

**PETROGRAPHY, MINERALOGY AND GEOCHEMISTRY CHARACTERISTICS STUDY OF Th-RICH LUNAR METEORITE NORTHWEST AFRICA 4485.** Chengxiang Yin<sup>1</sup>, Xiaohui Fu<sup>1,2,3\*</sup>. <sup>1</sup>Shandong Key Laboratory of Optical Astronomy and Solar-Terrestrial Environment, Institute of Space Sciences, Shandong University, Weihai, Shandong 264209, China (fuxh@sdu.edu.cn); <sup>2</sup>State Key Laboratory of Lunar and Planetary Sciences, Macau University of Science and Technology, Taipa, Macau, China; <sup>3</sup>CAS Center for Excellence in Comparative Planatology, Purple Mountain Observatory, Nanjing 210034, China.

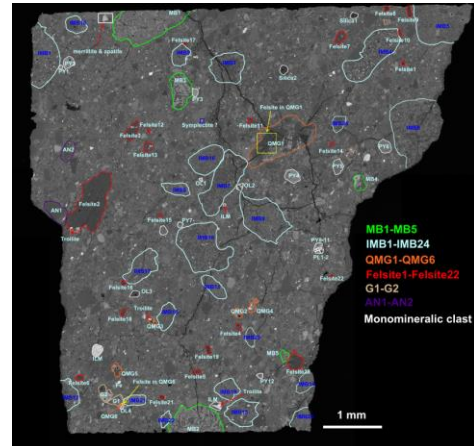
**Introduction:** Lunar samples provide basic information for our understanding of the moon. However, these precious samples were collected from a limited region (in or adjacent to the PKT). Lunar meteorites, on the other hand, are thought to be randomly samples from the full moon. In any case, these meteorites are complementary to Apollo samples [1].

In this study, we investigated the petrography, mineralogy and geochemical characteristics of the Th-rich meteorite Northwest Africa (NWA) 4485, which is thought to be paired with NWA 4472 [2,3], and its thorium (Th)-rich characteristic (6.24ppm [4]) reveals its association with PKT. Furthermore, highly evolved clasts (Quartz monzogabbro/diorite and felsite) present in HAS were identified in NWA 4485. Therefore, relevant studies will shed light on petrogenesis of HAS from the perspective of meteorites.

**Sample and methods:** The NWA 4485 is a KREEP-rich regolith breccia and has been proved to come from the Moon (e.g. [5]). In this study, one thick section of 4485 was investigated. This section was embedded in epoxy resin and polished. EMPA and LA-ICP-MS were used to obtain major elements and trace elements composition of lithic clasts and mineral fragments. In addition, Raman spectrometer was used to identify different silica phases.

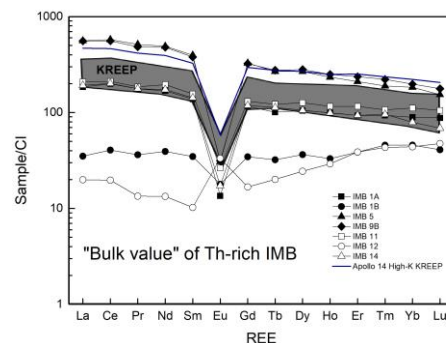
**Petrography:** NWA 4485 is a polymict breccia. Given its high content of thorium and other incompatible elements, it is considered to be a KREEP-rich breccia [2,6,7]. In this section, various mineral fragments and lithic clasts were embedded in a gray matrix (Fig. 1). Impact melt breccias (IMB) are the most abundant. Highly evolved clasts, including quartz monzogabbro/diorite (QMG/QMD) and felsite, are randomly distributed in the matrix. Mare basalts are less dominated. In fact, only five mare basalt clasts were identified.

**Impact melt breccias:** Twenty-four IMB clasts with different sizes were identified. They show various textures, including clast-bearing impact melt breccia, crystalline impact melt, hypocrySTALLITE impact melt, and clast-rich impact melt breccia. Pyroxenes and plagioclases are most abundant minerals in these IMB clasts. Other minerals include few olivines and oxides such as chromite and ilmenite.



**Fig. 1.** Back-scattered electron (BSE) images of NWA 4485 section. MB=mare basalt; IMB=impact melt breccia; QMG= Quartz monzogabbro/diorite; G=gabbro; AN=anorthosite.

Some IMB clasts are rich in Th, REE and other ITEs. REE pattern of representative Th-rich IMB clasts were shown in Fig. 2. Several Th-rich IMBs (IMB 5, IMB 9B, IMB 11 and IMB 14) have high REE abundance (68\*CI to 575\*CI, Eu except) and are characterized by light REE (LREE) enrichment and negative Eu-anomaly, which is very similar to Apollo 14 high-K KREEP and KREEP basalts (Fig. 2.)



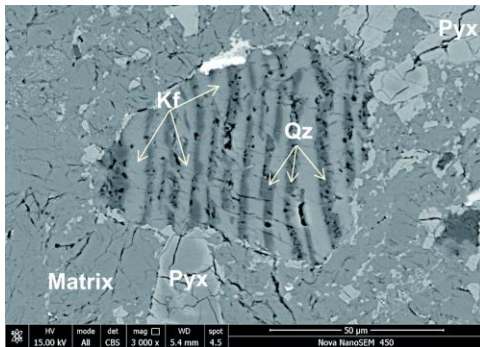
**Fig. 2.** CI normalized REE abundance of Th-rich (>2 ppm) IMB. KREEP field was modified after [8].

**Mare basalts:** Mare basalts all exhibit subophitic texture. Plagioclase has a slightly wider compositional range ( $An_{82-93}$ ,  $An=100 \times \text{molar Ca}/[\text{Ca} + \text{Na} + \text{K}]$ ). Compositions of pyroxene range from pigeonite to

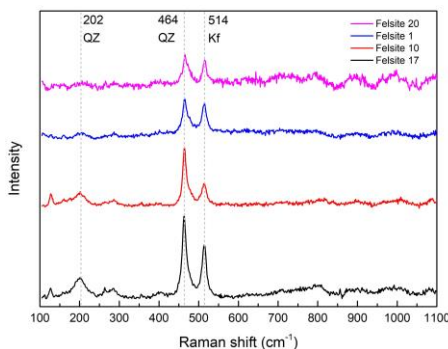
augite ( $\text{Wo}_{6-30}\text{En}_{32-50}\text{Fs}_{35-50}$ ,  $\text{Mg}\#_{40-56}$ ) and no compositional zoning was found.

$\text{Fe}\#$  ( $100 \times \text{molar Fe}/[\text{Mg} + \text{Fe}]$ ) and  $\text{Ti}\#$  ( $100 \times \text{molar Ti}/[\text{Cr} + \text{Ti}]$ ) of pyroxenes indicate that these basalts are in the very low-Ti (VLT) to low-Ti (LT) basalts range [9,10]. Trace elements contents are too poor to be classified as KREEP basalts and REE patterns are closest to that of the Apollo 12 basalts.

**Highly evolved clasts:** High evolved clasts identified in NWA 4485 include felsites and QMG/QMDs. Twenty-two felsites and six QMG/QMDs were found. The felsite is characterized by the intergrowth between quartz and K-feldspar (Fig. 3). Raman spectrum confirmed this and Raman peak of quartz and K-feldspar were identified (Fig. 4). QMG/QMD contains pyroxene ranging from mg-rich pigeonite to iron-rich augite, more sodium rich plagioclase ( $\text{An}_{63-73}$ ), and iron-rich olivine ( $\text{Fo}=5$ ). Furthermore, intergrowth of K-feldspar and quartz was also found in QMG/QMD.



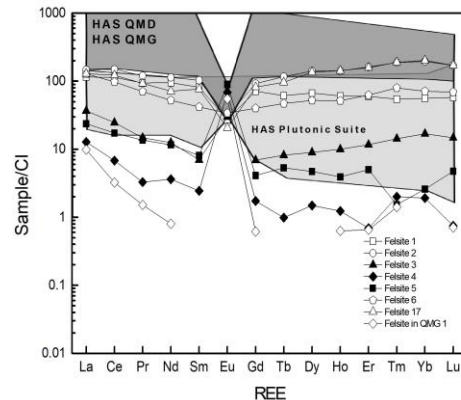
**Fig. 3.** BSE images of felsite in NWA 4485. Kf=K-feldspar, Qz=quartz.



**Fig. 4.** Selected Raman spectra of felsite in NWA 4485. Raman peak of quartz (Qz) and K-feldspar (Kf) were identified.

Bulk composition of these felsites ( $\text{K}_2\text{O}$ : 3.5-8.5 wt%, most >5.5 wt%;  $\text{SiO}_2$ : 60-80 wt%) were obtained by LA-ICP-MS. CI chondrite normalized REE patterns were shown in Fig. 5. Based on the REE patterns, these felsites can be divided into two types: REE-rich with

negative Eu-anomaly and REE-poor with positive Eu-anomaly. The REE-rich felsites fall in the HAS plutonic suite field and exhibit concave upward REE patterns, which is similar to the granite in previous studies [11,12]. The REE-poor felsites have a significant positive Eu-anomaly, similar to the granophyre fragment in NWA 4472, but showing lower REE content [8].



**Fig. 5.** CI normalized REE abundance of felsites. HAS QMG/QMD and HAS plutonic suite fields were modified after [8].

**Discussion:** Previous studies have demonstrated the paired relationship between NWA 4485 and NWA 4472. HAS, HMS and KREEP basalts were found in NWA 4472 [8], but only HAS was identified in our section of NWA 4485. The petrogenesis of secondary lunar crust (HAS and HMS) is still controversial, but their relationship with KREEP seems to be recognized [11,12,13]. Based on the major elements composition and REE patterns of felsite and QMG/QMD obtained in this study, we will explore the petrogenesis of HAS. That is the following work.

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