MAJOR AND TRACE ELEMENT BULK ROCK AND MINERAL CHEMISTRY OF NORTHWEST AFRICA 13669, A NEW NAKHLITE. S. Ramsey[1*], A. Udry[1], J. M. D. Day[2], A. Ostwald[1]. [1]Department of Geoscience, University of Nevada, Las Vegas, Las Vegas NV, USA; *ramses3@unlv.nevada.edu. [2]Scripps Institution of Oceanography, La Jolla, CA, USA.

Introduction: Martian meteorites are the only samples we possess from Mars, making their study critical to understanding the evolution of magmatic and volcanic processes on the red planet. Nakhlites make up ~8% of the total number of martian meteorites and are cumulate clinopyroxenite-rich rocks 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 nakhlites the largest coherent suite of igneous rocks from a common provenance on any planetary body besides the Moon and Earth. As such, nakhlites are vital to understanding relatively recent magmatic and volcanic processes on Mars, and each new nakhlite can potentially provide valuable insights into the formation and emplacement of the nakhlite suite. Northwest Africa (NWA) 13669 is a recently found nakhlite. Here we present the first detailed major, minor, and trace element mineral analyses in addition to bulk rock major and trace element chemistry for NWA 13669.

Methods: Bulk rock major and trace elements were conducted at Scripps Institute of Oceanography using an iCAP Qc quadrupole 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 (EPMA) housed at the University of Nevada, Las Vegas (UNLV). The EPMA analyses followed the method described in [2]. *In situ* mineral trace element analyses were conducted using a NWR 139 laser ablation system coupled to an iCAP Qc quadrupole ICP-MS at UNLV. The laser was operated at 15 Hz and a photon fluence of ~3 J/s was maintained throughout analyses. Spot size ranged from 50–100 µm depending on the size of the mineral of interest. An ablation time of 40 s was used with 20 s warmup and 10 s washout times. Standardization was done using the NIST 610 glass and BHVO-2 and LA-ICP-MS data was reduced using *iolite4* [6].

Results: Two sections of NWA 13669 display a cumulate texture with elongate euhedral to subhedral augite, with some crystals >4 mm in length, and cumulus olivine. Average modal abundances between both sections include 66% pyroxene, 14% olivine, and 20% mesostasis (Fig. 1). Plagioclase and glass are intercumulus phases and titanomagnetite occurs both as large and small interstitial crystals within NWA 13669. Minor phases include apatite and pyrrhotite.

Bulk rock chemistry: Northwest Africa 13669 has a bulk rock Mg# of 38.1, which is lower than most reported nakhlites (Mg# = 35.6–50.8) [2]. Compared to other nakhlites, CaO in NWA 13669 is low (11 wt%), and FeO (25.6 wt%) and MnO (0.65 wt%) content are at higher abundances. The CI-chondrite normalized rare earth element (REE) pattern for NWA 13669 has a light REE (LREE) enrichment with a $(La/Lu)_{CI}$ of 3.7, and a depletion in heavy REE (HREE), characteristics shared by the nakhlites (Fig. 2). CI-normalized incompatible trace elements for NWA 13669 show positive Ba and negative Pb, Zr and Hf anomalies.

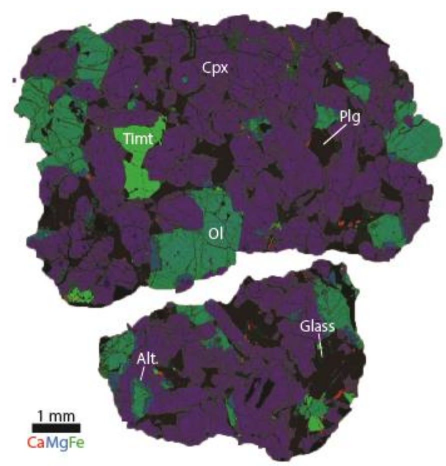

Figure 1. Elemental X-ray map of NWA 13669-A. Red = Ca, blue = Mg, and green = Fe.

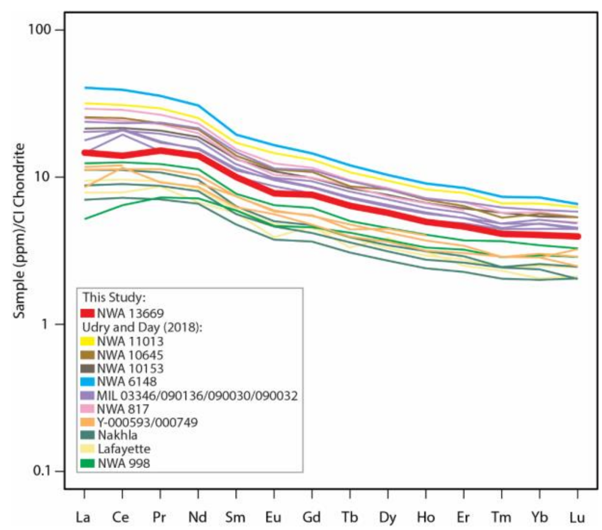

Figure 2. CI-chondrite normalized rare earth element diagram for bulk rock of NWA 13669 and previously reported nakhlites [2]. Normalization from McDonough and Sun [5].

Mineral chemistry: Pyroxene in NWA 13669 is augite and normally-zoned from Mg and Ca-rich cores ($En_{36}Fs_{25}Wo_{39}$) to Fe-rich rims ($En_{31}Fs_{32}Wo_{37}$) and Ti, Al, and Mn anticorrelate with Mg# (Fig. 3). Average pyroxene Ti/Al ratios for both core and rim analyses are 0.14. Pyroxene core REE profiles in NWA 13669 are relatively flat and do not show substantial variation between grains. Olivine is Fe-rich (Fig. 3) and homogeneous with an average Fo content of 28.8. The most Mg-rich olivine (Fo_{40}) in the two sections of NWA 13669 occurs as an inclusion in pyroxene. Plagioclase in NWA 13669 display limited major-element variations with an average composition of $An_{37}Ab_{60}Or_3$. Glassy intercumulus material is K-rich. Apatite is F-rich (>3 wt%) and the main REE carrier in NWA 13669. Titanomagnetite compositions are consistent with previous studies [2].

Discussion: The texture of NWA 13669, with cumulus pyroxene and olivine set in a plagioclase and glass mesostasis, is indicative of a two-stage cooling history, where cumulate phases crystallized slowly at depth before erupting at or near the surface. Texturally, NWA 13669 bears a strong resemblance to Lafayette and Governador Valadares [2]. Northwest Africa 13669 is more mesostasis-rich, with abundances comparable to the Miller Range nakhlites. Despite textural similarities, NWA 13669 is distinct from previous nakhlites based on major element bulk rock and mineral chemistry.

The major bulk rock chemistry of NWA 13669 is unique among the nakhlites with its lower Mg#, CaO and alkalis and higher FeO content. Northwest Africa 6148 has a similarly low Mg # (35.6) and CaO content but is more alkali-rich than NWA 13669. The REE profile of NWA 13669 and Ba, Pb, Zr, and Hf anomalies are consistent with previous studies [2, 7], where nakhlites are sourced from low degree partial melts of depleted mantle but have undergone subsequent modification by Cl and LREE-rich fluids to produce the LREE enrichment observed in NWA 13669. The REE profile of NWA 13669 falls between two proposed nakhlite groupings (i.e., low and high trace element) by Udry and Day [2] (Fig. 2), which also coincide with grouping based on mesostasis and apatite [7–8], making NWA 13669 a potential link between these nakhlite groups.

Pyroxene rims in NWA 13669 are not as Fe-rich compared to other nakhlites (Fig. 3) and display a Ca-depletion from core to rim, which is the expected trend for a single batch of melt. Similar to NWA 13669, unzoned olivine has been reported in NWA 998, Lafayette, and Caleta el Cobre (CeC) 022 [2, 4] and is associated with slower cooling times.

Further work using quantitative textural analyses (i.e., crystal size distribution and spatial pattern distributions) and melt inclusion compositions to constrain its emplacement and determine the parental melt composition of NWA 13669, respectively, is warranted and will be carried out to fully assess the formation and emplacement of this new nakhlite and its relation to previously studied nakhlites.

References: [1] Udry et al. (2020) *JGR: Planets*, 125, 1-34. [2] Udry, A., and Day, J. M. D. (2018) *GCA*, 238, 292–315. [3] Day et al. (2017) *GCA* 198, 379–395. [4] Krämer Ruggiu et al. (2020) *Met. Planet Sci.* 55, 1539–1563. [5] McDonough and Sun (1995) *Chem. Geo*. 120, 223–253. [6] Paton et al. (2011) *J. An. Atomic Spec*. 26, 2508–2518. [7] McCubbin et al. (2013) *Met. Planet Sci.* 48, 819–853. [8] Corrigan et al. (2015) *Met. Planet Sci.* 50, 1497–1511. [9] Sautter et al. (2002) *EPSL*, 195, 223–238. [10] Mikouchi et al. (2003) *Ant. Met.* Res. 16, 34–57. [11] Day et al. (2006) *Met. Planet Sci*. 41, 581–606. [12] Imae and Ikeda (2007) *Met. Planet Sci*. 42, 171–184. [13] Treiman and Irving (2008) *Met. Planet Sci*. 43, 829–854. [14] Jambon et al. (2016) *GCA* 190, 191–212. [15] Balta et al. (2017) *Met. Planet Sci*. 52, 36–59.

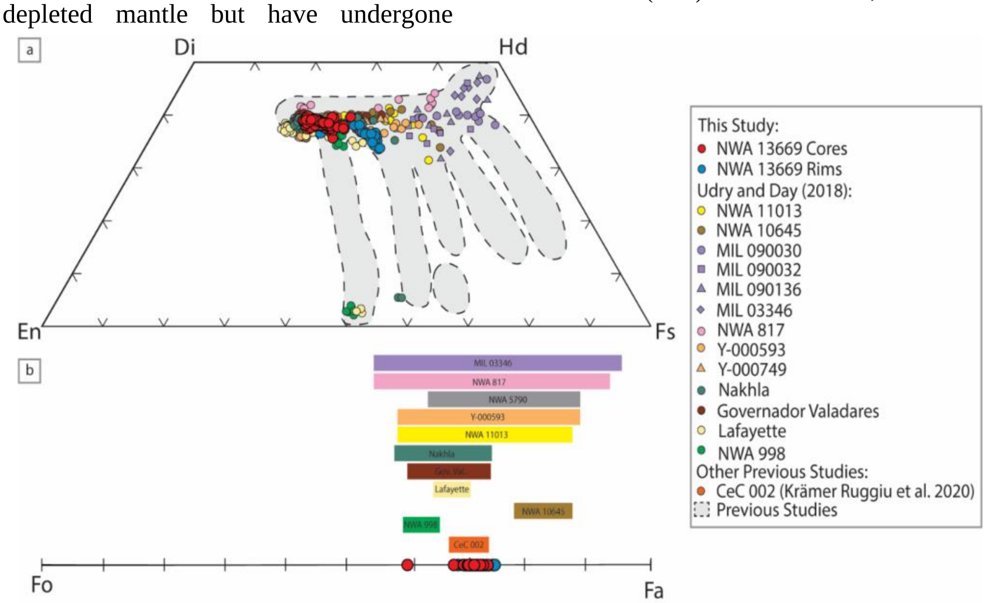

Figure 3. a) Pyroxene quadrilateral with core and rim analyses from NWA 13669 compared to previously reported nakhlites [2, 4]. Shaded grey envelopes represent analyses from [9–15]. b) Olivine core and rim compositions in NWA 13669 in comparison to other nakhlites [2, 4; 9–15].