Band 18 (1982), Heft 1, Seite 1—11

ZEITSCHRIFT FÜR
GLETSCHERKUNDE
UND GLAZIALGEOLOGIE

CORE DRILLING THROUGH A TEMPERATE ALPINE GLACIER (VERNAGTFERNER, OETZTAL ALPS) IN 1979

By H. OERTER, Neuherberg, O. REINWARTH, Munich, and H. RUFLI, Bern

With 4 figures

ABSTRACT

In 1979 a core drilling project was carried out on Vernagtferner in the Oetztal Alps (Austria). This report describes the field work of the drilling project, the recovered core material and the occurrence of water in the boreholes and compiles the succeding investigation program.

KERNBOHRUNG AUF EINEM TEMPERIERTEN ALPENGLETSCHER (VERNAGTFERNER, ÖTZTALER ALPEN) IM JAHR 1979

ZUSAMMENFASSUNG

Im Frühjahr 1979 wurde eine Kernbohrung auf dem Vernagtferner in den Ötztaler Alpen (Österreich) durchgeführt. Dieser Bericht beschreibt die Arbeiten während der Bohrung auf dem Gletscher, das gewonnene Kernmaterial sowie das Auftreten von Wasser in den Bohrlöchern. Ferner gibt er einen Überblick über das Untersuchungsprogramm, das sich an die Bohrung anschloß.

INTRODUCTION

In March 1979 on Vernagtferner in the Oetztal Alps (Austria) (fig. 1) an attempt was undertaken to drill through a temperate Alpine glacier, in order to recover firn and ice cores for isotopic and chemical investigations by various laboratories. It was the first time that a core drilling in the Eastern Alps reached the bottom of a temperate glacier (at a depth of 84 m). Various drillings with maximum depths of about 20 m were carried out earlier, for example at the neighbouring Kesselwandferner (Eisner, 1971, Ambach et al., 1978, Ambach and Eisner, 1980) with the aid of a modified Sipre-type coring auger. Two more boreholes of about 15 m were drilled on Vernagtferner in the year 1976 (Behrens et al., 1979). Furthermore core drillings were carried out in the Western Alps, for example shallow type core drillings at Jungfraujoch, Switzerland (Schotterer et al., 1977), and a deeper drilling on the Mer de Glace, France, down to 187 m (Vallon et al., 1976). A very extensive drilling program, covering several summer seasons, was carried out in the cold ice of Grenzgletscher (Colle Gnifetti, Monte Rosa), Switzerland. Results of this program have been presented by Oeschger et al. (1977) and Schotterer et al. (1978). A survey on the world wide activities in ice core drilling was compiled by the World Data Center A for Glaciology (1980).

The technical difficulties of core drilling in temperate glaciers and the interpretation of the results prove to be much greater than for polar ice sheets or for cold alpine glaciers. The meltwater percolation through the glacier and refreezing of parts of the meltwater in firn layers may blur the original stratigraphy and distribution of isotopic and chemical characteristics. Furthermore we have to deal with the problem that in

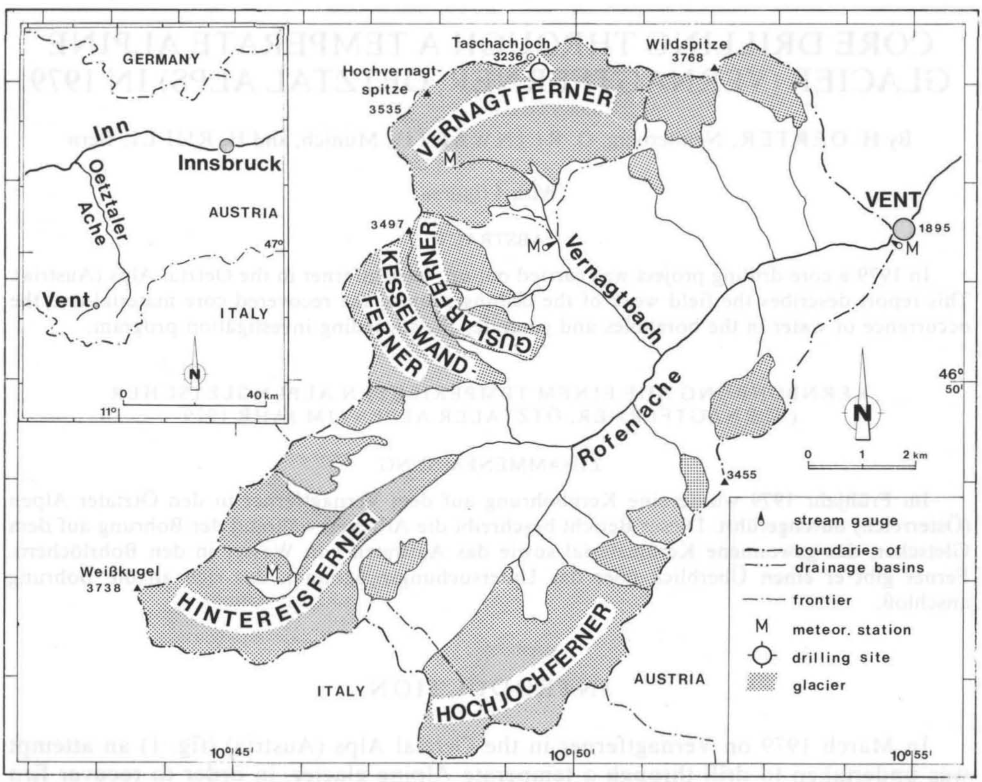

Fig. 1: Map of the drainage basin of Rofenache in the Oetztal Alps (Austria) showing the location *of the drilling site on Vernagtferner*

some years the relation of summer and winter layers may deviate considerably from the standard accumulation. During a summer with extremely high ablation there may not be any net accumulation left at all at the end of the ablation season. On the other hand it may also happen that the net accumulation is comprised almost entirely of winter or almost entirely of summer snow. Because of these complications only measurements at a core site itself can establish how much information on the accumulation history, the related meteorological conditions and the climatic variations, or on the meltwater storage is still recorded in a particular temperate Alpine glacier. For this reason core drilling was carried out in spring 1979 on Vernagtferner as a compliment to the extended hydrological research program there (Oerter et al., 1981). This report describes the field work of the drilling project, whereas the following papers in this volume give the results of the laboratory measurements at the cores, which were done in co-operation between German and Swiss institutes (see Table 4).

THE LOCATION OF THE BOREHOLES

The drilling operations were carried out on the Vernagtferner in the Oetztal Alps (9.30 km^2; lat. 46° 52′ N, long. 10° 49′ E) (fig. 1). On the glacier a rather extended flat area (about 3150 m a. s. l.) beneath Taschachjoch was chosen as site for the three boreholes (fig. 2). The thickness of the glacier at the drilling site was expected to be in the

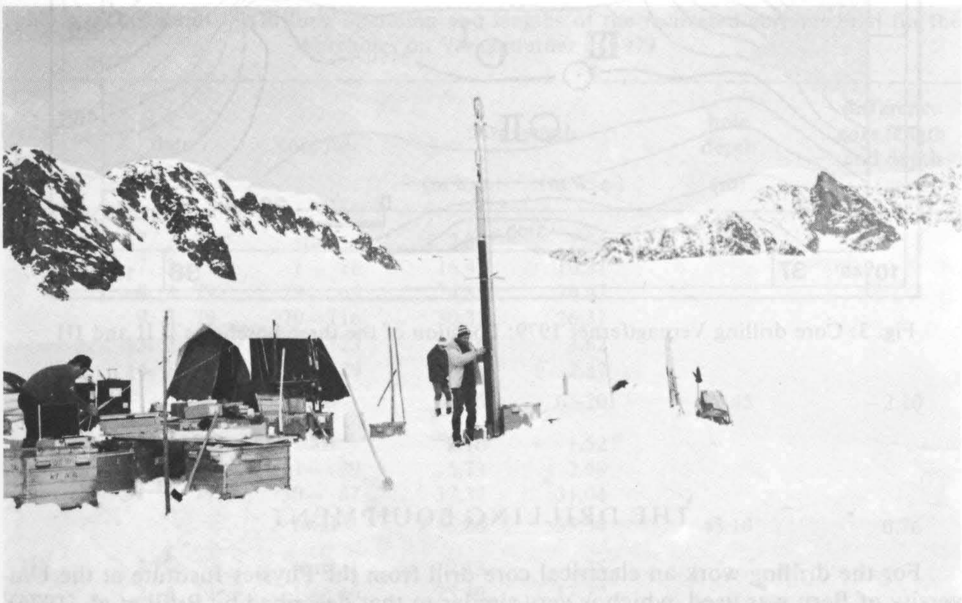

Fig. 2: Core drilling through a temperate glacier

range between 90 and 100 m, according to earlier thermal drillings (Oerter, 1977) and seismic measurements of Miller (1972). Accumulation data for this area can be derived from the mass balance studies since 1965 (Reinwarth, 1972).

During summer time in this area a water table in the firn can be found about 17—23 m below the glacier surface (Oerter, 1981, Oerter and Moser, 1982). During autumn and winter the meltwater drains again. Thus the month of March was thought to be the best time for drilling, because at that time the minimum of meltwater should be expected in the glacier. Judging from water table measurements the transition from permeable firn to solid ice occurs within a layer 20—25 m below the glacier surface.

The location of the three boreholes I, II, and III is shown in fig. 3.

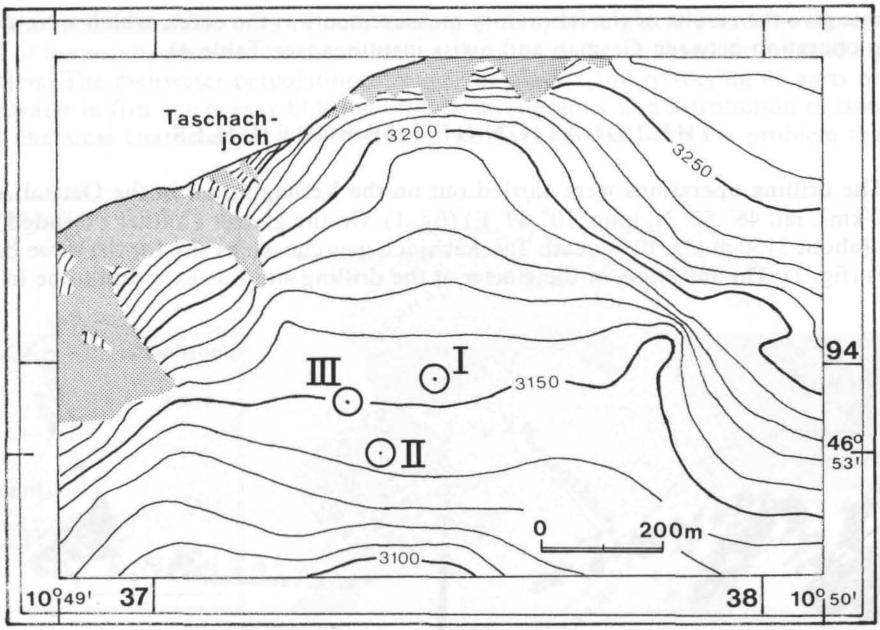

Fig. 3: Core drilling Vernagtferner 1979: Location of the three boreholes I, II and III

THE DRILLING EQUIPMENT

For the drilling work an electrical core drill from the Physics Institute at the University of Bern was used, which is very similar to that described by Rufli et al. (1976). The drill is suspended from a cable, and consists of a coring system, a driving system and an antitorque system. The core barrel, a 2-m-long steel tube (inside diameter 80 mm) and the outer tube were teflon coated. The drill bit is fitted with either two or three replaceable knives. The inner diameter, 75 mm, is also the core diameter; the outer diameter, 114.5 mm, cuts a hole with a diameter of 115 mm. A drill bit with two knives was used for core I, and one with three knives for the cores II and III. After raising the drill out of the borehole, the core barrel was disconnected and the core pushed out with the aid of a wooden stake. The chips were separated from the core and the core cut into pieces of approximately 65 cm length. Pictures were taken of each piece. Afterwards the cores were packed into PE-foil, already labelled with numbers, weighed with spring balance and then laid into boxes (about 25 core pieces in each box) which were stored in shallow snow pits and covered with snow. The snow temperature was −8° C.

After finishing the drilling work, the boxes were dug out again on April 4, and flown down to Vent by helicopter. From there the frozen cores were transported to Munich in deep freezers.

SCHEDULE OF THE DRILLING OPERATION

The field work started on March 6, 1979, when the drilling equipment was flown from the village Vent (1895 m a. s. l.) up to the glacier by helicopter. The weather conditions, however, were not very favourable at that time, so that the drilling work had to be interrupted several times in the first two weeks, each time for a day or more. After finishing borehole I on March 14, an additional interruption for a fortnight was necessary, because an avalanche covered the base camp at the gauging station Vernagtbach. Borehole II was drilled on March 30 and 31, and borehole III on April 2 and 3. Table 1 gives the time progress of the drilling operation.

Table 1: Schedule of the drilling operation and lengths of the recovered core material for the boreholes on Vernagtferner in 1979

bore-hole	date	core no.	core length (m b. s.)	core length (m w. e.)	hole depth (m)	difference core length and depth (m)
I	7. 3. 79	start	2.30	1.06		
	7. 3. 79	1– 28	16.42	10.81		
	8. 3. 79	29– 69	24.85	20.47		
	9. 3. 79	70–116	30.32	26.37		
	13. 3. 79	117–123	4.16	3.62		
	14. 3. 79	124–129	3.30	2.87		
		total	81.35	65.20	83.45	−2.10
II	30. 3. 79	start	3.16	1.52		
	30. 3. 79	21– 29	5.33	2.98		
	31. 3. 79	30– 87	37.37	31.04		
		total	45.86	35.54	45.10	0.76
III	2. 4. 79	start	2.13	0.75		
	2. 4. 79	1– 40	25.39	17.77		
	3. 4. 79	41– 50	6.17	5.54		
			33.69	24.06	34.45	−0.76

b. s.: below surface of the glacier
w. e.: water equivalent

The three boreholes, I, II, III (fig. 3), were drilled yielding cores with lengths of 79.05 m, 42.70 m, 31.60 m, respectively (table 1). An attempt was made to drill borehole I as deep as possible. At a hole depth of 83.45 m, probably close to the glacier bottom, rapidly raising water stopped further drilling. (On October 9, 1979, the borehole was deepened by electrical drilling by 6.20 m. The hot-point did not penetrate into the ice any further. After raising it, it was very dirty, thus indicating a contact with the bedrock or at least morainic material beneath the glacier.) It was decided not to drill borehole II any deeper than anticipated necessary for reaching tritium free ice. Borehole III was drilled to provide a core enabling the study of the transition zone from firn to ice. Table 1 contains the core lengths and measurd borehole depths. One recognizes that for boreholes I and III we lost core material (on an average 2.5 cm/m, 2.2 cm/m, respectively), whereagainst the core of borehole II is longer (1.7 cm/m on an average) than the borehole itself.

WATER IN THE BOREHOLES

Although it was anticipated that no water would come into the boreholes when drilling during the month of March, borehole I did not stay dry at all throughout the whole drilling operation. At clearly defined depths the cores suddenly became wet, and water filled the lower part of the borehole. On further drilling the cores would then become dry again. As it may be helpful for the discussion of the results of the isotope measurements and the water behaviour in the glacier, the depths at which water occured in borehole I are compiled in table 2.

Table 2: Borehole I on Vernagtferner:
Depths at which water occurred in the borehole during the drilling operation

core no.	depth	remarks
41— 44 (45)	26.40—ca. 29	
69— 75	43.50—47.40	
85	52.80—53.45	after interruption of drilling
107—116	67.46—73.29	
		during interruption of drilling (9.—13. 3.) rise to 67.03 m
117—121	73.29—76.94	
		during night rise to 73.08 m before drilling draw down of the water level to 77.10 m
124	78.05—78.36	
128—129	80.27—81.35	sudden water level rise up to 44.30 m (14. 3. 79, 15.00 h)

The cores first became wet at a depth of 26.40 m and remained wet till approximately 29 m (cores no. 41—44). Because the cores below became dry again it was, however, not necessary to empty the hole. Also the cores between 43.5 and 47.4 m (no. 69—75) were wet. Later, after an interruption of the drilling, water collected in the borehole at a depth of 53 m, which had to be removed. A third water horizon was determined within core no. 107 at a depth of 67.45 m; the cores remained wet till 73.29 m, the end of core no. 116. This piece of core was the last one drilled on March 9, when the operation was interrupted till March 13 (table 1). The water level rose up to 76.03 m below the head of the borehole, and the borehole had to be emptied before drilling could start again. The cores no. 117—121, drilled on this day were wet, as well as most of the cores (124, 128—129) of the next day. Over nigth the water level had risen again from 77 m up to 73 m and dropped to 77.1 m in the morning. At the depth of 81.35 m, so much water flowed from the bottom into the borehole that it could not be emptied again. The water level reached 44.3 m within approximately three hours. This meant the end of drilling core I. The later water level variations in borehole I are described by Oerter and Moser (1982).

In boreholes II and III no water occurred during the drilling operation. The water level measurements during summer 1979 yielded very small variations in borehole II, compared with the variations in borehole I, and a constant water level in borehole III at a depth of approximately 22 m below the original glacier surface (April 3, 1979).

STRATIGRAPHICAL FEATURES

During the drilling the cores were all photographed and a rough stratigraphical description was made, primarily with the purpose of documenting the ice layers in the firn, the dust horizons found within the ice and the general distribution of dirt found. The packed core segments were then weighted with a spring balance, and their density was calculated (fig. 4). Missing values for density in the figure indicate sections of the core which were either damaged or so infirm that no volume could be assigned to them. The core material in the first 35 m was in good condition. The condition of the core between 35 and 50 m varied considerably, and the worst material was found between 50 and 65 m.

The frequency of ice and dirt horizons varied along a given core, as can be seen from fig. 4. How different the yearly amount of dust and dirt deposits on a glacier may be, is revealed, for instance, by an investigation of Ambach and Eisner (1966) in a 20 m deep firn pit on Kesselwandferner, where dust was missing in the late summer horizons of the years 1959, 1955, and 1954. The individual dirt horizons in the three cores of Vernagtferner cannot by any obvious means be identified with each other. One horizon, at a depth of around 10 m water equivalent (w. e.), appears in all three cores. Other horizons appear recognizably in core I and III at depths of about 1.5 m, 5.5 m, and 6.5 m w. e. These horizons do not appear, however, in core II. Very noticeable dirt horizons appear in core I at depths of 16.4 m (10.0 m w. e.), 22.0 m (14.6 m w. e.), 37.2 m (27.2 m w. e.), and 68.0 m (53.6 m w. e.). The last of the above layers displays a noticeably yellow-brown colour. It is possible that the last two layers consist of Sahara dust deposits (cf. Haeberli, 1977, Klebelsberg, 1948, p. 49).

The firn in all three cores displayed ice horizons as well as sections containing corn snow. At around 11—13 m w. e. the firn changed over to layered ice. Although this transition to ice followed smoothly, it was always initiated with a pronounced horizon followed directly by compact ice underneath. Below this depth, the density became for the most part constant. In core I a clearly red colouring was observed between 19.40 m and 20.60 m (fig. 4) and was identified as Eosin and Rhodamine. Both dyes had been used in the previous year during tracer tests on the Vernagtferner near the drilling site (Behrens et al., 1982).

PROGRAM OF INVESTIGATIONS

The investigation program following the drilling is compiled in table 3. In this table the subjects of investigations are listed together with the institutions carrying out the research work and the authors presenting the results (all in this volume).

In addition some geophysical measurements were made by H. Miller, Institute of Pure and Applied Geophysics, University of Munich, which are not yet published. The movement of the boreholes, and the water level variations in these have been controlled since the time of drilling (Oerter and Moser, 1982).

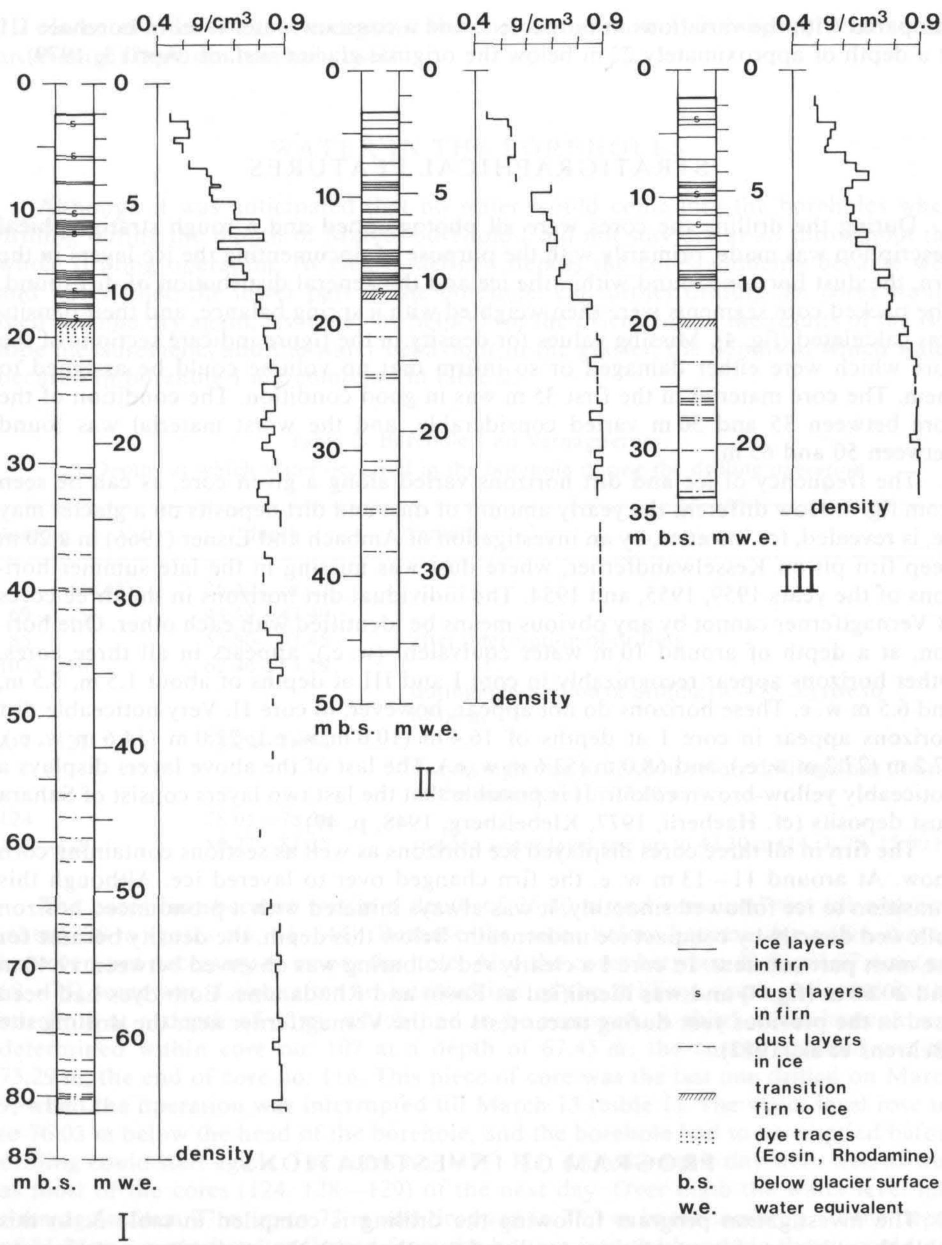

Fig. 4: Core drilling on Vernagtferner 1979: Rough stratigraphy of the cores I, II, III and distribution of density, as calculated by field measurements, along the three cores. The displacement of the zero level is due to the changes of the snow depth by snow fall during the drilling operation. The dye traces are remains of a tracer experiment in the previous year (Behrens et al., 1982). Missing density values indicate that the cores were either damaged or so infirm that no density value could be calculated. For further density values of core III cf. Good (1982), in this volume

Table 3: Core drilling on Vernagtferner 1979: program of investigation

subject	^3H	^2H, ^{18}O	total beta activity ^{90}Sr, ^{137}Cs	^{210}Pb	chemical analysis	structural parameters	CO_2-content
institution	GSF-Institut für Radiohydrometrie Munich, FRG		Swiss Federal Institute for Reactor Research, Würenlingen, Switzerland		GSF-Physikalisch-Techn. Abteilung, Munich, FRG	Swiss Federal Institute for Snow and Avalanche Research, Davos, Switzerland	Physics Institute University Bern, Switzerland
core	I, II	I, II	II	I	I, II	III	III, I
publication	Oerter and Rauert (1982)	Stichler et al. (1982)	v. Gunten et al. (1982)			Good (1982)	

ACKNOWLEDGEMENTS

We would like to thank Dipl.-Ing. (FH) E. Heucke, Dipl.-Ing. H. Rentsch, Mr. W. Stadler, and all the others who helped us in preparing and carrying out the drilling operation. We owe thanks to the Physics Institute of the University Berne, Switzerland (Prof. Dr. H. Oeschger), for providing the drilling equipment, and the Deutsche Forschungsgemeinschaft (German Res. Ass.) for the financial support of the project, carried out in the frame of "Sonderforschungsbereich 81, Teilprojekt A 1" (under the leadership of Prof. Dr. H. Moser) of the Technical University of Munich.

REFERENCES

Ambach, W., Blumthaler, M., Eisner, H., Kirchlechner, P., Schneider, H., Behrens, H., Moser, H., Oerter, H., Rauert, W. and Bergmann, H., 1978: Untersuchungen der Wassertafel am Kesselwandferner (Ötztaler Alpen) an einem 30 m tiefen Firnschacht. Z. Gletscherk. Glazialgeol. *14:* 61—71.

Ambach, W. and Eisner, H., 1966: Analysis of a 20 m firn pit on the Kesselwandferner (Oetztal Alps). Z. Gletscherk. Glazialgeol. *6:* 223—231.

Ambach, W. and Eisner, H., 1980: Neue Ergebnisse von Messungen der Gesamt-Beta-Aktivität in Tiefenprofilen am Kesselwandferner (Ötztaler Alpen). Z. Gletscherk. Glazialgeol. *16:* 131—133.

Behrens, H., Moser, H., Oerter, H., Rauert, W., Stichler, W., Ambach, W. and Kirchlechner, P., 1979: Models for the runoff from a glaciated catchment area using measurements of environmental isotope contents. In: Isotope Hydrology 1978. Vol. 2, Wien, IAEA: 829—846.

Behrens, H., Oerter, H. and Reinwarth, O., 1982: Results of tracer tests with fluorescent dyes on the Vernagtferner (Oetztal Alps, Austria) from 1974 to 1982. Z. Gletscherk. Glazialgeol. *18* (1): 69—87.

Eisner, H., 1971: Bestimmung der Firnrücklagenverteilung im Akkumulationsgebiet des Kesselwandferners (Ötztaler Alpen) durch Messung der Gesamt-Beta-Aktivität von Bohrproben. Z. Gletscherk. Glazialgeol. *7:* 67—78.

Good, W., 1982: Structural investigations of snow and ice on core III from the drilling on Vernagtferner, Austria, in 1979. Z. Gletscherk. Glazialgeol. *18* (1): 55—67.

Gunten, H. R. v., Rössler, E. and Gäggeler, H., 1982: Dating of ice cores from the Vernagtferner (Austria) with fission products and lead-210. Z. Gletscherk. Glazialgeol. *18* (1): 39—47.

Haeberli, W., 1977: Sahara dust in the Alps. A short review. Z. Gletscherk. Glazialgeol. *13:* 206—208.

Klebelsberg, R. v., 1948: Handbuch der Gletscherkunde und Glazialgeologie. Erster Band: Allg. Teil. Wien, Springer-Verlag: 403 pp.

Miller, H., 1972: Ergebnisse mit der Methode der Refraktions-Seismik auf dem Guslar- und Vernagtferner. Z. Gletscherk. Glazialgeol. *8:* 27—41.

Oerter, H., 1977: Wasserbewegung in einem Gletscher, dargestellt an den Feldarbeiten auf dem Vernagtferner. In: Vortragsveranstaltung 9. Febr. 1977 (Sonderforschungsbereich 81, Techn. Univers. München, Ed.), München: 67—92.

Oerter, H., 1981: Untersuchungen über den Abfluß aus dem Vernagtferner unter besonderer Berücksichtigung des Schmelzwasserabflusses im Firnkörper. Diss. Techn. Univers. München.

Oerter, H., Baker, D., Moser, H. and Reinwarth, O., 1981: Glacialhydrological investigations at the Vernagtferner glacier as a basis for a discharge model. Nordic Hydrology *12:* 335—348.

Oerter, H. and Moser, H., 1982: Water storage and drainage within the firn of a temperate glacier (Vernagtferner, Oetztal Alps, Austria). In: Proc. IAHS Scientific Assembly, Symposium 5 (Hydrological Aspects of Alpine and High Mountain Areas), Exeter, 27.—30. 7. 1982, IAHS Publ. *138:* 71—81.

Oerter, H. and W. Rauert, 1982: Core drilling on Vernagtferner (Oetztal Alps, Austria) 1979: Tritium contents. Z. Gletscherk. Glazialgeol. *18* (1): 13—22.

Oeschger, H., Schotterer, U., Stauffer, B., Haeberli, W. and Röthlisberger, H., 1977: First results from Alpine core drilling projects. Z. Gletscherk. Glazialgeol. *13:* 193—208.

Reinwarth, O., 1972: Untersuchungen zum Massenhaushalt des Vernagtferners (Ötztaler Alpen) 1965—1968. Z. Gletscherk. Glazialgeol. *8:* 43—63.

Rufli, H., Stauffer, B. and Oeschger, H., 1976: Lightwight 50-meter core drill for firn and ice. In: Ice-core Drilling (J. F. Splettstoesser, Ed.). Lincoln and London: Univ. of Nebraska press: 139—153.

Schotterer, U., Finkel, R., Oeschger, H., Siegenthaler, U., Wahlen, M., Bart, G., Gäggeler, H. and v. Gunten, H. R., 1977: Isotope measurements on firn and ice cores from alpine glaciers. Isotopes and Impurities in Snow and Ice, Proc. Grenoble Symp. 1975, IAHS Publ. No. *118:* 232—236.

Schotterer, U., Haeberli, W., Good, W., Oeschger, H. and Röthlisberger, H., 1978: Datierung von kaltem Firn und Eis in einem Bohrkern vom Colle Gnifetti, Monte Rosa. Jb. Schweiz. Naturf. Ges., wiss. Teil, Basel, Verlag Birkhäuser: 48—57.

Stichler, W., D. Baker, H. Oerter and P. Trimborn, 1982: Core drilling on Vernagtferner (Oetztal Alps, Austria) 1979: Deuterium and Oxygen-18 contents. Z. Gletscherk. Glazialgeol.: *18* (1): 25—37.

Vallon, M., Petit, J.-R. and Fabre, B., 1976: Study of an ice core to the bedrock in the accumulation zone of an Alpine glacier. J. Glaciology *17:* 13—26.

World Data Center A for Glaciology (Ed.), 1980: Ice Cores. Report GD-8, Boulder, Colorado, 139 pp.

Manuscript received December 27, 1982

Authors' addresses: Dr.-Ing. H. Oerter, Institut für Radiohydrometrie
Neuherberg
Ingolstädter Landstraße 1
D-8042 Oberschleißheim, FR Germany

Dipl.-Met. O. Reinwarth
Kommission für Glaziologie der
Bayerischen Akademie der Wissenschaften
Marstallplatz 8
D-8000 Munich, FR Germany

H. Rufli
Physikalisches Institut der Universität Bern
Sidlerstraße 5
CH-3012 Bern, Switzerland