A NEW LUNAR OLIVINE GABBRO METEORITE: NORTHWEST AFRICA 6177. Q. He[1] , N. Zhang[1], and L. Xiao[1], [1] Planetary Science Institute, School of Earth Sciences, China University of Geosciences, Wuhan, 430074, China (He_qi@cug.edu.cn)

Introduction: NWA 6177 has been listed in the Meteoritical Bulletin Database as "Unknown". Our study shows this meteorite is a lunar olivine gabbro, similar as those of NWA773 clan (NWA 773, NWA 2977, NWA 6950 and so on) [e.g.,1-5]. To further understand the petrogenetic history of this meteorite and NWA 773 clan, we performed a series of in situ microprobe studies on this new sample.

Petrography and mineral chemistry: NWA 6177 is mainly composed of olivine and pyroxene with minor plagioclase (Fig. 1). Olivine grains form a cumulate texture. Pyroxene are mainly anhedral in shape with a few occurs as lath-like crystals. Plagioclase occurs as irregular interstitial crystals between olivine and pyroxene. Accessory minerals include chromite, ilmenite, phosphate, baddeleyite, K-feldspar, troilite, and Fe-Ni metal. We visualized and processed X-ray map data and BSE images, using ImageJ software. Mineral abundances determined by thresholding yielded 34.1mod % olivine, 31.8 mod % pigeonite, 11.4 mod % augite, 14.6 mod % plagioclase, 3.7 mod % K-feldspar, 1.1 mod % phosphates and 3.2 mod % Troilite. This sample has less olivine than NWA 2977 [2] and olivine-gabbro clasts in NWA 773 [6]. The apparent difference may reflects the heterogeneous distribution of its constituent minerals.

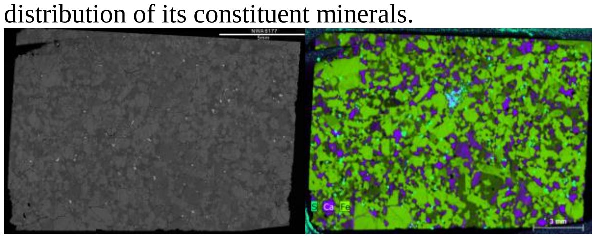

Fig. 1 Backscattered electron (BSE) image and combined elemental X-ray maps of NWA 6177. Left, BSE image of think section. The light grey is Ol, dark grey is Px, black gray is Pl, white is trolite or oxides. Right, Yellow green is Ol, dark green is Pgn, light purple is Pl, dark purple is Aug and blue is troilite.

The ratio of Fe/Mn in mafic minerals is indicative of planetary reservoirs. The Fe/Mn ratios of pyroxene and olivine in NWA 6177 plot close to previously determined lunar meteorite trend lines [7-8]. Plagioclase in NWA 6177 is calcic (An85-94, where An# = Ca/[Ca+Na+K]) that is also comparable with sampled lunar rocks and lunar meteorites [7-8].

Trace Element geochemistry: Olivine REE (Rare Earth Element) concentrations are generally low and their CI chondrite-normalized patterns are enriched in HREE, similar as observed in NWA 2977 olivines (Fig. 2a). Two analyses show anomalous LREE enrichment, which may be attributed to terrestrial contamination. Sr and Ba are expected to be extremely low concentrations in olivine when suffer limited contamination. The Sr and Ba concentrations in one olivine analysis (t-2) are 8.68 and 2.80 ppm, respectively. This analysis show LREE depleted pattern and lowest REE budget suggests low terrestrial weathering (Fig. 2a).

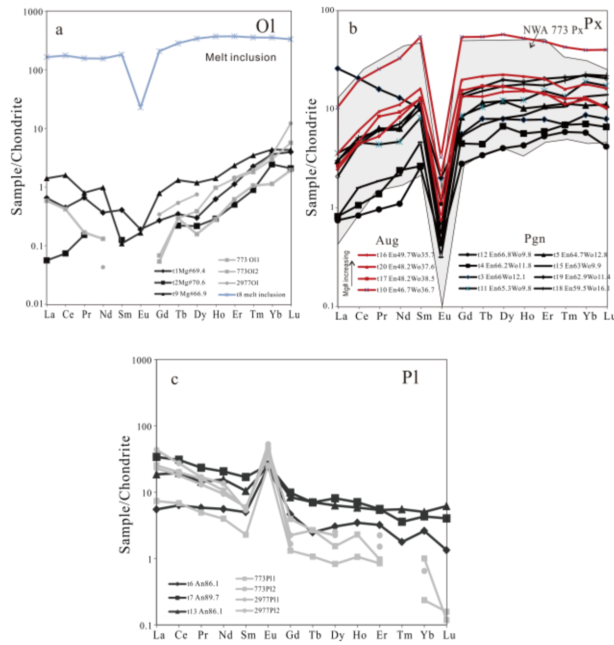

Fig.2 CI chondrite-normalized REE patterns of minerals and Si, Al -rich melt inclusions in NWA 6177. The gray lines shown in *a* and *c* are olivine and plagioclase in NWA 2977 and NWA 773 from [2] and [6]. Grey area in b is from [6].

Pyroxene in NWA 6177 shows a large variation in REE concentrations (Fig. 2b). Their REE concentrations vary according to their Mg# and Wo contents, with concentrations higher in augite than in pigeonite, in general. The augite and pigeonite with the highest Mg# always related to the lowest REE concentrations. All pyroxenes have HREE-enriched patterns and remarkable negative Eu anomalies. Augite shows increasing LREE from La to Sm, but slightly decreasing HREE concentrations. For pigeonite, the CI chondrite-normalized REE abundances generally increase gradually from La to Lu. t3 has a LREE enriched pattern which should be attribute to terrestrial contamination. All pyroxenes are well within NWA 773 pyroxene field [6].

Plagioclase has LREE-enriched patterns with positive Eu anomalies (Fig. 2c). Plagioclase do not show steeply decreasing slope from La to Lu like that observed in NWA 2977 with higher HREE [2].

The olivine-hosted Si, Al-rich melt inclusions show almost flat LREE and HREE patterns; however, HREE concentrations are slightly higher than LREE (Fig. 2a). This is in agreement with previous melt inclusion investigations on NWA 2977 [2].

Shock Metamorphism: The fragment of NWA 6177 is characterized by Planar fractures (PFs, Fig. 3a), a shock melt pocket and several melt veins (Fig. 3b). The ubiquity of PFs are observed within olivine grains (Fig. 3a). The melt veins are mostly crystallized (even at the nm scale) and are made up of silicate clasts (mostly of olivine, pyroxene and plagioclase stoichiometry), chromite, and sulfides grains. Within some thin veins, a few phosphate grains would transformed to be a high-pressure polymorph, Tuite. The contacting zone of host olivine has been partially transformed into its high-pressure polymorph, ringwoodite (Fig. 3b).

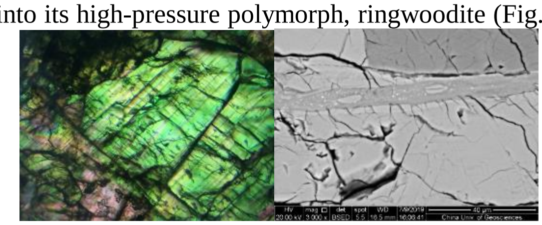

Fig. 3 left, The ubiquity of PFs are observed in olivines for NWA 6177. Right, BSE image of melt vein area. The main melt vein is ~10 μm wide. Within the melt vein, a partially converted olivine grain (the bright rim shows the Raman bands of ringwoodite whereas the partly enclosed dark area shows the Raman bands of olivine). Olivine adjacent to the melt veins has also been partially transformed into ringwoodite.

Discussion: Using REE partitioning coefficients appropriate for lunar magmas, we calculated the compositions of melts in equilibrium with various primary phases, assuming no REE redistribution after crystallization. We calculated trace element partition coefficients of pyroxene and plagioclase in NWA 6177 using the relevant major element compositions according to the methods of [9] and [10] at temperature T = 1200℃.

Equilibrium melts of augite core (t16) have the lowest REE budget with depleted LREE [$(La/Sm)_N$ =0.6] and flat HREE patterns [$(Gd/Lu)_N$ =1.2] (Fig. 4). However, the equilibrium liquid of pigeonite (t12) is LREE-rich and flat HREE patterns. The equilibrium liquid of plagioclase is also LREE-depleted and shows negative Eu anomaly. Equilibrium melts in augite has almost equal REE budget with NWA 773 whole rock OC, but different patterns, which is LREE-rich $(La/Sm)_N$ =1.6).

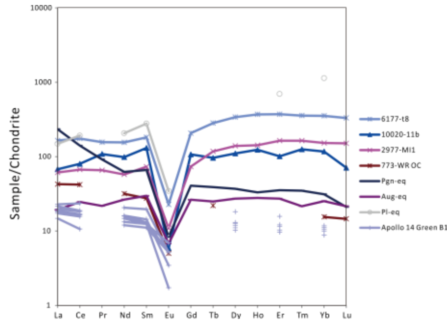

Fig. 4 the calculated REE patterns of melt that was in equilibrium with pyroxene and plagioclase in NWA 6177. The patterns of melt inclusions(6177-08 is from this study, 29977-MI1 is from [2] and 10020-11b is from [11]), NWA 773 whole rock (from [6]), and Apollo 14 Green B1 (from [12]) have also been shown for comparison.

The REE patterns of the melt inclusion (t8) is parallel to the REE patterns for the melt inclusions from NWA 2977 [2] with $(La/Sm)_N$ = 0.9, and 0.8, $(Gd/Lu)_N$ = 0.6 and 0.5, respectively, although melt inclusions from NWA 6177 have higher REE concentrations. Zhang et al. [2] explain that the Si, Al-rich melt inclusions represent a less-evolved melt parental to NWA 2977. If this is correct, the initial parental magma for olivine gabbro, should also slightly depleted in LREE, and elevated HREE or flat HREE feature. If the parent magma of NWA 6177 is similar to the equilibrium melts of augite core, then the parent magma is also parallel to the olivine-hosted melt inclusion 10020-11b [11], although the latter has higher REE budget. Both of them are LREE-depleted, with similar Sm/Yb (1.1 and 1.0, respectively) and La/Yb (0.8 and 1.1, respectively), indicating similar source or origin.

Conclusion: NWA 6177 is an olivine-gabbro lunar meteorite. Its trace element geochemistry is generally similar as NWA 773 clan, implying that it might be paired with NWA 773, or sourced from another region where there is similar rock type with NWA 773 on the Moon. Further works are undertaking to verify its origin and implication for lunar magmatism.

References: [1] Jolliff B. L. et al. (2007) *LPS XXXVIII*, Abstract #1489. [2] Zhang A. C. et al. (2011) *Meteoritics & Planet. Sci.*, 46:1929-1947. [3] Kuehner S. M. et al. (2012) *LPS XXXXIII*, Abstract #1519. [4] Shaulis B. J.et al. (2017),*GCA*, 213:435-456. [5] Valencia S. N.(2019) *Meteoritics & Planet. Sci.*, 54:2083-2115. [6] Jolliff B.L. et al. (2003) *GCA*, 67:4857-4879. [7] Papike J.J. et al. (1998) Reviews in Mineralogy, vol. 36:5-1–5-234.[8]Joy et al. (2014) *Meteoritics & Planet. Sci.*, 49, 677-695. [9] Sun C. and Liang Y. (2012) *Contrib. Mineral. Petr.* 163, 807-823.[10] Hui H.et al. (2011) *GCA*, 75, 6439–6460.[11]Chen et al. (2015) EPSL,427: 37-46. [12]Shearer C.K. and Papike J.J. (1993) *GCA*, 57:4785-4812.