Cosmogenic Radionuclides in the Bondoc Meteorite

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Abstract

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Long-lived cosmogenic radionuclides were measured in the stone phase and a mechanically separated metallic nodule from a fragment of the Bondoc mesosiderite. Activity levels of the various radionuclides in both phases, along with results of mass spectrometric measurements of rare gas isotopes in the stone phase, indicate that heavy shielding was the chief cause of the observed low specific activities.

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The discovery and some of the properties of the Bondoc meteorite, a mesosiderite of unusual structure, have been discussed by Nininger (1). A measurement of its Al^{26} content gave 5.0 ± 1.7 dpm (disintegrations per minute) kg^{-1}, about a factor of 10 lower than that in the average chondrite. The low Al^{26} activity can be explained by one or a combination of three causes; namely, short cosmic-ray exposure age, long terrestrial age, or shielding.

In order to better resolve these possibilities we have measured a number of cosmogenic radionuclides in both a metallic nodule and the remaining silicate phase of the Bondoc meteorite. The results are given in Table 1. The fact that both the metallic nodule and the remaining phase contain Mn^{53} activity ($T\frac{1}{2}$ = 2 x 10^6y) in reasonable amounts precludes a short cosmic-ray exposure age of 4 - 10 x 10^4y. Manganese-53 activity per unit mass of iron (the most probable target for production) is 0.13 ± 0.01 dpm g^{-1} in both samples, strongly suggesting that both nodule and stone phase were together in space at the same depth in the pre-atmospheric body for at least the last few million years. The Be^{10} activity ($T\frac{1}{2}$ = 2.7 x 10^6y) of 1.8 ± 0.3 dpm kg^{-1} is about a factor of 11 lower than found in most chondrites. If this were due to a short cosmic-ray exposure (370,000 y), then the expected Al^{26} activity ($T\frac{1}{2}$ = 7.4 x 10^5y) would be 29% of its saturated value, i.e., 54 x 0.29 = 16 dpm kg^{-1}, which is not in agreement with the measured values.

Table 2 lists stable rare gas isotope concentrations in the silicate phase of Bondoc; the data of Cobb (2) was obtained on a portion of the specimen studied here. The sample studied by Hintenberger, et al., (3) may have come from the same 10 kg parent fragment from which ours was taken. Values of the exposure age can be calculated from the data in Table 2, using isotope production rates of 2.0 and 0.249 x 10^{-8} cc (STP) g^{-1} per million years (4) for He^3 and Ne^{21} respectively. The resulting ages range from four to twelve million years. Even 4 x 10^6y is too long to account for the observed low activities. In view of the observed deficiencies in radionuclide contents, the actual exposure age is probably greater than 20 million years.

The appreciable levels of Ni^{59}, Cl^{36} and Mn^{53} activities in the nodule preclude the possibility that long terrestrial age is the cause of the general reduction in specific activities. The observed Ni^{59} activity is equivalent to about 0.7 dpm per gram of nickel, to be compared with an average of about 1 dpm g^{-1} nickel in most irons (5). This lower Ni^{59} activity corresponds to a terrestrial age of about 4 x 10^4y, sufficient to reduce the saturated Cl^{36} activity by about 10%, and too short to have any effect on Mn^{53} activities. Yet the observed Cl^{36} activity is a factor of 3-6 lower than average values in irons, and the Mn^{53} activity is a factor of 2-3 low. Even allowing for the probability that the production of Ni^{59} from nickel may be enhanced by a factor of 2-4 in a stony matrix (6, 7) only increases the possible terrestrial age to a maximum of 200,000 years, still too short to account for the Cl^{36} result, to say nothing of Mn^{53}.

A comparison of Be^{10} and Al^{26} in the stone phase yields a similar conclusion. If the Be^{10} activity has been reduced to 10% of its saturated value because of a long terrestrial age, then an age of 9 x 10^6y is indicated, sufficient that no measurable Al^{26} would remain.

This leaves only shielding as the major cause of the low activities. From a radiochemical analysis of stone meteorites (7) we would expect, in a shielded sample containing 1.8 dpm Be^{10} per kilogram of Bondoc silicate, about 6 dpm Al^{26} and 35 dpm Mn^{53}, in good agreement with the observed activities in the stone phase of Bondoc. The expected Ni^{59} activity is quite uncertain, but should probably be in the neighborhood of 1 dpm g^{-1} nickel, or 32 dpm kg^{-1} silicate. The observed Cl^{36}, Mn^{53}, and Ni^{59} activities in the nodule are compatible with a depth of 20-25 cm in a very large iron (5) or approximately 50 cm in a smaller stony-iron.

Assuming that the recovered Bondoc meteorite represents the center of the original body, a lower limit to the pre-atmospheric mass can be estimated. Our measurements were made on a fragment from the outer portion of the 890-kg recovered mass (equivalent to a stony-iron sphere of about 35-cm radius). Approximately 30 cm of stony-iron material would be required to equal the shielding effect of 20-25 cm of nickel-iron. The resulting 65-cm-radius stony-iron would have a mass of about 7000 kg.

In an independent calculation, assuming that the primary cosmic radiation is attenuated in a meteorite with a mean absorption of 200 g cm^{-2}, a pre-atmospheric mass of greater than 6000 kg is necessary to account for the factor-of-ten attenuation in Be^{10} and Al^{26} activities, assuming a logarithmic dependence of specific activity with depth. Since both the Be^{10} and Al^{26} are produced in significant amounts by the secondary flux in stone meteorites (which increases initially with depth before dropping off), this last assumption is not completely valid; i.e., the result is probably low. If the

Bondoc specimen did not come from the center of the original body, then, by either calculation, the pre-atmospheric mass was greater than 6000-7000 kg.

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References and Notes

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Table 1. Cosmogenic Radioactivities in Bondoc

	Mass g	% Fe	% Ni	Activity (dpm kg^{-1})				
				Be^{10}	Al^{26}	Mn^{53}	Ni^{59}	Cl^{36}
Nodule	120	84	7.7			106 ± 7	52 ± 6	3.0 ± 0.9
Silicate	360	33.9	3.19	1.8 ± 0.3	6.0 ± 0.9	43 ± 4	≤ 40	

Table 2. Stable Rare Gas Isotopes in Bondoc

Concentrations (10^{-8} cc (STP) g^{-1})

Phase	He^3	He^4	Ne^{20}	Ne^{21}	Ne^{22}	Ar^{36}	Ar^{38}	Ar^{40}	Ref.
Silicate	9.12	169	2.8	2.9	3.0	1.12	0.68	330	(2)
	8.28	206	1.75	1.67	1.68				(3)