U-Pb DATING OF PHOSPHATES IN LUNAR METEORITE DHOFAR 1442. Q. Zhou[1], Q. Z. Yin[2], R. Zeigler[3], R. Korotev[4], B. Jolliff [4], F. Y. Wu[5], X. H. Li[5], Q. L. Li[5], Y. Liu[5], G. Q. Tang[5] and C. L. Li[1]. [1]National Astronomical Observatories, Chinese Academy of Sciences, Beijing, 100012, China (zhouq@bao.ac.cn). [2]University of California, Davis, One Shields Avenue, Davis, CA 95616, USA. [3]NASA Johnson Space Center, Houston, TX 77058, USA. [4]Washington University in Saint Louis, St. Louis MO 63130, USA. [5]Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, 100029, China.

Introduction: Ca phosphates are an important group of common accessory minerals in meteorites with great potential for U-Pb geochronology [1-3]. Compared to zircons, the lower closure temperatures of the U-Pb system for apatite $Ca_5(PO_4)_3(F,Cl,OH)$ and merrillite $Ca_{18}Na_2Mg_2(PO_4)_{14}(F,Cl,OH)$ (the most common phosphates in achondrites) makes them susceptible to resetting during thermal metamorphism [4]. The different closure temperature of the U-Pb system for phosphate complements zircon geochronology in meteoritics. Here we report U-Pb dating results for phosphates from lunar meteorite Dhofar 1442, following our initial report of U-Pb ages on zircons from the same meteorite [5].

Samples: Dhofar 1442 is a glassy-matrix regolithbreccia that is rich in clasts, including basaltic, granulitic, and felsic lithic clasts [5,6]. With the exception of the impact-melt breccia (IMB) lithology of SaU 169 [7], Dhofar 1442 is the most KREEP-rich lunar meteorite to date [8]. The provenance of SaU 169 and Dhofar 1442 is almost certainly within the Procellarum KREEP Terrane (PKT), likely in the vicinity of a low-Ti mare in the case of Dhofar 1442 [6,7].

Experiment: In-situ isotopic analysis of U-Pb was performed on a large radius magnetic sector multi-collector Cameca IMS-1280 ion microprobe at the Institute of Geology and Geophysics, Chinese Academy of Sciences in Beijing. The experimental procedure for apatite followed those of [9-12]. NW-1 apatite (1160Ma) was used as a standard, which comes from the same complex of Prairie Lake where the apatite standard (PRAP) used by Sano et al. [13] also came from. The spot size is 20×30μm.

Results: Forty-nine analyses of U-Pb isotopic analyses were performed on 46 phosphate grains in Dhofar 1442, including 13 apatite and 33 merrillite. Uranium concentration is variable from 10 to 492 ppm, and thorium contents from 27 to 1457 ppm. The Th/U ratio for merrillite is variable from 1.3 to 22.3, but consistently low for apatite (0.4-1.4, with average of ~ 1). Compared to IMB clast and matrix, the Th/U ratios of merrillite are rather homogenous in granulite clast (6.8-10.3), norite clast (7-7.9), and basalte clast (10.6-13.4).

Shown in Fig. 1 is orthogonal projection of the total $^{238}U/^{206}Pb$ and measured $^{207}Pb/^{206}Pb$ composition onto the Terra-Wasserburg diagram following [14,15]. The important advantages of this method are that it is not necessary to know *a priori* isotopic composition of initial lead.

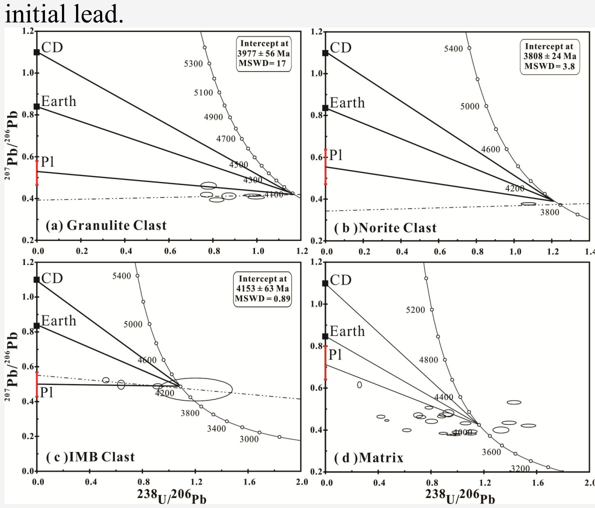

Fig. 1. Terra-Wasserburg diagram for phosphate from Dhofar 1442. Solid lines are mixing lines with terrestrial (Earth, black square on the y-axis), primordial (CD, black square on the y-axis) or measured *in situ* plagioclase (Pl, red bar on the y-axis) Pb composition. Dashed lines are discordia lines. Uncertainties are 2σ.

We obtained an concordia intercept age for granulite clast of 3977 ± 56 Ma (Fig. 1a), norite clast of 3808 ± 24 Ma (Fig. 1b), and IMB clast of 4153 ± 63 Ma (Fig. 1c). Due to the complex origin, the data points of phosphate in matrix are scattered (Fig. 1d) and no intercept age could be regressed. However, the data cluster cross the concordia at ~4Ga.

Compared to the terrestrial common Pb and primordial Pb isotopic composition, the arrangement of the data points appear to be best explained, for the most part, by mixing with the lunar common Pb sources represented by the in situ measurements of plagioclase in the respective lithologies (red bars on the y-axis in Fig. 1a-d). Therefore, the common Pb corrected $^{207}Pb/^{206}Pb$ age for phosphate with the plagioclase Pb isotopes as common-lead compositions was evaluated in our study. As seen in Fig. 2, the $^{207}Pb/^{206}Pb$ age age range of phosphate is comparable to that of zircons in Dhofar 1442. The major peaks of phosphate corresponds to the major peaks in relative probability plot of zircons.

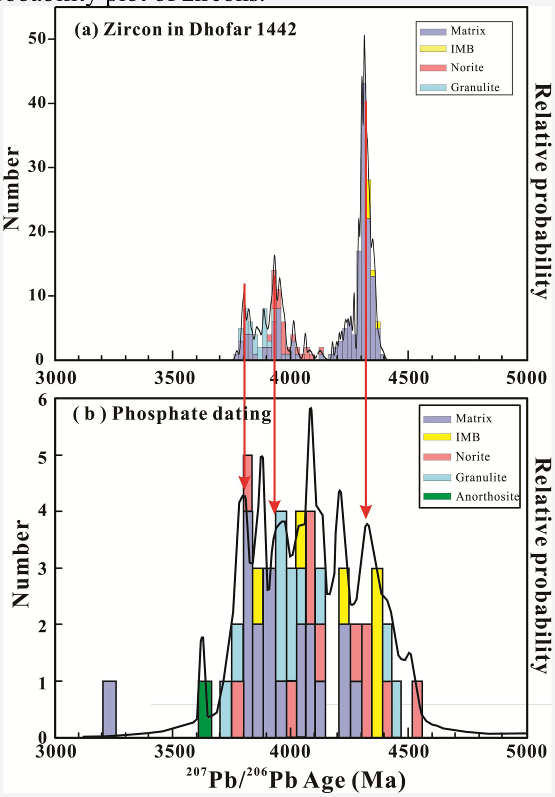

Fig. 2. The $^{207}Pb/^{206}Pb$ age distribution and probability density function of zircon and phosphate grains in Dhofar 1442. Data source for panel a include [5] and additional new data from this study. Panel b from this study.

Discussion: Granulitic clats in Dhofar 1442: Granulite is metamorphic rocks presumably formed at depth from older breccias associated with a large impact. From our study, the U-Pb age of zircon grains in granulite clasts of Dhofar 1442 indicate an metamorphic event at ~ 3850 Ma (Fig. 2a). However, the upper intercept age of 3977 ± 56 Ma (Fig. 1a) for phosphate in the same clasts is slightly older than the age of zircons. This is hard to be explained by disturbance of later impacts considering the low closure temperature of U-Pb systems for phosphate.

Norite clasts in Dhofar 1442: The 3-D concordia intercept age for phosphate in norite clasts is 3808 ± 24 Ma (Fig. 1b), which is significantly younger than the age of co-existing zircons (ca. 3950 Ma, Fig. 2a). This sugests that the U-Pb system for phosphate in norite clasts was disturbed by later impact at ~ 3800 Ma, which was also reflected as the youngest peak of $^{207}Pb/^{206}Pb$ age for zircon grains in matrix (Fig. 2a).

IMB clasts in Dhofar 1442: Impact melt breccias (IMB) are products of crystallization from shock-induced melt. From the earlier studies of Apollo samples, the majority of impact melt breccias have ages falling into a rather narrow time interval between 3.92 and 3.85 Ga. Tera et al. (1974) concluded that the age of ~ 3.9 Ga recored an intense bombardment on the moon and referred this catastrophic event as the "lunar cataclysm" (also known as the Late Heavy Bombardment, LHB) [16]. However, more recent work on returned lunar samples and lunar meteorites confirms that there are more impact melts older than 3.9 Ga [e.g. 3,5,17]. In Dhofar 1442, the U-Pb age of phosphate in IMB clasts (4153 ± 63 Ma, Fig. 1c) is also older than 3.9 Ga. Compared to the co-existing zircons in IMB clasts (Fig. 2a), the younger phosphate age indicated that the U-Pb system of phosphate in IMB clast probably was disturbed by the later impact events. In addition, the peak age of ~4.3 Ga is as prominent as ~3.9 Ga in the zircon age histogram for Dhofar 1442 (Fig. 2a). This reinforces the fact that the impact event at ~ 4.3 Ga was also evident on the Moon.

Phosphate grains in matrix: Due to limited petrographic information, phosphate in matrix could not be directly related to an igneous lithic clasts. However, the ^{207}Pb-^{206}Pb age distribution range of phosphate grains in the matrix of Dhofar 1442 was similar to that from lithic clasts (Fig. 2b). This suggests that separate phosphate grains in matrix was probably originated from the lithic clasts of granulite, norite and IMB in Dhofar 1442.

The ^{207}Pb-^{206}Pb age of zircon grains in matrix show a major peak at ~4.3 Ga. While the ^{207}Pb-^{206}Pb age of phosphate was variable from ~3.2 to ~4.3 Ga, with a major peak age around 3.8 Ga. It suggests that the U-Pb system of phosphate failed to preserve the old impact event, such as the impact of ~4.3 Ga recorded by zircons grains.

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