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Radiometric age of the snout ice of Nehnar glacier

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Abstract. The surface ice taken from the snout of the Nehnar glacier (Kashmir) in western Himalaya has been dated using radioisotopes ^{32}Si and ^{210}Pb to be 500 years. Based on the age distribution of ice and the expected activity of ^{32}Si in the fallout, the average rate of glacier movement over a period of the last few centuries is estimated to be about 6 m/yr.

The data obtained on ^{32}Si and ^{210}Pb activities in the surface ice samples in the ablation zone support our previous observation about the existence of five zones of alternately high and low activity of ^{210}Pb, which probably is a consequence of complex dynamics of Nehnar glacier.

The vertical profile of ^{210}Pb activity in an ice core correlates directly with the total beta activity. This radioactive horizon at an altitude of 4140 m appears to be located at a depth of 10-12m, which is lower compared to the 2-3 m observed earlier at an altitude of 4150 m.

Keywords. Snout ice ; radiometric age ; ablation zone.

1. Introduction

Nehnar, a small (about 3·5 km long and 0·35 km wide) valley type glacier situated in Panjtarni basin (34° 09′ 30″N, 75° 31′E) of Kashmir region in the Western Himalayas, has been extensively studied in the past decade for its surface dynamics and mass-balance (Vohra *et al* 1975, 76). The annual rates of movement so obtained have been compared with the results of the ^{32}Si and ^{210}Pb dating methods to understand the long term behaviour of the glacier in the past (Nijampurkar *et al* 1982).

With a view to check the earlier results on the rate of glacier movement, its age and surface dynamics, we have collected surface and ice core samples in the ablation zone of Nehnar glacier in 1978 for the second year in succession. The geographical, geological and geomorphological information, sampling techniques, radiochemical procedures and the methods of radioactive assay have been discussed in detail earlier (Nijampurkar *et al* 1982; Nijampurkar 1974).

Meanwhile better estimates of the fallout and half life of ^{32}Si have become available (Elmore *et al* 1980; Kutschera *et al* 1980) warranting a revision of the earlier data. The fallout value of ^{32}Si has been estimated from our work in other Himalayan glaciers. Using this information, the age of ice at various locations has been calculated. Implications of these results are discussed here in terms of glacier dynamics in the past.

2. Sampling details and experimental procedures

Three surface samples (nominally 2 tons) from the ablation zone of the glacier were collected and analysed for ^{32}Si and ^{210}Pb activities, following the procedures described by Nijampurkar *et al* (1982) and Nijampurkar (1974). Briefly ^{32}Si was counted *via* its daughter ^{32}P and ^{210}Pb *via* its daughter ^{210}Bi. After radiochemical purification, $Mg_2P_2O_7$ and $BiPO_4$ were counted on low background GM counters. The counting efficiency for ^{32}P and ^{210}Bi was 37·5% and 33% and the counter backgrounds were 2·8 cph and 8 cph respectively. Both the isotopes were counted for several half-lives and the initial activities were calculated from the decay curves.

In addition, an ice core of about 102 m length was raised in the ablation zone. Its location is shown in figure 1. Ten samples collected in 2 m section up to 20 m depth were melted, acidified and filled in air-tight plastic bottles. These samples were analysed for ^{210}Pb, total beta and gamma activity, TDS and concentration of K, Na, Ca and Mg following the techniques described by Nijampurkar *et al* (1982).

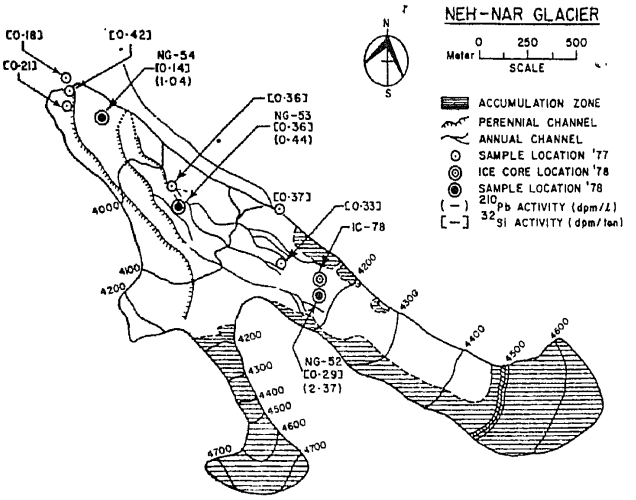

Figure 1. Distribution of ^{32}Si activity [dpm/ton] and ^{210}Pb activity [dpm/1] in surface samples of Nehnar gracier. ^{32}Si activity in surface samples collected in 1977 is also given for comparison. Altitude contours [in metres] accumulation zone for 1978 and equilibrium line [dash curve] are shown. The melt and trapped water channels *i.e.*, perennial channels occurring in the lower part of the glacier and annual channels observed in 1978 are also shown.

3. Results and discussion

3.1 *Surface samples*

The ^{32}Si and ^{210}Pb activities observed in the surface samples are given in tables 1, 2 and 3. The values are in close agreement with those obtained in the previous year (figure 1). Of particular importance is the ^{32}Si activity in the surface ice of snout sample NG-54 (0.14 dpm/ton) which represents the oldest ice, except for the deeper snout samlpes. The ^{210}Pb activity of the samples NG-52, 53 and 54 are 2·37, 0·44 and 1·04 dpm/l respectively as shown in figure 1. They agree well with the earlier measurements at these locations. Based on a more detailed work reported earlier, it was possible to identify five zones of alternate high and low activities of ^{210}Pb on the glacier, starting from accumulation zone (4300 m) to snout (Nijampurkar *et al* 1982). The present data are consistent with the existence of these zones.

The ages of ice can be calculated from the observed ^{32}Si activity based on the decay equation using the half-life of ^{32}Si and its fallout value. Recently the half-life of ^{32}Si has been measured using Tandem Accelerator Mass Spectrometer to be 108 ± 18 y by Elmore *et al* (1980) and 101 ± 18 years independently by Kutschera *et al* (1980). This value is much lower than the previously accepted value of 300 ± 30 y (Jantsch *et al* 1974; Clausen 1973; Demaster 1980), estimated from nuclear systematics and geophysical arguments. If the recently calculated average value of 105 years is correct then our earlier estimates of ice ages of 850 years have to be revised to lower values.

The second parameter, the average fallout value in the past precipitation, is difficult to estimate. Considering the latitude dependence of fallout values in 0-30°N and 30-60°N belts, the ^{32}Si value was assumed to be 0.5 ± 0.1 dpm/ton (Nijampurkar *et al* 1982). Recently Nijampurkar *et al* (1981a) have observed an altitude dependence of ^{210}Pb fallout in snow precipitation on the Changme-khangpu glacier. An increase of a factor of about 3 was observed from 4.6 km to 5·8 km altitude. This observation suggests the possibility of some altitude dependence of ^{32}Si fallout. Considering the fact that the production profile of ^{210}Pb and of ^{32}Si in the troposphere is similar, the altitude dependence of the fall-out could be assumed to be the same for the two isotopes which is confirmed by measurements of ^{32}Si or any other cosmic ray produced isotope. In a continuously receding glacier like Nehnar, it can be assumed that only the present accumulation zone has been having a positive mass balance. Hence the fallout value is significant in this region only and altitude variation throughout the glacier is not relevant for age calculations. The data recently obtained in Gara, Gorgarang and Changme-Khangpu glaciers in the Himalaya on ^{32}Si activity in ice in the ablation zones suggest that the fallout value should be about 0.7 dpm/ton (Nijampurkar *et al* 1981a). The error introduced in the age estimates due to uncertainty in the fallout value is however small. A factor of two error in fallout of ^{210}Pb and ^{32}Si introduces an error in age of one half life *i.e.* 22 and 105 years respectively.

In view of the above considerations, we adopt for the purpose of the present calculations. a halflife value of ^{32}Si to be 105 ± 18 years and the average fallout

Table 1. Experimental data on ^{32}Si measurements in surface samples of Nehnar Glacier (1978)

Sample	Location	Altitude (m)	Distance from A.Z. (km)	Water collected (tons)	SiO_2 recovered (g)	Net ^{32}P cph	^{32}Si dpm/ton	Mean ^{32}Si dpm	Apparent ^{32}Si age (years)
NG-52	Near Eq. Line	4175	1.15	1.5	3.5	4.0	0.285+0.03	0.285+0.03	136
NG-53-1m	Abl. zone	4050	1.95	2.0	14.5	7.8	0.44+0.45	0.36+0.03	101
NG-53-2m					12.5	6.2	0.3+0.03		
NG-54	Near snout	3900	2.55	1.5	8.2	2.0	0.14+0.02	0.14+0.02	244

A.Z Accumulation zone, The distance is measured from the centre of the accumulation zone. cph counts per hour, corrected for time of milking ($t = 0$)

Half life of ^{32}Si is taken to be 105 years and average fallout of ^{32}Si to be 0.7 dpm/ton.

1m 1st milking of ^{32}P

2m 2nd milking.

The statistical counting errors are less than 5% but a nominal error of 10% is given except where larger uncertainty is expected in chemical estimations.

Table 2. Experimental data on ^{210}Pb measurements and apparent ages of the surface samples of Nehnar Glacier

Sample Code	Water Processed litres	^{210}Bi counting rate t=0 (cpm)	^{210}Pb (dpm/L)	Apparent ^{210}Pb age (years)
NG-52	375	170.7	2.37±0.1	39
NG-53	500	60.6	0.44±0.03	93
NG-54	375	124.0	1.04±0.03	66

For abbreviations, see table 1

Table 3. ^{210}Pb — ^{32}Si data in Nehnar surface samples

Sample code	Location	Altitude (m)	Distance from A. Z. (km)	^{32}Si (dpm/ton)	^{210}Pb (dpm/L)	Corrected ^{32}Si (dpm/ton)	Corrected ^{32}Si age (years) / Velocity (m/y)
NG-52	Near Eq. Line	4175	1.15	0.285 ± 0.03	2.37 ± 0.1	0.078	330/40
NG-53	Ablation Zone	4050	1.95	0.36 ± 0.03	0.44 ± 0.03	0.321	120/17
NG-54	Near Snout	3900	2.55	0.14 ± 0.02	1.04 ± 0.03	0.049	400/6

For abbreviations, see table 1.

value of ^{32}Si and ^{210}Pb at an altitude of 5 km in Himalayas to be 0·7 dpm/ton and 8 dpm/l respectively.

As seen from tables 1 and 2, the apparent ^{32}Si and ^{210}Pb ages are not concordant. ^{210}Pb always yields lower ages indicating some influx of younger ice. We may use a two component model, ^{210}Pb determining the young component for which corrections can be made to ^{32}Si ages, to obtain true age of the ice (Nijampurkar *et al* 1982).

Using this approach the model age of ice near the snout of Nehnar glacier is calculated to be 400 years. The sample collected at the tip of the snout during 1977 yields an age of 500 years consistent with the present findings. Similarly the ages of ice at various locations on the glacier are calculated from the observed ^{32}Si and ^{210}Pb data. Considering that the glacier is 3.5 km long, the average velocity of the ice movement from acccumulation zone to the snout is estimated to be 6 m/y. Various ages and velocity estimates are shown in table 3. The high velocity of 17m/y in the middle of ablation zone agrees fairly well with that obtained by Vohra *et al* (1976).

3.2 *Ice core samples*

The upper 20 m section of the core was analysed in every 2m depth sections for ^{210}Pb, total beta activity and total dissolved salts. The dust content was measured in the whole core and chemical tracers and stable isotopes (^{18}O/^{16}O) were measured in 0-46 and 66-102m sections. Due to a possible contamination of 46-66m section by oil used in the drilling operation, this section was not analysed for the chemical and isotopic constituents. Some results are given in table 4 and are summarised below. The ^{18}O/^{16}O measurements will be reported elsewhere (Nijampurkar and Bhandari 1982).

3.2a. *Radioisotopes*: The results (given in table 4) show a maxima in ^{210}Pb activity (33.5 dpm/l) which is higher by a factor of four compared to its normal fallout value. This peak correlates with total beta activity (66·3 dpm/l) and a 0.66 MeV. γ emitter which is tentatively identified as ^{137}Cs. Even though the peak values are comparable with those observed in the previous year, maxima appears to be shifted to lower depths at 10-12 m (figure 2) compared to the depth of 2-3 m observed earlier (Nijampurkar *et al* 1980.) The location of the 1977 core was 50 m down slope from the 1978 core location.

Considering the recent work done on Greenland ice sheet cores at Dye-3 station (Nijampurkar *et al* 1981b), the high ^{210}Pb activities observed in this radioactive horizon cannot be solely attributed to the effect of nuclear weapons testing. The suspended dust probably plays a role in contributing some ^{210}Pb activity. Verification of its correlation with ^{226}Ra and uranium becomes important for understanding this phenomenon (Jawarowski *et al* 1978). The gamma analysis of the samples also reveal a marginal signal at 660 keV corresponding to ^{137}Cs (table 4), correlating well with ^{210}Pb and total beta activity. However since old ice ($\leq$100 years based on ^{210}Pb) is observed above this radioactive horizon, special mechanisms have to be invoked to transport the nuclear debris at such

Table 4. Experimental data on chemical tracers ^{210}Pb, ^{137}Cs and total beta activity in Nehnar core samples (1978)

Sample	Depth in core (m)	Vol. of water (ml)	T.D.S. (mg/L)	Dust (ppm)	K (ppm)	Na (ppm)	Ca (ppm)	Mg (ppm)	^{210}Pb (dpm/L)	^{137}Cs* (dpm/L)	Beta activity	
											dpm/L water	dpm/g T.D.S.
NG-1	0-2	589	859	270	0.40	0.75	128	5.60	0.2	0.2	3.6±0.3	4.2± 0.4
NG-2	2-4	654	504.6	164	0.50	0.50	92	7.60	6.3	0.0	9.3±0.9	18.5± 1.8
NG-3	4-6	760	101.3	23.6	0.60	1.12	17.5	1.40	1.5	0.0	5.2±0.5	50.5± 5.5
NG-4	6-8	860	70.7	5.8	0.50	1.00	11.5	0.40	0.8	0.06	2.1±0.2	28.8± 2.9
NG-5	8-10	810	132.2	7.7	1.10	1.63	13.5	0,80	3.02	1.48	11.1±1.1	83.5± 8.3
NG-6	10-12	530	584	41.0	1.00	1.13	62	9.8	33.5	9.6	66.3±6.5	113.5±11.2
NG-8	14-16	680	Lost	298	0.40	0.63	11.5	1.00	0.2	8.5	5.2±0.5	5.9± 0.5
NG-9	16-18	815	873	919	0.50	1.13	158	5.00	2.67	0.0	3.8±0.3	65.5± 6.5
NG-10	18-20	1930	58	1050	0.70	1.25	9.0	0.40	0.75	0.25	4.20±0.4	26.8± 2.7

*0.66 MeV signal is tentatively attributed to ^{137}Cs

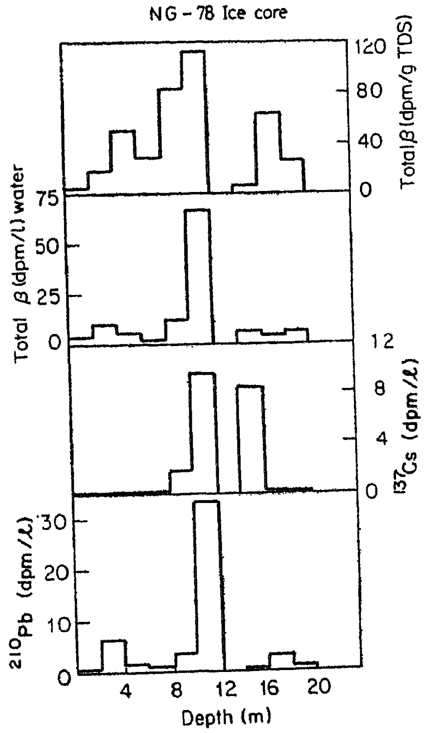

Figure 2. Depth profile of ^{210}Pb, and total beta activity [dpm/kg of ice and dpm/g dust] in the Nehnar core samples. The distribution of 0.66 MeV single tentatively attributed to ^{137}Cs is also shown.

horizons, which is not quite consistent with the present understanding of the glacier dynamics. Thus the conclusion that excess ^{210}Pb has an origin in nuclear weapons testing must await further analysis of cores, particularly from the accumulation areas.

3.2b *Chemical tracers*: Some major elements, *i.e.* K, Na, Ca, Mg were measured, using the atomic absorption spectrophotometry technique, in the melt water samples of core sections taken at 2m depth intervals. The suspended dust and TDS were also measured in all these samples (table 4). All major elements correlate with the suspended dust content, as expected. The dust itself varies between 0.1 and 8 g/ litre with three distinct peaks at 33, 45 and 61 m depth. Its correlation with oxygen isotopic ratio will be discussed elsewhere (Nijampurkar and Bhandari 1982; Bhandari *et al* 1982).

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