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Vertical distribution of ^{210}Pb in the Arctic glacier, Snøfjellafonna, in northwestern Spitsbergen

Toshitaka SUZUKI[1], Kazutake OHTA[1] and Okitsugu WATANABE[2]

1 Department of Chemistry, Faculty of Science, Yamagata University, Yamagata 990 Japan

2 National Institute of Polar Research, Kaga 1－9－10, Itabashi-ku, Tokyo 173 Japan

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Abstract

The activity of ^{210}Pb in an ice core obtained from the Arctic glacier, Snøfjellafonna, in northwestern Spitsbergen was measured and its vertical profile was obtained. The activities of ^{210}Pb at 1－10 m depth were lower than those at 10－20 m depth. This irregularity of ^{210}Pb profile suggest that the atmospheric input of ^{210}Pb to this site has large temporal variation or the initial concentration of the nuclide is not preserved as it was supplied on this site. Accumulation rate of the glacial ice throughout 10－40 m depth was estimated by the ^{210}Pb-chronology based on the assumption that the vertical profile of ^{210}Pb below 10 m depth obey the exponential decrease. The obtained result, 0.44 m-water/yr, well agreed with the result from other dating method, 0.43－0.49 m-water/yr. This result may suggest that the activity profile of ^{210}Pb below 10 m depth in the site approximately obey radioactive decay of the nuclide, and therefore, the irregularity may be due to the sudden decrease of ^{210}Pb activity in 1－10 m layer rather than the enrichment of the nuclide in 10－20 m.

1. Introduction

Arctic glaciers preserve gaseous and particulate components in Arctic atmosphere up to the present in the processes of snow deposition, air-snow/ice interaction and ice formation. Therefore, vertical profiles of these components in glaciers provide important information about change of past atmospheric environment in the northern hemisphere (Fujii *et al.*, 1990).

Lead-210 (half-life 22.3yrs) is one of the natural radioactive nuclide contained in atmospheric precipitation. The major source of ^{210}Pb is ^{222}Rn (half-life 3.82days) in the atmosphere which is emanated from earth's crust as a result of decay of ^{226}Ra (half-life 1620yrs). Lead is metal element having low vapor pressures at tropospheric environment and, thus, exist as a solid form of aerosol. At this point, the ^{222}Rn -^{210}Pb system in the atmosphere is very similar to the SO_2- SO_4^{2-} system or the NH_3-NH^{4+} system, because these systems are pairs of a gaseous parent and a solid daughter in the atmosphere (Tsunogai *et al.*, 1988). As a result, atmospheric ^{210}Pb regards as a tracer of terrigenous secondary aerosols in the atmosphere. These aerosols containing ^{210}Pb are transported to Arctic glaciers by both wet and dry deposition processes.

After removal from the atmosphere, ^{210}Pb is accumulated on glacial ice. Vertical profile of ^{210}Pb in a certain glacier is principally controlled by radioactive decay of the nuclide if the input of ^{210}Pb is not largely change during observed time scale and the post-depositional migration of ^{210}Pb together with melting water is negligible. Namely, the activity of ^{210}Pb decreases with depth of glacier as a function of time at a rate controlled by its half-life. Hence, accumulation rate of a certain glacier can be calculated from the slope of vertical profile of ^{210}Pb activity (Crozaz *et al.*, 1964 ; Crozaz and Langway, 1966 ; Nijampurkar *et al.*, 1982). Recent studies have shown that accumulation of ^{210}Pb in Greenland ice sheet has not remained constant over a period of this century and have suggested that we must pay attention to application of ^{210}Pb chronology to ice core dating (Nijampurkar and Clausen, 1990 ; Dibb, 1992).

Here, we report the preliminary result of ^{210}Pb measurement on ice core sample which has been

obtained from a glacier in the Arctic region and discuss about its vertical profile.

2. Samples and methods

The ice core samples using in this study were taken from Site-A on a glacier named Snøfjellafonna in northwestern Spitsbergen (79°08.2'N, 13°17.5'W ; 1190 m a.s.l.) by the Japanese Arctic Glaciological Expedition in 1992 (JAGE '92 ; Takahashi *et al.*, 1993 ; Kameda *et al.*, 1993).

Approximately 1 kg size of samples were prepared for ^{210}Pb analysis from eleven layers of this core (Table 1). The ice samples were melted in acid

Table 1. Depth and weight of samples for ^{210}Pb analysis obtained from Site-A on the Snøfjellafonna, Spitsbergen

Sample	Top (m)	Bottom (m)	Weight (kg)
C1	1.53	5.58	0.821
C2	5.58	9.55	0.749
C3	9.55	13.89	1.075
C4	13.89	18.04	1.041
C5	18.04	21.50	1.009
C6	21.50	25.00	0.946
C7	25.00	28.78	0.982
C8	28.78	33.19	1.343
C9	33.19	37.09	1.248
C10	37.09	41.22	1.174
C11	41.22	42.53	0.266

-washed polyethylene bottles and acidified with 20 ml of conc. HNO_3 at the sampling site. The sample solution were transported to Japan and analyzed ^{210}Pb by counting α-activity from its daughter nuclide, ^{210}Po. As the method has already been published by Suzuki *et al.* (1991), we only outline it. Yield tracer for Pb was added to each sample solution, and then, Pb and Po in the solution were concentrated by the $CaCO_3$ coprecipitation method. The precipitation was collected by centrifugation and dissolved in 0.5M HCl. And then the initial ^{210}Po originally included in the sample was removed by spontaneous deposition onto the silver spiral. The approximately 0.02Bq of ^{209}Po tracer and conc. HCl were added to the remaining solution and stored for more than 6 months. The chemical yield of Pb was determined from an aliquot of this solution by atomic absorption spectrophotometry. Repeating coprecipitation and spontaneous deposition procedure, ^{210}Po produced from ^{210}Pb during storage and ^{209}Po from tracer were plated onto silver disc. The α-activities emitted from each nuclides were measured by an α-spectrometer consisting of ion implanted passivated silicon detectors and a multichannel analyzer. The activity of ^{210}Pb was calculated from the chemical yield of Pb and the ^{210}Po/^{209}Po activity ratio. The reagent blank of this procedure was determined previously and subtracted from the activity of each samples.

3. Results and discussion

Average chemical yield of Pb and its standard deviation in our method was 94.1±3.8%. Measured activities of ^{210}Pb in the samples were reduced to the activities at the date of sampling and shown in Fig. 1 as a depth profile.

In general, the activity of ^{210}Pb in the glacier should decrease exponentially with depth according to radioactive decay, if the initial activity of the nuclide in surface firn remains constant and the each firn layer behaves as a closed system for the nuclide since the time of deposition of the snow (Picciotto *et al.*, 1967).

As clearly seen from Fig. 1, the activities of ^{210}Pb in upper two samples, 0.009−0.016Bq/kg, were lower than those at 3rd and 4th layers, 0.032−0.037Bq/kg. This irregularity of ^{210}Pb profile suggest that the atmospheric input of ^{210}Pb to the Site-A has large temporal variation or the initial concentration of the nuclide is not preserved as it was supplied on this site. If the activity profile of ^{210}Pb in the ice core is controlled by not only radioactive decay of the nuclide, we cannot apply the ^{210}Pb chronology to this core.

In 1987, JAGE '87 ice core drilling team obtained ice core samples from the top of the Høghetta ice dome on the Åsgårdfonna (79°17'N, 16°50'E, 1200 m a.s.l.), 80 km east from the Site-A of Snøfjellafonna. The average activity of ^{210}Pb from 2.22 m to 10.32 m in the JAGE'87 core was 0.068Bq/kg. The average activity of ^{210}Pb in upper two layer (1.53−9.55 m) in this study, 0.013Bq/kg, was one-fifth of the value which was obtained in the Åsgårdfonna. On the other hand, the average activity of 3rd and 4th layers (9.55−18.04 m) in this study, 0.034Bq/kg, was not different in factor of two compared with the average value from 9.88 m to 16.76 m of the JAGE '87 core, 0.053Bq/kg. This indicates that the difference of activities between two site at 1−10 m depth was larger than that at 10−20 m depth.

Temporarily, let us assume that the vertical profile of ^{210}Pb below 10 m depth in this study obey the first-order removal process, i.e. radioactive decay. Now, we have assumed the following formula ;

$$A_z = A_b + A_i \exp(-\alpha z)$$

where A_z is the activity of ^{210}Pb (Bq/kg) in the ice core at depth z (m-ice), and A_b, A_i and α are constants. The first term of the right side, A_b, refers to the background activity of ^{210}Pb which is supported from ^{226}Ra in mineral particles in the ice core. The second term is derived on the assumption that the initial activity of ^{210}Pb in surface firn, A_i, is exponentially decreased with depth, z, according to the rate constant, α. If we assume the rate constant, α, is governed by radioactive decay only, we can calculate the accumulation rate of glacial ice from α by the methods described elsewhere (Crozaz *et al.*, 1964, Suzuki *et al.*, 1991).

The constants A_i and α was determined by a least square method by fixing A_b. We used a fixed value 0.0008Bq/kg for A_b, because it was the activity of the deepest sample (85.3 m) obtained from Åsgårdfonna in northern Spitsbergen (Suzuki and Fujii, 1992). The constants obtained are as follows ;

$$A_z = 0.0008 + 0.062\exp(-0.057z)$$

and the equation are shown in Fig. 1 as a solid curve.

The accumulation rate throughout 10−40 m depth of the core expected from α of the equation is 0.55m-ice/yr. If we consider the average density from 10 m to 40 m depth of the ice core is 0.8g/cm^3 from the result of density profile (Kameda *et al.*, 1993), obtained ice accumulation rate is able to convert 0.44m-water/yr.

Kameda *et al.* (1994) estimated 0.48 m-water/yr of accumulation rate from the ^{3}H content in the same core in this study. Pinglot *et al.* (in preparation) also measured vertical profile of ^{137}Cs at the Site-A, and reported that the annual accumulation rate of the glacier was 0.43−0.49 m-water/yr. These annual water accumulation rates agree with the rate which have been obtained by our calculation. This result may suggest that the activity profile of ^{210}Pb below 10 m depth of the Site-A approximately obey radioactive decay of the nuclide. Therefore, the irregularity of ^{210}Pb profile in this study may be due to the sudden decrease of ^{210}Pb in 1−10 m layer rather than the enrichment of the nuclide in 10−20 m. Because, (1) the accumulation rate obtained by ^{210}Pb chronology

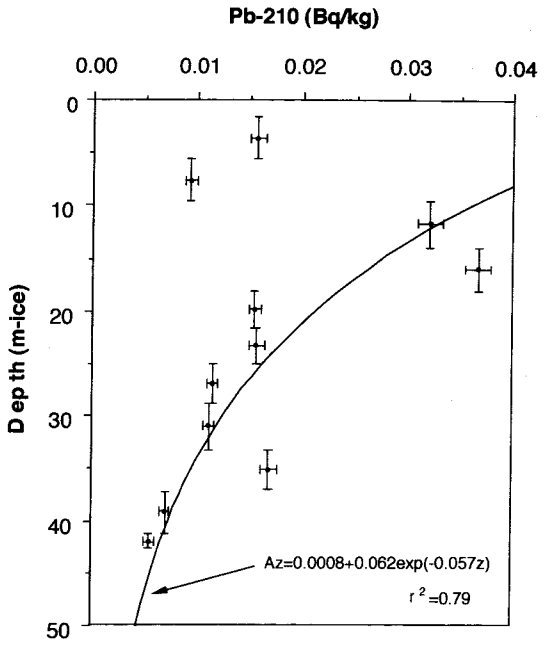

Fig. 1. Vertical profile of ^{210}Pb in the ice core from Site-A, northwestern Spitsbergen. The horizontal and vertical bars indicate the depth interval and the counting error, respectively. See the text for method of calculation of the solid curve given together with its formula.

using nine data below 10 m depth showed good agreement with the rate obtained by ^{3}H and ^{137}Cs method, and (2)the difference of activities between Åsgårdfonna and Snøfjellafonna at 1−10 m depth was larger than that at 10−20 m depth.

The sudden decrease of ^{210}Pb activity in 1−10 m layer may not be due to the seasonal variation of atmospheric flux of ^{210}Pb onto the glacier, because we measured average activity over 4 m depth of the core. Furthermore, the irregularity may not be brought by the past change of meso- and large-scale meteorological condition over the Svalbard, because we have not observed such irregularity at the top of the Høghetta ice dome on the Åsgårdfonna, 80 km northeast of Site-A (Suzuki and Fujii, 1992). Accordingly, the drastic change of the vertical distribution of ^{210}Pb obtained in this study may be caused by the local phenomenon occurred in the area near the Site-A.

Although we cannot wholly explain about the irregularity of ^{210}Pb profile at the present, this may be significantly affected by the post-depositional migration of water soluble Pb together with glacial melt water. Goto-Azuma *et al.* (1993) observed the verti-

cal distribution of major ionic species in the Brøgger-breen, western Spitsbergen, and reported that the ions were flushed out from the surface of glacier during the thaw. They also concluded that the leaching process not only reduced the concentration of ions but also created the characteristic vertical profiles of ions in the glacier surface.

At any rate, we cannot apply ^{210}Pb-chronology to ice core dating if the vertical distribution of ^{210}Pb in an interested glacier is controlled by not only radioactive decay but significant variation of atmospheric flux and/or post-depositional migration. Further investigation about the vertical profile of ^{210}Pb in various glaciers will provide information on the accumulation process of glacial ice and the application limit of ^{210}Pb-chronology.

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