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GEOLOGY AND MINERALOGY

EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM
Brussels (Belgium)

COMITATO NAZIONALE DELL'ENERGIA NUCLEARE - C.N.E.N.
Rome (Italy)

DEEP DRILLING AT KING BAUDOUIN STATION, QUEEN MAUD LAND, ANTARCTICA

by

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Contract Report N° 002/60/12/GEO-C

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DEEP DRILLING AT KING BAUDOUIN STATION,

QUEEN MAUD LAND, ANTARCTICA

SUMMARY

A drilling operation and core investigations at King Baudouin Station (70° 26' S - 24° 19' E) in January 1961 are discussed. The purpose of the drilling operation was to collect samples of snow and ice for geochemical investigation, which comprises the following measurements : isotopic composition of oxygen and hydrogen, concentration of Tritium and fission products, chemical composition and dust content of the ice.

The drilling attained a depth of 115,72 m. The depth of 79,33 was reached with a core yield close to 100 %. From this level downwards, core recovery was only 55 %. A stratigraphic profile of the first 43 m is described. For the latest six years an average annual accumulation of 38,3 cm of water was calculated. The depth-density curve is similar to those already observed on other antarctic ice-shelves. If one assumes an average annual accumulation of 38,3 cm of water, the whole drilling corresponds to approximately 240 years.

1 - INTRODUCTION

1.1. SCOPE OF THE CONTRACT

In January 1961, a drilling operation to obtain deep ice samples was carried out on the Breid Bay ice shelf at King Baudouin Station.

The main object of the operation was to study the isotopic composition of the ice with respect to stratigraphy, as well as to make certain radioactive measurements.

The value of such a study from the geophysical and geochemical angle is exemplified by the results which have already emerged (1, 2, 3, 4, 5, 6).

The works listed show that the isotopic composition of precipitations depends on a certain number of metereological factors, the most important of which is the temperature at which they are formed.

It is well-known that the snow and ice of the two polar caps (Greenland and Antarctica), by virtue of the fact that they have never, practically speaking, been melted, are the only means at our disposal which can be used to study the composition of old precipitations.

The variations in isotopic composition along a vertical section should yield a harvest of information on long-term seasonal and climatic changes. An "isotopic stratigraphy" of this kind, apart from making it possible to carry out interesting glaciological studies on the yearly rate of accumulation of snow and on the ice flow, could likewise be used for dating of the snow and ice layers by counting the seasonal deposits (3).

Measurements of radioactive isotopes such as tritium, radium D and fission products could, moreover, provide us with useful glaciological and metereological data.

The operation was made possible by a technical and financial collaboration scheme, arranged between The Italian National Committee for Nuclear Energy (C.N.E.N.), the European Atomic Energy Community (EURATOM) and the Belgian National Centre for Polar Research (C.N.R.P.B.). On-the-spot assistance was provided by the members of the 1960 Belgian Antarctic Expedition.

The Nuclear Geology laboratories of the Universities of Pisa and Brussels were jointly responsible for the scientific direction of the project.

It was originally planned to send a group of C. N. E. N. technicians with the Belgian Antarctic Expedition projected for 1961.

This plan had to be changed due to the Belgian Government's decision not to send out an antarctic winter expedition in 1961.

Because of the advanced status of the preparations and of the encouraging test results obtained, it was decided to carry out drillings near the King Baudouin Station during the 1960-1961 summer operations.

The principal difficulty was the limited time available for the carrying out of the operation. In fact, it was not possible, for various reasons, for the ship to remain off the Antarctic coast longer than twenty days at the most. If any success was to be achieved under these conditions, arrangements had to be made for the rapid assembly and dismantling of the equipment as well as for the possibility of round-the-clock all-weather operation.

This project may be considered as having been satisfactorily planned and successfully executed. A depth of 115 m was in fact reached after 19 days, with a core yield of close to 100 % between 0 and 80 m, and 55 % between 80 and 115 m. The core samples were brought back in excellent condition and are at the moment in storage in Brussels at a temperature of -15° C.

The operational success is in large measure due to the assistance afforded by the members of the 1960 Belgian Expedition, commanded by Guy DEROM.

1.2 SITUATION OF THE KING BAUDOUIN STATION

The Belgian Base was put up by the Belgian Antarctic Expedition of 1957-1958, under the direction of Gaston de GERLACHE. It is situated at 70°26'S and 24°19'E on the Princess Ragnhild coast (Queen Maud Land), about 15 km from the sea (figures 1, 2 and 3) (7).

The local conditions are well known as a result of the work carried out by the three Belgian Expeditions sent since 1958 (8, 9).

The Base is located on an ice shelf, approximately 20 km wide. The seismic soundings carried out under the direction of Frank BASTIN by the 1958 Belgian Antarctic Expedition indicated a thickness of about 200 m at this point of the ice shelf. The Base is located about 37 m above sea-level.

The mean annual snow accumulation estimated over the last six years is 38 cm water equivalent. The mean ground temperature in 1958 was -15° C. The maximum ground temperature has only very rarely risen above 0° C since 1958. The wind direction is almost always in the S. to E. quadrant.

Horizontal movement of the ice shelf appears to be very limited, the Northward displacement component probably not exceeding 50 m per year. Isotopic studies have already been carried out on precipitation samples collected at the Base during the 1957-1958 Expedition (4, 5).

All these features made the King Baudouin Station an appropriate site for a drilling operation of this nature.

1.3 PREVIOUS DRILLINGS

Core drillings in ice penetrating below the 100 m level are not numerous. None have been reported prior to 1949.

One of the first operations of this type was carried out by the French Polar Expeditions on the Greenland inlandsis during the summer of 1950. With astonishingly simple resources (dry drilling, single core barrel) it proved possible to drill two soundings of 126 and 151 m depth in a very short space of time (10). These results have been discussed by SCHYTT (11).

Up to the present, only four drillings of over 100 m depth have been performed in the Antarctic (Figure 1), and only two of them have produced a quasi-continuous coring.

The drilling on the MAUDHEIM ice shelf (71°03'S, 10°56'W), was carried out by the Norwegian - British - Swedish Antarctic Expedition 1949-1952 (11) over the years 1950-1951, using a single core-barrel without fluid circulation. A depth of 100 m was attained. The core yield was low; the integral and undeformed sections did not exceed 5 cm in length. As a result of the work of SCHYTT, however, they obtained the first data on the deep structure of an ice shelf.

Two deep drillings have been successfully carried out by the S. I. P. R. E. and the American Expeditions. The first one was undertaken at BYRD STATION (80°S, 120°10'W), on the polar plateau, between 16 December 1957 and 30 January 1958. It attained a depth of 308,80 m with a core yield of 98 % (12).

The second drilling was situated on the Ross ice shelf, at LITTLE AMERICA V (78°16'S, 162°28'W) and carried out over the period between 13 October 1958 and 30 December 1958. The 225 m deep drilling penetrated through the whole ice shelf, continuous cores being obtained (13).

Both these operations used the same techniques: special toothed drill bits, double core barrel, removal of the cutting by means of compressed air, casing of the first 30 or 40 m of the bore hole.

The Soviet Antarctic Expedition (Second Continental Expedition 1956 - 1958) carried out a deep drilling at 7 km South of Mirny Station. The drilling reached a depth of 371 m, with a core yield of 100 % down to 43 m (14).

2 - EQUIPMENT

2.1 DESCRIPTION

The technical preparations for the drilling were carried out by the "Divisione Geomineraria" of the C.N.E.N. The equipment was selected with a view to obtaining continuous cores with the least possible deformation.

The drilling was undertaken with light equipment of a type commonly used in prospecting, enabling a maximum depth of 300 m to be attained.

The removal of cuttings, the chief head-ache in this type of problem, was to be carried out by compressed air circulation, cooling being effected by heat exchange with the atmosphere.

The major items of equipment used on the site were as follows :

- THE DRILLING MACHINE was of Swedish manufacture, Craelius, type XCH/60, equipped with a 7 m derrick and powered by a 15 H.P. engine. The bit was hydraulically operated and automatically advanced. Pressure on the bit could be exerted both downwards and upwards, thus allowing compensation for the weight of the rods and of the core barrel, and enabling the bit working pressure to be maintained at practically zero.
- RODS 3 m long, 42 mm and 50 mm in diameter.
- CORE BARRELS: simple and double Craelius core barrels with external diameters of 65 , 75 and 85 mm, 3 m in length.
- DRILL BITS Craelius, of various types (toothed, in Wydia, and non-toothed, in diamond steel), with external diameters of 66, 76 and 86 mm.
- CASING TUBES 3 m in length, diameters of 77/84 and 89/98 mm.
- A COMPRESSOR Atlas, VT4 Dd, operated by a 45 H.P. Diesel engine. It gave a maximum output of 4 m^3/min at a pressure of 7 kg/cm^2.

COOLING : the air coming out of the compressor was cooled by heat exchange with the atmosphere. It was passed through a series of tubes (total length 58,50 m; 3 inches in diameter) equipped with two welded fins. The six straight sections of the assembly were connected by means of U-tubes fitted with taps to draw off condensed water. The refrigerant was supported by a metal tube scaffolding.

SHELTER : the drilling machine and the derrick were mounted on a wooden platform (10 x 4 m) reinforced with cross-beams, and placed directly on the snow. A prefabricated wooden shelter (9,76 x 3,66 x 2,40 m) was rigged up on the platform. The roof was pierced by a 3,66 x 1,20 m opening, over which was placed a 2,40 m high stack and which allowed the superstructure of the derrick to pass through, thus enabling the rods to be handled in 6 m sections (Figure 4).

This structure proved effective as a shelter against sun, wind and drift snow. It was designed in such a way that, in the event of a blizzard, it could be completely sealed off, so that work could continue with a 4 m high derrick, the rods being handled in 3 m sections (Figure 5).

The compressor was placed outside the shelter but was protected by an annexe built of planks.

2.2. PRELIMINARY TRIAL

Before being shipped to the Antarctic the materials were tried out on the "Glacier du Géant", in the "Mont Blanc" range (altitude 3,300 m) in October 1960 (~~Figure 6~~).

This trial, carried out with a low capacity compressor, served mainly to enable the team members to get some practice in the handling and rapid assembly of the drilling machine in polar conditions, and also to test the efficiency of the equipment for snow drilling.

It took two days' drilling to reach a depth of 14 m in the firn. The cores recovered were in good condition, but the yield was only 30 % . This result was regarded as satisfactory in view of the unfavourable conditions (low density snow, inadequate compressor) as compared with those expected in the Antarctic.

3 - OPERATION SCHEDULE

The Danish ship "Erika Dan", chartered by the C. N. R. P. B., left Zeebrugge on 10 December 1960, with the 22 members of the three summer task forces (oceanography, aerial photogrammetry and drilling) on board.

The drilling team consisted of seven members :

E. PICCIOTTO (University of Brussels), heading the operation,
J. GIOT (EURATOM), assistant,
T. NORLING (Craelius engineer),
R. GONFIANTINI (C. N. E. N., University of Pisa), chemist,
A. FONTANIVE, Q. DA ROIT, A. FIOCCO – drilling technicians in the "Divisione Geomineraria" of the C. N. E. N.
W. DE BREUCK, glaciologist of the 1960 Belgian Antarctic Expedition, who joined the team at King Baudouin Station.

In the course of the operation we benefited from the collaboration of all the members of the 1960 Belgian Antarctic Expedition under the command of Guy DEROM. M. FOCCROULLE, J. DUBOIS, M. PIERRE as well as Ph. de JAMBLINNE, geodesy expert for the summer campaign, took a direct part in the drilling.

After a short stop, the "Erika Dan" left Cape Town on 31 December 1960. The Antarctic convergence was passed at 45°S on 3 January 1961. The first icebergs were sighted on 4 January 1961 at 52°S, and the first ice-floes on 6 January. The next morning, at 67°S, the ice pack was reached. It was in good condition on this occasion: relatively thick, but altogether broken up.

At 11 p. m. on 9 January, the "Erika Dan" came alongside the ice pack at the bottom of King Leopold III bay, the scheduled landing point.

On 10 January, the 25 tons of equipment as well as the 2500 litres of kerosene and the 2500 litres of petrol to ensure the continuous running of the compressor and the drill for 400 hours were landed and rapidly transported to the spot chosen for the drilling. This spot was 2 km South of King Baudouin Station, outside the accumulation zone due to the presence of the Base.

The assembly of the equipment and the prefabricated shelter was completed in under 48 hours in favourable weather conditions at 4 h on the morning of 12 January.

(a) Drilling - The drilling began in the afternoon of the same day. Serious difficulties arose from the outset: slow progress, a jammed core barrel at a depth of a few tens of centimeters and discontinuous and partially molten cores.

In five days, all the available types of core barrels and drill bits at our disposal had been tried and the drilling reached the level of -17 m, but the cores obtained were useless.

The reasons for this set-back remain obscure. We initially put the blame on the exceptionally high air temperature, which at noon hit the +5° C mark. Progress was, however, no better at night, when the temperature of the compressed air coming out of the cooler was recorded as -3° C. The main cause appears to be the immediate loss of the circulating air in the firn, which prevented the cuttings from being removed and rapidly blocked the advance of the drill bit.

In the meantime, hand-drilling had been started in the neighbourhood of the shelter, using the well-known ice-drill developed by SIPRE (General Mechanical Company, U. S. A.), and designed to bring out the cuttings together with the cores (Figure 8).

The effectiveness of this method and the set-backs encountered in the previous mechanical trials impelled us to move the drilling machine 50 cm away and to begin a new bore-hole, this time using the SIPRE drill powered by the drilling machine drive.

This procedure proved effective, the only remaining disadvantage being the shortness of the core barrel (90 cm), which made it necessary to bring it up again after every 40 to 50 cm. The cores recovered (7,55 cm in diameter) were, however, in excellent condition.

After using this method for four days non-stop operation, (from 17 to 21 January) the drill had reached a depth of -44 m with a core yield of 100 %.

From the level of about -40 m, the advance of the drill fell to between 20 and 30 cm for every working process. At this stage the drill had reached a zone of high density (0,85), approaching that of ice. According to the experience gained from the American borings, an environment of this density could be expected to be sufficiently compact to allow air circulation in the drilling, provided the upper levels were cased. Moreover, the external air temperature had dropped to lower values, ranging between -6° and -15° C.

Our departure having been fixed for 27 January, we decided to make another attempt with the original technique, using a 3 m core barrel, but with an important difference : the toothed Wydia drill bit was modified by welding vertical ridges on the outside. The space between the body of the core barrel and the wall of the drilled hole was raised from 1 to 5 mm, thus facilitating the passage of the air which was to carry the cuttings up and out.

At 3 a. m. on 21 January the SIPRE drill was stopped, and the day was spent in putting down 43 m of casing tubes. At 9 p. m. the drilling started up again at a depth of -43,70 m with a transformed 66 mm Wydia toothed-drill bit, a 3 m double core barrel and the compressor set going.

The results were excellent : the first working process brought a core of 2,45 m in length (4,80 cm in diameter), and it was clear that the air was now circulating in the whole system, bringing the cuttings up towards the outside.

The drilling was thus continued for three days, to a depth of -79,33 m, with a core yield close to 100 %.

From this level downwards, progress continued to be rapid, but the coring became incomplete, and the recovered core fragments rarely exceeded 10 cm in length. This fragmentation appears to be caused by weaknesses in the cores due to pre-existing horizontal fractures in the ice.

On 27 January the drill had got down to the -115,72 m level, with an average yield of 55 % between the -79,33 m and this point. As the result of a technical mishap, the core barrel jammed at this level.

In view of the satisfactory results already obtained, coupled with the state of the ice-pack, which was causing us some anxiety, we decided to abandon the rods and the core barrel in order to get aboard as rapidly as possible.

The re-embarkation of men, samples and equipment was completed at midnight on 29 January, a few hours before the onset of a fierce blizzard which accelerated the break-up of the pack and caused the collapse of the King Leopold III Bay access ramp.

On extraction, the cores were rapidly examined, wrapped in plastic and paper sheets (Figure 6), placed in boxes, carried to the ship and placed in the refrigerated hold at -15° C.

(b) Technical Points - From the technical angle, drilling may be split up into three sections :

- section 1 : dry drilling with the SIPRE drill.
- section 2 : drilling with air circulation and a 3 m double core barrel; core yield 100 %.
- section 3 : drilling under the same conditions as above, but with incomplete coring.

The corresponding results for these sections are shown in the table. For the two types of core barrel used, the conditions under which the cores are obtained in the optimum state would appear to be a low rotation speed (about 100 r. p. m.) and a drill bit pressure in the neighbourhood of zero.

The speed of penetration of the bit varied (the average was 6 cm/min); the various stages of the operation, including all working processes, are shown in figure 7. The overall average comes out at 10 m/day.

(1) The use of the SIPRE drill, as already suggested by SCHYTT, has the advantage of not requiring air circulation (hence neither compressor nor cooler), and thus permits of operation with a very light drill and equipment. The drawback lies in the large number of extractions and re-insertions required. These could, however, be reduced by means of a longer core barrel.

The main disadvantage of this system lies in the fact that progress becomes exceedingly slow from -50 m downwards, when the density approaches that of ice. At this stage the core remains jammed in the core barrel after a penetration of only 15 to 20 cm. This is probably caused by the presence of hard cuttings wedged between core and core barrel.

(2) Drilling by conventional methods, using compressed air, gives good results beyond the level at which ice or a very compact layer is reached. This method, which gave excellent yields down to -300 m when used for the SIPRE drillings, proved ineffective, in our case, below -70 m.

This unfavourable result could be ascribed to the differences in the core diameters, which were of 10 cm for the SIPRE cores, and of 4,8 m for ours. The much heavier SIPRE equipment ensured greater rigidity on the part of the rods and a well-centred rotation of the core barrel.

On the other hand, in our drilling the small diameter of the rods caused eccentric rotation of the core, doubtless accompanied by a considerable amount of vibration. These factors, coupled with the small diameter of the ice cylinder and with the presence of numerous stresses and fractures perpendicular to the drill axis (also noted in the American drillings), would explain the heavy fragmentation of the core as it is cut and also the resulting loss.

Consequently, with the equipment and techniques used for the drilling at the King Baudouin Station, a depth of -100 m with continuous and integral cores of 4 to 7 cm in diameter can be reached within few days under the conditions normally prevalent on the snow cover of an Antarctic ice-shelf.

It also appears that heavier equipment must be used to penetrate beyond a depth of -100 m. However, the advantages afforded by the SIPRE hand drill warrant the development of a core barrel for deep drilling, based on the same principles. This would furnish lighter, more manoeuvrable and more economic equipment, easy to transport for ice traverses.

4 - PRELIMINARY OBSERVATIONS

It is planned to carry out a detailed stratigraphic and morphological study of the cores, which are at present in storage in Brussels at a temperature of -15° C.

The programme for the geochemical study of the cores provides for the following measurements :

- isotopic composition of oxygen and hydrogen
- tritium concentration
- chemical composition of the snow, and the occluded gases
- examination of dust content.

During the drilling, a preliminary stratigraphic description of the first section from 0 to -43 m as well as density measurements were undertaken.

(a) Temperature - Due to the limited time available, it was unfortunately impossible to take any temperature measurements in the bore hole. The equipment prepared for this purpose includes probes consisting of 4 thermistors, connected by a 200 m long cable to a Wheatstone bridge. A galvanometer was used as the reading instrument. The relative accuracy of this device was of the order of a few hundredths of a degree, and the apparatus gave full satisfaction in the on-the-spot trials.

(b) Density - The curve shown in Figure 9 indicates the density variations as a function of depth, integrated over one-metre sections.

The density increases as a function of depth on a pattern similar to that found by the N. B. S. Expedition at Maudheim, and by the SIPRE group on the Ross ice-shelf.

The appreciable dispersion of the points lying between 9 and 13 m is due to the presence of several ice làyers.

(c) Stratigraphy - A preliminary stratigraphic section is presented in Figure 10.

The horizontal stratification is marked by :

- variations in the diameter of the firn grains estimated by means of a magnifying lens. These variations become less marked with increasing depth.
- ice-crust layers of 0,5 to 2 mm in thickness, which are noticeable even in the compact ice at depths below 40 m.
- layers and lenses of melted ice, which may be as much as 10 cm thick.

No coloured or dust-rich layers were noticed.

Seasonal alternations are often discernible, on the basis of the criteria defined by SCHYTT (11). Summer layers are characterized by larger grains, and by the presence of ice in impregnation, in strata or in lenses.

These seasonal alternations are clearly perceptible for the last six years and make it possible to calculate the following annual accumulation values in cm of water for the years between 1954 and 1959 :

1959	41,5	1956	36,3
1958	33,2	1955	35,0
1957	38,3	1954	45,4

Average : 38,3 cm water per year.

A striking feature of the stratigraphic profile is the existence of two sections characterized by intense ice formation :

from 9 to 16 m
and from 41 to 44 m (or more).

Each of these sections doubtless corresponds to a period of several consecutive years (5 to 10) with hot summers with peak temperatures lying above 0° C. Hypothetically, these two groups could be considered as corresponding to the years 1949-1939 and 1890-1880.

Further discussion of these results, before more progress has been made with the morphological and geochemical studies, would be premature.

Characteristics of the Three Drilling Sections

	Total	Section 1	Section 2	Section 3
Demarcation levels of the sections in metres (x)	0 -115,72	0 43,70	-43,70 -79,33	- 79,33 -115,72
Length of the sections in m.	115,72	43,70	35,63	36,39
Core yield		100 %	100 %	55 %
Core diameters, in cm.		7,55	4,80	4,80
Mean density		0,65	0,85	0,85
Volume extracted, in dm^3	292	195	64	33
Weight extracted, in kg	209	127	54	28
Average weight/metre, in kg/m		2,9	1,5	
Average weight/year, in kg/year (xx)		1,7	0,7	
Approximate number of years (xxx)	237	77	80	80

(x) : the level 0 corresponds to the surface in January 1961.

(xx) : estimated on the basis of the stratigraphy.

(xxx) : assuming an average annual accumulation of 38 cm water equivalent over the whole drilling.

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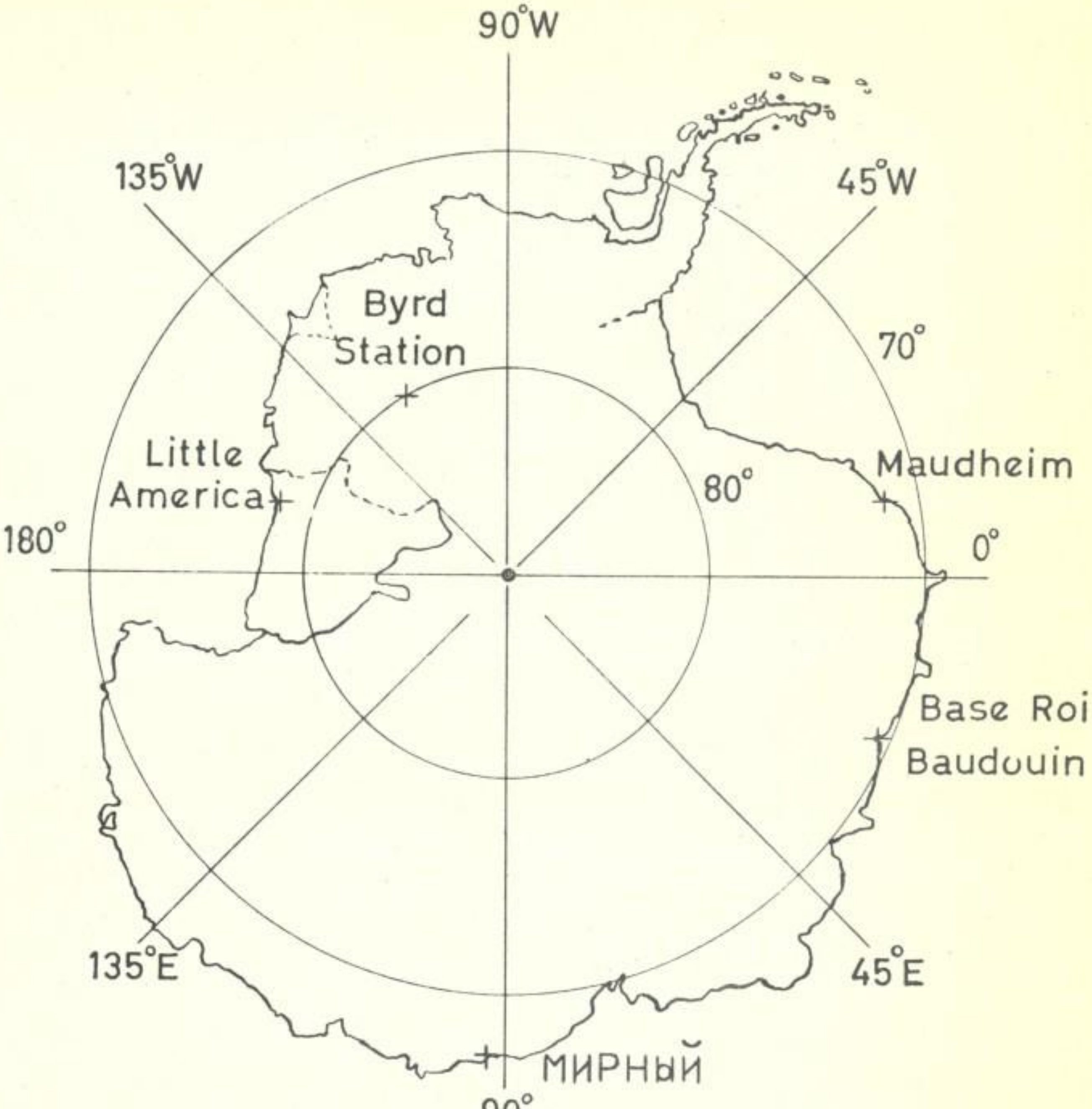


Fig. 1

Fig. 1 - General outlines of Antarctica with the location of the deep drillings carried out to date : Maudheim, Mirny Station, Byrd Station, Little America and King Baudouin Station.

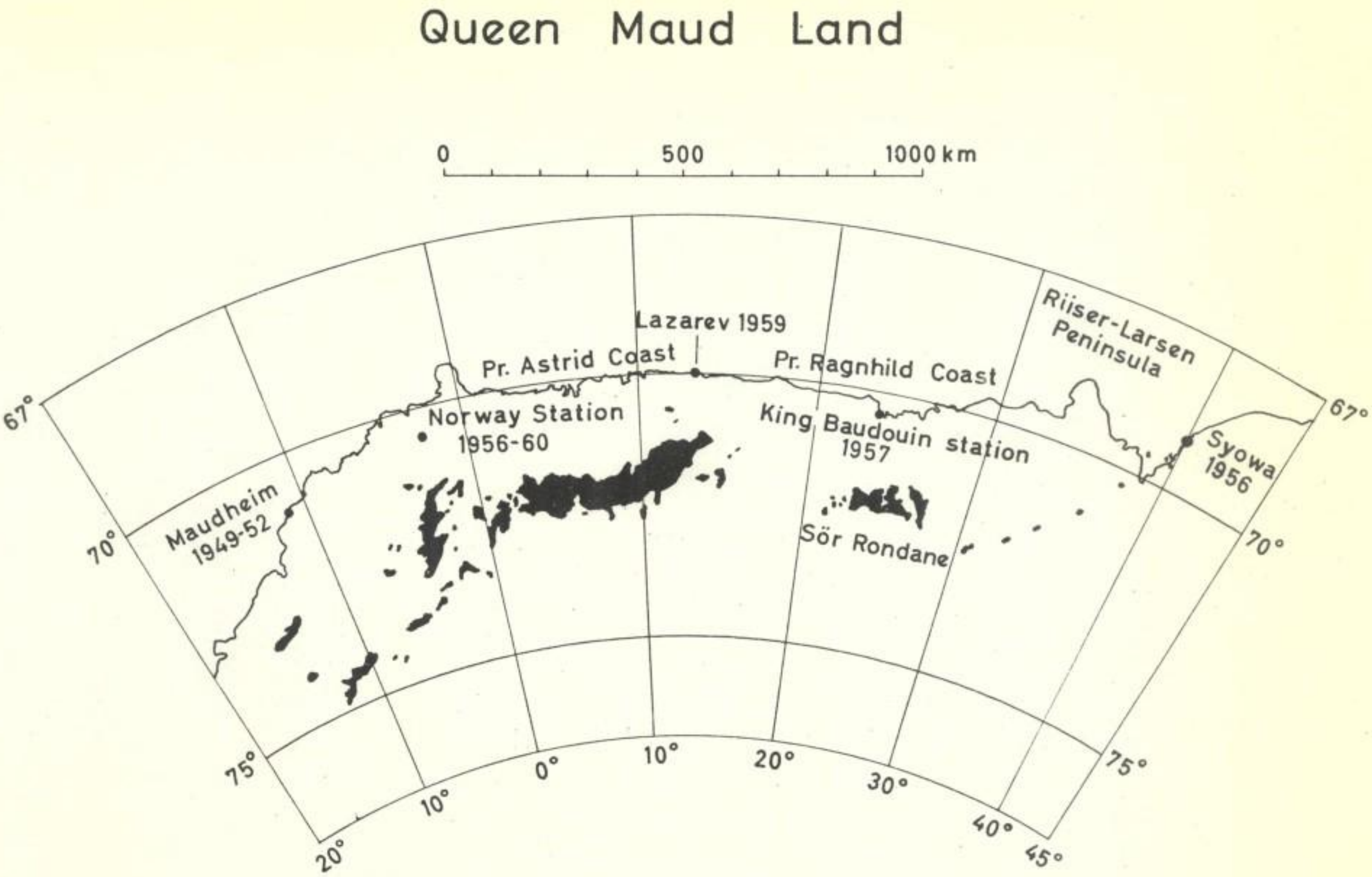


Fig. 2

Fig. 2 - Queen Maud Land (from a diagram of the Norsk Polarinstitutt).

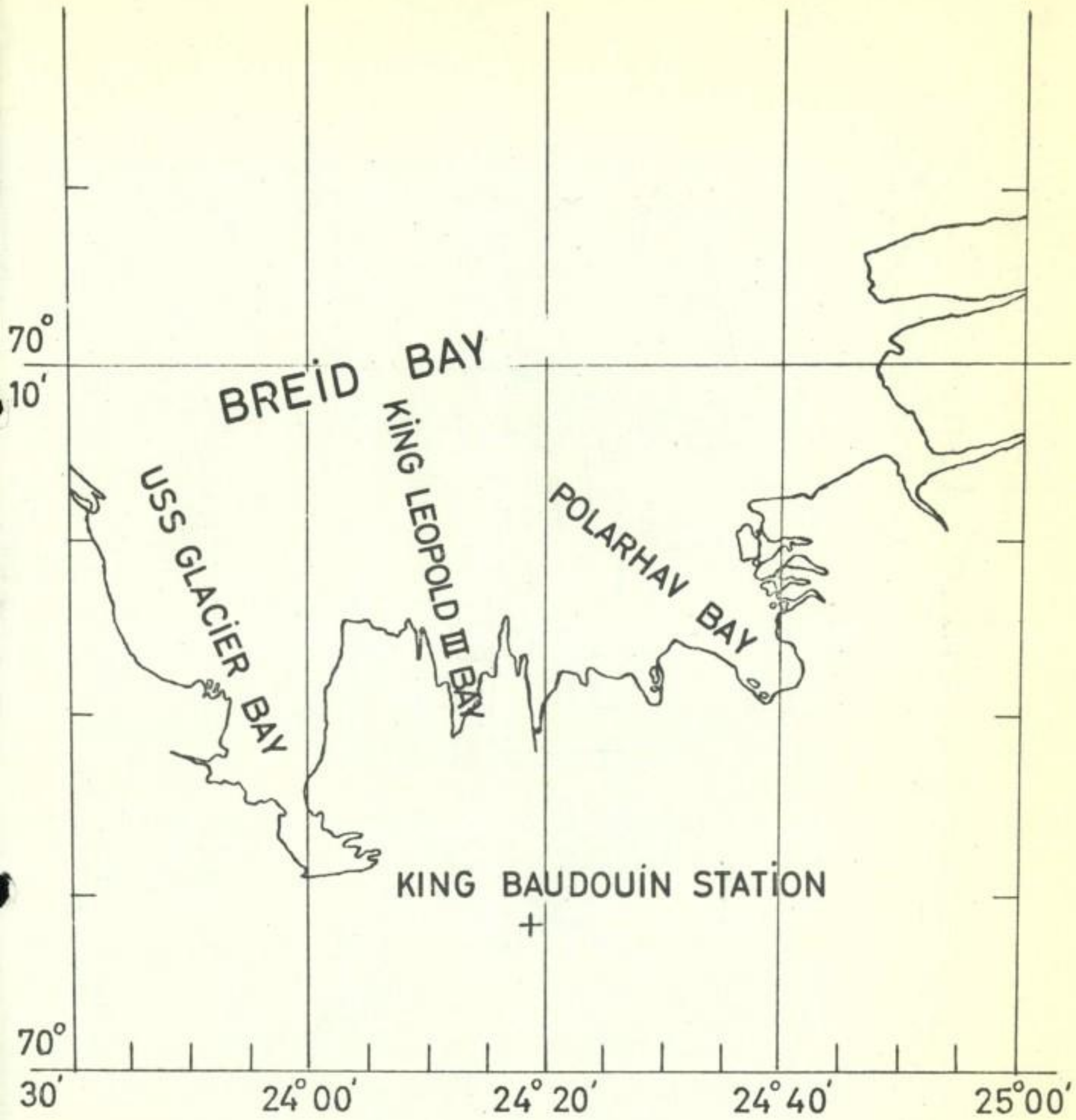


FIGURE 3

Fig. 3 - Outline of the Breid Bay, and drilling site at King Baudouin Station.

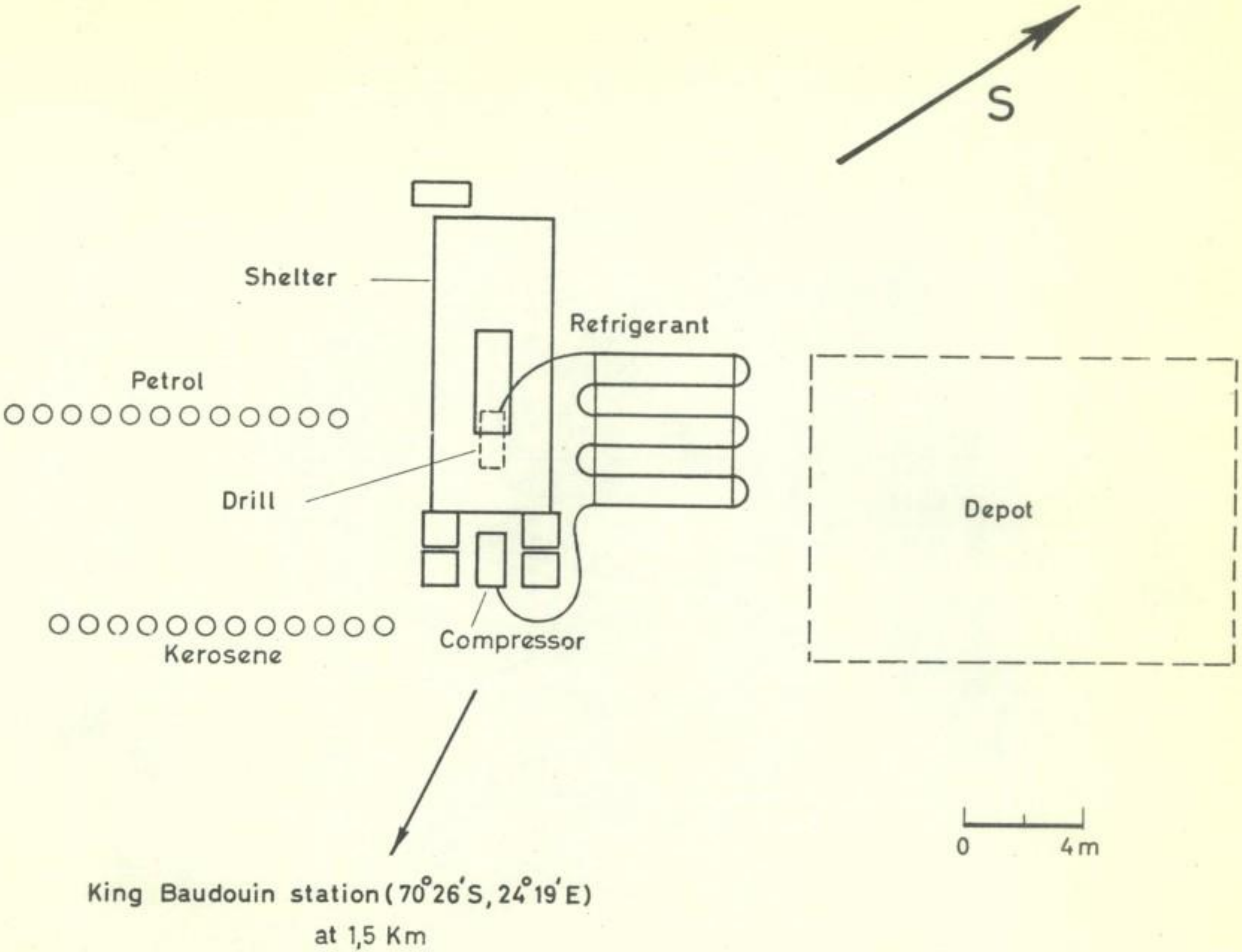


Figure 3a

Fig. 3a - Plan of the drilling site.

g. 4 - Photograph of the shelter with its stack for the derrick, together with compressor and cooling system (Photo L. Goosens).

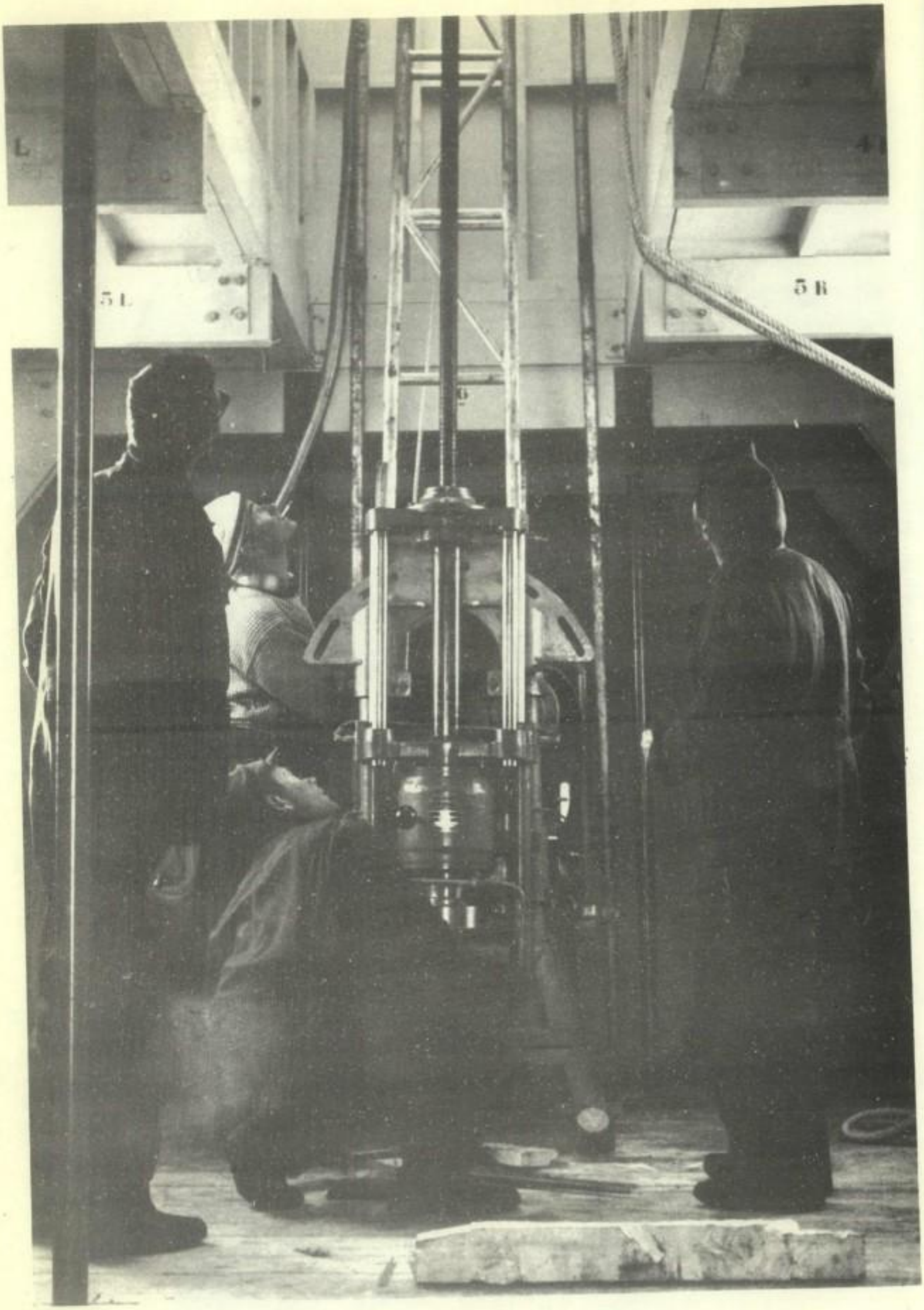
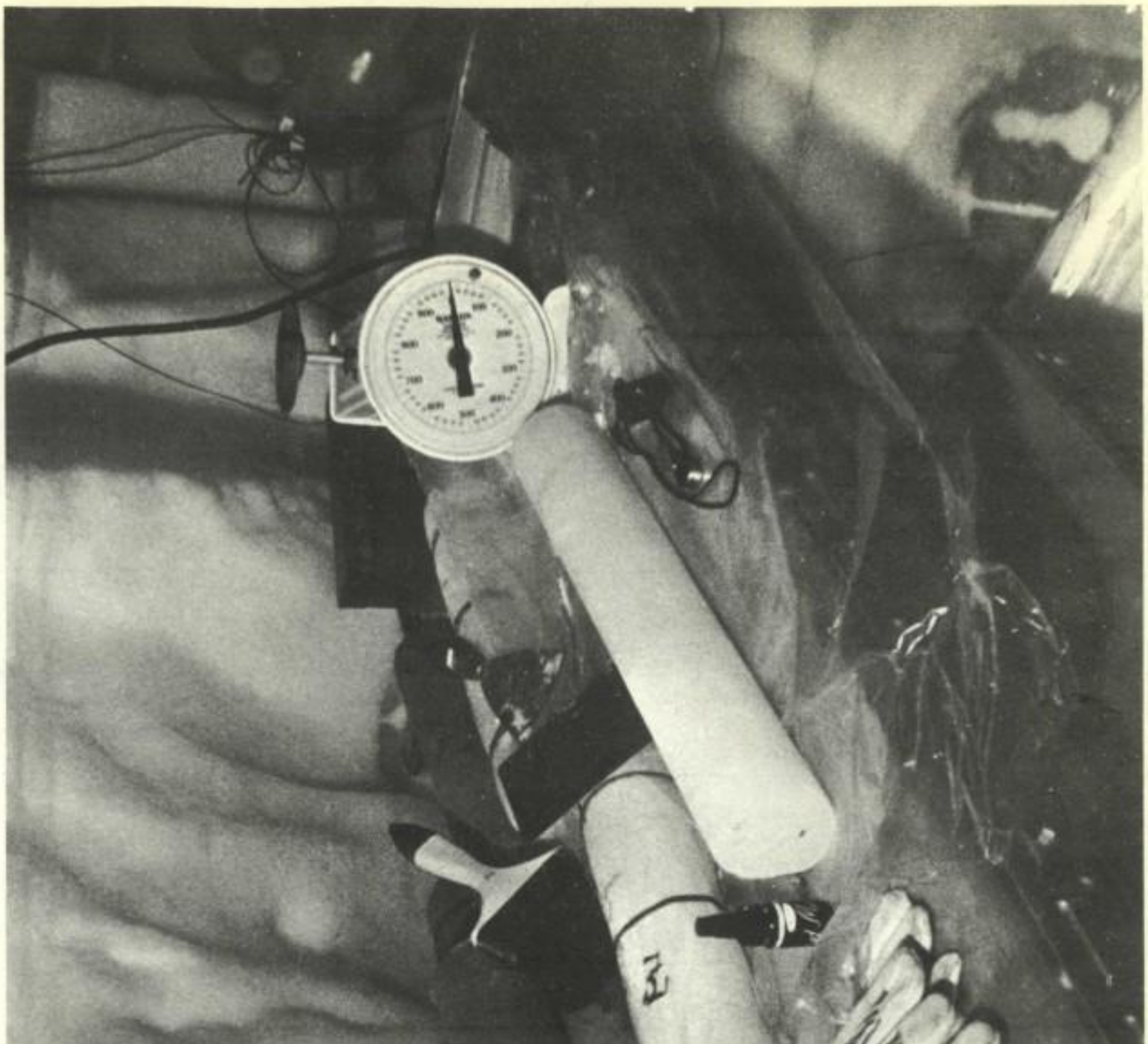


Fig. 5 - The drill operating inside the shelter.



. 6 - The work bench in the glaciological laboratory was dug out at King Baudouin Station. The laboratory 10 m below ground level. The cores shown were extracted by the SIPRE drill. (Photo L. Goosens).

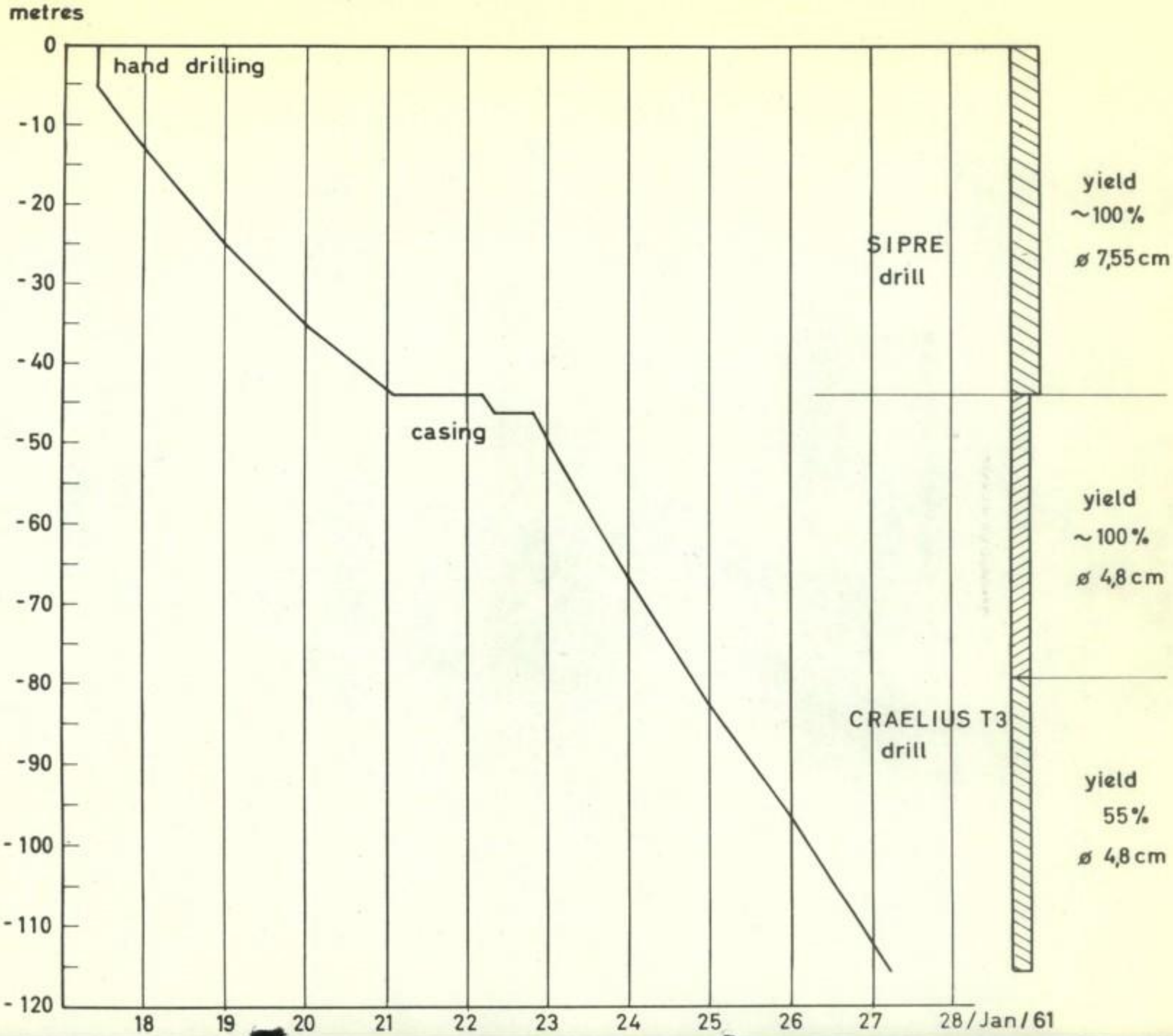


Fig. 7 - Graph showing the rate of penetration.

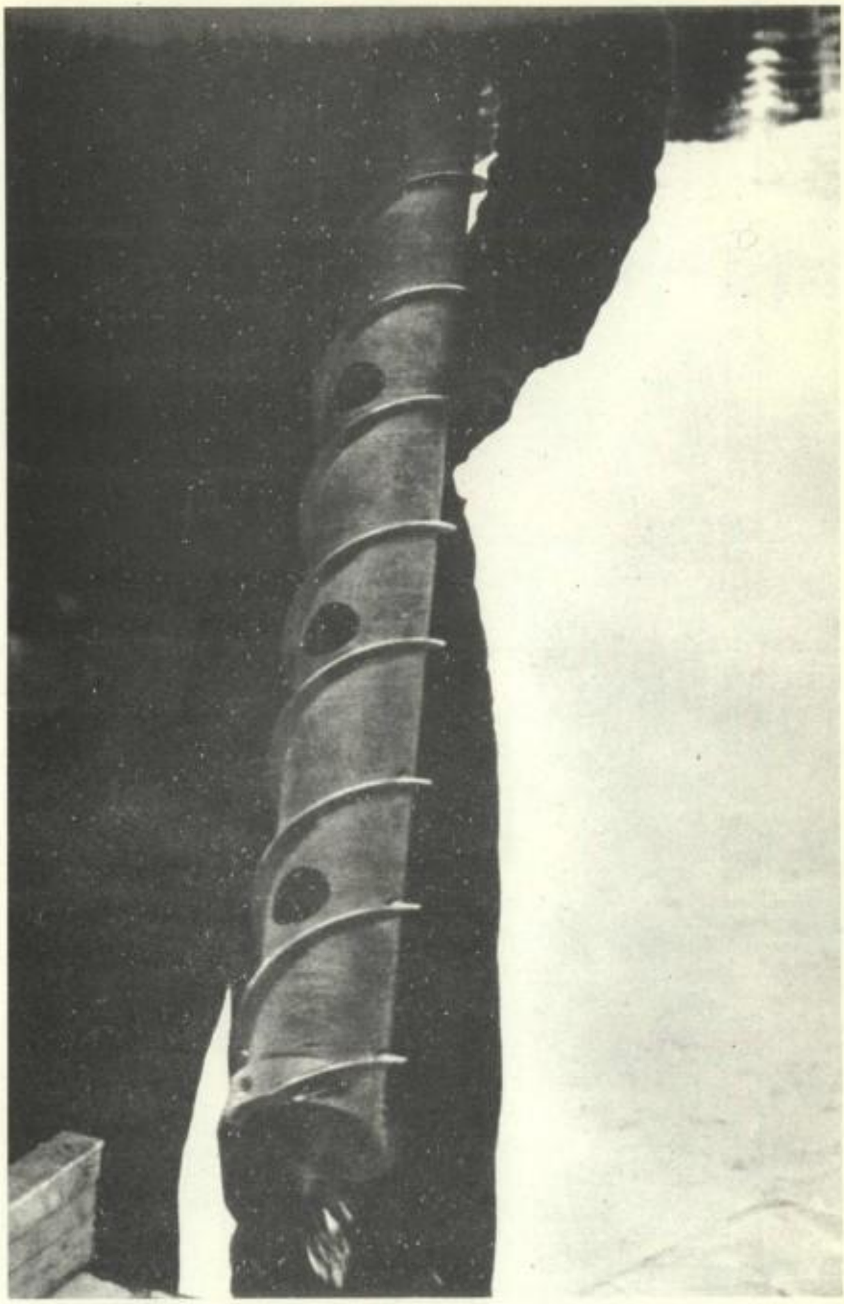


Fig. 8 - The SIPRE drill.

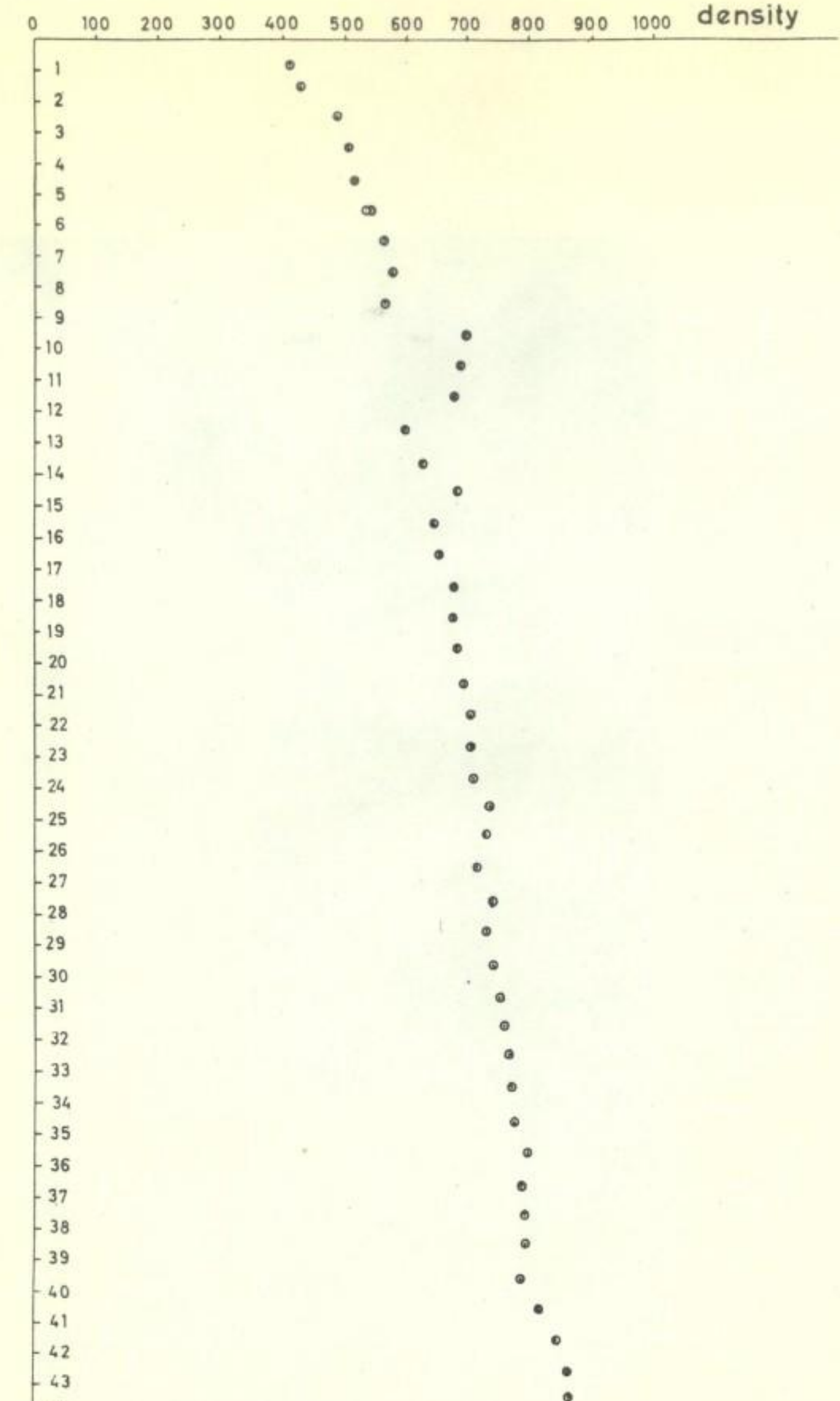


Fig. 9

Fig. 9 - Density variation as a function of depth.

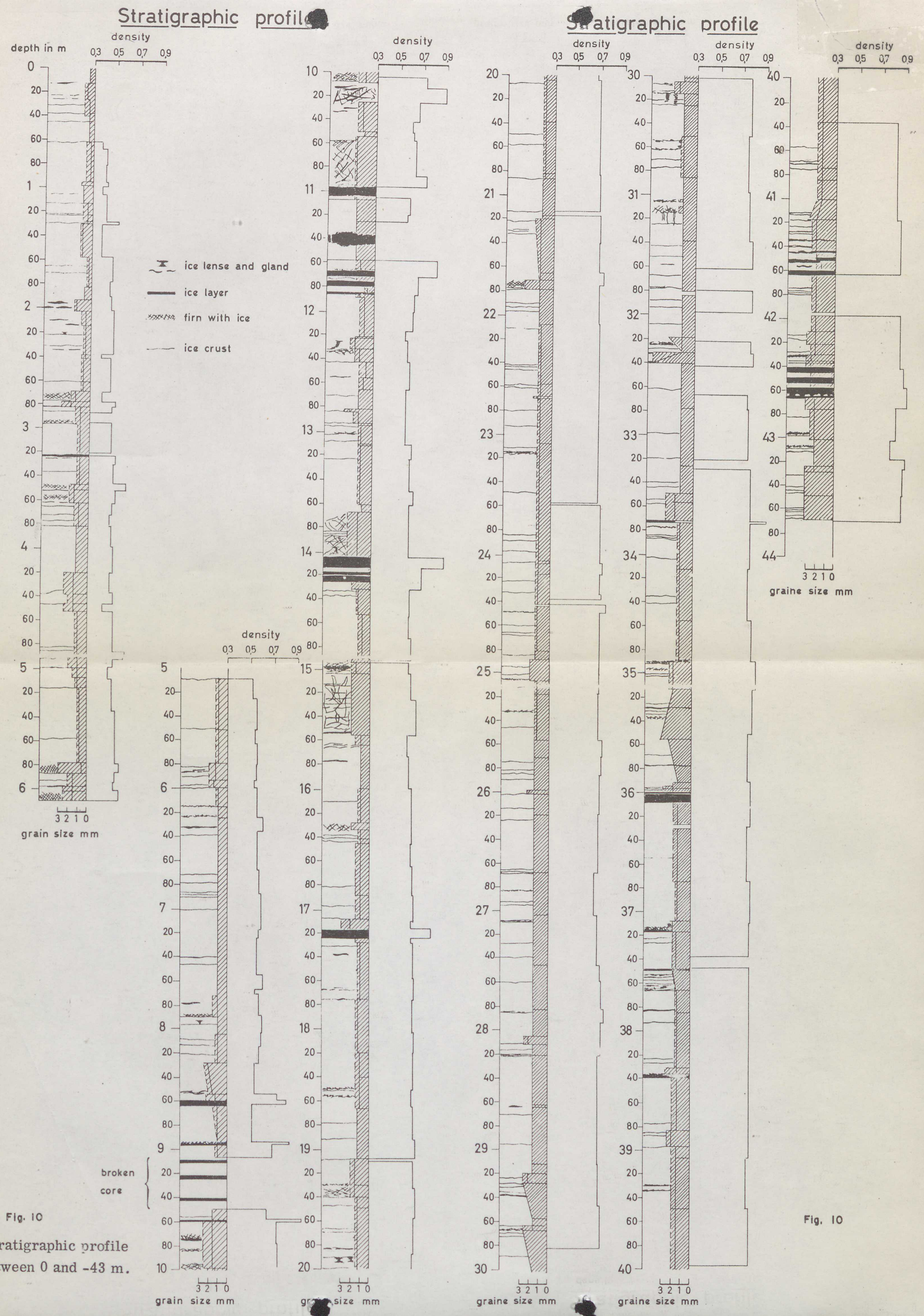


Fig. 10

Stratigraphic profile between 0 and -43 m.

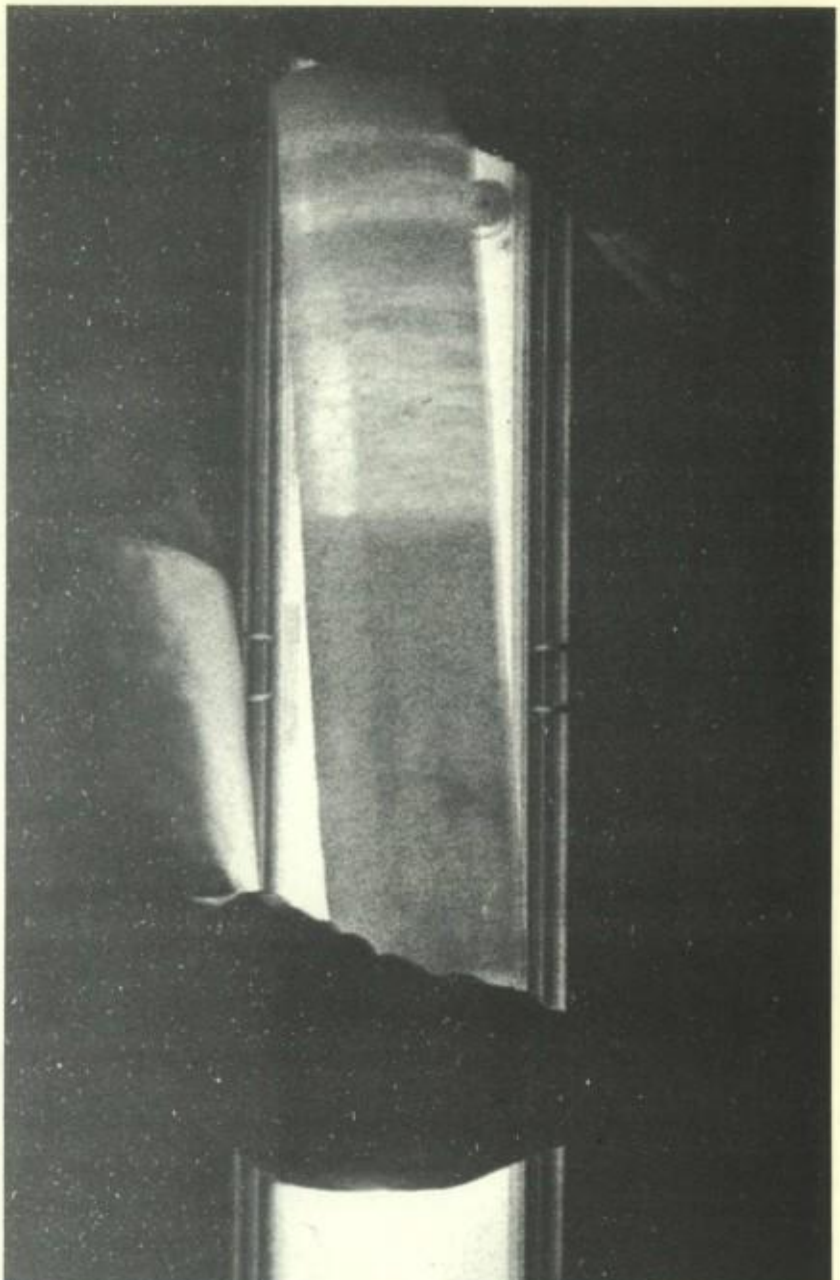


Fig. 11 - Photo of a sectioned core (7, 55 cm in diameter).
The core is placed in front of a luminescent tube.
The seasonal alternation is clearly defined : the summer layer in the upper part is formed of firn and considerable layers of melted ice indicate a particularly warm summer.
The winter layer is formed of homogeneous firn with a fine grain.