

FORMATION AND EMPLACEMENT OF THE NORTHWEST AFRICA 13669 NAKHLITE

S. Ramsey¹, A. Udry¹, J. M. D. Day², and A. Ostwald¹. ¹Department of Geoscience, University of Nevada, Las Vegas, Las Vegas NV, USA; ramses3@unlv.nevada.edu, ²Scripps Institution of Oceanography, La Jolla, CA, USA.

Introduction: Nakhilites make up ~8% of the total number of martian meteorites and are cumulate clinopyroxene-rich rocks from Mars linked by shared crystallization ages (1340 ± 40 Ma) and cosmic ray exposure ages (11 ± 1.5 Ma) [1–2]. These shared properties make the 26 known nakhilites the largest suite of igneous rocks from a common provenance on any planetary body besides the Moon and Earth. As such, nakhilites are important for understanding relatively recent magmatic and volcanic processes on Mars. Northwest Africa (NWA) 13669 is a recently-found nakhilite. Here we present major, minor, and trace element bulk rock and mineral analyses in addition to quantitative textural analyses to assess the formation and emplacement of NWA 13669 and its relation to other nakhilites.

Methods: Bulk rock major and trace elements were conducted at Scripps Institution of Oceanography using an ICP-MS following the sample preparation and analytical methodology described in [3]. Mineral major element analyses were performed *in situ* using a JEOL JXA-8900 electron probe microanalyzer housed at the University of Nevada, Las Vegas (UNLV) following the method described in [2]. Mineral trace element analyses were conducted *in situ* using an NWR 139 laser ablation system coupled to an ICP-MS at UNLV. The laser was operated at 15 Hz and a fluence of ~3 J/s was maintained with an ablation time of 40 s and 10 s washout times. Spot size ranged from 50–100 μm depending on the size of the mineral of interest. Standardization was done using NIST 610 glass and BHVO-2, and data was reduced using *iolite4* [4]. Crystal size distributions (CSD) were performed following the technique outlined in [5].

Results: Northwest Africa 13669 displays a cumulate texture of elongate euhedral to subhedral augite and cumulus olivine with intercumulus plagioclase and glass. Minor phases include Fe-Ti oxides, apatite, and pyrrhotite. Average modal abundances between both sections analyzed in this study are 63% augite, 16% olivine, 10% plagioclase, 8% glass, and 3% Fe-Ti oxide. Crystal size distribution profiles for both sections of NWA 13669 display a negative concave-up sublinear shape and are broadly similar to other nakhilite CSD [2, 6, 7].

The bulk rock Mg# of NWA 13669 is 38.1, lower than most reported nakhilites (Mg# = 35.6–50.8) [2, 6, 8]. Calcium in NWA 13669 is among the lowest (11 wt.%) reported for nakhilites, and FeO (25.6 wt.%) and MnO (0.65 wt.%) are the highest. The CI-chondrite normalized rare earth element (REE) pattern for NWA 13669 has a light REE (LREE) enrichment with a $(\text{La/Lu})_{\text{CI}}$ of 3.7 and depletion in the heavy REE (HREE), characteristics shared by the nakhilites. Pyroxene in NWA 13669 is augite and normally-zoned from Mg and Ca-rich cores ($\text{En}_{36}\text{Fs}_{25}\text{Wo}_{39}$) to Fe-rich rims ($\text{En}_{31}\text{Fs}_{32}\text{Wo}_{37}$). Rare earth element (REE) profiles in NWA 13669 augite cores are relatively flat with a slight negative Eu anomaly ($\text{Eu}/\text{Eu}^* = 0.75$). Olivine compositions are homogeneous ($\text{Fo}_{28.8}$) with only minor intra-grain variations from core to rim. Plagioclase in NWA 13669 is albite-rich ($\text{An}_{37}\text{Ab}_{60}\text{Or}_3$) with limited major-element variations, and intercumulus glass is alkali- and REE-rich with microlitic inclusions ($> 1\mu\text{m}$) of pyroxene, Fe-Ti oxides, and apatite. Apatite is F-rich (> 3 wt.%) and the dominate REE carrier.

Discussion: Pyroxene modal abundance in NWA 13669 is similar to NWA 817 (63%) and NWA 10645 (62%), though the occurrence of both plagioclase and glass in the intercumulus material is most similar to Caleta el Cobre (CeC) 022. The augite CSD profiles for NWA 13669 are also similar to NWA 10645 and the Yamato pairing group, suggesting similar emplacement conditions and supports the findings of [2] that nakhilites originate from multiple flows, dikes, or sills on Mars. The bulk rock and mineral REE patterns in NWA 13669 are similar to those observed for other nakhilites, indicating NWA 13669 crystallized from a parental melt derived from the same geochemically depleted source reservoir, then underwent subsequent modification by Cl and LREE-rich fluids [9]. Major element augite compositions display a Ca-depletion from core to rim, consistent with a single batch of melt. Overlap between pyroxene core and rim analyses in tandem with unzoned olivine, which has also been reported in NWA 998, Lafayette, and CeC 022, could be evidence for reequilibration and long-term magma storage for nakhilites [10].

Overall similarities in texture, modal abundances, and CSDs suggest NWA 13669 was emplaced under similar conditions to NWA 10645. However, the distinct bulk rock and mineral chemistry from previously reported nakhilites could indicate NWA 13669 is a previously unsampled flow, dike, or sill. Continued work using melt inclusion analyses is underway to further establish the relationship between NWA 13669 and previously studied nakhilites and to potentially determine the parental melt composition.

References: [1] Udry et al. (2020) *Journal of Geophysical Research: Planets* 125, 1–34. [2] Udry, A., and Day, J. M. D. (2018) *Geochimica et Cosmochimica Acta* 238, 292–315. [3] Day et al. (2017) *Geochimica et Cosmochimica Acta* 198, 379–395. [4] Paton et al. (2011) *Journal of Analytical Atomic Spectrometry* 26, 2508–2518. [5] Rahib et al. (2019) *Geochimica et Cosmochimica Acta* 266, 463–496. [6] Krämer Ruggiu et al. (2020) *Meteoritics & Planetary Science* 55, 1539–1563. [7] Balta et al. (2017) *Meteoritics & Planetary Science* 52, 36–59. [8] Jambon et al. (2016) *Geochimica et Cosmochimica Acta* 190, 191–212. [9] McCubbin et al. (2013) *Meteoritics & Planetary Science* 48, 819–853. [10] Ostwald et al. (2022) *LPSC LIII* Abstract #1206.