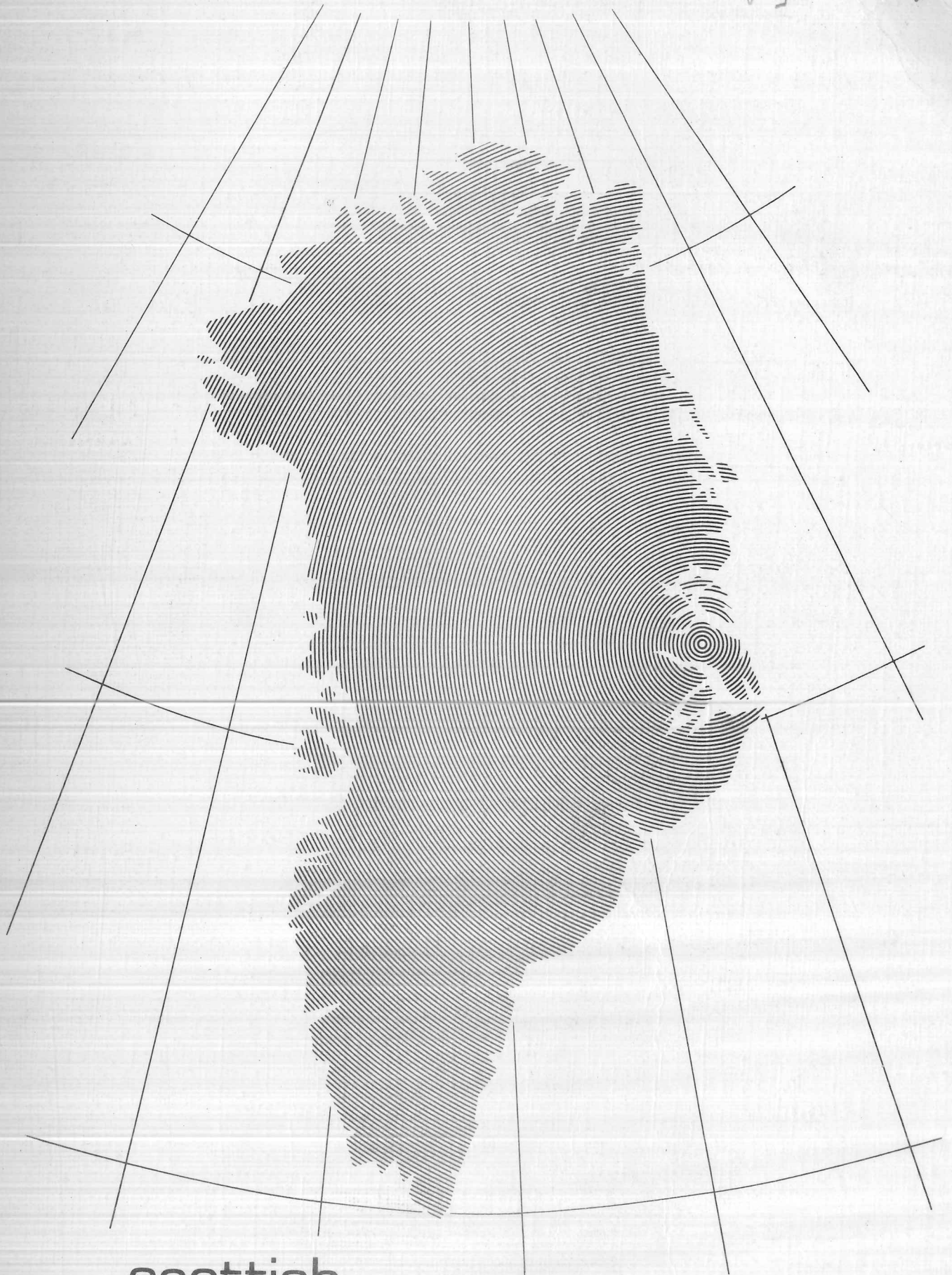


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scottish  
scoresby land expedition  
1975

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REPORT

of the

SCOTTISH SCORESBY LAND EXPEDITION 1975

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Dept. of Biology, University of Dundee (Price £2.00)



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## 1.0 INTRODUCTION

Scoresby Land lies between latitudes  $71^{\circ}20'$  N and  $72^{\circ}30'$  N on the East Coast of Greenland, and contains the spectacular mountain range of the Stauning Alps. It forms the landward part of the large and prominent peninsula lying to the north of Scoresby Sund and its inner arm Nordvest Fjord, the world's largest fjord system.

Scoresby Land is bounded to the north by Kong Oscars Fjord and Alpefjord, while its eastern margin is marked by the broad, flat Schuchert valley, with its impressive and dangerous braided river, beyond which, to the east, lie the low hills and rolling tundra of Jameson Land. Westwards, the peaks merge gradually into the vast expanse of the Inland Ice which covers ninety per cent of the country.

In the 1950's and 60's, intensive exploration of the North and Central Stauning Alps was carried out by both mountaineering and scientific expeditions from several countries. The southern part of the region, however, received little attention owing to the greater difficulties of access. During the Dundee University Scoresby Land Expedition of 1970, a seven man party which included Anthony Walker and John Peden, made a traverse of the south-east Staunings. Unfortunately, poor weather, logistic problems and a shortage of time prevented any ambitious exploration or mountaineering, but Walker and Peden resolved to return to the area to carry on the exploration and scientific work of that expedition.

The region is one of outstanding beauty and grandeur with its network of deep and dark fjords, embellished with countless glittering icebergs, its sinuous glaciers carving their way between spectacular rock spires and snow-capped peaks, and its myriads of brightly coloured tundra flowers carpeting the low ground. During the long summer days, settled anticyclonic weather is the norm giving clear blue skies, light winds and extraordinary atmospheric clarity. It is with good reason that the area has been dubbed the "Arctic Riviera", and perhaps understandable that it casts a spell of addiction over many who visit it.

The following report records the organisation, activities and achievements of the Expedition and will we hope, be of interest to our many sponsors, without whose help the expedition would not have been possible. We have described the organisation in some detail, as this is the key to the success of such a venture, and in the hope that the information will be of value to prospective visitors to this magnificent part of the world.



FIG.1. SCORESBY LAND

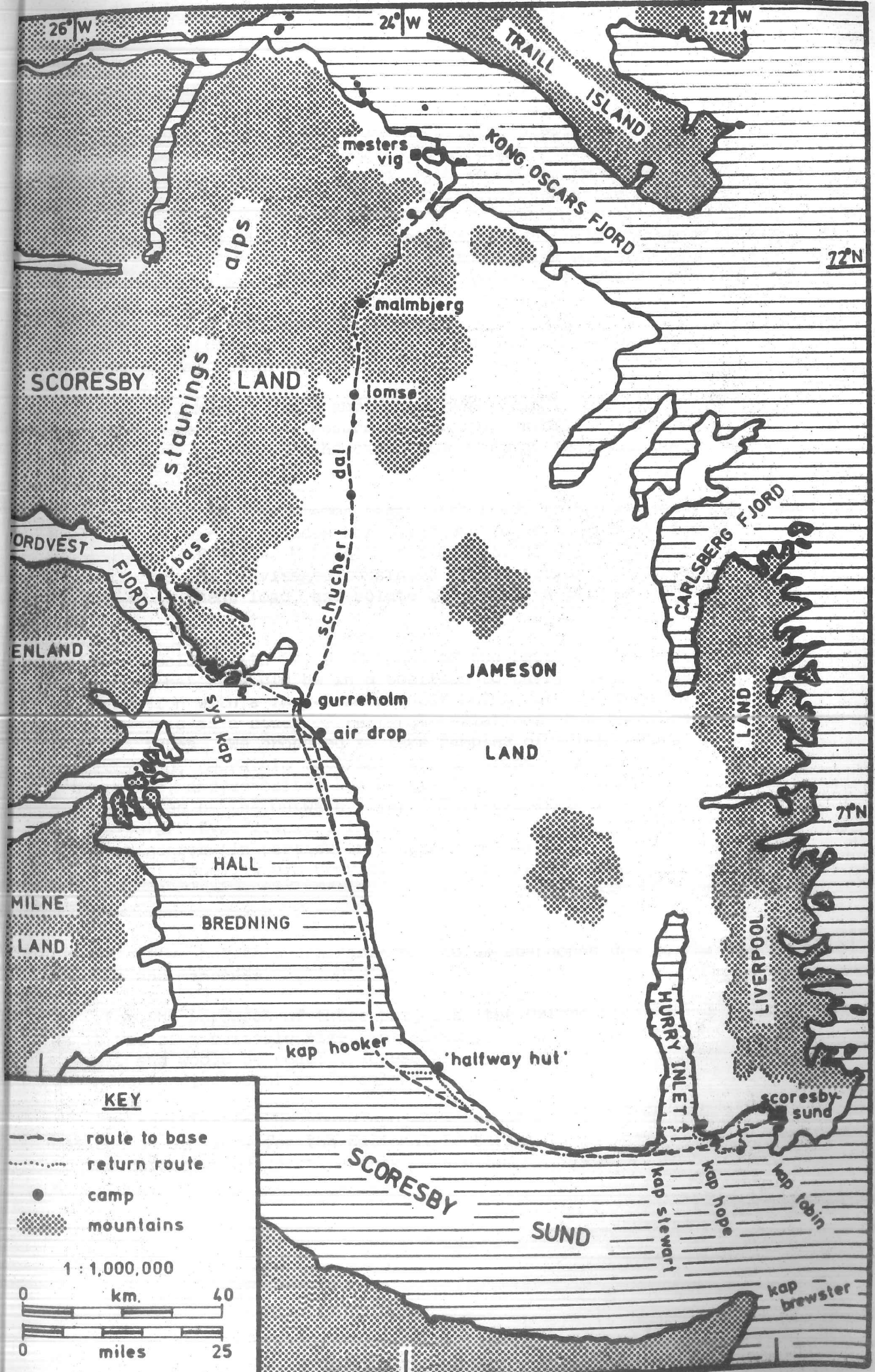
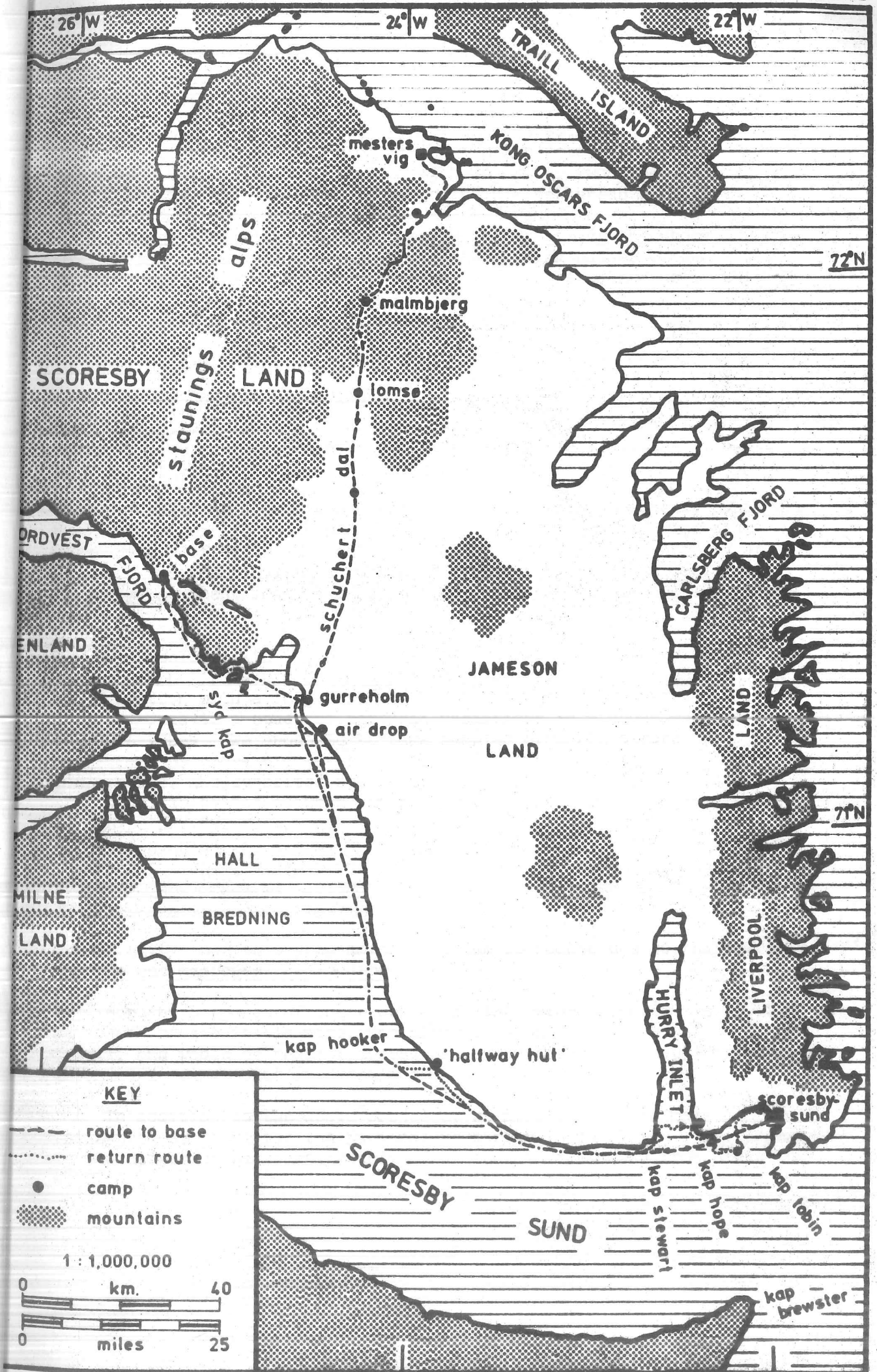


FIG.1. SCORESBY LAND





## 2.0 OBJECTIVES

The expedition was based on three main objectives. Firstly, we wished to continue the areas of field-work and research initiated by the Dundee University Expeditions, with which the two Dundee graduates were familiar, and to expand these to include new areas of interest.

Secondly, we wished to spend some time exploring the upper Oxford, Neptune and Jupiter Glacier systems, establishing passes between them. We also hoped to make a number of first ascents of mountains in this area. As we were not sure how much time would be available, our mountaineering plans were left somewhat vague, and although we had noted three impressive rock spires to the east of the Oxford Glacier in 1970, no particular mountain objectives were predetermined.

Thirdly, Messrs Peden and Walker were keen to assuage their thirst for the Arctic following recurrent bouts of "Arctic Fever", while the remaining two members of the expedition were no less willing to contract that infectious disease!

Our scientific programme began with the hydrology project. This was based on the earlier Dundee work, and was to be conducted with the co-operation of Mr. W. McNicoll of the Dept. of Civil Engineering at Dundee. The work envisaged consisted of monitoring the variation in discharge, sediment load, and solute content of a glacial outwash river, and examining the results.

Discussions with Dr. J. McManus of the Dept. of Geology at Dundee suggested that we would be in a position to carry out much useful work in connection with a long-term project being run by himself and Dr. A. Buller. This is a study of textural variations in a broad range of sediment types. We proposed to take samples of scree before englacial; morainic material both in transit on and within the glacier ice, and deposited by the glacier; and sediments suspended in and deposited by the outwash river. This examination of sediments for a "Sub-polar" type glacier, in addition to furnishing data for the Dundee research (in particular a comparison with the better documented "Temperate" type), would provide us with an interesting self-contained project.

We had also proposed to carry out a study of glacial regime and ice velocity, but this programme had to be abandoned due to the shortage of time and manpower.

For the purposes of these projects, the Oxford Glacier was ideal, as it was of a suitable size, was already known to provide safe and easy travel, and would be readily accessible by boat from Scoresbysund, our intended landing point in Greenland.

In addition to the above projects, we also planned to make a collection of flora for the National Herbarium in Edinburgh. Dr. Argent of the Herbarium was particularly interested in specimens from higher altitudes, and this fitted in well with our mountaineering proposals.

### 3.0 PLANNING & ADMINISTRATION

#### 3.1 General

Around 1972, Walker and Peden conceived an outline plan for the expedition, which appeared to offer no great logistic or other barriers to its successful accomplishment. The bulk of the food and equipment would be shipped by icebreaker to Scoresbysund, then the personnel would fly in to Scoresbysund and travel to Nordvest Fjord by inflatable boat. Return would be an exact reversal of the outward journey. Four was considered to be the ideal number for the expedition, being the smallest safe and efficient unit.

Douglas Anderson, a keen and ambitious expedition man, was invited to join the group. In addition to various other more successful ventures, he had previously visited East Greenland with the vague notion of a solo crossing of the ice-cap in mind. Perhaps fortunately, this plan did not reach fruition.

In our fourth member, Brian Cornock, we acquired a tower of strength. He had a gift for solving all those problems abandoned by the rest of us as insoluble, and having spent two years in Antarctica with B.A.S., he had patience and diplomacy down to a fine art.

The expedition's long gestation period did not finally end until January 1975, when detailed organisation began. All who have experience of planning such a venture will appreciate that six months is precious little time in which to make all the necessary arrangements. Nevertheless, despite a fair sprinkling of the usual "insuperable" problems, somehow all was completed in time and we left Scotland on the appointed date.

#### 3.2 Permission

Greenland is a sovereign state of Denmark, whose government exercises control over prospective expeditions. Permission must therefore be obtained from the Ministry for Greenland in Copenhagen.

Our application was sent to the Ministry in mid-February together with details of our travel plans and scientific programme. In mid-June, barely one week before our supplies had to be dispatched, permission for the expedition was received, subject to the following conditions:

- (i) Landing at Scoresbysund not permitted, but permission to land at Mestersvig may be obtained by the airline from the Danish Civil Aviation Authorities.
- (ii) Insurance for Search and Rescue up to Dkr 100,000 must be taken out, or a bank guarantee for that amount deposited with the Ministry.
- (iii) The expedition must be equipped with a radio, and permission to import and use it obtained from the "Grønlands Teknisk Organisation" in Copenhagen. A frequency and time for a radio schedule must be established with the appropriate radio station in Greenland.

These conditions, whilst not unreasonable, caused something of a panic, because of the very limited time available to comply with them, and because of their potentially serious cost implications.

### 3.3 Safety

The safety of the expedition had been a major consideration from the earliest stages of planning, as accidents place a heavy burden on the limited resources available for rescues during the short working season of the arctic summer. It was therefore the policy of the expedition to be self-rescuing if at all possible, and contingency plans were prepared with that aim in mind.

In the event of complete failure of the boat or engine, or if the boat were irretrievably trapped in the ice, we planned to walk out. If stranded west of the Schuchert River (which should be regarded as uncrossable), we would walk out to Mestersvig, taking advantage of emergency supplies at Malmbjerg.

If the immobilisation happened east of the Schuchert, we would walk back either to Scoresbysund or to Mestersvig, depending on the distance along the coast at which the disaster occurred. An emergency food-dump at Gurreholm would be utilised if necessary.

### 3.4 Insurance

Insurance for the expedition was arranged through Endsleigh Insurance Brokers of Cheltenham Spa. Cover was provided as follows:

<u>Class</u>	<u>Sum Insured</u>	<u>Premium</u>
(a) Search and Rescue	£8,000	£240.00
(b) All Risks:		
Boat and engine	£750	
Radio	£2,000	
Scientific equipment	£550	
Camping and climbing gear	£500	£123.50
(c) ISIS Mountaineering cover:		
Death	£1,000	
Disablement	£4,000	
Medical expenses	£1,500	
Repatriation	£500	
Baggage	£200	£106.00
		<hr/>
		£469.50
		<hr/>



The Search and Rescue cover was mandatory, as stated earlier. It was also a condition of loan of some items of equipment that they should be adequately insured. Indeed, this proved to be a worthwhile investment, as some of the equipment was seriously damaged by sea water during the return to Scoresbysund.

Only the mountaineering and medical cover might have been regarded as non-essential, but it was generally felt by the members of the expedition to be a sensible precaution which, happily, was not called upon in the event.

### 3.5 Freight

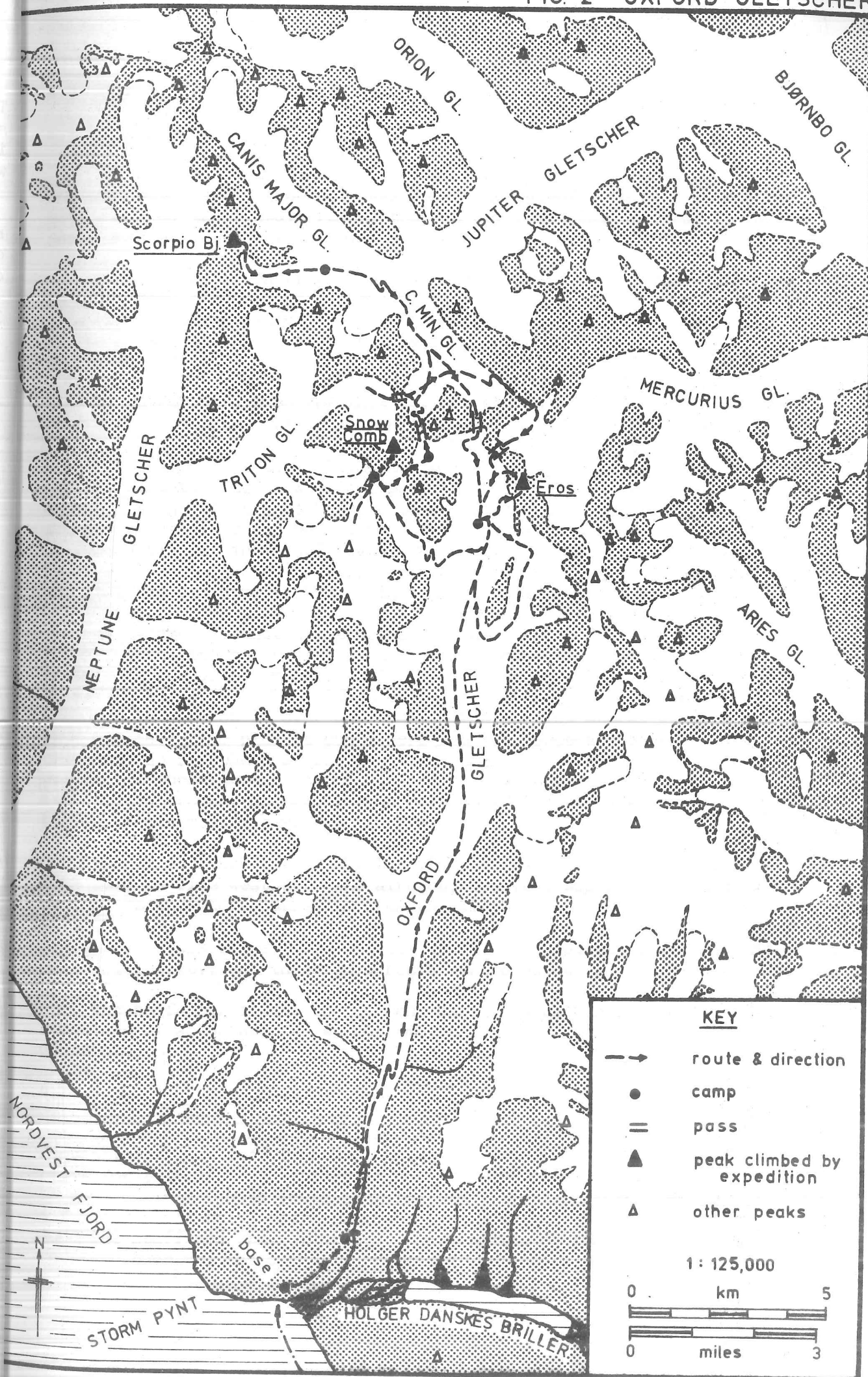
Six weeks or so before the expedition's departure, all our scientific and mountaineering equipment, our boat and camping gear, and most of the food, together with a hastily acquired radio, were sent as planned to Scoresbysund by sea, via Aalborg in Denmark.

Furness & Salvesen of Leith made the necessary arrangements for the shipping of the stores, and dealt with Customs clearances, transport to and from docks, etc.

The food, and the smaller items of equipment were packed in tea-chests, while the larger pieces were packed in a variety of home-made crates, some of doubtful quality. One of these, containing the outboard engine, burst open in transit, but fortunately nothing was lost or damaged.

In retrospect, more thought should have been given to the matter of packing, as the weight of the crates was considerable, apart from any other shortcomings. Time, however, was the ubiquitous villain.

FIG. 2 OXFORD GLETSCHER



#### 4.0 TRAVEL

##### 4.1 Outward

The refusal of landing permission at Scoresbysund caused some alarm and confusion, and although it was found subsequently to be due to the poor state of the runway, rather than to any political motives, it called for a substantial change of plan.

Our alternative approach involved an overland march from Mestersvig to Gurreholm, at the mouth of the Schuchert river, where we hoped to arrange a rendezvous with some of the Scoresbysund Greenlanders, who would then ferry us by boat the rest of the way to Scoresbysund, to rejoin our equipment.

To allow extra time for this devious approach, the party set off from Glasgow a week earlier than originally planned, on the 20th July.

We flew by scheduled flight to Reykjavik, and after spending some hours trying to track down the expedition's supplies of whisky, we arrived at the offices of Sverrir Thoroddsson, with whom the charter flight to Greenland had been arranged. There we discovered that fog at Mestersvig had inevitably delayed both the Stirling and the Cambridge University parties, and that we were third in the queue. The opportunity was taken to see some of Reykjavik and its environs.

We became somewhat concerned about the amount of equipment which had not been sent out by sea, and would now have to be carried from Mestersvig to Gurreholm in addition to food and personal gear. We therefore sorted out about 35kg. of relatively non-essential stuff and arranged to airdrop it over Gurreholm. The surplus stores were packed in a rucksack, two plastic containers and two cardboard cartons, and as there was no parachute available, each parcel was tied up with rope to prevent it bursting on impact. A larger polythene sack was tied to each to act as a drogue, so that the parcels would land right-way up, hopefully minimising damage.

We finally took off for Mestersvig in a Cessna C310 at 5.00a.m. on 25th July in fine weather. The airdrop, however, was rendered highly dubious as the whole Gurreholm area was blanketed by fog, with the exception of one short stretch of coast, which had no distinctive landmarks to assist later identification. Nevertheless it offered the only possibility, and the five parcels were ejected in quick succession.

The half-hour flight up the Schuchert towards Mestersvig was something of a torture, as we contemplated the four-day walk back to Gurreholm.

##### 4.2 Within Greenland

On our arrival at Mestersvig, we sent cables to Scoresbysund, requesting a boat lift from Gurreholm. After waiting in vain for a reply for 36 hours, we decided to set off for Gurreholm, expecting to get confirmation en route at Malmbjerg, two days away. Following a further day's wait there, where we were splendidly entertained by Nordmine staff and their families, confirmation of the boat lift was received over the radio and we proceeded with renewed confidence.



The tedium of the slog down the Schuchert valley was relieved for a while for two of the party, by a somewhat hair-raising trip down the river on a home-made raft. This utilised four oil-drums from the derelict hut at Lomsø, and worked well in the vicinity of the Roslin snout, where the flow is constricted. A family of musk-oxen, grazing quietly amongst the moraines by the river, looked up in astonishment and then fled as the apparition clattered towards them through the rapids. Lower down, however, in the maze of braided channels and sand-bars, the vessel's draught proved too great, and it was reluctantly abandoned.

The 125km. walk from Mestersvig to Gurreholm took a leisurely five days, and we had to wait a further two days for our lift to Scoresbysund. The 165km. speed-boat journey took eight hours with two stops, and although initially exhilarating, soon became miserably cold and wet. It also turned out to be expensive, as in addition to the rates being higher than we had expected, Danish regulations insist that Greenlander boats never travel unaccompanied. We therefore had to have two boats, and of course had to pay for both the outward and return journeys.

Thus the journey from Glasgow to Scoresbysund, which had originally been planned to take one or two days eventually took fourteen. It is possible that, had we arrived in Mestersvig at the appropriate time, we might have been able to take advantage of one of the infrequent scheduled flights to Scoresbysund.

Once reunited with its equipment, the expedition travelled by inflatable boat back up Scoresby Sund and on up Nordvest Fjord to the base camp at Storm Point, near the mouth of the Oxford river. From there, all sorties were made on foot, with skis invariably being used above the snow-line.

#### 4.3 Return

When we had eventually arrived at Scoresbysund, we were informed by the Trade Commander that the airstrip had recently been inspected, and was fit for use. We therefore cabled the charter company to collect us there in September, thus saving the walk back to Mestersvig. That the runway was useable was confirmed by Brian, who holds a Private Pilot's licence.

On returning to Scoresbysund, we received a variety of messages which indicated that we would be met at Mestersvig the following day. As this was clearly impossible, we cabled Iceland. Then on 5th September, after seeing all our equipment off on the last supply boat of the year, we waited in hope at the Scoresbysund airstrip, as originally arranged. We were pleasantly surprised and greatly relieved when our pilot duly arrived.

It was not until we returned to Reykjavik that we learned of the difficulties that Sverrir Thoroddsson had experienced in obtaining permission to land at Scoresbysund. Apparently this runway is now classified as "unsafe" by the Danish Civil Aviation Authority, and it would seem that landing permission will be granted only in exceptional circumstances, or perhaps after applying a great deal of pressure. Furthermore, Thoroddsson has indicated that he would land there again only in an emergency. Future travellers should therefore be warned that Scoresbysund airstrip appears now to be officially closed to charter flights from Iceland.

The regular Icelandair flight home to Glasgow seemed mundane by the rest of our travel arrangements.

## 5.0 HYDROLOGICAL OBSERVATIONS ON THE OXFORD GLACIER MELT WATER RIVER

A. Walker and J. Peden

### Introduction

One of the major physical barriers confronting travellers in the coastal areas of East Greenland are the fast flowing glacial melt rivers. Expeditions which attempt to cross large rivers of this type are courting disaster, while failure to make the crossing often involves long and arduous detours.

Water velocities of 4.5 m/s were recored during this study and considerably greater velocities are doubtless possible during flood periods. The scouring force causes continuous bed movement and may be sufficient to trundle sizeable boulders downstream. When the pressure of the water on a travellers legs and the turbidity are also considered it will be appreciated that the crossing of glacial melt rivers is a very hazardous business, not to be undertaken lightly.

In view of these problems it appeared that a study of melt water flows would be of general interest and that it would enable a better understanding of the hazards involved in river crossing and would help parties to avoid times of high risk.

Little glacio-hydrological work of this nature has been carried out on sub-polar glaciers and it was hoped that this study could amplify the existing sparse information, and that East Greenland data could be compared with observations from other areas concerning the factors most affecting runoff. In addition a knowledge of the flow in glacial melt rivers is necessary for the study of various aspects of glaciology and sedimentology.

The Oxford glacier and tributories has an area of  $68 \text{ km}^2$  draining a total basin of  $143 \text{ km}^2$ . The melt river is 4.5 km long from glacier snout to fjord and like other glacial rivers with very steep gradients and rough channels, is extremely turbulent. We were well aware of the difficulties involved in the gauging of such turbulent waters before leaving Britain and an important facet of the study was the adoption of simple techniques and apparatus for the measurements involved. It was hoped that this would be of considerable use and might enable future field work to be simplified and the reliability of results improved.

It had been hoped to carry out observations on supra-glacial melt streams at the same time as the main study on the outwash river, to give an indication of the basal discharge and the origins of the total outflow from the glacier. However, due to the curtailed length of time in the field and severe limitations on man power this was not possible.

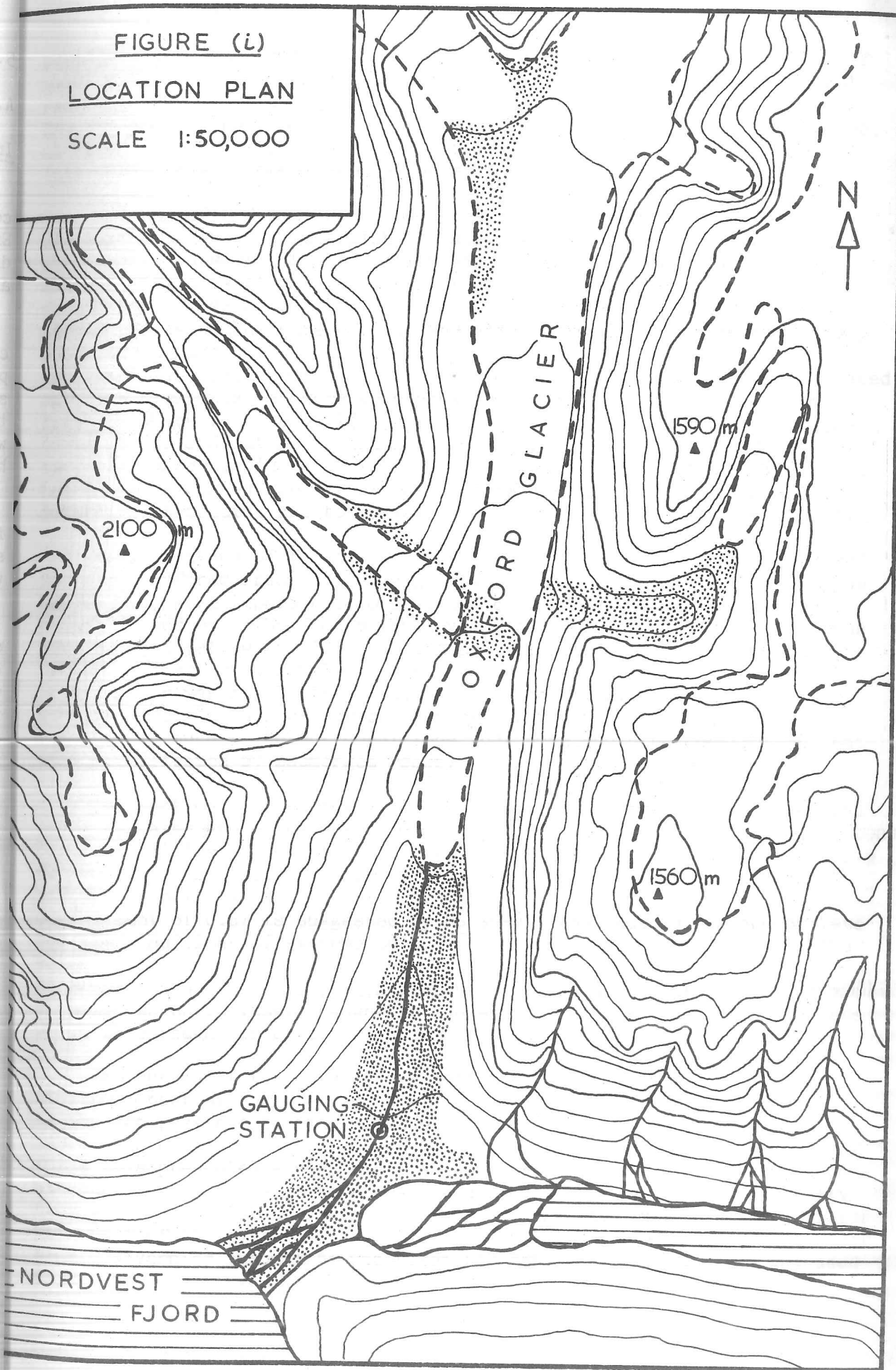
### Site, Equipment and Method

A site for river gauging was chosen 2.5 km below the snout of the Oxford Glacier and 2.0 km above the point where the river discharged into Nordvest Fjord. While the site was by no means ideal it was the best available. The 25m reach was too short for accurate work but was straight with a steady gradient and with no sudden discontinuities immediately above or below. A major drawback was that it was impossible to cross the river except by boat round the mouth, or by crossing the glacier and walking along the far bank. Figure (i) shows the glacier and location of the gauging site.

A stilling well was dug with considerable difficulty out of the morainic material adjacent to the lower section with a connection by



FIGURE (L)  
LOCATION PLAN  
SCALE 1:50,000



plastic pipe to the river. A Lea Rotary Level Recorder (Mk II) with self marking charts was established over the stilling well to give a constant record of the water level. The recorder was adjusted to give an eight day record per chart with a one third scale record of water level changes, although other time periods and vertical scales could be set. The instrument proved robust and reliable.

The use of a dilution method to measure velocity or discharge directly and hence to establish the stage - discharge relationship was considered. However the acquisition and transport of suitable injection and sampling apparatus was a considerable problem. Østrem (1964) recommends 0.5 kg of salt per  $\text{m}^3/\text{sec}$  discharge for the salt-velocity method and we would therefore have needed from 5 to 20 kg of salt for every measurement made. This was clearly prohibitive when the question of transport was considered. Dye or radioactive methods require sophisticated sampling apparatus and were considered inappropriate in this isolated location where failure would jeopardize the whole project. This was unfortunate as a dilution method would otherwise have been ideal for such turbulent waters. The extreme turbulence and high silt content ruled out the use of a current meter. We were therefore forced to use floats to determine velocities and to survey cross sections to find the discharge.

Various types of float were tried using locally available materials but most suffered from serious drawbacks; e.g., they were drowned in the turbulence, were impossible to see, tended to catch on the bed or get caught in eddies. The floats finally adopted were 200 x 250 mm polythene bags painted yellow and inflated and sealed, with a stone inside as ballast. These worked well as surface floats and while their resistance to still air was small, they could not be used in windy conditions. Vertical rod floats would probably have given a better representation of velocity in such turbulent conditions, but none could be constructed that were not affected by submerged rocks.

Two sections across the river 25 m apart were marked out, the floats being released above the upstream section and timed between the two sections. Float velocities were measured in this way for as many stages as possible. Østrem (1964) suggests multiplying by a coefficient of 0.85 to convert surface velocities to mean velocities for a turbulent glacial river. A coefficient of 0.67 is suggested by BS 3680 (1964) but is not appropriate for the conditions of extreme turbulence encountered in this study. The value of the coefficient chosen can only be an estimate based on field observations and will vary with different rivers and conditions. The amount of water which is itself caught in eddies is a constant factor and floats which were caught in or affected by eddies were therefore discounted.

The survey of the river cross sections proved to be the most difficult part of the field work since even at the lowest water levels it was not possible to stand in the main channel holding a staff. The survey was eventually carried out using a suitably marked cane as a staff since this presented a very small surface area to the flow. The cane was attached at right angles to a graduated length of tube held horizontally thus giving the distance from the datum. Using this method bed levels for each half of the section were obtained by holding the tube from the nearer bank. A vernier theodolite was taken for general survey use and was used as a level for surveying the river sections.

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## Water Level Record

The graph of water levels produced by the recorder for the period August 14th to 20th 1975 is shown in Figure (ii). Beyond August 21st the record becomes unreliable due to complete blockage by silt of the pipe from the river to the stilling well. Tranquil water is necessary for damping surface oscillations but rapid silting is inevitable with the high sediment load of glacial rivers. The use of a syphon to transmit water level changes to an otherwise unconnected stilling well is unlikely to provide a solution to the problem due to airlocking at its crest. It may be possible to site the recorder over turbulent water and use mechanical damping but the risk of floods washing away the apparatus is high and maintenance difficulties are likely in adverse climatic conditions. A recorder which uses a pneumatic depth gauge is likely to cause trouble due to temperature effects on the aneroid capsule which translates the pneumatic variations to the recorder pen.

Maximum water level occurred between 1500 and 1800 hrs (G.M.T.) lasting for a maximum of 2 hours and generally for much less. The level then fell sharply and at an approximately linear rate before starting to level off around midnight. Minimum was reached around 0900 hrs followed within an hour by a very steep and initially linear rise to the maximum. It is interesting to compare this pattern with that of the Ping Elv in Northern Scoresby Land for which O'Brien (1971) found a maximum water level at about 2000 hrs and a minimum at 0700 hrs. Some or all of the following factors could account for this difference:

- (i) The distance the water must travel from the farthest point on the glacier to the gauging station, and the slope and condition of the melt river, affect the time of arrival of the peak flow at the station.
- (ii) The height of the mountains surrounding the glacier relative to the height of the glacier, the angle of the sun above the horizon and the orientation and size of the glacier affect the time when the melt due to insolation begins and ends.
- (iii) Melt due to ambient air temperature varies with the height and location of the glacier.

One feature of note is the small discontinuity which occurs each day about 2½ hrs after the peak water level and which is probably due to a later brief period of insolation on the glacier caused by the local topography.

While the diurnal variations in water level are considerable, in this case up to 250mm, the annual variations are much greater. The maximum discharge in East Greenland occurs in June when the thaw of large accumulations of winter snow is at its height. The discharge gradually falls off throughout the summer until the complete freeze-up by the end of September. An overall pattern of declining water levels may be noted in Figure (ii) with a sudden drop in night-time water levels on 19th August with the onset of Autumn frosts.

A hydrographic analysis of these results is beyond the scope of this discussion but may yield interesting information.

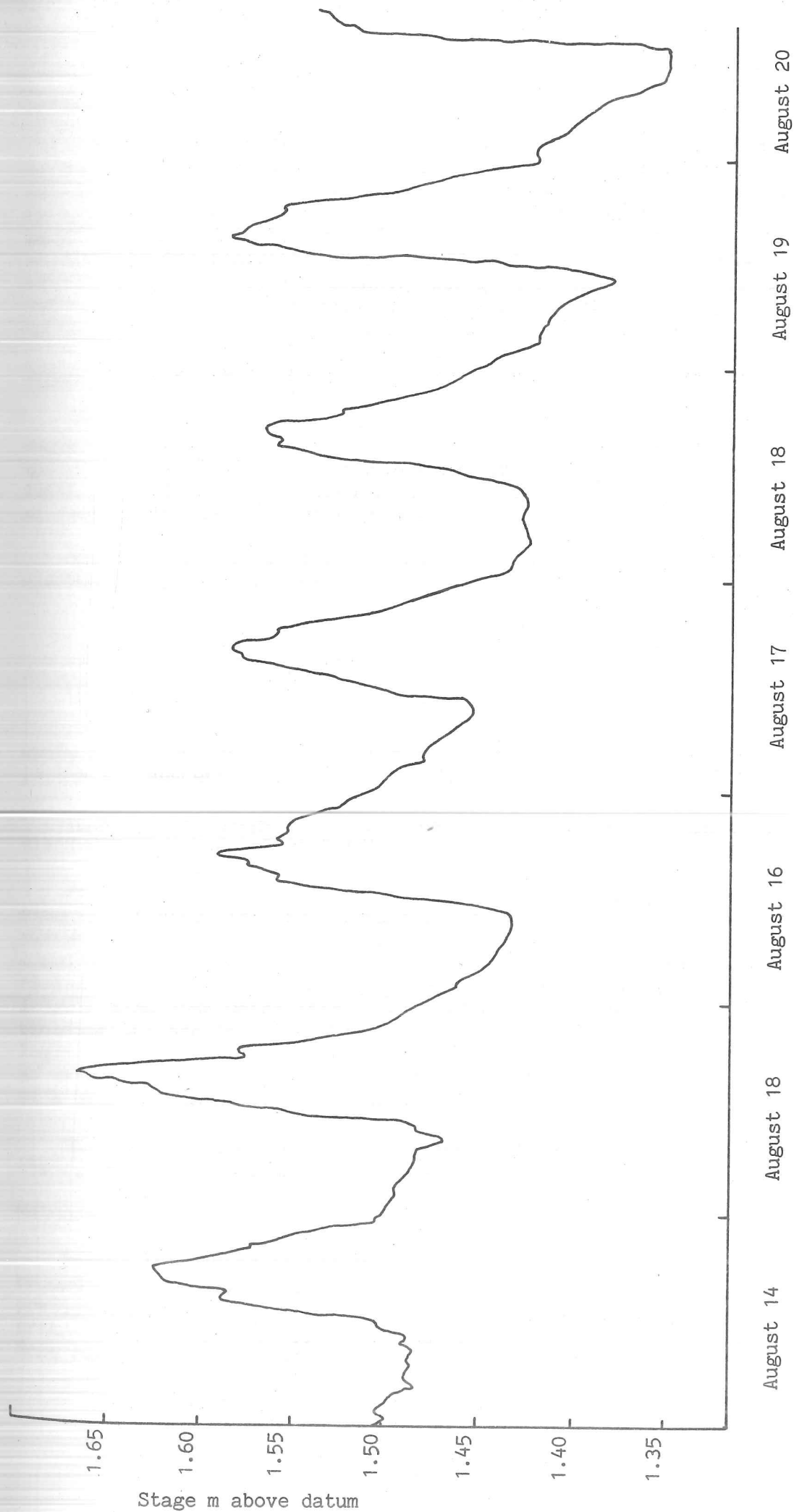


Figure (ii) WATER LEVEL AUGUST 14th to 20th



### Cross Sections

The upper and lower cross sections were surveyed on three occasions to assess bed movement and to enable a mean section to be calculated. Surveys on 18th and 20th August gave similar results but a later survey on 30th August showed a certain amount of bed movement. The actual amount is impossible to quantify as minor variations in the line surveyed or the placement of the staff would give rise to large variations in bed level obtained. Level variations up to 300mm were noted but the downward migration of boulders of this order of diameter was to be expected, and was indeed confirmed by visual observation.

### Stage Discharge Relationship

The section was divided into five segments of equal width and the segment in which each float was carried was noted during the velocity measurements. To obtain the mean velocity in the measuring reach the float velocity was multiplied by the coefficient (c), 0.85. The choice of coefficient has already been discussed.

The total discharge for the reach is given by the sum of the discharges of each segment.

$$Q = \sum_{i=1}^5 c a_i v_i$$

Where  $a_i$  is the area of the  $i^{\text{th}}$  segment and  $v_i$  is the surface velocity in the  $i^{\text{th}}$  segment.

Thus the discharge for each stage was calculated and hence the stage discharge curve was plotted (figure (iii)).

In general one would expect a looped stage/discharge curve, a slightly greater discharge being obtained for a given water level on a rising stage than on a falling stage. However, the possible error is considerable and the results do not justify the drawing of separate rising and falling level stage/discharge curves. The errors are discussed later. Also some water stages recorded were outwith the range of observations and the curve has been extrapolated. Plotting the curve logarithmically gave two straight lines which intersected at the stage at which the main channel was overtopped. This shows as a discontinuity at a stage of about 1.5 m in the stage discharge curve in figure (iii).

The maximum stage recorded corresponds to an estimated discharge of  $45\text{m}^3/\text{s}$  while the minimum corresponds to  $11\text{m}^3/\text{s}$ .

### Meteorological Factors

During the period of the study the following parameters were recorded at the gauging station, where possible at three hourly intervals: precipitation, temperature of ambient air, relative humidity, atmospheric pressure, cloud cover, type and height, and wind speed and direction. Some results are shown in figure (iv).

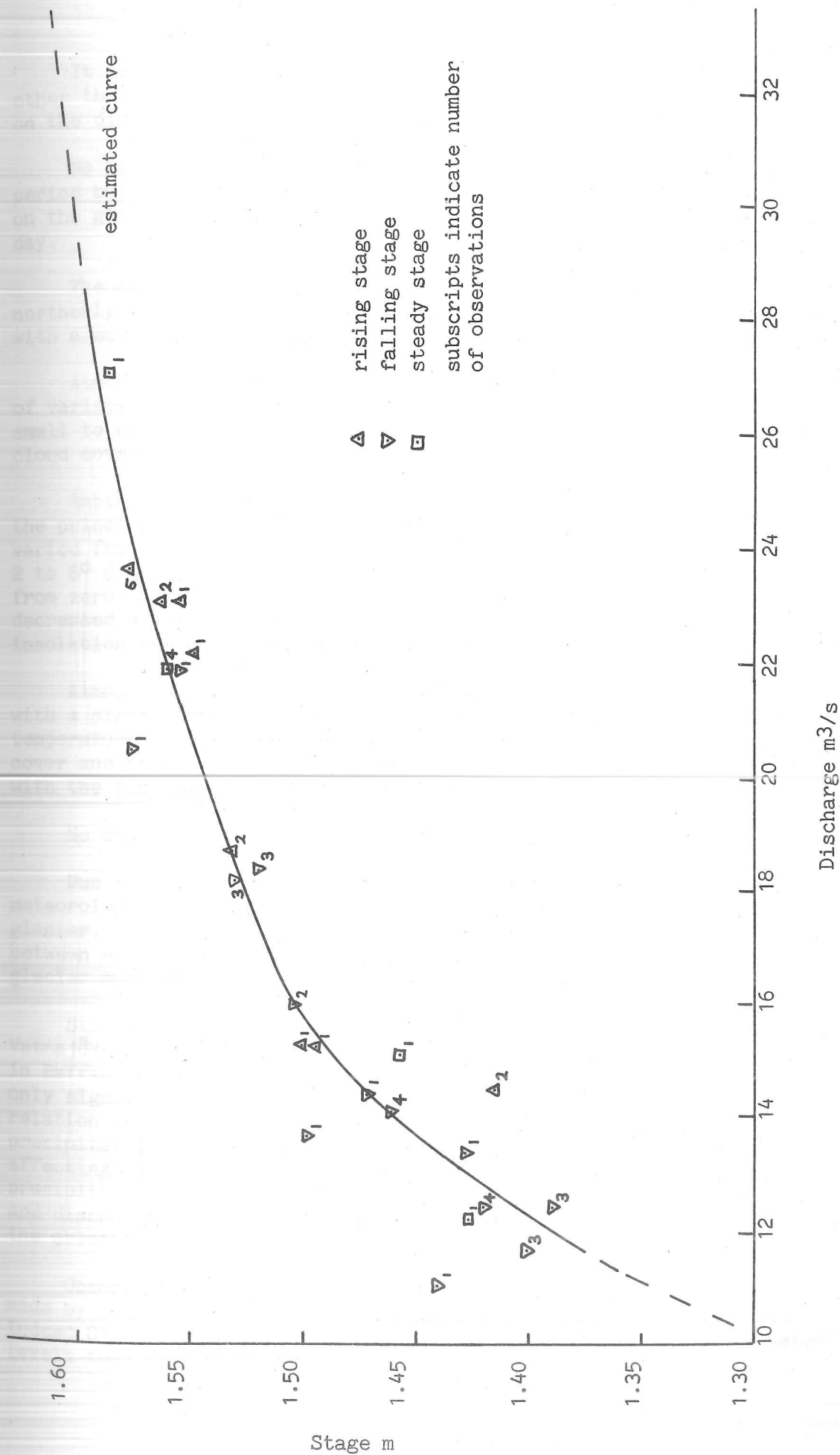


FIGURE (iii) STAGE VS. DISCHARGE

It is not possible from the limited data obtained to make anything other than general observations as to the effect of meteorological factors on the discharge.

No precipitation was recorded at the gauging station during this period but low cloud noted early on 15th August may indicate precipitation on the glacier which would account for the unusually high flow later in the day.

The surface wind tended to follow a similar pattern each day, being northerly and very light at night veering southerly during the day and with a maximum velocity of up to 15kt usually recorded around midday.

Atmospheric pressure varied from 995 mb to 1011 mb. Any direct effects of variations in wind speed or direction and atmospheric pressure are too small to be detected although they may be linked with precipitation or cloud cover.

Ambient air temperature and direct insolation are responsible for the principal regular diurnal fluctuations in discharge. The former varied from a maximum of 15 to 18° C at about 1400 hrs to a minimum of 2 to 6° C at about 0600 hrs (G.M.T.). Cloud cover tended to increase from zero around midday and early afternoon to 8/8 at 0300 and then decreased steadily in the morning. With the sun above the horizon insolation tended to follow an equivalent pattern.

Almost complete cloud cover on the afternoon of August 18th coincides with a significantly lower discharge despite a significantly higher ambient temperature. This, and other visual observations, suggests that cloud cover and hence direct insolation is of considerable importance, and agrees with the findings of O'Brien (1971).

No conclusions can be drawn regarding variations in humidity.

Due to restricted man power it was not possible to make simultaneous meteorological observations at the gauging station and at stations on the glacier. Østrem et al (1967) who did so generally found the variation between such observations to be small, but their observations were on a glacier much smaller than the Oxford Glacier.

Studies by Gudmundsson and Sigbjarnarsson (1972) on the temperate Vatnajökull in Iceland and Østrem et al (1967) on the polar Decade Glacier in Baffin Island concluded that temperature and precipitation are the only significant factors affecting discharge. Gudmundsson found little relation between cloud cover and water level and observed that, although precipitation was significant, temperature was the most important factor affecting runoff. Østrem, however, found a close connection between precipitation and discharge and only a weak correlation between temperature and discharge in the early summer which became more pronounced later in the ablation season.

Observations in this study and by O'Brien (1971) differ from those made by Østrem and Gudmundsson concerning the effect of cloud cover. Indeed O'Brien found that cloud cover could have more effect on water levels than precipitation.

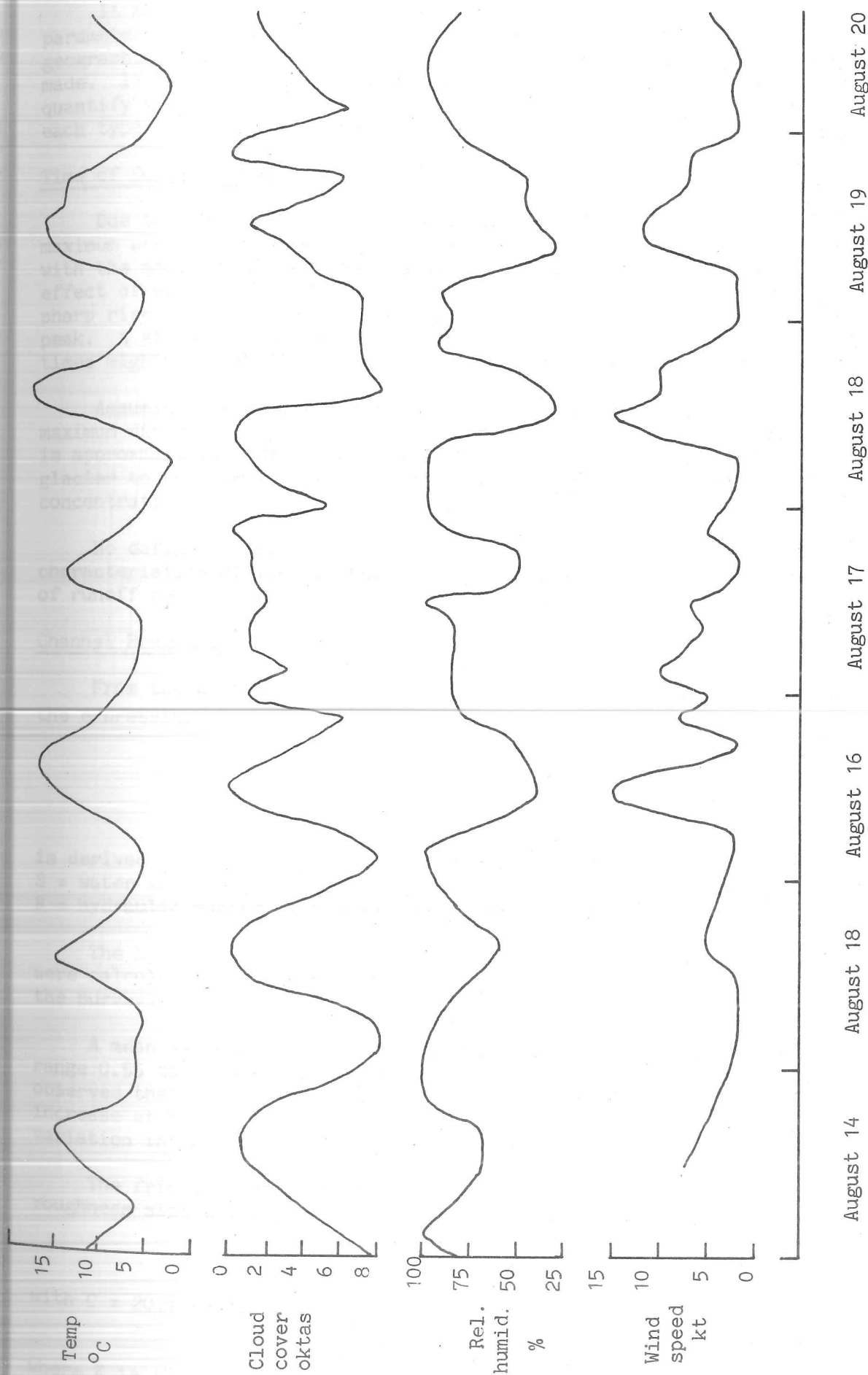


Figure (iv) METEOROLOGICAL OBSERVATIONS

It must therefore be concluded that the effect of meteorological parameters varies with the type of glacier, its location and other geographical features, and the season during which observations were made. It is not possible however, without a vast amount of data, to quantify the effect of each individual meteorological parameter for each type and location of glacier.

#### Time of Concentration

Due to the orientation of the Oxford Glacier, insolation over the maximum area was received at about 1430 hrs and this tended to coincide with the maximum temperature and minimum cloud cover. This makes the effect of each variable difficult to ascertain but explains the very sharp rise to, and fall from peak discharge and the short length of the peak. A study of the area of glacier exposed to the sun at different times might give further information but has not been attempted here.

Assuming the maximum melt to be at 1430 hrs the time lag to maximum discharge at the gauging station (the time of concentration) is approximately 2 hrs. The time for the flood wave to travel from the glacier to the gauging station is negligible compared with the time of concentration over the glacier itself.

No definite conclusions can be drawn from this regarding the characteristics of flow in melt water channels as the relative amounts of runoff on the surface and at the base are not known.

#### Channel Roughness

From the widely used combination of the Manning and Chézy formulae the expression

$$n = 1/V R^{2/3} S^{1/2}$$

is derived for turbulent flow in open channels, where  $V$  = mean velocity,  $S$  = water surface gradient,  $n$  = Mannings roughness coefficient and  $R$  = hydraulic radius of the section (= Area/wetted perimeter).

The hydraulic radius was obtained from the survey and values of  $n$  were calculated for various stages using a water gradient obtained from the survey.

A mean value of  $n$  of 0.063 was thus calculated. This is within the range 0.55 to 0.75 found by Barnes (1967) for similar channels. He also observed that  $n$  varied considerably according to the flow, tending to increase at high flows, but there is insufficient data to confirm such a variation in this study.

The friction coefficient has also been analysed in terms of the bed roughness size using the Chézy equation

$$V = C \sqrt{RS}$$

$$\text{with } C = 20.7 + 17.7 \log_{10} \frac{R}{K}$$

where  $K$  is the equivalent roughness size.



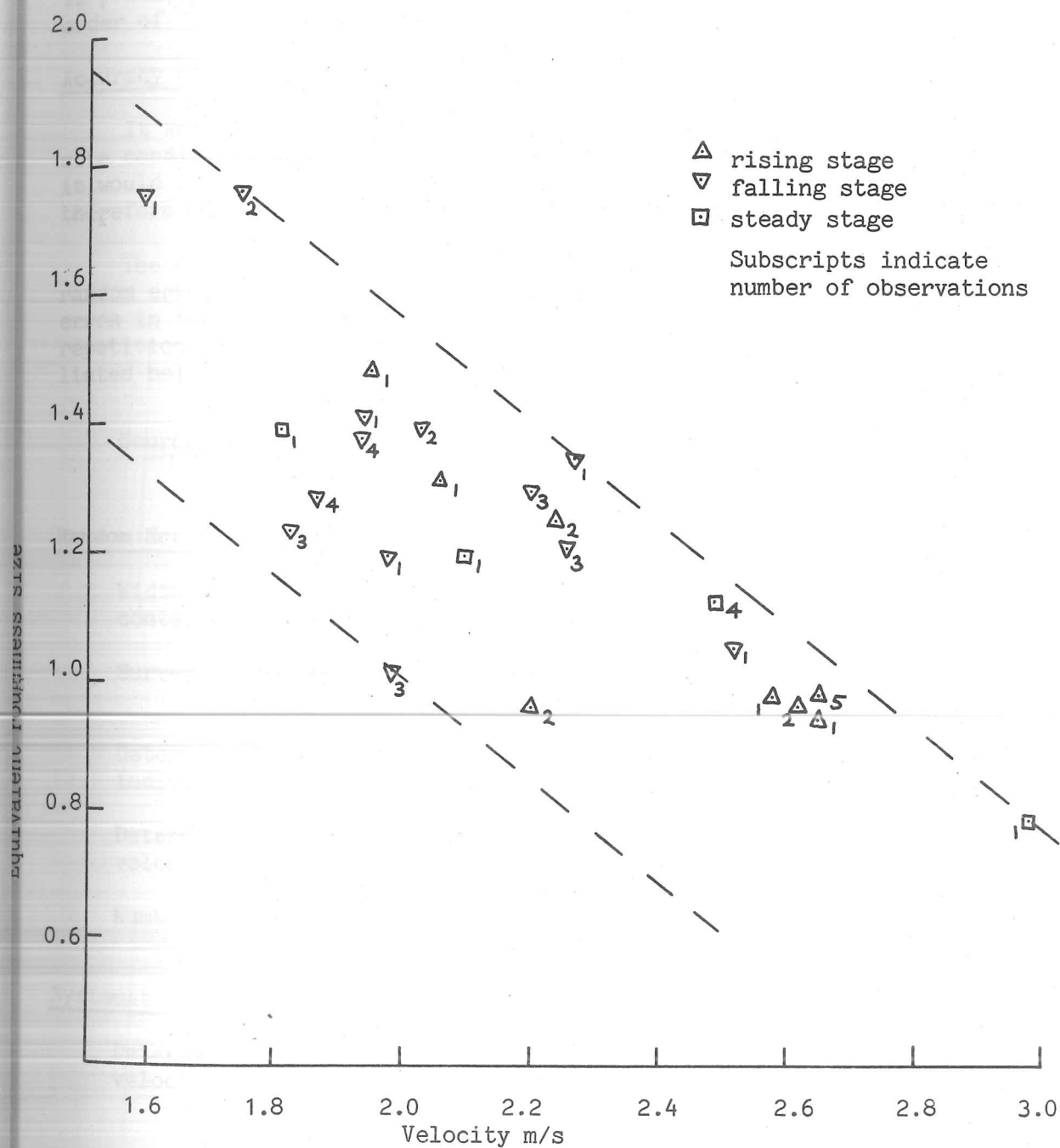


Figure (v)

EQUIVALENT ROUGHNESS SIZE VS VELOCITY

When plotted against the mean velocity in the channel (figure (v)) the envelope of points shows a marked reduction in equivalent roughness size as the velocity increases. The variation in equivalent roughness is probably related to the Froude number of the flow which is in the order of 1.0 in this channel.

### Accuracy of Results

It was realised at the beginning of the study that, due to difficult site conditions and inherent inaccuracy of the technique and equipment, it would only be possible to achieve estimates of discharge. It is therefore of importance to assess the probable error in the final results.

The overall error in the measurement is due to a combination of random errors in the equipment and method, and systematic bias caused by errors in the standardising equipment. Random errors are reduced by repetition of observations. The major sources and amounts of error are listed below:

<u>Source of Error</u>	<u>Reason</u>	<u>Approx. % error per reading</u>
<u>Random Errors:</u>		
Width of segment containing float	visual estimation	20
Survey of depths	bed movement, placing of staff	30
Determination of individual velocities	random fluctuations	30
Determination of mean velocity	variation in vertical velocity distribution	10
Number of segments	variation in horizontal velocity distribution	10
<u>Systematic Errors:</u>		
Determination of mean velocities	choice of coefficient	15

When overall random and systematic errors were combined as described in BS 3680 (1964) the overall error was about 25%. Using 95% confidence limits (i.e. 19 times out of 20) the accuracy of the discharge measurements for a given stage may be expected to be within  $\pm 50\%$ . While this seems a large error in absolute terms it is not unreasonable given the nature of the river and the unsophisticated equipment, and is sufficiently accurate for many purposes.

### General Comments

Although the equipment and methods used were reliable they were subject to large inherent errors. In future studies using similar techniques, a far greater number of observations of velocity would be necessary to reduce random errors. This could well be prohibitively expensive in man-hours. It may be possible to reduce systematic errors by a fuller assessment of the relationship between surface and mean velocities.

Considerable improvements in the accuracy of the survey could be made by carrying it out later in the season when water levels are much lower, and by several repetitions. However, it would not then be possible to assess bed movement.

On balance a dye or radioactive dilution method, despite the attendant risk of equipment failure should be considered as this would give much improved accuracy. Salt dilution must be ruled out for remote locations because of the quantity of materials required, however the possibility of taking sufficient materials for a small number of observations should be considered as this would provide a valuable check on the coefficient applied to the float velocities.

With more accurate measurements and further work elsewhere a more reliable estimate could be made of the roughness coefficient and of its variation under differing conditions. This could be used to simplify future discharge measurements on other glacial melt rivers.

Future studies must overcome the problem of stilling well silting and should endeavour to make records over a much longer period. Ideally meteorological observations should be made continuously and simultaneously both at the gauging station and on the glacier. Sufficient data would then be available for a more detailed study of the effect of meteorological factors on the melt water discharge, and a proper comparison could be made with studies on other polar and temperate glaciers.

### River Sediments

Some 53 samples of suspended sediments were collected during the study of which about half were filtered. Unfortunately it was not possible to obtain suitable sampling apparatus before our departure to relate sediment content to flow. The filtered samples were analysed and the results are included in the report on sediment samples.

### Acknowledgements

The authors wish to thank Mr. W. McNicoll of the Department of Civil Engineering at Dundee University for valuable advice and assistance before and after the expedition. Thanks are also due to Prof. A.R. Cusens for allowing the use of the departments surveying equipment and to Messrs. J. & A. Leslie & Reid, Chartered Engineers, Edinburgh for the loan of the Water Level Recorder.

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## 6.0 SEDIMENTS FROM THE OXFORD GLACIER AND RIVER

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### Introduction

A total of 86 samples of scree, lateral, medial and englacial moranic debris and stream transported sediments collected in the Oxford Gletscher basin returned with the Expedition. These samples were dried prior to mechanical analysis in accordance with BS 1377: 1975 using sieves of mesh sizes ranging by 0.25 phi intervals from -5.25 phi (37.5mm.) to + 4.0 phi (63 microns) in diameter.

( $\phi = -\log_2$  of grain size in millimetres). The percentage by weight retained on each sieve was determined, and plotted as a cumulative frequency and probability scale against size to show the grain size distribution of each sample. Some typical examples of these curves are shown in Fig. (i).

In attempting to characterise grain size distributions a variety of percentile values may be read from the cumulative curves. In many instances values less than the 10th percentile could not be determined with confidence as gross extrapolation would have been required. In consequence methods using less extreme percentiles were applied. These were the Percentile Deviation (PD $\phi$ ) which uses the 10th and 90th percentiles. Inman sorting ( $\sigma\phi$ ), using the 16th and 84th percentiles, and the Quartile Deviation (QDa) which analyses only the central part of the curve and involves the 25th and 75th percentiles.

### Percentile Deviation versus Mean Size (Fig. (ii))

Analysis of the glacial and scree sediments reveals that over a broad range of average grain size the percentile deviation varies considerably. The greater the particle size (increase of negative phi value) the greater the deviation: for any given coarse mean size the morainic material may exhibit a broad spectrum of percentile deviation values. As the sediments become finer the range of percentile deviation values appears to decrease towards minimum values which occur around means of 1.0 phi (0.5mm).

### Inman parameters - Figure (iii)

The scatter plot of sorting ( $\sigma\phi$ ) against mean ( $M\phi$ ) appears to reveal a curving pattern with highest sorting values around -1 to -2 phi diameters, decreasing towards minimum values near 0.5 to 1 phi. All of the sediments analysed appear to conform to this pattern.

### Quartile Deviation-Median Diameter Relationship - Fig. (iv)

The scatter plot reveals sample points following a well defined linear envelope across the grid. On the diagram are also fields previously defined by Buller and McManus (1972, 1973) for normal distributions of analyses from screes and glacial moraines in the source belt, and from both fluvial and quiet-water deposits.

The scree samples are all coarse and show relatively large quartile deviations. The lateral and medial moraines in general plot in virtually the same positions. Englacial materials plot out along the scree and crushed materials field. The dirt cone sediments follow a trend to one

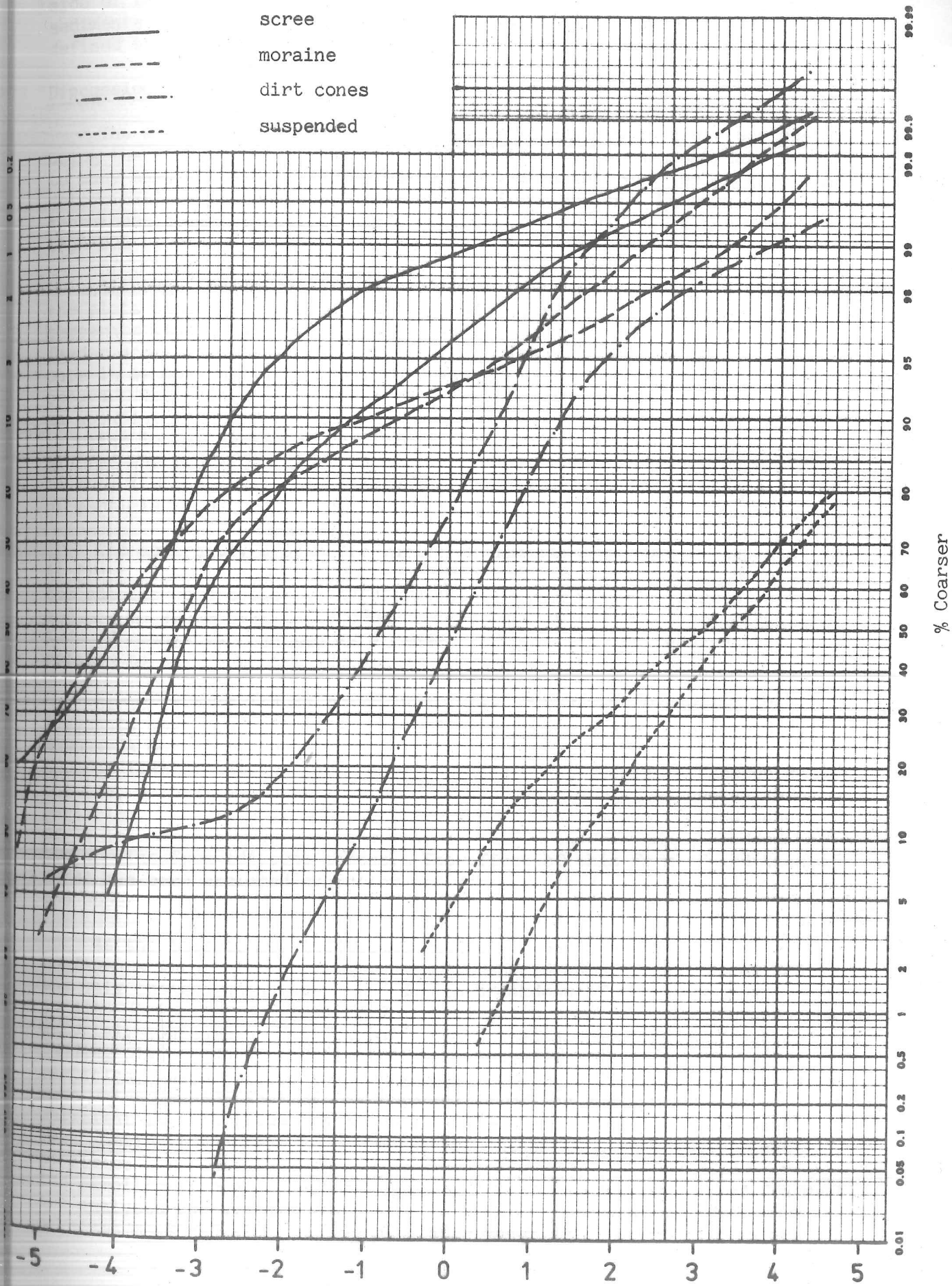


Fig. (i) TYPICAL GRAIN SIZE ANALYSES

side of the scree pattern and coincident with the field of fluviatile sediments. The finer samples, from river suspensions plot within the field defined by suspension deposits in lakes and deep marine areas.

### Discussion

The attempt to characterise the sediment grain size distributions using the statistical techniques normally used by sedimentologists leads to many samples being rejected owing to inadequate precision of size determinations in the coarse tail of the distribution. Thus only three techniques could be applied and of these only one was valid for more than 80% of the samples.

Although the Oxford glacier is classified as sub-polar, in general the plots agree with previously reported distributions observed in temperate glaciated regions. When samples are taken serially from a feeder scree, the resultant lateral moraine, and along the lateral moraine once it becomes medial in position, an apparent sequence of changes occurs. According to all forms of analysis applied there is initially an apparent increase in the average grain size and generally a slight increase in the spread of particle sizes. In the lower reaches of the glacier the medial moraines later show a decrease of average grain size. In some instances this is clearly accompanied by a decrease in the spread of particle sizes, but in others the spread increases. (Figure (v)).

The apparently systematic variation demands some form of explanation. At first sight it may be considered as due to collector bias. However, the samples were collected by different personnel over a range of sites and not in sequential pattern per se, so that this form of artificially induced change is rejected as a cause. If natural, the changes must be related to environmental factors.

Scree is produced by frost-shattering of bedrock exposures. The fragments move downhill under the influence of gravity. As they slip downwards more scree debris is supplied from further up the slope or the outcrop itself. At the lower margin of the scree debris is removed by the ice, so that there is a balance between the supply and removal of particles. The lateral moraine is not an unchanging sediment because, as it is carried forward by the ice more scree material may be added to the moraine from adjacent screes. The effect of this form of addition of scree has been explored by Buller and McManus (1973) and shown to follow the upper envelope indicated on Figure (iv).

As the lateral moraine becomes medial in position below the confluence with tributary glaciers no further debris is available, and the only changes which occur are due to breakdown of the particles in situ on the ice. Freeze-thaw action, which produced the initial scree material, continues. This exploits major weaknesses in rocks, such as bedding planes, joints, foliations and cleavages. As a result the larger particles, which possess these features break into smaller fragments at a rate which exceeds that of the comminution of the small particles deficient in such flaws, in particular the finer monomineralic grains. Thus samples taken from medial moraines contain more moderately sized particles in place of large ones, which would normally be excluded from the sampling through operator selection. As the moderately sized fragments are analysed the average grain size is seen to increase, and the spread of sizes measured also increases. Later inter-granular boundaries are

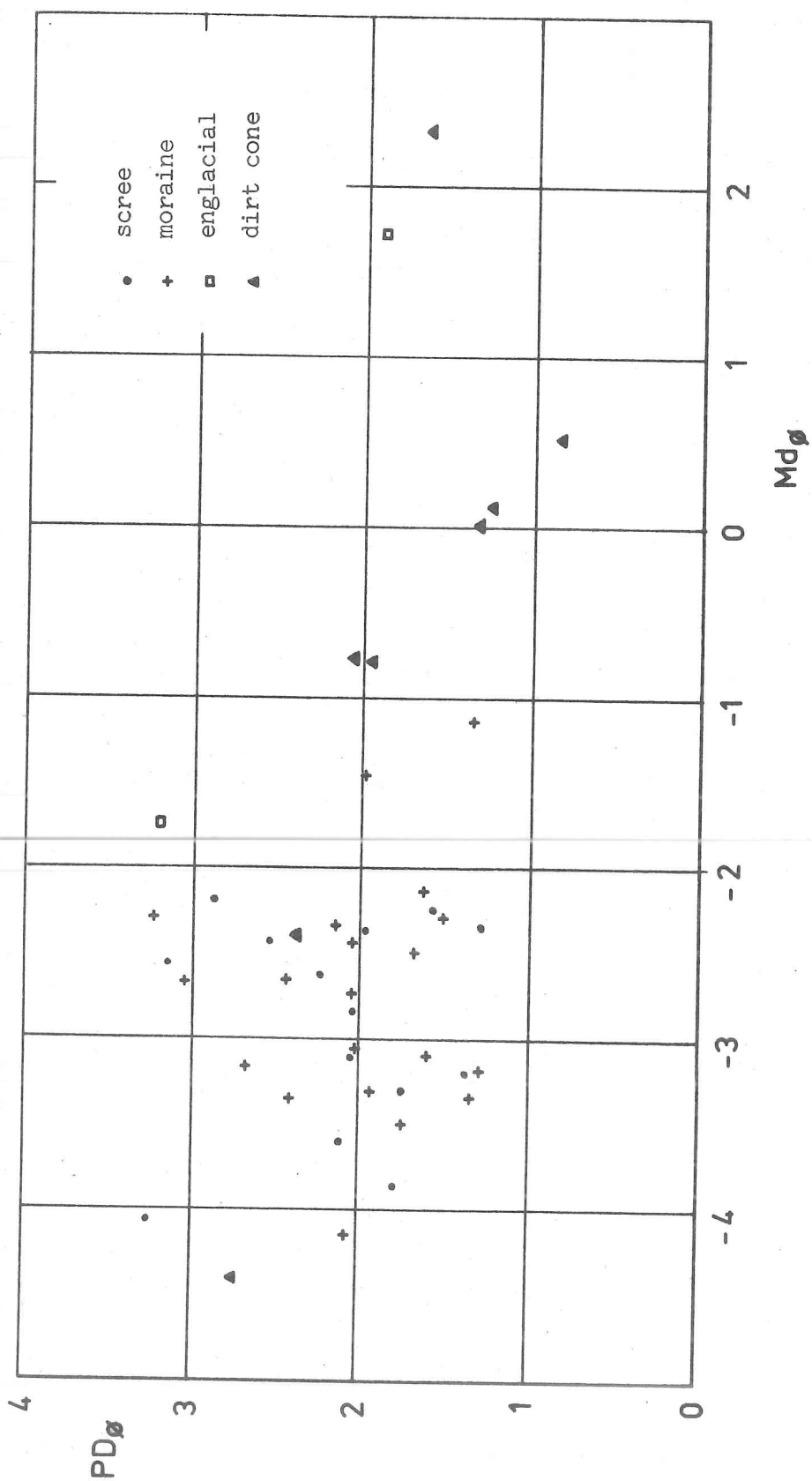


Fig. (ii) PERCENTILE DEVIATION VS. MEAN SIZE



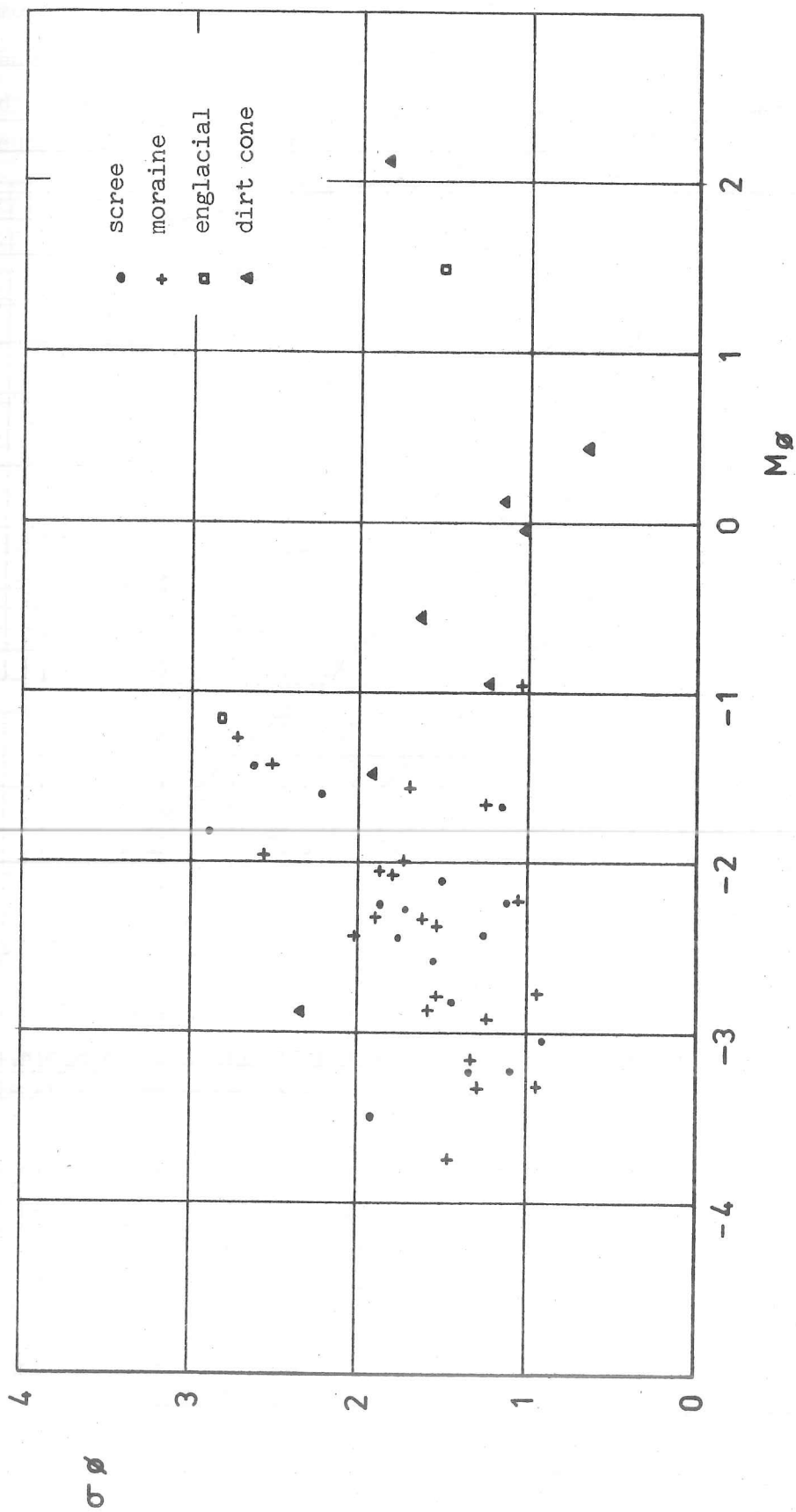


Fig. (iii) INMAN PARAMETERS

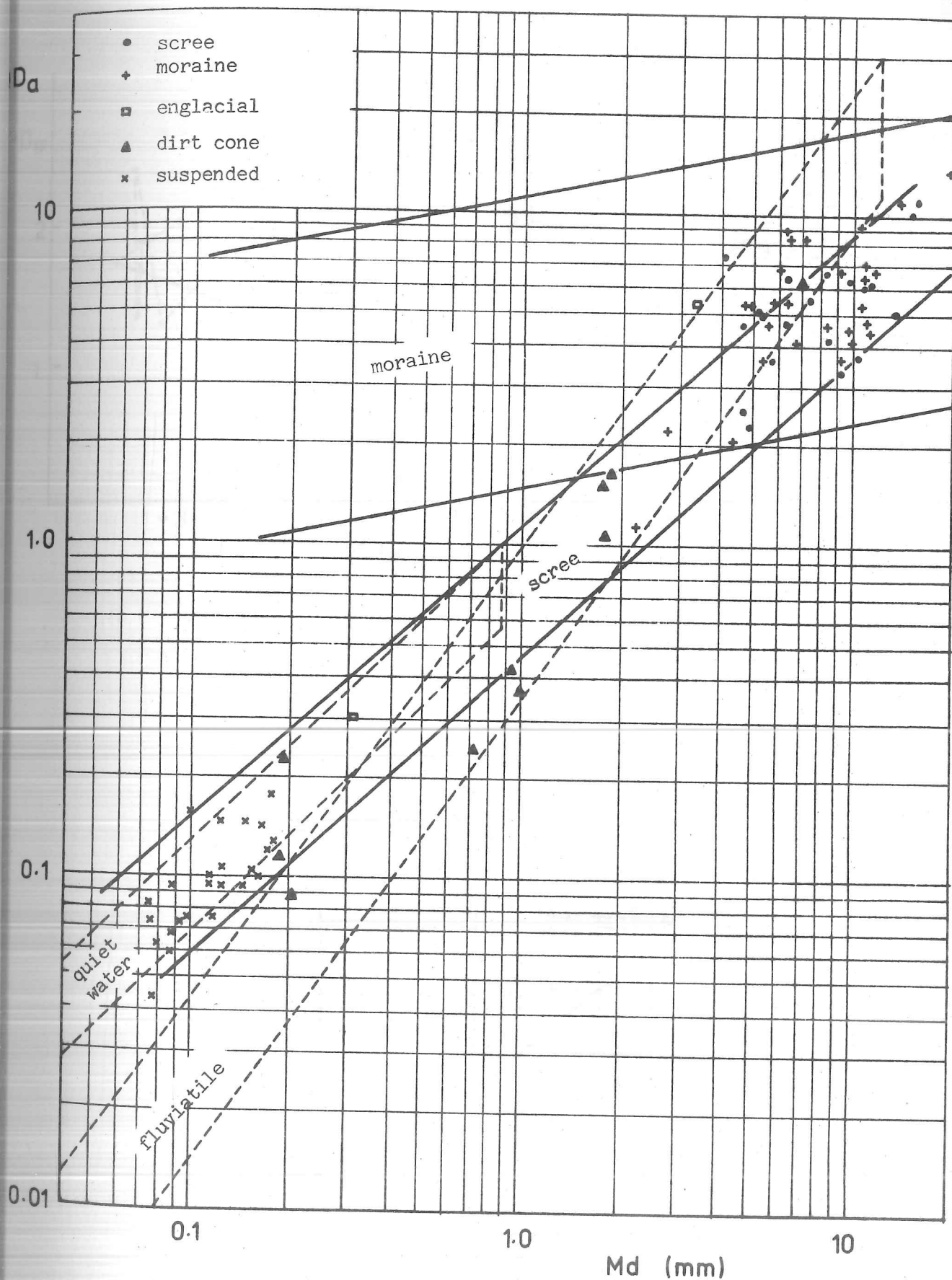


Fig (iv) QUARTILE DEVIATION VS. MEDIAN DIAMETER

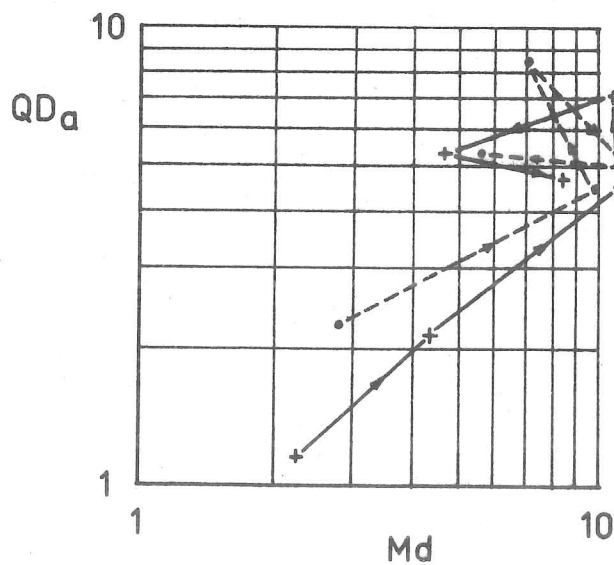
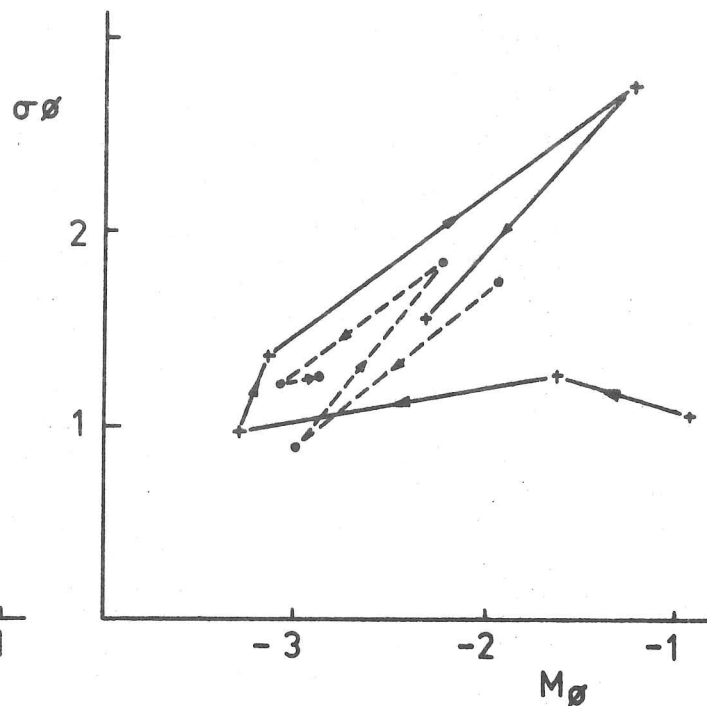
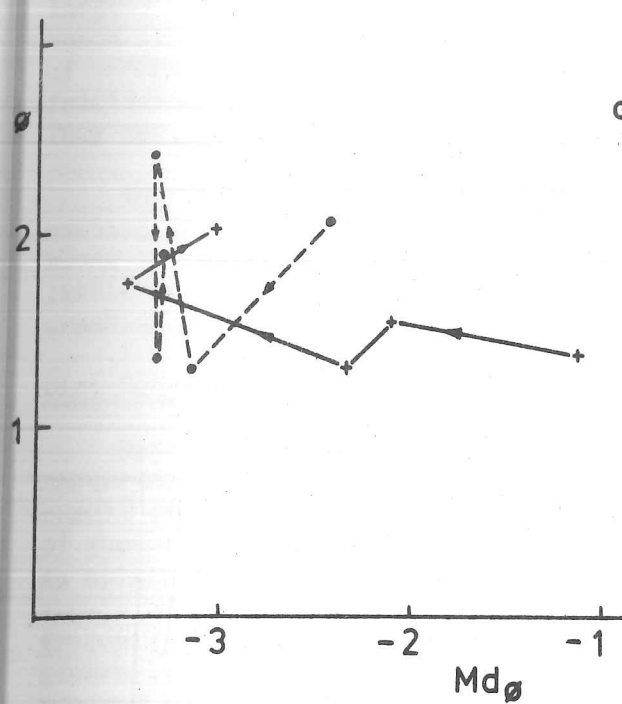


Fig. (v) ANALYSES OF TYPICAL SERIAL SAMPLES

subjected to attack, but in this particular catchment the rocks are largely of igneous and metamorphic character, and the strength of such bonds is high. In catchments of mainly sedimentary rocks this pattern of change might not be expected to show so clearly, for intergranular fracturing occurring early would dampen the changes to the median size. They may, however, accentuate variations of sorting.

The englacial material liberated from dirt bands within the ice by melting is represented directly by only two samples. However, these lie along the scree and crushed rock envelope and conform to the pattern of little alteration to included rock fragments other than by marginal crushing once they have become incorporated within the ice.

#### Dirt Cones

Dirt cones were commonly observed on the Oxford Glacier, frequently occurring in linear groups and ranging in height from 300mm to 6m. They result from the material deposited in pools and pot-holes in the channels of superficial melt-streams which have subsequently become diverted. As ablation takes place the debris protects the underlying ice from the agents of melting and what was a depression in the surface of the ice gradually becomes a projecting cone of ice, with the overlying sediment generally forming a thin covering layer. In time the surface material is removed by sub-aerial erosion and by solifluction movement, and the cone degenerates. Drewry (1972) has described the dynamics of dirt cones on an East Greenland glacier.

Dirt cones may occur at almost any position on the glacier below the ablation line. Internally most show some sorting of the sediments by size, and a degree of rudimentary bedding, in accordance with the action of water in the early stages of their development. These effects become less apparent with increasing maturity. In consequence, it is not surprising to note that the plots of dirt cone sediments are drastically different from those of the moraines proper. They mostly lie within the envelope for river-deposited sediments, which is partly coincident with that for scree in the larger size range. The finer sediments from dirt cones show affinities with the envelope defined for lacustrine deposits.

It is expected that, following further sampling and analysis, more thorough discussion and comparisons will be published in due course.

Acknowledgement is given to the valuable assistance of Miss L. Brown in carrying out the sieve analyses.



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## 6.1 SEDIMENTS OF THE BERSAERKERBRAE GLACIER, EAST GREENLAND

J. McManus

A total of 60 sediment samples from the screes, lateral, medial and terminal moraines, and from material held within the ice itself obtained from the region of the Bersaerkerbrae Glacier during the 1976 expedition were examined for grain size distribution. The cumulative frequency plots revealed generally low gradient, and often rather irregular curves. From these curves various percentile values have been abstracted in order to characterise the sediments in terms of Percentile Deviation PD  $\phi$ , the Inman (1952) sorting value  $\phi$ , and the Quartile Deviation QDa (mm).

Many of the glacial and scree sediments analysed contained substantial fractions of coarse particles, so that the more extreme values of size could not be determined without unacceptable extrapolation. As a result the numbers of samples suitable for analysis decreases as more extreme percentiles are used, so that whereas 12 samples enabled analysis by the Percentile Deviation method, 26 were suitable for examination using the Inman method, and 48 by the Quartile Deviation technique.

### Percentile Deviation

The scatter plot appears to show a snake like progression of the points, with glacial, fluvial and scree deposits intermixed in position. The 'snake' pattern may be a result of so few points being available. There is an apparent peak of deviation value around -2.0  $\phi$  median, with minima around medians of -4 and 0  $\phi$ .

### Inman Sorting

The general arrangement of points shows a concentration of coarse sediments with sorting values of 0.50 - 1.75. Most of these are morainic sediments, although two scree plots fall in this general field. Fluvial and englacial sediments are generally finer and show a greater range of sorting. Again a 'snake' like distribution pattern emerges with peak sorting values in the -2  $\phi$  median diameter range, and with minimal values around -4 and 0.5  $\phi$ . Not all sediments conform to the pattern, and two show substantial deviations from the 'snake'.

### Quartile Deviation

Envelopes have been previously defined for glacial fluvial and scree environments of deposition (Buller and McManus, 1972, 1973). As most sediments analysed were coarse there is a clustering of points in the coarser median sizes, and these show a considerable range of Quartile Deviation values. Without exception the samples fall in the envelope defined for glacial sediments in the source area. The remainder of the sediments fall within or near the fluvial envelope. Not all fluvial sediments plot within the envelope, especially the coarser ones, and likewise several of the scree samples plot outside their defined envelope. It is noteworthy that the englacial deposits, which had often accumulated as a result of inwashing of sediment by running water before relegation, conform with the fluvial distribution pattern, rather than with that for glacial deposits.

Due to the unusually low snow line the moraine pattern was obscured and in few cases were serial samples collected from a source scree, its dependent lateral moraine and along the moraine as it assumes a medial character.