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CORE DRILLING ON VERNAGTFERNER (OETZTAL ALPS, AUSTRIA) IN 1979: TRITIUM CONTENTS

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With 4 figures

ABSTRACT

In March 1979, on Vernagtferner (Oetztal Alps, Austria) two cores, I (81 m) and II (45 m), had been drilled the ^3H content of which was measured. The cores show clearly the increase of the ^3H content in the deposited precipitation due to the nuclear weapon tests which were performed mainly in the time between 1953 and 1962. However, it is difficult to correlate the ^3H profiles of core I and II for the layers below 15 m. From the results of core I one can calculate a mean net accumulation rate of 0.7 m water equivalent per year during the time period 1952—1977, the corresponding value of core II being about 0.9 m w. e. per year. The ^3H content of former precipitation and of core I is in agreement. Comparing the ^3H content of core I with that of a core drilled in 1976 on Vernagtferner one finds general agreement but the concentration peaks do not very well coincide. Traces of up to 10 TU were measured in samples of ice of core I which were taken randomly from depths below. These are supposed to originate from young meltwater penetrating into the glacier.

KERNBOHRUNG AM VERNAGTFERNER (ÖTZTALER ALPEN) 1979: TRITIUMGEHALTE

ZUSAMMENFASSUNG

An den zwei Bohrkernen I (81 m lang) und II (45 m lang), die im März 1979 auf dem Vernagtferner (Ötztaler Alpen, Österreich) erbohrt worden waren, wurde der ^3H-Gehalt bestimmt. Es konnte in beiden Bohrungen die durch die Kernwaffentests (1953 bis 1962) verursachte deutliche Erhöhung des ^3H-Gehalts im Niederschlag nachgewiesen werden. Die ^3H-Profile in den Bohrungen I und II weichen ab einer Tiefe von 15 m voneinander ab. Für Bohrung I errechnet sich für die Zeit 1952 bis 1977 eine mittlere Nettoakkumulationsrate von 0,7 m Wasseräquivalent pro Jahr, für Bohrung II 0,9 m. Der ^3H-Gehalt in den früheren Niederschlägen und der ^3H-Gehalt der Bohrung I stimmen angenähert überein. Der zeitliche Verlauf des ^3H-Gehalts einer Flachbohrung aus dem Jahr 1976 auf dem Vernagtferner gleicht insgesamt dem der Bohrung I, jedoch sind die maximalen ^3H-Gehalte um ein bis zwei Jahre gegeneinander verschoben. An einzelnen Proben, die aus Bohrung I zwischen 30 m Tiefe und dem Gletscheruntergrund entnommen worden waren, wurden immer ^3H-Spuren mit einem maximalen Gehalt von 10 TU nachgewiesen, die von in den Gletscher eingedrungenem, jungem Schmelzwasser stammen dürften.

1. INTRODUCTION

The low natural ^3H content of precipitation has been enriched in the years since 1953 mainly by the fallout of nuclear weapon tests. It reached its maximum in 1963 and has been decreasing since then. The ^3H content is a proper means for hydrological dating in a time scale of at least 30 years back from today, as well as an indicator for young water mixed with older water. In glacier studies one can try to date the firn lay-

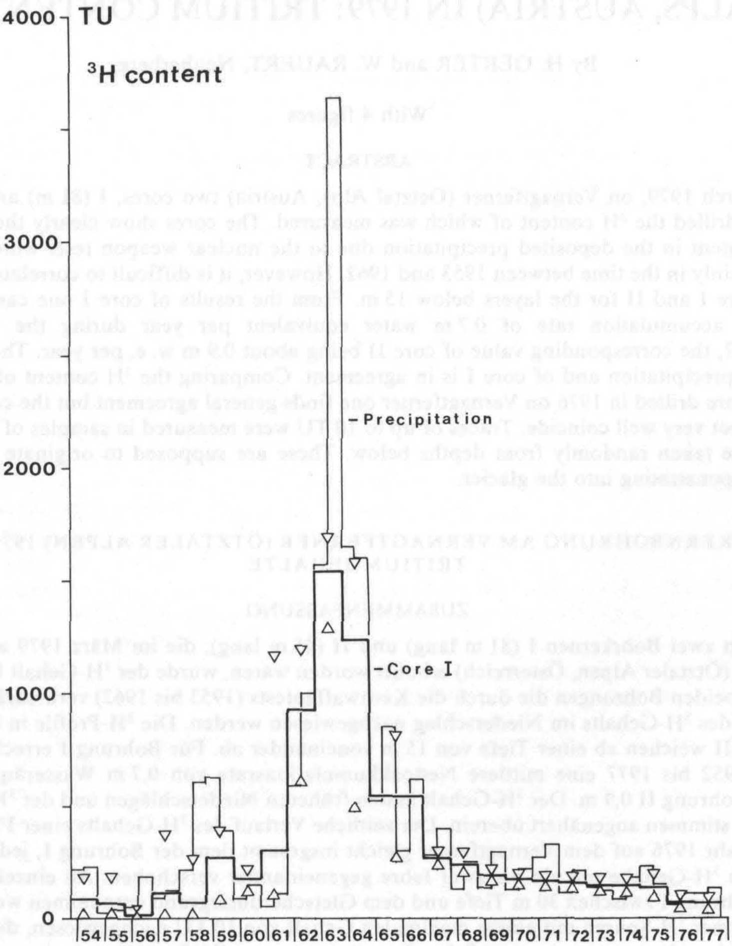

Fig. 1: Core drilling on Vernagtferner 1979: Comparison between the ^3H content of core I, referred to the most likely year of deposition, and the ^3H content of precipitation (half-year means) in the years 1954—1977. The ^3H contents of precipitation in the years 1972—1977 are values for the village Vent close to the Vernagtferner (Behrens et al., 1979). In the years 1954—1976 the values are those for the area of Davos, Switzerland (Martinec et al., 1974).

▽, △: Measured maximum and minimum of ^3H contents in the annual layers of core I.

ers back to 1953 by means of the ^{3}H content, thus determining the mean net accumulation rate over this period.

In the catchment area of Rofenache (Oetztal Alps, Austria; cf. Oerter et al., 1982, fig. 1) first attempts were made by Ambach and Eisner (1965) to date the firn layers of Kesselwandferner by measuring the vertical distribution of radioactive fall-out (total beta- and ^{137}Cs activity). Later on, also the ^{3}H contents of firn layers were determined on samples taken from snow pits and boreholes (Ambach et al., 1968, 1969, 1976, 1978). In 1976, drill cores were taken at a distance of about 5 km from the Kesselwandferner site on Vernagtferner, among others, for ^{3}H analyses (Behrens et al., 1979). All these investigations reached to firn and ice depths corresponding to deposition times not earlier than about 1950. From March 7 to April 3, 1979 deep core drilling was done in the accumulation area of Vernagtferner at an altitude of about 3150 m a. s. l. The drilling operation, the location of the boreholes, as well as stratigraphical features of the recovered cores are described by Oerter et al. (1982). Investigations on the ^{3}H content were carried out on core I (total length 81.35 m) and core II (45.86 m), which were drilled 160 m apart from each other.

2. EXPERIMENTAL

The cores were cut parallel to their axes into four parts. One part with a cross section of about 14 cm² was further cut perpendicular to the axis into pieces which were 2.5 cm (core I) or 3 cm (core II) long, respectively. These small pieces were carefully melted and poured into glass bottles. The meltwater was used for ^{3}H measurements and also for ^{18}O und ^{2}H measurements (Stichler et al., 1982).

The ^{3}H contents of most of the samples were measured by direct liquid scintillation counting of 10 ml water samples for a time of 500 to 1000 min each, which yields a detection limit of about 10 TU[1]. Electrolytic enrichment of ^{3}H in 200—400 ml water samples was used prior to liquid scintillation counting to lower the detection limit to about 3 to 1 TU, respectively. For a few selected samples ^{3}H gas counting was applied after electrolytic pre-enrichment and propane synthesis, resulting in a detection limit of 0.2 TU. For details of the measuring techniques see, for example, Eichinger et al. (1981).

3. RESULTS AND DISCUSSION

3.1 CORE I

On core I the ^{3}H content at first was determined every 10 to 20 cm down to a depth of 41.60 m by direct liquid scintillation counting (fig. 2). Below 27.50 m the ^{3}H content lies mostly below 10 TU. Therefore additional measurements had to be carried out along this core section on electrolytically pre-enriched samples of about 25 cm length each. Some further core samples of about 65 cm length each were measured for ^{3}H by gas counting after electrolytic enrichment. This most sensitive analysis technique was

[1] 1 TU (tritium unit) ≙ 3.2 pCi or 0.12 Bq per litre of water. The detection limits and the intervals of measuring incertainty indicated in this article have a confidence level of 95 %. All ^{3}H contents presented are referred to the date of sampling unless an other reference date is given.

used for samples taken from great depths in which bomb-produced ^3H was not expected to be found.

In discussing the shape of the ^3H profile, we can distinguish four main sections of the core, each with a different ^3H pattern. Along section 1, from the glacier surface to a depth of 14.75 m, the ^3H contents lie between 37 ± 9 and 153 ± 13 TU, with the ^3H content tending towards larger values with increasing depth. This corresponds to the general decrease of the ^3H content in precipitation in recent years, but shows no pronounced peaks due to the annual variation of the ^3H content in precipitation. One small peak is found at a depth of 6.4 m, with a maximum value of 152 ± 12 TU. This firn layer is attributed to the hydrological year 1974/75, in which also higher ^3H concentrations in precipitation had been measured (fig. 1, cf. also Behrens et al., 1979). Section 1 is assumed to represent the firn layers deposited after 1964.

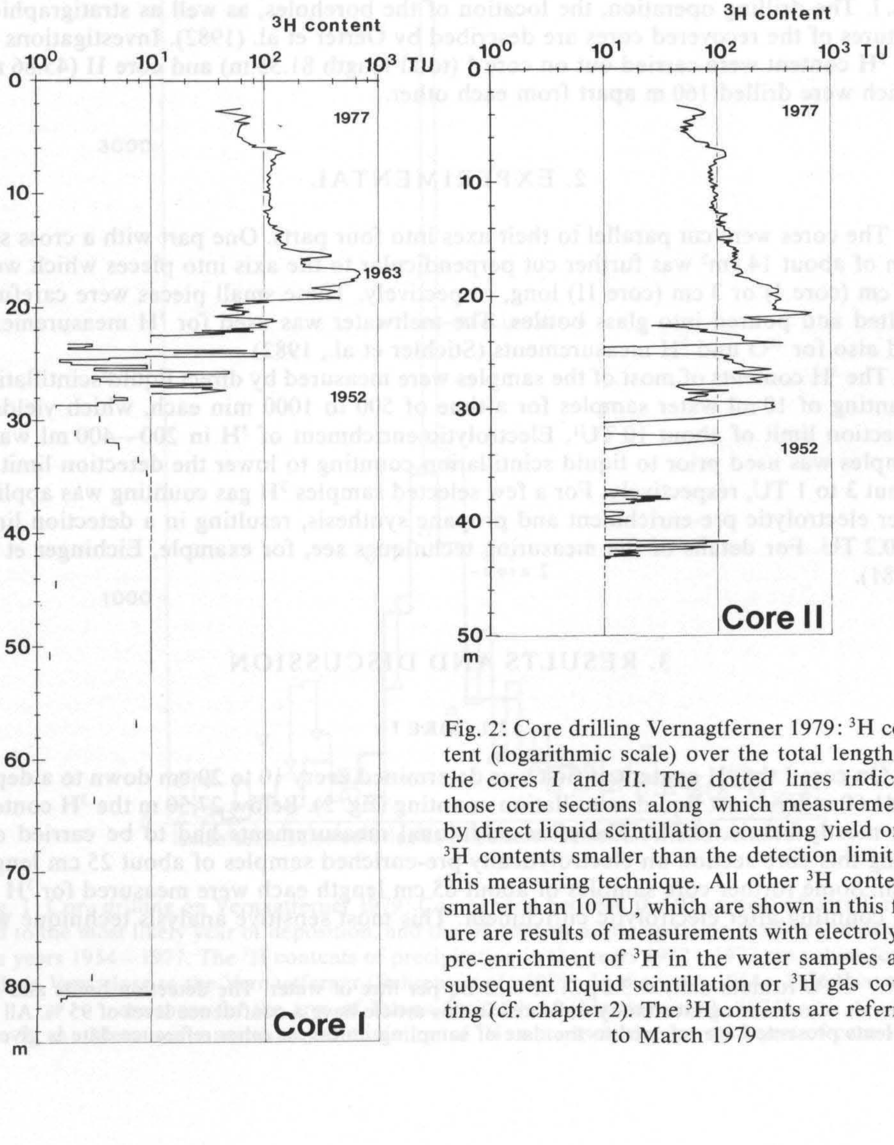

Fig. 2: Core drilling Vernagtferner 1979: ^3H content (logarithmic scale) over the total length of the cores I and II. The dotted lines indicate those core sections along which measurements by direct liquid scintillation counting yield only ^3H contents smaller than the detection limit of this measuring technique. All other ^3H contents smaller than 10 TU, which are shown in this figure are results of measurements with electrolytic pre-enrichment of ^3H in the water samples and subsequent liquid scintillation or ^3H gas counting (cf. chapter 2). The ^3H contents are referred to March 1979

Section 2, from a depth of 14.75 to 19.5 m, is characterized by ^3H contents reaching from 107±17 TU to the absolute maximum of 695±28 TU and displaying three further peaks with 382±12, 427±26, and 456±33 TU. These firn layers were probably deposited within the years 1961—1964, when the greatest ^3H concentrations in the precipitation occured. The maximum peak at a depth of 17.0 m (corresponding to 10.5 m water equivalent (w. e.)) is probably due to precipitation deposited in 1963 (fig. 2).

Along section 3, from a depth of 19.5 to 27.5 m, the ^3H contents vary between 1.6±1.4 TU and 128±18 TU. Four distinct peaks can be recognized. These eight meters of the core presumably cover the time period from 1953, the early stage of the nuclear weapon test era, through 1960.

Along section 4, below 27.50 m down to the end of the core at 81.35 m, the measured random samples showed ^3H contents only smaller than 10 TU, but there are traces of ^3H throughout the whole core. In discussing this phenomenon, we first try to determine the probable location of the transition zone from firn to ice, as well as the firn aquifer, in the year 1953/54, when the first fallout was deposited. Since 1979 we have found this zone on the Vernagtferner in a depth of 20 to 25 m or 13 to 17 m w. e., respectively (Oerter and Moser, 1982). Assuming that the accumulation of the year 1953/54 lies between 27 and 27.50 m depth (approx. 19.5 m w. e.) below the surface in 1979, the ice layers down to 43.5—48.3 m depth (32.5—36.5 m w. e.) had been permeable firn at that time. Thus remains of the percolating ^3H loaded meltwater might be found there. For 1963, the year with the maximum tritium input, the firn aquifer perhaps had been in a depth of 33—38 m below the top of the core. Indeed, ^3H contents up to 9.3±0.8 TU (mean content of the core sample from 34.6—35.0 m depth) were measured. The smallest ^3H content measured was 1.3±0.2 TU and belonged to a depth between 50.5 and 51.1 m. Towards the bottom of the glacier another peak, 9.9±2.2 TU, was found. These ice layers possibly are influenced by recent meltwater, penetrating to a certain extent from the bottom of the glacier into the glacier ice.

3.2 CORE II

In core II the ^3H content was determined by direct liquid scintillation counting of samples, taken at 10—15 cm intervals along the 45.9 m long core. Figure 2 shows the measuring results. Analogous to core I we divided also core II into four sections: section 1 from the glacier surface to 18.5 m, section 2 from 18.5 to 24.5 m, section 3 from 24.5 to 33.5 m, and section 4 below 33.5 m to the last measured samples at 45.5 m.

Along the section 1 one finds a small but distinct peak, 120±11 TU, at a depth of 7.5 m (3.6 m w. e.). This is probably the firn layer deposited in 1975 (fig. 3). Further down along section 1 only small variations are found with greatest values coming up to 194±17 TU. These 18.5 m probably cover the time after 1965. Along section 2 and 3 the pointed maximum ^3H peak, 677±25 TU, was found at a depth of 21.5 m (13.9 m w. e.). It should be assigned to the precipitation of 1963. Below the main peak significant peaks appear at 22.2 m (412±17 TU), at 24.1 m (385±19 TU), a double peak at 26.45 and 27.05 m (296±16 and 307±15 TU), another peak at 29.9 m (320±30 TU) and one at 32.5 m (107±23 TU). The layers of section 2 and 3 might represent the precipitation deposited from 1953 through 1965. From the beginning of section 4 down to 37.2 m, the ^3H content sinks below 10 TU, and it does so between 40.0 and 41.6 m as well as along the last meters from 43.0 to 45.5 m.

Between these minima, however, three more distinct peaks appear, the largest of which, at a depth of 41.7 m, having a ^3H-content of 123 ± 13 TU. It is unlikely that the ice at this depth was deposited during the nuclear weapon test period, but this peak is located at a depth at which permeable firn could have existed during the time period 1953—1963. Thus the relatively high ^3H content could be explained by contamination of the firn by percolating meltwater of this period, probably in particular from the years 1962—1963 with the maximum ^3H contents in precipitation. This peak and the main peak at 21.5 m depth lie 20.2 m (17.9 m w. e.) apart from each other, a distance which would be likely for the location of the firn aquifer and the transition zone firn to ice during 1962—1963.

3.3 COMPARISON OF THE ^3H CONTENT IN BOTH CORES

There are some discrepancies between the ^3H profiles of core I and II. A correction of 1 m must be applied because, when the drilling of core II started, the snow depth on the glacier had increased by approximately 1 m, due to heavy snow falls since the begin of the drilling operation of core I. Furthermore we have to consider that there were losses from core material at core I (2.1 m over the whole length), and that there was a small excess of material (chips) at core II (0.8 m) (cf. Oerter et al., 1982, table 1). Applying these corrections, the first 14.5 m of core I and the first 15.8 m of core II display ^3H profiles which are consistent with each other within small variation limits (fig. 3). Especially the first significant peaks, due to 1974/75 snow falls, coincide. However, neither the values of the ^3H content nor the distribution along the core axis correspond below these coinciding sections.

We now consider the second sections of the cores. The length of section 2 of core I is 4.75 m, of core II 6 m. The shape of the main peak is more pointed in core II than in core I, whereas the heights of both ^3H peaks do not differ significantly. Thus one could assume that the peaks originated at the same time, but the peak of core II lies 3.5 m (2.4 m w. e.) deeper than that of core I. The peak of core I at 15.4 m could correspond to the peak of core II at approximately 19 m, but the minimum below that peak in core I is not so obvious in core II. Also no agreement is found when the ^{18}O content of core I at that depth (Stichler et al., 1982) is compared with the ^{18}O content of core II which was measured in depths from 15.0 to 21.4 m. Taking into account stratigraphical features one could try to relate the dust horizons at 16.3 m of core I and 18.5 m of core II with each other. These horizons could be the late summer horizons of the ablation season of 1964 with its high ablation and thus only small accumulation. This correlation would be supported by the results of total-beta-activity measurements (Gunten et al., 1982) on core II, as well as by a later γ-log in borehole I in 1982 (Drost and Hofreiter, 1982). At the moment no final conclusions on this problem are possible, so that only the depth interval 19.0 to 21.0 m of core II can be assigned to the time period 1963—1964.

Looking at the sections 3 of the cores, we find a comparable number of peaks with comparable widths, but the amplitudes of the peaks are greater by a factor 2 in core II than in core I. In this case the ^3H content at core II looks more likely to be undisturbed. The ^3H contents of core I might have been reduced by exchange with the meltwater flowing within the firn aquifer (Oerter and Moser, 1982). Indeed, during the summer 1979 the water table in both boreholes showed a different behaviour, with greater amplitudes in borehole I, thus indicating a well developed firn aquifer. The amplitudes were very small in borehole II, which could mean that the meltwater did not build up into a firn aquifer, but immediately drained through a nearby crevasse.

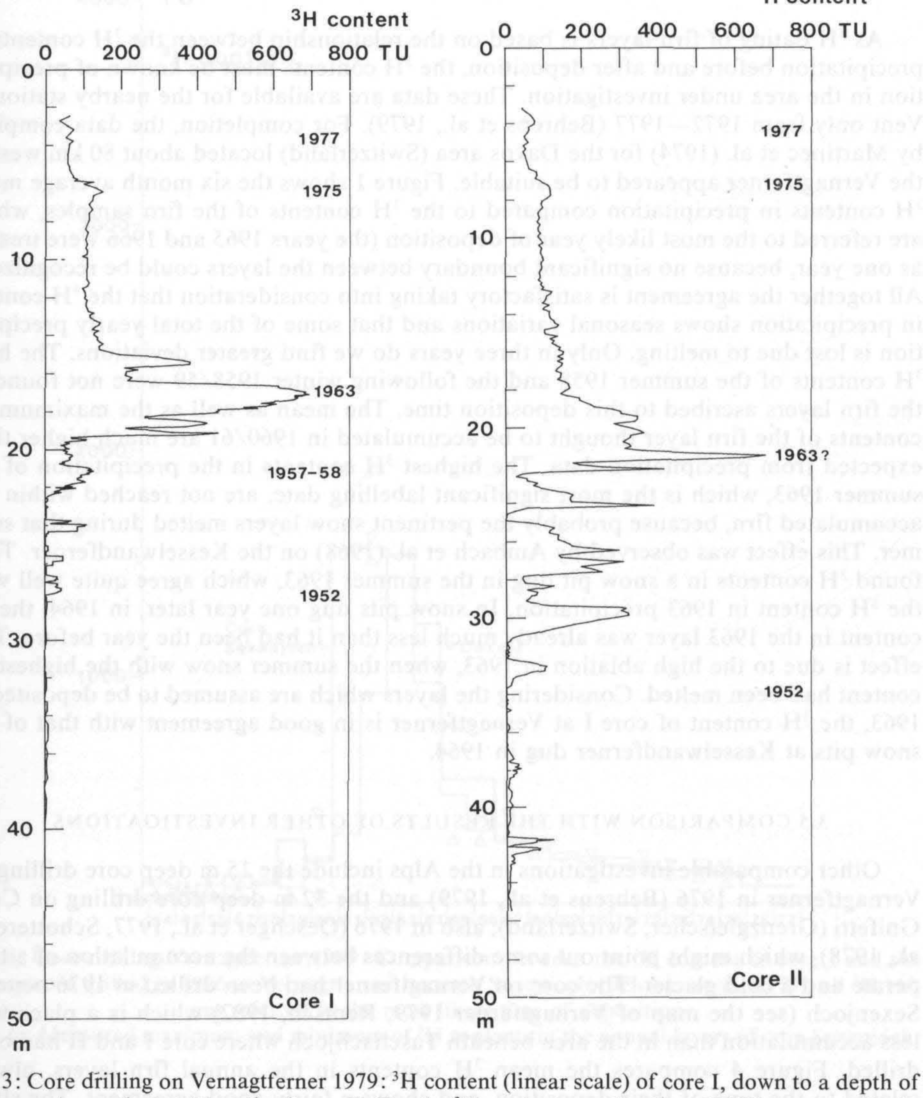

Fig. 3: Core drilling on Vernagtferner 1979: ^{3}H content (linear scale) of core I, down to a depth of 50 m, and over the total length of core II. For the ^{3}H contents smaller than 10 TU compare fig. 2

This hypothesis must still be proven by another core drilling which will be done in 1983 on Vernagtferner at the same drilling site as in 1979.

The mean annual accumulation in the surroundings of both cores can be calculated with the aid of the ^{3}H content for the time period 1952—1977. From the results of core I one obtains mean accumulation rates of 0.70 m w. e. per year for the time span 1952—1977, 0.79 m w. e. per year for 1952—1963, and 0.68 m w. e. per year for 1963—1977. For core II one obtains a accumulation rate of 0.93 m w. e. per year for the time span 1952—1977 which is by 33 % greater than that for core I.

3.4 COMPARISON WITH THE TRITIUM CONTENT IN PRECIPITATION

As ^3H dating of firn layers is based on the relationship between the ^3H contents in precipitation before and after deposition, the ^3H contents must be known of precipitation in the area under investigation. These data are available for the nearby station at Vent only from 1972—1977 (Behrens et al., 1979). For completion, the data compiled by Martinec et al. (1974) for the Davos area (Switzerland) located about 80 km west of the Vernagtferner appeared to be suitable. Figure 1 shows the six month average mean ^3H contents in precipitation compared to the ^3H contents of the firn samples, which are referred to the most likely year of deposition (the years 1965 and 1966 were treated as one year, because no significant boundary between the layers could be recognized). All together the agreement is satisfactory taking into consideration that the ^3H content in precipitation shows seasonal variations and that some of the total yearly precipitation is lost due to melting. Only in three years do we find greater deviations. The high ^3H contents of the summer 1958 and the following winter 1958/59 were not found in the firn layers ascribed to this deposition time. The mean as well as the maximum ^3H contents of the firn layer thought to be accumulated in 1960/61 are much higher than expected from precipitation data. The highest ^3H contents in the precipitation of the summer 1963, which is the most significant labelling date, are not reached within the accumulated firn, because probably the pertinent snow layers melted during that summer. This effect was observed by Ambach et al. (1968) on the Kesselwandferner. They found ^3H contents in a snow pit dug in the summer 1963, which agree quite well with the ^3H content in 1963 precipitation. In snow pits dug one year later, in 1964, the ^3H content in the 1963 layer was already much less than it had been the year before. This effect is due to the high ablation in 1963, when the summer snow with the highest ^3H content had been melted. Considering the layers which are assumed to be deposited in 1963, the ^3H content of core I at Vernagtferner is in good agreement with that of the snow pits at Kesselwandferner dug in 1964.

3.5 COMPARISON WITH THE RESULTS OF OTHER INVESTIGATIONS

Other comparable investigations in the Alps include the 15 m deep core drilling on Vernagtferner in 1976 (Behrens et al., 1979) and the 32 m deep core drilling on Colle Gnifetti (Grenzgletscher, Switzerland), also in 1976 (Oeschger et al., 1977, Schotterer et al., 1978), which might point out some differences between the accumulation of a temperate and a cold glacier. The core on Vernagtferner had been drilled in 1976 beneath Sexenjoch (see the map of Vernagtferner 1979, Rentsch, 1982) which is a place with less accumulation than in the area beneath Taschachjoch where core I and II had been drilled. Figure 4 compares the mean ^3H contents in the annual firn layers, always related to the time of their deposition, and shows a fairly good agreement. The slight difference between the ^3H profile of Colle Gnifetti, measured down to a depth of 17 m, and the Vernagtferner profiles might be due to the fact that there is much less ablation on a cold glacier than on a temperate one like the Vernagtferner. On a cold glacier only the heavy winds, which may sometimes blow away the freshly fallen snow, disturb the accumulation. The maximum ^3H content given by Schotterer et al. (1978) for the year 1963 is approximately 1200 TU (referring to the date of drilling, September 1976) and for 1958/59 approximately 320 TU. Indeed, these values are closer to the original ^3H content in precipitation, especially the summer precipitation, than the ^3H contents of the Vernagtferner cores. For both years we have to assume high ablation

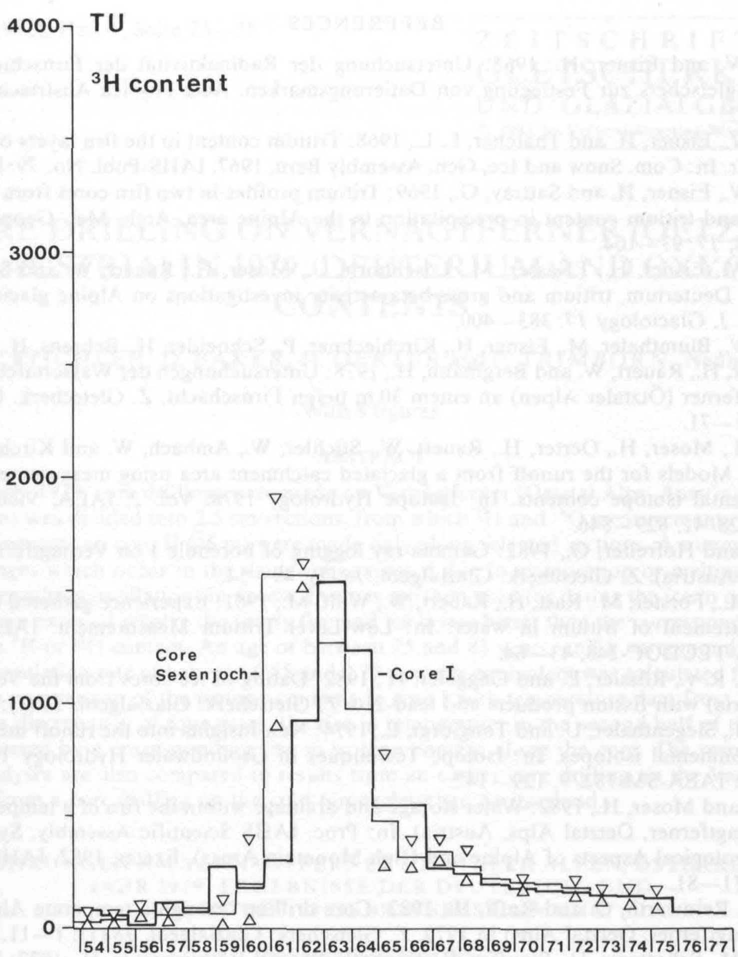

Fig. 4: Core drilling Vernagtferner 1979: Comparison between the ^{3}H content of core I and the former core drilled in 1976 at Vernagtferner beneath Sexenjoch (Behrens et al., 1979), all ^{3}H values referred to the most likely time of deposition.
∇, Δ : Measured maximum and minimum of ^{3}H contents in the annual layers of core Sexenjoch

on the Vernagtferner. This could mean that there the summer snow, with the highest ^{3}H content, was lost due to melting.

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