# THERMAL HISTORY OF LUNAR METEORITE DHOFAR 280.

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**Introduction:** Dhofar 280 was found in the Oman desert in 2001 [1]. It is a lunar impact melt breccia of anorthositic composition with abundant schlieren and vesicles, with minor traces of terrestrial weathering. A unique and important discovery in Dho 280 is the presence of Fe-silicides, which were initially interpreted as a result of space weathering [2]. Later it was suggested that the Si-rich association of Dho 280 has an impact origin and was formed by condensation of an impact-induced vapor, then remelted and mixed with the Dho 280 host rock [3]. To reveal the thermal history of this rock and to provide new chronological insights in the evolution of the lunar lithosphere we performed high-resolution $^{40}$Ar-$^{39}$Ar stepwise heating analyses on Dho 280 whole rock material (31.1 mg). Dho 280 was previously investigated by laser $^{40}$Ar-$^{39}$Ar dating [4], but the Ar isotope systematics appeared unclear.

## Results and Discussion

*$^{40}$Ar-$^{39}$Ar chronology:* Dho 280 turned out to be not as gas-rich as previously measured lunar meteorite Dho 1436 [5] - the total concentrations of $^{36}$Ar is ~$60.0\times10^{-8}$ cm$^3$STP/g. The age spectrum of this meteorite is complex due to the presence of trapped argon. At low to intermediate temperatures up to 1040°C, a trapped argon component of air-like composition is released (Fig. 1), likely incorporated during terrestrial weathering. At higher temperatures, the sample releases extraterrestrial trapped argon with $^{40}$Ar/$^{36}$Ar ratios of 17.5±0.2 (1180-1270°C) and of 10-14 (> 1300°C). The minimum age of the age spectrum - uncorrected for trapped argon - is 1523±46 Ma which could be considered as an upper limit of a relatively young impact event. Correcting low temperature fractions with an air-like trapped argon composition, the resulting age is 0 within uncertainties: in an isochron plot these extractions form a trend almost parallel to the $^{39}$Ar/$^{40}$Ar-axis that indicates an age close to 0 Ga (Fig. 1). Note, as impact ejection can hardly cause a reset of the Ar-Ar clock [e.g., 6], this means that two different impact events are necessary: one caused a quite recent thermal event causing partial reset of the Ar-Ar age and another one caused the ejection of the meteorite from the Moon. The isochron plot of high temperature extractions (>1300°C), where no terrestrial argon contamination should be present, show very similar $^{40}$Ar/$^{36}$Ar ratios at a given $^{39}$Ar/$^{36}$Ar ratio. Correction of high temperature extractions for extraterrestrial trapped argon results in apparent ages < 1 Ga. Recent impact events were also recorded by other lunar meteorites (e.g., SaU 169, NWA 5000, 4472, EET 96008 [7-10]). Dho280 would be one of the youngest samples in the lunar meteorite collection. Recent impact melting events were also specified on other parent bodies, e.g. on the HED and ordinary chondrite parent bodies [e.g., 11,12].

In Dho 280 the Si-rich association and its surrounding matrix are enriched in highly volatile elements and/or elements with low sensitivity to oxygen, including alkalis. While the K concentration in plagioclase – frequently the K-bearing phase in meteorites – is below detection limit [3], the K concentration in Si-rich associations and in their surrounding matrix is high, up to 1 %. However, this kind of material is very rare and small in size, so its contribution to the total K content of the whole rock is not quite evident in our sample: Dho 280 contains 0.02% of $K_2O$ [13] and according to Ar-Ar dating the potassium content is 189±3 ppm. This is consistent with the main source of K in Dho280 being low K-plagioclase which is the dominant phase of this rock, and thus the age of <1Ga would date the last total degassing of the whole rock. If the Si-rich association was formed as a result of a strong impact, it should be a very retentive Ar material and could be older 1 Ga. However, our data do not yield compelling evidence that the Si-rich association was formed before the impact event < 1 Ga ago and its genesis related to this event is the most straightforward interpretation.

*Source areas on the Moon from which the meteorites could be derived:* Based on mineralogy and petrology it was suggested that Dho 280 may originate from a highland terrain on the farside of the Moon [14]. In this locale, lunar rocks are distinctly more FAN-rich, and remote from KREEP-rich regions. However, recently [15] stated that KREEP-enrichment is “typical of Dhofar 280”, based on the occurrence of a KREEP enriched mare clast in Dho 280. If Dho 280 indeed experienced a large energetic impact event < 1 Ma ago, it alternatively may be derived from KREEP- rich lunar frontside terrains, possibly associated with the 800 Ma old Copernicus crater [16]. On the other hand, Nazarov with coauthors [3] relate the genesis of the condensate associations of Dho 280 to a significant impact event, likely to the origin of the South Pole-Aitken (SPA) basin. The latter is concluded based on the assumed large scale of this impact event, rather not on chronological data. The impact event <1Ga dated in this study had to be energetic enough to cause a total reset but hardly can be connected with SPA basin formation which is one of the oldest basins on the Moon [e.g., 17] if not this recent significant impact event took place on SPA deposits.

*Is there a correlation of antiquity and trapped argon composition?:* Trapped "orphan" argon with $^{40}$Ar/$^{36}$Ar ratios of up to 15 is a well known feature of lunar soils and considered as surface antiquity measure [18]. This study presented a model in which orphan argon was considered as a mixture of solar wind argon and degassing radiogenic $^{40}$Ar from the lunar interior reimplanted by solar wind ions into lunar surface rocks. As lunar degassing rates were stronger in the past, the trapped $^{40}$Ar/$^{36}$Ar ratios were expected to be higher for older surfaces than for rocks exposed more recently. However, simultaneously measured $^{40}$Ar-$^{39}$Ar ages and the trapped Ar compositions are not always in accordance with the antiquity model, i.e. measured $^{40}$Ar-$^{39}$Ar ages can significantly differ from the model antiquity age [5, 19-21] (Fig. 2). The values of trapped argon released at high temperatures from Dho 280 correspond to an antiquity >3.5 Ga that is evidently inconsistent with our data. This indicates the necessity to decipher the origin and siting of trapped "orphan" argon and to verify the consistency of correlation of antiquity and trapped argon composition, before to use extensively this model to estimate the time that passed since the solar wind was acquired using $(^{40}\mathrm{Ar}/^{36}\mathrm{Ar})_{\mathrm{trapped}}$ ratios [22,23].

To summarise, Dho 280 recorded at least four impact events within the last 1 Ga: 1) the last total degassing <1 Ga ago generated by a large impact event possibly resulting in formation of unique Si-rich associations found in impact-melt breccia Dho 280. 2) the excavation by an impact event and as a consequence of that irradiation by GCR and by SCR (solar gases are present in Dho 280 [24]) on the Moon during ~400 Ma [25]; 3) possibly reburial, perhaps produced by the same event that caused recent partial degassing; 4) impact event, ejecting Dho 280 from Moon.

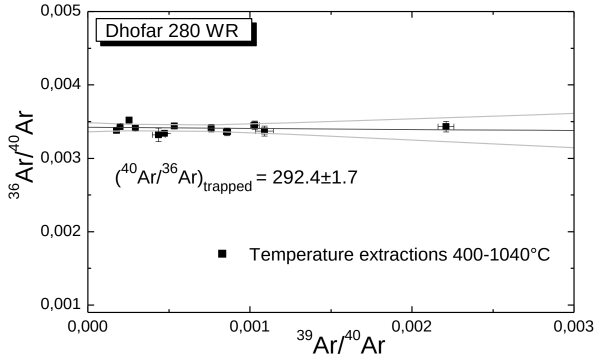

Fig. 1. Three isotope correlation diagram $^{36}$Ar/$^{40}$Ar vs. $^{39}$Ar/$^{40}$Ar ratios for Dhofar 280.

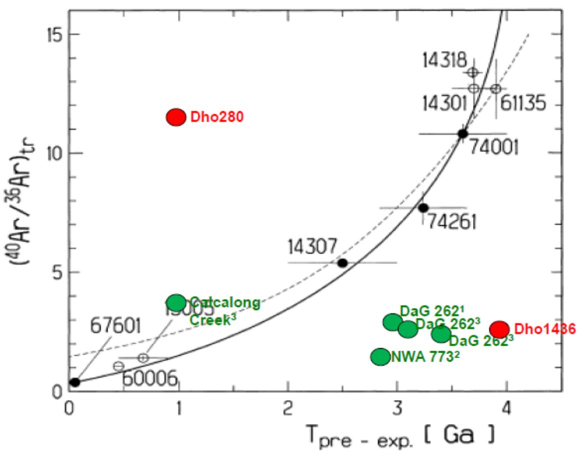

Fig. 2. Correlation of antiquity and $(^{40}\mathrm{Ar}/^{36}\mathrm{Ar})_{\mathrm{trapped}}$ [18]. Green circles – data from [19-21], red circles – our data [this study and 5].

*Acknowledgements:* Authors acknowledge support by RFBR grant №14-05-31192 and Klaus Tschira Stiftung gGmbH.

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