Proc. NIPR Symp. Antarct. Meteorites, 7, 225–229, 1994

TERRESTRIAL AGES OF THE ANTARCTIC METEORITES MEASURED BY THERMOLUMINESCENCE OF THE FUSION CRUST: II

Shigeyoshi MIONO[1] and Akio NAKANISHI[2]

[1] *Department of Physics, Osaka City University, Sumiyoshi-ku, Osaka 558*
[2] *Department of Physics, Shiga University of Medical Science, Otsu 520–21*

Abstract: The acquired doses of Antarctic meteorites for dating of terrestrial ages were measured by the thermoluminescence (TL) intensity of fusion crust. It is now clearer that there is a significant correlation between the acquired dose and terrestrial age, which was previously measured by cosmogenic radionuclide abundance. Also, the ^{36}Cl method by accelerator mass spectrometry seems to provide a large terrestrial age occasionally.

1. Introduction

It is important in research on Antarctic meteorites to know their terrestrial ages as well as exposure ages, however, there are only a small number of meteorites of which terrestrial ages have been measured. For measurement of terrestrial age, the thermoluminescence (TL) technique is easier than other methods. The TL intensity of the fusion crust was reset to zero due to heating during atmospheric passage, and subsequently increased with time due to environmental radiation. The terrestrial age can thus be derived from the acquired dose of the fusion crust divided by the annual dose. In a previous study (MIONO *et al.*, 1990), we confirmed that the TL intensity decreases from the interior to the fusion crust, and the terrestrial age can be measured within 1 mm of the fusion crust. We also measured the acquired doses of 14 Antarctic meteorites. In this study, 13 Antarctic meteorites have been added to the results. The procedures of sample preparation and measurement are the same as described in the previous paper.

2. Results

Five mg powdered samples of fusion crusts were measured. An additive dose of 30 Gy from a ^{60}Co gamma ray source was given to some of the samples of each meteorite. The acquired dose of the fusion crust was estimated from the ratio of natural TL intensity to natural + artificial TL intensity. The terrestrial ages of 19 out of 27 meteorites were known, having been obtained by measuring the abundances of cosmogenic radionuclides with accelerator mass spectrometry (AMS) (NISHIIZUMI *et al.*, 1989). The plots of the acquired doses against the terrestrial ages are shown in Fig. 1, also summarized in Table 1 with ages measured by AMS. Four Yamato meteorites marked M, Y-74647, Y-791630, and P; Y-74155, Y-74156 (to be paired) in this figure deviate from other Yamato meteorites. Since we noticed that there is a possibility of contamination from the interior part in the sample preparation, because these fusion crusts are curved inward about Y-791630 and Y-74647, we recently measured the acquired doses using new samples and obtained new values which shift as shown in the same figure. It is indisputable that Y-74155 and Y-74156 are paired, because these pieces were found approximately 30 m apart on bare ice and matched mechanically (Yanai, 1981), and the terrestrial age of Y-74156 was given by AMS (Nishiizumi *et al.*, 1989).

3. Discussion

It can be considered that there is no contribution of radioactivity in ice, and meteorites move with the ice sheet. They, accordingly, had been irradiated by cosmic rays and radiation from radioactive nuclides which were contained in themselves. Generally, U and Th contents in ordinary chondrites are lower than

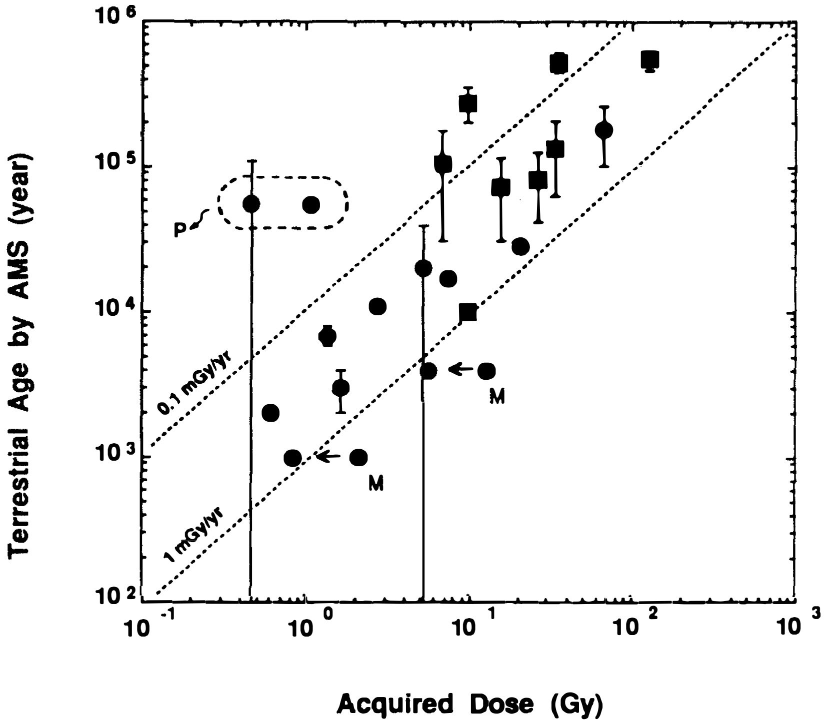

Fig. 1. A plot of terrestrial age measured by AMS against acquired dose measured by the TL.
●; Yamato meteorites.
■; Allan Hills and Meteorite Hills meteorites.
The upper and lower dotted lines show the annual dose, assumed to be 0.1 mGy/yr and 1 mGy/yr respectively.
The solid line shows a mean value, $T=2\times10^3 D(Gy)$.
Yamato meteorites marked M and P are explained in the text.

Table 1. Terrestrial ages acquired dose of Antarctic meteorites.

Meteorite		Terrestrial age by AMS ($\times 10^3$ yr)	Acquired dose (Gy)	Terrestrial age by TL ($\times 10^3$ yr)
Y-7304,90	(L6)	7±1 (^{14}C)	1.4	
Y-74014,100	(H6)	11 (^{14}C)	2.8	
Y-74156,89	(H4)	55±55 (^{36}Cl)	0.46	
Y-74191,110	(L3)	17 (^{14}C)	7.5	
Y-74192,89	(H5)	20±20 (^{36}Cl)	5.3	
Y-74364,92	(H4)	180±80 (^{36}Cl)	66.8	
Y-74647,98	(H5)	4 (^{14}C)	5.7	
Y-75102,75	(L6)	3 (^{14}C)	1.7	
Y-75271,88	(L5)	2 (^{14}C)	0.6	
Y-791500,86	(H3)	28 (^{14}C)	20.7	
Y-791630,90	(L4)	1 (^{14}C)	0.83	
ALH-76008,79	(H5)	100±70 (^{36}Cl)	7	
ALH-77281,95	(L6)	520±80 (^{36}Cl)	133	
ALH-77282,89	(L6)	270±70 (^{36}Cl)	10	
ALH-77294,86	(H5)	10±1 (^{14}C)	10	
ALH-77297,81	(L6)	80±40 (^{36}Cl)	27	
ALH-78043,81	(L6)	500±80 (^{36}Cl)	36	
ALH-78076,81	(H6)	130±70 (^{36}Cl)	34	
MET-78028,81	(L6)	70±40 (^{36}Cl)	16	
Y-74115,101	(H6)		3.0	6
Y-74155,87	(H4)		1.1	2
Y-74190,96	(L6)		36.6	73
Y-74362,89	(L6)		47.2	94
Y-74371,87	(H4)		2.9	6
Y-75097,44	(L6)		20.0	40
Y-81124,93	(H5)		7.8	16
ALH-76009,102	(L6)		34.6	69

Terrestrial ages by TL are estimated from the annual dose to be 0.5 mGy/yr.
At present, it is difficult to estimate the standard error of measurement. In most measurements, it is impossible to measure several times because sufficient quantities of the meteorite samples were not provided. However, they are estimated to be less than ±20% at maximum.

those in terrestrial rocks, therefore the radioactive nucleides are ^{40}K and long-lived cosmogenic nucleides (*i.e.* ^{14}C, ^{26}Al, ^{36}Cl). However, typical activities of ^{40}K, ^{14}C, ^{26}Al and ^{36}Cl in an ordinary chondrite are 26, 0.83, 0.95 and 0.38 Bq/kg, respectively (BEUKENS *et al.*, 1988; EVANS and REEVES, 1987; NISHIIZUMI *et al.*, 1989), where typical activity of ^{40}K was calculated using a mean K content for chondrites (MASON, 1971). Then we take the annual dose from ^{40}K into account; it is estimated to be approximately ~0.1 mGy/yr. The upper and lower dotted lines represent the annual doses which are assumed to be 0.1 mGy/yr and 1 mGy/yr respectively in Fig. 1. Most data are suppressed within the two dotted lines except Y-74155, Y-74156, ALH-76008, ALH-77282 and ALH-78043. A mean annual dose except these meteorites was calculated to be ~0.5 mGy/yr. Therefore, if we express the relation of terrestrial age, *T*, and acquired dose, *D*, by an emprical equation using the data except these, we obtain the following;

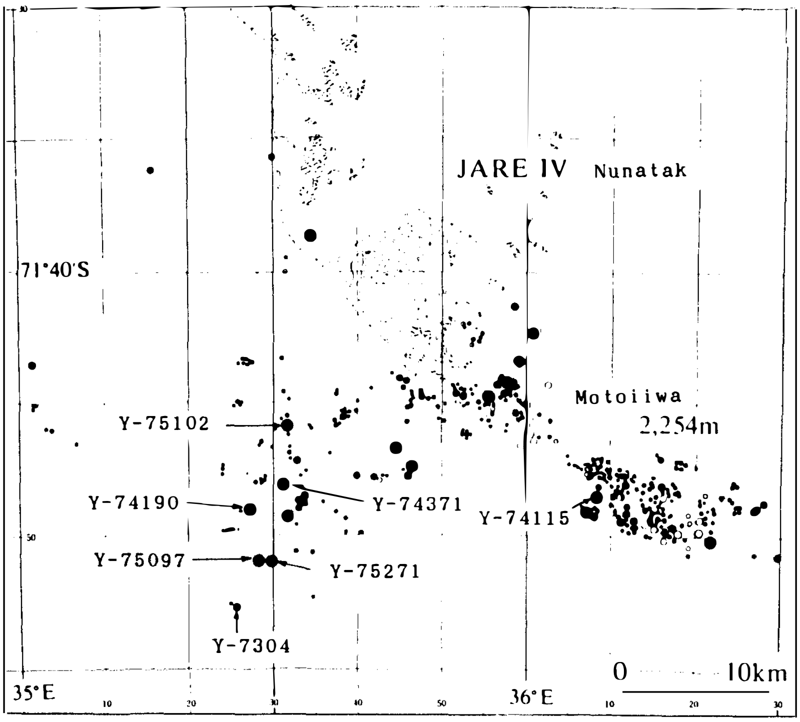

Fig. 2. Occurrence of the Yamato meteorites from YANAI *(1983).*

$$T=(2\pm0.4)\times10^3D(\mathrm{Gy})\ .$$

The annual dose contributed from cosmic rays at the surface of ice sheet where the meteorites were collected is calculated to be 0.3–0.4 mGy/yr (PRESCOTT and STEPHAN, 1982). Then the annual dose can be expected to be 0.4–0.5 mGy/yr, and this value is consistent with the obtained result in Fig. 1.

The terrestrial age of Y-74155 by TL technique is 2000 year. According to NISHIIZUMI *et al.* (1989), ^{36}Cl terrestrial age shorter than 60000 year provides only an upper limit. Thus it is a plausible that the terrestrial ages of Y-74155 and Y-74156 become much shorter than the age given by AMS.

In this study, a set of five meteorites (Y-7304, Y-75102, Y-75271, Y-74190, Y-75097) and another set of two meteorites (Y-74115, Y74371) are suggested to be paired (HONDA, 1981; TAKAOKA *et al.*, 1981). Y-74115 and Y-74371 show almost the same terrestrial age, but the set of five meteorites show different terrestrial ages. It is preferable to regard these five meteorites as meteorite shower from the occurrence configuration map of the Yamato 69–75 series meteorites shown in Fig. 2, but not plausible to explain this difference of acquired doses by experimental error. Consequently, it seems that the all were parted from same parent body but fell to the earth sequentially between 1200 and 74000 years ago. In any case, further study is necessary.

4. Conclusions

We offer a firm basis for establishing the TL method using fusion crust for the terrestrial ages of Antarctic meteorites. In conclusion the following should be emphasized:

1) It is necessary to prepare a much greater quantity (~50 mg) of the fusion crust sample from the flat surface of the meteorites, then we would be able to provide the reliable terrestrial age within ±20% standard error.

2) Judging from our terrestrial ages measured by TL, the ^{36}Cl method by AMS provides too large terrestrial age occasionally. Especially in the case of ALH-76008, ALH-77282 and ALH-78043, ^{36}Cl ages by AMS should be reexamined at a future opportunity.

3) It is inadequate suggestion of "same fall" or "meteorite shower" by results of noble gas mass spectrometry, because they only provide extraterrestrial history of meteorite. They don't provide information of time sequence of meteorite fall. Consequently, it is also important for pairing study to measure the terrestrial age of meteorite.

Acknowledgments

The authors are indebted to Prof. K. YANAI and Dr. H. KOJIMA of National Institute of Polar Research for offering the meteorite samples.

References

BEUKENS, R. P., RUCKLIDGE, J. C. and MIURA, Yasunori (1988): ^{14}C ages of 10 Yamato and Allan Hills meteorites. Proc. NIPR Symp. Antarct. Meteorites, **1**, 224–230.

EVANS, J. C. and REEVES, J. H. (1987): ^{26}Al survey of Antarctic meteorites. Earth Planet. Sci. Lett., **82**, 223–230.

HONDA, M. (1981): Terrestrial history of Antarctic meteorites recorded in the cosmogenic nuclides. Geochem. J., **15**, 163–181.

MASON, B. (1971): Handbook of Elemental Abundances in Meteorites. New York, Gordon & Breach.

MIONO, S., ONO, H., KUJIRAI, K., YOSHIDA, M. and NAKANISHI, A. (1990): Terrestrial ages of Antarctic meteorites measured by thermoluminescence of the fusion crust. Proc. NIPR Symp. Antarct. Meteorites, **3**, 240–243.

NISHIIZUMI, K., ELMORE, D. and KUBIK, P. W. (1989): Update of terrestrial ages of Antarctic meteorites. Earth Planet. Sci. Lett., **93**, 299–313.

PRESCOTT, J. R. and STEPHAN, L. G. (1982): The contribution of cosmic radiation to the environmental dose for thermoluminescence dating. Latitude, altitude and depth dependences. PACT, **6**, 17–25.

TAKAOKA, N., SAITO, K., OHBA, Y. and NAGAO, K. (1981): Rare gas studies of twenty four antarctic chondrites. Mem. Natl Inst. Polar Res., Spec. Issue, **20**, 264–275.

YANAI, K. comp. (1981): Photographic Catalog of the Selected Antarctic Meteorites. Tokyo, Natl Inst. Polar Res., 104 p.

YANAI, K. comp. (1983): Locality map of Antarctic meteorites of the Yamato Mountains Queen Maud Land, Antarctica—Yamato-69, -73, -74 and -75 Meteorites Collections—. Tokyo, Natl Inst. Polar Res.

(Received August 2, 1993; Revised manuscript received January 4, 1994)