DEPTH AND SIZE EFFECTS ON COSMOGENIC NUCLIDE PRODUCTION IN METEORITES

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1. Introduction. The galactic cosmic particle radiation (GCR) can cause changes in condensed extraterrestrial matter in different ways. It can lose energy via ionization processes or induce nuclear reactions which lead to a wide variety of stable and radioactive cosmogenic nuclides. Which process dominates depends on the charge and the energy of the particle radiation and on the nature of the extraterrestrial object exposed to this radiation, i.e. its size, chemical and mineralogical composition. Heavy particles ($Z \geqq 20$) incur radiation damage in minerals such as olivine and pyroxene. Light particles predominantly tend to induce nuclear reactions, causing the development of a secondary particle cascade of neutrons, protons, pions and γ-rays and the production of cosmogenic nuclides. Such processes are described in detail by various models [1,2], which predict the depth and size dependent production of cosmogenic nuclides.

The two principal approaches to the study of these effects are simulation experiments and direct observations of meteorites. While the simulation experiments may have advantages with respect to a better understanding of the production processes and the development of secondary hadron cascades in extended matter [3], measurements of depth profiles of cosmogenic nuclides in meteorites fulfill two functions: They are the criterion for the validity of the model calculations and simulation experiment results and they establish an empirical network of cosmogenic nuclide relations, which may help to answer questions about the history of both the GCR and the meteorites. This study focusses on the long-lived cosmogenic nuclides ^{53}Mn, ^{26}Al and ^{10}Be, the light noble gases and cosmic ray tracks (CRT), keeping in mind that many other nuclides determined also bear valuable information.

2. Methods. In order to systematically study depth and size effects of cosmogenic nuclides in meteorites, one has to find objects of known preatmospheric size which survived entry into the earth's atmosphere with only a few cm of ablation losses. In addition, well-documented samples from a core drilled through the meteorite or from otherwise accessible parts must be available for a successful study. Table 1 lists a number of meteorites which fulfill these criteria and of which cosmogenic nuclides and CRT's have been measured extensively. In addition, several other meteorites are reported in the literature, for which a part of these measurements have been done [4,5]. The meteorites are listed in order of increasing preatmospheric radius ranging from 5 cm (77003) to approx. 1m (Jilin)[6]. The coverage of the full range of shielding depths is not always complete, as in

Table 1: Cosmogenic nuclide depth profiles in meteorites

Meteorite	Preatm. radius [cm]	^{53}Mn	^{26}Al	^{10}Be	light rare gases	cosmic ray tracks
ALHA77003	6	[T1]	[T2]	----	[T1]	P
ALHA78084	14	[T3,4]	[T3,4]	[T5]	[T4]	[T4]
Lost City	18	[T6]	[T7]	----	[T8]	[T9]
St. Severin	25	[T10,11]	----	[T12]	[T13]	[T14]
Keyes	25	[T15]	[T16]	P	[T17]	[T18]
Dhurmsala	>30	[T3,19]	[T3,19]	P	[T19]	[T19]
Jilin	85	[T20]	[T20]	[T20]	[T20]	[T20]

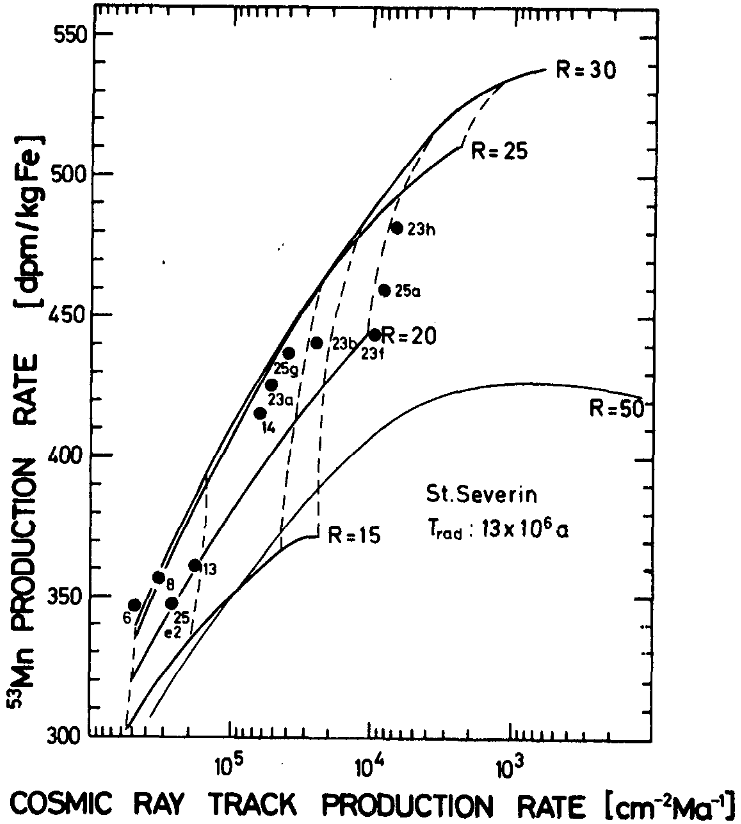
Footnotes: P - in preparation. [T1] P.Englert et al. (1982), Lun. Planet. Sci. XIII, 201. [T2] J.C. Evans et al. (1979), Proc. Lun. Planet. Sci. Conf. 10th, 1061. [T3] P.Englert et al. (1982), Fifth Int. Conf. Geochron., Nikko, Japan, 89. [T4] R.Sarafin et. al (1985), Earth Planet. Sci. Lett., to be published. [T5] R.K. Moniot et al. (1982), Nucl. Instr. Meth. 203, 495. [T6] P.Englert (1985), Lun. Planet. Sci. XVI, 215. [T7] P.J. Cressy (1971), J. Geophys. Res. 76, 4072. [T8] D.D. Bogard et al. (1971), J. Geophys. Res. 76, 4076. [T9] J.C. Lorin and P.Pellas (1975), Meteoritics 10, 445. [T10] P.Englert and W.Herr (1980) Earth Planet. Sci. Lett. 47, 361. [T11] S.K. Bhattacharya et al. (1980) Earth Planet. Sci. Lett. 51, 45. [T12] C.Tuniz et al. (1984), Geochim. Cosmochim. Acta 48, 1867. [T13] L.Schultz and P.Signer (1976), Earth Planet. Sci. Lett. 30, 191. [T14] Y.Cantelaube et al. (1969), In: Meteorite Research, (P.Millman, ed.), 705. [T15] P.Englert (1984), Lun. Planet. Sci. XV, 248. [T16] P.J. Cressy (1975), J.Geophys. Res. 80, 1551. [T17] R.J. Wright et al. (1973), J. Geophys. Res. 78, 1308. [T18] J.C. Lorin and G.Poupeau (1978), Meteoritics 13, 410. [T19] J.T. Padia et al. (1984), Meteoritics 19, 288. [T20] Jilin Consortium Study I (1985), Earth Planet. Sci. Lett. 72, 246.

Dhurmsala and Lost City. In the case of 77003, possible contributions of the solar cosmic radiation to the ^{26}Al- and ^{53}Mn production are discussed [7]. Jilin, which underwent a two stage irradiation, provides a model for different irradiation geometries in space, depending on the half life of the cosmogenic nuclide considered [6].

Figure 1 is an example of the kind of multiple two dimensional relations which have been established for depth and size studies of the cosmogenic nuclide production in meteorites. The solid lines compare the semiempirical models for the ^{53}Mn production [1] and the CRT-production [8] in meteorites. The symbols represent same sample measurements of the ^{53}Mn and CRTs in core AIII of St. Severin [9,10]. If several cosmogenic nuclides are determined in one or two samples, this and other relations can be used to derive shielding depths in and preatmospheric sizes of meteorites.

3. Results and Discussion. Table 2 combines results of ^{53}Mn and other cosmogenic nuclides measured predominantly in meteorite falls with high exposure ages (exception: Leedy and

FIGURE 1



New Concord). All of these meteorites are saturated with respect to the long-lived cosmogenic nuclides. Thus, only depth and size effects or complex irradiation histories can be responsible for the GCR-product signatures.

In general, $^{22}Ne/^{21}Ne$-ratios on the order of 1.1±0.3 indicate well-shielded locations within a meteorite. Thus the majority of the meteorite samples in Table 2 come from shielding depths as they can be found in Dhurmsala [11] and Jilin [10]. This conclusion is in agreement with most of the ^{53}Mn, ^{26}Al and ^{10}Be data.

Preatmospheric mass determinations via CRTs are given for Aztec (18kg) and Hainhotz (260 kg) and were tried for Rangala and Leedy without conclusive results [12]. In the case of Hainhotz, the ^{53}Mn activity of 352±21 dpm/kg Fe confirms the CRT result. Aztec, however, must have been a larger object in space than indicated by the CRT measurements, because of its low $^{22}Ne/^{21}Ne$ ratio and a ^{53}Mn production rate of 339±28 dpm/kg Fe, exceeding that of small bodies if compared with ALHA 77003 and ALHA 78084 [13,14]. Discrepancies between the ^{53}Mn production rates and $^{22}Ne/^{21}Ne$ ratios exist for some meteorites with very long exposure ages, such as H-Ausson, Charsonville, Breitscheid and Yocemento and are probably best explained by complex irradiation histories. [15].

Table 2:

Meteorite	Class	Recov.(a) mass [kg]	$(^{22}Ne/^{21}Ne)_c$	^{21}Ne(b) $[10^{-8} cm^3 STPg^{-1}]$	T_{21}(c) $[10^6 y]$	^{53}Mn(d) [dpm/kg Fe]	^{26}Al [dpm/kg]	^{10}Be(h) [dpm/kg]	(i)
Alfianello	L6	228S	1.103	8.40	26.2	490±25	55.5±3.5(f)	--	NNNN
Aztec	L6	2.83	1.103	11.20	35.0	339±28(e)	--	--	YYOO
Breitscheid	H5	1.0	1.075	9.25	27.0	297±18(e)	--	--	YYOO
Charsonville	H6	>27	1.066	22.00	61.2	333±23(e)	--	--	YYOO
Ergheo	L5	20	1.089	7.31	16.3	415±20	57.0±2.5(f)	--	YYNO
Kuyahinya	L5	500S	1.098	11.20	34.2	403±32	57.0±2.5(g)	--	NNNO
Merzö-Madras	L3	27.7S	1.085	9.77	28.0	447±23	55.0±2.3(g)	--	YYNO
Rangala	L6	3.2	1.078	9.14	25.2	485±25	54.2±2.2(d)	--	YYYO
Rose City	H5	>11	1.042	9.42	22.7	464±25	56.0±3.5(f)	--	YYNO
Khairpur	E6	>15	--	--	--	401±24	--	--	OOOO
Leedy	L6	50	1.085	2.34	6.1	410±34	--	--	NNOO
New Concord	L6	226	--	0.90	3.0	174±11	--	--	NNOO
H-Ausson	(H)	(50)	1.101	21.70	72.2	302±20(e)	--	--	YYOO
Ausson	L6	50	1.094	20.20	60.5	356±21	62±5(h)	--	NNNO
Menow	H4	10.5	1.16	4.90	17.5	382±32(k)	60±6(h)	19.6±2.0	YYYY
Selden	LL5	1.56	--	15.50(h)	≧50	359±28(k)	--	19.2±2.8	OYOY
Yocemento	L5	5.92	--	20.10(h)	≧65	256±26(k)	--	17.6±2.2	OYOY
Hainholtz	MES	16.5	--	5.80	19.5	352±21	--	--	ONNO

Footnotes: (a) M.H.Hey (1966), Catalogue of Meteorites. (b) L.Schultz and H.Kruse (1978), Nucl.Track Det. 2, 65. (c) K.Nishiizumi et al. (1980), EarthPlanet.Sci.Lett. 50, 156. (d) this work. (e) W.Herr et al. (1981), Meteoritics 16, 324. (f) I.R.Cameron and Z.Top (1975), Geochim.Cosmochim.Acta 39, 1705. (g) D. Heymann and E.Anders (1967), Geochim.Cosmochim.Acta 33, 653. (h) R.K.Monict et al. (1983), Geochim. Cosmochim.Acta 47, 1887. (i) Two Y confirm that aliquots of the same sample were analyzed for cosmogenic nuclides. (k) preliminary results.

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