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Determination of Net Accumulations from Gross Beta Activity Measurements in the North Water Region

By W. Ambach and F. Müller *

Summary: Measurements of the gross beta activity of firn samples taken from drillings in the region of the North Water polynya allow us to identify deposits of the radioactive fall-out of 1963, due to a maximum of gross beta activity in a vertical profile. Drillings were made in the lower region of the accumulation area (Percolation Zone). The reference horizon of 1963 in this area is well marked by a concentration of deposits of radioactive fall out. This method of dating still enables us to determine the mean annual net accumulation since 1963.

Zusammenfassung: Messungen der Gesamt-Beta-Aktivität von Firnproben aus Bohrungen im Bereich der North Water Polynya lassen die Ablagerungen des Jahres 1963 aufgrund eines Maximums der Gesamt-Beta-Aktivität erkennen. Die Bohrungen wurden im unteren Bereich des Akkumulationsgebietes (Percolation Zone) angelegt. Durch Konzentrierung der Spaltproduktablagerungen an der jeweiligen Oberfläche während der Ablationsperiode ist in dieser Zone der Bezugshorizont 1963 besonders deutlich ausgeprägt. Durch diese Datierung sind Bestimmungen der mittleren jährlichen Rücklagen seit 1963 möglich.

INTRODUCTION

To determine the annual net accumulation in the accumulation area of a temperate or cold glacier, nuclearphysical methods have been applied repeatedly. These methods can be classified as follows:

— Measurements of stable isotopes: the analyses of deuterium and 0-18 yielded good results, especially in cold firn. Annual layers can thus be examined individually, owing to the seasonal fluctuations of deuterium and 0-18 concentrations in the precipitation (REEH et al., 1975).

— Measurements of individual radioisotopes: the law of decay is applied in order to date firn layers in a vertical profile by measuring the decrease in radioactivity of a radioisotope, e. g., Pb-210 (NEZAMI et al., 1964; CROZAZ & LANGWAY, 1966).

— Measurements of radioactive fission products: activity peaks found in a firn profile were caused by the fall-out of radioactive fission products during intensive nuclear weapon tests in the atmosphere from 1961 trough to the end of 1963 (PICCIOTTO & WILGAIN, 1963). Peaks of radioactivity in a vertical profile may thus be used as a time reference level to measure the net accumulation. This group includes analyses of tritium profiles and profiles of gross beta activity. Because of its attachment to the water molecule, tritium is partly displaced by melt water. However, radioactive fission products which are traced by the gross beta activity, remain adsorbed to aerosols, thus generally being bound to the respective snow layer. Analyses of tritium profiles and profiles of gross beta activity have so far been applied to determine net accumulations in cold, as well as in temperate glaciers. In accumulation areas with strong snow melt, especially in the region near the equilibrium line, analyses of gross beta activity are preferable, because of the concentration of radioactive fission products in summer ablation horizons. Examples are given by JOUZEL et al. (1979) and AMBACH & DANSGAARD (1970) in cold firn. Examples for net accumulation determinations in temperate firn are studies by EISNER (1971) and BEHRENS et al. (1979).

AREA OF SAMPLING

To assess the influence of the North Water polynya on the accumulation rates and the thermal regime of the surrounding ice masses firn pits were dug and samples collected for isotope analyses from the surrounding ice caps. Additionally, cores were drilled to determine the values of the mean annual net balan-

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ce by gross beta activity measurements, taking the 1963 horizon as a reference level. It was expected that the environmental impact of North Water polynya, particularly the precipitation and climatic warming, would be strongest in the low lying areas of the surroundings, as in the lower part of the Lower Percolation Zone, in the Slush Zone and the Superimposed Ice Zone. For zonation scheme see MÜLLER (1962). For this reason, the analyses were carried out, using gross beta activity measurements, as the gross beta activity was expected to resist the influence of percolating melt water.

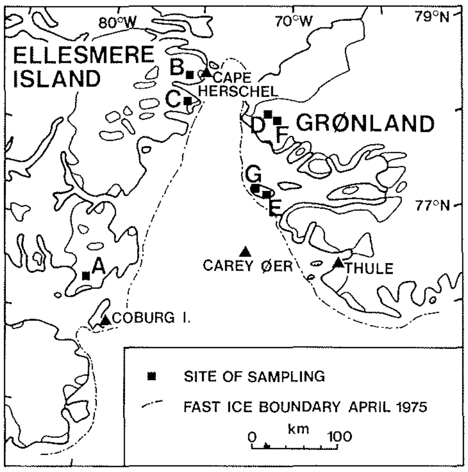


Fig. 1: Sites of core sampling. Core WG—L1 is situated on White Glacier, Axel Heiberg Island, Canada.

Abb. 1: Lageplan der Bohrstellen. Bohrung WG—L1 wurde am White Glacier, Axel Heiberg Island, Kanada, durchgeführt.

Fig. 1 shows the location of the sites of sampling in the region of the North Water polynya. In addition, drilling WG-L1 was done on White Glacier on the Axel Heiberg Island. Detailed data on the sites of sampling such as altitude, location in the Percolation Zone, depth of drilling, temperature in a depth of 10 m, and date of sampling are reviewed in Tab. 1.

Core	Elevation m NN	Zone	Depth m	$T_{10\ m}$ °C	Date of sampling
A	1100	Lower Percolation Zone below middle	12,2	—12,0	01. 05. 1976
B	1200	Lower Percolation Zone middle	12,4	—15,5	02. 05. 1976
C	1070	Lower Percolation Zone middle	12,5	—13,5	03. 05. 1976
D	1080	Lower Percolation Zone below middle	12,5	—15,0	07. 05. 1976
E	410	Lower Percolation Zone middle, possibly, higher	11,3	— 2,0	27. 04. 1977
F	1500	Lower Percolation Zone lower end	14,8	—17,0	19. 05. 1977
G	410	Slush Zone	11,0	— 7,0	04. 05. 1977
WG—L1	1400	Upper Percolation Zone	13,0	—	15. 08. 1978

Tab. 1: Sites and data of sampling.

Tab. 1: Angaben zur Probennahme.

DISCUSSION OF RESULTS AND CONCLUSIONS

1. *Method of measurement*

The dry residue of the samples was analyzed in an automatic counting device for low beta activities, Type LB100L, Berthold Analytic Instruments. K-40 samples were used for calibration, so that the activities were obtained as K-40 equivalents. To eliminate misinterpretation as far as possible, the results are discussed for the three graphs a, b, c (Fig 2). Because of the relation

$$\frac{\text{dpm}}{\text{kg sample}} = \frac{\text{dpm}}{\text{mg dry residue}} \cdot \frac{\text{mg dry residue}}{\text{kg sample}}$$

the activity peak in graph b may be due to two different causes: either the specific activity of the dry residue is high (dpm/mg dry residue) or the specific dry residue of the sample is high (mg dry residue/kg sample); only the first case would indicate higher radioactive fall-out.

2. *Interpretation of results*

Experience shows that in the Northern Hemisphere the highest values of gross beta activity in firn layers were measured for the year 1963. This may be interpreted as follows: in the fall 1961, a new series of intensive nuclear weapon tests was started in the atmosphere which was continued up to 1963. Due to a mean residence time of approximately 16 months of radioactive fission products in the atmosphere, the radioacative fall-out was higher in this period of time. Maximum values of radioactive fall-out are thus assumed to date back to this period, with the deposits of fission products from 1963 showing maximum values of gross beta activity. A precise outline of the 1963 ablation horizon, however, is not always possible. The following criteria were applied for interpretation: an activity peak in profile b (Fig. 2) must correspond to an activity peak in profile c (Fig. 2), activity being linked to dry residue. In general, this peak does not correspond to a maximum value in profile a, since the peak in profile a is caused by a higher level of dry residue, regardless of the content of radioactive fission products. Systematic errors which may occur, partly due to a spilling of the sample during transportation, can be recognized by coinciding peaks in profiles a and b, whereas profile c does not show the corresponding peak. Other criteria applied for interpretation are stratigraphic results, such as the fact that the year 1962 is known as a year of strong melt in the Canadian Arctic (ANONYMOUS, 1962).

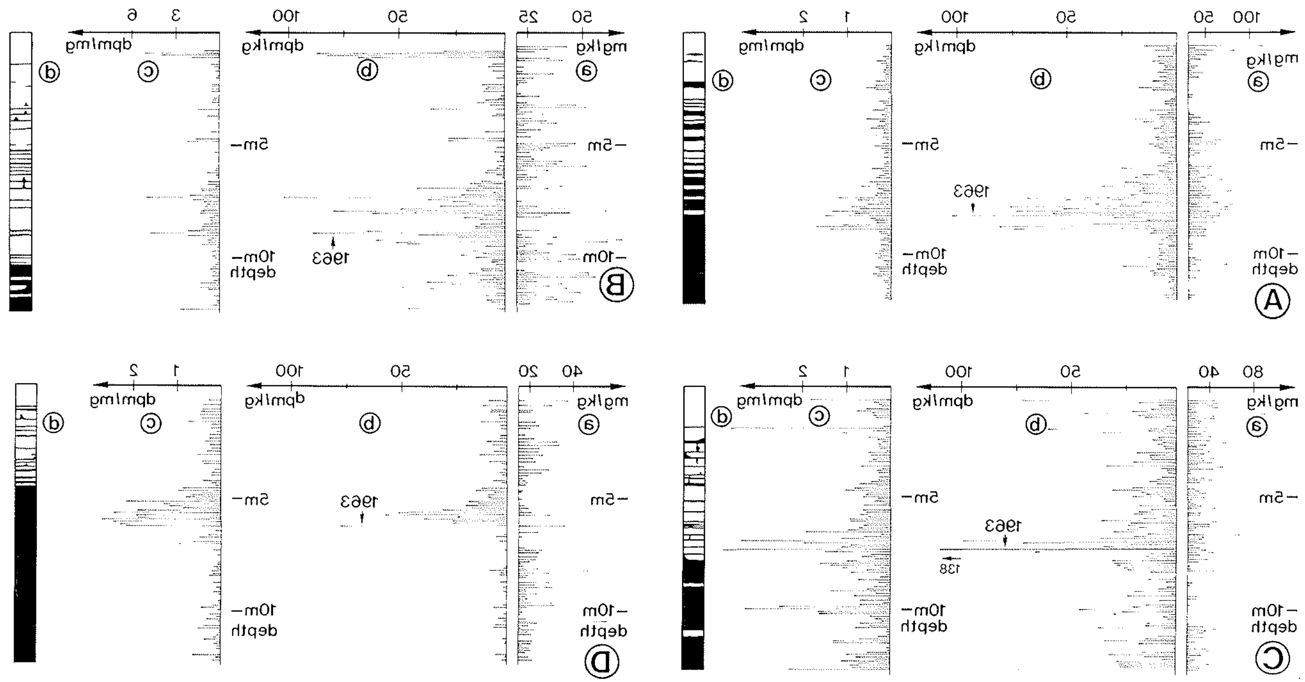
Core	Depth of 1963 level	Mean net balance since 1963	Date of sampling
A	8,35 m	40,0 cm w. e.	01. 05. 1976
B	8,95 m	34,0 cm w. e.	02. 05. 1976
C	7,45 m	28,7 cm w. e.	03. 05. 1976
D	6,20 m	30,0 cm w. e.	07. 05. 1976
E	10,55 m	38,2 cm w. e.	27. 04. 1977
F	6,95 m	18,4 cm w. e.	19. 05. 1977
G	2,35 m	6,9 cm w. e.	04. 05. 1977
WG—L1	10,55 m	34,8 cm w. e.	15. 08. 1978

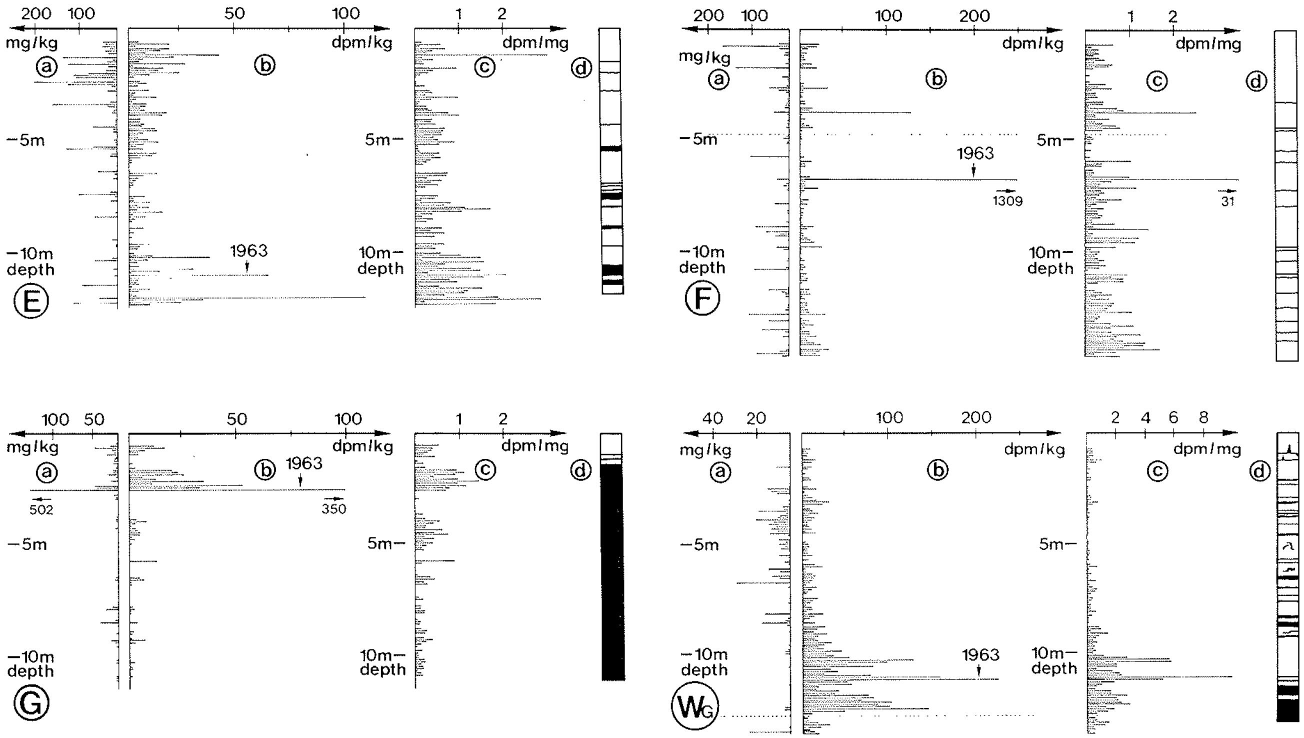
Tab. 2: Depth of the reference level 1963 and mean annual net balance since 1963.

Tab. 2: Tiefen des Bezugshorizontes 1963 und mittlere jährliche Rücklagen seit 1963.

Fig. 2: Vertical profiles of the following data: a) concentrations of the dry residue in the samples (mg/kg), b) concentrations of the gross beta activity in the samples (dpm/kg), c) concentrations of the gross beta activity in the dry residue (dpm/mg), d) stratigraphy of the cores. Dotted lines belong to samples with systematic errors which may originate partly by spilling the samples during transportation. 1 dpm = 0,45 pCi and 1 dpm = 0,017 Bq.

Abb. 2: Tiefenprofile für a) Konzentrationen der Trockenrückstände der Proben (mg/kg), b) Konzentrationen der Gesamt-Beta-Aktivität der Proben (dpm/kg), c) Konzentrationen der Gesamt-Beta-Aktivität der Trockenrückstände (dpm/mg), d) Stratigraphie der Kerne. Strichliert wiedergegebene Ergebnisse beziehen sich auf Proben mit systematischen Fehlern durch teilweisen Verlust der Proben während des Transportes durch Ausrinnen. 1 dpm = 0,45 pCi und 1 dpm = 0,017 Bq.




200 100
mg/kg
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Tab. 2 gives the depths of the reference horizon of 1963 and the water equivalents of the mean annual net accumulations since 1963.

Core A, originating from the south-eastern peninsula of Ellesmere Island, reveals a high amount of mean net accumulation for this area; this corresponds well, however, with the mean annual precipitation quantities recorded by the North Water Project at the Coburg Island station (34.3 cm water).

Core B, this site is situated 30 km directly west of Cape Herschel on the ice divide on Johan Peninsula 1220 m a. s. l. From here, ice flows to Leffert Glacier to the north, to Alfred Newton Glacier to the east and to McMillan Glacier to the south.

Core C, situated 17 km west of Cape Isabella, also lies on the summit of a small ice called Wyville Thomson Glacier.

Core D, situated 7 km west of Site F, 1090 m a. s. l., lies on a small ice cap east of Cape Alexander.

Cores E and G were both collected on the mountainous Northumber Island 400 m a. s. l. The island is certainly within the bounds of the North Water polynya. It was expected that the precipitation of this area would be enhanced by local moisture of North Water origin. Thus a mean net accumulation of some 40 cm w. e. per year seems acceptable, in spite of the much lower precipitation amount recorded at the nearest weather station: for the period 1964—1975 a mean annual total of 11,3 cm only is reported at Kanak. Of much greater surprise was the large variability of the combined precipitation and energy balance conditions on the island, as indicated by the great differences between the two cores. Local topography seems to play a major role here. In Core G the radioactive peak was found at a depth of 2,35 m. An unknown quantity was lost by run off from this site. On the other hand, Core E, extracted from a shallow basin, may contain drift snow, thus giving a large accumulation quantity.

Core F, collected in the highest portion of the very flat and smoothed ice dome north of Kanak, contained an easily identifiable 1963 beta activity peak. The resulting mean net accumulation is much smaller than expected for this area. The annual total precipitation had been estimated to amount to 60 cm w. e.

Core WG-L1 was taken in the centre of the accumulation basin of White Glacier on Axel Heiberg Island. The findings place considerable confidence in the gross beta activity dating technique: the compilation of annual firn pit measurements carried out at this site confirm the 1963 horizon to be within 10 cm of the depth indicated by the beta activity measurements taken on the core.

3. *Conclusions*

Firn layers from 1961 right through 1963 in the Northern Hemisphere can still be dated by measuring the gross beta activity. A vertical profile yields the net accumulation from the moment of deposit up to the moment of sampling; the mean annual net accumulation can be calculated for this period of time. Despite considerable percolation of melt water, this method can also be applied to low regions of the accumulation area, on account of physical conditions such as adsorption of radionuclids on aerosoles and their concentration in ablation horizons. As far as superimposed ice is concerned, this activity remains linked to the developed ice layer, so that this method may be applied also to regions with superimposed ice. If, however, the superimposed ice layer melts in a later year of strongly negative mass balance, misinterpretations may result. This study shows that net accumulation can still be successfully determined by measuring vertical profiles of the gross beta activity, especially in regions of strong melt water flow where other methods would fail.

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