [2]. Based on petrologic and chronologic analyses, the HED parent body underwent accretion and differentiation very early in solar system history (4563-4565 Ma) [e.g. 3-5], experienced igneous activity for perhaps its first 50 Ma [e.g. 6], and was subjected to significant impacts, perhaps culminating between 4.1 and 3.3 Ga [e.g., 7-8]. Nearly all HED meteorites show signs of thermal and/or impact metamorphism.

Diogenites are coarse-grained, ultramafic igneous rocks characterized as orthopyroxene-rich with smaller, but variable abundances of clinopyroxene, plagioclase, chromite, and olivine [9-10]. Many diogenites are cataclastic although some samples such as (Dhofar 700) are poorly crushed. These stones are important because they serve as records of lower crustal processes in the parent body [11]. Constraints on the temperature-time histories of lower-crustal materials have been difficult to constrain due to limited chronologic options for these typically mineralogically simple meteorites in addition to thermal equilibration/metamorphism.

NWA 10666 is one among a series of noritic and feldspathic diogenites and the first reported zircon-bearing diogenite [Fig. 1; 9-10; 12]. The meteorite also contains Cl-apatite, making this specimen well suited for combined chronologic and petrologic investigations. Here, we present new Fe-Mg exchange and REE thermometry and U-Th-Pb chronology of apatite to better constrain its temperature-time history.

**Methods:** A ~2mm thick polished section was prepared and imaged by FE-SEM followed by electron probe microanalyses at NASA-JSC to determine major element concentrations of pyroxene, plagioclase, phosphate, and oxide phases within NWA 10666. E-beam conditions were 15 kV 30 nA for pyroxenes and oxides, while plagioclase was analyzed at 15kV 20 nA.

In situ trace element analysis and U-Th-Pb dating were conducted by laser ablation ICP-MS at the University of Houston (UH) using a Varian 810 quadrupole ICPMS coupled with a Photon Machines Exite excimer laser ablation system following methods outlined by [13-14]. The laser ablation was performed using a 25 µm laser spot diameter. A 8-10 Hz repetition rate over 20-30s, a fluence of 3-11 J/cm², and a He carrier gas flow rate of 0.5 L/min was used during the analyses. The U-Pb dating of Ca-phosphates used the Bear Lake apatite and Yates Mine as standards. Instrumental mass fractionation of Pb isotopes were corrected with NIST 612 glass. Whole rock analysis of cutting dust made from thin section preparation was analyzed by QQQ-ICPMS at UH.

**Results:** NWA 10666 is composed of ~70-75% orthopyroxene that are 1-3 mm in the long dimensions (Fs34.9-35.0Wo1.9-2.1), ~5-8% clinopyroxene that are <0.1-0.3 mm (Fs14.8-14.9Wo42.-43.3), 15-20% calcic plagioclase that are 0.5-1 mm (An 80.5-89.8Or0.3-0.7), < 1% silica, chromite, and ilmenite, and accessory apatite and zircon that are <0.1 mm. Coexisting pyroxene compositions are transitional between diogenites and cumulate eucrites (Fig. 2). Chondrite-normalized REE data (Fig. 3) of the whole rock is relatively flat averaging 3.5*chondrite with an Eu/Eu* = 1.2. Two-pyroxene thermometry yielded 850°C [15] and REE in CPX and plag thermometry yielded 1262 ± 4°C [16]. U-Th-Pb analyses of four apatite grains yielded an inverse Pb-Pb isochron age of 4198 ± 17 Ma (2σ; Fig. 4).


**Figure 3.** REE concentrations. Red: OPX, Blue: plag, Green: CPX, Black: whole rock. Open circle: max value

**Figure 4.** Pb-Pb inverse isochron diagram for apatite. Black line = best fit line between radiogenic and common Pb, blue curves = 2σ error envelope for the best-fit mixing line, red ellipses = measured data.

**Discussion:** NWA 10666 contains minerals that are uncommon in diogenites, including ilmenite, silica, and zircon. The presence of ilmenite, silica, and ferroan pyroxene compositions are most similar to Yamato type-B diogenites [e.g. 17], which may represent compositions transitional between ‘normal’ diogenites and cumulate eucrites [11], the noritic diogenites. REE contents of NWA 10666 are nearly identical to those of Yamato type-B and QUE 93009, except it has a positive Eu anomaly. Thus, this meteorite represents another member of a group of enriched or transitional diogenites, this specimen perhaps being one of the most incompatible element enriched.

The REE equilibration temperature based on partitioning between CPX and plagioclase is 1260°C and equilibration temperature of Fe-Mg between OPX and CPX is 850°C. The minerals are equilibrated and the rock likely experienced a protracted thermal history. Insights into the high-temperature history is in progress with the analysis of U-Pb in zircon chronology and Ti in zircon thermometry.

The lower-temperature thermal history (~550°C based on Pb closure in apatite [18]) is constrained by the U-Pb chronology of apatite. An inverse Pb-Pb isochron yielded an age of 4198 ± 17. Figure 4 shows that there is one analysis with measureable common Pb (206Pb/204Pb = 0.0021), if excluded, the three data yield a U-Pb concordia intercept date of 4159 ± 83 Ma and there is no evidence for partial Pb loss. The Th-Pb data yield a weighted average age of 4145 ± 75 Ma. All dates are identical within uncertainty. The chronology indicates a significant heating event at 4200 Ma, a date that falls outside most measurements with low-temperature chronometers such as Ar-Ar. Most Ar-Ar data of HEDs range between 3.3 and 3.8 Ga and cluster at their igneous ages (4.55 Ga) and perhaps a major parent body metamorphic event at 4.5 Ga [19,20]. It is unlikely that the parent body remained above the closure temperature of Pb in apatite for 300 m.y. after formation; the apatite age most likely reflects a thermal metamorphic event associated with impacts. Dates between 4.1 and 4.4 Ga are more common in higher-temperature systems than Ar-Ar (e.g. Pb-Pb [21], U-Pb in zircon EET 90020 [22], Lu-Hf and Sm-Nd Jonzac [23]) and may indicate that the Ar-Ar age cluster between 3.3-3.8 may reflect waning impact intensity.

**References:**