THE CAMBRIDGE STAUNINGS EXPEDITION 1970

VOL. I

GENERAL REPORT AND THE GLACIOLOGICAL PROJECTS

Summary

Vol. I is primarily concerned with reporting the glaciological projects including the radio echo-sounding work which was satisfactorily completed using a modified, Government-surplus, radar altimeter SCR 718. The electronic equipment, mounted on a sledge, was man-hauled over the surface of the Roslin Glacier and a profile of a valley ice system was recorded. This technique is recommended for future studies on non-temperate valley glaciers.

The complementary work on ice-temperature measurements is also recorded. Several Technical Notes are incorporated into the report to assist future expeditions who may wish to further this work.

Vol. II will be concerned with Survey, Oxygen-Isotope Analysis of ice samples, Snout Recession studies, the Meteorological Report and Computer programmes.

Vol. III will compile statistics on Food, Equipment, Finance, Medical Supplies, etc. and will conclude with impressions of the expedition by its members.

Editor
K.J. Miller
Trinity College
Cambridge
June 1971

FIG. 1 CHRIS AND DAVE DRILLING BORE NO.3

PREFACE

The Cambridge Staunings Expedition was conceived during the Easter Term of 1969 in the University Engineering Laboratories. The basic planning was done by Danby, Miller and Padfield and by the beginning of Michaelmas 1969 the undergraduate contingent was completed by Bishop, Halliday, MacKeith and Young joining the party. Davis, an ex-student of the Laboratories, also became a participant at this time, being recommended by a member of the Engineering Department teaching staff. All expedition members were allocated individual tasks and the detailed work required to construct the project began in early October. The party was completed by the selection of Hall and Thompson in April 1970 after considering 55 applicants from Cambridge townspeople who wished to join the expedition.

The Staunings Alps of East Greenland (see page 50) were chosen for the site of the expedition because the leader had knowledge of the area and the 24 hour daylight period experienced in the Arctic would permit a satisfactory work output each day. Obviously a further major advantage was the relatively short distance and transit time from the U.K. to an Arctic Alpine Glacier system.

This volume attempts to give an insight into some of the activities, particularly the glaciological work, of the expedition.

NOTES

1. The name of the glacier on which this expedition was based has constantly been referred to, in this report, as

   THE ROSLIN GLACIER

   A recent letter from the Danish Geodetic Institute informs us that the Glacier will now be referred to as

   THE IVAR BAARDSØN GLETSCHER

   on all future maps of this zone, published by the Institute.

2. Weights of items of equipment are given in metric or British units as per their purchase specification. The rationalist may wish to note that 1 kgf = 2.2046 lbf.

3. 1 mile = 1.60931 km.

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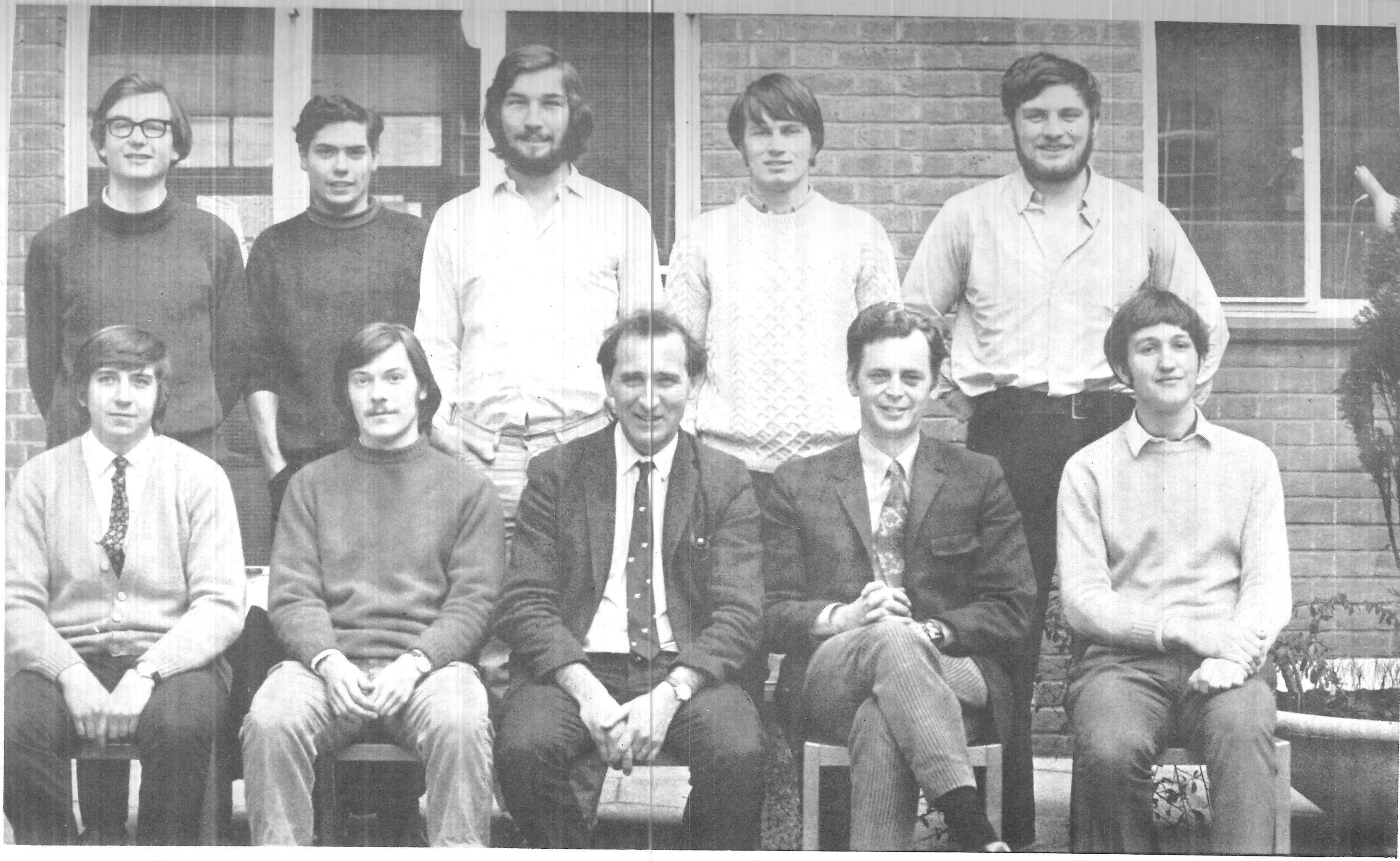
MEMBERS OF THE EXPEDITION

(see also Figure Two, page 6)

1.	Leader Dr. Keith J. Miller Trinity College (Surveyor)	38 years Two Himalayan, One Arctic, One African, expeditions.
2.	Deputy Leader J. Les Davis Electronics Research Engineer (Glaciologist)	26 years Canadian Canoe Expeditions.
3.	Jim F. Bishop St. John's College (Survey equipment and associated projects officer)	20 years Alpine experience.
4.	C. John Danby, St. John's College (Surveyor & Food Officer)	19 years Alpine experience.
5.	Mike A. Hall Research Assistant (Medical Officer, & Oxygen Isotope Project)	23 years
6.	John S. Halliday St. John's College (Glaciologist and Electronics Officer)	21 years U.K. climbing experience.
7.	Peter L.C. MacKeith Churchill College (Equipment Officer)	20 years Two Arctic expeditions.
8.	Chris J. Padfield Fitzwilliam College (Surveyor)	21 years U.K. climbing experience.
9.	John (Tim) A. Thompson Quantity Surveyor (Surveyor)	25 years U.K. climbing experience.
10.	David K. Young, Queens College (Ice-Temperature Equipment Officer)	21 years Alpine experience One Expedition to Turkey



JOHN(D) LES CHRIS JOHN(H) DAVE
MIKE PETER KEITH TIM JIM

FIG. 2 MEMBERS OF THE EXPEDITION

GENERAL REPORT

The final two weeks before departure were chaotic, the major cause being due to strike-bound ships. This necessitated the arranging of alternative transport facilities in order to meet our Icelandair air-charter deadlines. However all this was quickly forgotten as we flew from Reykjavik to Mesters Vig, East Greenland during the early hours of July 10. Twelve months of detailed planning now lay behind us and ahead lay the beautiful sight of Scoresby Sund bathed in early morning sunshine. We were anxious to get ourselves organized and away to the area of our studies as quickly as possible whilst we still heard the best wishes of our countless helpers ringing in our ears. Thus, that same evening, a party of eight left for their first stage of the walk-in, a 20 mile march over the tundra and low mountain cols. Thompson and Miller meanwhile organised a helicopter-lift of sensitive scientific equipment to the Roslin Glacier snout and then they too started on the 4 day march-in, see Fig.3 page 50.

Within 24 hours the entire party was reunited since the main party were repulsed below the Mellom Glacier pass due to the unknown and heavily crevassed terrain being hidden by low cloud cover that reduced visibility to only 50 to 100 yards. The delay meant a loss of a minimum of some 20 man-days of food and possibly 80 man-days should we wait for the weather to improve. This could not be tolerated especially since we had been informed that our scientific programme would have to be curtailed by one week due to the early departure of the helicopter from East Greenland. A further and possibly more serious drawback was the uncertainty as to whether or not the R.A.F. had been able to penetrate the heavy cloud and air drop our supplies on the Roslin Glacier. Somewhat despondently we therefore retreated to Mesters Vig where we were informed that the R.A.F. had managed to drop the supplies albeit under atrocious conditions. Thus on July 14, to minimise lost time, all members were lifted out by helicopter to the tundra close to the Roslin Glacier snout.

Although somewhat loosened by our previous 40 mile walk with pack loads, our first day on the Roslin Glacier was hard and long. With little sleep and minimal food we trudged up the glacier hoping to locate the air drop of the bulk of our stores some 20 miles upstream. This drop was made during a 55 minute radio blackout period between the Hercules plane and Mesters Vig whilst the aircraft made its runs up and down the Roslin Glacier. It was a great relief, in many ways, to locate the major portion of the air drop, set up a bivouac, eat and sleep.

The weather deteriorated the next day, July 16, and so we were happy to locate an excellent base camp site, put up tents, and begin ferrying stores across the mile of glacier that separated base from the drop zone.

Davis had meanwhile built several wigwams from parachute materials. One served as a laboratory tent whilst the others covered our food boxes and equipment. The sledge for carrying the radio-echo sounding equipment was soon erected.

Poor weather conditions continued and so July 18 all members went down to the snout carrying food required for the march out. En route we located a zone suitable for a fly camp and from here Hall and Thompson returned to base, Hall having sustained what had become a serious ankle injury, which to our subsequent great fortune modified his role to camp cook for many days. On the route between fly camp and the snout, Davis and Miller spotted a possible parachute over on the far moraines and hoped this was the 108 man-days of food still unaccounted for. The return journey from the snout, during which we brought up all the sensitive scientific equipment, was interrupted by a bivouac at the fly camp.

Relaying of stores from the drop zone to base continued spasmodically for several days. Meanwhile the sun appeared on July 20 and the survey work then started, Within three days the map of the Roslin Glacier area around base camp was completed with the assistance of a 1245 m base line situated on the Glacier. On July 21 the radio-echo team of Davis and Halliday produced their first echo sounding signal on the relatively inexpensive SCR 718 equipment.

July 23 found Bishop and Miller off to locate the lower (snout) air drop, deploy kerosene and en route to try and spot possible future survey stations. The drop was located and fly dump (Roslin Right Bank) built. On the way up the Glacier on July 15 we must have approached well within 100 m of the drop without spotting it.

The next day was a memorable one for Davis who fell into a melt stream during a sledge run. The sledge was an ungainly creation and back heavy, not the easiest of devices to man-haul along the undulating surface. Fortunately the accident was not as serious as Hird's experience in 1968[(1)*] and it served two useful purposes. First, it taught all members that however innocuous these streams look they can be exceedingly dangerous and should be treated with the utmost care. Secondly the weight distribution on the sledge was re-arranged by MacKeith. Furthermore a safety rope was always carried on the sledge thereafter.

Padfield and Danby had meanwhile started on the theodolite work necessary to determine flow rates of the Roslin and Dalmore glaciers. This was to be achieved by following the movement of three separate stake lines each consisting of nine approximately equi-spaced stakes. The stakes were plastic poles

*References are listed on page 48.

and were sunk some 4-5 feet into the ice with the aid of a Teles motor drill and ice auger. This work was carried out by Bishop, Padfield, Young, Danby and Thompson and was completed in 3 days.

Two major problems that still required solution towards the end of the month were the SPRI radio-echo sounder and the corer. The former was malfunctioning due to a short circuit in a transformer and since transformers seldom give trouble this was one of the few items for which we had no replacements. It was fortunate however that we had forseen the possibility of having serious faults and we were glad therefore to have an alternative, although somewhat less sophisticated echo-sounder. The second problem was the loss of cutting ability of the boring bit as it approached depths of only 1 m. Since we hoped to achieve 10 m bores this problem also caused some concern.

The hard work of Halliday and Davis cannot go without mention as they worked with little respite attempting to modify the SPRI instrument. Alas it was in vain. Full attention was then given to the SCR 718 instrument, a modified radio altimeter, which later was to give us the results we needed. The corer problem was eventually solved by removing the hardened teeth and sawing new ones, at a different rake angle, into the remaining tubular section. Young took control of the coring work at this stage and a most laborious and somewhat uninteresting task was completed by various parties of 4 men who took approximately 5 to 6 hours drilling some six cores 9 m deep by 6 cm dia.

During this period kerosene and parachutes were relayed down the glacier. Schedules of work had to be arranged so that all equipment could be accumulated at the tundra camp by August 18 so that it could be airlifted back to Mesters Vig. Time was not on our side and the sledge runs upstream from base did not start until August 4. Thompson had meanwhile traced out the early sledge runs, located the stake lines and superimposed these on the map of Roslin Glacier base camp area. Hall too was doing invaluable work, his ankle having become slightly less painful, and with amazing speed he collected scores of ice samples for future oxygen isotope analysis. A theodolite team climbed Junction Peak but unfortunately could not see more than a few metres and returned to camp through much new snow. Signs of the end of the season appeared in the first few days of August, namely the melt stream flow rates were decreasing and some freezing of the streams occurred in the night, maximum and minimum temperatures decreased and the rapid changes in the Glacier surface texture ceased.

The sledge parties of 4 men, 2 pulling on harnesses and 2 pushing, had by now moved onto night runs so as to minimise the effect of any surface water on the quality of the results. A top camp was set up from which a coring party and a theodolite party worked for two days, the tent being used by the sledging party during the daytime. Regretfully snow conditions close to the Roslin watershed did not permit the heavy sledge to be pulled to the Roslin col. Thompson and Miller continued to use all clear days to plot the sledge runs and map the Roslin Glacier and its environs respectively.

At this time Bishop was taking transverse profiles and ablation measurements as well as assisting in all projects in order to facilitate our progress downstream. Fly camp was established in a more favourable position i.e. closer to a running water source and away from a zone prone to danger from a hanging glacier. Base camp was evacuated in parts to the fly camp and more parachutes were taken downstream. The air drop zone was cleared up and with no time available for any major mountains to be climbed all members looked back somewhat despondently at the peaks.

The sledging party, now led by Halliday, moved rapidly down to Tundra camp, taking in several transverse soundings en route. Meanwhile Hall and Padfield having worked on their respective tasks at Tundra, worked their way back to Base. This enabled the final stake measurements to be left until the last possible moment.

Coring and Plane Tabling continued as the main party made their way downstream ferrying stores. However in the last two days at Base Camp fine weather and a hopefully completed project permitted Padfield and Danby to climb Hird Peak.

On the night of August 17 all essential kit was assembled at Tundra camp, all members having worked long hours in order to ferry the stores across the near-snout moraines. However it was not until August 27 that the helicopter arrived to remove the equipment. This fact illustrates the point that helicopter assistance, however necessary or desirable,is, and must be, at the convenience of the Nordisk Mineselskab Co. who charter this craft for their own work. Expeditions therefore cannot and should not rely on its use. The pilot was working non-stop on Company business during the light hours of this period. This work plus maintenance periods coupled with the vagaries of the weather and one hazardous mountain rescue did not allow the removal of our equipment to be brought forward.

During this waiting period more plane tabling was done in the glacier snout zone & a woody willow project started on the terminal moraines, see Volume II. However the fine weather was too good to waste and so a party of six led by Young left on the evening of August 22 for the Lang River, the Malmbjerg Mine, the Sortejhorne Hut and the coast. They had an uneventful crossing of the Mellom col and reached Mesters Vig three and a half days later to report that all members of our party were fit and well.

Five days later, Bishop, Davis, Halliday and Miller began their walk out happy in the knowledge that all the scientific results and instruments plus some food for the Mesters Vig camp had been transported to the coast. Thus it was with some relief that we moved towards the Lang River and home since we knew we were the last humans in some hundreds of square miles and soon the area would be sealed off by winter. Unfortunately, whilst crossing the Lang River, Miller lost his footing in a deep pool, unseen beneath the murky torrent, but thankfully he gained the bank before being swept too far down-stream. A hasty bivouac in the distant moraines, a hot drink, a vigorous rub down, a warm sleeping bag from Davis and all was well.

The passage over the Mellom was simple, the route being in excellent condition. The expedition was now almost over and, thank God, all men returned safely to the coast. A few sorties were made around the Mesters Vig/Sortejhorne Hut areas by small parties in a last attempt to scale at least a few mountains and on September 8 the party boarded a charter plane to take them back to Reykjavik and a totally different world.

THE RADIO ECHO-SOUNDING PROJECT

INTRODUCTION

Radio waves can be reflected from rock but can pass through ice, hence the depth of glacier ice can be measured by determining the time lapse between a transmitted signal and the received signal when radio waves are passed through the ice and are reflected back from the ice-bedrock interface.

The depth of the Antartic ice cap has been investigated by this technique with equipment attached both to surface vehicles and aircraft (2)*. However very little work has been done on narrow glacial systems.

The determination of the depth of valley ice is difficult because of the possible interference of the required signal by the echos from the valley walls. However, these spurious echos may be reduced by using directional aerials and by operating the equipment on the surface of the glacier.

This section of the report is concerned with a project to determine the depth of a valley glacier in the Staunings Alps of East Greenland during the Cambridge Expedition of 1970.

*References are listed on page 48

TECHNICAL DISCUSSION OF THE RADIO ECHO SOUNDING PROJECT

AIMS OF THE PROJECT

The initial field objectives of the project included the following:-

(1) The establishing of a satisfactory method for determing valley ice depths.

(2) The comparison of two instruments operating at different frequencies.

(3) The determination of longitudinal and transverse ice-depth profiles of the Roslin glacier.

(4) The construction of a map of the glacier that would indicate the exact routes taken by a sledge carrying the echo sounding equipment.

(5) The determination of a suitable design for a man-hauled sledge carrying radio-echo sounding equipment.

(6) The evaluation of a new type of electrical power source.

(7) To acquire a technique whereby film could be rapidly developed in order that the continuously recorded signals could be analysed with a minimum of delay.

The method adopted for determining valley ice depths.

The system finally chosen involved the mounting of aerials on a sledge which could be man-hauled along the surface of the glacier. To provide the required directionality the aerials were of the trough reflector type, see Fig. 4, and dimensions of the larger aerial determined the length and spacing of the sledge runners, see Fig.5,. The trough aerial being of simple shape did not present too difficult a construction problem and all the echo sounding equipment was mounted on the sledge by the rear of the aerial structure, see Fig. 6.

The dimensions of the aerials, being a function of the wavelength, were determined by the frequency of the instruments. The small aerials of the higher frequency machine were mounted at the sides of the larger aerial. The sledge, with all components mounted, required four men to haul it over the glacier surface.

Details of the two instruments

The two instruments taken to Greenland were:-

1. A Scott Polar Research Institute

   SPRI Mk III

   which operates at a frequency of 150 MHz.

2. A radio altimeter

   model SCR 718

   which operates at a frequency of 440 MHz.

The first instrument was specifically designed to measure ice depths. Previous models worked at a frequency of 35 MHz and these have been used with success both on the Greenland Ice Cap and on the Antarctic continent. The development of the 150 MHz machine permitted the use of smaller and more directional aerials, compared with the 35 MHz instrument, without increasing absorption losses or significantly decreasing the signal-to-noise ratio.

The second instrument was originally designed as a radio altimeter but has been used for ice depth measurements (3) within the range 50 to 550 m on an Ice Cap on Baffin Island. Although this instrument was not specifically designed for determining ice depths it is a relatively inexpensive instrument and could be used by scientists, with a minimum of knowledge of electronics, on low-budget expeditions. A further advantage of this instrument is the small size of aerials required, see Fig. 6.

Comparison of the instruments

The intention of the expedition was to use both instruments over identical routes in a valley ice system and compare results. Regretfully the SPRl machine was not used in the field because of a short circuit in the bias transformer which could not be repaired. However, from tests conducted in Cambridge laboratories prior to leaving for Greenland and from data collected from other sources (4) (5) it is possible to compare certain parameters of the two instruments and this information is presented in Table I, pages 15 & 16.

PARAMETER	SPRI MK III	SCR 718	COMMENTS
Radio Frequency	150 MHz	440 MHz	For the same gain, the aerial dimensions at the higher frequency are one third of those at the lower frequency.
Transmitter peak-pulse power	500 W	7 W	
Pulse width	0.3 μs	0.3 μs	The pulse width and the rise time are two factors which determine the minimum depth measureable.
Rise time	0.06 μs	0.1 μs	
Pulse repetition interval	64 μs	10.17 μs	
Range calibration waveform	0.1 μs duration 2 μs interval	none	Means of inserting calibration markers on the film is necessary in order to accurately assess the results.
Overall bandwidth	10 MHz	3 MHz	The greater the bandwidth the greater the resolution of information that can be recorded, such as ice layer discontinuities. Note; the aerial system must maintain the bandwidth.

TABLE I COMPARATIVE DATA OF THE SPRI MARK III AND SCR 718 INSTRUMENTS

PARAMETER	SPRI MK III	SCR 718	COMMENTS
Overall system performance. Transmitter peak-power to receiver sensitivity ratio.	160 db	120 db	To increase the range of measureable depths the greater the system performance required to overcome losses due to absorption, scattering and reflection.
Estimated maximum depth in ice at approximately -5 ^{o}C	800 m	450 m	
Aerial gain	8 db	8 db	'Trough' reflector aerial gain tests performed in Cambridge.
Power supplies	12V d.c. Transmitter 4A Receiver 0.12A	240V a.c. 50 Hz, 120 W	This expedition modified the SCR 718 instrument from 400 Hz, 115V a.c. to 50 Hz, 240V a.c.
Dimensions	12 x 10 x 8 inches	14 x 8 x 8 inches	
Weight	Approx. 14 lbf.	14.5 lbf.	
Cost	£2000	£15	The SCR 718 instrument needs, in addition, a power converter, recording oscilloscope and recording camera. Prime power supply and antennas not included in either total.

TABLE I (CONTINUED)

PARAMETER	SPRI MK III	SCR 718	COMMENTS
Overall system performance. Transmitter peak-power to receiver sensitivity ratio.	160 db	120 db	To increase the range of measureable depths the greater the system performance required to overcome losses due to absorption, scattering and reflection.
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TABLE I (CONTINUED)

Diary of The Radio Echo-Sounding Project

The work on preparing the SPRI Mark III and the SCR 718 echo-sounders was performed at the Scott Polar Research Institute and the Engineering Laboratories of Cambridge University. Work went on at an increasing rate between February and June 1970 when it became a full time occupation for Davis and Halliday. The sledge, designed by Young, was assembled on the flat roof of the Institute complete with its thirteen foot long ski-runners. Many hours were spent in brilliant weather testing and making adjustments to the aerials.

Fortunately, the R.A.F. were able to air-drop all sections of the dismantled sledge along with the less delicate items of the echo-sounding equipment. Thus the expedition was in a position to re-assemble the entire sledge within a few hours of arriving at the base camp zone on the Roslin Glacier.

Unfortunately however a serious fault was soon discovered on assembling the SPRI Mark III equipment; a transformer in the power supply circuit of the transmitter had burned out and although there was a comprehensive stock of spares, this unlikely and therefore unexpected fault could not be repaired. It was reluctantly decided therefore to temporarily lay aside the more promising of the two instruments and to assemble and commission the SCR 718 equipment.

After slightly modifying the SCR 718 circuit, due to using one of its diodes in the SPRI Mark III instrument, the project had its first success on receiving an echo which indicated an ice depth of more than 200 m in the vicinity of the laboratory tents. The next step in the commissioning procedure was to tow the sledge, carrying the echo-sounding equipment plus recording camera, over a short trial run on the glacier surface. This test indicated that the weight was badly distributed, the major portion being at the rear of the sledge, and on crossing large melt streams the whole structure would rear alarmingly and then drop with a sickening crash on the opposite bank. A further problem was the generator which was towed behind the main sledge in order to reduce vibration and electrical interference. This double sledge system was clearly unsatisfactory and so it was decided to mount the generator on the aerial sledge.

The next few days were spent on fresh trials in order to determine optimum conditions for producing a clear trace on the film and also to become accustomed to the operating conditions of the equipment on sledge runs. MacKeith joined Davis and Halliday on these runs and how fortuitous this proved to be. Crossing melt streams was still a major hazard and on the first major test-run up the glacier Davis fell into a large stream whilst manoeuvring the sledge across. Fortunately he was rapidly rescued by MacKeith and Halliday after having been swept some thirty yards downstream and under two snow bridges. This accident together with the immense labour of pulling the heavily laden sledge convinced us that the minimum number of members in the sledge party should be four.

Trial runs indicated that surface melt water caused a large attenuation of the echo. However this effect was minimised after the decision to work during the night when the surface was frozen. As compensation, the sledge party were provided with spectacular skies. The season was now well advanced and the sun set for a few hours behind the valley walls. As the sun reappeared the clouds took on a pinkish hue and the mountain snow summits glinted with a pale fire. Another bonus, equally pleasing, was the fact that the food officer allowed the night shift an extra ration of chocolate!

By the twenty-seventh of July the performance of the SCR 718 instrument was sufficiently promising to permit some time to be spent on attempting to get the SPRI Mark III to function correctly. In order to supply the correct voltage to the transmitter all available batteries were assembled. These included two lead-acid accumulators, two Met-Air batteries, and an assorted bunch of torch batteries. A most frustrating seven days was then spent on signal pick-up and earthing problems and an unsolved problem as to why the receiver took too long to recover after the transmitted pulse. The Solatron twin-beam oscilloscope, which had been brought solely for monitoring purposes, proved invaluable during this period. By this time the name of our work zone had changed from "the drop zone", through "the wigwam zone" to "the electronic research laboratory." However it still seemed incongruous to be working over a hot soldering iron in the ice-cold wind on a Greenland glacier. In this period a separate four element Yagi aerial was built for the receiver in an attempt to improve the isolation between the transmitter and the receiver. The aerial was made from plastic poles and copper wire, the latter item being taped in position. Regretfully this attempt failed and work on the SPRI Mark III was finally abandoned. However the balance of the sledge had meanwhile been greatly improved with the lead-acid batteries and petrol driven generator being mounted at the front of the sledge skis. Furthermore the SPRI Mark III provided the timing circuitry for the SCR 718 thus enabling vertical calibration marks to be made on the recording film.

It was now the fourth of August and the SCR 718 was quickly prepared. Little time remained. Hall joined Davis, Halliday and MacKeith for a longitudinal traverse of the upper Roslin Glacier. Bishop and Thompson had previously reconnoitred the route and marked every 500 m with Ryvita tins painted in Day-Glo. The upward haul proved exceedingly hard work; all members being silently convinced that someone was not contributing their fair share of work! All looked forward to reaching the powder snow close to the glacier col where it was expected the sledge skis would glide effortlessly over the smooth surface, but on arrival at the snow line, our disappointment was intense; friction was far worse in the powder snow and the sledge run eventually came to stop just above Camp Lorien, see Fig. 7. A further attempt the next night proved equally impossible and now snow was falling and visibility was minimal. Only by much hard labour was it possible to make a transverse-section traverse in this zone. The sledge party then returned to Base Camp taking soundings on the north flank of the glacier.

At base, a preliminary examination of results was encouraging and it was then decided to include a traverse of the lower part of the glacier. This time the party comprised Danby, Halliday, MacKeith and Young. The work took three days and included several transverse profiles. These latter profiles were hampered by a long deep gorge which extended down most of the middle section of the glacier. Films were developed in the morning after the previous night's run in order to have an immediate check on results. Unfortunately some isolated and brief sections of film did not exhibit a record owing to triggering difficulties with the oscilloscope. However most of the missing zones were subsequently re-run by the sledge party.

On the long run from Base Camp to the snout area there was little opportunity for recharging batteries and here the Met-Air cells proved invaluable since they could be re-energized in approximately ten minutes. It was with great jubilation that the sledge party reached the snout of the glacier at a position almost opposite Tundra Camp. The programme had been completed satisfactorily but only just in time. A boulder was decorated in bright orange paint to mark both the location and the occasion. The sledge could not have traversed another kilometre because all struts were buckled and ties torn. Still, that's optimum design!

RESULTS OBTAINED WITH THE SCR 718

Fig. 8 shows two displays. The visual monitor, or 'A' display, oscilloscope shows the transmitted and received pulse. The time interval between peaks is 1.6 μs. However, for the photographic recording of results only amplitudes greater than B-B were transmitted to the oscilloscope carrying the Z type display. Thus, for the same signal, the distance between the leading edges of the Z display is 1.65 μs, hence, due to the differing heights of the two pulses, corrections must be made. It is convenient to do this whilst interpreting traces on the film; the maximum correction was found to be 0.2 μs. It should be noted that a possible error of 0.05 μs may occur during correction. A quartz crystal oscillator was used to calibrate the time scale and, since this has negligible error and the resolution on the film due to the spot size on the oscilloscope was about 0.05 μs, the depth of ice can be measured accurately to within a tolerance of ± 5 metres. Note, the velocity of radio waves in ice at the ice temperatures encountered in the Roslin Glacier (see page 46) is 169 m/μs at radio frequencies of 150 and 440 MHz (6).

Although the results of the radio echo-sounding programme were recorded on film, depth spot checks from the monitor oscilloscope were noted at every survey marker and recorded in a log book. The routes of the slege runs are shown in Fig.9 and the corresponding longitudinal and transverse profiles are given in Figs. 10 and 11 respectively. A more detailed appraisal of the film recordings, a typical example of which is shown in Fig.12, will be made when an exact analysis of distances is compiled by the surveyors.

On the longitudinal profiles in Fig.10 the vertical scale to horizontal scale exaggeration is approximately 5:1. On the transverse profiles, Fig. 11, the ratio is 1:1. The profiles shown in Figs. 10 and 11 were obtained either from the film recordings or from the periodic spot-checks visually recorded on the monitor; dashed lines represent estimated profiles.

Discussion of Results

Examination of the depth profile, Fig.10, run H to M, shows a sharp double rise and fall close to M. On a parallel run, section XG, a similar sharp profile in the bedrock is recorded. Measurements on run XG indicate fluntuations from 250 m to 180 m followed by a dip to 230 m returning to 200 m before increasing to a depth of 275 m. The comparative figures taken from the film run HM give fluctuations of 350 m, 300 m, 310 m, 290 m and 345 m. This latter set of data is noticeably deeper than the former and this is probably due to the former run being close to the maximum depth of this section, a conclusion which is substantiated by the transverse depth profile given in Fig.11, run F to W. A similar phenomenon is recorded some distance below Z, see Fig.10. The causes for these fluctuations in bedrock profile are not known.

At the highest point reached, see H, Fig.10, two reflections from within the ice were noted and similarly on the transverse profile L to B an echo was recorded from within the ice at a depth of 200 m. It has been suggested that these echoes may be due to a medial moraine at a depth that bounds the flow of the Roslin from the west and the glacier ice from the northern tributary. Regretfully a fault in the camera mechanism did not permit a film recording during a section of the transverse run, otherwise more information on this interesting phenomenon would be available.

Unlike rivers of water, streams of ice do not diffuse but have parallel courses. In this context it is interesting to study the transverse profile FW, Fig.11. This figure presents both the surface profile and the bedrock profile and the Dalmore Glacier stream is seen to be quite separate from the main stream of the Roslin ice.

Conclusion

The results obtained by the modified SCR 718 instrument are encouraging and it has been shown that man-hauling radio-equipment is a feasible way of determining not only the depths of enclosed ice systems but also a means of studying bedrock profiles and glacier ice sub-surface discontinuities.

A discussion on ice-absorption losses.

In an endeavour to further understanding of the behaviour of radio waves in ice, the following sections will consider absorption losses in the Roslin Glacier.

Absorption of radio waves in ice can be calculated knowing the ice depth, d, and echo strength, E. Normally the echo strengths on the Roslin Glacier were between 15 dB and 30 dB above the receiver noise level. Table II page 24 shows the approximate dielectric absorption calculated from

$$A = S + R - E + G \qquad \text{.................... (1)}$$

where

A = the total dielectric absorption

S = the system performance, i.e. ratio of transmitter peak-power to receiver power sensitivity, see Table I page 15.

R = the power reflection coefficient of the ice-bedrock interface

E = the observed echo strength above receiver power sensitivity

G = a geometrical factor which includes aerial gain, refraction, and the inverse square law,

$$\frac{n^2 g_a^2 \lambda_a^2}{64\pi^2 d^2}$$

where

n is the refractive index of ice;

g_a is the aerial gain in air;

λ_a is the wavelength in air;

and d is the depth of ice in metres.

SLEDGE RUN	DATE	LOCATION	ALTITUDE metre	ICE DEPTH metre	Temp. at 9 Metre Depth °C	ECHO STRENGTH dB	Power Reflection Coeff. dB	GEOMETRICAL FACTOR dB	TOTAL DIELECTRIC ABSORPTION dB	TOTAL DIELECTRIC ABSORPTION dB/100m	REMARKS
		[see vol II]		d		E	R	G	A		
2	23-7-70	W	1100	220	-9·3	20	-20	-57·3	22·7	5·16	
7	6-8-70	W	1100	220	-9·3	20	-20	-57·3	22·7	5·16	
3	24-7-70	W	1100	220	-9·3	10	-20	-57·3	32·7	7·43	VERY WET SURFACE.
8	11-8-70	T_{50}	1000	220	~ -7	~ 0	-20	-57·3	42·7	9·7	
8	12-8-70	Q	900	210	-6·7	~ 0	-20	-57·0	43	10·25	
6	27-7-70	M_3	1200	250	~ -9	10	-20	-58·5	31·5	6·3	
5	26-7-70	M_3	1050	250	~ -8	10	-20	-58·5	31·5	6·3	
8	11-8-70	T_{41}	1000	250	~ -7	10-15	-20	-58·5	31·5	6·3	
8	12-8-70	B_5	800	240	~ -6	5	-20*	-58·1	36·9	7·7	REFLECTION WITHIN ICE
5	26-7-70	BETWEEN M_2 & M_3	1000	170	~ -8	5	-20*	-55·1	39·9	11·8	" "
7	6-8-70	P	1100	130	~ -9	10	-20*	-52·8	37·2	14·3	" "
7	6-8-70	T_4	1300	290	~ -8	10	-20	-59·7	30·3	5·23	FIRN ZONE.
7	6-8-70	T_8	1350	290	~ -7·5	20	-20	-59·7	20·3	3·45	" "
7	6-8-70	H	1500	270	~ -11	15	-20	-59·1	25·9	4·8	
7	6-8-70	H	1500	185	~ -11	5	-20*	-53·9	41·1	11·1	REFLECTION WITHIN ICE

TABLE II. ABSORPTION DATA: ROSLIN GLACIER

For the present system,

$$n^2 = 4.8 \text{ dB}$$

$$g_a^{\,2} = 16 \text{ dB}$$

$$\lambda_a^{\,2} = (0.68\text{m})^2 \equiv -3.3\text{dB}$$

thus

$$G = \left[-10.5 - 20 \log d\right] \text{dB} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

For a perfect diffuse reflector G is multiplied by $\frac{4vt}{d}$, ref (6) *

where

v is the velocity of propagation in the medium, i.e. $\frac{169 \text{ m}}{\mu s}$

t is the pulse length, i.e. 0.3 μs, and

d is the depth in metres

this factor causes a variation in G in the present work between extremes of 0.6 to 2.0 or, at most, 3 dB. This factor is not considered in the subsequent analysis since its effect is minimal.

Discussion of absorption results

The values of absorption deduced in the Roslin Glacier are higher than those commonly found in cold polar ice sheets which includes measurements taken in North-west Greenland, ref. (6). The Roslin values are approx. between 3 and 10 dB/100m, with a mean value of 6.4 dB/100m, if only echoes from the ice-bedrock interface are considered. The ice temperatures at 9m depth, vary between -6°C and -11°C., at zones in which the absorption is determined. The absorption of pure, dry ice at 0°C is usually taken as 5.7 dB/100m and at -10°C is 2.7 dB/100m. (ref. 6)

Possible explanations for the apparently high Roslin absorption values, see Table II, are discussed below.

*References listed on page 48

Possible causes

From Equations (1) and (2)

$$A = S + R - E - 10.5 - 20 \log d$$

and since S for the SCR 718 instrument is constant and E and d are constants at a particular locality then the deduced value of A appears only to depend on the value of R. Thus the assumed values of R may be too high and possible causes for variations in R should be examined, however it should be noted that reflection coefficients arithmetically < -20 dB are most unusual.

(1) If one considers the possibility of a continuum of a thick layer of water at the ice-bedrock interface then the value of R would increase and theoretically could attain 0dB thus making the calculated values of A even higher than those given in table II.

If R is not the cause of high absorption losses it becomes necessary to examine other possible causes of losses of signals in the ice.

(2) The true bulk absorption of the medium may be increased by the presence of liquid water in ice pores. The effect of water is dependent on its impurity level, i.e. on its conductivity. Taking a conductivity of 4×10^{-3} mho/m i.e. rainwater, and supposing that all the pores are filled in snow of density equal to 0.5 Mg/m^3 then to produce an additional 20 dB of absorption in the two-way signal path, a thickness of approximately 30 m of water-saturated snow is required, ref (7). Such a consistent effect however is highly improbable.

(3) A layer of liquid water, such as a pool or melt stream, is an effective reflector of power, because of the high permitivity of water. At 440 MHz a layer of melt-water 5 mm. thick reduces the transmitted wave by 5dB or by 10 dB in the two-way path. A 19 mm. layer of water, which is equivalent to a quarter wavelength, reduces the transmitted wave by 22 dB in the two-way path, ref (7). These attenuations are almost independent of the purity and conductivity of the water.

It is of interest to note that echo strengths, at night, were greater by about 10 dB when compared to the echo strength during the day at the same locations. During the daytime of course a great deal of ablation occurred whilst there was little or no melting at night. Thus a variation of a few mm. in the thickness of water layers is possible between day and night. The fact that very few reflections from within the ice are noticed below a depth of about 150 m may indicate that most of the water layers are near the surface of the ice.

The above argument is one possible explanation of the high losses.

(4) An alternative explanation is that the dielectric absorption is increased by high impurity content. In order to study this effect, conductivity of melted water at + 25°C was measured in the laboratory. The samples used were intended for the oxygen isotope project, see vol. II, and so the precautions necessary to meet the extremely high standards of cleanliness necessary for conductivity measurements were not taken. However, these samples should provide an indication of conductivity variations. The samples were taken from about 0.45 m. below the ice surface. A large amount of rock-flour is evidenced in the specimens.

Sample	Location	Conductivity μ mho/cm.
A6	1100m altitude (just below the firn zone)	34.8
B6	600m altitude (5 Km above the snout)	23.5
Cold Polar Ice		1.5 to 8

The high conductivity of the Roslin Glacier ice suggests that there is a high concentration of impurity. Glaciers slowly self-purify, and Renaud, ref(8) has shown that ice near a glacier snout has a lower conductivity value. Present measurements agree with this but the absolute values are high.

The effects of impurities in ice

Paren and Walker, ref(9) have discussed the effect of common salt impurities on the electrical behaviour of ice. They assert that the attenuation of polar ice will be independent of impurity content until a critical content is exceeded at which electrolytic conduction in brine veins is the dominant loss mechanism. Experimental evidence by Hochstein and Risk, ref(10) who worked on the McMurdo Ice Shelf, confirms the belief that meltwater samples, when tested at 25°C and having a conductivity greater than 20 μ mho/cm, have higher D.C. conductivities at -12°C than purer polar ice. Furthermore, one core from Camp Century obtained at a depth of 59 m had a conductivity of 40 μ mho/cm, at + 25°C, and higher V.H.F. losses than purer polar ice. However, both the McMurdo Ice Shelf and the Camp Century ice discussed above were of density between 700 and 800 kg/m^3. When endeavouring to predict the absorption behaviour of solid ice with a high impurity concentration similar to that found on the Roslin, the problems of choosing a dielectric mixture model which can accurately describe the composition will be a difficult but necessary task.

The VHF attenuations of the McMurdo and Camp Century ice, having known meltwater conductivity, together with the values from the Roslin Glacier, and more pure polar ice is given in the following table:-

Ice	Melted Conductivity µ mho/cm	VHF Attenuation (dB/100m)	
		at $-12^{o}C$	at $0^{o}C$
Camp Century	40	5.6	10.2
McMurdo Ice Shelf	30	5.9	-
Pure polar ice	2	2.5	5.7
Roslin Glacier A6	34.8	6.8 ± 2	
Roslin Glacier B6	23.5		

Perhaps it should be stated that V.H.F. absorption losses had not previously been measured in polar ice of such high impurity level as that found in the Roslin Glacier.

Possible models for explaining absorption losses

Choosing a model of straight brine veins in polar ice with the majority of impurities in the brine, thus causing an over-estimation of the role of conduction of the veins, values of absorption for the Roslin samples are:-

A6	31 dB/100 m	at $-10^{o}C$
B6	21 dB/100 m	

An alternative model assumes sea salt impurities, and deduces the necessary chloride concentration to account for the observed conductivity of the meltwater. However the samples contain a great deal of rock-flour, and this impurity may significantly affect the meltwater conductivity but not the radar absorption. Calculations based only on sea salt impurity give radar absorption values for the Roslin samples of:-

Sample A6	23 dB/100 m	at $-10^{o}C$
Sample B6	18 dB/100 m	

The presence of rock-flour makes these values upper limits.

Regretfully there is no ice with which to compare the Roslin Glacier measurements, since solid glacier ice with this impurity concentration is rare. The best that can be done is to examine the D.C. conductivity measurements on permeable firn of similar impurity concentration, although results must overestimate the attenuation. An alternative model which works well for sea ice can be used but again the predicted attenuation is higher than that found in the Roslin Glacier.

The above arguments have been considered to help understand the behaviour of radio waves in ice and to assist in making design improvements to radio-echo sounding equipment.

Technical Note No. 1

The Construction of the Sledge and its Performance in the Field

Introduction

The major factor in the design of the sledge was that it had to act as the transporter of a 150MHz trough aerial, see Fig. 5. Originally the sledge superstructure only consisted of the large 150MHz aerial; all other equipment to be mounted on an auxiliary Nansen-type sledge.

When it proved impossible to obtain a Nansen sledge the aerial sledge was redesigned to incorporate most of the equipment including the additional 440MHz SCR718 aerials. The exception was the generator since this was thought to be a likely source of electrical interference. It was originally intended to mount this item on a 'pulka', a small lightweight sledge of Swedish design, which would be pulled along the surface some distance away from the aerial sledge. Field trials, however, indicated that this was not necessary. The total load accommodated by the aerial sledge, finally, was approximately 245 lbf, see Fig. 6.

Frame construction

Four considerations governed the choice of frame material

(a) it had to be easily packed to facilitate transportation

(b) it had to be in unit parts that could be quickly re-assembled in the field

(c) it had to be as light-weight as possible to reduce the dead load on the skis

(d) it had to be versatile in order that modifications to the structure could be readily incorporated should field conditions necessitate drastic alterations.

The material finally adopted was Aluminium Dexion Angle. Some 170 ft. of 'Dexion 225' and 90 ft. of 'Dexion 150' was requested. Thankfully Dexion Ltd. donated an excess quantity thus providing spare lengths for repair work and field modifications.

Ski runners

Discussions with Dr. B. Harland and other members of the staff of the Sedgwick Museum, Cambridge indicated that the runners were likely to suffer very severe punishment. Therefore the design was based on the runners of the Nansen-type sledge, which consists of strips of ash faced with a low friction material.

Grays of Cambridge provided two strips of ash, measuring 13 ft. x 6 in. x 1 in. each, as well as advice on how to shape the wood. The bending of the front of the strips in the form of an arc was performed at Banham's Ltd., the boat builders, who steamed the wood to the form of a steel template previously made in the University Engineering Department Workshops.

Tufnol Ltd. provided two strips of 'Bear-Brand' laminate to face both runners and CIBA of Duxford donated a quantity of Aerodux adhesive to join the laminate to the bent ash runners.

Equipment Rack

The dimensions of the various items of electronic equipment required that a shelf 2 ft. wide be built on the sledge and this dimension dictated that the shelf be at least 2 ft. above the runners, see Fig. 6 . To allow easy access to, and adjustment of, the equipment, it was decided to construct the shelf at the rear of the aerial.

A major problem concerned the stability of the aerial and the instrument shelf. Obviously no metal could be used as stays within the trough aerial volume and so to reduce the sway tendency of the superstructure the centre of gravity of the instrument shelf was required to be as low as possible.

The final design thus permitted a ground clearance of only 1 ft. at the centre of the sledge structure but this was considered an adequate allowance for the undulations of the Roslin Glacier surface.

Harnesses

The Irvin Air Chute Co. Ltd. supplied the expedition with some nylon webbing offcuts which Simpers Ltd., a local tent-maker, tailored to five crude harnesses of varying sizes. These harnesses although satisfactory for short duration man-hauling were not as satisfactory as the harnesses made specially by Britax Ltd. These latter type belts were designed by Mr. Michael of the Special Belts Department, and incorporated a quick release buckle, similar to those used on car seat safety belts.

Notes on Sledge Assembly

The sledge was initially assembled in the workshops of the C.U.E.L. and the expedition must thank the workshop staff for the advice given during the course of assembly. Because of the nature of the Dexion Angle it was possible, with care, to cut the angle in such a manner that no extra holes had to be drilled, or special bolts fitted, when assembling the structure. Special fittings such as fish plates were avoided wherever possible. Sharp edges and corners were fitted facing inward to minimise the possibility of cuts to clothing and personnel.

When the sledge construction was completed, including minor modifications incorporated during assembly, the whole structure was dismantled and moved to the Scott Polar Research Institute roof and there re-assembled for electrical tests. All joints were painted and given serial codes to facilitate field assembly and the sledge was finally dismantled and suitably packed for the R.A.F. air drop.

The Performance of the Sledge in the Field

The performance of the sledge was very satisfactory but not perfect; imperfections in the design in no way impeded the successful completion of the programme.

Faults determined during field operations

1. The most significant fault in the design was an imbalance in the weight distribution. This manifested itself in various ways but most conspicuously in its effect on the handling of the sledge.

   Fortunately, this problem was solved in the field. The weight redistribution was achieved by moving the generator and lead-acid battery, combined weight ~ 85 lbf., to the front of the sledge and mounting them on the ski runners.

2. The technique of towing the generator on the pulka proved unsatisfactory, and ultimately unnecessary, since electrical interference was not a significant problem. It was extremely difficult to manouvre two sledges in convoy, especially across streams, and interruptions in the power supply were frequent. The generator was eventually sited at the front of one of the runners.

3. The sledge had a tendency to side-slip when traversing a slope. This problem was accentuated by the faulty weight distribution. To minimise slipping a tow-line was attached to the rear of the framework. Using this and one of the front sledge traces the side slip was minimised and the sledge kept on course.

4. The sledge stuck badly on freezing powder snow, and it required great effort to move the contraption. It was almost impossible to restart after a rest in these conditions due to the layer of snow that froze onto the underside of the runners. On all other types of glacier surface the runners performed satisfactorily.

Field Modifications

The only two modifications concerned the weight redistribution and the strengthening of some of the dexion members. Mountings for the battery and generator were improvised from wood and dexion and these necessitated minor modifications to the front of the aerial frame. At the same time a mounting for a spare fuel can was constructed. The structural work consisted of replacing all joints that had broken under the original load distribution and the addition of plates as stiffeners. The struts under the equipment shelf required special attention since these had suffered considerably.

Comments on Runners and Harnesses

Wear of the Tufnol surfaces was not significant despite the number of rocks over which the sledge had been dragged. Mechanically the runners survived exceedingly well. The only sign of damage was a small crack at one of the bends and this may have occurred during the air-drop. The Tufnol laminate, the bonding adhesive and the ash were very satisfactory materials from which to make runners.

The Britax harnesses were magnificent. Their adjustibility meant that only three were required irrespective of the size of the members who were pulling the sledge. The quick release mechanism was invaluable especially during the occasion of the melt-stream accident, see page 18, since the rescuers were able to unclip and render assistance within split seconds. The fabricated harnesses were rather less satisfactory and it appears essential to have the shoulder-straps cross-over behind one's back to prevent the straps slipping off one's shoulders.

Suggestions for future designs

1. It is recommended that some form of flexible mounting between runner and frame be introduced in order to reduce the shock loadings on the frame. Perhaps Moulton rubber suspension mountings may be suitable.

2. There should be some form of harness provided for the people behind the sledge. This would facilitate braking of the sledge on downhill slopes.

3. Rope would be a better form of trace than nylon tape, since such trace material could be used to effect rescues. A 15 ft trace was found to be a satisfactory length.

4. The possibility of using <u>steel</u> Dexion should be considered. The overall weight increase, an estimated 100 lbf, represents only about 20% increase in the total sledge weight but a much stronger structure would result.

5. A second equipment rack should be provided to take rucksacks and camping equipment for the sledge party. Manhauling whilst carrying a full pack load, though possible, is awkward.

6. The wooden, electronic-equipment container box, which provides essential protection against the environment, should be the full width of the sledge.

Technical Note No. 2

THE AERIALS

For valley ice soundings this important component must

(a) efficiently radiate a narrow beam of electromagnetic waves into the ice

(b) be able to receive a very weak echo from the ice-bedrock surface

(c) have as wide a band width as the transmitter and receiver, and

(d) be easily transportable.

The trough reflection aerial satisfies these conditions. A diagram of such an aerial is shown in Fig. 4 . The reflector may be made from sheet metal or wires spaced at intervals $\leqslant$ one tenth of the wavelength and parallel to the dipole. The antenna for the 150 MHz instrument designed by the expedition had a forward gain of 8 dB and a voltage standing wave ratio (V.S.W.R.) $< 2{\cdot}2:1$ within the range 140 to 160 MHz. The 150 MHz aerial could be easily dismantled and transported and this feature was important since the individual items had to be packaged for the R.A.F. air drop. Because of its large size and shape the 150 MHz aerial distorted somewhat when passing over rough terrain, causing a considerable variation in its electrical characteristics. Smaller sized aerials would therefore be more advantageous especially if these could be carried above the surface of the glacier.

The 440 MHz aerials, although similar in shape to those of the 150 MHz instrument, were approximately only one-ninth the area. When in use they were mounted on the sides of the larger aerial. Two of the smaller aerials were necessary because the SCR 718 instrument does not have an electronic transmit-receive switch. Echoes from the valley walls were noticeable only when the sledge was very close to the glacier edges. The design of the trough antenna proved to be a compact, high gain and high efficiency aerial system.

Instrumentation

Fig.13 gives a schematic layout of the equipment. The transmitted pulse is radiated from the aerial and then travels through the ice to the bedrock to be reflected back through the ice and received by the aerial. The receiver amplifies the weak echo signal which is then displayed on both of the oscilloscopes. The photographic film is run continuously. The range calibrator is normally used at known positions on the glacier surface in order to assist the interpretation of film records.

Technical Note No: 3A

Radio-Echo Sounding Project: Power Supplies

1. Summary of Power Requirements

SPRI Mark III Transmitter		12V	3·5A
Receiver		12V	0·12A
Tektronix Scope (Main Display)		12V	0.8A
	or	240V AC	
Solartron Scope (Monitor)		12V	2·0A
	or	240V	
Recording Camera		12V	1·8A
SCR 718		115V	400Hz
	modified to	240V	50Hz
	and		~ 120W
Soldering Iron		240V	25W

A 12V soldering iron would have been more convenient.

2. Power Sources Available

Conventional Lead-Acid batteries, charged by a portable generator, were initially chosen as the principal power source. Such a source was capable of supplying 12V to a maximum of 50 amp-hours and was used to operate the SPRI Mark III system.

The SCR 718 initially required a 400 Hz supply. However a suitable DC-AC convertor would have been heavy, bulky and hence inconvenient so the SCR 718 instrument was modified to take 240V at 50 Hz. This could be supplied from the Honda E300 generator which could produce either 240V AC or 12V DC.

When "Met-Air" batteries, see page 37, were offered for field trials it was decided to use this source of power to its maximum capability and that the Lead-Acid cells would be used only when necessary. The main advantage of the "Met-Air" batteries is that they can be re-energized simply and quickly without electrical charging. It was hoped therefore that even if the generator should fail, the SPRI Mark III equipment could still be run for some time.

3. Honda Generator Type 300

Specification		240V AC	300W	50/60Hz
	or	12V DC	100W	

This generator was admirably suited for the project both in terms of application and field conditions. It gave no trouble, except on one occasion when the fuel had not been correctly filtered. The siting of the generator on the sledge provided a problem because of its weight, 18 kg Fortunately vibrations caused no trouble and there was minimal voltage fluctuations even though the sledge occasionally tipped at alarming angles.

4. Lead-Acid Batteries 12V 50 Amp-Hours

In order to satisfy the cold conditions of the 1969 summer, when temperatures of -20 and -30°C were not uncommon, a more dense than normal electrolyte was used of S.G. 1·280. The batteries were dry-charged and parachuted by the R.A.F. onto the glacier along with other expedition supplies. The weight of these batteries, 20 kg, caused sledge balancing problems.

Technical Note No: 3B

"METAIR" BATTERIES

Energy Conversion Ltd. of Basingstoke have designed a range of zinc-air primary, non-rechargeable batteries. These batteries are particularly well suited to applications calling for a lightweight source of stored power coupled with compactness and high power output. For example, these batteries are approximately a quarter the size and one eighth the weight of Le-Clanché and lead acid types of battery of comparable capacity and rating, and the air-breathing cathode of these zinc-air batteries can support much higher current densities than conventional designs. The Metair batteries provide up to 80 watt-hours/kg of battery and can maintain high continuous power levels. Specific power levels of up to 40 watt/kg and 0.5 kw/m^3 are possible. Furthermore, they keep their on-load voltage steady to within a few per cent until 90% of the available stored energy has been discharged. In service the cells absorb oxygen which reacts with the potassium hydroxode electrolyte and the zinc anode to form zinc oxide.

Batteries of different characteristics can be obtained by varying the cathode design.

Specification of cells used by the 1970 expedition

12 volt, 24 ampere - hours

Weight 1·5 kg

Working Temperature range -40°C to +55°C

1970 Expedition Experience

These batteries proved invaluable, especially on sledge runs of several days duration, when the recharging of the Lead-Acid cells by the generator would have been both inconvenient and wasteful of fuel.

The sledge carried four "Metair" recharge kits, each containing new anode plates and electrolyte ampoules, and the whole recharging operation took just over ten minutes, and did not interrupt a run. Moreover, the re-energising of the batteries could be carried out at night, in fairly cold conditions, without discomfort.

The advantages of the light weight of the "Metair" batteries are obvious, and their rated voltage did hold throughout 90% of the specified life. However the load did prove to be a little too much for one "Metair" battery alone, so they were used in conjunction with the Lead-acid batteries. The latter type batteries in this arrangement, did not need to be recharged regularly, and then only when convenient at base camp.

TECHNICAL NOTE NO. 4

Photographic Recording

The Camera

The recording camera was an old Telford model having six different speeds and was mounted on the oscilloscope such that the continuously moving film ran in the y-axis direction of the Z type display, see Fig. 8 . A continuous profile of glacier depth was thus recorded by filming at a speed of 5 mm/min. This speed was determined as the optimum during trial runs.

Films and Processing

The film used was 35 mm "Kodak" Tri-X Pan and was processed in 'Diafine' two bath developer. Although 'Diafine' is relatively expensive it has the advantage that so long as the minimum recommendations are observed, development time and temperature are not very critical. However it may be that a Monobath developer would be a more satisfactory and less expensive alternative. Furthermore such a combined Developer/Fixer may be stored in one bottle and not three. However the Monobath would be required to have similar time-temperature behaviour as the Diafine.

The small spiral-loading daylight developing tank proved adequate on most occasions. The "Morse" tank, taken to develop long lengths of film, was only used twice.

There were the usual problems of developing film in the field, such as rapid changes in temperature in the late evening and poor facilities for the washing and drying of film. A rapid washing solution could have been used with advantage. The large film changing bag was in frequent demand, not only for the echo-sounding project, but for the personal use of members who wished to change films in their own cameras.

TECHNICAL NOTE NO.5

Equipment Lists

Key:- L = Loan M = Home Manufacture G = Gift B = Bought
D = Discount P = Parachute Drop C = Carried by Members

ITEM	NO. OFF	RATE	ENTRY	SUPPLIER
1. ELECTRONIC EQUIPMENT				
SPRI Mk III	1	L	C	Scott Polar Research Institute
SCR 718	1	B	C	Government Surplus Stores
Tektronix Oscilloscope	1	L	C	S.P.R.I.
Solatron Oscilloscope	1	L	C	Solartron Limited
Leads	Many	L	P	S.P.R.I.
2. POWER SUPPLY EQUIPMENT				
Generator	1	D	C	Honda (UK) Ltd. [Choppen Cambridge]
Lead-Acid Batteries	2	G	P	Electric Power Storage Ltd. and Cambridge Battery Services
Electrolyte	4 gall	B	P	Cambridge Battery Services Ltd.
Met-Air Batteries	2	L	C,P	Energy Conversion Ltd., Basingstoke
Recharge Kits	9	L	P	"
Ammeter	1	L	C	C. U. Engineering Department
Charging and Power Cables	Many	B	P	Several
3. PHOTOGRAPHIC EQUIPMENT				
Camera	1	L	C	S.P.R.I.
Camera mount	1	M	C	C. U. Engineering Department
Developer ('Diaphine')	4 pkts	B	P	Pelling and Cross Ltd.
Fixer (Kodafix)	1 gall	B	P	Kodak
'Morse' tank	1	L	P	C. U. Engineering Department
Small Tank	1	L	P	"
Wetting Agent	1 btl	B	C	Local Purchase
Funnel	1	B	P	Woolworths
Plastic Bottles	4	B	P	"
Changing Bag (large)	1	B	P	University Cameras, Cambridge
Cans for Exposed Film	20	G	P	"

EQUIPMENT LISTS (continued)

ITEM	NO. OFF	RATE	ENTRY	SUPPLIER

4. AERIAL EQUIPMENT

ITEM	NO. OFF	RATE	ENTRY	SUPPLIER
Wooden Equipment Box	1	M	P	
Elastic Straps	16	B	P	
Canvas Cover	1	M	P	
Odometer	1	M	P	
Aerial (150 MHz)	1	M	P	See Technical Notes 1 and 2.
Aerial (440 MHz)	2	M	P	See Technical Notes 1 and 2.
Copper Wire	20lb.	B	P	Mackays Ltd., Cambridge
Aluminium Sheet		B	P	
Accumulator Box	1	M	P	

5. SPARES ETC.

ITEM	NO. OFF	RATE	ENTRY	SUPPLIER
Electronic Components, Valves etc.	assorted	L	C	S.P.R.I.
Bicycle Pump	1	B	P	
Generator Oil (10/30)	1 qt.	B	P	
Multi Test Meter	1	L	C	
Spare Leads and Wire	assorted	L	P	S.P.R.I.
Insulating Tape	2 rolls	B	P	
Magic Markers	3	B	P	
Spare Nuts, Bolts, etc.	assorted	B	P	

6. THE TOOL BOX

A tool box was also air-dropped and included the following items:

Mole Wrenches (1 large, 1 small), Hacksaw and blades, Hand-drill and bits, Pliers (1 ordinary, 1 thin-nosed), Screwdrivers (1 large, 2 medium, 2 small), File, Rasp, Dexion Spanners (2), Tin Snips, Soldering Iron (240 V, 25 W) [12V would have been more versatile], Solder, Wire, Wire Strippers, Side Cutters, Tape Measure, Puncture Outfit, Emery Paper, Sand Paper, Araldite.

Note:

Electric Power Storage Ltd. generously supplied two charged and filled Lead-Acid batteries. However, because of transportation difficulties, Cambridge Battery Services Ltd. kindly changed them at the last minute for comparable dry charged batteries.

TEMPERATURE PROFILES IN THE ROSLIN GLACIER

In order to study the attenuation of radio signals in ice and compensate for the effect of variable temperatures of ice on the velocity of radio waves through the glacier it was decided to determine temperature profiles. Such an investigation necessitated the boring of holes 10 metres deep along the route of the sledge. The spacing of holes at various altitudes of the glacier was dependent on how many holes could be drilled in the time available.

With only one week to plan this late addition to our projects two possibilities were studied.

(a) Thermal drilling

(b) Mechanical drilling

Thermal drilling

Thermal methods have been used to drill to depths of over 200 m, ref. (11) (12) and (13)* with the prime source of heat being either electrical power or steam. However the expedition did not have sufficient electrical generating capacity that would permit an acceptable rate of drilling. Experiments were therefore carried out in the Engineering Laboratories with "THERMIT", a refractory material which, when ignited, can raise the temperature of steel, having four times its mass, by 650 °C. Cartridges of the material measuring 2 in dia by 3.5 in long, including inserts of a suitable primer, were specially prepared for the expedition but regretfully laboratory tests showed drilling rates to be completely unacceptable. An illustration of the device is shown in Fig.15.

It was perhaps fortunate that no suitable thermal means of drilling was attained since the subsequent field work showed that heat inputs would have seriously disturbed the equilibrium conditions of the ice, see page 46.

Mechanical drilling

After discussions with Dr. C. Swithinbank of the Scott Polar Research Institute it was decided to use a trepanning drill. Such a device could also be used to obtain core samples at various depths. Experience in Antarctica predicted the possibility of drilling 10 m deep holes within the hour and this was the deciding factor to go ahead and manufacture two drill bits with extension rods. At this point in time only two days remained to despatch equipment and the expedition must thank those members of the Engineering Department who freely gave their time that critical weekend in order to manufacture the drills. Two drill bits were made from tube, each measuring 2 ft long, 2½ in outside diameter by 1/16 in thick, teeth being cut in one end, see Fig. 14. Both bits were subsequently quench hardened and tempered but this proved to be a mistake.

* References are listed on page 48

Temperature measuring devices

It was required to measure englacial temperatures to an accuracy of ± 0.1 °C and due to shortage of time it was decided to opt for the standard technique of mercury-in-glass thermometer with the thermometer bulbs capped in wax so as to reduce the temperature changes as the thermometer was withdrawn from bore holes.

The possibility of using thermistors was investigated with Standard Telephone & Cables who recommended a type G24 thermistor and kindly donated 12 samples to the expedition . Regretfully no time was available to fully develop the associated circuitry to the required accuracy. However this report should discuss the advantages of this system if only for the benefit of future expeditions. The thermal capacity of the device is low so thermal equilibrium is quickly attained; the device need not be removed from the bore hole to affect a temperature reading; the device is not as delicate as the mercury-in-glass thermometer system. Perhaps it should be stated here that several thermometers were broken during the course of the expedition and NPL calibrated thermometers are expensive instruments. Müller (14) has used thermistors and obtained satisfactory results although reservations were expressed on the stability of the system. However modern developments in this field may have provided more stable thermistors.

Field experience of the mechanical drill

During the early period of the expedition two faults of the drill caused concern. First and most important the drill ceased to cut after penetrating approx. 8 cm (centimetres!) of hard ice, and it was concluded that Antarctic experience of this device must have been in hard packed snow. Secondly the capstan arrangement and the extension rods were a little too cumbersome.

During the early attempts to drill holes it was noticed that an ice plug formed at the entrance to the bore of the drill bit and this plug was difficult to remove. The plug of ice undoubtedly prevented a sufficient tooth-bearing-area thus reducing the cutting efficiency. The plug was formed by layers of ice lenses, of variable density, being forced into the tube and on freezing to an homogeneous mass the lenses had a sufficient internal bearing surface as to prevent the plug being pushed further down the tool-bit core.

The fault was eventually remedied by cutting away the original hardened and tempered teeth, and consequently losing some 6 inches of the drill bit, and then cutting new teeth at a steeper rake angle, see Fig.14. This operation was carried out with not a little apprehension especially when, during new trials, one of the new teeth immediately broke off. However our fears were unfounded and the new teeth proved adequate.

The new arrangement of teeth undermined the disadvantage of the weight of the drill since it was now possible to drill cores of 15 to 20 cm height per cut before removing the drill and clearing the tube. The new teeth shattered the ice into smaller fragments thus reducing the tendency for the drill to jam.

The speed of drilling bore holes was now dependent on three factors, the speed at which the drill could be withdrawn after each cut, the tube cleared of ice and new 1 metre extension rods added at appropriate intervals. The extension rods were joined together by 0.5 in Whitworth threads which self tightened when torque was applied during drilling. Indeed the applied force was such that one of the studs eventually sheared off thus limiting future maximum depths of bore holes to 9 m. Mole wrenches were necessary to unscrew the extension rods and perhaps future designs should include either a quick-release mechanism or flats on the rods to fit standard type open-ended spanners. Towards the end of the expedition a co-ordinated effort of four men could drill one 9 m bore hole in approximately six hours.

ICE-TEMPERATURE MEASUREMENTS

1. Introduction

The questions to be answered by field experiments before satisfactory results could be obtained, were

(a) What depth of hole was required to attain ice-temperature conditions?

(b) What time-interval (T.I.) was necessary after the hole had been bored to allow the thermometer and ice-hole to attain equilibrium conditions?

(c) What was the effect of time on the temperature reading once the lagged thermometer had been withdrawn from the hole?

The answers to these questions are given in the following sections.

2. Borehole Sites

Number	Height above sea level metres	Location	Date
1	1200	Wigwam	31 July
2	1600	Tin 23	6 August
3	1400	Tin 14	9 August
4	950	Tin 35	17 August
5	570	Boulder 103	18 August
6	270	Boulder 112	19 August

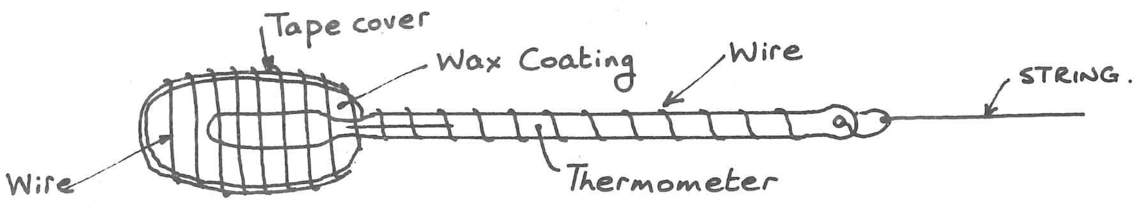
Notes

(i) Tin 35 was opposite Fly Left Camp

(ii) Boulder 103 was opposite Fly Right Dump

3. Thermometers Used

N.P.L. calibrated thermometers correct to 0.1 °C (2 off) and 0.2 °C (1 off). A standard thermometer was also available which was checked against the N.P.L. thermometers. All thermometers were lagged in a thick, approximately 15 mm, coating of candle wax which was then supported by tape and a wire coil, see sketch below.



The thermometer was suspended down a hole by string attached to the wire.

4. Determination of optimum bore-hole depths.

The table below presents the data recorded at three boreholes.

Bore-hole No.	Time Interval (T.I.) hours	DEPTH/metres								
		1	2	3	4	5	6	7	8	9
		NEGATIVE TEMPERATURE / °C								
ONE	16 to 24	3.65	6.3	8.3	9.4	9.6	9.65	-	-	9.7
ONE	~ 50	-	-	-	-	-	9.85	9.6	9.5	9.35
THREE	~ 20	-	-	-	-	-	7.6	7.6	7.4	7.3
FOUR	9 to 14	-	-	5.8	5.8	6.5	6.7	6.5	6.5	6.6

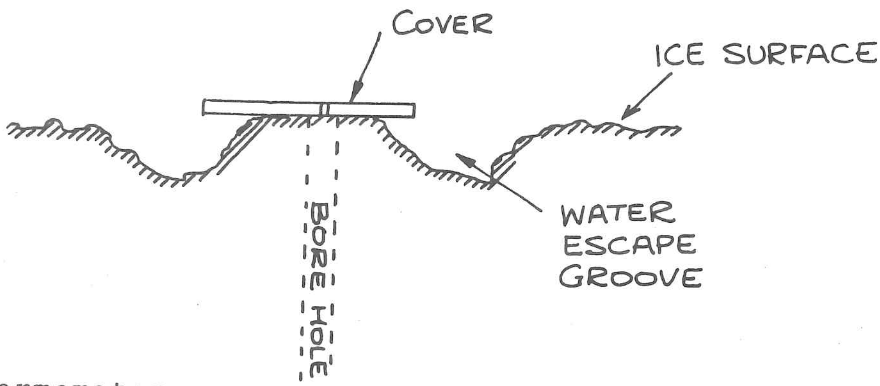
Note: Final reading at borehole 4 was at a depth of 8.85 m.

Comments

The temperature variation with depth for borehole number 1 is shown in Fig.16. Readings show that change of temperature was minimal at depths > 6 m and negligible at 9 m. Eventual water percolation probably affected readings at maximum depth in borehole 3 and the second experiment at borehole 1.

5. Time for hole to reach equilibrium

See Fig.17 for results obtained at borehole No.1. The borehole requires at least 10 hours to gain equilibrium. The final reading taken after 40 hours indicates an increase in temperature and is highly probably due to water percolation. This point illustrates the necessity to maintain boreholes as dry as possible. To avoid entry into the holes of water and/ or ice particles covers were placed over the mouth of the holes immediately after drilling.



6. Lagging of thermometers

Fig. 18 illustrates the results taken at borehole No.1 to determine the recovery characteristics of a lagged thermometer. Note the drop in reading immediately after withdrawal. This is of the order of 0.2°C after only six seconds which was the time interval required to withdraw and take a reading. This unusual effect was possibly due to differential heating rates of the lagged bulb and unlagged stem.

7. Nine metre depth temperatures

Altitude/metres	270	570	950	1200	1400	1600
Borehole No.	6	5	4	1	3	2
Time Interval/hours	24	12	10	20	20	7
Temperature/°C	-3.8	-5.8	-6.6	-9.7	-7.4	-12.0

Fig.19 illustrates the results of all boreholes drilled on the Roslin Glacier. The hole drilled at 1600 m was only 7 m deep (see section 4 above) since two of the drill extension rods were broken and had not been repaired at that time. Furthermore the time interval was only 7 hours and so the true reading should possibly have been slightly lower.

The apparent departure from linearity at 950 and 1400 m holes may be due to water percolation and not variations in time intervals. The deviation is greatest at 1400 m.

The 1400 m reading

Below the firn line the ice is solid and surface melt is carried away by melt streams. Above the firn line the ice is more porous and surface melt may percolate through the ice thereby raising the ice temperature. The firn line was well below the 1400 m hole and some difficulty was experienced in obtaining an apparently dry hole in the wet firn. Previous to obtaining an apparently "dry" hole several frustrating attempts were terminated when holes became wet.

Comments

(i) Melt streams only occurred below 1500 m.

(ii) 1 g of water at 0°C when freezing to ice @ 0°C will cause the temperature of 160 g of ice to increase by 1°C. (ref 15)

8. Lapse rate correlations

Fig. 19 also indicates that the ice temperature variation is similar to the saturated adiabatic lapse rate. This suggests a very damp climate over the ice surface and meteorological measurements show high humidity values, see vol. II.

Extrapolation of experimental results indicate that the temperature at sea level is approximately 8°C warmer than the mean annual temperature of -10°C recorded at Mesters Vig. However the Roslin is about 60 km inland but it is subjected to winds that blow off the inland ice-cap. It is worth noting that Müller recorded the mean annual ice surface temperatures in ablation areas on Axel Heiberg island and that these temperatures were 8.5°C higher than those predicted from theory. He thought that this was possibly due to the effect of percolating melt water. (ref 14)

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15. Paterson, W.S.B. "The Physics of Glaciers". Pergamon Press 1969, p.171.

FIGURES

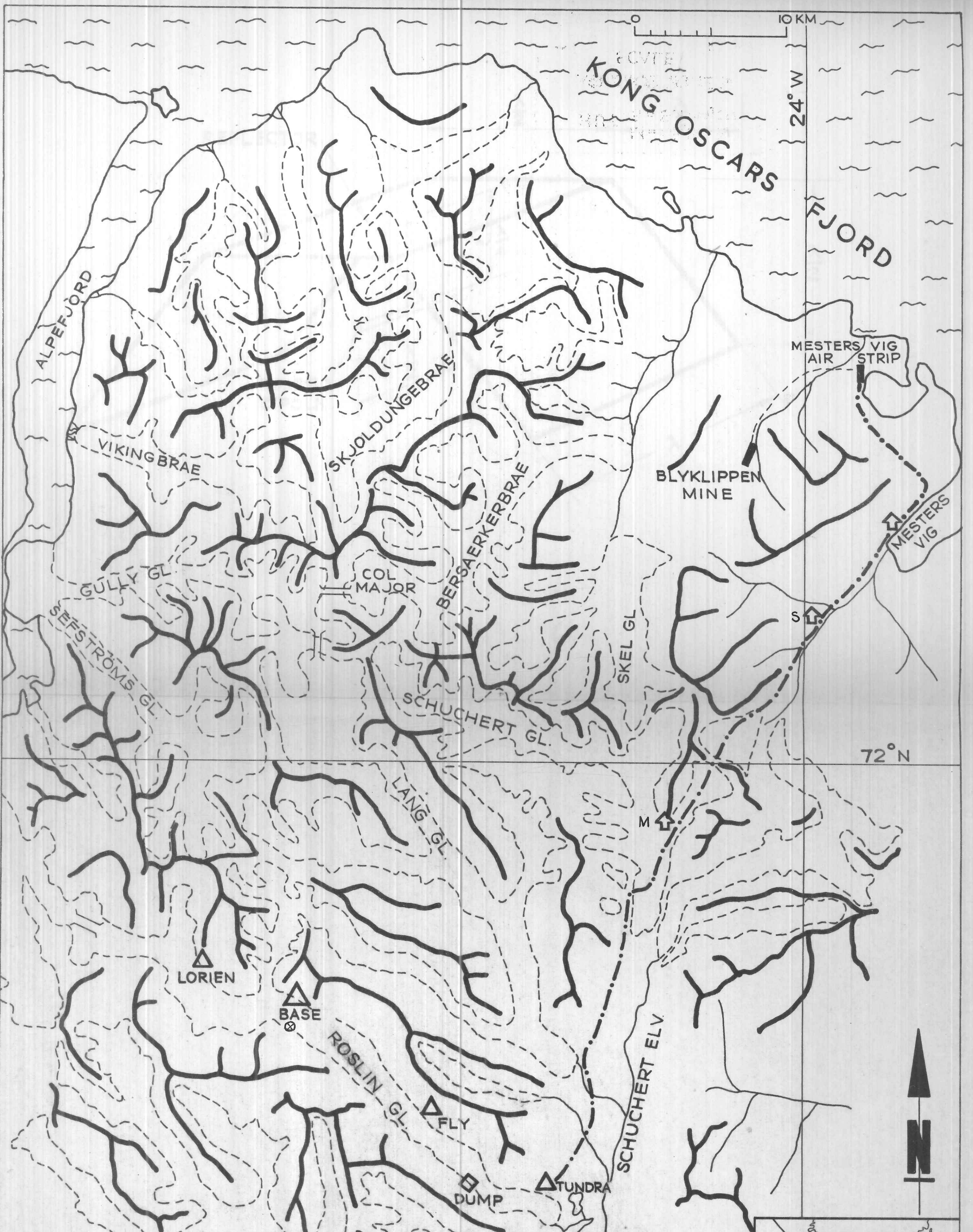


FIG. 3 THE STAUNINGS ALPS
EAST GREENLAND.

△ CAMP —·—· ROUTE OF WALK OUT

HUT M = Malmbjerg, S = Sortehjorne
⊗ AIR DROP ZONE No.1.
SCALE 0 10 km

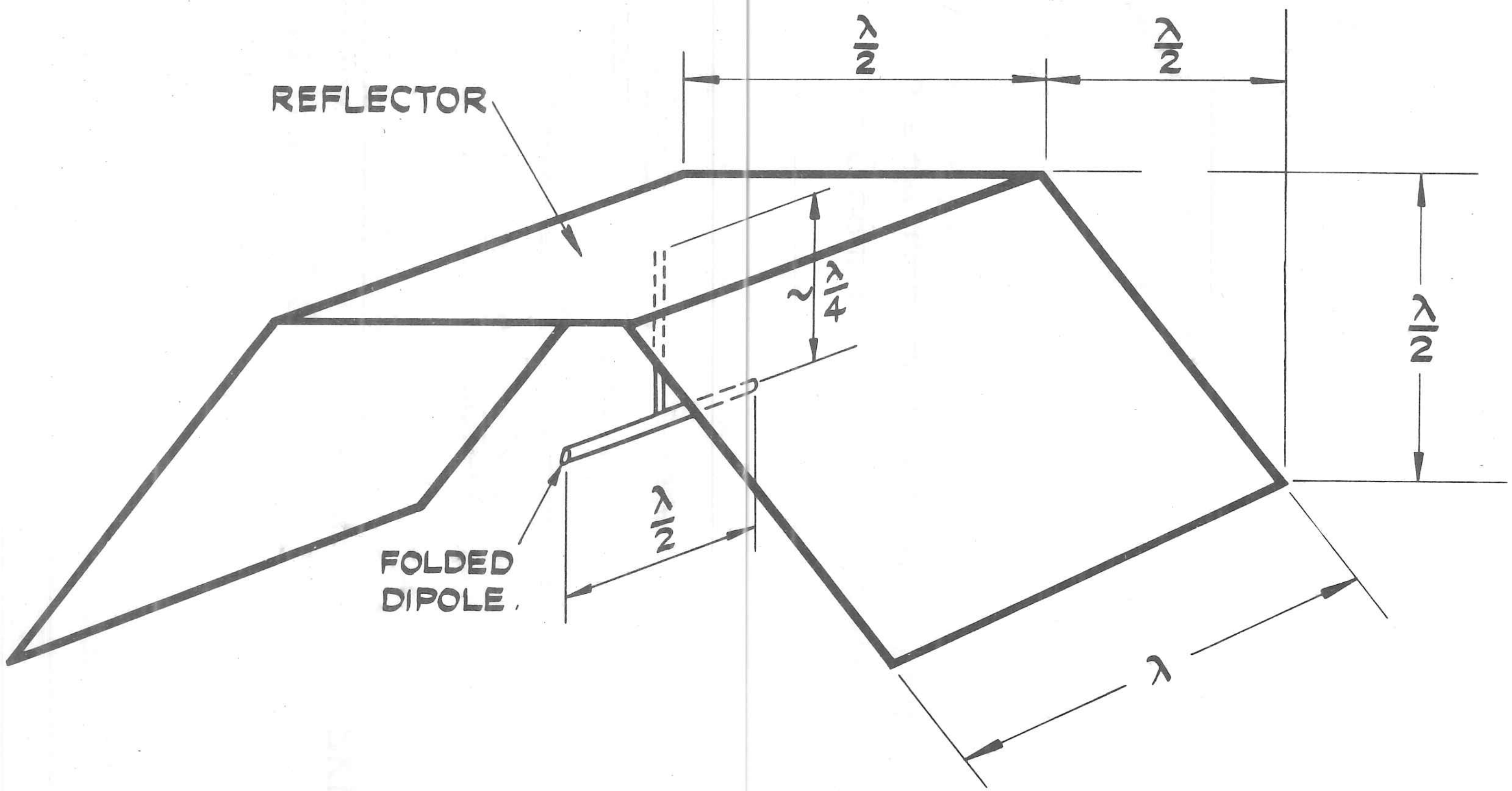
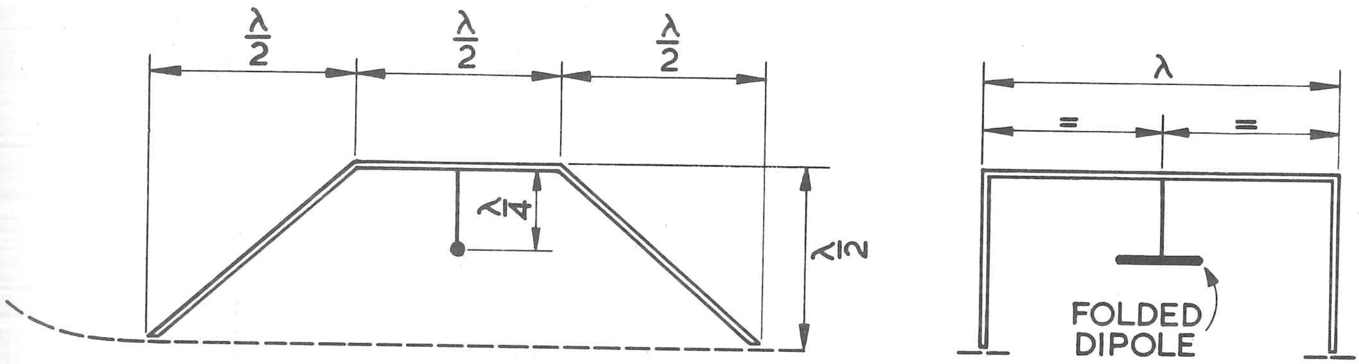


FIG. 4 TROUGH REFLECTOR.



KEY ---- SKI
λ = 2m FOR THE 150 MHz AERIAL
(λ = 0·68m FOR THE 440 MHz AERIAL, SEE FIG 6)

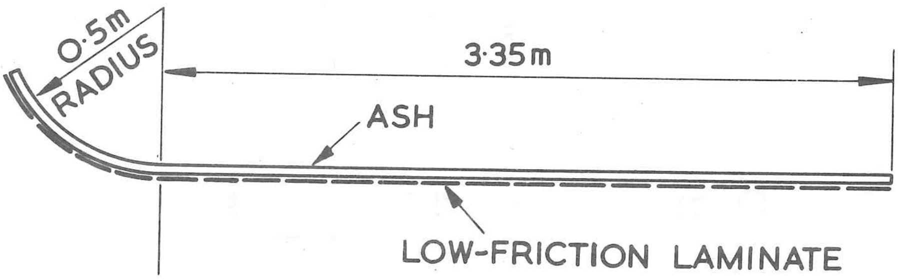
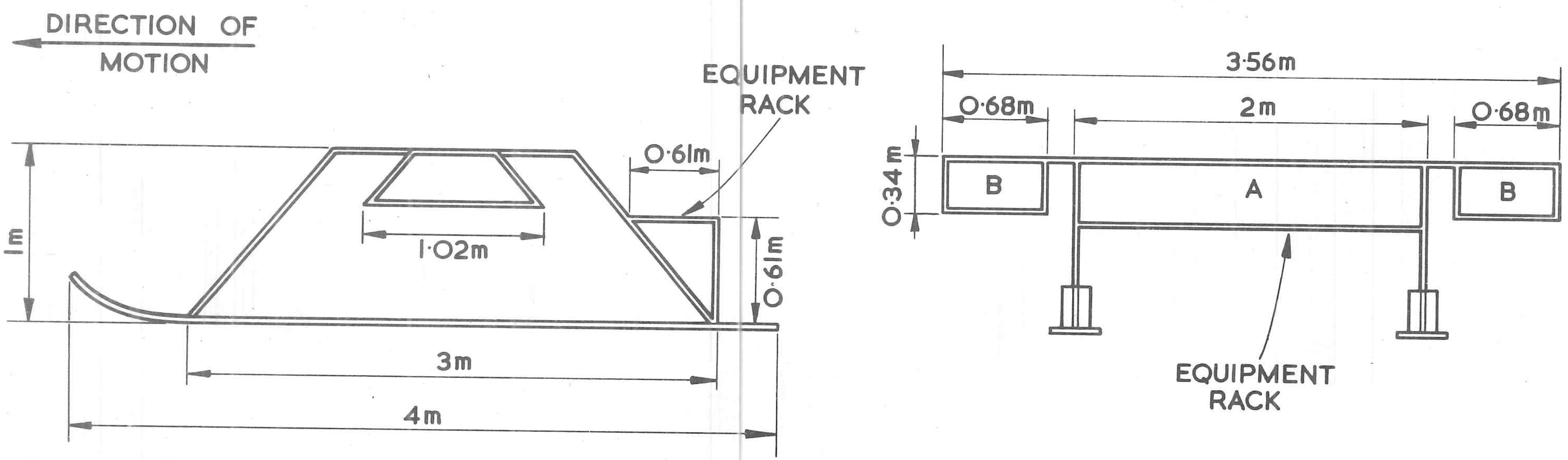


FIG. 5. BASIC TROUGH AERIAL AND SKI DESIGN
(see also FIG 6)



KEY. A AERIAL FOR THE 150MHz INSTRUMENT
B AERIALS FOR THE 440MHz INSTRUMENT

NOTES:- (1) FOR THE SAKE OF CLARITY, ALL BRACING MEMBERS HAVE BEEN OMITTED.
(2) NO METAL BRACING IS PERMITTED INSIDE THE VOLUME OF THE AERIALS.
(3) WEIGHTS; STRUCTURE 1,000N (225lbf); GENERATOR, BATTERY AND FUEL 533N (120lbf); ELECTRONIC RECORDING EQUIPMENT 555N (125 lbf).

FIG. 6 BASIC SLEDGE DESIGN. (see also FIG. 5)

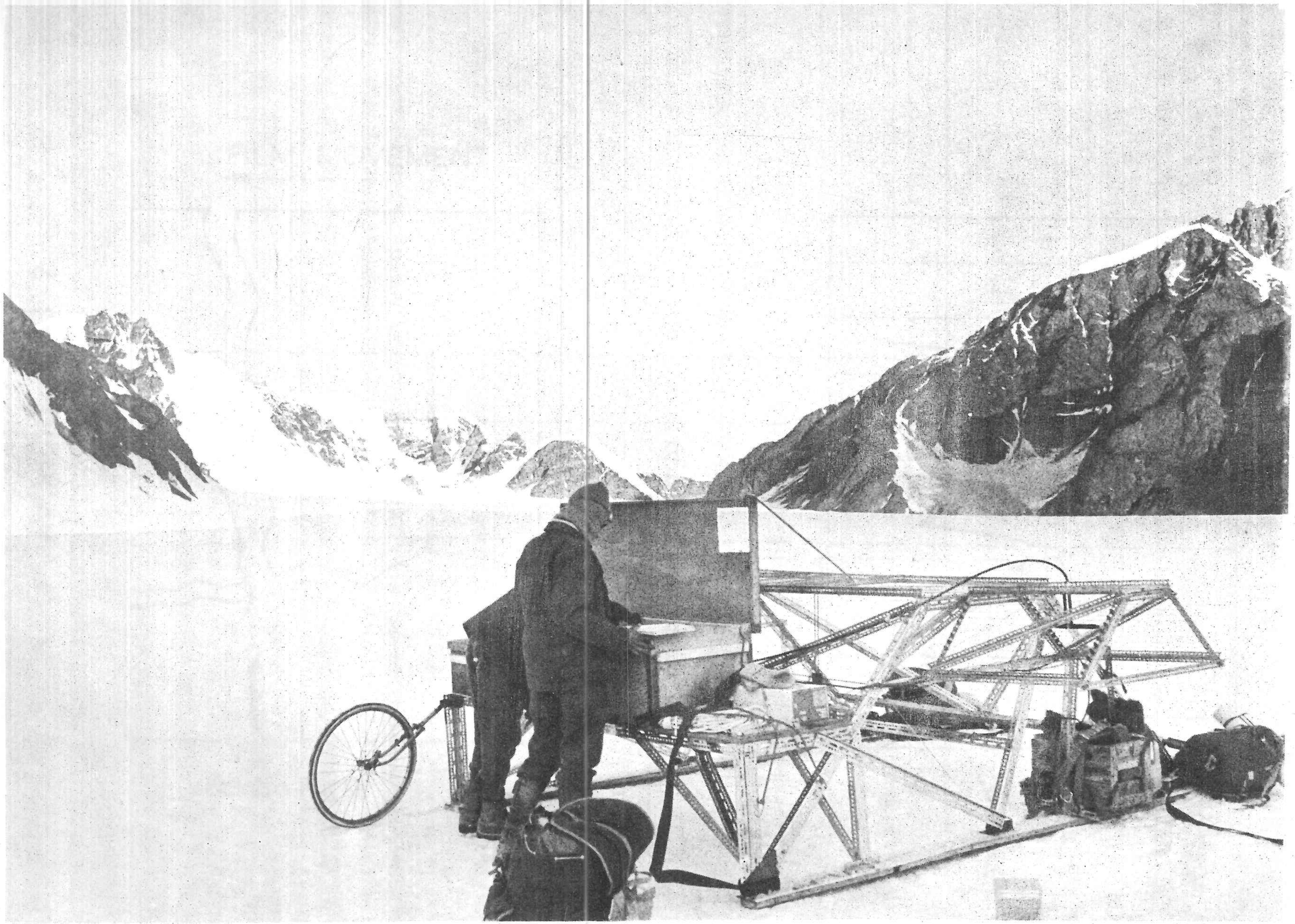
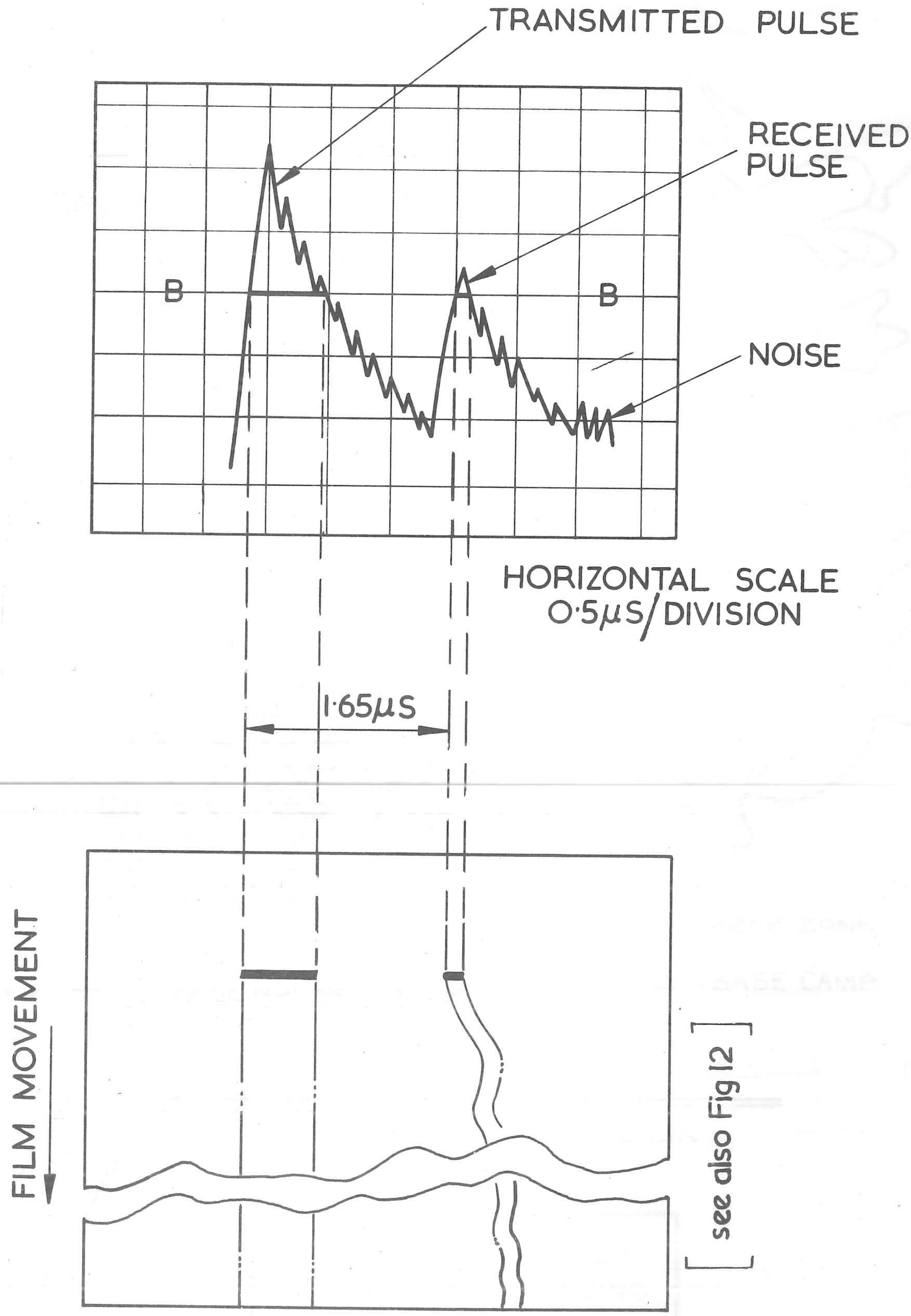


FIG. 7 THE SLEDGE ABOVE CAMP LORIEN

A-TYPE DISPLAY



Z-TYPE DISPLAY

FIG. 8 OSCILLOSCOPE DISPLAYS

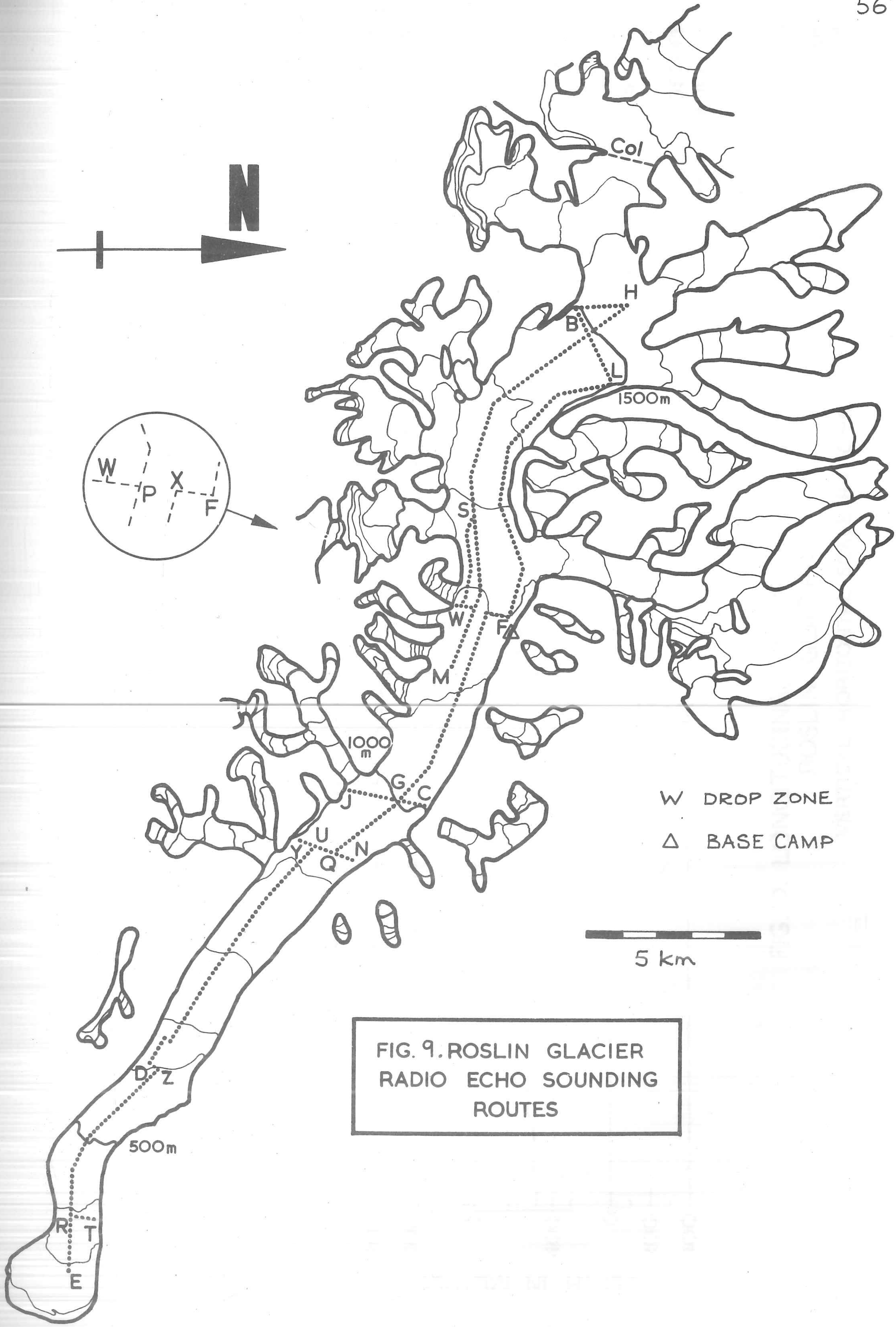


FIG. 9. ROSLIN GLACIER RADIO ECHO SOUNDING ROUTES

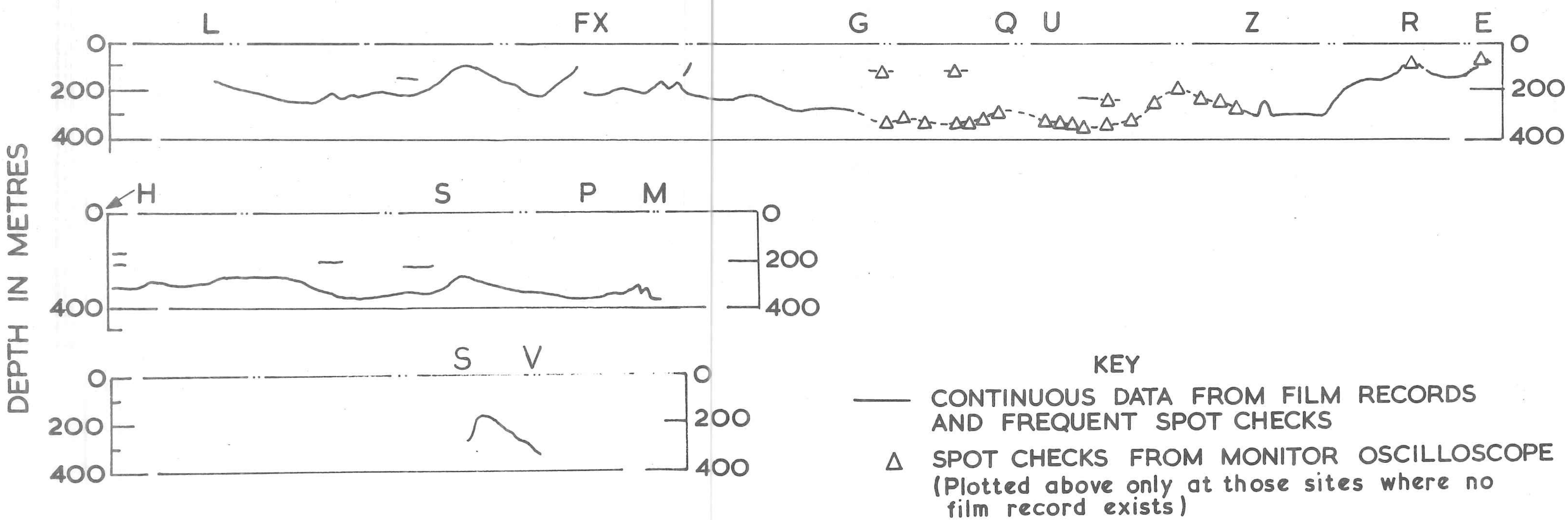
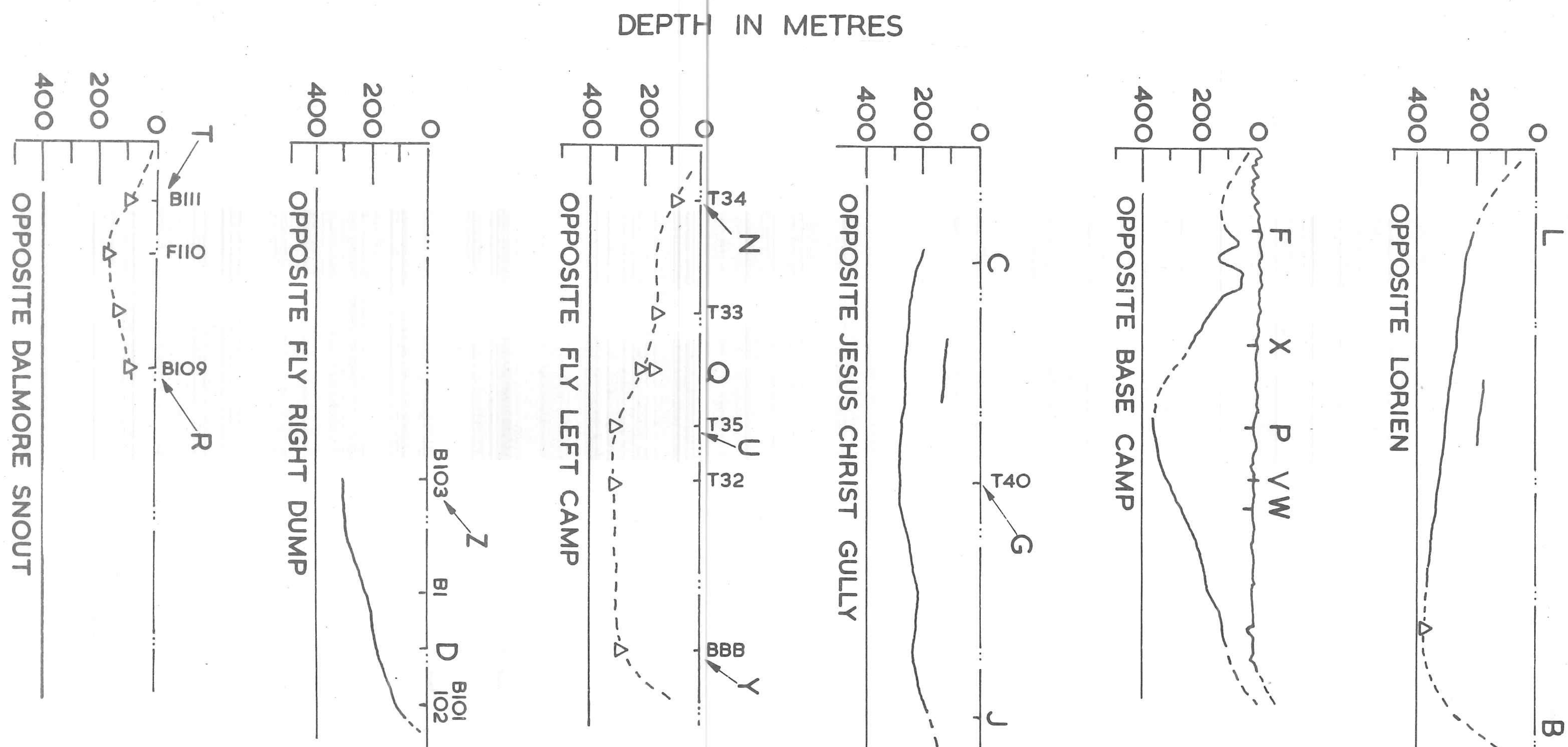


FIG. 10. LONGITUDINAL PROFILES OF THE ROSLIN GLACIER

VERTICAL : HORIZONTAL SCALE RATIO ~ 5:1



KEY

—— CONTINUOUS DATA FROM FILM RECORDS AND FREQUENT SPOT CHECKS

Δ SPOT CHECKS FROM MONITOR OSCILLOSCOPE

FIG. 11 TRANSVERSE PROFILES OF THE ROSLIN GLACIER : LOOKING DOWNSTREAM

VERTICAL : HORIZONTAL SCALE RATIO 1:1

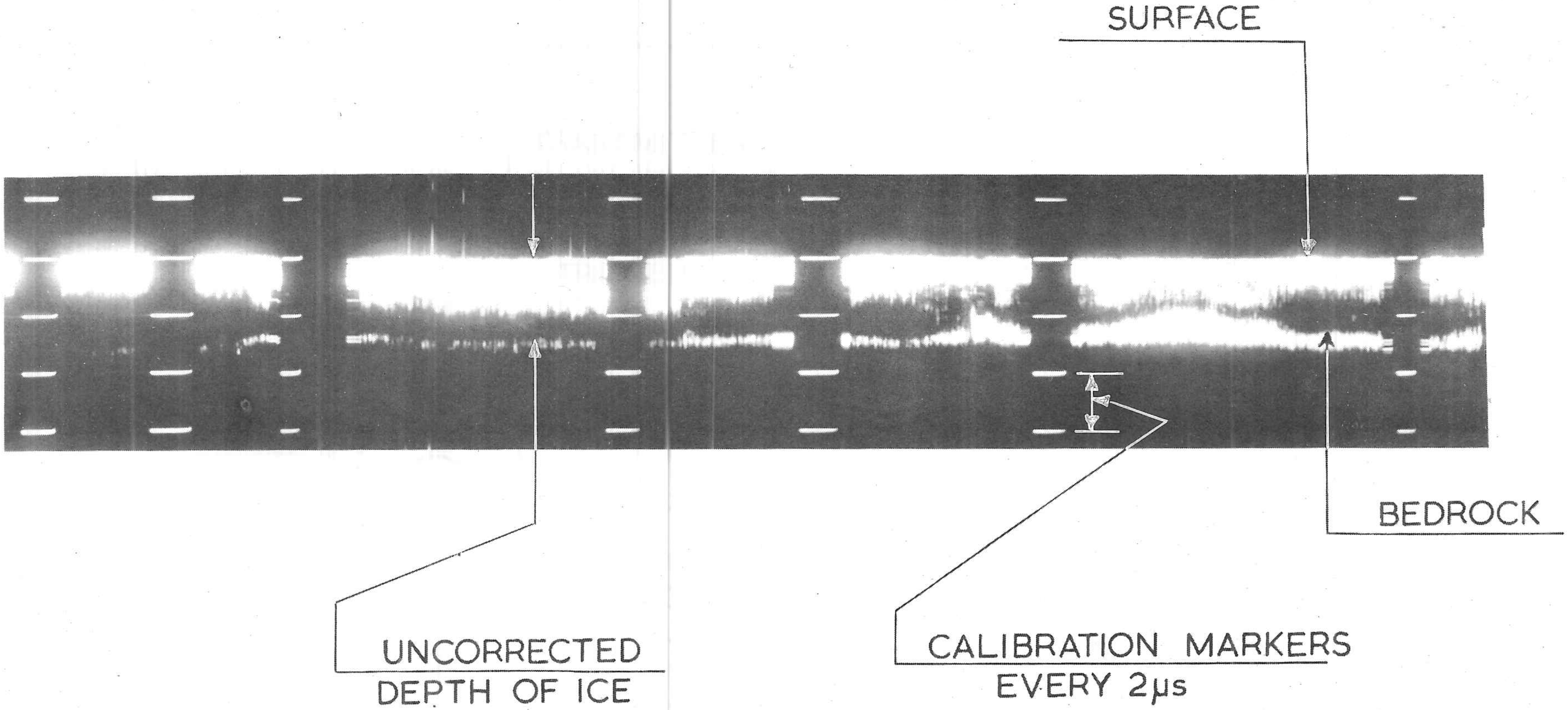


FIG. 12 A TYPICAL FILM RECORD OF ICE DEPTHS

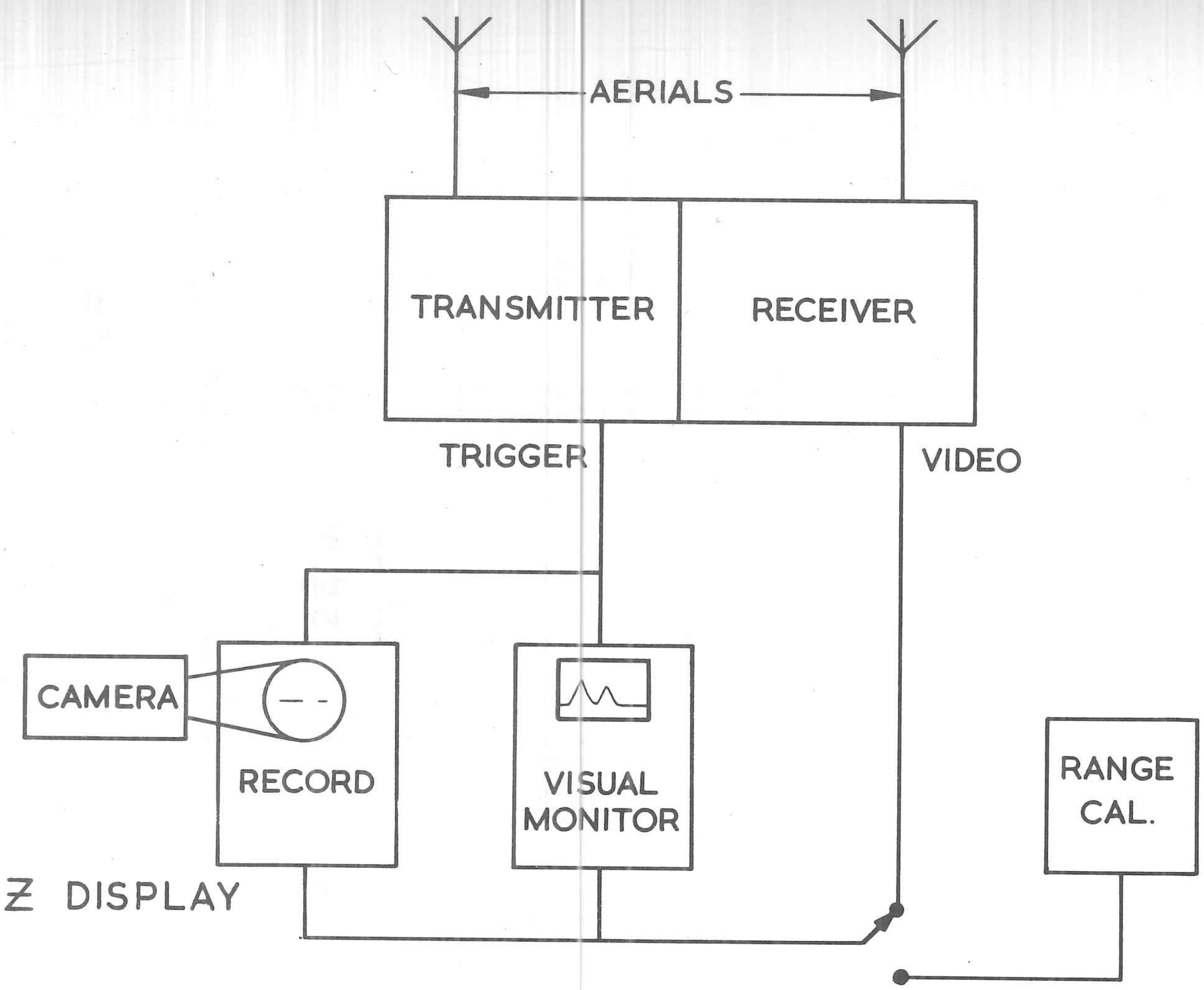
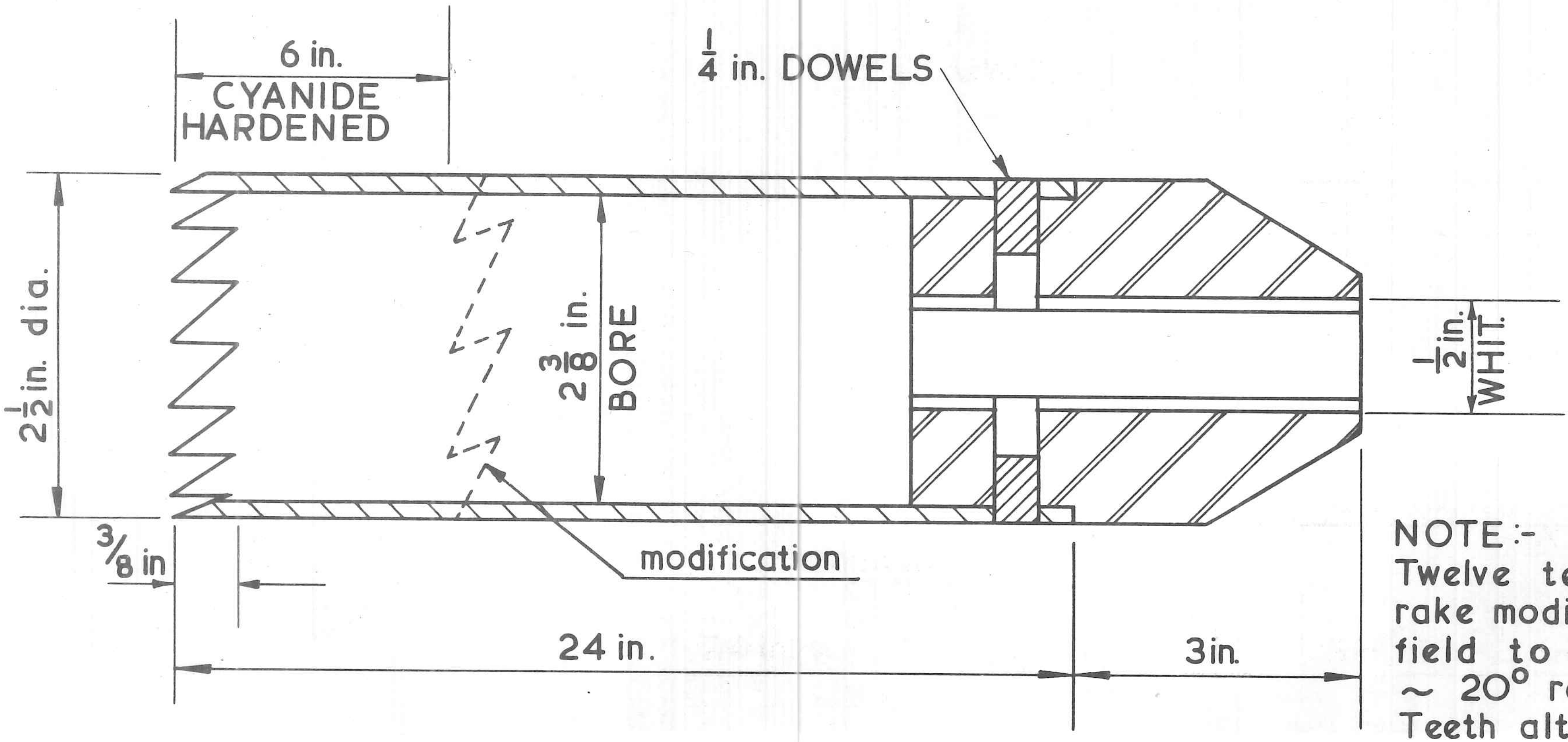


FIG. 13. LAYOUT OF RADIO ECHO SOUNDING EQUIPMENT



NOTE:-
Twelve teeth of zero rake modified in the field to six teeth ~ 20° rake.
Teeth alternately flared.

ALSO:- 1m EXTENSION RODS $\frac{3}{4}$ in. DIA. — 10 off.

Not to scale.

FIG. 14. THE CORER.

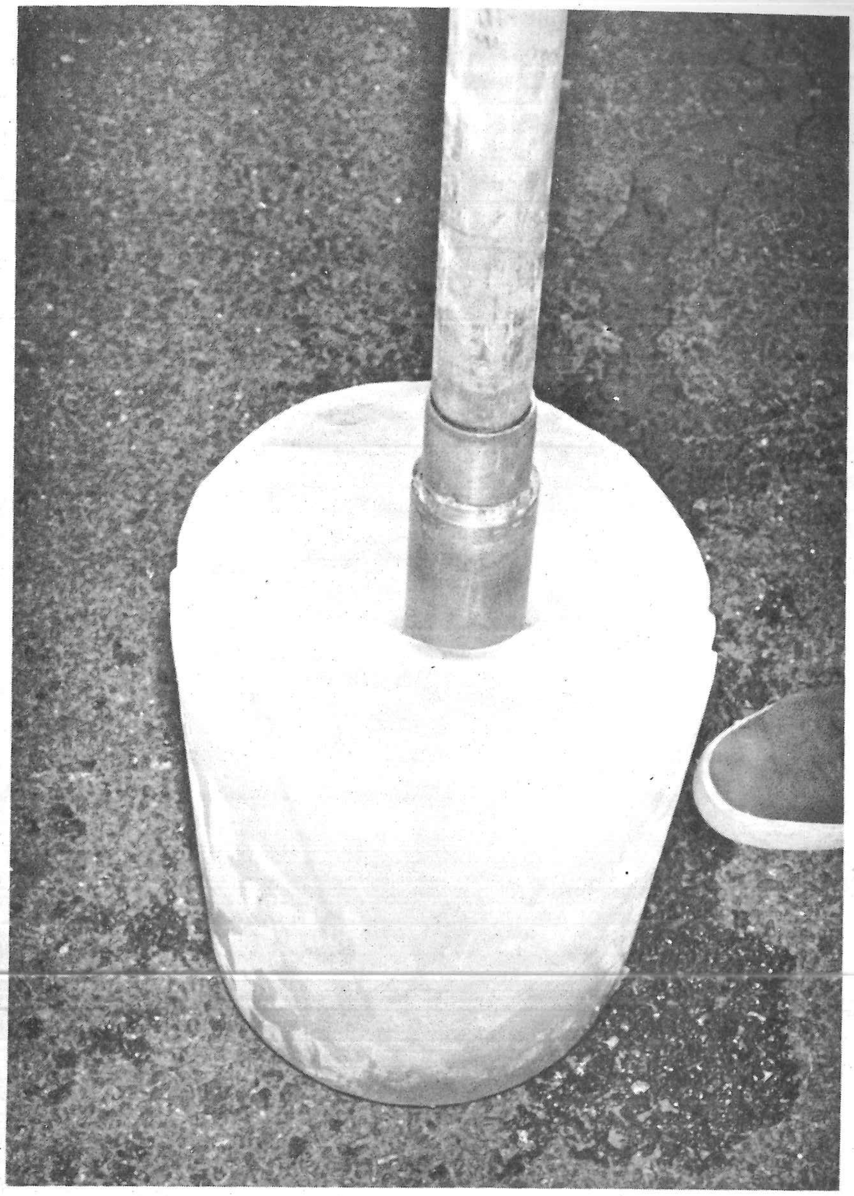


FIG. 15 THERMAL DRILL IN A 12 INCH

DIAMETER ICE BLOCK

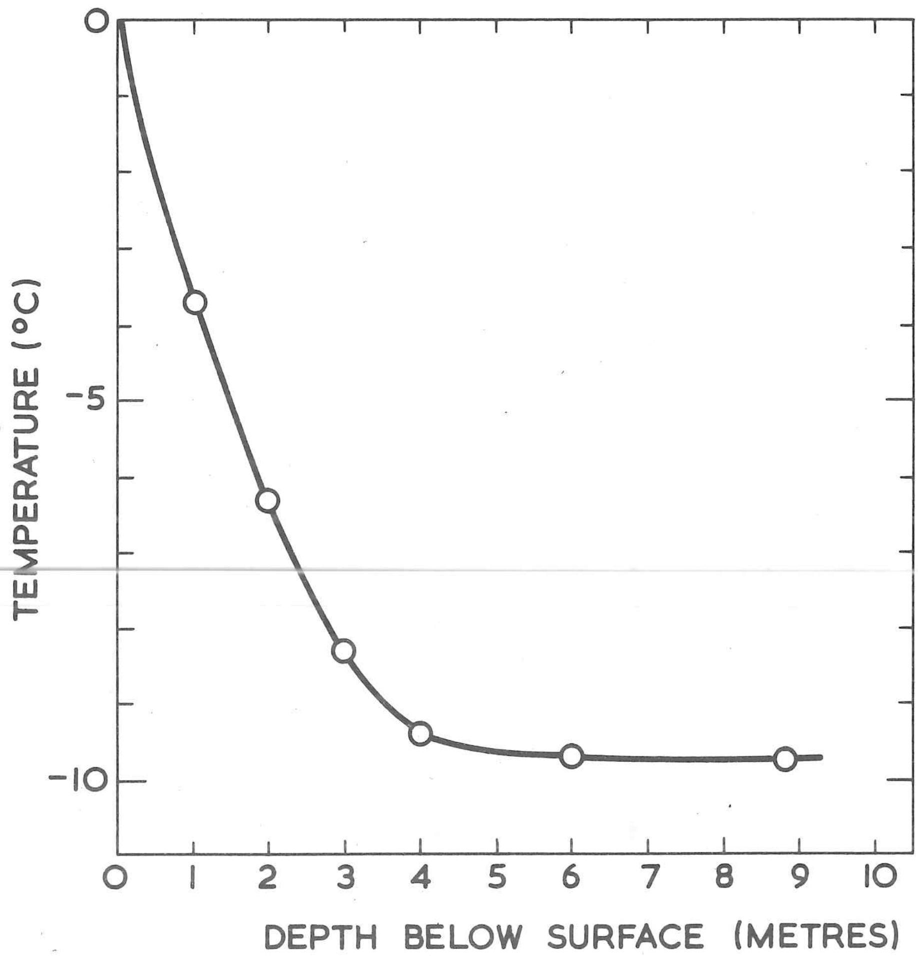


FIG. 16. VERTICAL TEMPERATURE PROFILE BORE HOLE No. 1, ELEVATION 1200m.

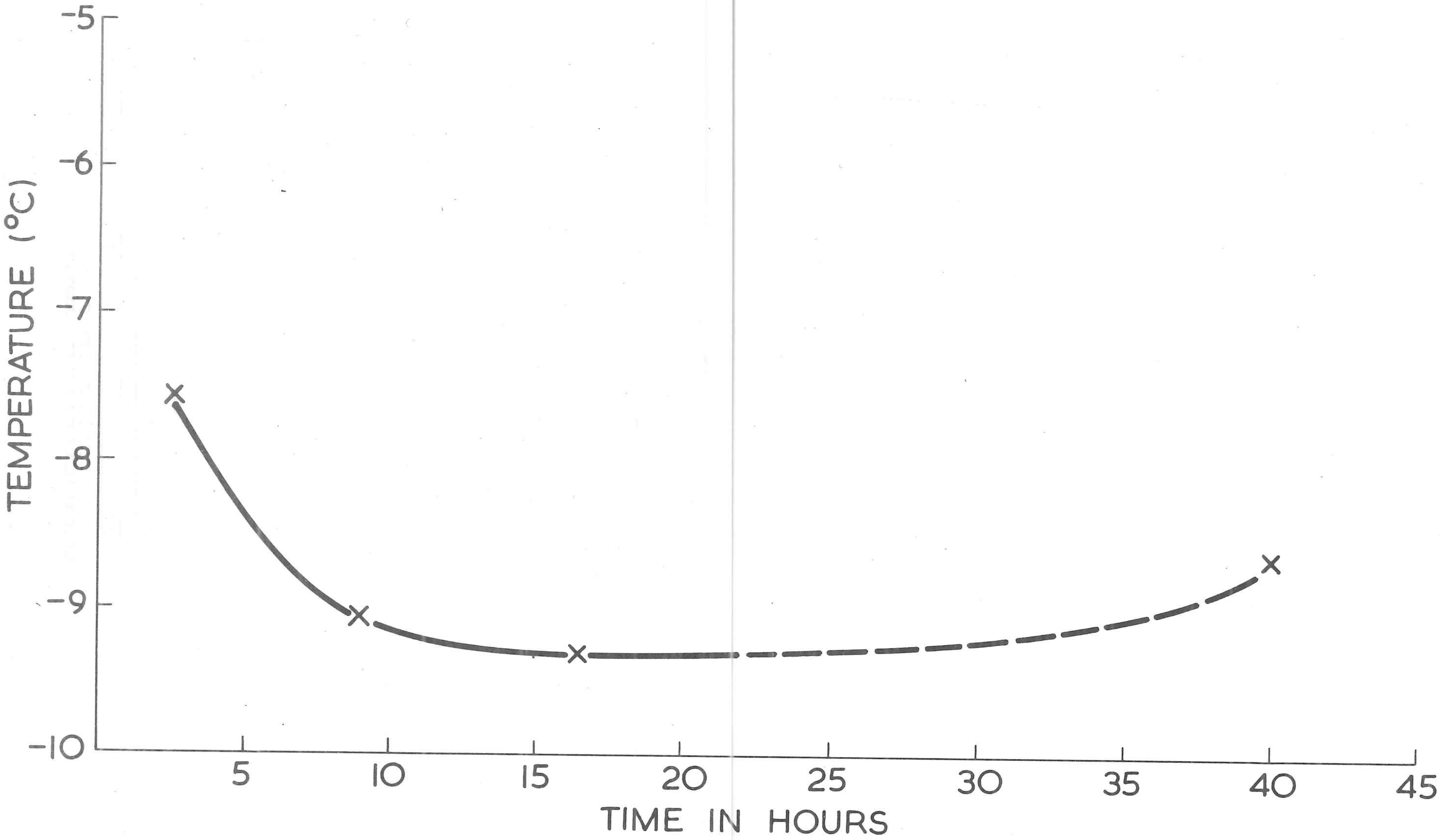


FIG. 17 TEMPERATURE READINGS AGAINST TIME.

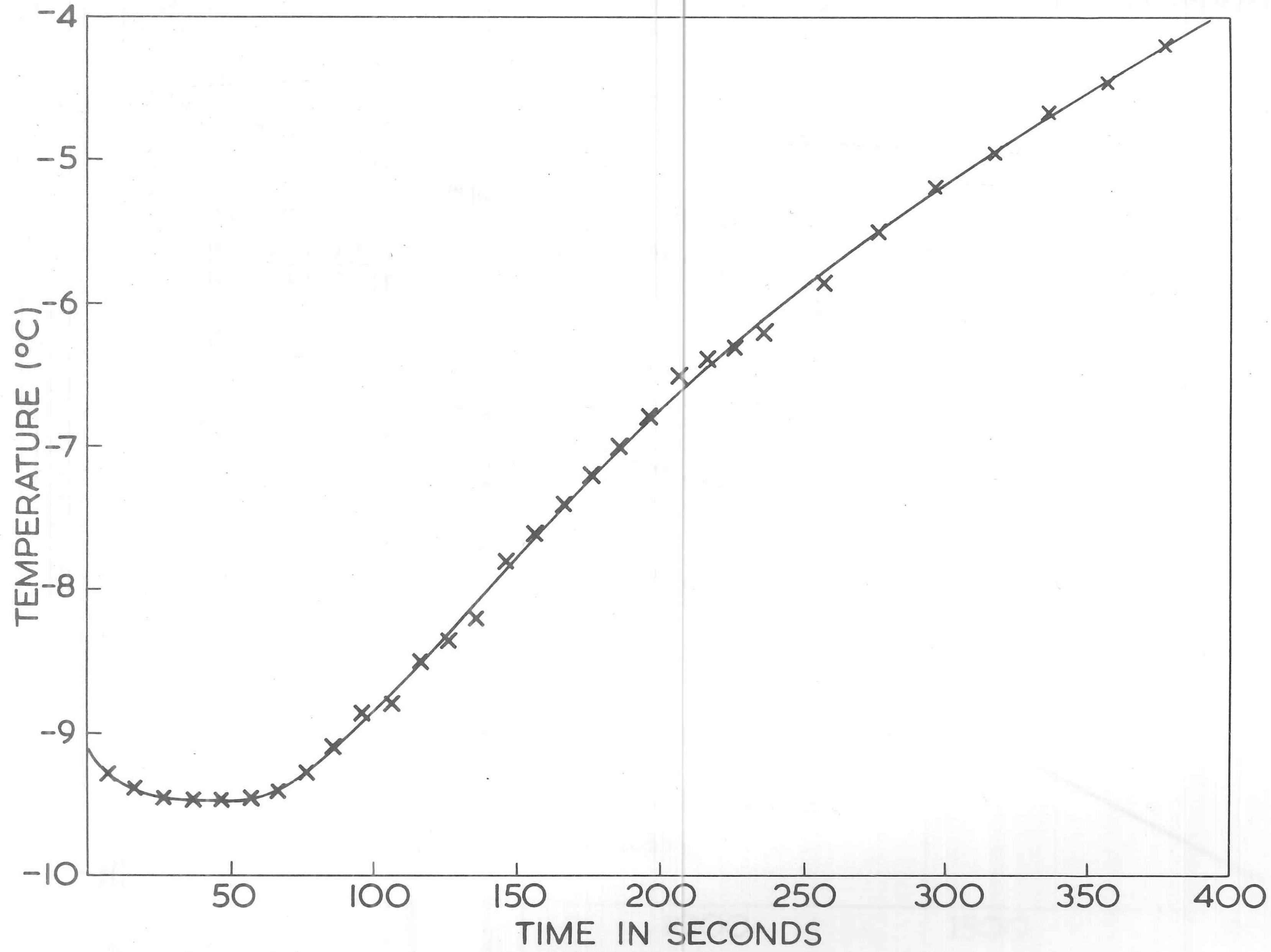


FIG. 18 RECOVERY OF THERMOMETER READING TO SURFACE CONDITION AFTER WITHDRAWL (ambient air temperature + 2°C)

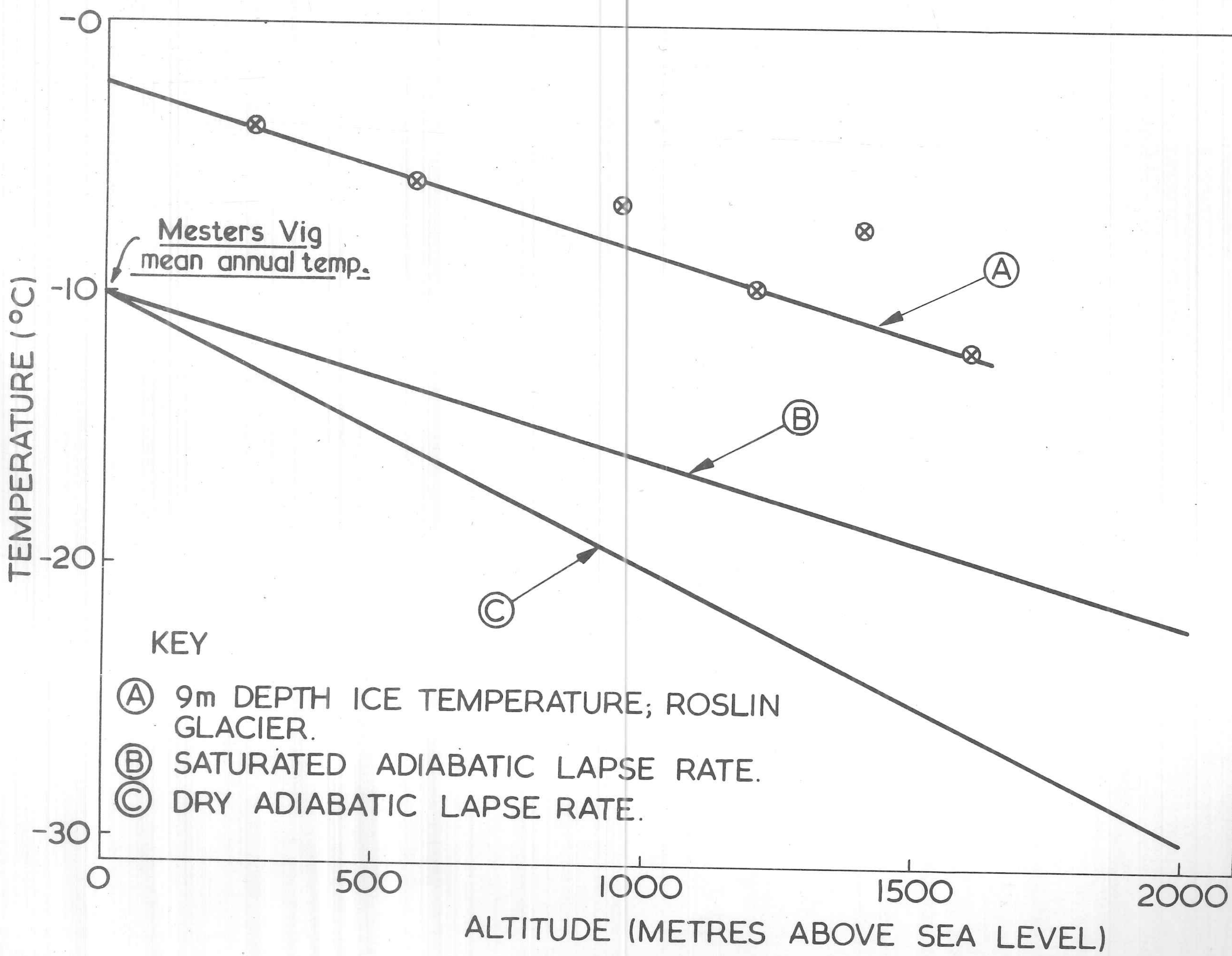


FIG. 19. **TEMPERATURE VARIATIONS WITH ALTITUDE**