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MARS–EARTH TRANSFER TIME OF LHERZOLITE YAMATO-793605

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Abstract: We determined the cosmic-ray exposure age of Yamato-793605 based on cosmic-ray produced ^{3}He, ^{21}Ne, and ^{38}Ar. The average age is 4.4±1.0 Ma and agrees with the exposure ages of the two other martian lherzolites ALH77005 and LEW88516. The similarity in petrology, chemistry, oxygen isotopic composition, and cosmic-ray exposure history shows that the three lherzolitic martian meteorites originate from the same parent magma and were ejected from Mars by the same ejection event. The basaltic shergottites EET79001, QUE94201, Shergotty, and Zagami strongly differ from the three lherzolites in mineralogical and chemical composition and were ejected by events that occurred 1 Ma and 3 Ma (EET79001) later than that responsible for the delivery of the lherzolites. We propose that these differences are sufficiently important to merit distinct meteorite classification and to name ALH77005, LEW88516, and Y-793605 "lherzolites", in contrast to the "shergottites" EET79001, QUE94201, Shergotty, and Zagami.

1. Introduction

In the framework of a consortium study of martian meteorite Yamato-793605 (hereafter Y-79) organized by H. KOJIMA, P. WARREN, M. MIYAMOTO, and K. YANAI we obtained a sample for the determination of the cosmic-ray exposure age and the abundances of trapped noble gases. Y-79 (recovered mass 16 g) shows strong affinities in petrography and mineral chemistry to two other martian meteorites Allan Hills 77005 (ALH77) and Lewis Cliff 88516 (LEW88) as demonstrated by MIKOUCHI and MIYAMOTO (1996a, b). These meteorites were classified as lherzolitic shergottites, that strongly differ from the basaltic shergottites Elephant Moraine 79001 (EET79), Queen Alexandra Range 94201 (QUE94), Shergotty, and Zagami in mineralogical and chemical composition. Hence these two classes of martian meteorites do not appear to originate from the same parent magma.

Before having analyzed Y-79 we have shown that the above mentioned meteorites originate from three different asteroidal or cometary impact events on Mars (EUGSTER *et al.*, 1997). The time of Mars ejection is given by the sum of the cosmic-ray exposure age and the terrestrial age. The following ejection times were obtained: EET79-0.8 Ma ago, Shergotty, Zagami, and QUE94-2.8 Ma ago, and ALH77 and LEW88-3.8 Ma ago. In this work we shall show that Y-79 yields the same cosmic-ray exposure age (and, assuming a typically brief terrestrial age, also the same ejection time) as the latter two and, thus, belongs to the same ejection event as ALH77 and LEW88. The terrestrial age of Y-79 is presently not known; but because the terrestrial ages of the martian meteorites are typically relatively short the ejection times are not significantly higher than the cosmic-ray exposure ages.

The basaltic shergottites and, on the other hand, the lherzolitic martian meteorites ALH77, LEW88, and Y-79 do not originate from the same ejection event and, as mentioned above, not from the same parent magma. We shall show in the discussion that the compositional difference between the basaltic shergottites and the lherzolitic martian meteorites is very large, even larger than between the basaltic shergottites and the three nakhlites, another class of martian meteorites. The absence of any genetic relationship between the basaltic shergottites and the lherzolites, except for being martian, does not justify to consider them to be two subgroups of the same class. We, therefore, propose to use the term "lherzolites" for ALH77, LEW88, and Y-79 and not "lherzolitic shergottites".

2. Sample Preparation and Analytical Procedure

We obtained several representative chips with a total weight of 53 mg. The largest chips were gently crushed in a stainless steel mortar and this material was split into two samples of 20.79 mg and 20.53 mg, respectively. Grain sizes were between 0.5 and 3 mm.

The two samples were analyzed using our standard procedure and mass spectrometer system B. For details, such as background and blank corrections see EUGSTER *et al.* (1993). The analytical results are given in Table 1. All errors correspond to a 95% confidence level (2σ errors). Considering the relatively small sample sizes, resulting in possible inhomogeneities and low noble gas amounts, the agreement between the results for the two analyses is satisfactory. In the following discussion we use average values of these two runs.

Table 1. Results of He, Ne, and Ar measurements of Y-793605.

Sample (g)	^{4}He	^{20}Ne	^{40}Ar	$^{4}He/^{3}He$	$^{20}Ne/^{22}Ne$	$^{22}Ne/^{21}Ne$	$^{36}Ar/^{38}Ar$	$^{40}Ar/^{36}Ar$
	$10^{-8}cm^{3}$ STP/g							
0.02079	35.4	1.21	188.6	4.54	0.884	1.211	1.29	557
	±1.2	±0.04	±8.0	±0.05	±0.012	±0.035	±0.10	±40
0.02053	34.9	1.19	197.0	4.72	0.910	1.241	1.15	593
	±1.1	±0.04	±10.0	±0.09	±0.020	±0.080	±0.10	±55
Average	35.2	1.20	192.8	4.63	0.897	1.226	1.22	575
	±1.0	±0.04	±5.0	±0.10	±0.015	±0.015	±0.07	±20

3. Cosmic-ray Produced Noble Gases

Helium. If $^{4}He/^{3}He=5$ (HEYMANN, 1967) is adopted for cosmogenic He, the low $^{4}He/^{3}He$ ratio of 4.54 and 4.72 (Table 1) excludes both trapped He and radiogenic ^{4}He contributions. Thus, we conclude that all ^{3}He and ^{4}He are of cosmogenic origin.

Neon. Adopting $(^{20}Ne/^{21}Ne)_{c}= 0.9$ and non-cosmogenic Ne to have terrestrial atmospheric isotopic composition we obtain $^{21}Ne_{c}$, $^{20}Ne_{tr}$ and $(^{22}Ne/^{21}Ne)_{c}$ as given in

Table 2. Cosmogenic and trapped noble gases in lherzolites.

Meteorite	Cosmogenic				Trapped	
	^{3}He	^{21}Ne	^{38}Ar	^{22}Ne	^{20}Ne	^{36}Ar
	$10^{-8}cm^{3}$ STP/g			^{21}Ne	$10^{-8}cm^{3}$ STP/g	
Y-793605	7.60	1.09	0.241	1.207	0.23	0.178
	±0.30	±0.10	±0.012	±0.020	±0.10	±0.020
ALH77005 [1]	6.17	0.75	0.18	1.19	1.12	0.187
LEW88516 [2]	6.98	0.90	0.25	1.227	0.35	0.74

[1] BOGARD *et al.* (1984); [2] Average for data of OTT and LÖHR (1992), BECKER and PEPIN (1993), BOGARD and GARRISON (1993), EUGSTER and WEIGEL (1992), and EUGSTER *et al.* (1997).

Table 2.

Argon can be partitioned into a cosmogenic and trapped component for ^{36}Ar and ^{38}Ar by adopting $(^{36}Ar/^{38}Ar)_{tr}=5.32$, as for terrestrial atmospheric Ar and $(^{36}Ar/^{38}Ar)_{c}=0.65$, as typically observed for stone meteorites. The results are also given in Table 2. The partitioning of ^{40}Ar into a in situ produced radiogenic and a martian atmospheric trapped component is discussed below. For Y-79 we observe the lowest trapped Ne and Ar concentrations of the three lherzolites.

4. Cosmic-ray Exposure Ages and Ejection Times

The cosmic-ray exposure age of Y-79 was calculated based on the concentrations of cosmogenic ^{3}He, ^{21}Ne, and ^{38}Ar. As literature data for the chemical composition of Y-79 are presently not available we adopted average values for the production rates of the two other lherzolites (Table 3). These production rates were derived using the method of EUGSTER and MICHEL (1995) and are given in EUGSTER *et al.* (1997). The average cosmic-ray exposure age, $T_{av}=4.4\pm1.0$ Ma for Y-79 agrees within errors with those of ALH77 and LEW88.

The ejection time from Mars is given by the sum of the cosmic-ray exposure age, that is, the transfer time from Mars to Earth, and the terrestrial age, that is, the time since the meteorite fell on Earth. The terrestrial ages of the martian meteorites are in the range of a few thousand to about 300000 years (*cf.*, NISHIIZUMI and CAFFEE, 1996).

Table 3. Cosmic-ray exposure ages of lherzolites.

Meteorite	P_{3}	P_{21}	P_{38}	T_{3}	T_{21}	T_{38}	T_{av}
	$10^{-8}cm^{3}$ STP/g per Ma			Ma			
Y-793605	1.60	0.218	0.070	4.8	5.0	3.4	4.4
				±0.5	±0.7	±0.4	±1.0
ALH77005	1.61	0.233	0.062	3.8	3.2	2.9	3.3
							±0.5
LEW88516	1.60	0.204	0.079	4.4	4.4	3.2	4.0
							±0.8

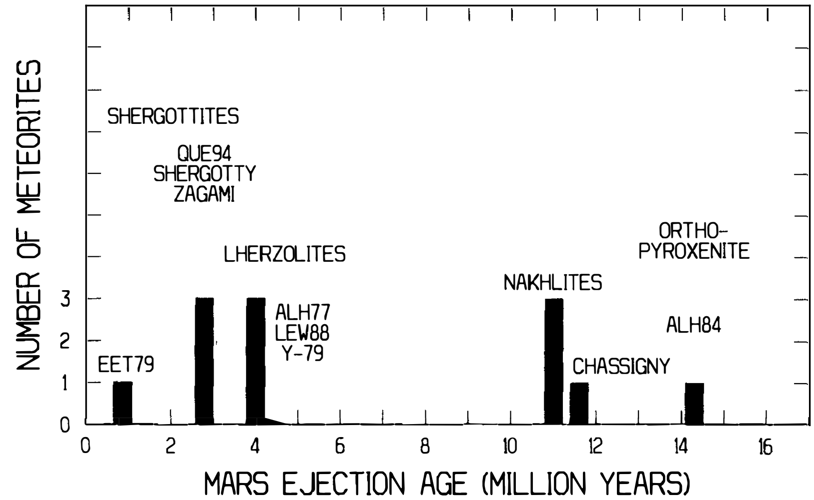

Fig. 1. Ejection times (sum of cosmic-ray exposure age and terrestrial age) for martian meteorites dated until now. For references see EUGSTER *et al. (1997).*

Thus, the ejection of Y-79 from Mars occurred 4–5 Ma ago. This time agrees within errors with that observed for ALH77 and LEW88. The three lherzolites yield an average ejection age of about 4.0 ± 0.5 Ma whereas that for the shergottites QUE94201 (2.91 Ma), Shergotty (2.71 Ma) and Zagami (2.76 Ma) is 2.79 ± 0.12 Ma (EUGSTER *et al.*, 1997). Figure 1 shows the ejection times for all martian meteorite classes, demonstrating that at least five ejection events are responsible for the production of the recovered martian meteorites. It is presently not clear whether the nakhlites and Chassigny represent one or two ejection events.

5. The Lherzolites Should Not Be Called "Shergottites"

The martian meteorite classes differ in mineral and, consequently, in chemical composition (*cf.*, MCSWEEN, 1994). The basaltic shergottites EET79, QUE94, Shergotty and Zagami consist predominantly of the clinopyroxenes pigeonite and augite, whereas the lherzolitic martian meteorites ALH77, LEW88 and Y-79 mainly consist of olivine, chromite, and orthopyroxene. In order to quantify the differences in composition (in wt%) between the martian meteorite classes we plot in Fig. 2 the Mg/Ti *versus* the Mg/Al and the Mg/Ca *versus* the Mg/Al ratios. The rectangles shown for the shergottites, lherzolites, and nakhlites represent the range of all values for the members of the respective class. Obviously, the three lherzolitic meteorites ALH77, LEW88, and Y-79 are distinct from the basaltic shergottites by factors of about seven for the three ratios shown in Fig. 2. The difference in chemical composition between the lherzolites and the basaltic shergottites is even larger than that between the nakhlites and the basaltic shergottites. Furthermore, on the oxygen isotope fractionation line for martian meteorites all three lherzolites plot in a range for $\delta^{18}O = 3.88–4.14$ and $\delta^{17}O = 2.18–2.39$, that is, below the range for the basaltic shergottites with $\delta^{18}O = 4.23–4.97$ and $\delta^{17}O = 2.31–2.76$ (CLAYTON and MAYEDA, 1996). Finally, we conclude from the noble gas isotopic studies that the Mars ejection times of the basaltic shergottites and

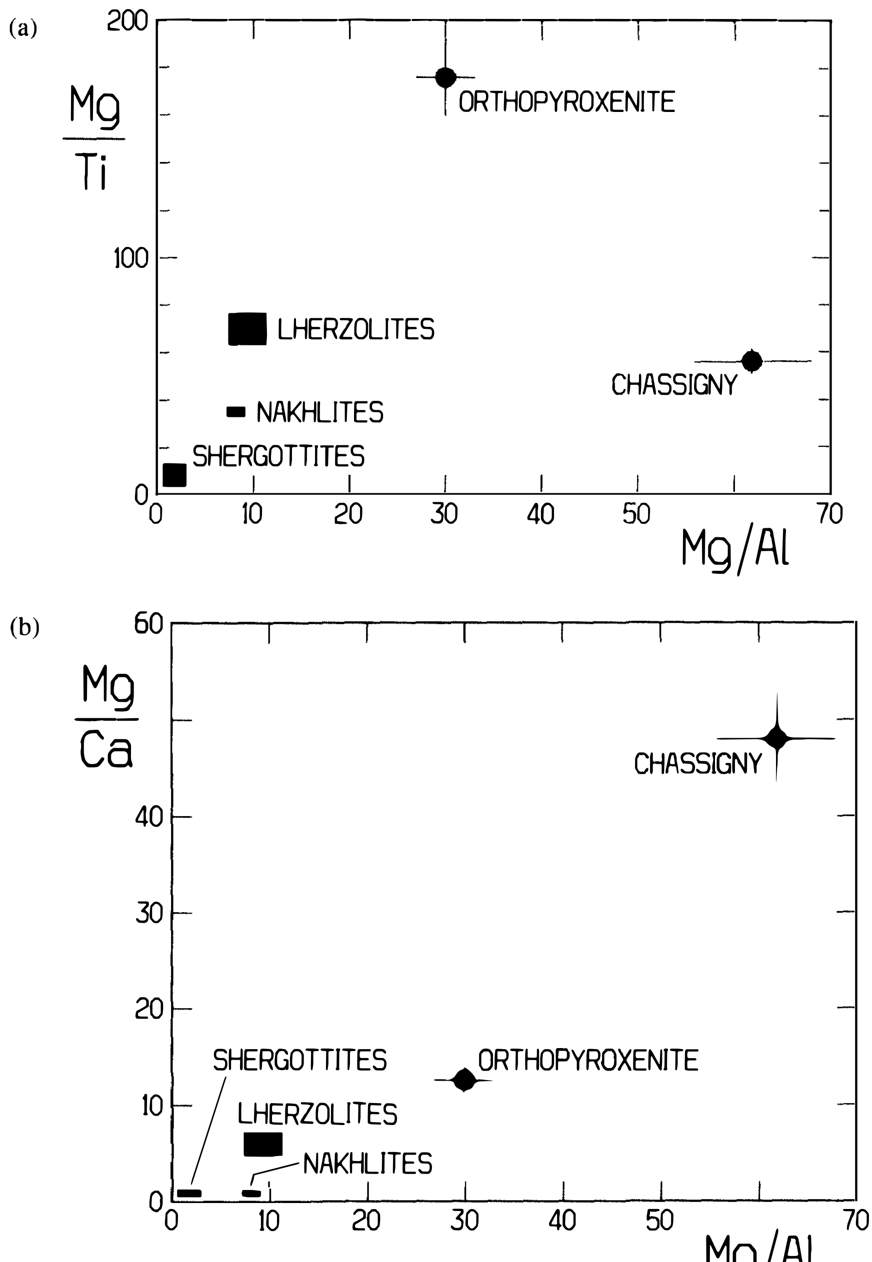

Fig. 2. (a) Mg/Ti versus Mg/Al, (b) Mg/Ca versus Mg/Al for martian meteorites. The rectangles indicate the range of the elemental ratios for the meteorites of each class. Data from TREIMAN *et al. (1986),* DREIBUS *et al. (1992),* MITTLEFEHLDT *(1994), and* WARREN *et al. (1996).*

the lherzolites do not overlap: the former ones were ejected in two events–0.8 Ma (EET79) and 2.8±0.1 Ma (QUE94, Shergotty, and Zagami), whereas the latter ones (ALH77, LEW88, and Y-79) in a earlier event 4.0±0.5 Ma ago. Hence, we propose to name the two classes "shergottites" and "lherzolites", respectively.

6. Is There a ^{40}Ar Excess in Y-793605?

Clear evidences for entrapped martian atmospheric gases characterized by an excess of ^{40}Ar and $^{40}Ar/^{36}Ar$ ratios >1600 were observed in EET79 (BOGARD and JOHNSON, 1983; BECKER and PEPIN, 1984; SWINDLE *et al.*, 1986) and in Zagami (MARTI *et al.*, 1995). If the K concentration of Y-79 is in the range of those for the other lherzolites (Table 4) a small ^{40}Ar excess is present, even assuming a gas retention age of 1300 Ma (igneous formation age of lherzolite ALH77, SHIH *et al.*, 1982). If the radiogenic ^{40}Ar is 15×10^{-8} cm^3 STP/g (180 Ma gas retention age, JONES, 1986 and MCSWEEN, 1994) the $(^{40}Ar/^{36}Ar)_{tr}$ would be 1000, indicating martian atmospheric Ar. On the other hand, if $^{40}Ar_r = 155 \times 10^{-8}$ cm^3 STP/g (1300 Ma gas retention age) the resulting $(^{40}Ar/^{36}Ar)_{tr} = 213$, close to terrestrial atmospheric $^{40}Ar/^{36}Ar = 296$.

Table 4. Excess ^{40}Ar in lherzolites.

Meteorite	K (ppm)	$^{40}Ar_{meas}$	$^{40}Ar_r$ produced in 180 Ma	$^{40}Ar_r$ produced in 1300 Ma	Excess ^{40}Ar to 180 Ma	Excess ^{40}Ar to 1300 Ma
		$10^{-8}cm^3$ STP/g				
Y-793605	210	193	15	155	178	38
ALH77005	224	137	16	166	121	0
LEW88516	199	781	15	147	766	634

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