PETROGENESIS OF LUNAR METEORITE NORTHWESTERN AFRICA 2977: RARE EARTH ELEMENT GEOCHEMISTRY AND BADDELEYITE PB/PB DATING. A. C. Zhang[1,2], L. A. Taylor[2], W. B. Hsu[3], C. Floss[4], X. H. Li[5], and Y. Liu[2], [1]Purple Mountain Observatory, Nanjing 210008, China (aczhang@pmo.ac.cn); [2]Planetary Geosciences Institute and Departartment of Earth and Planetary Science, University of Tennessee, Knoxville, TN 37996, USA; [3]Faculty of Earth Sciences, China University of Geosciences, Wuhan 430074, China; [4]Laboratory for Space Sciences and Physics Department, Washington University, Saint Louis, Missouri 63130, USA; [5]Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China.

Introduction: Northwestern Africa 2977 is an olivine gabbro cumulate lunar meteorite, which is similar to the olivine gabbro portion of lunar breccia NWA 773 [1-3]. However, chronological studies gave various Sm-Nd ages for NWA 773 and NWA 2977 (~2.865 ± 0.031 Ga [4] and 3.10 ± 0.05 Ga [5], respectively). To better understand the petrogenesis of NWA 2977, we performed a detailed petrographic and geochemical study on this meteorite. Here, we report the results of *in situ* REE geochemistry and baddeleyite Pb/Pb dating of NWA 2977.

Analytical methods: REE concentrations in minerals were measured at Washington University, St. Louis with the Cameca IMS-3f ion microprobe following the procedures of [6]. Baddeleyite Pb/Pb dating was carried out by using the Cameca IMS-1280 ion microprobe at the Institute of Geology and Geophysics of Chinese Academy of Sciences, China following the procedures of [7]. Multicollection was used to simultaneously measure secondary ion beam intensities of ^{204}Pb, ^{206}Pb, ^{207}Pb, and $^{90}Zr_2{}^{16}O_2$. The relative yield of each electron multiplier was calibrated using a Phalaborwa baddeleyite standard [8]. Correction for common Pb was made by measuring ^{204}Pb and assuming a common lead composition of $^{206}Pb/^{204}Pb = 14 \pm 4$ and $^{207}Pb/^{206}Pb = 0.84 \pm 0.2$. Only data with $^{206}Pb/^{204}Pb$ >1000 were accepted for the calculation of ages.

Results: REE concentrations in olivine are low and the CI chondrite-normalized pattern is enriched in the HREE, with Nd = 0.04 × CI and Yb = 3.6 × CI (Fig. 1). REE concentrations in pyroxene are related to their occurrences. Low-Ca pyroxene has a CI-normalized HREE-enriched pattern (Fig. 2) with deep negative Eu anomalies. Coarse-grained pigeonite (IP2, IP37, and IP38) has low REE concentrations (La 0.3–1.1 × CI), whereas relatively fine-grained late-stage orthopyroxene (IP8 and IP30) and pigeonite (IP16, IP26, and IP34) have higher REE concentrations (La 3.1–6.6 × CI). Coarse-grained augite (IP1) has a flat HREE pattern, but increasing LREE from La to Sm. Late stage augite (IP20 and IP39) has higher REE concentrations (La ~14–16 × CI) and shows increasing LREE concentrations from La (~14–16 × CI) to Sm (~55–58 × CI), but decreasing HREE concentrations from Gd (47–85 × CI) to Lu (23–41 × CI). An augite inclusion in olivine has the highest REE concentrations (La 215 × CI) and an essentially flat LREE pattern. All augite grains also show deep negative Eu anomalies.

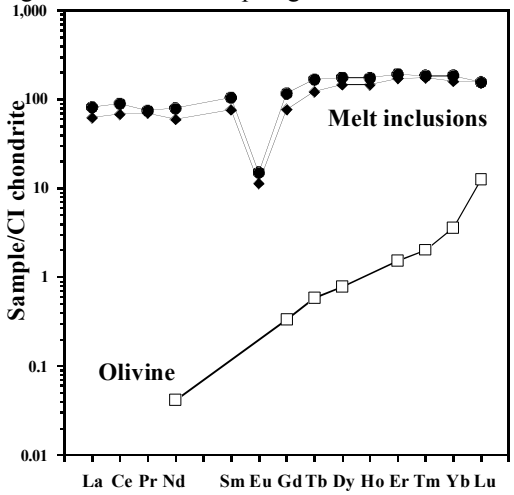

Figure 1. CI chondrite-normalized REE abundances in olivine and melt inclusions.

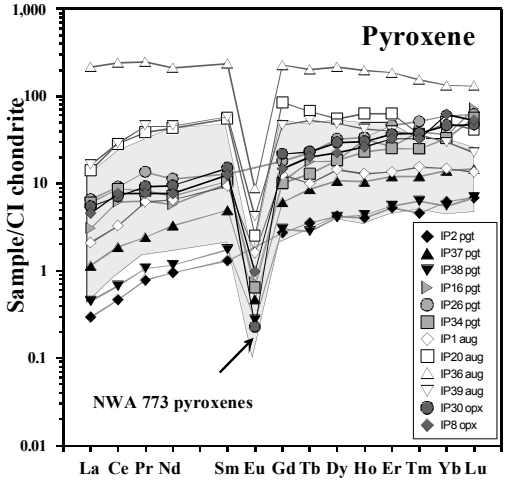

Figure 2. CI chondrite-normalized REE abundances in pyroxene. The shaded area shows data from [9].

Plagioclase has a LREE-enriched pattern with a positive Eu anomaly (Fig. 3). K-feldspar has steeply decreasing LREE from La (~20–76 × CI) to Nd (~1 × CI), a positive Eu anomaly(~18–124 × CI) and low HREE abundances that are below detection limits.

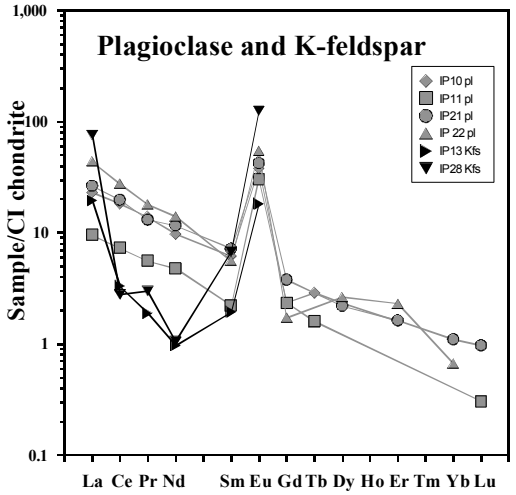

Figure 3. CI chondrite-normalized REE abundance in plagioclase and K-feldspar.

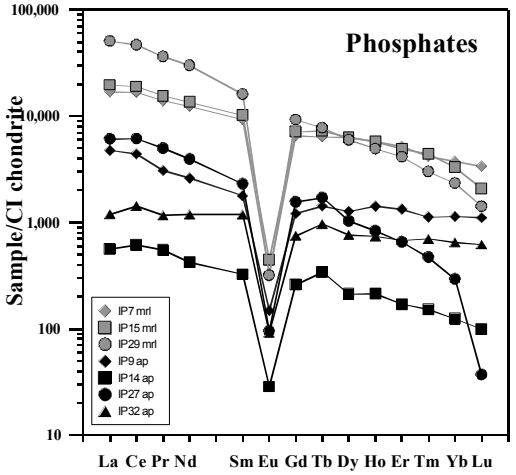

Figure 4. CI chondrite-normalized REE abundances in phosphate minerals.

Merrillite and apatite show LREE-enriched patterns with deep negative Eu anomalies (Fig. 4). Apatite has lower REE concentrations (La 560–6090 × CI) than merrillite (La 16,865–50,696 × CI) and shows large variations in REE patterns and abundances. Chlorine-rich apatite (IP9) has higher REE concentrations (La 4754 × CI) than F-rich apatite grains IP14 and IP32 (La 560 × CI and 1195 × CI, respectively).

Two Si,Al-rich melt inclusions in olivine have almost identical REE concentrations (La 62–81 × CI) and patterns. HREE concentrations are slightly higher than LREE concentrations and both inclusions show a flat pattern with negative Eu anomalies (Fig. 1).

Ten Pb/Pb measurements on seven baddeleyite grains gave almost identical results within errors (Fig. 5) and yield a weighted mean $^{207}Pb/^{206}Pb$ age of 3128 ± 5 (2σ) Ma.

Discussion: The REE abundances and patterns in the NWA 2977 minerals are generally similar to those in the olivine gabbro portion of NWA 773, which suggests that they could come from a common parent magma. Combined with petrographic and mineralogical information on this meteorite [10], these data show that NWA2977 originated through fractional crystallization. After crystallization of olivine, low-Ca and high-Ca pyroxene, containing relatively low REE concentrations, crystallized almost simultaneously before precipitation of plagioclase. Subsequently, late-stage low-Ca and high-Ca pyroxene, containing high REE concentrations, crystallized together with or after the formation of plagioclase. Finally, phosphate minerals form from the REE-rich residual melt.

Our SIMS baddeleyite Pb/Pb age is in excellent agreement with Sm-Nd and Rb-Sr isochron ages [5], indicating that the crystallization age of NWA 2977 is about 3.1 Ga. The different Sm-Nd ages for NWA 2977 and 773 probably suggest that they have different thermal histories following their crystallization from a common source region.

References: [1] Bunch T. E. et al. (2006) *LPS XXXVII*, Abstract 1375. [2] Burgess R. et al. (2007) *LPS XXXVIII*, Abstract 1603. [3] Zeigler et al. (2007) *LPS XXXVIII*, Abstract 2109. [4] Borg L. E. et al. (2004) *Nature*, 432, 209–211. [5] Nyquist et al. (2009) *MAPS*, 44, A159. [6] Floss C. (2000) *MAPS* 35, 1073–1085. [7] Li X. H. et al. (2009) *G*^{3}, 10. Q04010. [8] Heaman L. M. (2009) *Chemical Geology*, 261, 43–52. [9] Jolliff B. L. et al. (2003) *GCA*, 67, 4857–4879. [10] Zhang A. C. and Hsu W. B. (2008) *MAPS*, 43, A176.

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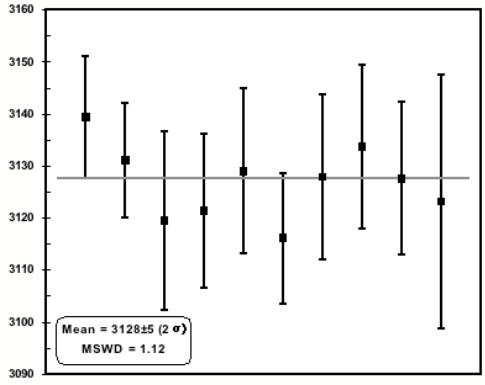

Figure 5. Weighted mean Pb/Pb age of baddeleyite grains in NWA 2977.