

NORTHWEST AFRICA 6698: DIORITIC PARTIAL MELT OF THE UREILITE PARENT BODY. Z. Vaci¹, K. Ziegler¹, S. Yang², M. Humayun², and C. B. Agee¹, ¹Institute of Meteoritics, University of New Mexico, Albuquerque, NM, USA (zmoney@unm.edu), ²National High Magnetic Field Laboratory and Dept. of Earth, Ocean & Atmospheric Science, Florida State University, Tallahassee, FL 32310, USA.

Introduction: The ureilites are thought to represent residues of partial melting that segregated Fe-Ni-S and low-degree silicate melts from a chondritic protolith [1,2]. While the basaltic components of anatexis have been identified as feldspar-rich clasts within polymict ureilites [3], only a single evolved melt, the trachyandesite ALM-A, from the 2008 Almahata Sitta fall, has been discovered [4]. We report here new triple oxygen isotopic analyses and revisit mineralogical, petrological, and major and trace element geochemical data for the diorite Northwest Africa 6698, which was previously classified with ordinary chondrites [5,6]. The new data suggest that NWA 6698 is the second evolved igneous rock associated with the partial melting of the ureilite parent body (UPB).

Oxygen Isotopes: Figure 1 shows our results for laser fluorination of seven acid-washed bulk fragments with values of $\delta^{18}\text{O} = 7.527, 7.671, 7.989, 7.657, 7.937, 8.113, 8.135$; $\delta^{17}\text{O} = 2.954, 3.008, 3.191, 3.037, 3.143, 3.267, 3.270$; $\Delta^{17}\text{O} = -1.020, -1.042, -1.027, -1.005, -1.048, -1.017, -1.026$ (linearized, all per mil, TFL slope = 0.528); weighted average $\delta^{18}\text{O} = 7.929$; $\delta^{17}\text{O} = 3.161$; $\Delta^{17}\text{O} = -1.026$. These values plot in the field of the ureilites and overlap with the carbonaceous chondrite anhydrous mineral (CCAM) line, indicating that the original values, which plotted with the ordinary chondrites [5], were erroneous.

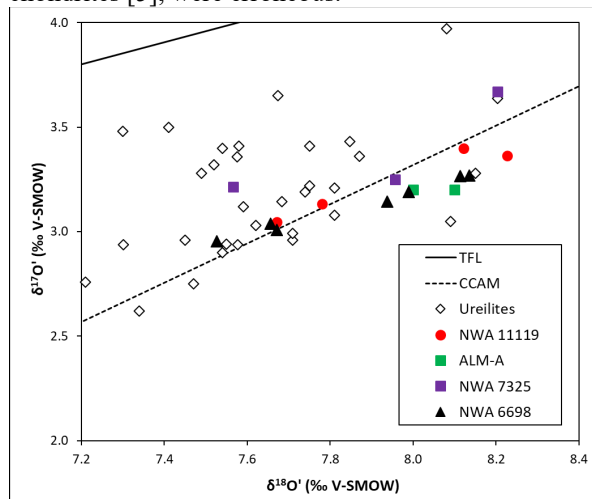


Figure 1: Triple-oxygen isotope diagram showing NWA 6698, ureilites [7], and other achondrites [4,8,9].

The oxygen isotopic measurements of NWA 6698 form a line with a slope of 0.52 ($R^2 = 0.99$), suggesting that the spread in values is due to igneous fractionation

between its minerals. The values overlap with those of the trachyandesite ALM-A, which is associated with the ureilite parent body because it was found among the 2008 Almahata Sitta ureilitic meteorites. Other achondrites that plot in this area of the triple oxygen diagram include the olivine gabbro NWA 7325 and the andesite NWA 11119, both of which are sourced from differentiated parent bodies with evolved crusts.

Mineralogy and Petrology: NWA 6698 is composed of oligoclase to labradorite plagioclase (61 wt%), pigeonite (18 wt%), augite (11 wt%), interstitial microlitic glass (6 wt%), phosphates including apatite and merrillite (2 wt%) a Cr- and Ti-rich spinel (1 wt%), sulfides (1 wt%), and trace FeNi metal grains associated with sulfides. The rock is poikilitic, with large >1 mm feldspars enclosing 0.1-1 mm pyroxenes. The average grain size appears somewhat larger than in ALM-A, and while it compositionally overlaps this meteorite as a trachyandesite, its cumulate textures (Fig. 2) suggest that it is a diorite.

The major phase compositions of NWA 6698 overlap those of ALM-A, with the latter showing more variation in feldspar composition (Fig. 3). The two meteorites also share a quartz-normative interstitial microlitic glass component, of which the ALM-A glass is higher in SiO_2 by ~5 wt.%.

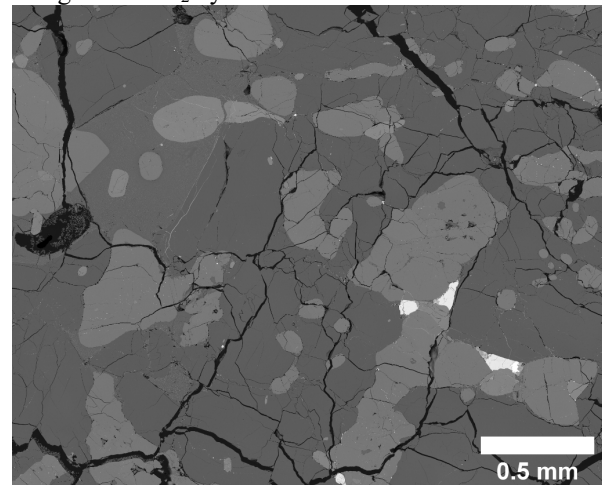


Figure 2: Backscattered electron (BSE) image of NWA 6698 showing, in ascending brightness, plagioclase, glass, pyroxene, phosphate, Fe-sulfide, and FeNi metal.

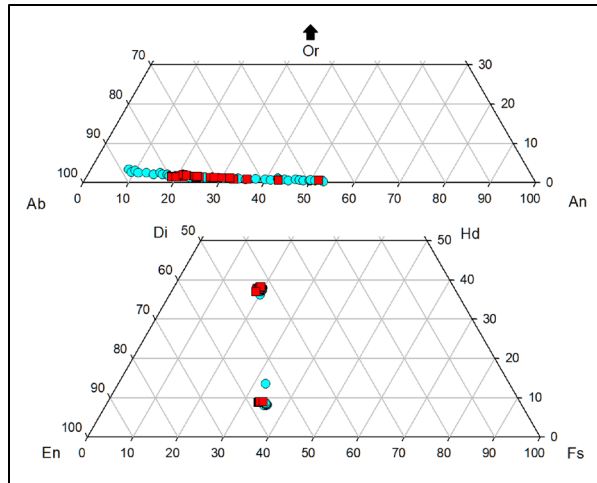


Figure 3: Feldspar (top) and pyroxene (bottom) ternary diagrams showing NWA 6698 (red squares) and ALM-A (blue circles) [4].

Trace Element Geochemistry: The trace element abundances in NWA 6698 are typical for a plagioclase cumulate, showing elevations in Sr and Eu relative to CI chondrites. The bulk rare earth element (REE) composition is close to chondritic except for Eu, with a slight elevation in HREE relative to LREE (Fig. 4). The glass in NWA 6698 is elevated in REE relative to the bulk rock. Although it plots closer to the bulk REE composition of ALM-A, it shows a similar positive slope, suggesting that it is a residual liquid that has lost LREE relative to HREE.

Additional trace element abundances in NWA 6698 broadly follow those of ALM-A, with the exceptions of elements affected by terrestrial weathering and the high-field strength elements (HFSE) (Fig. 5). NWA 6698 shows enrichments in Ba and U that are likely the result of addition from weathering, resulting in an anomalous Th/U value of 0.96. In terms of HFSE, bulk NWA 6698 is slightly elevated above chondritic values, while its residual glass is more enriched than bulk ALM-A.

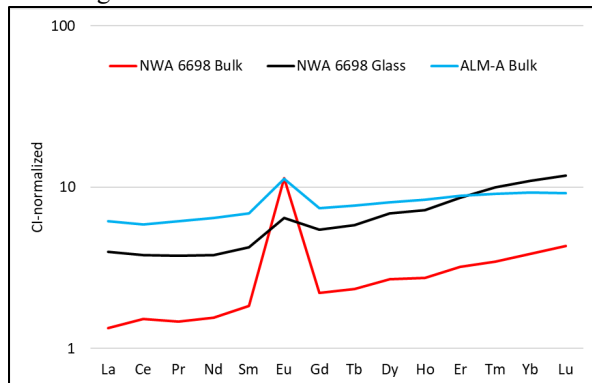


Figure 4: REE compositions for NWA 6698 and ALM-A [4], normalized to CI chondrites.

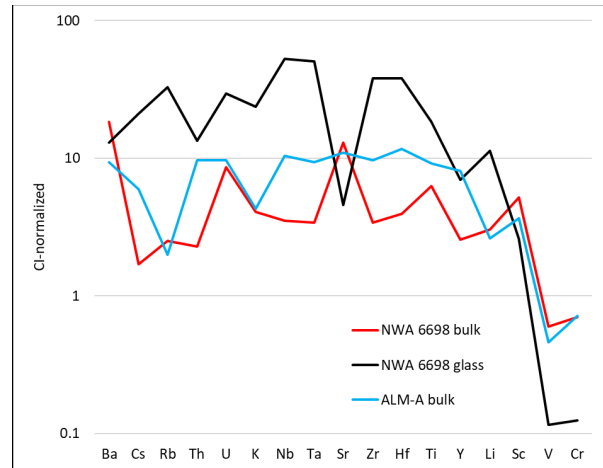


Figure 5: Selected trace element compositions for NWA 6698 and ALM-A [4], normalized to CI chondrites.

Petrogenesis: The trachyandesite ALM-A was suggested to have formed through low degrees of melting of the UPB and subsequent extrusive volcanism [4]. NWA 6698 likely represents a cumulate formed through the same process. Because the degree of melting on the ureilite parent body was low [9], the melts were elevated in alkalis and incompatible elements relative to other crustal solar system material such as eucrites. The high silica content in NWA 6698 might also reflect the reduction of FeO by smelting reactions on the ureilite parent body [10]. Within the fractionating magma chambers formed by these evolved melts, NWA 6698 was a cumulate, while ALM-A was a more rapidly crystallized lava. This relationship is reflected in the major phase chemistry, as plagioclase compositions are overlapping but more albitic in ALM-A. As pyroxenes were likely the liquidus phases in both rocks, their compositions are identical. Incompatible element abundances in NWA 6698 are in general depleted relative to those of ALM-A, while the residual microlitic glass in NWA 6698 is likely representative of the liquid that ALM-A crystallized from.

References: [1] Warren P. H. et al. (2006) *GCA* 70 2104-2126. [2] Goodrich C. A. et al. (2007) *GCA* 71 2876-2895. [3] Kita N. T. et al. (2004) *GCA* 68:20 4213-1235. [4] Bischoff A. et al. (2014) *PNAS* 111:35 12689-12692. [5] Bunch T. E. et al. (2011) *MetSoc* 74, #5224. [6] Vaci Z. et al. (2020) *LPSC* 51, #1697. [7] Greenwood R. C. et al. (2017) *Chemie der Erde* 77 1-43. [8] Irving A. J. et al. (2013) *LPSC* 44, #2164. [9] Srinivasan P. et al. (2018) *Nat. Comm.* 9:3036. [10] Collinet M. and Grove T. L. (2020) *MaPS* 55:4 832-856. [10] Singletary S. J. and Grove T. L. (2003) *MaPS* 38:1, 95-108.