IRRADIATION HISTORY OF LUNAR METEORITE DHOFAR 280.

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Introduction: Lunar meteorites have usually complex exposure histories, containing cosmogenic nuclides acquired on the Moon. As for many other lunar rocks a short ejection age and significant irradiation age on the Moon have been reported for the lunar impact melt breccia Dhofar 280 [1-3]. The transit and ejection ages are ≤0.01 Ma and 0.04 ± 0.02 Ma, respectively [1]. But the exact irradiation time on the Moon remains uncertain. CRE ages determined by laser ^{40}Ar-^{39}Ar dating yield a range of values between 46 and 686 Ma [2]. Shukolyukov and co-authors [3] also determined CRE ages for Dhofar 280, but as production rates were underestimated, their CRE ages must be reevaluated. Dhofar 280 is possibly paired with highland lunar meteorites Dhofar 081, 910, 1224 [4] and with mare meteorite Dhofar 287 [5]. Here we report ^{40}Ar-^{39}Ar results concerning the exposure history of Dhofar 280 and the possibility of its pairing and common irradiation history with the above-mentioned meteorites.

Results and Discussion

Cosmic ray exposure ages: The calculated concentration of cosmogenic ^{38}Ar is 22.1×10^{-8} cm^3 STP/g in Dhofar 280. Cosmogenic Ar is derived assuming ^{36}Ar/^{38}Ar=5.35 and 0.65 for the trapped and cosmogenic components, respectively. The stepwise release cosmic ray exposure spectrum of Dhofar 280 surprisingly shows two parts with quite different CRE ages (Fig. 1). The high temperature extraction part yields information about the irradiation by GCRs on the Moon. The CRE age plateau indicates that cosmogenic nuclides were acquired during ~400 Ma, likely at some time after the last total degassing <1 Ga ago. The production rate for cosmogenic ^{38}Ar of 8.49*10^{-10}cc/gMa for 2π irradiation has been calculated according to [6] for a shielding depth of 225 g/cm^2 (after [1]) and using the chemical composition of this meteorite reported by [7]. For Dhofar 280 the contributions from Ca to production rates for 2π irradiation according to [6] and for 4π irradiation (see below) according to [8] comprise 99.7% and 98.4%, respectively, supporting the reliability of the CRE age spectrum.

A short transit time from the lunar surface to the Earth of ≤1 Ma is derived from the low temperature extractions that also display the about zero Ar-Ar age [9]. The identification and quantification of the recent ≤1 Ma transit exposure is only possible due to the thermal partial degassing event that occurred just before ejection [9]. The production rate of cosmogenic ^{38}Ar for 4π irradiation is determined according to the method of [8] and is 23.91×10^{-10} cc/gMa. The chemical composition of whole rock Dhofar 280 [7] is used here as well; but a shielding correction has not been applied [10]. A transit age of ≤ 1 Ma is typical of lunar meteorites [11] and agrees with the very short transit age for this meteorite reported by [1]. In our case, some addition of cosmogenic nuclides acquired on the surface of the Moon after the recent partial degassing event before the ejection event may also be considered, but cannot be quantified here. Concerning the partial reset of the CRE age clock in low temperature extractions, it is worth mentioning that terrestrial weathering is an unlikely cause for such significant loss of cosmogenic (and also radiogenic) argon and thus cannot explain the difference of apparent ages between high and low temperature extractions: 1) this meteorite has only a low degree of weathering; 2) we have never observed such low CRE ages in the beginning of CRE age spectra relative to high temperature extractions, even in strongly weathered meteorites; 3) CRE ages of low temperature extractions are usually overestimated because of Cl-bearing terrestrial contaminants. In fact, the very first several extractions of Dhofar 280 also demonstrate elevated CRE ages relative to the following ones.

Pairing and common irradiation history: Dhofar 081 and Dhofar 280 have been considered to be paired because the stones were found close to one another (about 200 m apart) and are similar in texture and mineral chemistry [12]. This conclusion is supported by identical ^{10}Be and ^{41}Ca concentrations [1], although [13] were not certain about pairing in view of the presence of Fe-silicides in only one of these meteorites.

While pairing (i.e. common ejection, transit and terrestrial residence time) is certainly possible, our results indicate that arguments for a common thermal and irradiation history on the Moon are not compelling:

1) The concentrations of cosmogenic ^{38}Ar of 20.8-22.1×10^{-8} cm^{3}STP/g in Dhofar 280 [3; our data] and of 25.5-31.2×10^{-8} cm^{3}STP/g in Dhofar 081 [14,15] are similar, but this difference results in a remarkable difference in the exposure ages on the Moon: As Nishiizumi et al. [1] determined identical ejection ages for Dhofar 081 and Dhofar 280, the difference of total cosmogenic ^{38}Ar must be due to irradiation by GCRs

on the Moon. Due to the diffusional loss of Ar_{cos} recognized by Lorenzetti et al. [14] and in this study in the CRE age spectrum (where ~40% of fractional ^{37}Ar release shows diffusional loss of cosmogenic ^{38}Ar and lower CRE ages than the irradiation age on the Moon; Fig. 1) the difference in total cosmogenic ^{38}Ar must arise from the 60% of the high temperature extractions. For example, assuming a single irradiation history on the Moon for Dhofar 280 and Dhofar 081 (i.e. uniform shielding depth, the same degree of diffusional Ar_{cos} loss and identical chemical composition) and taking the production rate for 2π irradiation calculated by us, irradiation times on the Moon of ~400 Ma for Dhofar 280 and 500-600 Ma for Dhofar 081 are inferred. Currently the most reliable evaluations of the irradiation time on the Moon for Dhofar 081 are 680±140 Ma based on the heavy noble gases [14].

2) In contrast to Dhofar 081, Dhofar 280 contains the Si-rich association of impact origin [16] and shows KREEP-enrichment [17], which indicates a somewhat different location and thermal history of these two possibly paired meteorites on Moon.

The thermal and irradiation history on the Moon can be different even for subsamples of a single lunar rock [e.g., 18]. Thus, Dhofar 280 and Dhofar 081 may have had distinct thermal and irradiation histories on the Moon including a somewhat different original location, though not too distant because of their final common ejection.

Recently pairing of Dhofar 280 with mare meteorite Dhofar 287 was suggested, based on the finding in Dhofar 280 of a huge clast of a basaltic breccia similar in texture and mineral chemistry to Dhofar 287 [17]. Since, at the same time Dhofar 280 and Dhofar 287 were found more than hundred kilometers apart, the authors raise the question about the criteria for establishing the pairing of meteoritic breccias. The only safe one is equal ejection age including equal transit time and terrestrial residence. Currently there are no studies on the ejection age for Dhofar 287 nor for Dhofar 910, 1224 that would allow to confirm their pairing. The solution of this question is not possible without studies of cosmogenic radionuclides.

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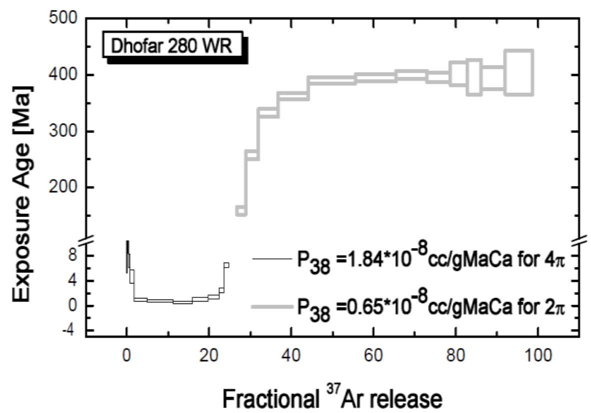

Fig. 1. CRE age spectrum of Dhofar 280.

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