Proc. NIPR Symp. Antarct. Meteorites, **3**, 264–269, 1990

AGE OF YAMATO K-26 ICE BASED ON URANIUM-SERIES DISEQUILIBRIUM

Edward L. Fireman

Smithsonian Astrophysical Observatory, Cambridge,
Massachusetts 02138, U.S.A.

Abstract: The ^{226}Ra, ^{230}Th, ^{234}U, and ^{238}U dissolved in two ice samples removed from a 20-kg block of Yamato ice with tephra band K-26 were measured. One sample, 1.50 kg of ice containing the band, had 252 mg of particulates; the other sample, 1.78 kg of ice outside the band, had 5.7 mg of particulates. The activities are disequilibrated in the 1.50-kg ice sample, with 0.0333 ± 0.0010 dpm/kg (decays per minute per kilogram of ice) of ^{226}Ra, 0.0178 ± 0.0005 dpm/kg of ^{230}Th, 0.0148 ± 0.0005 dpm/kg of ^{234}U, and 0.0128 ± 0.0005 dpm/kg of ^{238}U. On the other hand, these activities are equilibrated, being, each, 0.013 ± 0.001 dpm/kg, in the 1.78-kg ice sample. The activities are also in equilibrium in the tephra. The tephra particles contribute a significant amount of ^{226}Ra, a lesser amount of ^{230}Th, a small amount of ^{234}U, and no ^{238}U to the ice. The results are consistent with the idea that alpha decays in the small tephra particles cause daughter products to recoil into the ice. The age of the ice based on the ratios of the daughter activity excesses in the 1.50-kg ice sample is $(38 \pm 7) \times 10^3$ years. This age is at the lower bound of the $(75 \pm 30) \times 10^3$ year terrestrial age of three lunar meteorites recovered 25 km north of the K-26 site.

1. Introduction

The ice ablation zone near the Yamato Mountains was the first meteorite collecting area discovered in Antarctica (Yanai, 1981). During the past year, we received a 20-kg block of ice with tephra band (K-26) from F. Nishio of the National Institute of Polar Research, Tokyo, Japan. The physical and chemical properties of the tephra in this ice had been studied (Nishio *et al.*, 1984, 1985; Fukuoka *et al.*, 1987) and compared to the tephra in ice from Allan Hills. The tephra consists almost entirely (95%) of fine glass shards (8–63 μm in length), which are smaller than the particulates in the Allan Hills tephra (Nishio *et al.*, 1984). The K-26 tephra also differs in its chemical composition from the Allan Hills tephra having much lower thorium and uranium contents; the Th contents in the K-26 shards are between 0.06 and 0.11 ppm, nearly a factor of 100 lower than in the Allan Hills shards (Fukuoka *et al.*, 1987). The Yamato K-26 glass shards resemble magmas associated with volcanos in the South Sandwich Islands, while the Allan Hills glass shards resemble magmas associated with volcanos in the McMurdo Group.

Figure 1 is a map of a section of the Yamato ice field giving the direction of the ice flow and the locations of the K-26 tephra band and several nearby tephra bands (the wiggly lines in the map) and the locations of several meteorites. The terrestrial

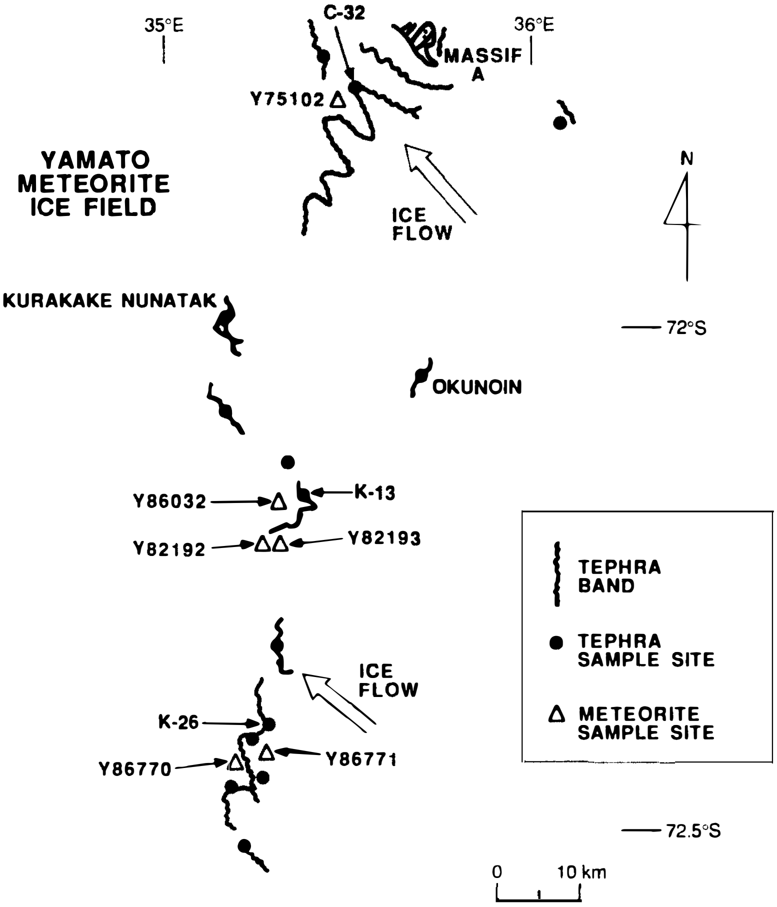

Fig. 1. Map of the Yamato ice field in the neighborhood of the K-26 tephra band.

ages of several of the meteorites in the neighborhood of this ice sample have been measured and range from $(3.0 \pm 1.2) \times 10^3$ to $(83 \pm 35) \times 10^3$ years. Their terrestrial ages are younger than most meteorites from the Main Allan Hills Icefield.

We measured the ages of tephra-laden polar ice samples by the uranium-series method (FIREMAN, 1986a, b). W. A. CASSIDY has supplied us with a number of tephra-banded ice samples from the Allan Hills Main Icefield (76°15'S, 159°E); their uranium-series ages are very old, ranging from 100×10^3 to 300×10^3 years old (FIREMAN, 1986a, b, 1988). It is of interest to see how the uranium-series age of the Yamato K-26 sample compares to those from Allan Hills.

2. Experimental Procedure

Two ice samples were removed from the 20-kg block of ice. One was 1.50 kg of ice with the K-26 tephra band; the other was 1.78 kg of clear ice without the band. The ice was melted in quartz beakers with $^{232}U + ^{228}Th$ carrier, keeping the pH of the melt water between 0.8 and 1.0 by the addition of HCl. The melt is kept acidic to reduce the loss of dissolved uranium and thorium to the walls. Previous studies with polar ice melt samples indicated that the dissolved uranium and thorium yields were low if the melt water was not this acidic and that the yields were independent of the

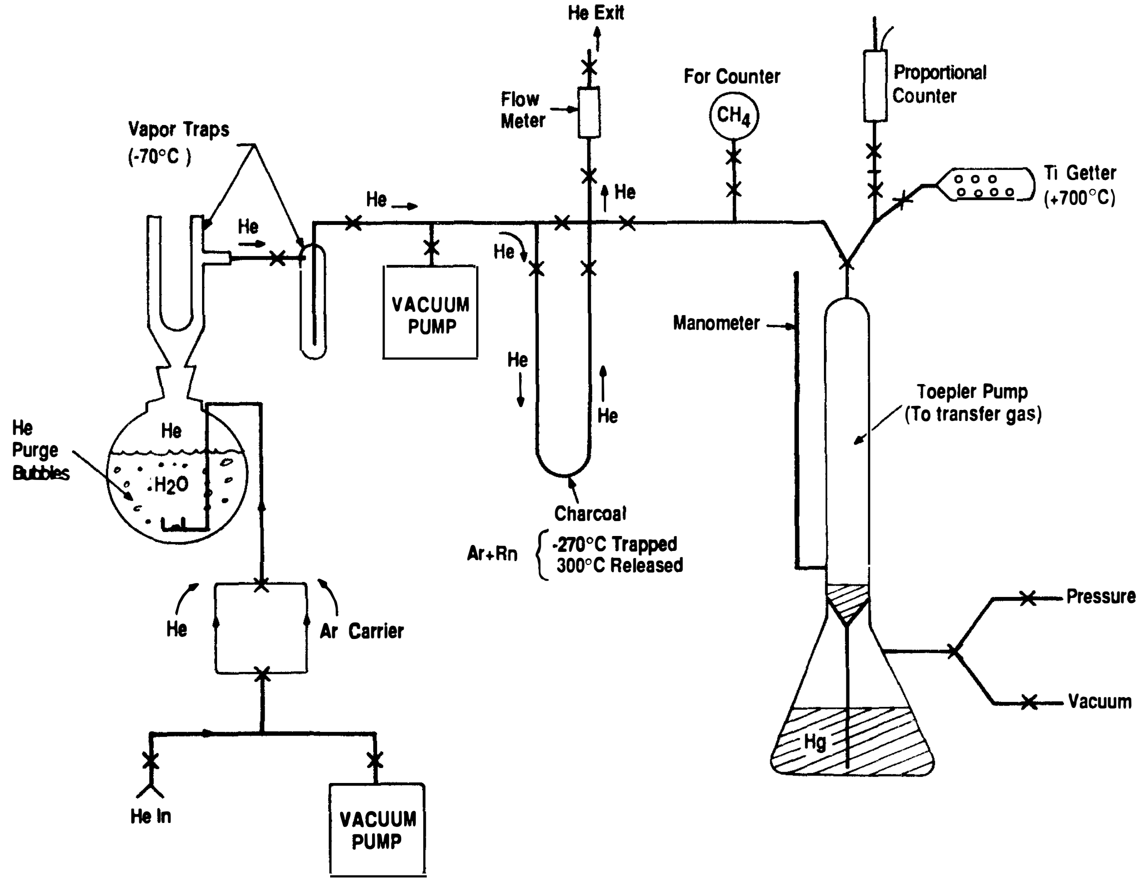

Fig. 2. Diagram of radon extraction unit.

acidity below pH = 1. The melt water was then filtered through 0.45 μm Millipore paper. The 1.50-kg sample had 252 mg of particulates; the 1.78-kg sample had 5.7 mg of particulates.

The filtered water was then sealed in a gas-extraction system shown in Fig. 2. The water is then purged of radon by bubbling purified helium through the water. The gas exit is closed and 0.5 ml STP of argon is added with additional helium to raise the gas pressure to 1.5 atm. After a 4- to 8-day waiting period, the ^{222}Rh (3.8-day half-life), which is the daughter of ^{226}Ra (1720-year half-life), is swept out of the water by another helium purge and collected with the carrier argon on charcoal at liquid-nitrogen temperature. The radon and argon are removed from the charcoal at 300°C purified over a titanium getter, placed in a small proportional counter, and counted for several weeks to determine accurately the ^{222}Rn, from which the amount of dissolved ^{226}Ra is calculated. A second determination of ^{222}Rn is carried out by simply adding argon to the purged water and repurging the water after a similar waiting period.

The water is then removed from the gas-extraction system and evaporated to 50-ml volume and the uranium and thorium are solvent extracted and electroplated on to stainless-steel disks by a procedure previously described (Fireman, 1986a). The disks are then alpha-counted with surface barrier counters and multichannel analyzers. The ^{238}U and ^{234}U are determined by comparing their peaks with that of the ^{232}U, and the ^{232}Th and ^{230}Th are determined by comparing their peaks with that of ^{228}Th.

3. Results

Table 1 gives the weights of the Yamato K-26 and Allan Hills 85-1 ice samples analyzed, their tephra contents, and the dissolved ^{226}Ra, ^{230}Th, ^{234}U, and ^{238}U activities. The activities in the dusty Yamato K-26 sample are considerably lower than in the dusty Allan Hills sample; however, the activities in the clear ice samples are essentially identical. The uranium-series activities in the clear ice reflect their abundances in the original precipitation; the activities in the dusty ice show what activities the tephra contributed to the ice. In the Yamato K-26 ice the tephra contributed no ^{238}U and a very small amount of ^{234}U to the ice, showing that no ^{238}U was dissolved from tephra into the ice and that only a very small amount of ^{234}U went into the ice from the tephra. On the other hand, the tephra contributed significant amounts of ^{230}Th and ^{226}Ra to the Yamato ice. If the ^{230}Th and ^{226}Ra additions were caused by recoils from alpha decays in the tephra, then the age of the Yamato K-26 is $(38\pm7)\times10^3$ years old according to the calculations of Fireman (1986a, b). The small addition of ^{234}U to the ice is consistent with this age. If the ^{230}Th and ^{226}Ra were caused by the dissolution of alpha-damaged surface tephra material, then the age of the alpha-damaged tephra material is also $(38\pm7)\times10^3$ years according to Fireman (1989). At the time when the molten debris from the volcano solidified into fine glass shards in the upper atmosphere there were no alpha-damaged sites in the tephra. The age of the ice containing the tephra is essentially the same as the tephra because the time between the volcanic eruption and the deposition of the tephra on the snow plus the compression time of snow into ice is short compared to a thousand years.

According to our preliminary analysis, the uranium content of the Yamato tephra is 0.027 ± 0.005 ppm and the uranium-series nuclides in the tephra are in radioactive equilibrium. The uranium abundance in the tephra is a factor of 400 higher than in the ice and is sufficient to determine the age of the Yamato ice.

Table 1. Uranium-series activities in Yamato and Allan Hills ice.

Sample	Yamato K-26	Allan Hills 85-1[†]
Dusty ice (weight)	1.50 kg	1.63 kg
Dust (g)/Ice (kg)	0.168	0.210
^{226}Ra (filtered H_2O)*	0.0333 ± 0.0010	0.144 ± 0.004
^{230}Th (filtered H_2O)*	0.0178 ± 0.0005	0.080 ± 0.001
^{234}U (filtered H_2O)*	0.0148 ± 0.0005	0.049 ± 0.001
^{238}U (filtered H_2O)*	0.0128 ± 0.0005	0.031 ± 0.001
^{226}Ra**/^{230}Th**	4.1 ± 0.6	2.3 ± 0.1
Age of ice (years)	$(38\pm7)\times10^3$	$(100\pm10)\times10^3$
Clear ice (weight)	1.78 kg	1.40 kg
Dust (g)/Ice (kg)	0.003	0.002
^{226}Ra (filtered H_2O)*	0.013 ± 0.001	0.014 ± 0.002
^{230}Th (filtered H_2O)*	0.013 ± 0.001	0.013 ± 0.002
^{234}U (filtered H_2O)*	0.014 ± 0.001	0.014 ± 0.002
^{238}U (filtered H_2O)*	0.013 ± 0.001	0.015 ± 0.002

* Activity dpm kg^{-1} (decays per minute per kg) units.

** Activity minus ^{238}U activity.

[†] Fireman (1989).

4. Comparison with Terrestrial Ages of Neighboring Meteorites

It is of interest to compare the terrestrial ages of meteorites recovered in the general locale with the uranium-series age of the K-26 ice. Figure 1 is a map of a 5000-km^2 area extending from 10 km south to 90 km north of the K-26 site showing interesting tephra bands and meteorites that have been found in this area. Two meteorites, Y-86770 and Y-86771, were recovered approximately 5 km south of the K-26 ice near the extension of the tephra band; however, their terrestrial ages have not been determined. If these two meteorites were deposited with the tephra and traveled in the ice with the tephra, one expects their terrestrial ages to be close to $(38\pm7)\times10^3$ years.

Approximately 25 km north of the K-26 site is a tephra band labeled K-13 and the Y-86032, Y-82192, and Y-82193 lunar meteorites, whose terrestrial ages are $(72\pm30)\times10^3$, $(83\pm35)\times10^3$, and $(75\pm30)\times10^3$ years, respectively (EUGSTER and NIEDERMANN, 1988a, b). Although these terrestrial ages appear to be older than that of the K-26 ice, the uncertainties in the terrestrial ages overlap with the uncertainty of the age of the K-26 ice so that the K-26 tephra band could be an extension of the K-13 band and the meteorites and the ice could both be 45000 years old along a 25-km line nearly perpendicular to the direction of the ice flow.

Near the top of the map, 80 km north of the K-26 ice, is the meteorite, Y-75102, whose age has been determined to be $(4.3\pm1.0)\times10^3$ and $(3.0\pm1.2)\times10^3$ years (FIREMAN, 1983; JULL *et al.*, 1984). This meteorite is clearly much younger than the K-26 ice and either landed relatively recently directly onto the ice or 4000-year-old ice exists 80 km north of the K-26 site. The meteorite, Y-75102, is close to tephra band C-32; it would be important to determine the age of this tephra-banded ice. The identification of a bare ice region where 4000–45000-year-old ice is sequential arranged would supplement ice core studies which cover this time span. Age determinations on the C-32 tephra-banded ice and other tephra-banded ice samples at intermediate locations are required to establish a sequential arrangement.

Acknowledgments

This work is supported by National Science Grant DPP8716835.

References

EUGSTER, O. and NIEDERMANN, S. (1988a): Noble gases in lunar meteorites Y-82192 and Y-82193, and history of the meteorites from the moon. Earth Planet. Sci. Lett., **89**, 15–27.

EUGSTER, O. and NIEDERMANN, S. (1988b): Yamato-86032 lunar meteorite; Cosmic-ray produced and trapped noble gases. Meteoritics, **23**, 268.

FIREMAN, E. L. (1983): Carbon-14 terrestrial ages of Antarctic meteorites. Papers Presented to the Eighth Symposium on Antarctic Meteorites, 17–19 February 1983. Tokyo, Natl Inst. Polar Res., 246–250.

FIREMAN, E. L. (1986a): Uranium-series dating of Allan Hills ice. J. Geophys. Res., **91**, B4, D539–D544.

FIREMAN, E. L. (1986b): Uranium-series dating of Allan Hills ice. J. Geophys. Res.. **91**, B8, 8393.

FIREMAN, E. L. (1988): Ice chronology at meteorite stranding sites. Antarct. J. U. S., **23**, No. 5

49–50.

FIREMAN, E. L. (1989): Uranium-series dating of tephra-banded Allan Hills ice. Proc. NIPR Symp. Antarct. Meteorites, **2**, 335–343.

FUKUOKA, T., ARAI, F. and NISHIO, F. (1987): Correlation of tephra layers in Antarctic ice by trace element abundances and refractive indices of glass shards. Bull. Volcanol. Soc. Jpn., Ser. 2, **32**, 103–118.

JULL, A. J. T., DONAHUE, D. J., ZABEL, T. H. and FIREMAN, E. L. (1984): Carbon-14 ages of Antarctic meteorites with accelerator and small-volume counting techniques. J. Geophys. Res., **89**, C329–C335.

NISHIO, F., KATSUSHIMA, T., OHMAE, H., ISHIKAWA, M. and TAKAHASHI, S. (1984): Dirt layers and atmospheric transportation of volcanic glass in the bare ice areas near the Yamato Mountains in Queen Maud Land and the Allan Hills in Victoria Land, Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **34**, 160–173.

NISHIO, F., KATSUSHIMA, T. and OHMAE, H. (1985): Volcanic ash layers in bare ice areas near the Yamato Mountains, Dronning Maud Land and Allan Hills, Victoria Land, Antarctica. Ann. Glaciol., **7**, 34–41.

YANAI, K. (1981): Collection of Yamato meteorites in the 1979–1980 field season, Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **20**, 1–8.

(Received August 28, 1989; Revised manuscript received February 20, 1990)