^{53}Mn in Martian Meteorites

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Up to now, only 13 meteorites from Mars have been discovered on Earth. They have been launched by very large meteorite impacts on the Martian surface. The time of the launch can be deduced from concentrations of cosmogenic nuclides, i.e. nuclides produced by nuclear reaction of the cosmic rays with the meteoroids during their travel from Mars to Earth [1,2].

In the last years the number of these launches (and therefore, the number of the impacts) has been creeping upward with the analysis of these Meteorites. Eugster and coworkers call for three: one for EET79001 0.8 My ago; one for the three other basaltic shergottites QUE94201, Shergotty, and Zagami 2.8 My ago; and one for the three lherzolites ALH77005, LEW88516, and Y793605 4.0 My ago [3,4]. Other workers agree that the apparent cosmic-ray exposure (CRE) age of Y793605 was even longer, perhaps 5.5 My. Noting the petrographic similarity of the lherzolites, Nagao et al. [5] accommodate a single lherzolite launch through a complex exposure for Y793605. Nishiizumi and Caffee [6] comment that the shergottite data seem to call for four or more ejection events but leave the door open to a complex history for Y793605 on Mars and hence to fewer launches.

Meteorite	T_3	T_{21}	T_{10}	T_{53}
EET79001	0.61	0.65	0.69 ± 0.05	0.30 ± 0.06
QUE94201	2.1	3.2	2.5 ± 0.2	1.9 ± 0.2
Zagami	2.9	3.0	2.8 ± 0.4	2.7 ± 0.3
ALH77005	3.8-4.5	3.2-4.9	–	3.0 ± 0.4
LEW88516	4.3	4.3	3.6 ± 0.7	3.7 ± 0.3
ALH84001	15.0	14.2	–	≈ 6

Table 1: Cosmic ray exposore ages for Martian Meteorites [My]: T_3: ^{3}He age [3,15], T_{21}: ^{21}Ne age [3,15], T_{10}: ^{10}Be age, T_{53}: ^{53}Mn age.

Nyquist et al. [7] favor fewer events on the basis of two general observations: i) six of seven shergottites, all but QUE94201, have crystallization ages consistent with an origin in one area $\approx$170-180 My ago; and ii) volcanic terrain thought suitable as a source region comprises only 4% of the Martian surface. Based on new noble gas analyses and a reconsideration of production rates, L. Nyquist [8] observes that ALH77005 and Zagami could both have a CRE age between 3.5 and 5 My. By extension, perhaps all the shergottites came from one crater.

The activities of cosmogenic radionuclides can provide useful information about CRE. Unfortunately, the CRE ages of some lherzolites and shergottites approach or exceed the practical limit of two-to-three half-lives for the use of the radionuclides most commonly determined, namely, ^{14}C, ^{41}Ca, ^{36}Cl, ^{26}Al, and ^{10}Be. To obtain independent information about the CRE ages of shergottites and lherzolites, we set out to determine the activities of a longer-lived cosmogenic radionuclide, ^{53}Mn ($T_{1/2} = 3.7$ Ma). Recent developments at the Munich Tandem Laboratory have made it possible to determine ^{53}Mn/^{55}Mn ratios as low as 3×10^{-14} by using accelerator mass spectrometry [9]. ^{10}Be and ^{26}Al (in some samples) have been measured via AMS at the Prime Lab, Purdue University.

Table 1 shows published ^{3}He and ^{21}Ne CRE ages, T_3 and T_{21}, along with CRE ages calculated from measured radionuclide activities, A, through the relation $T = -ln(1 - Ae^{\lambda t} P^{-1})\lambda^{-1}$, where P is the production rate, λ the decay constant and t the terrestrial age. For a first estimate of the CRE ages a typical value for $P(^{53}\mathrm{Mn})$ under normal shielding of 420 dpm (kg Fe)$^{-1}$ [10] has been used.

EET79001 - CRE ages from noble gases, ^{10}Be (Table 1), and ^{26}Al (0.69 ± 0.08 My) agree. Estimates of the preatmospheric radius of EET79001 range from 10 to 15 cm and solar cosmic ray (SCR) irradiation apparently was unimportant [11,12], suggesting normal production rates. Unaccountably, our ^{53}Mn activity is considerably lower than reported values of 65 dpm (kg Fe)$^{-1}$ for samples [11,13], leading to a low ^{53}Mn CRE age.

QUE94201, Zagami, LEW88516 - The ^{53}Mn CRE ages agree within the uncertainties.

ALH77005 -Track data combined with an assumed CRE age of 2.5 My suggest a preatmospheric radius of 4-6 cm [11,12]. Absent SCR effects, GCR production rates at the centers of such small objects are depressed. Therefore, $P_{10} \approx 18$ atoms min^{-1} kg^{-1}, and $P_{53} \approx 300$ atoms min^{-1} (kg Fe)$^{-1}$ [14]. A much higher published ^{53}Mn activity of 270$\pm$15 dpm (kg Fe)$^{-1}$ [11] (compared to 128$\pm$9, measured in this work) in different sample ALH77005,11 reflects irradiation by SCR.

ALH84001 - ^{26}Al and ^{10}Be activities are close to normal production rates, placing a lower bound on the CRE age of 3-4 My, and indicating normal shielding during that time. Noble gas CRE ages of $\approx$14 My imply a 4π irradiation long enough to have saturated ^{53}Mn, contrary to observation. The measured activity is consistent with a 4π irradiation lasting 6 My. One interesting difference between SNC meteorites and lunar meteorites has been the absence of evidence in the former for pre-irradiation on the parent body. Perhaps ALH84001 inherited an appreciable portion of its noble gases, but not of other radionuclides, during pre-exposure deep on Mars. Relatively high ^{21}Ne/^{22}Ne ratios may pose a difficulty for this scenario, however. Xenon isotopic ratios could provide a check.

References

[1] M. Honda, J.R. Arnold, Science **143** (1964) 203
[2] D.E. Alvarez *et al.*, Jahresbericht 1997, p. 66
[3] O. Eugster *et al.*, Geochim. Cosmochim. Acta **61** (1997) 2749
[4] O. Eugster, O. Polnau, Antarct. Meteorite Res. **10** (1997) 143
[5] K. Nagao *et al.*, Antarct. Meteorite Res. **10** (1997) 125
[6] K. Nishiizumi, M. Caffee, Antarctic Meteorites **XXII** (1997) 149
[7] L.E. Nyquist *et al.*, Lunar Planet. Sci. **XXIX** (1998) 1688
[8] L.E. Nyquist, pers. comm. to G.F.H.
[9] K. Knie *et al.*, Nucl. Instr. Meth. B **2000** (in press)
[10] S. Vogt *et al.*, Rev. Geophys **28** (2000) 253
[11] K. Nishiizumi *et al.*, Meteoritics **21** (1986) 472
[12] N. Bhandari *et al.*, Geochim. Cosmochim Acta **50** (1986) 1023
[13] R. Sarafin *et al.*, Earth Planet. Sci. Lett. **75** (1985) 72
[14] N. Bhandari *et al.*, Geochim. Cosmochim Acta **57** (1993) 2361
[15] D.H. Garrison, D.D. Bogard, Meteoritics **33** (1998) 721