SEQUENCES OF SEDIMENTATION ON HIGH ARCTIC SLOPES

DOWNSLOPE SEQUENCES OF SEDIMENT TRANSPORT AND DEPOSITION ON HIGH ARCTIC SLOPES.

by

T.J. WILKINSON, B.Sc.

A Thesis

Submitted to the Faculty of Graduate

Studies in Partial Fulfilment of the Requirements

for the Degree

Master of Science

McMaster University

May 1972

MASTER OF SCIENCE (1972)
(Geography)

McMASTER UNIVERSITY
Hamilton, Ontario

TITLE: Downslope Sequences of Sediment Transport and Depostion on High Arctic Slopes.

AUTHOR: Tony James Wilkinson B.Sc. (London)

SUPERVISOR: Dr. B.T. Bunting

NUMBER OF PAGES: 156

SCOPE AND CONTENTS:

The transport of solid material in the form of movements of suspended and bed load in overland flow is examined. This movement achieves considerable magnitudes in many rills flowing across low angle slopes during the Arctic spring and summer. The occurrence of suspended load is related to the intense runoff during the spring thaw and summer rainstorms and also to the washing of fine sediments trapped in the basal ice of transverse snowpatches. These sediments which are transported from the interflow zone upslope form small but significant sedimentary deposits on backslopes and low angle slopes. The latter deposits are more extensive and appear to be incorporated in the regolith by processes of frost action and turbulation.

ACKNOWLEDGEMENTS

I owe many thanks to my supervisor Dr. B.T. Bunting for providing finances and field assistance during the two seasons field work required for this study.

In addition I owe a great debt to the members of the McMaster University Arctic Research Group who provided psychological and gastronomic sustenance during the summers of 1970 and 1971.

Dr. S.B. McCann helped considerably in the moulding of certain details of the thesis and provided many hours of animated field discussion.

The production team of Denise (Cartography), Jessie (typing) and J.B. Hutto (stippling) are warmly thanked for their spirited conduct in the face of severe hazards and fierce opposition.

TABLE OF CONTENTS

LIST OF FIGURES

DOWNSLOPE SEQUENCES OF SEDIMENT

TRANSPORT AND DEPOSITION ON SOME HIGH ARTIC

SLOPES.

T.J. Wilkinson

ABSTRACT

The main study areas of Radstock Bay and Resolute, located in the Canadian High Arctic at 75°N, were examined to ascertain the affect of runoff from melting snow, melting ground ice and summer rainstorms on the transport of fine particles across the land surface. Drainage was in the form of overland flow (rills and sheet flow) across low gradient surfaces rich in fines and interflow (through the active layer, across the permafrost table) through openwork gravels of talus and backslopes.

Sediment transport in the case of talus foot rills was significant and occurred as wash load movement, the former being quantitatively more important in the transport of solid material in most rills. During the spring thaw of 1970 when evacuation of meltwaters was rapid, sediment transport was vigorous and extensive supranival deposition occurred on talus foot slopes. This condition was brief and by early July the drainage system had stabilized into the regimes of interflow and overland flow outlined above.

Some rills transported sediment as washload throughout the summer but usually such movement was limited to the spring thaw and certain periods in the summer.

This latter condition prevailed if the rill received some of its water from a rill head snow patch. Such snowpatches located at the break of slope, possessed basal ice layers rich in silts and fine sands. The fines were indirectly demonstrated to be washed from the interflow zone of the talus or backslopes. Interflow on steep slopes (greater than I2°) was as small 'channel' flow with velocities of only one tenth of those of rills. Direct evidence of sediment movement in this zone was difficult to establish but small deposits of relatively well sorted 'fluvial' fines demonstrated that transport could operate in steges.

Downslope at the break of slope, deposition from snowpatches was prevalent and lead to a variety of tubular, laminar and fan-like deposis. On low angle slopes deposition from supranival flow and rills was dominant and contributed significant quantities of relatively well sorted fines.

Accumulations of such sediments did not occur on most slopes. Instead low angle slopes consisted of fines in a framework of gravels and stones. A proportion of these fines are considered to be contributed by transport from the interflow zone. Silts and sands are washed from this zone into snowpatches and rills and then deposited on the ground surface as fresh deposits. Frostaction, multigelation and turbation processes are then thought to act upon these fresh sediments and mix them with the existing fines rich regolith.

Plate 1: The major sites 1970,

0 1 km

Plate 11: Sites near the Mecham valley,1971a

CHAPTER I

INTRODUCTION

Investigation of periglacial landscapes have, in the past, been concerned with morphological and other phenomena unique to high latitudes. Such studies concerning patterned ground, mound topography, segregated ice features, permafrost and certain types of mass wasting form a large and important contribution to the geomorphic literature. In the realm of soil studies emphasis is usually placed on the diminished rate of soil forming processes in high latitudes (Tedrow 1968) and the immaturity of the profile; little information is available on the translocation of physical and chemical constituents through the soil and regolith.

The purpose of this investigation is to evaluate the effect of quantities of water, derived from the melting of snow and permafrost ice, on the transport and deposition of fine sediments across the high Arctic land surface.

An intuitive approach to this problem can be made by examining the overall snowmelt run-off system associated with high Arctic drainage basins.

Cogley (1971) states that the throughput time for meltwaters and storm runoff is short as any excess waters are evacuated rapidly from the land surface in the form of overland flow and interflow. Basin storage is minimal due to the high permafrost table which acts as an impermeable barrier, always less than 80 cm. below the surface.

In the regolith and active layer the fine and coarse materials are very much disturbed by the widespread occurence of turbation phenomena. Patterned ground formation, solifluction, talus fall and frost heaving all represent processes which lead to disruption and displacement of the regolith fabric. Such disturbance, could potentially release quantities of fine material into the system.

If these two distinct processes, one of transport and one of release or supply are combined, a situation leading to significant rates of sediment movement can be envisaged. If large quantities of meltwater move across and through the shallow active layer of the ground it is likely that this could lead to the mechanical washing of fines from the regolith. Through this, release and entrainement of fines would be enhanced further by the variety of turbation processes in operation.

The question as to whether such processes of sediment movement actually operate in the Canadian High Arctic can be partially answered by the application of qualitative and quantitave observation of sediment movement in certain overland flow types. These studies will be supplemented by observations of sedimentary features located on and within the regolith and extended by inferential extrapolations from such data.

The system to be considered is a subsystem of the overall meltwater runoff system comprising the entire drainage basin and its inputs and outputs of material load and water. The main members of this subsystem are, for the convenience of study, divided into the flow types: supranival flow, overland flow and interflow, and within these dominant flow types the movement of solute and sediment load takes place. Solute load, in the limestone basins under consideration is dominated by the movement of Ca and Mg in solution (Cogley 1971), and is reported as Ca and Ca + Mg in mg./litre of $CaCO_3$. Unless reprecipitation is important, such materials will be completely removed from the drainage basin.

Sediment transport will be considered to be the movement of discrete particles entrained in a transporting medium (water) which varies in intensity through space and time. This variation, together with the supply of sediment load, will directly influence the sediment transport rates of such particles and lead to the redistribution, as well as the removal, of solid material.

The main emphasis of field work was upon sediment transport and deposition, but in addition the examination of solute load, specific topographic features and soil profiles was undertaken to provide additional information. Further data on the bedrock geology and climate of the main High Arctic study areas was supplied by reference to Fortier (in Fortier 1963), Thorsteinsson (1958), Bird (1967) and the Meteorological Branch Arctic Summary.

Methods and techniques:

Field and laboratory methods entailed obtaining a record of sediment movement from a variety of rill types, ascertaining certain characteristics of the sediments trapped and comparing these to the sediments recently deposited, as well as to the fine sediments of the regolith. Depositional features were classified and mapped on a large scale and traverses were surveyed as an aid to the description of the terrain. In addition the solute load was measured daily for three rills in 1970 and for a variety of other rills and water bodies in 1970 and 1971.

Sediment movement: General information on the amount of sediment moved and the times of movement were required for the prime features of study, rills, and such information was obtained by the use of bedload sediment traps. These were small sediment traps measuring 10.5 x 7.5 x 2 cm. (fig. 1:1) lowered into the rill bed. Such traps caught a combination of bed material load and suspended load and therefore lead to information on sediment movement and sediment deposition at a point. These studies will be elaborated in chapter IV.

Accompanying these measurements, occassional spot samples of suspended loads were taken from turbid rills. Such sediment concentrations, when multiplied by total water discharges, enable

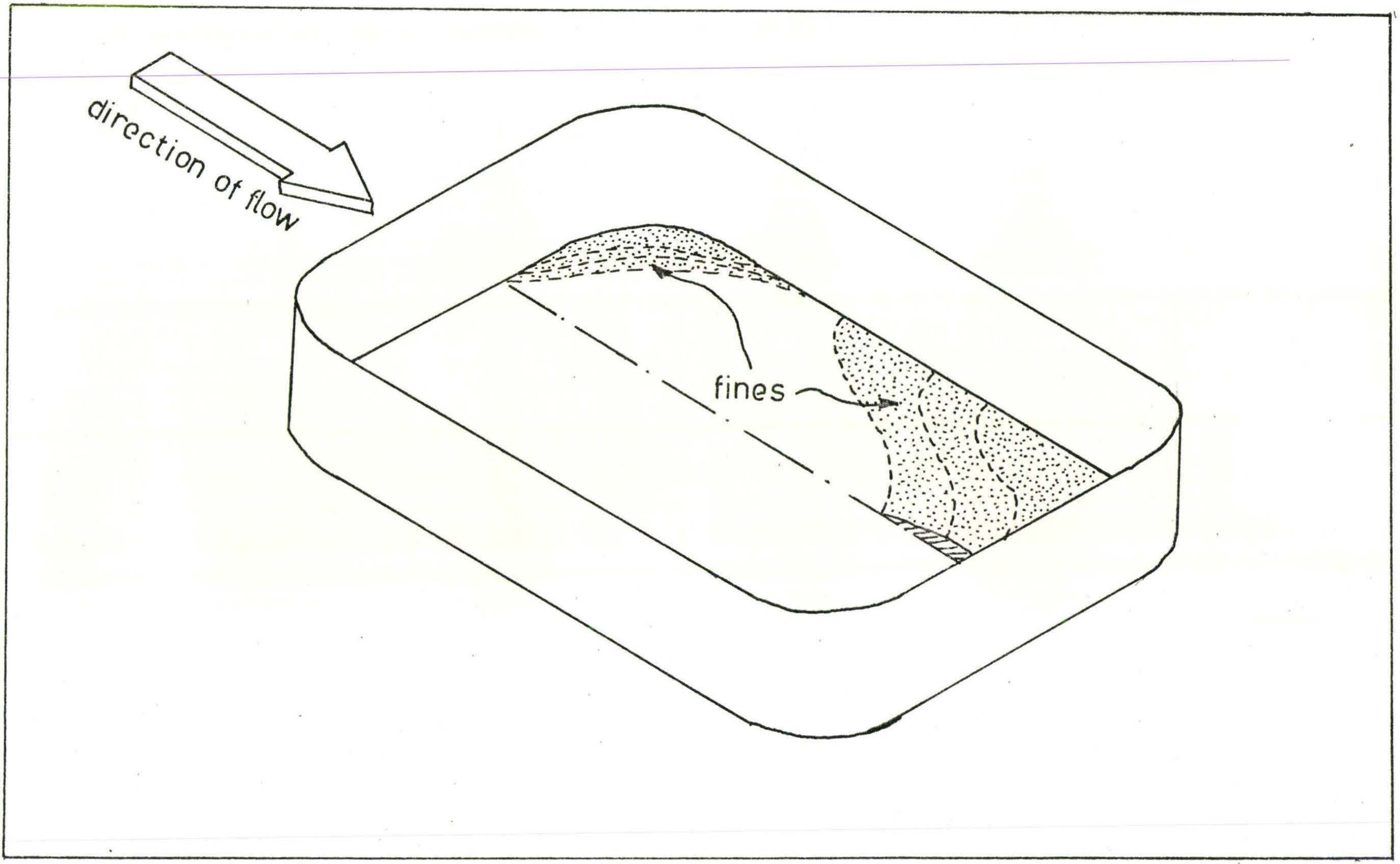


Fig. I:I Scale drawing of Sediment trap.

a tentative statement of total sediment discharge to be made.

Suspended loads were calculated as weight per unit weight i.e. p.p.m.; this figure is readily comparable to the solution load figures in mg/litre.

Sediment texture: Sediment textures were established for a wide variety of trapped sediments and surface deposits. These textures will be discussed in chapters IV, V and VI. All sediments trapped were finer than coarse sand (2 mm.) hence only the fine fraction (< 2 mm.) of the regolith was analysed.

Aggregates were initially destroyed by mortar and pestle and between 10 and 20 grams were used and dispersed in dilute sodium hexametaphosphate solution. Due to the low organic matter content no H_2O_2 treatment was required. Dispersion was further aided by mechanical agitation in a 'Hamilton Beach' agitator and after standing overnight the sediment suspension was wet seived and pipetted as described by Galehouse (in Carver 1971). If the proportion of sand was high, the initial sample was dry seived down to 0.2 mm. (no. 75 seive), wet seived and the remainder pipetted as above.

The resulting data was plotted on log normal cumulative paper as cumulative curves and histograms (see Appendix) and means and standard deviations using Folk and Ward's Formulae (1957):

$$M_z = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$ and

(inclusive graphic standard deviation)

$$\sigma = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

The data from these tests is listed in table 6:2.

The solution load: Samples of rill, interflow and soil water were taken from a variety of sites, see chapter IV, and were analyzed for dissolved Ca and Mg concentration by complexometric titration with E.D.T.A. after Schwarzenbach (1957); all samples were analysed within 12 hours and the accuracy for total and calcium hardness values is thought to be within ± 3 mg./liter (as $CaCO_3$).

Water flow characteristics: Flow patterns and velocities were established for interflow, polygon margin flow, flow through snow patches and rill flow. Velocities and flow patterns for the first three categories were established using fluorescent dye (Rhodamine T) and for the last named by timing discrete particles floating along the rills.

Topographic surveying: Deposits and sediment sequences at particular localities were mapped on scales between 1:25 and 1:100 using tapes set in a grid pattern. Spot heights and accurately surveyed contours were added where they were considered useful. In addition, traverses were levelled, using a Kern 'Quick set' level, along most sediment-gauging sites. The accuracy of ± 0.3 cm. in the vertical plane and ± 2 cm. in the horizontal plane was well within the plottable error of ± 6.25 cm. (ground equivalent) on the largest scale used.

Miscellaneous recordings: These included the monitoring of permafrost depth through time, for a variety of sites by augering; the measurement of certain soil bulk densities and concentrations of sediments on snow patches. These will be elaborated where encountered.

Such a study is therefore aimed at an analysis of the redistribution of solid material on the ground surface by the flow of water. The working hypothesis, as outlined, suggests an intuitive approach to the problem. In addition, differences in the nature of the regolith on different Arctic slopes as outlined in chapter II hint that other processes in addition to those of mass wasting, glaciation, frost sorting and marine deposition are, or have been, in operation. This semi-quantitative study will use evidence of overland flow sediment transport as well as fresh depositional features to link the initial hypothesis to the observed differences in regolith type. Such studies, as undertaken in chapters IV, V and VI, will form the bulk of the present study.

CHAPTER II

THE ENVIRONMENT AND SETTING

Location:

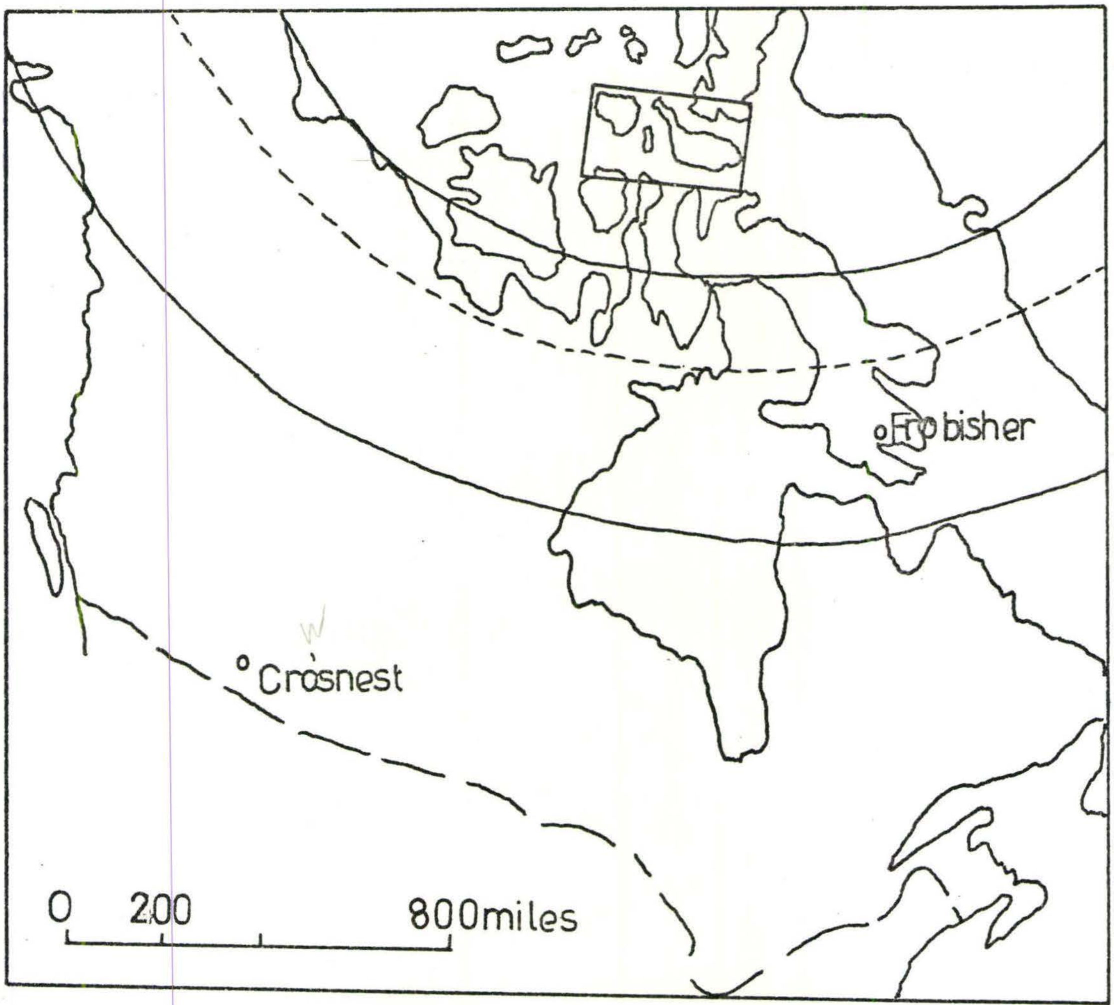
The main study areas were located on Devon Island (1970) and Cornwallis Island (1971) in the Queen Elizabeth Islands of the Canadian High Arctic. The former site lies (fig. 2:1, 2:2, 2:3) on the western shores of Radstock Bay (74° 40'N, 91° 10'W) while the 1971 site lies close to Resolute in south Cornwallis Island (74° 40'N, 94° 50'W)

Brief supporting studies were also made in the low Arctic on south eastern Baffin Island (Frobisher Bay, 63° 45'N, 68° 30' W) and in the alpine environment of the Canadian Rockies at 6,500 feet above M.S.L. at Crowsnest Pass near Lethbridge Alberta.

The bedrock geology:

Both High Arctic sites were located in regions of Palaeozoic sediments to the north of the Canadian Shield. The rocks at Radstock Bay are mainly gently southerly-dipping Upper Silurian limestones of the Read Bay formation (Fortier 1963) with varying proportions of silty, cherty, argillaceous dolomitic and conglomeratic limestones.

Similarly, the geology of the Resolute area is dominated



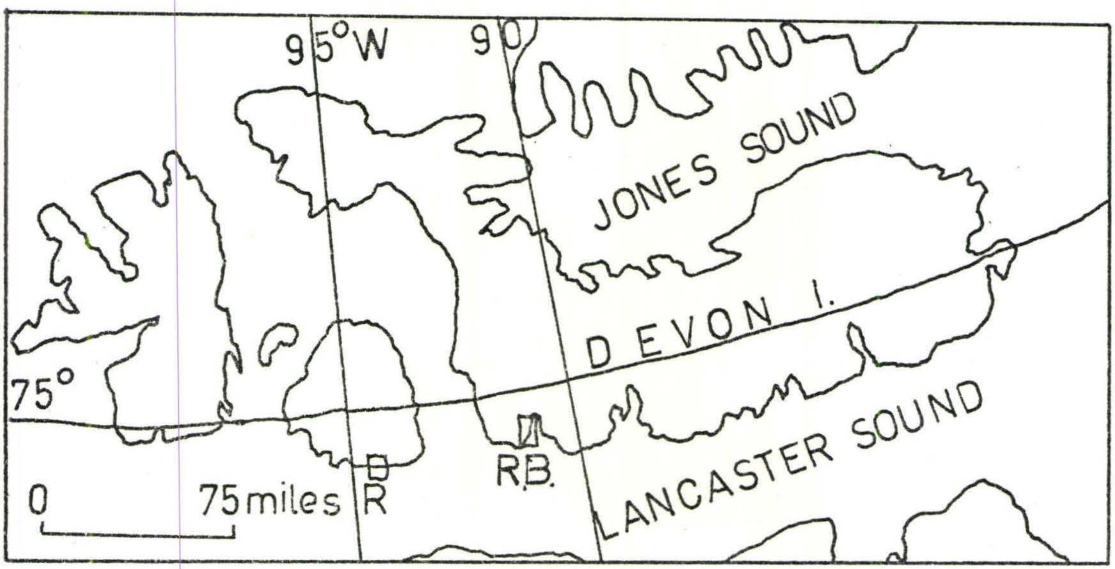


Fig. 2:I and 2:2 The situation of the study areas.
R.B. -- Radstock Bay
R. -- Resolute

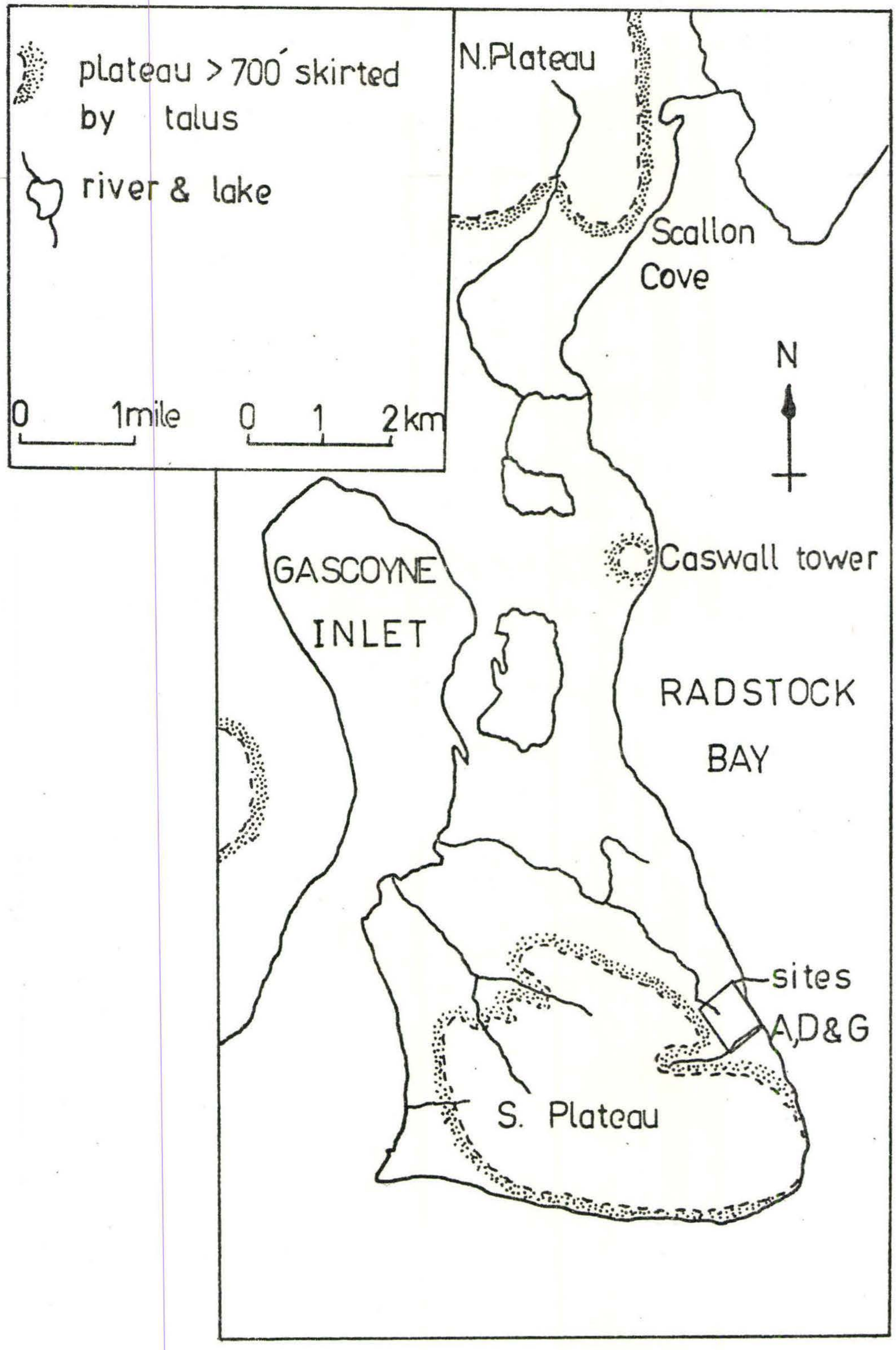


Fig. 2:3 The overall sampling area 1970.

by limestones, this time of the Cornwallis, Allen Bay and Read Bay formations, varying in age between Middle Ordovician and Upper Silurian (E. Thorsteinsson,G.S.C. 1958); lithologies vary and include argillaceous limestone, crinoidal limestones and dolomites.

The subsidiary study areas of Frobisher Bay and Crowsnest Pass are located on acid Pre-Cambrian rocks of the Canadian Shield and Cretaceous Alpine folded limestones respectively.

The topography:

South-west Devon and south Cornwallis Islands are dominated by wide sweeping plateaus of low relative relief ascribed to the Barrow surface (Bird 1967). This surface, thought to be of late Tertiary age, stretches across parts of Prince of Wales Island, Somerset Island, Baffin Island and Devon Island and crosses a variety of rocks from Proterozoic metamorphics to Devonian sandstones and conglomerates. Its height range on the broad interfluves is from 360 to 400 m. with occassional peaks at 450 m.

At Radstock Bay the 'South Plateau', possessing a mean height of 280 m(see fig. 2:3) is an outlier of the main Barrow surface. In contrast the plateau areas surrounding Resolute, located on the south-western periphery of the Barrow Surface, are lower with undulating surfaces varying between 130 and 200 m above M.S.L.

In both areas the plateaus are drained and incised by a youthful dendritic river network and only occas ionally is this pattern broken by the occurrence of lakes and bog. The rivers appear to be eroding rapidly into these plateaus and usually flow in deep narrow gorges flanked by talus.

Similarly the plateaus are skirted by talus sheets and cones which are replenished with material from the exposed free face above. Frequently these talus slopes extend right up to the plateau surface thus obscuring the free face, leaving only occassional upstanding residual buttresses.

The foot of the talus sheet is frequently terminated by a marked break in slope representing a change in gradient from 30° - 38° to the gradients of less than 8° of the talus foot slopes. In the Radstock Bay study area these foot slopes extend in a smooth concave-up curve from the break in slope to the valley bottom (fig. 2:4, 2:5a, 2:6). The lowest segment of slope represented by the subhorizontal surfaces of the silt plains is in the form of terraces or flood plains adjacent to the river (fig. 2:4)

In contrast, at the foot of the talus slopes overlooking Char Lake, Resolute (fig. 2:7) the low angle talus foot slopes are terraces and lobes between 0 and 70 m. above lake level. These terrace and lobate forms sometimes exhibit symptoms of solifluction although others could be considered to be altiplanation terraces or nivation hollows as argued by Cook (1962).

Complex gravel slopes of lower gradients (12-25°) occur on areas of raised beach materials, which frequently flank the

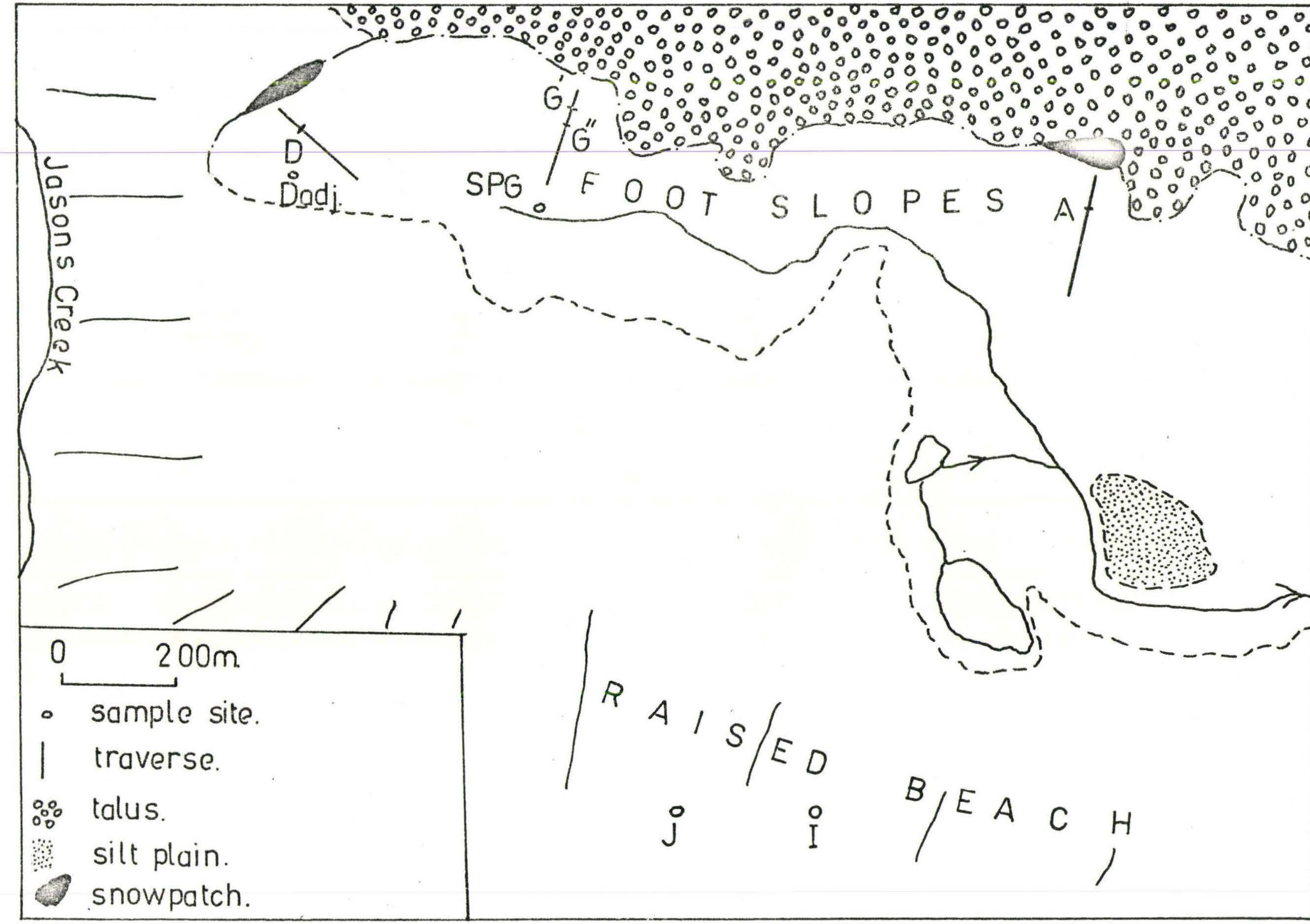


Fig. 2:4 Site map os major sampling area I970.

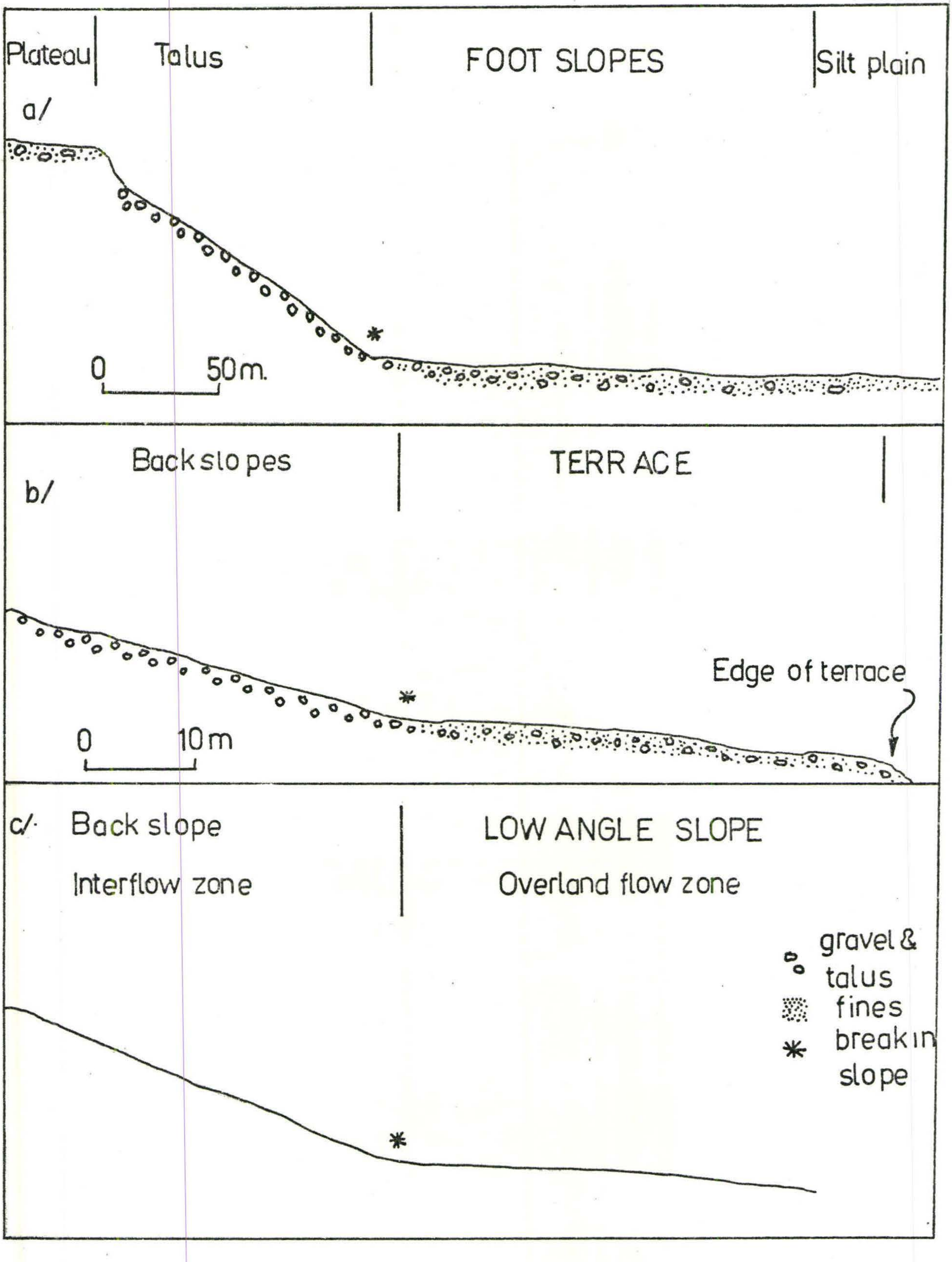


Fig. 2:5 a,b,c
a,b - profiles for talus foot and raised beach slopes generalized from surveyed profiles (vertical and horizontal scale equal).
c - essentials of a and b describing the fundamental topographic unit.

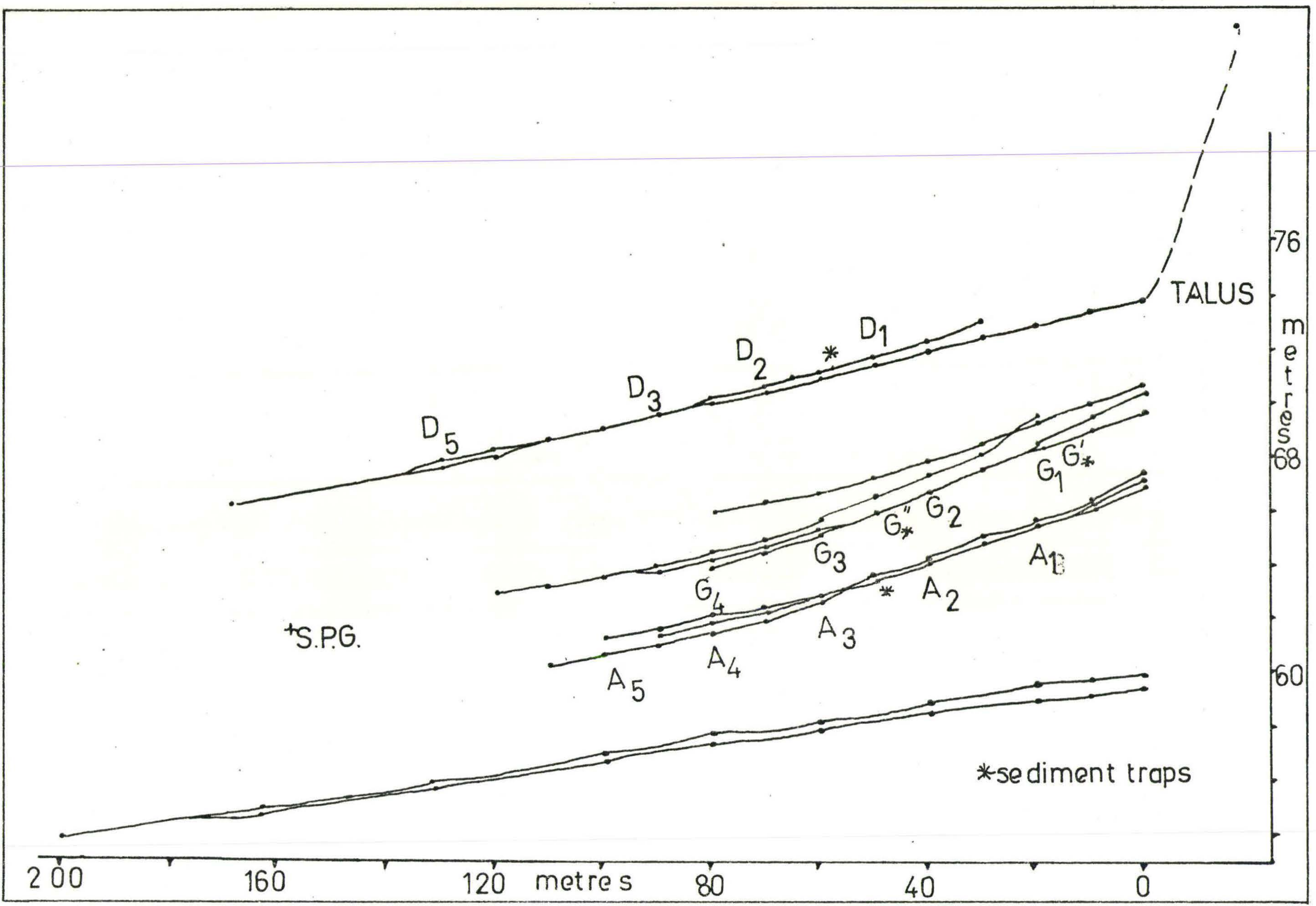


Fig. 2:6 Surveyed profiles of foot slopes.

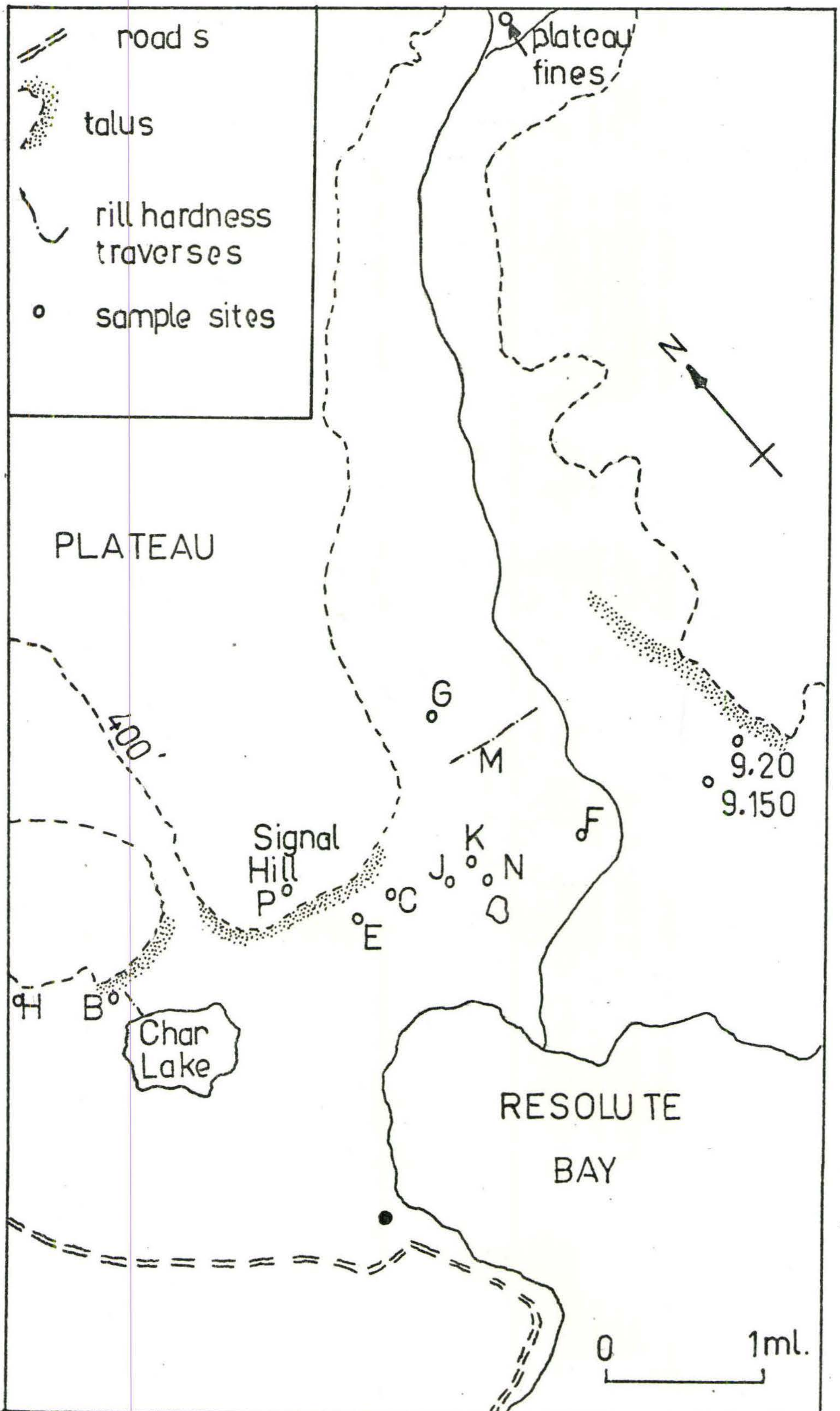


Fig. 2:7 Sample sites I97I.

plateaus or form ridges and low hills up to 100 m. above M.S.L., the approximate height of the extreme transgression (Bird 1967). Such terrain occurs in both study areas and frequently possesses a distinct stepped topography divided into steep back slopes bounded below by the break in slope whilst beyond this stretch the low angle slopes, dominated by fines (fig. 2:5b, 2:8). As in the case of the Resolute talus foot slopes, these are frequently formed into lobes, suggesting the presence of solifluction. Such features at Resolute were designated nivation hollows by Cook (1962), but were associated with raised beach forms.

As nivation hollows are considered by many e.g. Waters (1962), to be a polygenetic form, both solifluction lobes and raised beaches could contribute to the final form.

Despite the differences in scale, these features can be seen to belong to a similar topographic class (fig. 2:5c); the basic members of this class being:

a) A steep (15-40°) back slope of gravel or talus exhibiting an open work texture and an associated deficiency in surface drainage.

b) A break in slope which is usually straight but occassionally interrupted by hummocks of fines or talus cones.

c) Low gradient (less than 8°) foot slopes consisting of gravels and stones with a matrix of fines. These are mainly slopes of overland or polygon margin flow (see the drainage of the land surface).

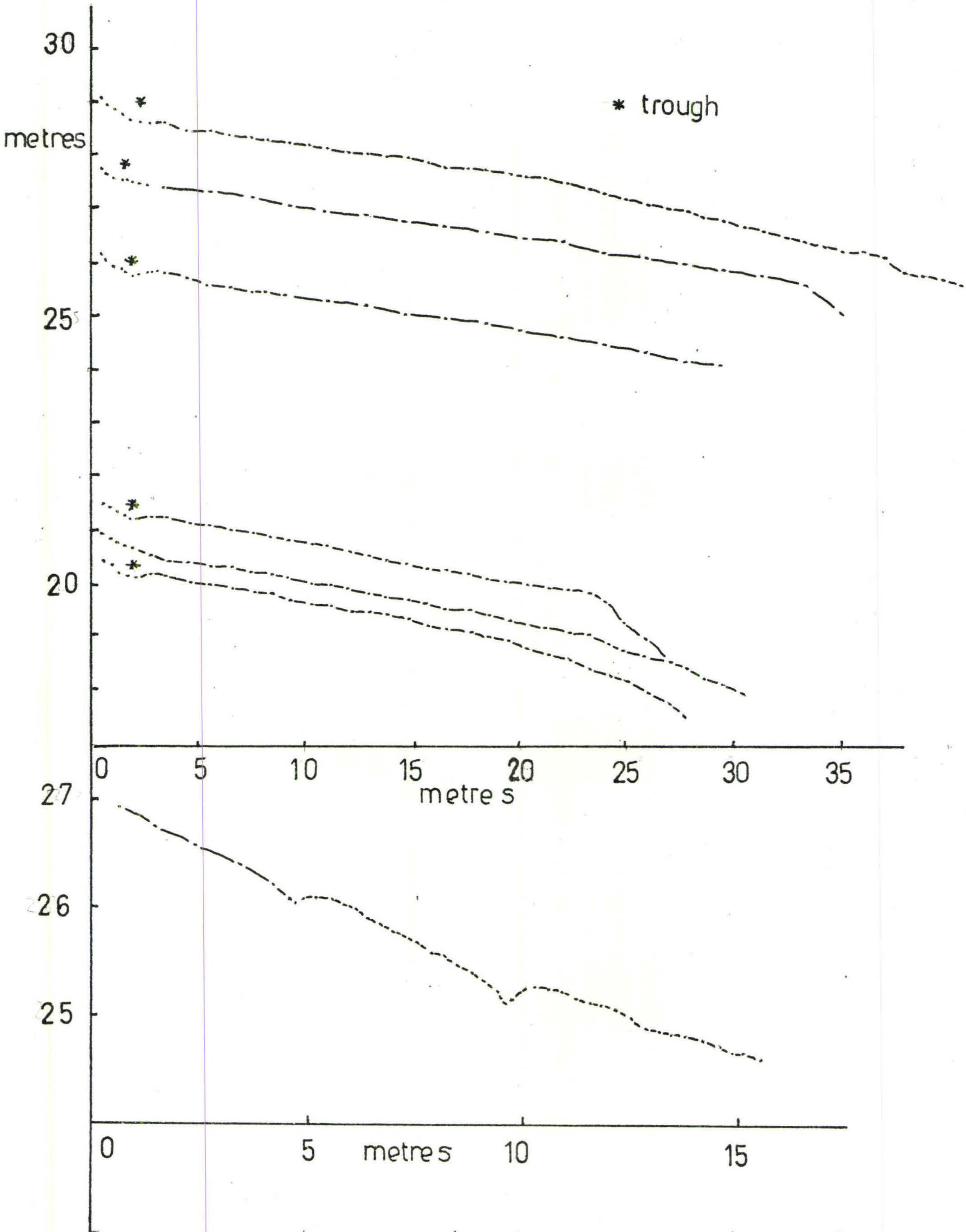


Fig. 2:8 Surveyed profiles of raised beach terraces 1970.

Such elementary features are common but compound features, possessing less well-marked breaks in slope, regolith variations or drainage characteristics, also occur. The above features are not limited to the talus foot slopes or raised beach areas. Small features of similar form were examined on the 'South Plateau' between Gascoyne inlet and Radstock Bay.

Feature (b), the break in slope, is usually orientated transverse to the drainage fines and the hollow so produced frequently retains a snowpatch through much or all of the summer.

The bulk of the thesis will examine sediment transport and deposition by fluvial and niveo-fluvial processes across this topographic unit.

Regolith and soils:

Soil development was usually observed to be minimal and the salient features of the surface debris and regolith will be described with particular reference to the main topographic class delimited in the previous section.

The plateau cover: The 'soil' cover varies between felsenmeer and fine-centred polygonal nets with stony rims. In general the textures approximate to gravelly sands and sandy gravelly loams but variation is great in the horizontal and vertical planes due to frost action and multigelation (Jackson 1970).

Surface erratics and glacial striae on the top of Beechy Island (Fortier 1963) and the occurence of tills around the coast of Radstock Bay and Gascoyne inlet demonstrate the possible glacial origin of much of the surface cover of the plateaus. In contrast, Jackson (1970) considers that these poorly-differentiated plateau soils are derived from frost weathering of the local bedrock.

<u>The detritus slopes:</u> Below the cliffs or free face, debris slopes accumulate as talus sheets and cones. They consist of a wide variety of angular debris varying between boulders and silts and clays. Bones (1971) points out that the fall sorting of these deposits can be drastically altered by the action of slush avalanches and basal erosion. Of major interest to this thesis however is not the details of the coarse components of the talus, but the occurrence of fines. These fines, clays, silts and sands occur as well — poorly-sorted mixtures in the talus gravels and between the bedding planes in the rocks exposed from under the talus (fig 2:9). Also, large exposures of poorly-sorted detritus, rich in fines, were found where the Cape Lidden talus sheets were being undercut by wave action. The existence of such fines could represent an extensive source of sediment load for the water drainage through the talus.

<u>The foot slopes:</u> At the talus foot the major break in slope forms the boundary of the talus foot slopes as described, and the regolith textures, like the surface gradients, contrast markedly on either side of this line. At the break in slope these slopes are comprised of coarse, angular debris, probably

Fig 2:9 Fines included in talus slopes near site A 1970

Fig 2:10 Patterned ground representative of the mid talus foot slopes, site A, 1970.

derived from the talus, and exhibit occassional small fine-centred polygons. Down slope the surface cover of gravel and boulders decreases and the matrix of fines gradually predominates until, at the silt plains, gravels are rare or absent.

Patterned ground is apparent in the form of well developed nets of high centred polygons and vegetation stripes following rill courses(fig. 2:10). This co-existence of striped and polygonal features on the same slope appears to be a response to two different slope processes or conditions, namely the availability of water (vegetation stripes) and the presence of frost sorting (high centered polygons).

These talus foot slopes are referred to frequently in the periglacial literature, although the genesis of the deposits and the slope profile remains unlcear (chapter III).

<u>The silt plains</u>: These can be considered to be a member of the morphological and textural continuum of the talus foot slopes, although a textural boundary could sometimes be distinguished thus defining them as a distinct terrain unit. In either case, they were found to vary little in texture, being predominantly silts, silt loams, or loams with rare occurrences of gravels. The vegetation cover consists of grasses, mosses, Papaver and Arctic Willow which had colonised much of the hummocky surface. The so called 'contemporary silt plains' at site S.P.G. (fig 2:4) are still being added to by slope sedimentation and are not hummocky in surface relief, merely possessing an unsorted net surface.

The silt plain <u>sensu stricto</u> possess a buried organic horizon at 8-24 cm. and another one at 38-45 cm. Judging by its slope position this feature was probably caused by the accumulation of sediment in a fluvial or lagoonal environment.

In similar topographic positions occur meadow tundra; poorly drained areas with a continuous organic cover usually developed on a thin, black fibrous peat cover. The underlying mineral matter was found by Jackson (1970) to vary within the range loams, sandy loams and sandy gravels.

Raised beach areas: These areas are not merely raised areas of gravel, but vary within the bounds of coarse gravels, gravelly loamy sands and gravelly loams depending on slope position. As stated, the terraced features present on the raised beach terrain possessed a contrasting surface cover. The back slopes consist of gravels occassionally sorted into stone stripes but fines do occur often in the form of parabolic hummocks which merge downslope into the surrounding gravels. Such features are, as yet, undocumented and are not sufficiently well understood to warrant a genetic name.

The foot slopes contrast markedly with the back slopes by possessing a high proportion of fines in a framework of subrounded to rounded medium gravels. Unlike the talus foot slopes, the surface cover of stones tends to increase away from the break in slope (i.e. down slope). This phenomenon will be discussed in Chapter VI.

These five units represent the main soil/geomorphic classes examined. All sites show that soil development is inhibited, horizonization is not apparent, apart from the surface layer in certain tundra soils and translocation of physical and chemical constituents, although documented (Jackson 1970), is rare. The soils of the area fall into Tedrow's (1966) Polar Desert class, soils that are associated with a down slope catena of well drained (Polar desert), gley (Tundra) and organic soils (Bog). Features of pedogenisis are poorly developed although gleying occurred at depth in waterlogged silt loams near site D (fig. 2:4) and surface effloresenses of silts sometimes appear during dry periods. In such rigorous environments weathering is presumed to be predominantly mechanical with chemical weathering playing a subsidiary role; Jackson states that only Ca^{++} is mobilized to any significant degree in the soil.

Tedrow and Cantlon (1958) and Hopkins and Sigafoos (1951) consider in situ weathering combined with inheritance from the bedrocks to be of major importance in the genesis of the texture of Arctic soils although tills, as stated, could also provide a sourse of fines in many areas.

Climate:

Devon and Cornwallis Islands come well within all definitions of the periglacial environment although they are only loosely 'peripheral to the glacier ice of today...' (Embleton & King 1968),

- the nearest glacial ice being approximately 75 miles to the east. Conditions are rigorous with a mean daily temperature for February and July of -33°C and +5°C respectively at Resolute (fig. 2:11). Climatic data for Resolute can be taken as reasonably accurate for S.W. Devon Island because Radstock Bay is at the same latitude and within 100 miles of the Resolute meteorological station.

Much significance must be attached to the quantity of precipitation and the metereological factors influencing spring thaw as these critically affect the amount and timing of the spring thaw meltwaters.

Precipitation occurs mainly in the summer and early fall and is associated with influences of cold air from the Arctic Ocean and Beaufort Sea which, when crossing the relatively warm land lead to atmospheric instability with associated storms. In the months of September and October the precipitation falls mainly as snow which then remains through winter to form the bulk of the snowpack during the spring thaw. Total precipitation is not very reliable for, as Cook (1960) indicates, the trace falls of snow can accumulate to form a significant snow thickness (12-62% of annual total water equivalent) and consequently the measurement of snowpack thickness is prefe rable. This has the disadvantage of requiring a rigorous snow survey and therefore cannot be assessed from precipitation records.

The mean annual precipitation is low, around 135 mm. p.a. (Resolute), but the hydrological environment differs markedly from that of low latitude , low rainfall, areas because most water

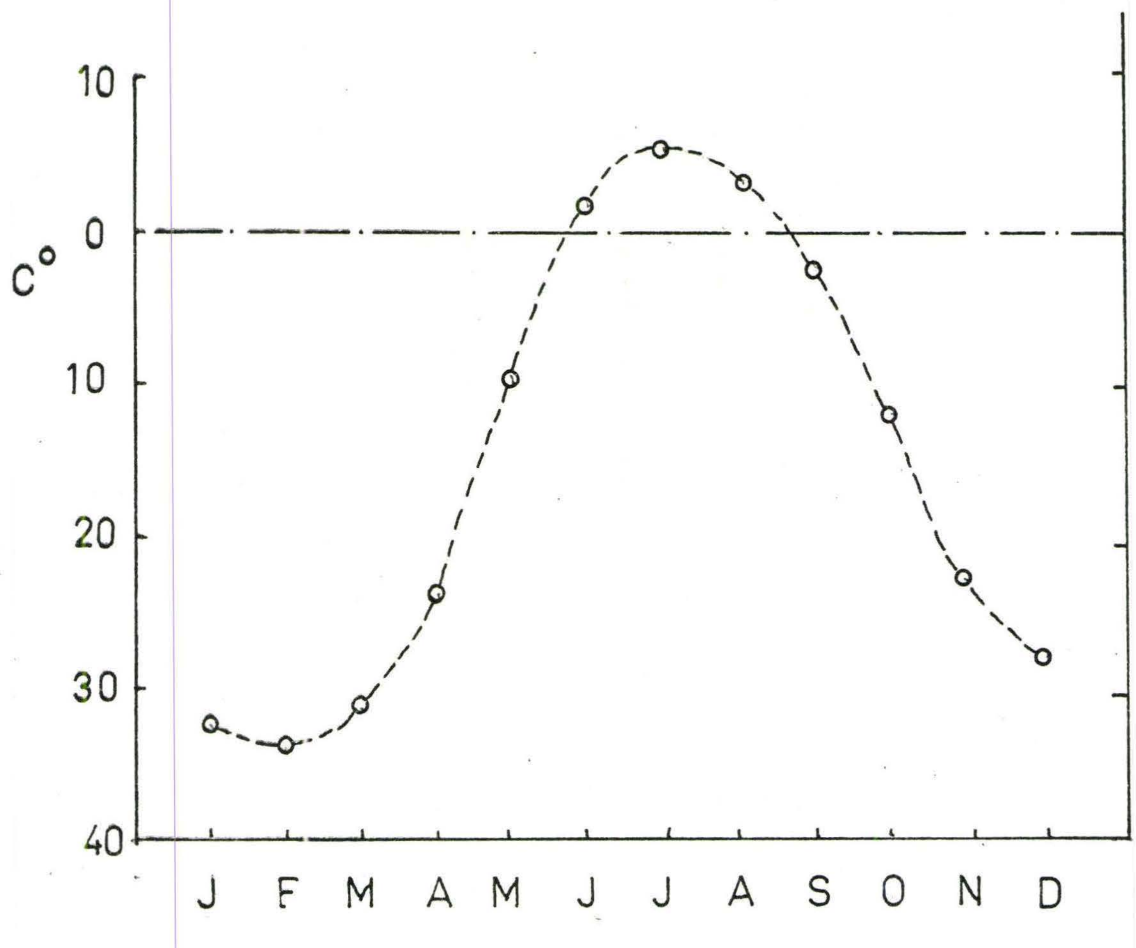


Fig 2:11 Mean daily temperature at Resolute 1950-1960.

is in storage as snow and permafrost ice during nine months of the year. Fristrup (1952) however, considers areas of similar climate in Peary Land, N. Greenland, to be analogous to low latitude arid areas and he designates such areas : Arctic Desert.

The snow, on melting, leads to rapid discharges of water although some remains behind as soil water and storage in snow-patches. Evaporation is usually low throughout the spring and summer due to frequent foggy and cloudy conditions.

The thaw season is usually under way by mid June. Temperatures, although not very well correlated with the rate of snow melt, can be used as a general guide to the onset of the spring thaw. Data from Arctic summary for 1964-68 indicates that in early June, mean daily temperatures rise above freezing sporadically but this rise is not consistent until the period 15th-26th approximately. By late June/early July the daily mean minimum temperatures also rise above freezing and remain just above until around mid August.

In the summer of 1970 at Resolute, the thaw season was late and the mean daily temperature did not rise above freezing until the 21st of June. At this time the snow depth reading was 11", the same as at the beginning of the month and the final snow, recorded as a trace, fell on the 23rd. This period from the 21st of June until early July (when the rivers reached peak discharge) can be considered to define roughly the duration of the peak snow melt season for 1970.

The 1971 thaw season at Resolute started earlier, for by the 8th-9th of June mean daily temperatures were consistenly above freezing and by the 21st even the minimum daily temperature was above freezing. The final snow fall was recorded on the 11th when snow depth was still 15"; the snow depth in fact decreased from 19" on June 1st to a trace on the 21st.

In general, in 1970, the snow depth was low and the thaw season was late, commencing around June 21st. This thawing was accelerated by a 12 mm. fall of rainfall on June 26th which led to higher input of water into the drainage systems. In contrast, the snow depth on June 1st 1971 was higher and melting started early, around 11th-15th of June. The thaw period therefore occurred well before the arrival of the writer on June 25th and by then the overland flow system was stabilized into its summer pattern.

The drainage of the land surface:

Water in the drainage system was supplied by the melting snow pack, interstitial and vein ice of the permafrost and occassional inputs of rainwater. Cogley (1971) considered the first named to be the most important in the spring with rainwater assuming the prime role during the summer when the snow cover was limited to snow patches.

Such inputs of water combined with the early season high permafrost table led to a rapid evacuation of waters accross the land surface and through the shallow active layer. As the summer developed the relative significance of these drainage types changed and no attempt will be made here to establish a hierarchy of importance.

1. Supranival flow:

This occurs early in the thaw season when surface drainage is deranged and immature and the active layer shallow. Flow takes place through and across the snow pack, the latter condition being represented by anastomosing channels which merge into supranival sheet flow in an unpredictable manner downslope. Supranival flow also occurs in conjunction with mid and late summer snow patches that remain at breaks in slope. This will be elaborated in chapter V.

2. Overland flow:

a) Rill flows: After the ground surface cleared of snow a stable subparallel set of rills developed (fig. 2:12, 2:13, 2:14) on a variety of less permeable surfaces. These rills appeared to flow across the frozen ground surface early in the thaw, but as the active layer deepened it became apparent that a frozen ground surface was not necessary for the support of the rill system.

A large proportion of rills have their source between 0.5 and 10 m. from the talus foot. In general, water from the talus slopes flows onto the foot slopes via the coarse margins of patterned ground and after several minor channel confluences this

Fig 2:12 Sub-parallel sets of rills, site A, 1970. Snowpatch A in foreground.

Fig 2:13 The interflow--overland flow junction, site D. Staff divided into 10cm. sections.

Fig 2:14 Rill flowing across talus footslopes, late June 1970

water emerges at the surface in the form of rills. Dimensions, flow velocities and discharges are given in (table 2:1)

TABLE 2:1

RILL PARAMETERS 1970

Rill Station	Width cm.	Depth cm.	Velocity cm.	Discharge cc/sec	Mean * S.D.R. gm/day	Mean hardness mg/litre Ca + Mg	Ca
D	35	2.5	47.4	2277	3.5	72	55
A	26	3	44.2	1728	6.3	85	60
G 1	20	4.6	52.8	2385	49.5	97	66
G 11	---	---	----	3998	37	--	--

* Sediment discharge recorded (chapter IV)

b) Sheet flow: This flow type was not common in the study area but occassionally occurred along the downslope portions of rills, for example, on rill D 1970. As stated by Emmet (1970), sheet flow tends to occur in a series of channels separated by sheet flow; this and the fact that sheet flow actually occurred along rill channels indicates that sheet flow was mainly a member of the rill system.

c) Polygon margin flow: Early in the thaw season overland flow is conducted along the margins of high centered polygons. These temporary anastomosing channels could be traced later by the small dunes and 'fluvial' deposits remaining on the surface.

3. Interflow:

This is defined in the context of this thesis as the relatively rapid flow of water through the active layer of the ground, usually across the impermeable surface of the permafrost table.

a) The porous openwork talus and gravel backslopes are usually drained by interflow systems of small channel flows and stone stripe flows conducted across the permafrost table. Interflow also takes place as sheet flow through the macro voids in the gravel, although the dominant evacuation was via the rapidly flowing 'channel flows'.

b) Interflow was observed to be less common on the impermeable low gradient slopes, but the coarse and depressed margins of high centered nets usually transfer a significant quantity of water through the regolith. Dye tests indicated patterns (fig 2:15) and flow velocities (table 4:1) for this flow type, but as available water decreased through the summer this polygon margin interflow assumed less significance.

Such flow types are the dominant interflow types on low angle slopes, but a peculiar situation was noted near site D late in the summer, 1970. Here fines possessing a low infiltration capacity overlay open work gravels which conducted a rapid discharge of percolating water from upslope. No similar instance of this flow type was found.

The later features of the drainage system (2 and 3) became established after the early thaw season supranival flow period. Their regime appeared not to be fixed. As the summer developed,

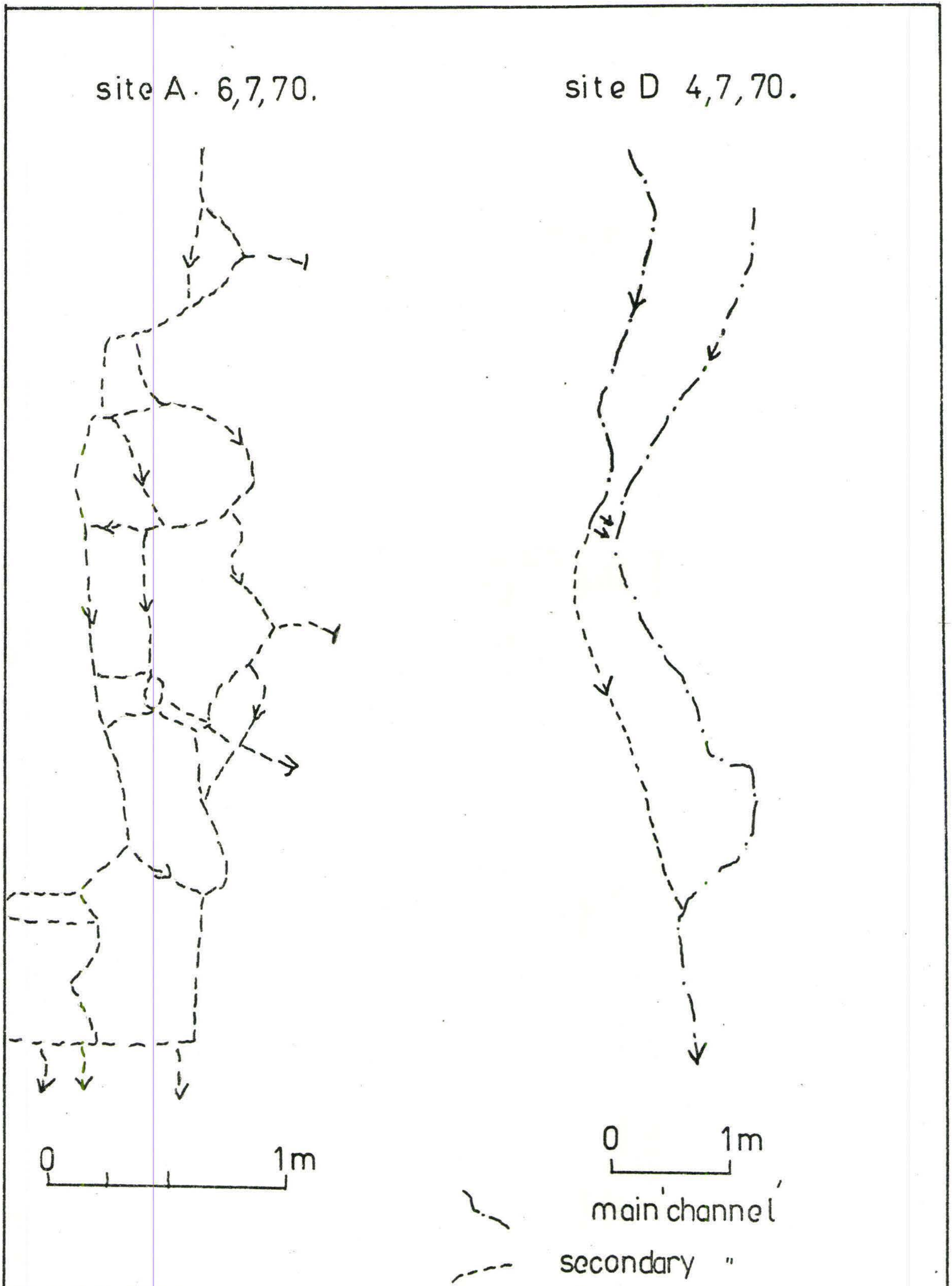


Fig. 2:I5 Subsurface polygon margin flow patterns.

rills dried up, usually at the upslope end first and consequently interflow expanded, albeit at diminishing rates. Zones of rill flow frequently alternate with interflow downslope depending upon surface conditions, infiltration capacity and water content. Sometimes this alternation was spasmodic and irregular, especially on complex slopes, such as those at the foot of Signal Hill, Resolute, which consisted of felsenmeer, talus, and gravelly sands and loams distributed in an unpredictable manner.

CHAPTER III

LITERATURE AND PREVIOUS INVESTIGATIONS

The examination of the literature pertaining to overland flow and interflow in the periglacial environment is complex and involves the study of a variety of associated processes and environments.

The following topics, all relevant to overland sedimentation or Arctic fluvial processes, will be briefly considered:

a) Fluvial activity in the Arctic.

b) Surface wash and rill flow in the Arctic.

c) Snowpatch and nivation phenomena.

d) Previous descriptions of topographic types similar to those on which the present study is based.

e) Evidence of slope wash from Pleistocene periglacial environments.

f) Sediment movement in semi-arid areas.

a) Fluvial activity in the Arctic:

Little information on this topic is available, but Cook (1967) working on the Mecham river, Resolute, outlined the salient features of the snow melt runoff system as:

i A pre-melt period in early June during which snow is lost, mainly through sublimation.

ii A period of intensive melting lasting about a week after the daily mean air temperature rises above 32°F.

iii A period of catastrophic flood and continued rapid melting of snow in the basin. This period is of about ten days duration and discharges c. 90% of annual runoff.

iv A period of sharply decreased flow which continues until the river freezes to the bottom.

v After mid-September a period of snow accumulation until June.

Cook considers that the period of catastrophic flood is not primarily an agent of erosion, but one of removal; i.e. material supplied by weathering and mass movement is finally removed completely by fluvial action.

Cogley (1971) working on 'Jason's Creek', a small river flowing into Radstock Bay, adds quantitative confirmation and further details to the generalizations made by Cook.

This pattern of events as outlined by Cook and substantiated by Cogley seems well established, but Rudberg, working on Axel Heiberg Island (in Pewe 1969) considers the production of the 'obvious and widespread evidence of running water' to be somewhat of a mystery. In the season under consideration little water was added to the system by spring snow melt and it was not until after the mid July rains that fluvial action became significant. Such a difference could be ascribed to temporal or spatial variations within the periglacial environment. That is, due to the spatial variation of the climate of Arctic Canada or because the summer in question, 1961, was atypical of the climate of the area. Such problems are not resolved by Rudberg, but they indicate that generalizations about the periglacial environment should be restricted to the area and time period under consideration.

Pissart (1967), working on Prince Patrick Island considers erosion during the spring flood to be diminished due to the presence of ice on the river beds. This, however, is not in contradiction with Cook, who as stated, considers fluvial action to be mainly an agent of removal and transport.

Arnborg et al (1967) made investigations at 70°N on the Colville river in Alaska and in general corroborates the sequence of Cook. The summer is longer though and the thaw season of slightly greater duration, being three weeks during which about 43% of the water and 73% of the annual inorganic load are discharged.

b) Surface wash and rill flow in the Arctic:

Studies of slope wash in the Arctic are meagre and many workers treated slope wash as a subsidiary process; hence the little studied process was deemed to be of little significance. Two studies giving more emphasis to slope wash are those of Jahn (1960) and Czeppe (1965), both were made on Spitzbergen between 77 and 80° N.

Jahn (1960) measured slopewash by setting sediment traps on seven different slopes in Spitzbergen and reported that slopewash was of significance especially during the spring melt season. He interprets this as a slope lowering process (1 mm. per 150 years) per unit area thereby assuming that all of the sediment trapped was coming from within a defined catchment area. Such a condition is considered weak by the writer for it is possible that material was being swept from upslope, was partially deposited in the catchment area with only the residue being caught in the traps. Jahn does not state whether this movement is by suspended or bed material load.

Czeppe (1965), in a qualitative study on south west Spitzbergen, is in favour of slopewash as an active agent of denudation. The overland flow occurs on and just below the surface as rills and sheet wash. The latter was noted mainly on the lower slopes and was observed to have swept down a significant amount of material from upslope. The rills, flowing in subparallel lines downslope had the appearance of non-sorted stripes, but such patterns were later 'retouched by autumn multigelation'. In conclusion he states that sheet flow dominates over rill flow and acts more as a denuding agent than an erosional one. Accumulation of sediment was in the form of thin covers and thus easily escaped the attention. This study places much emphasis on the recording of events during the snow melt season as well as on observations of the wide variety of overland flow types. In addition, the observation of subtle features of slope deposition and the possible disturbing effect of multigelation show that, although no attempt is made to evaluate the quantitative effect of slope wash in denudation, the study outlines the salient features well.

Many other studies either consider overland flow as one aspect of a large geomorphological study (Bird 1967, Rudberg 1961, Cook 1960, 1967) or relegate it to unsystematic observations subsidiary to the main study (Rapp 1960 a. and b.). Bird considers slopewash to be of greater significance towards the base of slopes but little evidence is quoted to support such an observation. Rudberg, working on Axel Heiberg Island, stated that: 'samples taken showed that the transporting ability of subparallel rills was insignificant'. The only evidence of such activity was after the July rains when erosional forms and immature fans were observed. It is unclear whether these features were normally formed during the spring melt season or just during mid summer storms.

Cook (1967) also considers rill wash to be of significance only during summer rain storms after which he noticed extensive surface depositional forms.

In his extensive studies in Karkevagge (1960 a.) and Templefjorden (1960 b.) Rapp considers rill action in its context of being one of the processes of removal of material from talus slopes. He states that in the hierarchy of slope movement processes under consideration, running water (removing solute load) is of greatest importance whilst talus creep is of least significance. Slope wash was not placed in the hierarchy, but was considered to be of minor importance on the till and grass covered slopes of Karkevagge (68° 26'N). Similarly in Templefjorden (Spitzbergen) he judges rill action to be of minor importance , for only on three occasions did rills possess suspended sediment load and on one of these the turbidity could be related to a mud flow on the talus slopes. He concludes that neither bed load nor suspended load was able to form deposits in front of the talus base.

Of the papers examined, the ones treating slopewash specifically judged it to be a significant process and those of a more general nature or on another topic deemed it to be only a minor factor. The conclusions were therefore, almost auto-catalytic, intensive study led to an increased significance in the process studied, hence further intensive study was required. Such factors are also confused by the widely differing environments studied and illustrate that great variability exists within periglacial areas.

c) Snow patches and nivation phenomena:

Just as the winter snow pack melts in the spring to provide meltwater for rills and rivers, the residual snow patches that remain into the summer continue to supply the ever diminishing rill systems. The actual proportion of rills supplied by snow patches is uncertain from the literature, for Lewis (1936 and 1939) considers the snow patch to be the main source whereas, McCabe (1939) and Dinely (1954), both working in Spitzbergen agree that some moisture could seep into snow patches from upslope.

Lewis (1939) describes snow patch conditions and then continues by relating the features found to the theory of nivation.

The hollow in which the main snow patch was located consisted of a gentle slope of stones in a matrix of 'mud' backed by a steeper back slope of boulders and stones in clay. Features observed associated with the snow patch included bands of 'grey snow' which were thickest at the base of the snow patch. The snow patch base was usually frozen, but when heavy rain was falling the snow patch was saturated and the basal layers melted; associated with this melting were small runnels which constantly moved materials up to the grade of medium sand. Later, when basal melting continued up into the snow patch, such runnels carrying sediment were found in pits sunk into the snow and were observed to form minor debris fans. Lewis considered that melting was a temporary condition and freezing would again set in; this alternative freezing and thawing would then comminute the bedrock, thereby supplying fine materials. He 'confirms' this freeze-thaw process by observing that large amounts of fines occurred beneath and adjacent to snow patches. This nivation effect thus, finally leads to the entrenchment of the snow patch into the backslope forming a true nivation hollow. The analysis is only tentative though, for freeze-thaw cycles are not of great significance in the Arctic as previously supposed, (Cook and Raiche 1962 b.) and are diminished further under a thick snow cover (Embleton and King 1968). They are probably more significant under a thin snow cover where meltwater is available, but the actual degree of mechanical weathering is unproven. Lewis (1939) quotes the occurrence of fines under the snow patch as proof of mechanical weathering, but fails to consider any other source of supply.

McCabe (1939) makes similar observations. The snow patches studied were underlain by a concave-up layer of basal ice probably formed by freezing of water from melting ice or from upslope. Sometimes, however, a thin surface layer of thawed soil, underlying the snow patch was observed. Like Lewis, McCabe assumed that such a situation would promote freeze-thaw action. Deposits of fine mud were noticed to occur beneath snow patches and when disturbed, these would flow out into the snow patch rills. During undisturbed conditions transport in such rills was negligible.

McCabe continues by stating that the above quoted information points strongly towards nivation as an active process, but Balchin working nearby on snow patches at the foot of raised beaches observed that such snow patches played a protective role. The conclusion finally drawn by McCabe is that nivation is more active on solifluction slopes, but varies with the nature of the rock.

Observations made in the McMurdo sound region by R.L. Nichols (1963) showed that the base of snow patches was frozen to the ground, and that ground previously covered by snow patches was covered in sand flows and fans. Although such snow patches were incised up to 1½-2m. into the underlying deposits, Nichols considers this to be a minor process.

Dinely (1954) examined gully snow patches and showed that water passed under the snow patch as a thin film or along minute channels; this water, supplied from upslope as well as from the melting snow was then able to bear away the fine mud and comminuted particles resulting beneath the snow patch.

Pissart (1967) essentially agrees with the above observations although he adds that the evolution of steep slopes which shed water rapidly is slower than that of gentle slopes where solifluction is active. This he considers to be the mechanism producing the sharp break in slope in nivation hollows.

The above papers emphasize that water from the snow patch, or possibly from upslope seepage, flows beneath the snowpatch and washes material away. Most writers then conclude that such fines were produced by freeze-thaw action; the existence of such fines demonstrates that freeze-thaw processes are present in such micro-environments. This tendency towards circular argument could be resolved by either a more intensive study of freeze-thaw processes associated with snow patches or an examination of alternative sources of fines.

Topographic nomenclature:

The fundamental topographic types under consideration, namely talus and foot slopes and terraces located on raised beach gravels were described in chapter I. Previous investigators, when discussing such morphological types, have tended to use genetic terms in the basic descriptions, thus imposing a degree of certainty not justified by the present state of research.

Jahn's (1960) classification can be summarised as follows:

1) Weathering rock walls (>40°) and slopes covered with a thin talus cover (25-40°).

2) Dry gravity talus slopes and cones (30-40°) and humid slopes (15-25°).

3) Solifluction terraces a) high short talus terraces 15-25°.
   b) medium length terraces 10-15°.
   c) long low terraces 3-10°.

4) A zone of sedimentation by slope water and disappearing solifluction symptoms, 2°-5°.

Bird (1967) makes a similar classification by dividing such slopes into: a steep rock wall, a talus zone and a solifluction bench. This lowest bench is considered to develop frequently from marine silts or glacial deposits and is thought to be associated with slope wash on its lowest sections.

Tricart (1963) when examining slopes in cold climates makes a three fold classification similar to that of Bird. Its lack of genetic terms makes it less misleading than the previous two descriptions by Bird and Jahn, but he does add that solifluction attempts to smooth the low angle slopes and that such slopes also receive deposits from slope runoff processes.

The writer considers Jahn's lower two divisions (3 and 4) to be misleading because at the present time no research has demonstrated the existence of two mutually exclusive lower slope zones. Such slopes are probably polygenetic being subjected to solifluction and sedimentation by slope waters.

In addition to these slopes of complex genesis, many periglacial slopes possess a complex, stepped morphology. Jahn (1960) observed stepped slope profiles on Spitzbergen and stated that, although in many respects they resembled altiplanation terraces, they could more readily be attributed to denudation of less resistant strata.

The terms altiplanation terrace and nivation hollow refer to features that are essentially similar in form and possibly in genesis (Embleton and King 1968). These features consist of treads of predominantly fine materials, backed by steep slopes of bare and angular talus (Eakin 1916); sometimes this backslope is replaced by rock walls (Czudeck 1964). The feature has also been observed to be cut in bedrock (Te Punga 1956, S.W. England) and such cases have been covered with a thin veneer of superficial deposits.

The genesis of such features, if indeed they are all related to the same process, is not yet clear. Waters (1962) and Botch (1951) state that the upslope edge of initial transverse depressions is worn back by 'frost sapping' and nivation, thus leading to parallel slope retreat. The fines produced by snow patch action (Waters 1962, Lewis 1939, Cook and Raiche (1962 a.) are then removed by rill wash and solifluction. If these processes are operative it is likely that a delicate balance will exist between supply (frost action and comminution of slope materials) and removal.

As stated above however, many nivation processes are yet to be empirically substantiated and the addition of such nebulous terms as frost sapping to such theories leads to a fragile theoretical structure and such terms are not yet justified by quantitative studies.

Both of the above slope sequences examined, i.e. those associated with rock walls, talus slopes and foot slopes and those associated with altiplanation/nivation terraces have been described in chapter II. Some processes acting upon these features will be examined in subsequent chapters, although no final explanation of the forms will be attempted.

e) <u>Evidence of slope wash from Pleistocene periglacial environments:</u>

It has been shown that information on slope wash in areas of contemporary periglacial activity is sparse. This is not so in continental Europe which was subjected to periglacial conditions throughout most of the Pleistocene glacials; in these areas much evidence from slope deposits has been accrued and interpreted as evidence of slope wash.

Pecsi (1969) actually attempts a genetic classification of slope sediments using classes depending upon: sediment dip, layers and microstratification, characteristics of grain surface (worn and unworn), sorting and particle size. Such sediments vary between coarse angular debris with open work texture (collapsia) to deposits of well sorted fine sands and silts (deluvial slope Loess).

Only some of the slope sediments are classified as deluvial and these are thought by Pecsi to be produced in the following manner: "Rains and snow melt give rise to a sheet of water which carries away fine particles of sediment and deposits them in the form of finely striated sediments either on the slope itself or at its foot." Such deposits, which are frequently micro-stratified, usually alternate in layers with products of wind blown sediments, collapsia and solifluction. As well as this vertical layering Pecsi considers that variations occur depending upon aspect; deluvia being most abundant on south facing slopes while solifluction predominates on north facing slopes.

Dylik (1960) examines rythmically stratified slope sediments within the context of variation of characteristics in Europe. Essentially the Polish deposits consist of lower layers of coarse open work materials grading into upper alternations of layers of sand, silt and debris sometimes streaked with humus layers. The lower coarse sediments are similar to the grèzes litées of France whereas the upper layers of slope wash and solifluction deposits contrast markedly, hence Dylik prefers the all encompassing term 'rythmically stratified slope waste deposits'. The above textural contrasts are paralleled by contrasts in sediment dips; the dip of the Polish deposits being about 15° whereas those of France dip more steeply, up to 40°. He concludes by relating the deposits of France and Poland to the prevailing continentality of the

Pleistocene central European climate and states that the recurrent bands of sediment deposited by running waters offer convincing evidence of the preponderance of downwash in these formations.

Other workers in this field in Central Europe include Czudek (1964) who describes slope sediments of alternating coarse and fine bands of gravels, sands and loams dipping between 10 and 20°. These deposits, common on slopes of the Bohemian Massif are considered to be products of solifluction and slope wash. Leszek Starkel (1960) actually divides similar slopes into zones dominated by solifluction and down wash but each zone is considered to be effected by the simultaneous operation of such processes.

In west central Wales, Watson (1965, 1967) has examined series of deposits occurring on hill slopes and divides them into products of gravity screes, solifluction and down wash depending on texture, dip, slope position and aspect. In the Aberystwyth region features are described consisting of gentle (3-8°) terraces backed by steeper slopes [(12°-20°) covered in fine scree, or (25°-35°) consisting of rock and coarse debris.] The lower slopes consist essentially of upper and lower stony clays divided by beds of washed and well worn gravels; these he considers from textural and fabric properties to be solifluction and slope wash deposits respectively.

'Niveo fluviatile' deposits were studied in the Netherlands by Maarleveld (1960) and Maarleveld and Van der Hammen (1952). Such deposits were presumed to modify the Pleistocene glacial drifts by washing out the fines thus producing colluvial debris fans.

Apparently abundant evidence can be quoted from the above regions, but it is clear that many of the interpretations are clouded by hypothesis.

Sedimentological properties are examined briefly but no reference is made to empirical or field work pertaining to such deposits and until such a sound experimental base is provided, such descriptive terms as Dylik's 'stratified slope waste deposits' must be retained.

f) Sediment movement in semi-arid areas:

This topic is extensive and only references of particular relevance will be discussed.

Periglacial areas, especially the high Arctic and Antarctica are areas of rainfall deficiency and have come within many definitions of aridity (Fristrup 1952). This study does not attempt to tackle such definitional problems, but merely examine one aspect namely the potential annual sediment yield in relation to effective precipitation and vegetation cover.

Langbein and Schumm (1958) state that a general relationship can be shown to exist between sediment yield (s), mean annual runoff (R) and mass density of vegetation (V). This relationship $S = \frac{R}{V}$ shows that increasing mean annual runoff (which is loosely correlated with mean annual rain fall) leads to an increasing sediment yield which is then cancelled out by the increasing mass density of vegetation (which again can be loosely correlated with mean annual rainfall.).

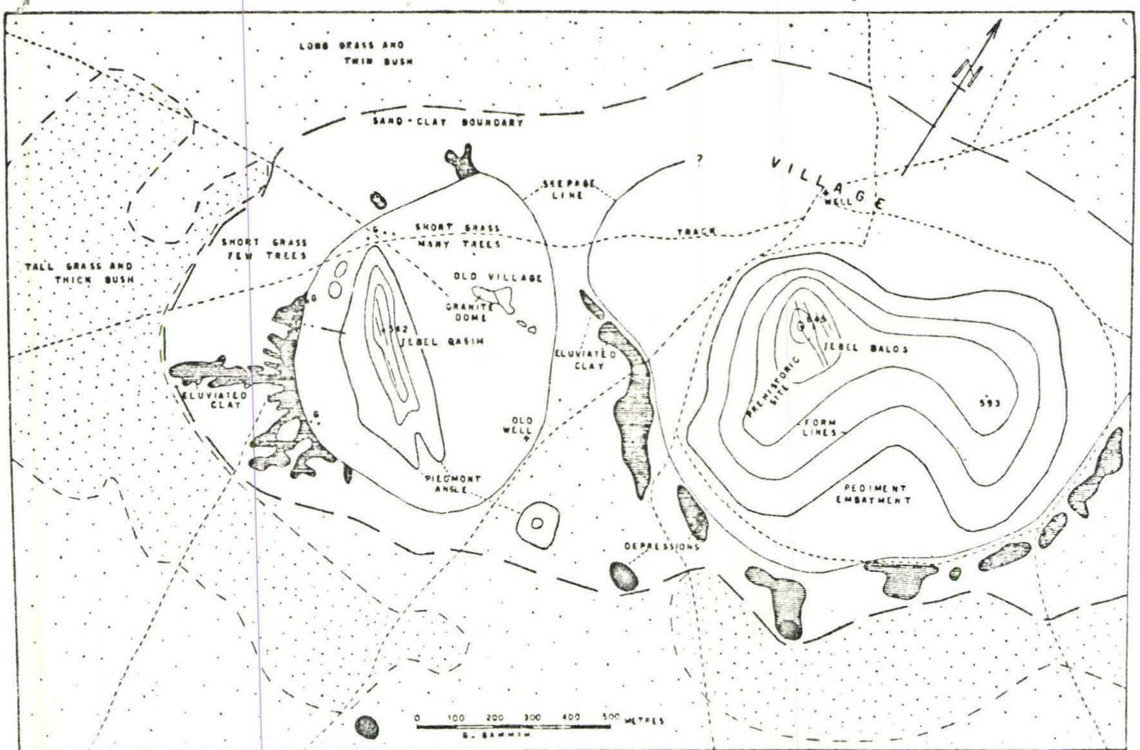
Such a relationship is only very generally applicable and is liable to wide misinterpretation, but empirical evidence was supplied from gauging stations and reservoirs and lent some justification to the equation. In general with an effective precipitation of 0" p.a. sediment yield is nil and as effective precipitation increases sediment yield increases to a peak around 12-15" of effective precipitation p.a. . After this peak, vegetation density increases sufficiently to impede erosion hence, sediment yield then decreases with increasing precipitation. The sediment yield/effective precipitation graph peaks at the boundary between desert scrub and grassland, therefore it is logical to examine Arctic areas possessing low vegetation densities within this context.

The density of the Arctic vascular plant cover does not simply decrease with decreasing rainfall for temperature, length of growing season and available plant nutrient must also be considered. Polunin's high Arctic vegetation zone (in Bird 1967) extends across most of the islands of Arctic Canada and within this zone mean annual snowfall varies between 20cm.and 50cm.p.a. (Atlas of Canada). No detailed analysis is possible here, but the high spring runoff (analogous to storms of semi arid regions) when incorporated with the low vascular plant cover could well bring large areas of the Arctic archipelageo within Langbein and

Schumm's zone of maximum sediment yield.

In semi-arid areas of the Sudan, Ruxton (1958) has sought to demonstrate the existence of 'eluviation' of fines through the subsurface mantle of pediment slopes. The topography is similar to that of the study area with rocky hills occurring at intervals fringed by steep boulder strewn slopes footed by sandy pediment slopes leading into sub-horizontal clay plains. A sharp piedmont angle between 5 and 13° occurred at the foot of the hill slope. Downslope of this piedmont angle a zone of moisture seepage occurred along which moisture flowed during intense rainfall. Beyond the upper limit of seepage lobate deposits of eluviated silt/clay (fig. 3:1) were deposited, according to Ruxton because of the washing of fine particles through the interstices of the coarse materials of the regolith by subsurface drainage waters.

The above mentioned similarities of topography are widely apparent, but to draw too many conclusions from this is dangerous. Tricart does however, point out the obvious parallels by stating that a periglacial equivalent of the 'piedmont glacis', built up by sheet flow from hill slopes, could well exist, but later he concludes that the role of running water in low lying periglacial areas has often been exaggerated.



TEXT-FIG. 2.—Geomorphic map of Jebel Balos and Jebel Qasim, drawn from an aerial photograph.

Fig 3:1 'Eluviation'of fines on pediment surfaces in the Sudan (after Ruxton 1958).

CHAPTER IV

THE DYNAMICS OF SEDIMENT MOVEMENT

As stated, the drainage of the land surface was performed by a complex of rills, sheet flow, inter flow and supranival flow. Early in the thaw season snow meltwaters were evacuated rapidly due to the high permafrost table and the limited basin storage. Runoff was also increased by the melting of the underlying permafrost ice and contributions of rainfall throughout the summer.

This study of sediment movement will be limited to rills and interflow associated with topographic features described in chapter II comprising a backslope, a break in slope and low angle slope sequence. These features associated with talus slopes and raised beach gravels are drained by interflow on the back slope and overland flow (rills) on the low angle slopes. Sediment movement in such rills will be examined and related to processes occurring in the rills at the break of slope and in the interflow zone.

This quantitative study of sediment transport in certain rills was supported by a large number of qualitative observations in both 1970 and 1971. The measurement of sediment movement in rills commenced on June 30th, 1970, that is when the rill system had stabilised. Before this, however, qualitative observations had been made on the retreat of the snowpack and permafrost table and on details of niveo-fluvial activity.

Snowmelt and the developement of overland flow:

Most of the studies of sediment movement were conducted in small rills 20-40 cm. wide, 2-8 cm. deep and with velocities less than 60 cm./sec. (table 2:1). Discharges were less than 4000 cc/sec.

On arrival at Radstock Bay, June 20th 1970, snow cover in the study area was virtually continuous and by 24th June was estimated to cover 90% of the surface. On the talus footslopes, between sites A and G, a transverse strip of ground then appeared, leaving snow covered upper and lower slopes. meanwhile, the valley bottom area remained completely covered and was drained by a river flowing through and across the snow surface.

This transverse strip expanded in area on the 27th, but snow cover was still continuous on the lower slopes and valley bottom. During this period the snow pack was ripe and became saturated with percolating water. Gradually, this transverse strip grew and by June 30th rills were established every 2-8 m. along the slope. By July 2nd ground became exposed in the valley bottom and portions of the supranival river were superimposed on the ground surface (fig. 2:4).

Exposure of the ground surface was almost complete by July 5th with the talus footslopes being virtually clear whilst the valley bottom possessed a snow cover of 10-15%. The thaw period was delayed on the south plateau and on July 8th supra-nival rill flow still existed (fig. 4:1).

The 1971 snowmelt season at Resolute was earlier than in 1970 (chapter III) and on arrival (27th June) snow cover was limited to snow patches with a more extensive cover remaining on the plateaus. From this date the only obvious change was the melting of the plateau snowpack and the gradual recession of the snowpatches.

The presence of the impermeable permafrost table at a depth of less than 80 cm. led to a rapid throughput of melt and rain waters in the form of overland flow and interflow. Depths to the permafrost table were established by augering for two sites throughout the summer of 1970 (fig. 4:3). Other augerings were made on a variety of terrains ranging from meadow tundra (v fig. 4:3) to loose gravels.

Depths were found to vary with soil texture, water content and vegetation cover. Organic rich soils, especially those incorporating peat, possess low thermal conductivities which do not increase markedely with increasing water content (de Vries 1963). Hence the active layer at such sites remains shallow throughout the summer. Due to the considerably higher thermal conductivities (λ) of clay minerals and sand, heat penetration through the regolith would be greater for the silt plains and regolith of the talus footslopes. The difference between graphs K and A, both representative of active layer thickness at their site as verified

Fig 4:1 Supranival sediment movement in south plateau rill. Observed movement associated with bedmaterial transport.

Fig 4:2 Supra-nival sediment movement across the talus foot snowpack, June 1970.

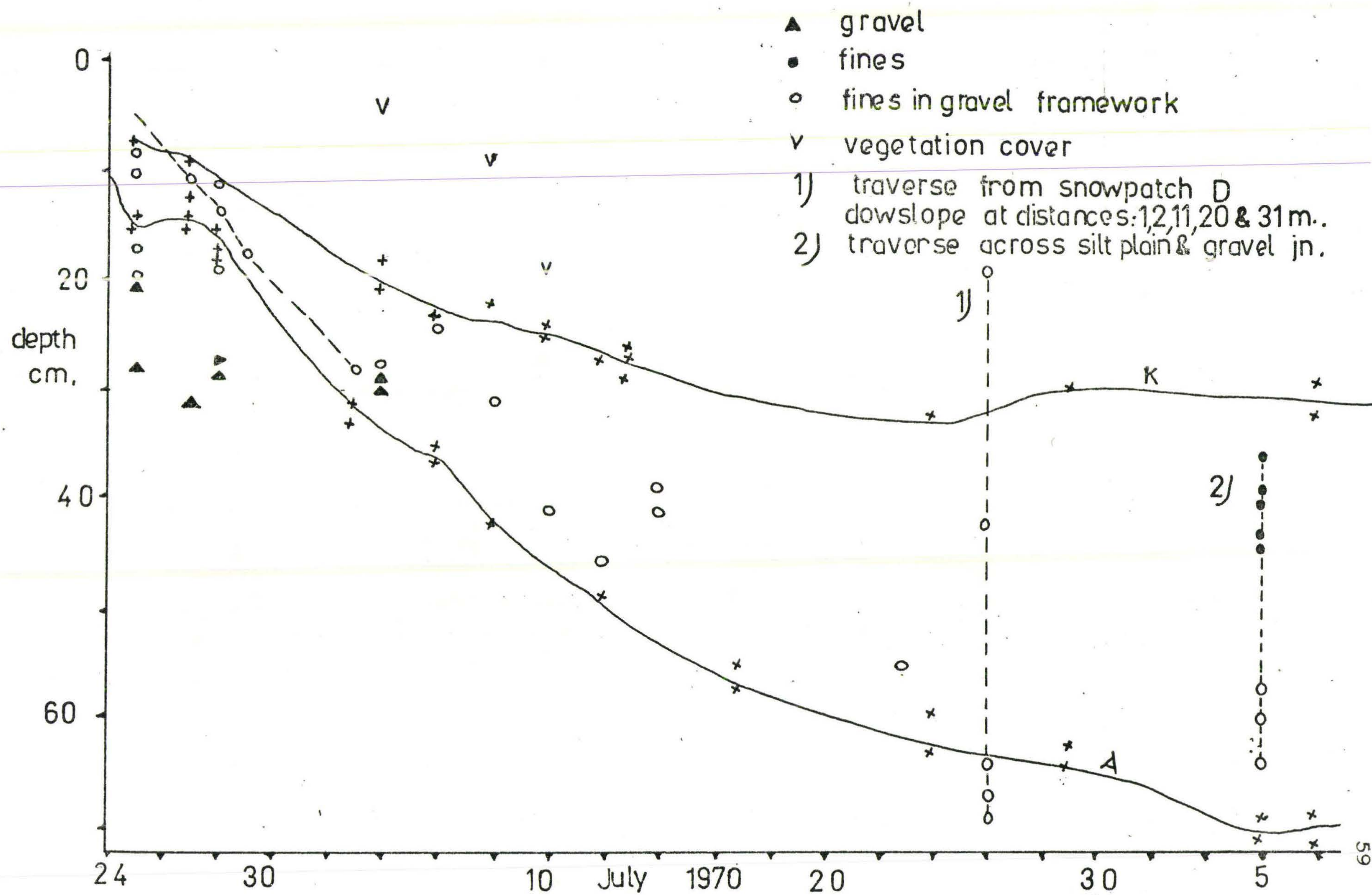


Fig. 4:3 Active layer thickness at various locations 1970.

by a series of spot samples, is thought to be due to the differing textures of the soils.

Site K although not a clay site possesses a high proportion of fine sediments and very few sands and gravels. This contrasts with site A located on soils with a framework of sand and gravel (traverse B fig. 4:3 crosses these contrasting terrains). In general, for any given water content λ is less for clay (7 mcal. cm.$^{-1}$ sec.$^{-1}$ °C^{-1}) than for quartz (21 mcal. cm.$^{-1}$ sec.$^{-1}$ °C^{-1}) or sand; in sands λ is variable and depends upon the packing of the grains (de Vries 1963). If site A is considered to be loosely analogous to quartz and sand with variable packing indices and site K analogous to a clay site, the difference in λ for these contrasting materials will account for the differences in permafrost depth for the two sites. The detailed variation for any type of material will also vary with water content, the presence of which markedly increases λ for clays and sands.

At any one time the depth to permafrost also varied due to the proximity of snowpatches; traverse A on fig. 4:3 illustrates how the depth increased away from the snowpatch which was frozen at the base.

None of the rills examined actually flowed across the permafrost table except during the period of first exposure, however, the table was slightly raised under rills.

In late June 1970 drainage conditions were observed to be disorganized with supranival flow, rill flow, sheet flow and interflow changing rapidly through space and time. Later, conditions stabilized and the domain of each flow type became established.

The two main types of interflow examined were channeled flow through the back slope gravels and talus slopes (chapter II) and percolation along polygon margins. Velocities of the former flow type were found by the use of tracer dye deposited in the channel on steep slopes. These micro channels, measuring from 2-10 cm. in width, possessed velocities between 1 and 6 cm./sec. (table 4:1) considerably less than the velocities of rills (Bones 1971).

Percolation along polygon margins was found to be most significant during the first week of the thaw when the permafrost table was still within 40 cm. of the surface (site A) and water availability was high. Velocities of flow, once more established by dye tests, were low (around 0.1 cm./sec table 4:1), but the frequency of channels was high, between 1 and 4 'channels' per metre. This high 'channel' frequency could not compensate for the low discharge per margin and the evacuation of water per unit area was less than that of rills.

The development of this interflow type was observed on the plateaus behind Resolute in 1971. At the onset of melting, water was conducted over the surface of the patterned ground with major concentrations developed in the low margins. As the permafrost table lowered and available meltwater decreased, these marginal

TABLE 4:1

VELOCITIES OF FLOW. RILLS AND INTERFLOW.

RILL FLOW

Location	Date	Velocity
D	3/7/70	40-50 cm/sec.
G'	"	48-56 cm/sec.
A	"	40-50 cm/sec.

INTERFLOW
(a)
Polygon margins

	Date	Velocity
near D	4/7/70	0.1 cm/sec.
D	"	0.25 cm/sec.
D	"	0.25 cm/sec.
A	5/7/70	0.1 cm/sec.
A	14/8/70	0.15 cm/sec.
A	"	0.33 cm/sec.
A	"	0.15 cm/sec.

(b)
Stripes (on steep slopes (> 10°) raised beach gravels.)

	Date	Velocity
near J	14/7/70	1.0 cm/sec.
J	"	1.33 cm/sec.

(c)
Talus

	Date	Velocity
A	9/8/70	4.6 cm/sec.
20 m. (length of flow)		1.4 cm/sec. *
20 m. (length of flow)		2.1 cm/sec. *
100 m. (length of flow)		5.5 cm/sec. *
20 m. (length of flow)		2.1 cm/sec. *
20 m. (length of flow)		1.7 cm/sec. *
20 m. (length of flow)		0.6 cm/sec. *
20 m. (length of flow)		3.7 cm/sec. *
50 m. (length of flow)		7.9 cm/sec. *

(d)
Snowpatch (A)

* from Bones (1971)

	Date	Velocity
Through snow	9/8/70	0.9 cm/sec.
Over ice	"	2-4.4 cm/sec.
Through thin snow cover	"	1.25 cm/sec.

channels became subsurface flows which gradually diminished in significance as the summer developed. Replenishment of these margins probably occurred not only from upslope and from the melting permafrost ice, but also from polygon centers which retained soil moisture well into the summer.

Rill flow was the main form of flow studied (fig 2:12). Because they were open channels, a minimum disturbance was required to set sediment traps whereas in the interflow zone disturbance of sediments was widespread and the sediments trapped were contaminated by adventitious material.

The sediment load of rills:

According to Einstein (in Chow 1964) the solid load of open channels can be divided into bed material load and wash load;

a) Bed material load is the coarser part of the load and its rate of transport is limited by the transporting ability of the flow. Movement is by rolling, sliding and saltation.

b) Wash load is the finer part of the load and can easily be transported in large quantities, the amount being limited by the availability of fine materials within the water shed.

Some rills were turbid to the naked eye, these usually flowed out of talus sheets (rills G (1970) and B (1971)). This turbidity was caused by the high amount of suspended material (wash load) and measured concentrations varied between 150 and 1700 p.p.m.

TABLE 4:2

SUSPENDED LOADS P.P.M.

G' 1	596	G' 3	315
G' 2	722	B	383
Za'	552	L 0 m. (4/7/71)	581
Z	750	L 40m. (4/7/71)	178

These readings were higher than those taken on nearby 'Jasons Creek' which were not greater than 450 p.p.m. (Cogley 1971). Differentiation between bed material load and wash load is frequently difficult as one tends to grade into the other downslope.

A large proportion of rills were clear throughout the hydrological year and turbidity was only apparent at certain times (see sediment load record). When the rills were clear the load was mainly in the form of bed material load which moved as single grains, flocs of fine silt and clay and by the downstream migration of dunes. Such modes of transport also occurred in turbid rills but were less apparent due to the interchange of particles with the wash load.

The sediment traps used (as described in chapter I) did not only trap bed material load, they also retained suspended material which was in the process of deposition. The quantities of sediment recorded in gms/day will be termed sediment discharge recorded (S.D.R.).

In turbid rills, it was noticed that high flow velocities frequently gave relatively low S.D.R. (e.g. G' July 10th, 18 gms/day) as sediment was only deposited in slack water around the trap margin. Similarly, low flow velocities give low S.D.R. readings with the sediments being distributed in a thin sheet over the base of the trap (A, 18th July load negligible). This effect was also apparent when the sediments trapped were analysed (seeTextures of the trapped sediments).

<u>The sediment load record:</u>

Measurements started on June 30th 1970 (fig. 4:4) and continued until August 10th when all rills showed a negligible sediment and water discharge. Before this date, during the chaotic early thaw season when rills flowed through and across the snow pack, only qualitative observations were made. During this period rills flowed in many temporary channels and transported and deposited large quantities of fine sediment on the snow and ground surface (fig. 4:2). With the subsequent melting of the snow pack these deposits were superimposed on the ground surface. With the final melting of the snowpack the rills became established as stable features and sediment recording commenced.

Five rills yielded a record of sediment load although only three gave sufficiently long runs of data to be examined graphically; these were rills A, D and G (Traps G' and G'') located on the talus footslopes. Although rill D flowed across these foot slopes it did not debouch from the talus; as its source was a mass of hummocky raised beach material located at the foot of the talus slopes (fig. 2:4). The sediment traps were placed in positions 50 m., 35 m., 20 m. and 50 m. from the rill source at the break

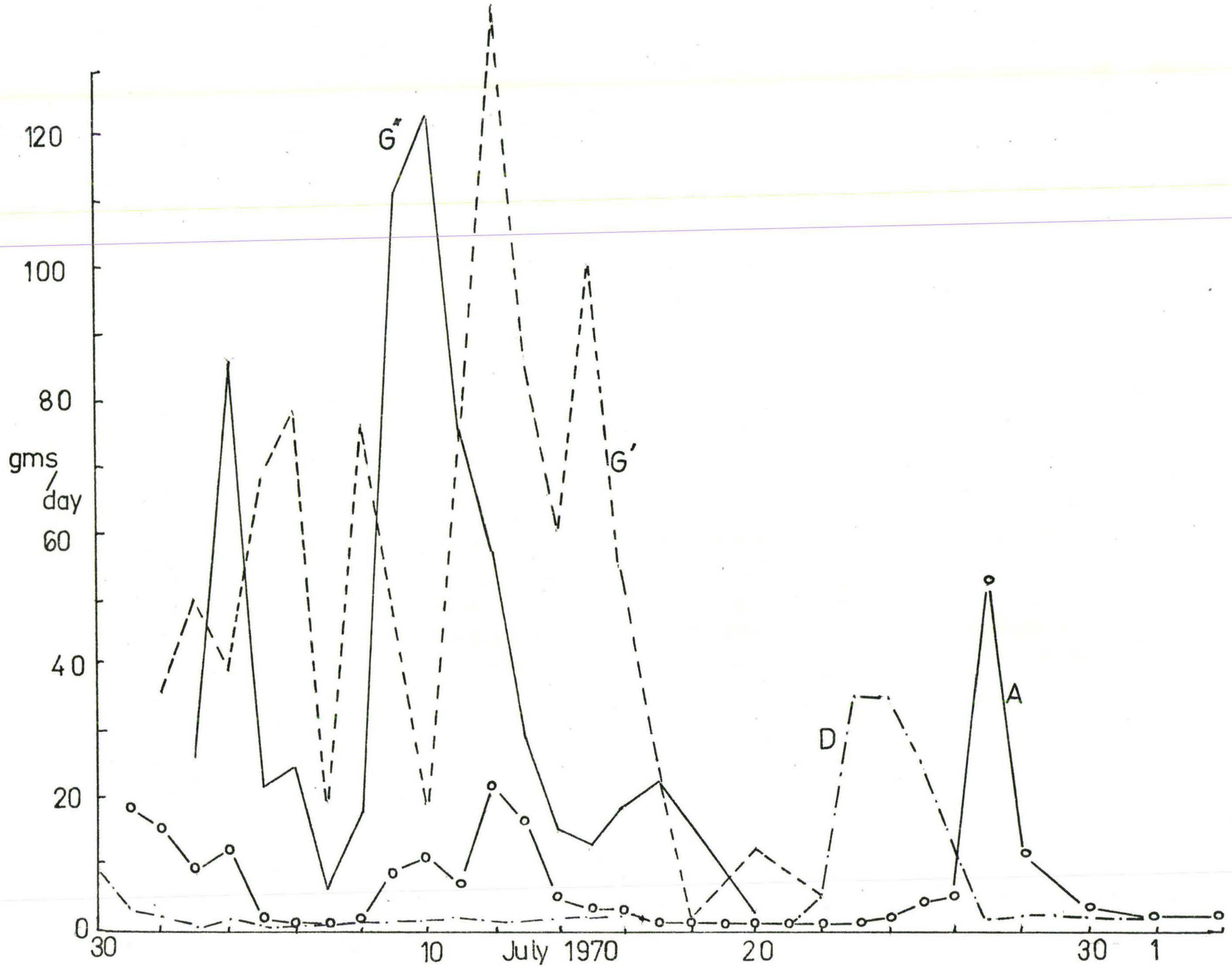


Fig 4:4 S.D.R. for rills 1971.

of slope hence, direct comparison of the absolute amounts trapped is less valid than the comparison of relative movements on the S.D.R./time graph. Such movements indicated the timing of sedimentation 'events' in different rills.

It should be noted that sediment trap G'' was placed downstream of a rill confluence which brought in additional water and sediment. Prime parameters for the rills examined shown in table 2:1 included: depth, width, velocity, discharge (all taken for one day, July 3rd) mean S.D.R., mean solution load and grain size. Rills A and D were predominantly clear with short periods of turbidity whereas rill G (G' and G'') was mainly turbid.

Traps G' and G'': Measurements of S.D.R. at stations G' and G'' started on the 2nd and 3rd of July respectively; mean S.D.R.s were high, namely 49.7 gms/day at G' and 37.0 gms/day at G''. The high S.D.R. at G' is lent added significance when the confluence upstream of G'' is taken into consideration, for this extra influx of water and sediment did not make up for the apparently rapid deposition downslope.

Fluctuations in S.D.R. were great, but on the majority of days S.D.R. G' was greater than S.D.R. G''.

Such conditions predominated during periods of low to average water flow which prevailed from July 4th to July 8th and from July 11th onwards. During periods of high water flow which occurred on the 4th and 10th of July sediment was apparently swept through G' whereas, G'' recorded a high S.D.R. Sediment textures also reflected this trend (see Textures of the trapped sediments) and it appears that at such times the zone of rill sedimentation was displaced downslope.

In general the sequence of events in rill G could be summarized as:

i An early period of high water flow with high, but fluctuating S.D.R.s.

ii Water discharges decreased considerably up to the 7th July with low S.D.R.s for both stations.

iii A sudden increase in discharge on the 7th and S.D.R.s from the 8th to the 10th reflected this by the predominance of deposition in G''.

iv On the 11th S.D.R. G' equalled S.D.R. G'', and from then onward deposition was greater in G' than G''.

Recording finally ceased at both stations on the 20th to 22nd July when rill flow ceased. Later, in response to the rainstorm of 26th-28th July, rill G flowed again, but no recordings were made during this period.

<u>Trap A:</u> S.D.R.s were high in the early period when rill discharges were high but by the 5th the S.D.R. had decreased to a negligible amount of 1.02 gms./day. With the sudden increase of discharge on the 7th and 8th July rill A once again recorded high S.D.R. values which reached 11 gms/day on the 10th and 21 gms/day on the 12th. Subsequently S.D.R.s decreased to their previous negligible values.

Just before and during the heavy rain of the 26th-28th July S.D.R.s for A increased again; this was not in response to the increased discharge, but was due to the increased availability of sediment from the rill head snow patch which had melted down to a dark silt laden layer of basal ice. This condition will be expanded upon in chapter V.

Finally, from the 27th onward S.D.R.s for A showed a steady decrease and finally recordings ceased on August 2nd.

Trap D: Like rill A, this rill possessed relatively high S.D.Rs during the initial sampling period from 30th June-5th July, but then S.D.R.s fell to negligible values. There was no apparent response to the increase in discharge on the 7th and S.D.R.s remained low until July 20th when S.D.R. increased in response to the unloading of the rill head snowpatch as recorded at A. After the peak of 35 gms/day on the 23rd and 24th S.D.R.s decreased to negligible values on the 27th and remained negligible until recording ceased on August 10th.

Isolated measurements of S.D.R. were made on rills flowing across the raised beach zone at Radstock Bay. These rills flowed from the break of slope across the low angle terrace slopes and alternations between rills and interflow were common. The rill waters were mostly clear and sediment traps revealed that sediments moved mainly as low discharges of bed material load; this varied with flow conditions, but was not greater than 1.82 gms/day. One rill, however, was observed to be turbid at the beginning of July when the basal ice of the rill head snowpatch started to melt. The fine material from the basal ice was deposited rapidly below the break in slope in the form of a thin transverse strip of silt 0.5-1.0 m. wide.

Sediment discharge recordings were also made for channeled flow along coarse stripes on the steep slopes (10-15°) developed on raised beach gravels around Radstock Bay. The sediments trapped varied between medium sands and fine gravels, but the effect of the disturbance of overlying materials could not be ascertained.

Similar but less extensive measurements were made on rills in the Resolute area in June/July 1971.

On arrival on the 30th June 1971 much of the snowpack had melted and rills were well established on the land surface. Rill B with a mean S.D.R. of 17.5 gms/day was a turbid rill flowing across a short talus foot slope (fig. 2:7). Apart from fluctuations the S.D.R. gradually declined to a minimum of 3 gms/day on July 9th (fig 4:5).

Rills C and E were clear and consequently showed low S.D.R. values (means of 1.9 and 1.6 gms/day). The decrease in S.D.R. was again similar to that of rill B. Most of the rills were observed to be clear throughout most of the thaw season, only becoming turbid during the melting of the basal ice in rill head snowpatches.

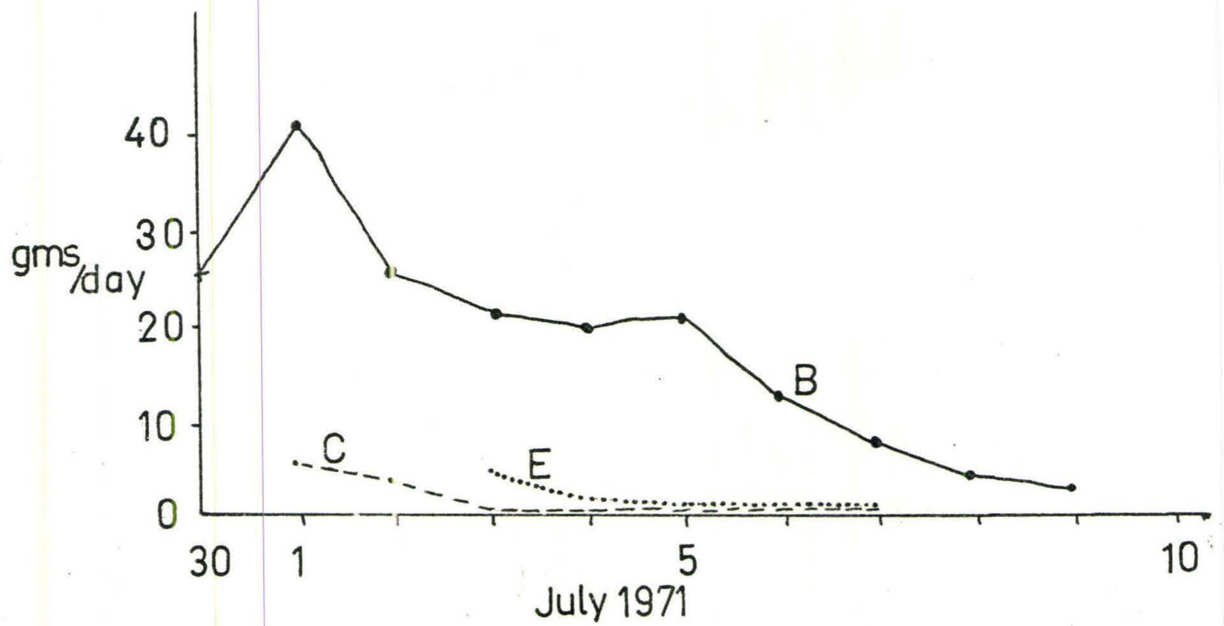


Fig. 4:5 S,D,R for rills I97I.

Textures of the trapped sediments:

So far it has been shown that rills differ in their transportation and deposition of sediments, also, on rill G, the differential deposition of sediments downslope has been shown to exist. The next step is to examine the textures of sediments trapped and establish whether similar differences between and within rills exist for measured grain size.

Textural analysis by wet sieving and pipette as described in chapter I was carried out on the following samples: G'(6), G'' (6) and D (2), A (2), A_{71} (1), B_{71} (1), Z (2), S.B. (snow bank sediments) (2) and W (1); the number of samples analysed is indicated in parenthesis. Nearly all of the sediments when computed for Folk and Wards Mean - Inclusive Graphic Standard Deviations (see chapter I) appeared to be moderately to poorly sorted silts with mean diameters ranging from 0.009 mm. to 0.043 mm. The only exception is sample W_3, sands of mean diameter 0.085 mm. Both histograms and cumulative frequency curves (see appendix) indicated that usually the sediments are well sorted in the medium to coarse silt range with modal values extending up to 70%. Most of the samples however possessed a fine 'tail' extending down to the clay range thus giving rise to the high standard deviations. In the population of samples taken during the investigations these rill sediments proved to be the best sorted and will therefore be referred to as: 'relatively well sorted'. The relevant parameters for these sediments are given in table 6:2.

The twelve samples from G' and G" are not directly comparable, due to the rill confluence up stream of G". Of the six days samples analysed, four days samples showed G' to be coarser than G" and on two days G" was coarser than G'. The mean grain sizes for G' and G" were established as 0.036 mm. and 0.031 mm. respectively.

The samples showing G" to be coarser than G' were taken on July 4th (during the early fast flow period) and on July 14th, (during the late diminishing period when S.D.R.s for G' were considerably greater than for G"). Although a trend towards fining downslope is apparent no concrete conclusions can be drawn from these twelve analyses.

The analyses of % sand, obtained by wet sieving, for 12 sample days (fig. 4:6) were more conclusive. On ten days G' showed a higher % sand than G"; this percentage varied between one and 28%. Significantly the maximum sand percentage for G' was on July 10th and for G" on July 4th and 10th. This corresponded to the period of maximum water flow for rills, that is, when S.D.R. for G, was low and for G" was high. It appears therefore that sands, due to their higher entrainment velocity, were transported at a maximum rate at this time. The higher % of sands caught in the upper trap aligns with the limited evidence of the mean grain size shown above. This diminution of mean grain size and sand % could be due to two factors:

a) a progressive 'fining' of sediments downslope.

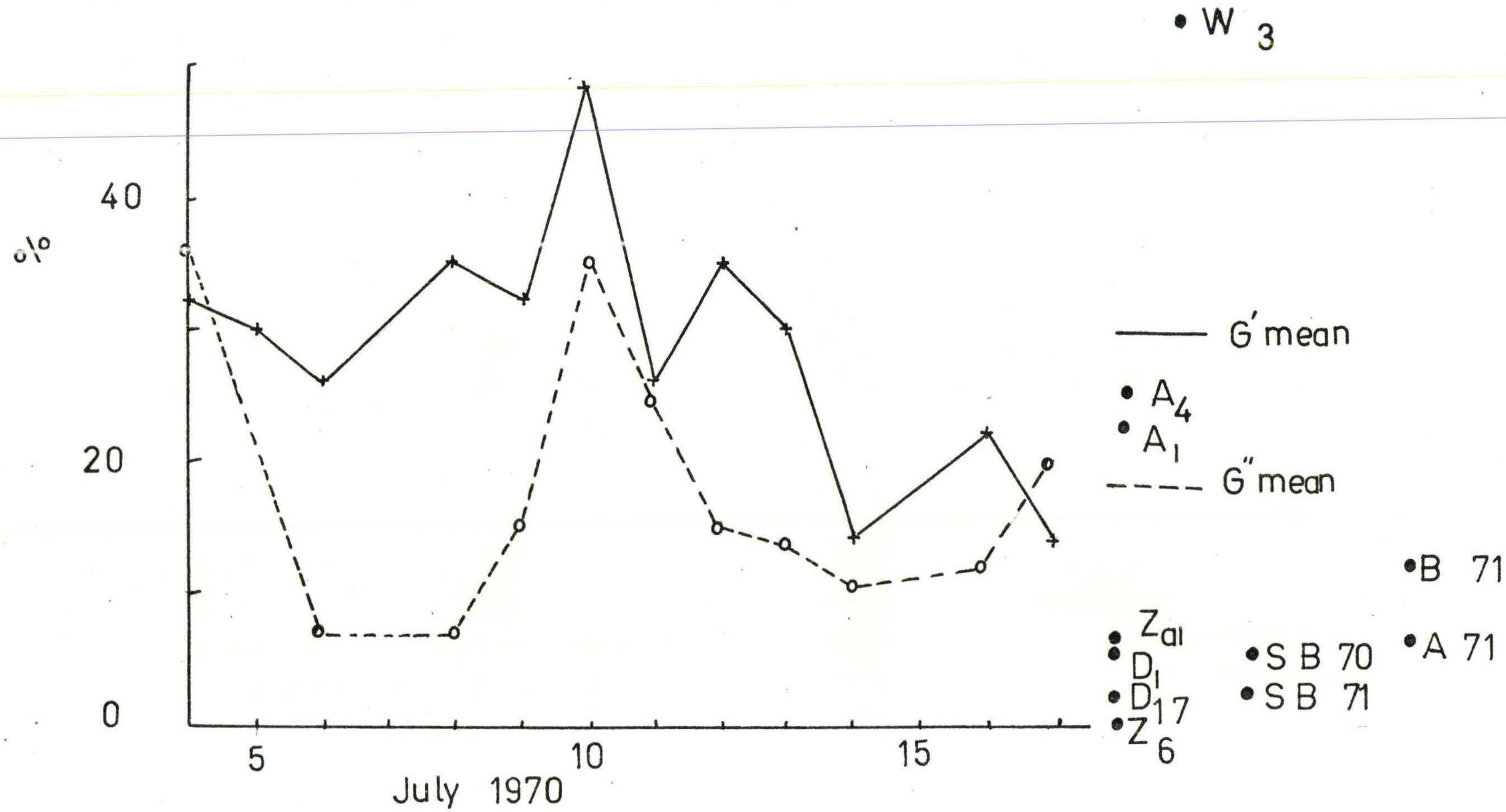


Fig. 4:6 Percentage sand from traps G' and G" 1970

b) Dilution of the sediment load by the influx of finer sediments from the incoming rill above G".

As both the main trunk rill and the minor rill flow within 10 m. of one another from the same source in the talus, conclusion b) is considered unlikely and a) is favoured. Although not conclusive, this evidence when examined in conjuction with that of the S.D.R. readings from the two traps indicates that a greater quantity of sediments, possessing more sands are deposited up slope.

Sand percentages for the other traps are shown in figure 4:6. A_1 and A_4 possessed sand percentages between the means for G' and G" and the only sample possessing more sand was the poorly sorted sample from rill W.(see chapter IV). Rill B_{71}, flowing from the talus sheets, overlooking Resolute came next in the ranking, and the remainder of samples, A_{71} (rill A from Resolute raised beaches) SB_{71} (snowbank sediments), Z_{a1}, Z_6, D_1, and D_{17} were all sampled from snowbanks, snowbank rills, raised beach rills or from rills flowing late in the summer.

When the mean grain size of the trapped sediments was examined the hierarchy shown below was established:

G .034mm; A .029; Z .026; D .023; B_{71} .017; A_{71} .012 and SB .010.

The rills flowing from the talus slopes in 1970 possessed the coarsest sediment loads and the rills flowing from raised beach snow patches and the one raised beach rill were finest. The lower mean value for sediments from rill D could possibly be related to the nature of the subadjacent regolith. Figure 2:4 indicates that rill D was supplied by water percolating through a large mass of raised beach gravels rich in fines and not as in rills G and A from talus drainage waters.

The percentage clay varied between 0 and 10% for all samples analysed and even the samples W and G' 10th, deposited as bedload on days of high flow velocity showed the presence of a significant amount of clay. This was probably deposited in a flocculated state (as observed in other rills) and subsequently dispersed during analysis.

In summary, the sediments varied little, with mean diameters grouped around 0.022 mm. (medium and coarse silts); all were 'relatively well sorted' except W_3, a special case (chapter IV). In rill G more sand was deposited in the upper trap than the lower one and mean diameters also reflected this trend, thus indicating that fining took place downslope. 1970 talus foot rills appeared to possess coarser loads with more sands than any other sediments analysed.

The solution load:

The measurement of solution load, in this case, the Ca and Mg content, was undertaken to provide a basis for comparison with movements of solid load across the land surface. Essentially this was an attempt to find whether transport of solid load or solute load was more important in the evacuation of material from the system.

Daily samples were taken from rills A, D and G during the 1970 sample season (fig. 4:7 and 4:8) to show general trends of total and Calcium hardness through time and these were supplemented by a series of water samples (fig. 4:9) taken from a variety of positions. These sample sites are indicated on figure 2:3 and can be seen to encompass a wide variety of topographic sites from the N. plateau southwards.

Rill sampling is problematic, for hardness values can change rapidly downslope and over short time periods, hence the samples from rills A, D, and G were gathered at the same point and at the same time everyday.

Rills flowing across lobes on raised beach terrain over looking Char Lake Resolute (1971) were sampled to establish the increase in hardness downslope. These two rills were interrupted by short interflow zones and samples were taken several meters from these re-emerging rills. The three samples for each rill, taken over a total horizontal distance of 110 meters, increase in total and calcium hardness downslope as shown in table 4:3a. Further measurements were taken from a long rill flowing across and through gravels on the right bank of the Mécham River, Resolute. As can be seen in table 4:3b and figure 4:10 total and calcium hardness values increased asymptotically to values of

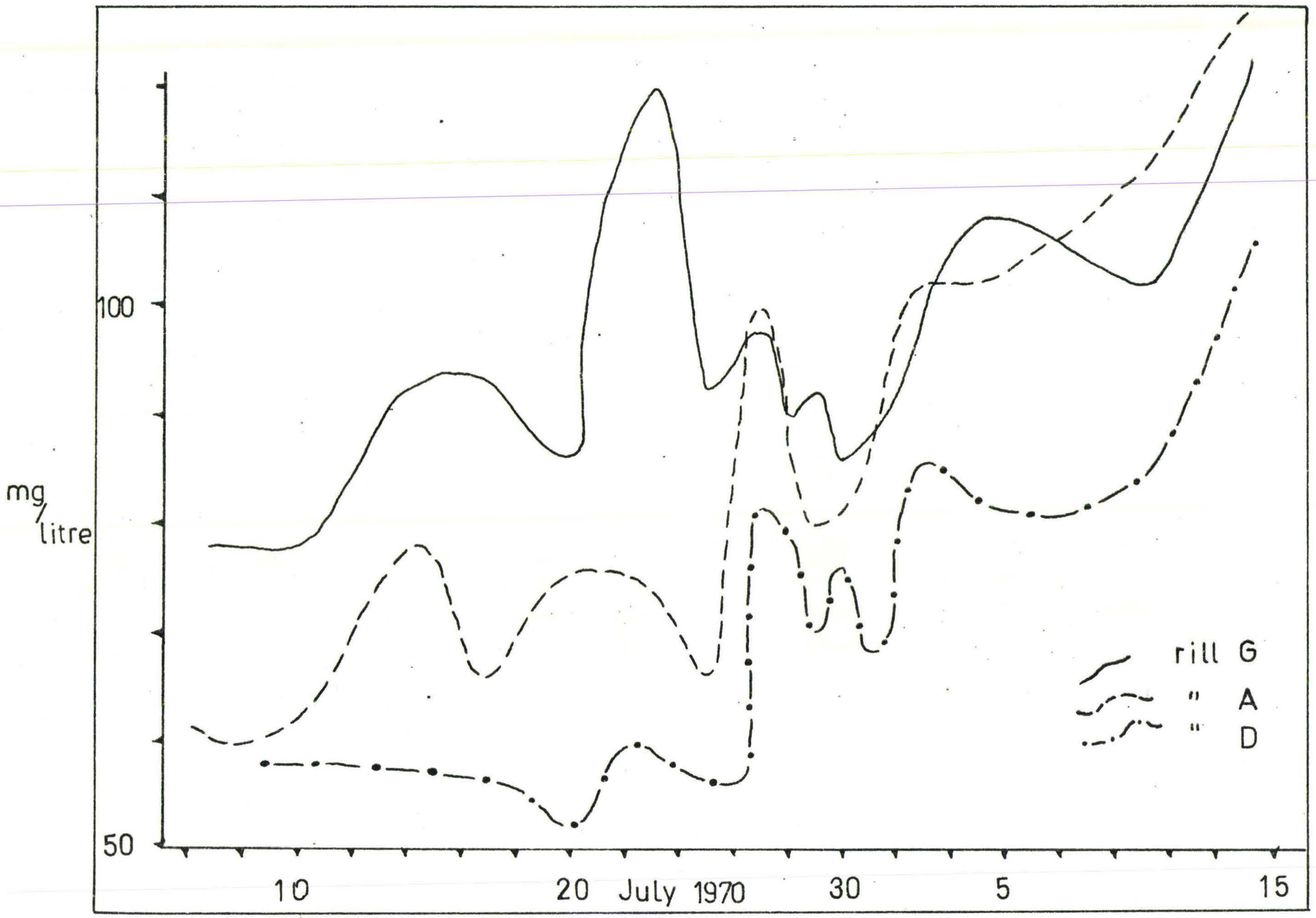


Fig. 4:7 Total hardness for rills A,D and G.

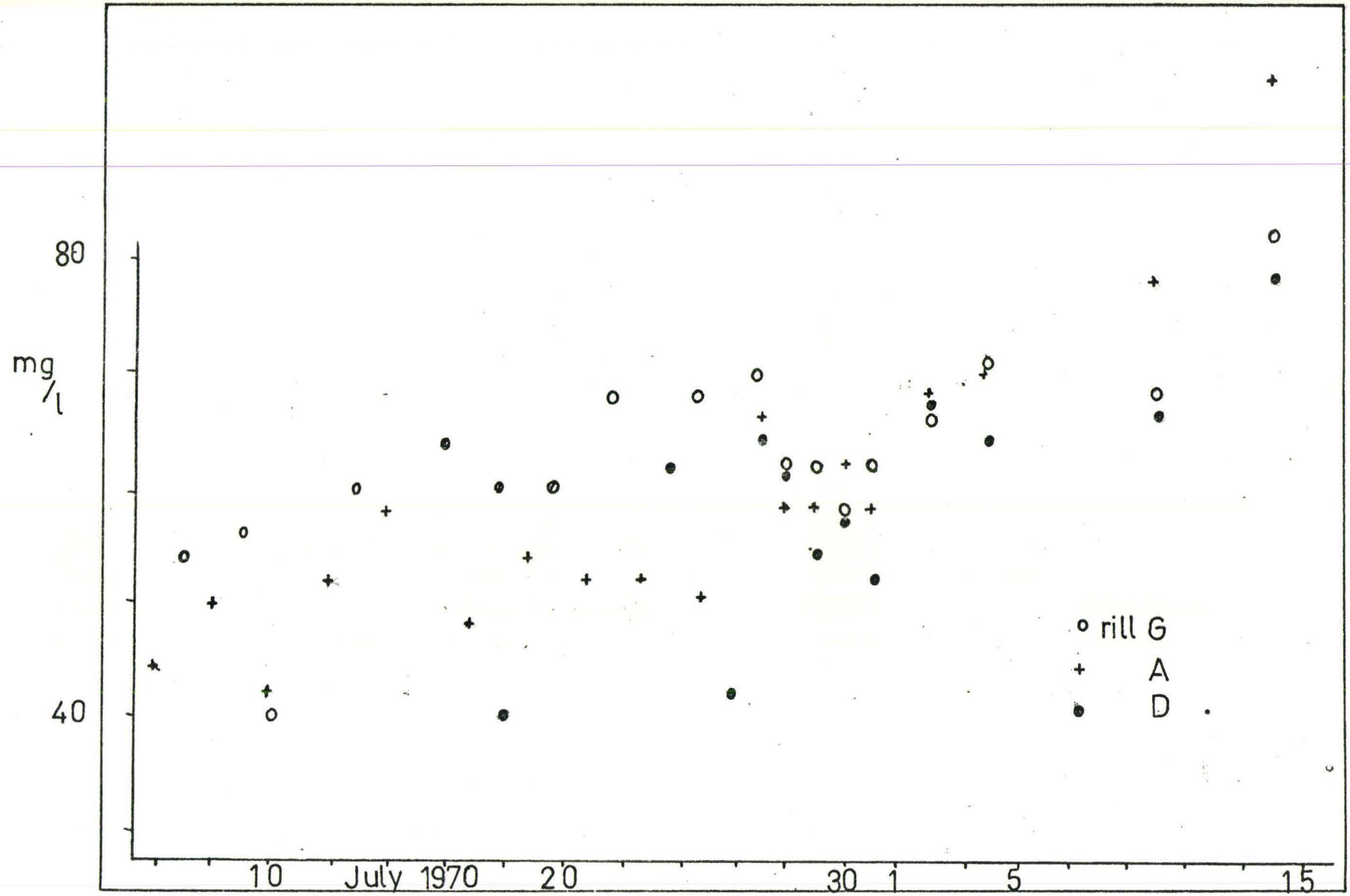


Fig. 4:8 Calcium hardness for rills A,D and G I970.

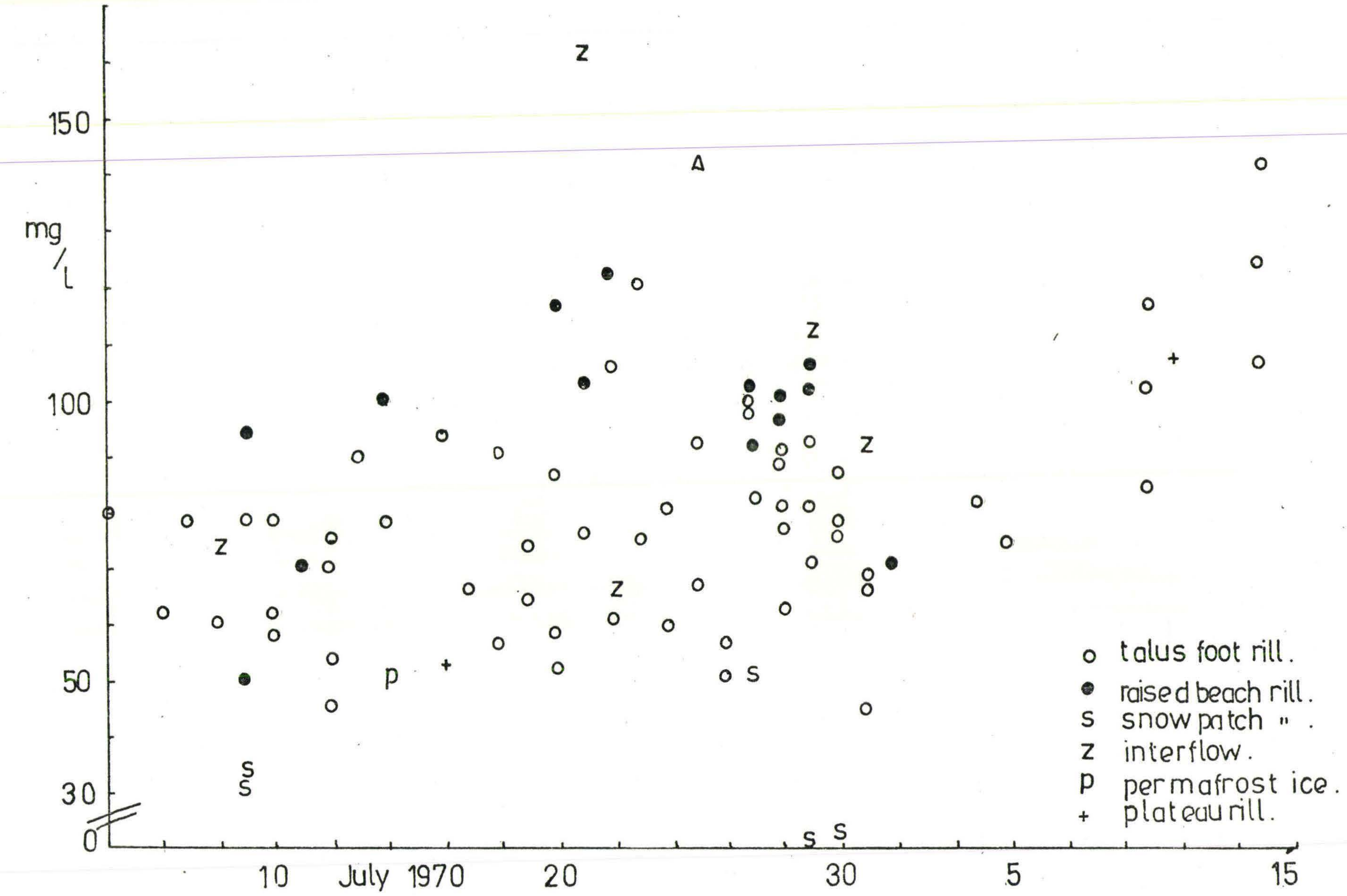


Fig. 4:9 Total hardness values for 1970.

Table 4:3

Station	date	position	hardness: Ca.+ Mg.	hardness: Ca.	pH
I	7/7/71	upper	56	44	8.15
"	"	middle	70	46	8.10
"	"	lower	80	58	8.10
II	"	upper	58	44	8.15
"	"	middle	72	48	8.00
"	"	lower	82	56	8.15
M1	8/7/71	10m.*	28	20	8.10
M2	"	100m.	54	40	8.10
M3	"	250m.	70	52	7.90
M4	"	330m.	72	52	8.05
M5	"	480m.	78	56	8.10

* at snowpatch

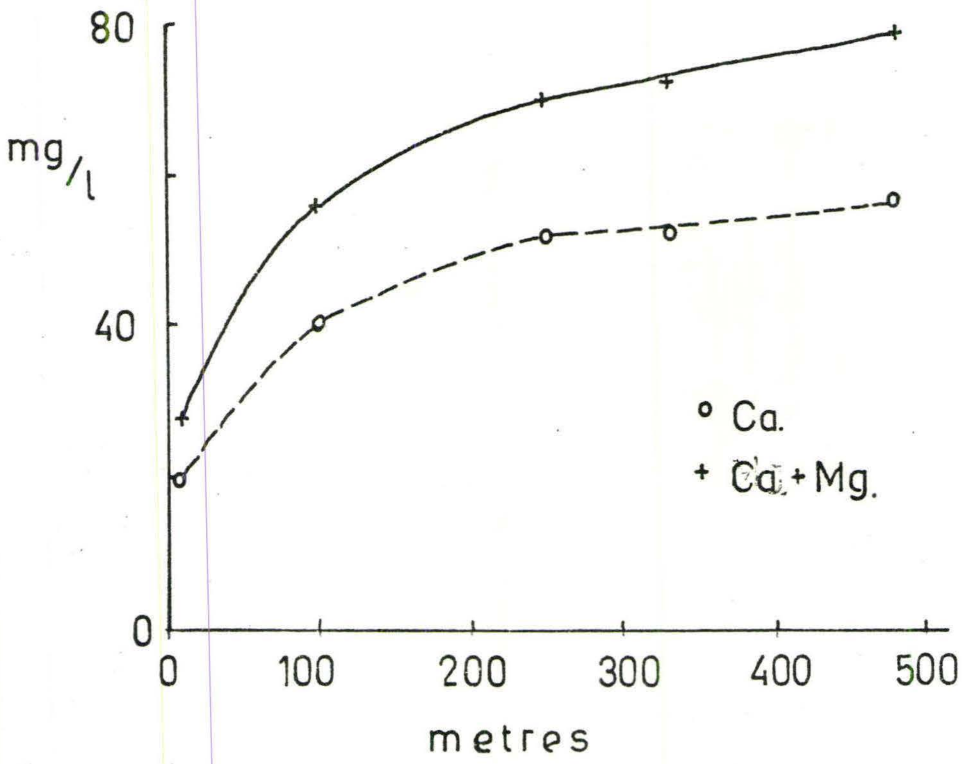


Fig 4:10 Increase in rill hardness values downslope on rill M 1971.

80 and 60 mg/litre respectively. The initial low hardness values are due to the diluting effect of melt waters from the rill head snowpatch.

Such spatial trends were reinforced by complications imposed on the rill system by the diurnal melting cycle of snowpatches. Such a meltng cycle operated on rill W, adjacent to rill A 1970, and could clearly pose complications (chapter V). It is apparent from the above data that the conditions of minimal solution load variations probably occur well downslope on rills where the increase in hardness values flattens out and on rills not directly supplied by snowpatches.

Such conditions could not be rigorously adhered to on rills A, D and G. Sampling took place between 30 and 40m. from the break of slope and rills D and A were supplied with water from rill head snow patches until the 24th and 28th July respectively. After these dates the rills were supplied from upslope sources of water.

Rills A, D and G recorded mean total hardness values of 85, 72 and 97 mg/litre and Calcium hardness values of 60, 55 and 66 mg/litre respectively. Although rill G dried up sufficiently to impede S.D.R. readings after the 22nd July, enough flowing water was still visible to sample for solute load. Thus, a continuous sequence could be maintained.

The general trend over the sampling period (fig. 4:7, 4:8) was for Ca and Mg hardness values to increase through time. Until July 23rd, values fluctuated about the means with maximum

(Ca + Mg) values being recorded on 14th, 16th July and 21st - 23rd July. After this, values decreased until 25th, 26th July possibly in response to the rainfall of the 21st, 22nd and 24th. It is unlikely that this was due to dilution as no noticeable influx of water was noted during this time. Almost immediately values increased dramatically for all three rills especially D and A. This was in response to the heavy rainfall of 26th, 28th July which also produced a similar affect on nearby 'Jason's Creek' (Cogley 1970). Immediately after this rise, decline set in and the three rills reached minimum values between July 29th, 31st. Subsequently rill discharge gradually declined and the Ca + Mg hardness values increased until the termination of sampling on August 14th.

The final melting of the snowpatches A and D produced a confused response. Snowpatch D finally melted at the peak of the rainstorm of the 27th July, therefore any increase of Ca+Mg hardness due to the cessation of inflow of low hardness snow meltwater was masked by the reported drop in hardness during the storm. The case of snowpatch A was more readily understood for, after the final melting of the snow, the Ca+Mg hardness values increased until sampling terminated.

Sampling from a wider variety of stations in 1970 showed that most rills sampled from the plateau areas and other talus foot slopes possessed total Ca+Mg hardness values similar to the intensively studied rills, that is, with total hardness values between 50 and 90 mg/litre and Ca hardness between 40 and 80 mg/litre.

Such waters had probably been in contact with the soil for longer periods due to the lowered percolation velocities through the raised beach gravels. Such standing and sluggish waters were probably warmer than rill waters, thus could lead to, as Bogli (1960) suggested, an increase of solutional activity greater than the decrease in CO_2 solubility at high temperatures.

Conclusions:

After the early thaw season of supranival rill flow and deposition three classes of rills could be distinguished:

a) Those that were clear throughout the summer period.

b) Those that possessed a continuous, but erratic sediment discharge in the form of suspended load.

c) Those rills that exhibited a S.D.R. peak during the unloading of sediments from rill head snowpatches.

When rills were clear, sediment movement was in the form of bed material load, this was usually transported in small amounts and only assumed large figures when rill discharges were exceptionally high.

When rills were turbid the sediment load was much less clearly related to discharge. This turbidity could be traced up-stream without any diminution, to the break of slope. In some rills e.g. A and D this turbidity was related to the conditions in the rill head snowpatch and in others, e.g. rill G no source of sediment could be directly found. It merely appeard that the sediment load came with the rill waters from the talus slopes.

All streams exhibiting any turbidity were found to have their source of sediments upslope of the low angle slope, either at the rill head snowpatch or in or above the talus interflow zone. The former case will be examined in greater detail in the next chapter. From the above mentioned evidence the precise delimitation of supply areas therefore appears unclear.

The deposition of sediment on the low angle slopes presented a clearer picture. In the turbid rills sediment was noticed to be deposited downslope in a zone of deposition that oscillated depending upon rill discharge fluctuations. This tentative conclusion will be reinforced for late season flow in chapter V. In addition, fining of rill sediments took place downslope but this did not affect the whole spectrum of grain sizes, for samples from the two sediment traps in rill G showed a diminution in the sand fraction downslope but a much less clear decrease in the mean grain size.

This deposition of sediment downslope contrasted with the solution load which, according to samples from Resolute in 1971, increased downslope. Such an increase was also established by Cogley (1971).

Sediment discharges in the rill were sporadic. However, the total sediment discharge from such rills calculated from suspended loads and water discharge was considerably lower for most rills than the total discharge of Ca+Mg in solution.

The importance in this study lies not in the total amount of material moved, but in the redistribution of the materials across the land surface. Here the sediment load is more important because zones of redistribution and concentration have already been pinpointed whereas most of the solution load is transported straight out of the system without any precipitation. Other redistributions will be examined and elaborated for the break of slope zone in chapter V.

CHAPTER V

THE SNOWPATCH CASE

As stated in the previous chapter, the occurence of a peak in sediment discharge recorded (S.D.R.) late in the thaw season was usually related to the washing of fine sediments from well decayed snowpatches situated at the break of slope. Such snowpatches therefore, demanded further investigation.

Three main aspects of snowpatches were examined:

1) Their effect upon the water discharge of rills.
2) Their effect upon the sediment discharge of rills.
3) Their effect upon sediment deposition at the break of slope.

Before these aspects are treated it is necessary to outline the type, location and characteristics of the snowpatches studied.

All of the snowpatches examined would belong to Lewis's (1939) first category, namely, transverse snowpatches whose major axes are transverse to the major drainage lines. They were located along the main breaks of slope, situated at the foot of talus slopes, on the terrace features mentioned in chapter I and on plateau surfaces. The actual snowpatches studied were located at sites A, D and J (1970) (fig. 2:4) and at A, B, L and M (1971) (fig. 2:7). These snowpatches were found on a variety of terrain types including the plateau surface, raised beaches and talus foot slopes. In addition, a large number of snowpatches were qualitatively examined, photographed, sampled and mapped for specific features: supranival gravels, depositional features, ice tunnels etc. The aspect of the snowpatches examined varied between north through south to west.

In 1970 snowpatches began to exist as separate features in early June after being isolated by ablation from the shallow snowpack covering most of the ground surface. Lewis (1939) stated that a major factor affecting the perpetuation of snowpatches was their bulk as well as aspect and prevailing micro-climatological conditions. On departure from Radstock Bay August 21st, 1970 occasional snowpatches remained, including snowpatch A, thus indicating the perennial and complex nature of some of the snowpatches.

Characteristics of the snowpatches:

Snowpatches, being the sole surviving remnant of the winter snowpack, exhibit marked signs of metamorphosis and by July and August the snow is compact, granular and ripe. Ripeness is associated with the readiness of the snowpack to transmit and discharge liquid water and is defined as such when it contains all the water it can hold against gravity (snow hydrology 1956).

Pits were dug in a variety of snowpatches during the 1970/71 season and those sunk in snowpatch A, August 1970 were typical of those in other snowpatches. The first pits excavated in snow patch A revealed alternations of ripe snow and ice as reported by Lewis (1939) and McCabe (1939). The lower layers of snow were frequently saturated with percolating water, especially during periods of thaw, this saturation was apparently aggravated by the presence of a layer of basal ice as noted by McCabe in Spitsbergen and Lewis in Iceland (1939).

Fluorescent dye deposited by the snow surface percolated vertically through the snow, formed slight concentrations at the thin ice layers and then proceeded vertically downward until the basal ice was reached. At this layer the dye percolated downslope in a long wavelength 'percolation channel' c. 15 cms. wide.

The percolation channel proved to be the response to a point source of dye, for when the snowpatch basal ice was cleared of snow and a linear source of dye added, the dye then flowed in a 'percolation sheet' with an advanced guard of more rapidly percolating 'fingers' of dye (fig. 5:1). These tests were supported by further work on the same and other snowpatches during 1970, 1971.

Excavations of the basal ice layer at site D (July 22nd 1970) and site P (July 13th 1971) showed this layer to be up to 30 m. thick and below it the ice was usually frozen to the underlying ground surface. Under the periphery of the snowpatch especially during periods of rapid melting, a shallow layer of melted ground, saturated with water, could occassionally be observed.

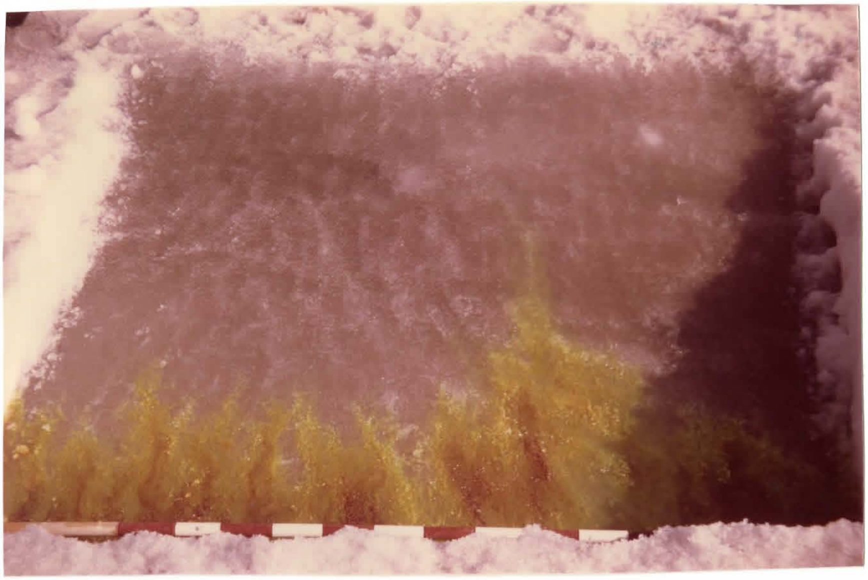


Fig 5:1 Water flow across the basal ice layer, snowpatch A 1970.

Fig 5:2 Gravel lined tunnels conducting water into snowpatch

Such a case was noticed under snowpatch P (1971) and in this case the melted layer was overlain by old snow or decayed ice saturated with water. When these observations were made, melting was rapid and many sections of the snowpatch were conducting large discharges of percolating water.

Auger borings, made at increasing distances from various snow patches showed that the permafrost table rose to within a few centimeters of the surface at the snowpatch edge, the base of the snowpatch being frozen within 40 cms. of the edge (fig. 5:3).

It appeared, therefore, that meltwater from the snowpatch percolated mainly across the basal ice surface in partly channelised sheets and only occassionally was the underlying ground surface thawed; in such conditions it was saturated and could have conducted a certain quantity of meltwater.

Contributions of snowpatch meltwaters to rill flow:

In chapter III it was noted that Lewis (1939) considered the snowpatch to be the chief source of water for the rills down--slope whereas McCabe (1939) and Nichols (1954) made allowance for the possible seepage of moisture from upslope. In the area under consideration rills did not only flow from below the foot of snow-patches, they were also observed to flow from breaks of slope where rill head snowpatches were absent. Therefore, on the basis of this evidence and the statements of McCabe and Nichols it seemed important to outline the relative contributions made by individual snowpatches to rill flow.

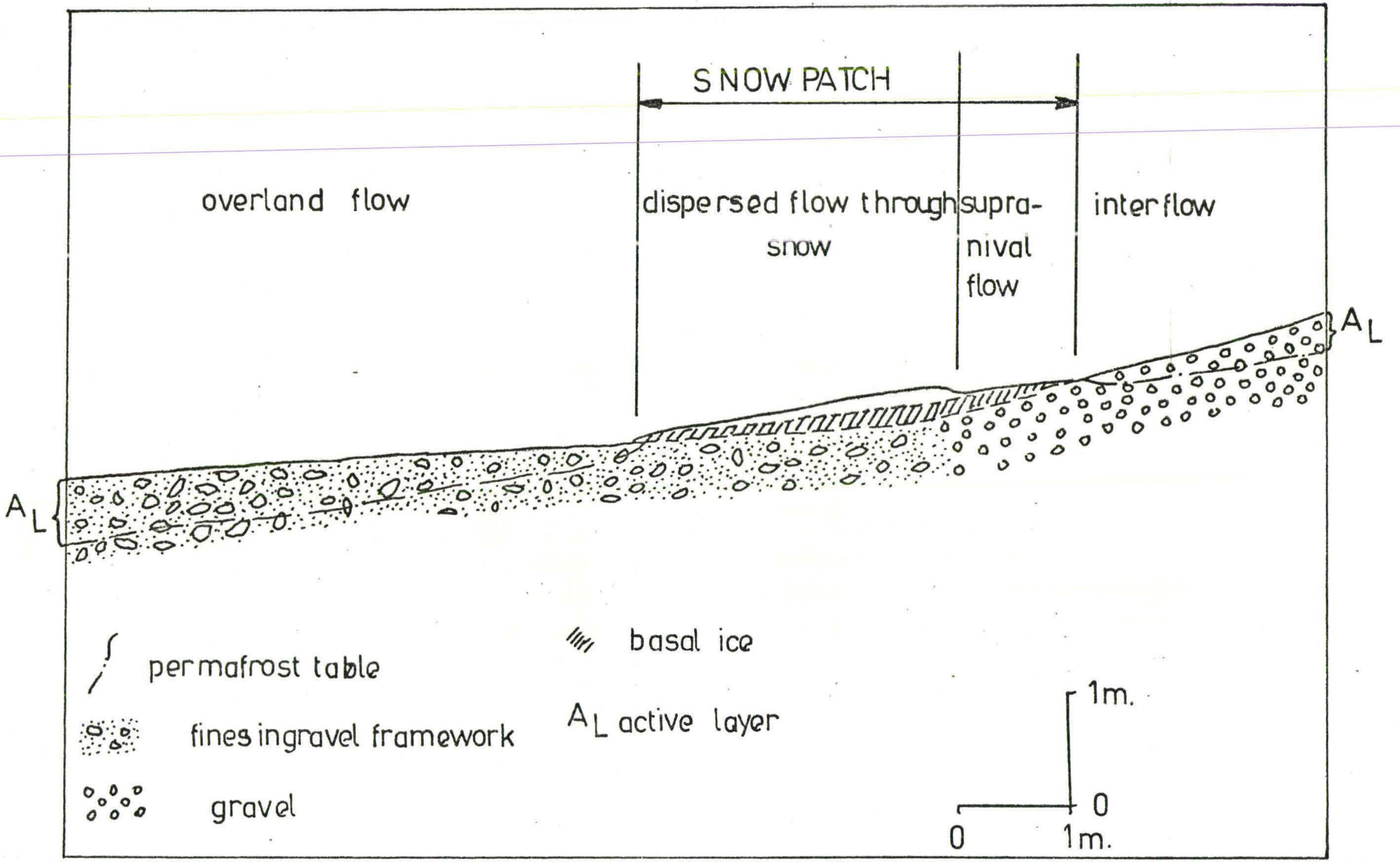


Fig. 5:3 Flow types associated with snowpatch D 1970.

Many snowpatches were seen to be supplied with water from the talus and detritus slopes above and as stated in chapter III this flow was mainly along small channels up to 10 cm. wide with velocities up to 4 cm/sec. Such percolation through gravels and detritus was frequently clearly audible and this fact was noted by Cook (1962) who did not comment further. This partially channelled flow could not flow under snowpatches, due to their partially frozen base, but was directed by the rising permafrost table into the snowpatch (fig. 5:3). This entrance was occassionally marked by ice channels and tunnels which frequently possessed gravel beds (fig. 5:2). Once within the snowpatch, the water flowed in percolation channels and sheets across the basal ice. Velocities of flow depended upon the thickness of the overlying snowcover and in snowpatch A were measured to vary between 0.7 cm/sec for percolation through a thick snow or ice cover and 2-3.8 cm/sec. over the exposed basal ice; where channels started to develop, velocities reached 4.4. cm/sec, comparable to velocities of flow within the talus.

On the talus foot slopes water percolated out from under the loweredge of the snowpatch, through the coarse margins of the patterned ground at the break of slope and emerged, a few metres from the break of slope to form rills.

On the 20th - 22nd July 1970 at snowpatch D it became apparent that the small remnant of decaying basal ice could not supply rill D with all of its water, therefore water was sampled from upslope and downslope of the snowpatch to ascertain the diluting effect of the remaining snow and ice. Total hardness values decreased by only 6 mg/litre during this passage, thus indicating that at this time the relative contributions of water from the snowpatch to the rill was slight (table 5:1).

TABLE 5:1

HARDNESS DILUTION JULY 20/22nd 1970 RILL D

	Upslope	Basal Ice	Snow	Downslope
20th	58	26	8	52
22nd	66			60

All values represent total hardness in mg/litre

The basal ice possessed a total hardness of c. 26 mg/litre, considerably more than the snow above. This is considered to be due to the freezing of water from upslope during its passage through snowpatch.

As snowpatches varied greatly in size it is logical to assume that their relative contributions of meltwater to rill flow also varied, hence the small decaying snowpatch D, was not necessarily typical of all snowpatches.

A rill, rill W, was selected, flowing from under a large deep snowpatch (snowpatch A) and the total and Ca hardness values were monitored at 6 hourly intervals to establish the diurnal march of solute concentrations. The results (fig.5:4) demonstrated the existence of a well marked diurnal march of solute concentration; this lasted from 29th July to 4th August and finally decayed into a less well marked pattern on the 5th and 6th.

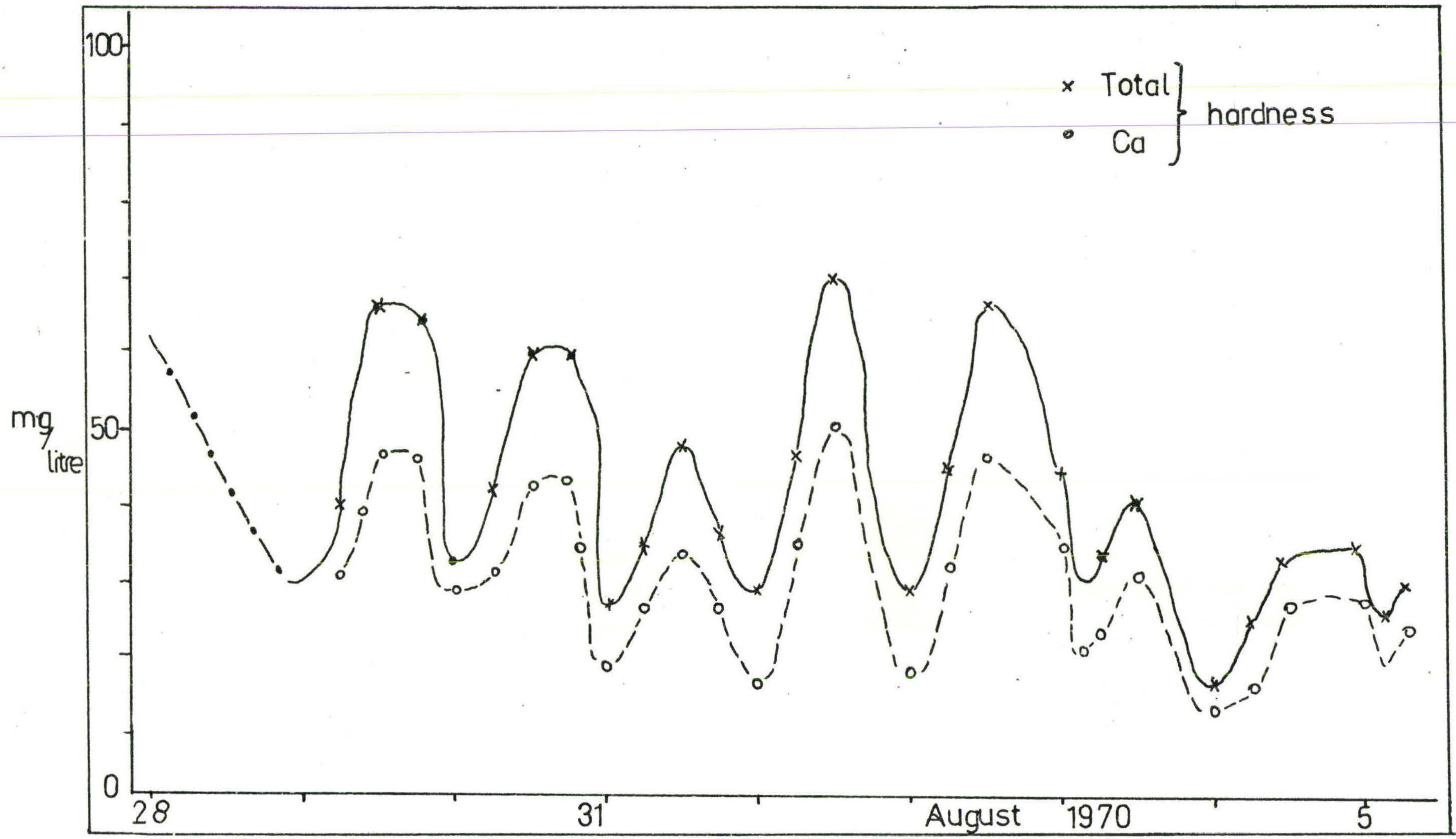


Fig. 5:4 Diurnal march of Ca and total hardness 28/7/70 - 6/8/70.

Occassional samples of solute load were taken in the talus zone upslope and these values were considerably higher than those from rills, thus demonstrating that considerable dilution occurred due to inputs of snowpatch meltwaters. Although melting of the snowpatch was diminished at night, dilution of rill waters still continued as the day's meltwaters gradually drained into the rills. As the snowpatch became shaded during early afternoon, melting decreased rapidly and minimum hardness values prevailed during this period.

The well marked march of solute concentrations became less clear by the 5th and 6th and on the latter day samples were taken every 2 hours from 1200 to 2400 hours in rills W and Z.

Rill W was clear and flowed, as stated, from the centre of the snowpatch whereas rill Z was turbid and was supplied by water flowing across the basal ice of the decayed snowpatch periphery, a situation similar to that at snowpatch D. As can be seen (fig. 5:5) during the sampling period rill W possessed uniformly low hardness values where as rill Z possessed a march of hardness values of amplitude 28 mg/litre.

Clearly, melting (and dilution) was continuous throughout in the snowpatch centre; whereas it was inhibited at night around the periphery. The 6th was a day of warm, cloudy conditions and by 0830 hours aided by a warm northerly wind, thawing had already commenced and this situation continued all day. The screen temperature declined to 6° C at 1800 hours, but was still well above freezing (3.5°C) at 2400 hours.

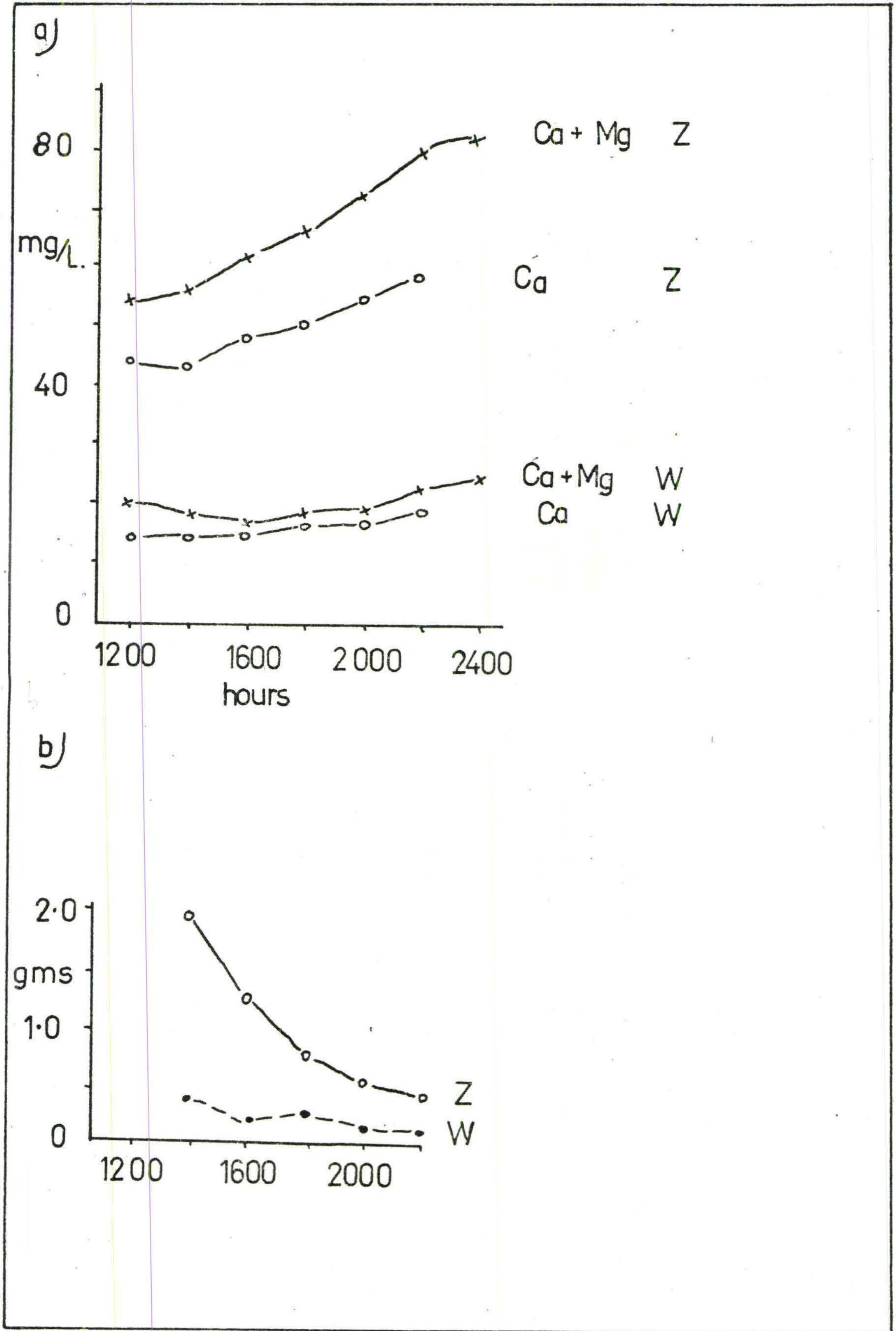


Fig. 5:5 Changes in solute concentration and SDR on 6/8/70.(rills Z and W.)

The snowpatch centre appeared to be continuously melting whereas the meagre vestigial basal ice layer was contributing less meltwater at night. Such a situation is probably polygenetic, depending upon both the differing thermal properties of the ice and snow as well as on an inertial effect due to the delay caused by the slow percolation of snowpatch melt water through the bulky snowpatch centre.

Snowpatches were not, therefore, the sole suppliers of water to the rill systems, and the magnitude of their contribution depended upon the size and condition of the snowpatch involved. Small decaying snowpatches apparently contributed little water to rills whereas the bulky snowpatches examined, supplied large quantities of meltwater, depending on the metereological conditions. As summer developed, however, snowpatches were seen to be contributing relatively more water to the overland flow system until many adjacent rills, not supplied by snowpatches, dried up.

The sediment load of snowpatches:

The significance of snowpatches in the sediment movement system lay partly in their supply of water to rills, but mainly in the dark layer of basal ice which, when exposed, gave rise to an S.D.R. peak in certain rills (fig. 5:6, 5:7, 5:8).

In the 1970/71 studies this thick continuous basal ice layer was seen to be permeated by large quantities of fine sediments, mainly 'relatively well sorted' medium and coarse silts of mean

Fig 5:6 The silt laden basal ice layers of snowpatch D during the washing of fines into the rill.

Fig 5:7 The exposed basal ice of snowpatch A, 1970.

diameters around 0.01 mm. These fines, occurring in voids and pores gave the ice its characteristic dark colour, and were present in concentrations of less than 27 gms/litre. All concentrations determined were in fact greater than 4 gms/litre, but clear ice, which was not sampled, occurred and possessed lower concentrations.

Fines also occurred in the snow above the ice but concentrations were lower, around 2 gms/litre, and compared favourably with Czeppes (1965) figures of 2 gm/litre for fines 'embedded in the snow cover' of snowpatches in Spitsbergen.

The vertical variation of silts in the basal ice was not simple, although apparently they were concentrated into zones, the lower-most zone being devoid of fines (table 5:2)

Coarse sands and gravels were occassionally obseved on the basal ice (fig. 5:9, 5:10) but were usually limited to the upslope portions where they frequently formed deltas or channel linings focusing upon the inlet ice channels. These tongues and deltas of coarse material were up to 15 cm. wide and 40 cm. long and became dispersed downslope into areas of ice permeated with fines.

As the basal ice melted the small clusters of silt particles originally distributed throughout the void system became more concentrated in furrows and depressions on the basal ice surface. The rapid melting of ice associated with the coalescence of voids was probably due to the preferential absorbtion of solar radiation

TABLE 5:2

CONCENTRATIONS OF SNOWPATCH SEDIMENTS

DATE	SITE	DEPTH	CONCENTRATION gm/kg	CONCENTRATION gm/sq.cm.
I970	A		27	
"	J	snow surf*	2	
"	J	I5 cm.	8	
"	J	28 cm.	I7	
"	J	34 cm.	9	
"	I	ice subsurf.	I4	
"	I	ice base	4	
I97I	P	ice surf.	54	.I2
"	P	ice surf.	44	.09
"		ice subsurf.	2.5	.004

* - surface

Fig. 5:8 Minor concentrations of silt at edge of snow patch, 1971.

Fig 5:9 Supra-nival gravels in process of deposition, site P, 1971.

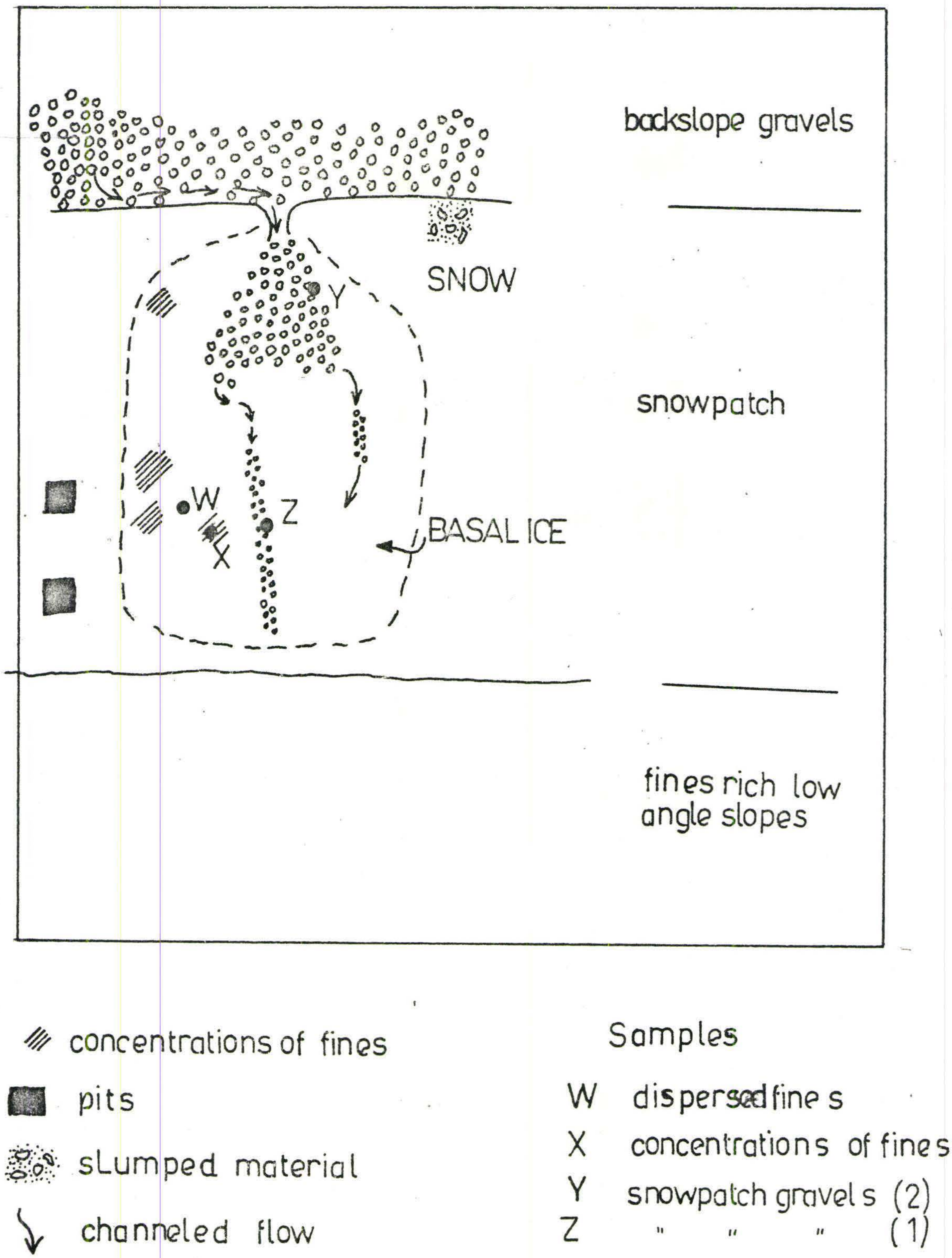


Fig. 5:10 Supranival deposit site P 197I.

Fig 5:11 Concentrations of silts in depressions on basal ice surface.

0 1 2cm

by the dark silt particles. Such coalescence leads to large concentrations of silts in voids varying in size from 0.5 mm. to 5.0 mm. diameter (fig. 5:11).

These large voids and depressions with their associated particle groupings were gradually enlarged and percolating water concentrated the silts into progressively larger sheets and linear concentrations. Such concentrations were washed, or moved as mud flows, across the basal ice surface either into rills draining the snowpatch or back into the snow lower down the snowpatch. In the latter case they could be washed out again or deposited _in situ_ depending upon the prevailing conditions. These two basic situations of washing into rills and _in situ_ deposition will now be expanded.

The sediment load of the snowpatch rills:

Washing of fines from the basal ice was studied in more detail in the rills flowing from snowpatch A. The period of intensive study from July 28th 1970 to August 6th 1970 followed immediately after the S.D.R. peak in rill A and the water discharge peak corresponding to the storm of 27th-29th July.

Figure 5:12 showing the plan view of snowpatch A presents the details of sediment trap positions for July 28th-August 6th. Four sediment traps W, X, Y and Z were placed in four rills 20 m. from the snowpatch and three W_a, Z_a, and Z_b were placed in rills W and Z 35, 40 and 60 m. from the snowpatch. Only extended records from rills W and Z were taken. Rills W and X flowing from the snow

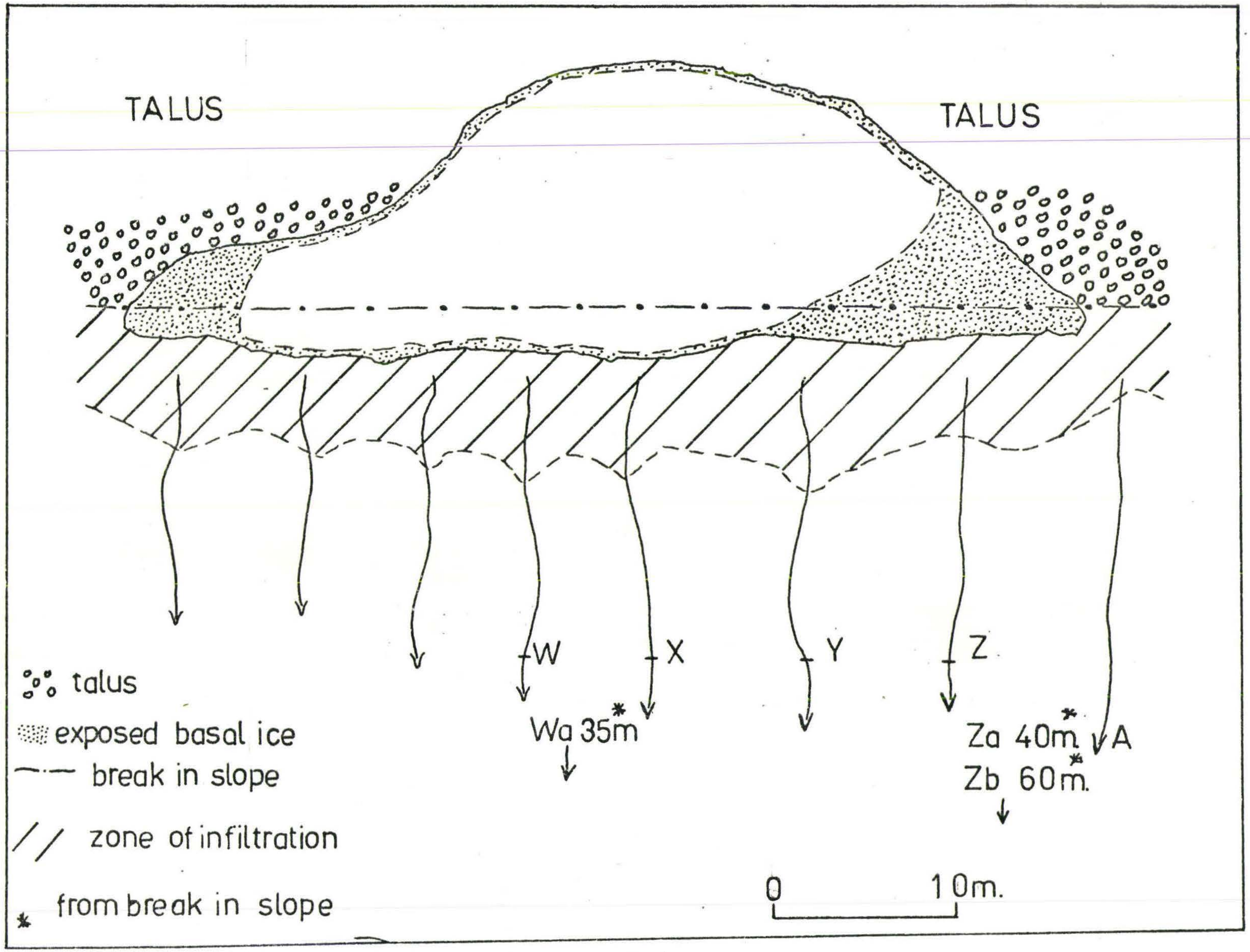


Fig. 5:I2 Rills sampled for SDR Snowpatch A.

covered central portion of the snowpatch were clear throughout the relevant period and rills Y and Z, being supplied with water flowing across the exposed peripheral basal ice, were turbid.

Rill W: readings started on July 29th when water discharges were still high from the influx of storm runoff. Figure 5:13 illustrates the high S.D.R. which occurred on the 29th and the abrupt decrease that followed. The later low S.D.R. could be qualitatively correlated to the decreasing water discharge. Significantly, W_a located 15 m. downstream of W showed similar S.D.Rs per day indicating that for this short stretch of rill, bedload movement was approximately constant downslope. The load from the trap on 29th July was subjected to textural analysis and consisted of very poorly sorted clays, silts, sands and gravels (up to 8 mm.), the mean diameter being 0.085 mm. These material were only moved under high velocity conditions and the motion was mainly by saltation, rolling and bouncing along the rill bed.

Rill Z: for trap Z, the S.D.R. record was the reverse of that for trap W (fig. 5:14). The first reading, on the 28th July, taken during the peak of the water flow, demonstrated that little sediment was being deposited in trap Z and on the 29th the S.D.R. was still low. As the water discharge stabalized S.D.R.s increased to a maximum of 18 gms/day and subsequently decreased to around 6 gms/day. This trend was basically followed with decreasing amplitude by the lower traps, Z_a and Z_b except for the first day, the 29th. On this date the S.D.R. for Z_a was

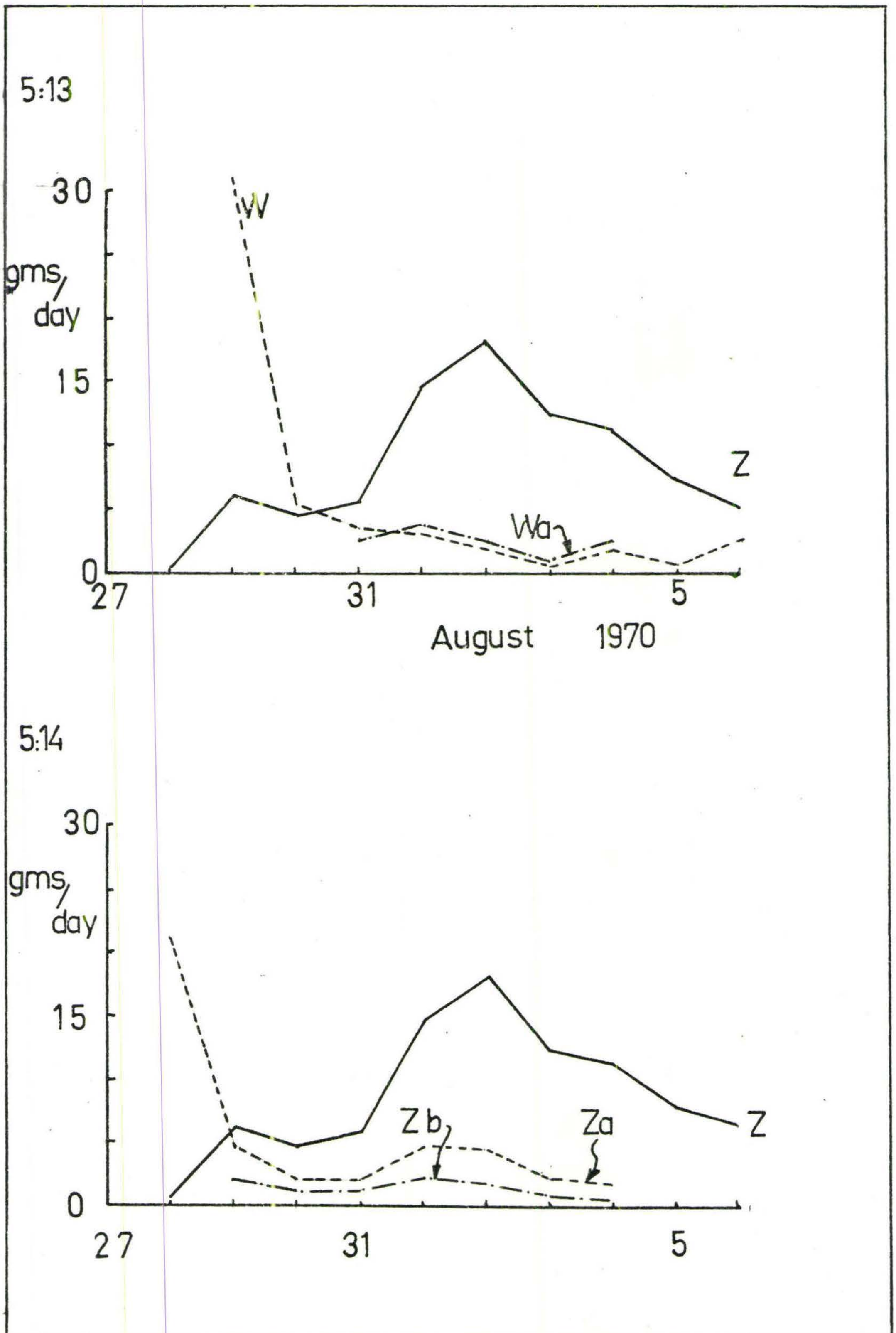


Fig. 5:I3 and 5:I4 SDR for rills W and Z I970.

considerably higher than that of Z; this was considered to be due to washing of sediment through the upper trap and the subsequent deposition in the lower one; a similar situation as discussed for rill G.

As in rill G the zone of maximum deposition was seen to fluctuate although the most usual sequence was one of high deposition in the upper trap with decreasing S.D.R.s downslope. Such a sequence of downslope deposition also took place in rill D during the S.D.R. peak of 23-27th July when suspended loads sampled at increasing distances downslope gradually decreased from a maximum value of 1600 p.p.m. to zero at 80 meters from the snowpatch (fig. 5:15). A similar decrease, but relying on only two readings occurred on rill L 1971 (table 4:2).

It became apparent that a diurnal march of sediment deposition paralleled the diurnal marches of discharge and solute concentration and such a march was demonstrated for August 6th 1970. S.D.R.s were measured every two hours from 1400 to 2200 hours (fig. 5:5b). Rill W possessed low S.D.R.s which decreased slightly during the evening, this corresponded to the continuous melting of water from the snowpatch centre. Rill Z, however, exhibited a marked decrease of S.D.R. throughout the evening, this corresponded to the decrease in discharge as demonstrated in the section: Contribution of snowpatch meltwater to rill flow.

The sediments trapped corresponded closely in texture to the snowpatch silts, that is, they were 'relatively well sorted'

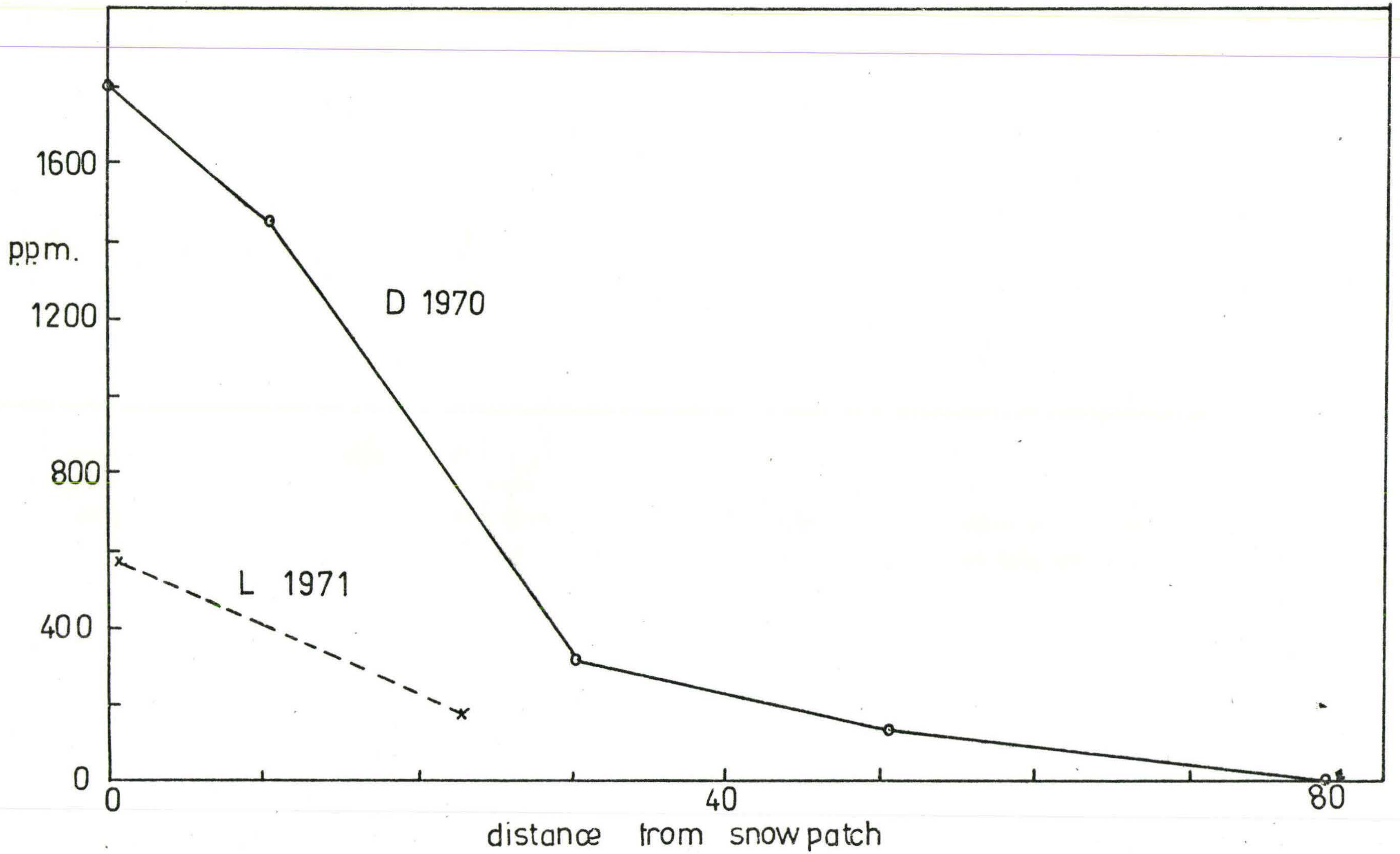


Fig. 5:I5 Decrease in suspended load downstream in rills D and L.

medium/coarse silts with mean diameters between 0.02 and 0.03 mm.

The two rills therefore, contrasted markedly. Rill W was clear throughout the period and its coarse, very poorly sorted bedload was moved mainly during peaks in water discharge. Rill Z, with three sediment traps along its length demonstrated how, after the initial water discharge peak, a depositional sequence existed with the bulk of sediment being deposited upslope.

Deposition from snowpatches:

When surface wash was weak on the exposed basal ice the contained sediments tended to remain behind and as the snow-patch ablated they were eventually superimposed on the underlying ground surface (fig. 5:16)

If no mechanical concentration had taken place the original void clusters of silt were seen to be superimposed as a thin surface layer of silts. This skin later dried to form a white coating on most of the surface; such a skin was difficult to distinguish from the underlying gravel and its existence was usually confirmed merely by the existence of a thin powdery cover on stones. In contrast, the thicker laminar deposits when super-imposed were more readily distinguished and the final vestiges of snowpatches were frequently marked by thick silt covers and miniature deltaic deposits in the process of deposition in pools of water. The tongues of gravel that occurred as channel linings at the inlet edge of snowpatches were deposited on the gravel of the steep backslopes and remained as tubuler gravel deposits.

Fig 5:16 Superimposition of basal ice fines on backslope gravels,1971.

The classification and history of these sediments will be elaborated in the following chapter.

As a rider to the above, brief observations were made on snowpatches in Baffin Island (Frobisher Bay) and in the eastern Rockies (Crowsnest Pass) to ascertain the nature and significance of snowpatches in low Arctic and Alpine environments. The Frobisher snowpatches usually possessed organic fragments up to 5 mm. diameter strewn in a thin cover across their surface. This cover, sometimes up to several centimeters thick, contained only small quantities of mineral matter and appeared to have been blown onto the snow surface by wind action.

A similar, but more sparse covering, was also observed in the Rockies and occassionally laminar and tubular organo-mineral deposits remained on the ground surface adjacent to ablating snowpatches. From the areas examined it appeared that sediment sequences associated with snowpatches were of lesser importance from the low Arctic and Alpine sites.

Discussion and Conclusions:

It has been shown that water flowed from the interflow zone, upslope of snowpatches, and percolated through the snowpatches. Some of this percolating water froze to form the thick basal ice layer, but most continued through the snowpatch to be joined by the snowpatch meltwaters. These combined water sources then emerged as rills on the low angle slopes.

If the basal ice was in fact caused by the freezing of percolating waters from upslope it is logical to conclude that the fines contained within the basal ice travelled with these waters, that is from upslope, either from the interflow zone or from the land surface above.

The occurrence of gravels focusing upon the inlet ice channels which supplied water from upslope also implies an upslope source for sediments. That is, if this source supplied coarse materials it could also supply fines.

If such conclusions are correct it appears that the High Arctic snowpatches act as large sediment traps located conveniently at the base of the interflow zone, that is, at the break of slope. Their efficiency is difficult to establish, it is quite possible that a large proportion of sediments from the interflow zone pass straight through the snowpatches. If they do, however, such small concentrations would be difficult to detect using conventional sediment traps.

CHAPTER VI

THE DEPOSITS

Fine particles have been shown to move across the land surface entrained in fluid flow which varies through time. Such particles form deposits, which may be termed 'fresh', found on backslopes, at the break in slope and on low angle slopes. Such fresh forms although, not continuous, could be expected to produce, over the years, significant thicknesses of sediment. Few permanent or long lasting accumulations of sediments similar in nature to the fresh ones were found; instead, low angle slopes consisting of fines with a skeletal framework of angular-subangular stones or gravel predominated.

This lack of continuity between the 'fresh' deposits and the regolith of low angle slopes, although perplexing, could be ascribed to the subsequent history of the deposits. Some 'fresh' deposits, merely because of their position on back slopes exist in a state of unstable hydrodynamic equilibrium, whereas others, resting on low angle slopes, although in a state of stable hydrodynamic equilibrium, could be subject to a variety of cryogenic or turbation processes. The morphology, position and character of 'fresh' depositional forms will be discussed first and related to the process environment. Then the topographic situation of such deposits will be examined, in section and plan, to evaluate their distribution and finally their possible history will be tentatively outlined.

'Single season' deposits:

In table 6:1 are listed seven basic classes of 'single season' deposits, defined as : deposits of fresh appearance occurring on or within the regolith and relating to that season's fluvial and niveo-fluvial activity.

These deposits can be found if the ground surface is carefully examined after the spring thaw or during the summer, although their discovery is usually enhanced if the processes are observed in operation and then the field worker traces them from the final stages of deposition.

In table 6:1 classes 1, 2, 3, 4 and 5 possess distinct morphologies that can be related directly to the process environment as discussed in chapter V. The process environment is, in this case, the deposition of materials ranging from silts to gravels from on or within the basal ice. These niveo-fluvial processes can be directly related to the topographic position, as most snow patches linger at breaks in slope. The quantitative parameters used in this study, namely the mean and standard deviation of grain size, do not, at this level in the investigation, lead to any mutually exclusive divisions. As can be seen from

TABLE 6:1

MEAN DIAMETER	MORPHOLOGY	RELATIVE SORTING	POSITION	PROCESS
1) m/c silt	Laminar sheets <1cm. thick	well	Along break in slope.	Superimposition from surface concentrations on basal ice.
2) m/c silt	V. thin cover	well	"	Superimposition of dispersed fines.
3) m/c silt	Scrolls, bars & deltas	"	"	Superimposition from surface concentrations on basal ice.
4) silt & sand	Tubular & spherical deposits max. dia. 7 mm. max. length 12 mm.	well-average	Back slope & along break in slope.	'Peeling of silts from basal ice.
5) Gravel	Tubes & fans up to 50 cm. length.	well-poor	Back slopes	Linings of inlet channels of basal ice.
6) c. silt/ f. sand.	Scrolls & bars.	well	Talus foot slopes.	Superimposition of early thaw season supranival deposits.
7) m/c silt	Curvilinear & meandering	well	Talus foot slopes, raised beach, & plateau surface.	Rill transport.
8) m/c silt	Polygon patterns	well	" "	Linings of polygon margin overland flow.

table 6:2 most 'single season' and rill sediments were medium-coarse silts with inclusive Graphic Standard Deviations (Folk and Ward 1957) of between 1.0 and 2.0 Ø. Deposits of snow patch sediments came within this category and were found on all slopes; in addition, gravels sometimes occurred on the steeper back slopes of gravel terrain.

Tubular and spherical deposits of silts and sands occurred on and within the regolith as individuals, or in small concentrations (fig. 6:1). Usually they were directly related to the 'peeling' of sediments from the basal ice and associated deposition on the underlying stones.

In addition these deposits could be formed on gravels within the regolith as demonstrated in the following section. The genesis of such deposits is unclear, but their textural characteristics are those of rill or snowpatch sediments (table 6:2 sample F1 fines talus) and they are clearly related to a washing or fluvial action.

Category 5, tubular and deltaic deposits consisting of gravels, are also related to niveo-fluvial activity. In this case they are formed by the superimposition of ice channel and tunnel linings (fig. 6:2) on the underlying ground surface. As gravels are limited to the upslope portion of snowpatches, deposition usually takes place on back slopes whilst the fines are dispersed downslope as well, thus leading to a more widespread domain of fines.

Classes 6 and 7 shared many textural, distributional and

TABLE 6:2

DATE	SAMPLE NO.	CAT-EGORY	POSI-TION	SD.	MEAN	MEDIAN	MODE
4/7/70	G'3	F	a(1)	2.00	.028	.035	Coarse silt
"	G"2	F	a(1)	1.69	.032	.041	" "
6/7/70	G'2 N.	F	" "	0.98	.045	.048	" "
"	G"4	F	" "	1.14	.034	.037	" "
10/7/70	G'6 N.	F	" "	1.70	. 04	.058	Fine sand
"	G"8	F	" "	1.93	.028	.030	Coarse silt
11/7/70	G'7 N.	"	" "	1.31	.034	.040	" "
"	G"9	"	" "	1.47	.032	.033	" "
14/7/70	G'10N.	"	" "	1.61	.030	.046	" "
"	G"12	"	" "	1.10	.032	. 04	" "
16/7/70	G'11N.	"	" "	1.11	.043	.048	" "
"	G"13	"	" "	1.28	.030	. 04	" "
1/7/70	A_1	"	" "	1.63	.042	.043	" "
4/7/70	A_4	"	" "	2.14	.026	.038	" "
30/6/70	D_1	"	" "	1.47	.025	.030	" "
24/7/70	D_{17}	"	" "	1.29	.020	.025	" "
	FA	"	a(2)	1.71	.012	.010	Medium silt
	PF	"	c	1.86	. 03	.035	Coarse silt
	SDB	"	a(1)	1.68	.017	.020	" "
	SP(1)	SP	a(2)	1.62	.012	.012	Medium silt
28/6/71	28/1	SP	a(2)	1.73	.012	.014	" "
1970	SB silt	"	a(1)	1.05	.031	.041	Coarse silt
	SP Gr_1	"	a(2)	1.25	1.00	. 9	Coarse silt
	SP Gr_2	"	a(2)	0.52	5.00	5.5	Gravel
	W_3	F	a(1)	3. 4	.085	.080	Medium sand
	Z_6	F	a(1)	1.26	.022	.023	Coarse silt
	Za_1	F	a(1)	1.17	. 03	.035	Coarse silt
	SP Fines$_2$	Rec	a(2)	1.61	.009	.012	Medium silt
	Fl.Fines Talus	Rec	b	1.55	.021	.022	Coarse silt
	Plateau Fines	"	c	1.86	. 03	.035	" "
	J	"	a(2)	2.0	.019	.041	" "
	13/2	"	a(1)	1.94	.013	.014	" "
	9.20	"	a(1)	1.53	.049	.046	" "
	9.150	"	" "	1.31	.042	.042	" "
	A_1	Sld	a(1)	2.45	.019	. 02	Med/coarse Silt
	A_2	"	" "	4.1*	.014	. 01	Medium silt
	A_3	"	" "	3.3*	.019	.018	Medium silt
	A_4	"	" "	2.4*	.004	.005	Clay/M. silt

DATE	SAMPLE NO.	CAT-EGORY	POSI-TION	SD'.	MEAN	MEDIAN	MODE
	A_5	Sld	a(1)	2.55*	.006	.009	M.silt/clay
	Silt Plain	"	d	2.10	.012	.015	Coarse silt
	G_1	"	a(1)	2. 8*	.032	.038	" "
	G_2	"	" "	2. 8*	.014	.013	Coarse/Med.silt
	G_3	"	" "	2. 0*	.012	.012	Medium silt
	G_4	"	" "	2. 0*	.015	.013	" "
	SPG	"	d	2.65*	.008	.013	" "
	D_1	"	a(1)	1.81	.012	.014	" "
	D_2	"	" "	3.65*	.017	.01	" "
	D_3	"	" "	2.65*	.015	.014	" "
	D_5	"	" "	3.35*	.009	.008	" "
	Dadj	"	" "	2.60*	.007	.008	" "
	13/1	"	d	2.65*	.013	.015	" "
	T.F.	O	b	3.24	.065	.072	Coarse silt/ medium sand
	Mfl	O	"	3.9*	.019	.014	Medium silt
	STF	"	"	2.52	.05	.035	Coarse silt

2 { Fluvial	F	Low Talus Foot	a(1)	Inclusive)	
Snowpatch	SP	Low Raised Beach	a(2)	Graphic)	
Recent Deposit	Rec	Steep Slope	b	Standard)	SD'
Other	O	Plateau	c	Deviation)	
Slope deposit	Sld	Valley	d	Gravels	Gr.

* Due to high clay % 95% missing and Inmans 'Ø Deviation Measure' used $\sigma\phi = \frac{1}{2}(\phi 84 - \phi 16)$.

2 Single season deposits

Fig 6:1 Tubular deposits of fines in the process of formation. Snowpatch near Ptolemy mountain, Crowsnest Alta.

Fig 6:2 Tubular deposits of gravel channel linings superimposed on backslope, 1971

morphological characteristics. In 1970, when these features were observed, the only significant difference between the two types was the time and process of deposition. Class 6 deposits were formed early in the thaw season on the remaining snow and ice and were superimposed on the ground surface of the talus footslopes. Class 7 deposits were more ordered in their distribution and occurred in sub-parallel lineations on most low angle slopes; this distribution constrasted with the more deranged pattern of the superimposed sediments. Despite the extensive supranival deposition in 1970 the evidence of class 6 rapidly faded and within three weeks no clear evidence of their existence could be discerned.

Class 8 features, though not obvious, occurred as thin nets of sediment over extensive areas of ground (fig. 6:3). These nets were particularly noticeable on the plateaus surrounding Resolute just after the snowpack had ablated. Such deposits, in conjunction with class 6 and 7 sediments formed on similar plateaus, provided evidence of sediment movement across low gradient surfaces not supplied with material from steep backslopes.

The eight above mentioned depositional classes can be fairly objectively classified into non-genetic classes based upon morphology, slope position and sediment texture, the last named being least useful because of the homogeneity of the sediments. This classification is strengthened by the addition of major operative processes.

Fig 6:3 Deposits from polygon margin overland flow, Resolute plateau 1971.

Such deposits are not monogenetic; for example the slumping of gravels onto the snowpatch can proceed niveo-fluvial sorting in the production of class 5 deposits and the supranival rill deposits (6) are not always readily distinguished from the linear rill linings (7) formed later. Furthermore, laminar deposits could be produced by early thaw season supranival flow and such sheets, if formed near the break in slope, could be difficult to distinguish from class (1) features. Also, much of the sediment must later merge with the underlying ground surface, therefore observations are best made during or immediately after deposition.

Deposits in relation to topography:

a) Talus and blockfield slopes:

The examination of fluvial action within the interflow zone was problematic due to reasons stated in chapter IV and most of the evidence supporting fluvial transport within this zone has been gleaned from minor sedimentary features. Fines within the talus had a varied origin and history and only a small proportion could be directly attributed to fluvial action. For example, sample Mfl. (table 6:2) was taken from a recent mud flow (material > 2 mm. removed before analysis) on the talus slopes overlooking Scallons Cove 1970 (fig. 2:3). This sediment proved to be a poorly sorted mixture of clays, silts, sands and gravels exhibiting positive skewness. Sample T.F. from the talus slopes above site A although poorly sorted and of similar texture to

Mfl. proved to be negatively skewed with modal particle sizes of coarse silt and medium sand. The former deposit possessed a 'tail' of fines whereas, sample T.F. from a structureless mass of fines within the talus was a lag deposit with a low proportion of fine silt and clay. This contrasting situation could be related to washing action within the talus slopes; the deposit Mfl. being relatively free of washing action in contrast to T.F. Such a conclusion assumes however that fine silt and clay was originally present in the latter material.

Tubular and spherical deposits of fines, as stated, were in evidence on and within talus gravels and blockfield detritus. Investigations proceeded further to establish the distribution of such features. Pits J, K and N were excavated in a variety of positions on blockfields skirting Signal Hill, Resolute in 1971. These complex slopes consisted of large quantities of angular blocks ranging in size from a few cms. to 0.5 m. Occasional mounds of fine material with a framework of subrounded, subangular gravels, showed above the surface on the gentler (0-10°) slopes (fig. 6:4).

<u>Pit J:</u> Angular blocks, similar to those mantling the surface excavated to 20 cm. Frequent occurrences of fines in tubular and spherical forms. After several days the permafrost table melted down to 28 cms. where a stiff, sandy clay occurred.

<u>Pit K:</u> Angular blocks excavated to 23 cm. Evidence of deposition in the form of spherical and tubular silt/sand deposits (sample Fl. fines talus, table 6:2) as well as lemming foecal pellets and well washed mosses. Below 23 cm a stiff, sandy clay located and sampled (S.T.F. table 6:2). This was later demonstrated to be a relatively poorly

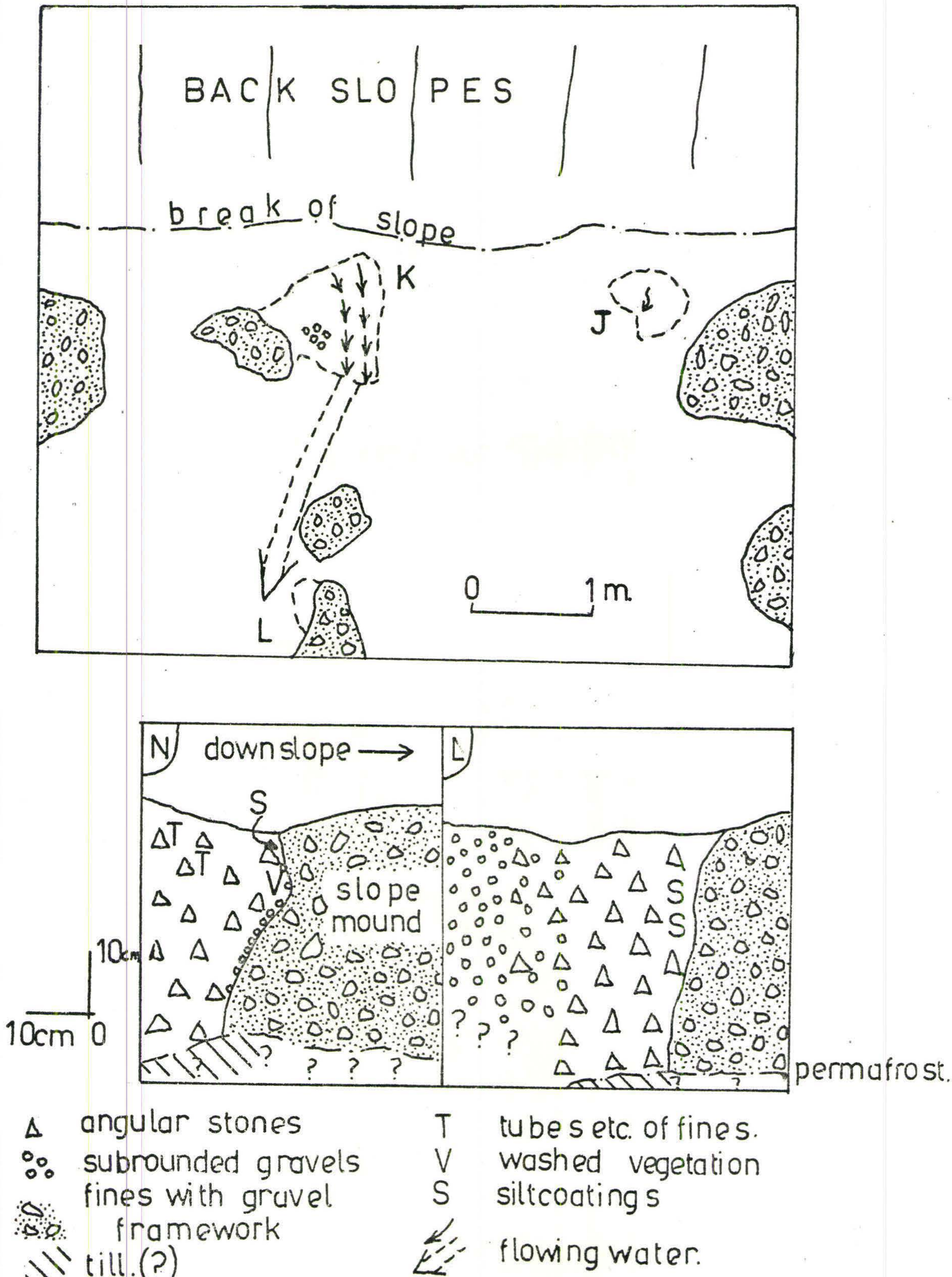


Fig 6:4 Pits on flanks of Signal Hill, Resolute 13/7/71.

sorted coarse silt with a mean diameter of 0.05 mm. Water flowed across sandy-clay surface despite the fact that the permafrost table several cm. below. Much washing in evidence on this surface including dunes and bars of silts and fine sands. Adjacent to the pit a stony sandy loam occurred on the surface in the form of small slope mounds. The sloping sides of this mound showed signs of washing in the form of clean gravels and sands.

<u>Pit N:</u> Excavation of upslope portion of sandy-loam slope mound. At 37 cm. upslope of the mound water observed to flow across interstitial ice of permafrost. A zone of gravel occurred around the mound perimeter as well as some silt coatings. On angular blocks a profusion of spherical deposits occurred whilst against 'walls' of mound washed strands of vegetation encountered. The slope mound widened towards the base.

Three major points appeared from the evidence in the above pits and others not mentioned:

i) Washing was observed to exist as demonstrated by the flowing water with associated dunes and bars.

ii) Deposits of tubular and spherical fines, foecal pellets and washed strands of vegetation were in evidence. These occurred at a variety of depths and are considered to be caused by washing action at progressively lower levels as the permafrost table lowered.

iii) The presence of a stiff, sandy clay was found in a variety of subsurface positions and is interpreted as being a glacial till. In its position greater than 20 cm. below the surface it would be protected from the washing action of early thaw season melt waters.

b) Talus foot break in slope:

Around the major break in slope a variety of 'single season' deposits occurred associated with the occurrences of snow patches. In general a zone of class 4 deposits occurred on talus slopes in conjunction with a thin sometimes imperceptible 'skin' of silts (class 2). Along the break in slope laminar deposits and fans (class 1) predominated with frequent skins of silt occurring on stones and gravels. From below the break in slope rills with associated channel linings (class 7) contributed sediment downslope.

It should be emphasised that such zones merely delimit regions of probable occurrence of specific deposits not the location of continuous or extensive sheets of such features.

c) The foot slopes:

As stated in chapter II immediately downslope of the break in slope, water percolates through a zone of rubble before forming rills. This zone frequently lacked accumulations of fines other than 'single season' deposits. On the talus foot slopes proper linear rill deposits (class 7) supranival deposits (6) and polygon margin deposits (8) occurred sporadically.

Subsurface samples of the fraction less than 2 mm. were taken at regular intervals downslope on three traverses (fig. 2:4). These samples were of material from throughout the fine centred polygons, hence a certain degree of sorting may be exhibited by the included data.

Information on mean, modal and median particle size and sorting is given in table 6:2 and can be compared with such data for 'single season' deposits (fig. 6:5). The talus foot slope

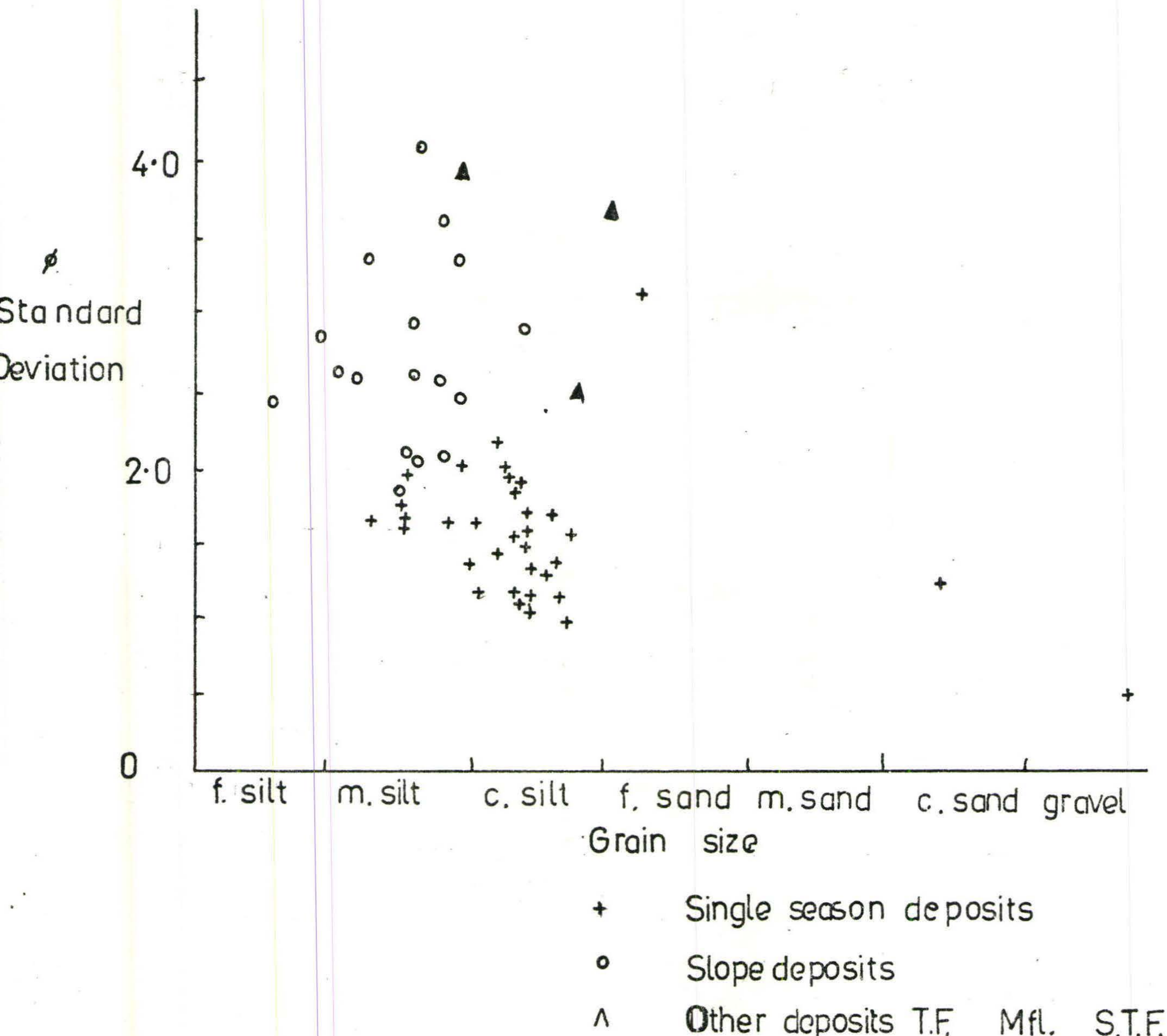


Fig. 6:5 Scatter diagram plotting standard deviation against mean grain size.

deposits (Sl. D.) were finer textured, more poorly sorted and richer in clays than 'single season' deposits. Mean diameters for the 'single season' and slope deposits (fig. 6:6) were shown to be significantly different at the 0.1% level (student's T. test). In addition sample sorting demonstrated the existence of two distinct populations with the slope deposits being less well sorted than the 'single season' deposits (fig. 6:6).

Samples from the three traverses A, D and G did not exhibit any differences in sorting or mean diameter between traverses at the 10% level of significance, but a slight downslope decrease in grain size could be discerned. This decrease was erratic (fig. 6:7) but differences between sample means from the upslope and downslope ends of the traverse showed samples A_1, D_1 and G_1 to be significantly coarser (at the 5% level) than samples A_5, D_5, G_5.

d) Deposits associated with terrace topography:

Terraces examined on raised beach gravels and Mecham Valley side debris although acted on by the same fluvial process as talus and talus foot slopes were found to possess different details of sedimentation. Backslope deposits were essentially the same as those on talus slopes and consisted of tubular and spherical deposits and thin 'skins' of silts all of which occurred on or just below the gravel surface.

Pit F, excavated on a 15° slope consisting of raised beach gravels on the right bank of the Mecham (fig. 2:7) exhibited well the range of fluvial deposits occurring on backslopes (fig. 6:8)

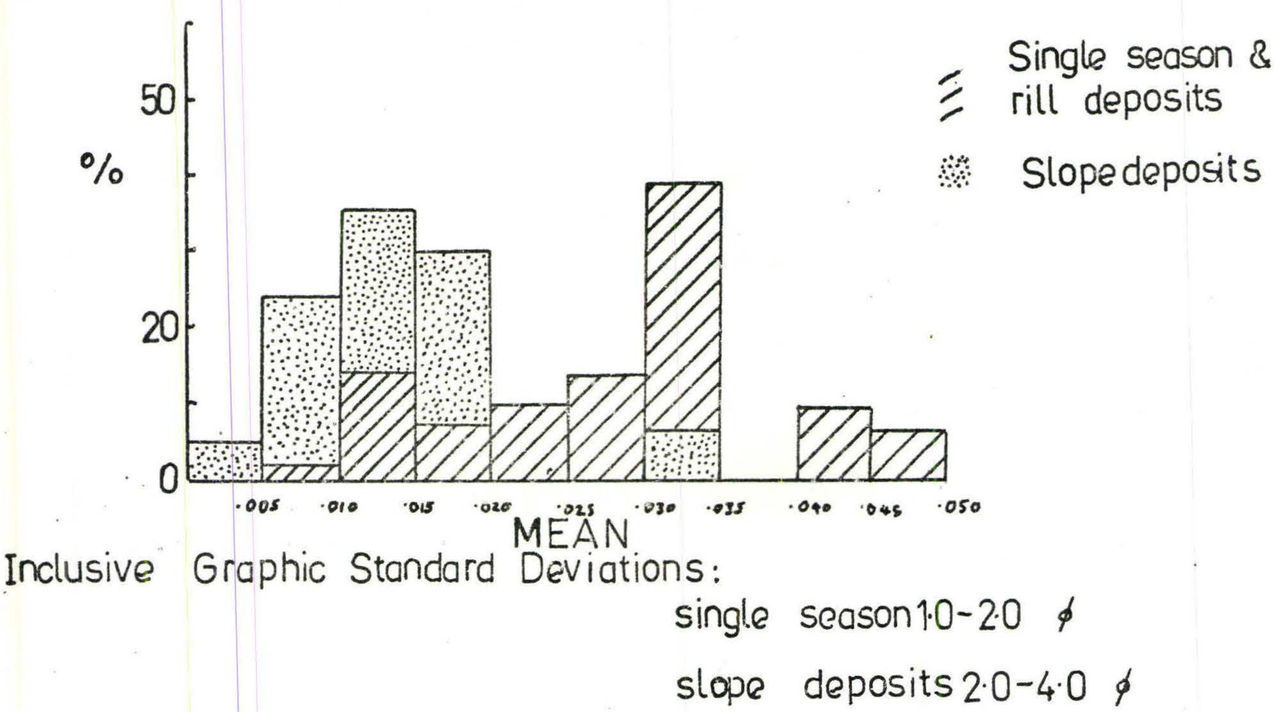


Fig. 6:6 Mean grain size for single season and slope deposits.

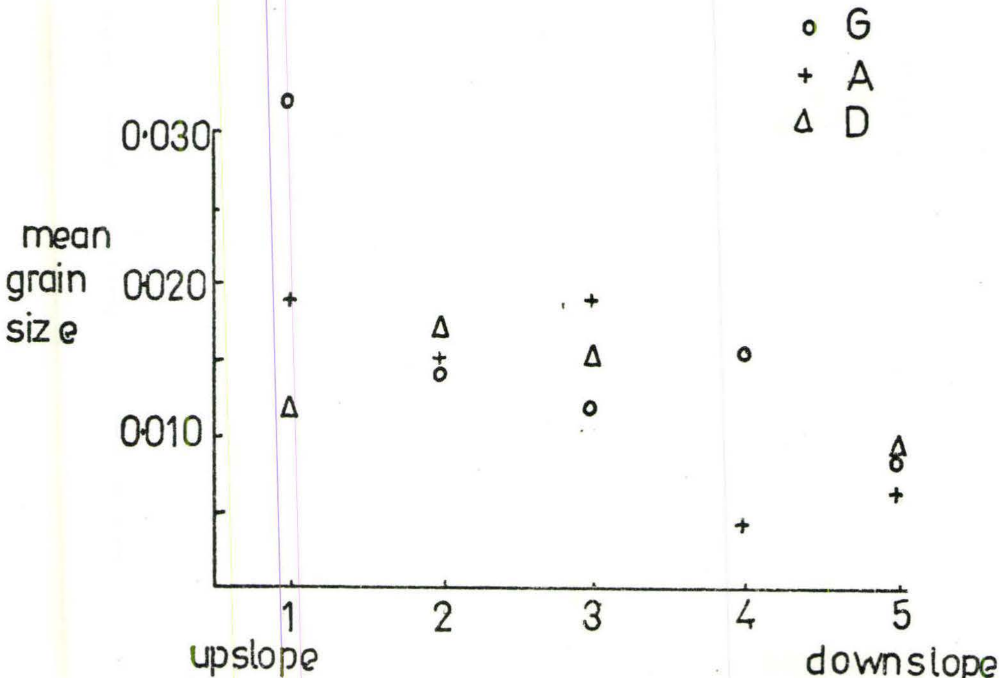


Fig. 6:7 Decrease in mean particle size down slope
Sample positions shown in Fig. 2:6.

Surface: laterally for one metre in trough tubular, spherical and laminar deposits of silt observed. On edge of slope mound a thick (up to 5 mm.) deposit of fines occurred which became white when dry. Upslope of the trough surface stones were clean.

1-3 cm. Deposits of fines common as well as strands of washed moss.

3-15 cm. Stones moist, silt skins occurred but were not thick except in one area where they 'cemented' stones loosely together by silt bridges to 1 cm. thick.

15-30 cm. Surfaces of stones moist-wet. Very thin, slippery silt coatings.

37 cm. Standing and slowly flowing water. Below 37 cm. poorly sorted sandy clay.

This situation, similar to that already noticed on the blockfield slopes, demonstrates that most of the washing and associated deposition of fines occurred at shallow depths, presumably during the early thaw season when the active layer was shallow.

Figures (6:9, 6:10) show a terrace feature in plan and in section. This terrace overlooked Resolute airport and conformed closely to nivation hollows described by Cook (1962).

<u>Pit H:</u> A) A steep back slope (mean gradient 16° 30') divided into two vague zones:

i) 'Clean' angular and subangular stones sorted into stripes.

ii) Gravel zone similar to A, but exhibiting thin discontinuous deposits (class 1, 2, 3 and 4) of fines from snow patch.

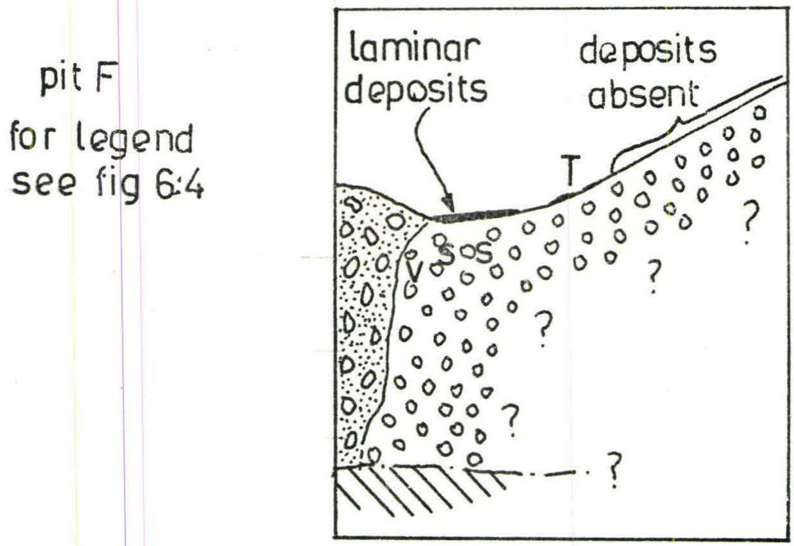


Fig: 6:8 Backslope deposition pit F,1971.

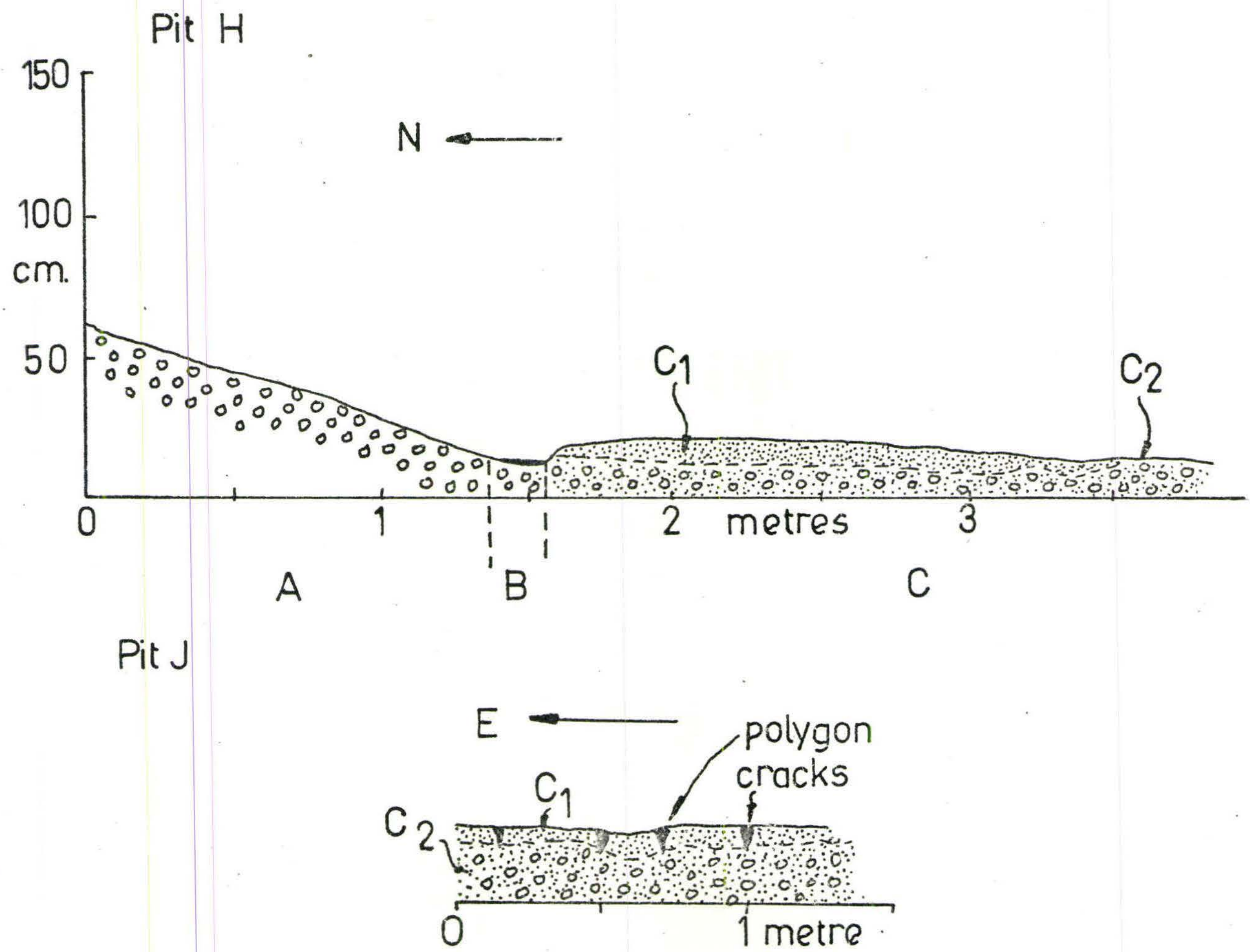


Fig 6:9 Sections at site H 1971.

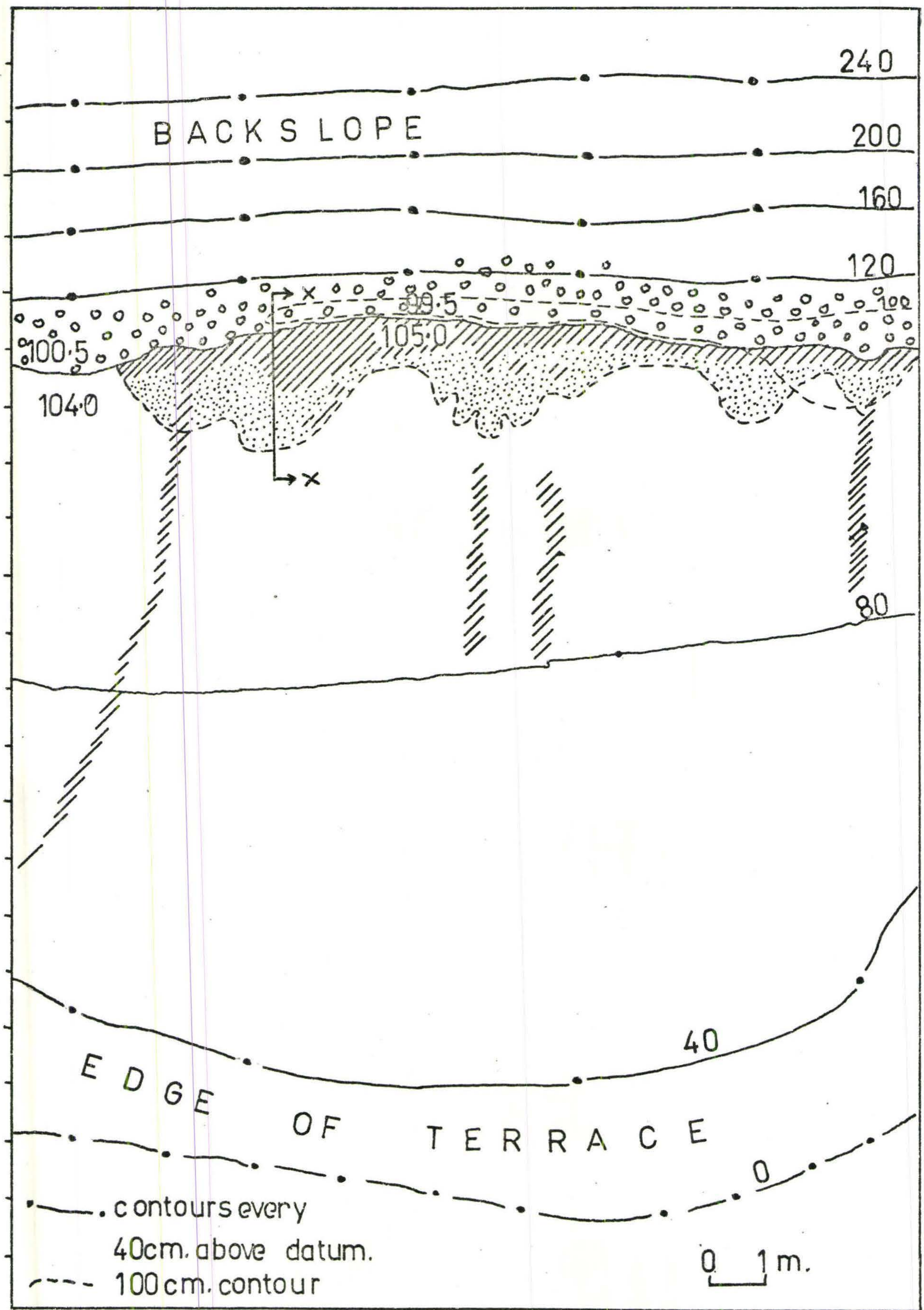


Fig. 6:10 Plan site H showing distribution of fines.

(B) Narrow transition zone conforming to break in slope trough; stones similar to those in zone A covered in a thin layer of silts (class 1, 2, 3 and 4).

(C) The major bench mainly covered by old fines (fig. 6:11).

(i) Silt cover of 'old' silts up to 10-12 cm. thick. Small non-sorted nets 14-17 cm. diameter, frequently hummocky and colonised by mosses and grass.

(ii) Underlying skeletal mass of dirty subrounded gravels possessing a matrix of fines. This layer reaches the surface at about 2.3 m. from the trough, and stones, when they appear on the surface appear clean.

<u>Pit I:</u> Section taken transverse to section H, but 2 m. to east. Essentially the same as revealed in section H (zone C), but possesses a thinner surface layer of silts.

Figure 6:12 shows a plan and section of pit G situated on valley side gravels of the Mecham river.

<u>Pit G:</u> <u>Surface</u> A: i. Essentially the same as zone A<u>i</u> pit H.

ii. Angular gravel with thin fresh silt coatings. The increase in thickness towards the trough.

Fig 6:11 Section through silt deposits(C_1),site H,1971.

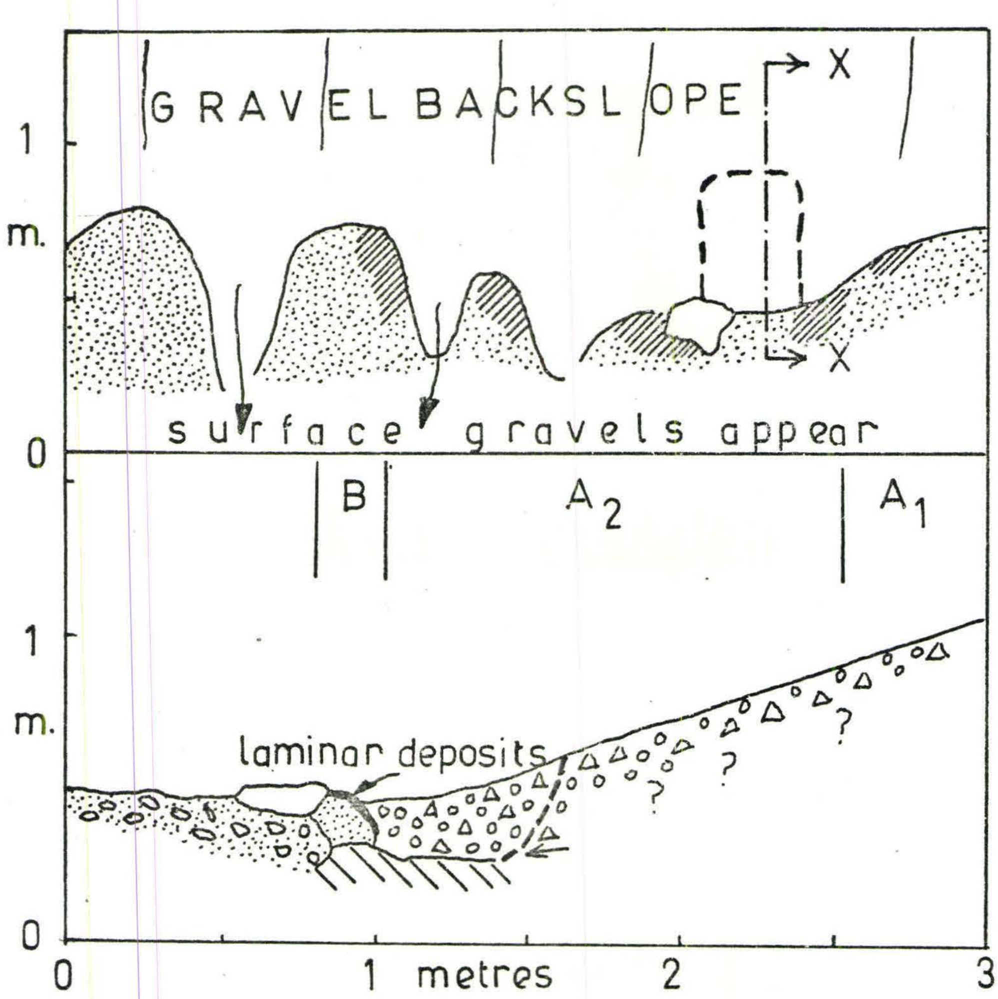


Fig 6:12 Plan and section of Mecham valley site, pit G.

Symbols used on plans.

gravels

homogeous fines

fines in gravel framework.

thick single season deposits.

water flow.

B. Mosses and fresh silts. Deposits up to 1.0 cm. thick on downslope edge of trough (fig. 6:13).

<u>Subsurface:</u> Mainly angular-sub-rounded gravels; at 20 cm. water occurred above stiff sandy clay.

In addition to the sequences outlined above occassional tubular and fan shaped deposits of gravel (class 5) could be discerned resting unconformably on the backslope gravel.

Figures 6:14 and 6:15 show, on different scales, contoured plans of two terrace features H, on raised beach gravels and B (i) below talus slopes (fig. 2:7). The zone of maximum 'single season' deposition (class 1 and 3) is delimited by the close hatching whilst the older silts, some colonised by mosses, extend within the broken line. Fig. 6:14 and 6:15 show the contribution of rill channel linings (class 7) to the terrace surface.

In most cases on the raised beach terraces and below certain talus slopes the zone of maximum deposition was located just downslope of the break in slope. Observations showed that the location of this zone of maximum deposition corresponded to the position of surface silt concentrations on the basal ice. Such surface concentrations of silt, if not removed by niveo-fluvial washing will be superimposed on the underlying ground surface. The position of the snowpatch will change little through time because it is determined by the break in slope. Therefore, if the zone of

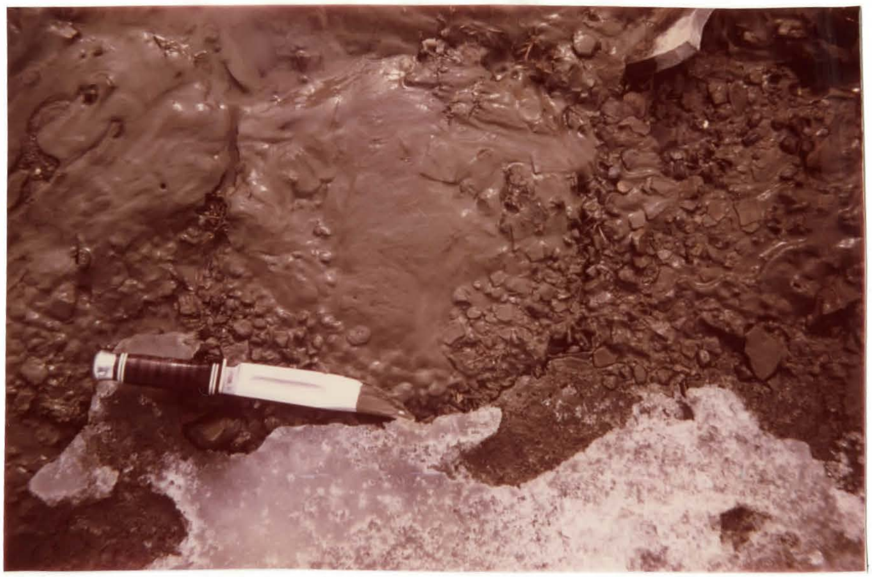


Fig 6:13 Laminar and extensive break of slope deposits,
sites,G and H ,1971.

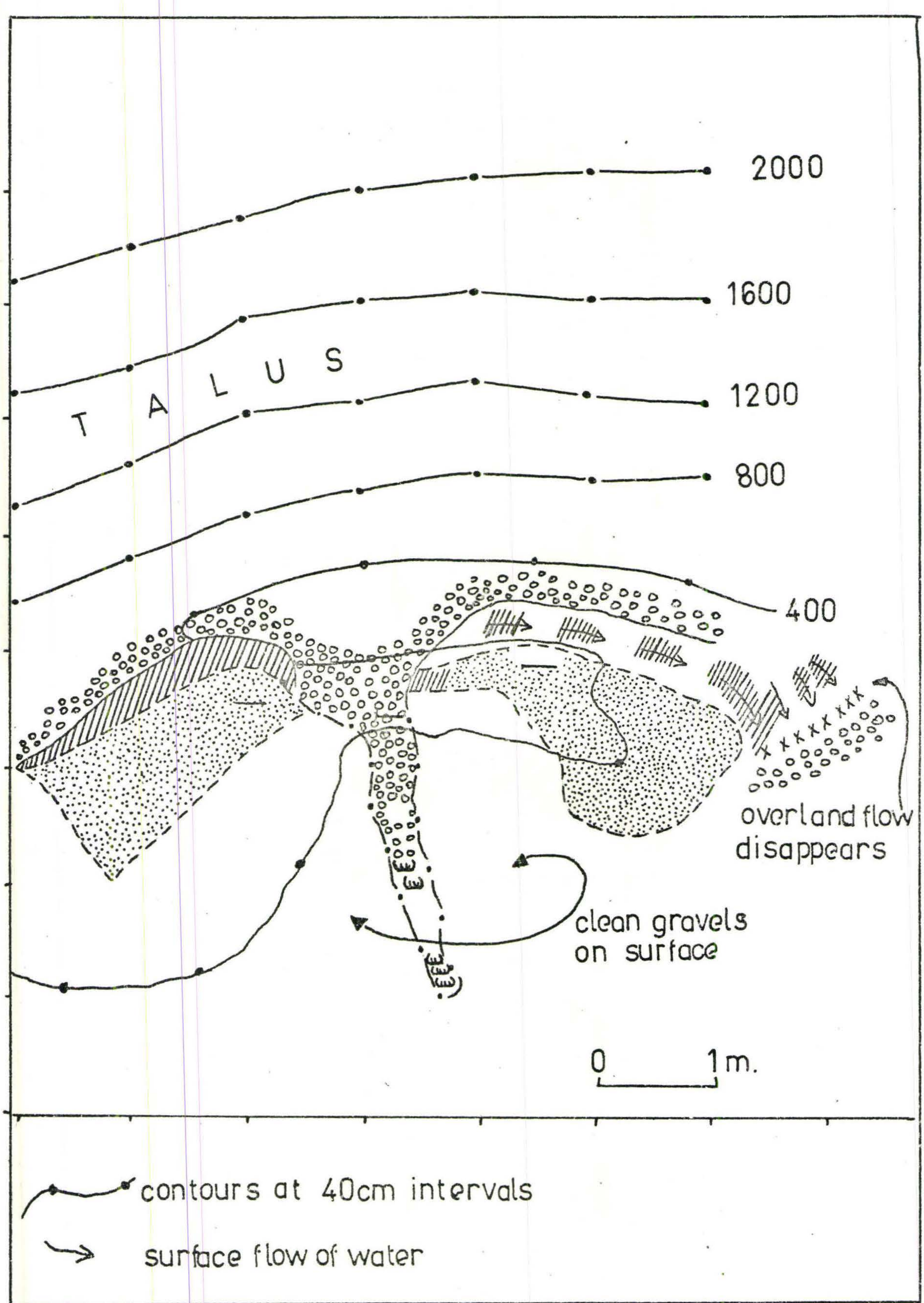


Fig. 6:I4 Distribution of fines at break of slope site B I97I.

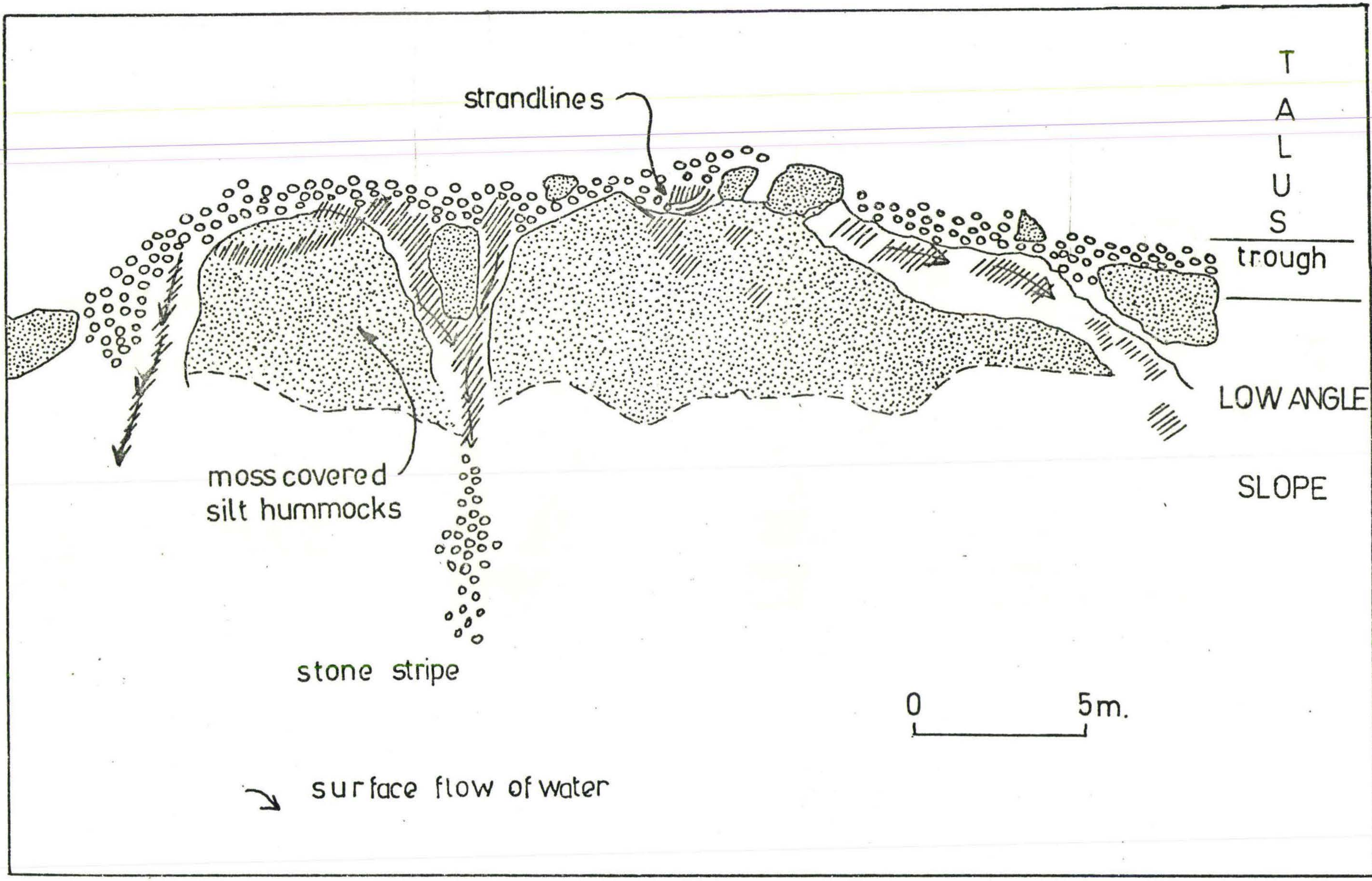


Fig. 6:15 Distributions of fines at break of slope near site B 1971.

surface silt concentrations remain within the same area of snow patch, the zone of maximum deposition will be perpetuated and could produce deposits similar to C1 (fig. 6:9, 6:10).

It is not clear whether such a mechanism operates through time, but if 'single season' deposition from snow patches did operate for long periods and contributed an arbitrary small increment of silt per annum to break in slope positions, it would be expected that surface concentrations of 'old' silt would be considerable. This is not so.

Figure 6:11 shows a large accumulation at site H, but very few areas exhibited such great extents of well sorted silts. The paucity of 'old' stoneless silts at optimum locations could be due to the lack of 'single season' deposits in most years or to the incorporation of fines into the existing regolith. The plausibility of the latter statement will be examined below.

Stability of the deposits:

'Single season' deposits are laid down in a variety of slope positions and although when deposited they may form a homogenous, stable deposit, further fluvial or cryogenic activity could lead to their disruption.

Fluvial disruption:

Features 4 and 5 (table 6:1) are deposited in a particular fluvial regime, but subsequent melting of snowpatches or a recession of the permafrost table leaves them in vulnerable positions. Any such deposits, whether they are within the interflow zone gravels or on the surface are liable to further disruption and transport if a change of regime occurs. Surface tubular or laminar features of fines could be dislodged by summer rainstorms and similar sub-surface features could be re-entrained by the following spring meltwaters flowing across the high permafrost table. Gravel deposits (class 7) could be rearranged by frost sorting, frost creep or gravity fall, all of which operate on steep gravel slopes.

Residence times in such vulnerable positions will be short, but if sediments are deposited on low angle slopes rich in fines, disruption and subsequent downslope movements by fluvial processes will be less frequent and residence times will be increased. Deposits can then be considered to be hydrodynamically stable.

Cryogenic disruption:

'Single season' deposits of classes 1, 2 and 3 when studied on raised beach terraces, usually occurred immediately downslope of the break in slope as described above. The thicker of these fresh deposits usually possessed a massive structure; sometimes this was platy due to stratification of sediments. Such deposits contrasted markedly with the 'old' silts occurring in such positions; these were friable silts possessing a weak crumb structure and were frequently permeated by a large number of spherical vesicles ranging in size from 0.1 mm. - 2.0 mm. Organic matter, usually in the form of short fibrous rootlets, was common especially in silts colonised by mosses and grass.

The differences between 'old' and fresh' was further emphasized by bulk densities. These ranged from 1.62 gm/cc for fresh non-vesicular silts down to 1.33 gm/cc for old friable or vesicular silts; however, these figures were not simply related to vesicle number or size (table 6:3)

TABLE 6:3

BULK DENSITIES OF OLD AND FRESH SILTS: SITES H & B 1971

Description and Type	Vesicles (V)	Bulk density (gm/cc)
New		1.620
Old		1.510
New	V	1.470
New		1.440
New		1.403
Old		1.396
Old	V	1.360
Old	V	1.350
Old	V	1.331

Similar vesicular structures were found by V.E. Miller (1971) studying the influence of wetting and drying cycles associated with irrigation on the structure of Hawood and Shano silt loams. Such structures were considered to be caused by capillary pressure within air filled voids surrounded by water; as the number of wetting and drying cycles were increased small vesicles merged to become larger cones and consequently the bulk density of the soils decreased.

A similar process acting within the Arctic silts under discussion is plausible and would lead to the subsequent destruction of preexisting structures, in fact the vesicular structures may eventually tend to collapse thus giving rise to the common friable crumb structure.

Downslope of the surface layers of old silts 'clean' gravels occur on the ground surface with increasing frequency away from the break in slope. If sedimentation occurs on such stones, frost heaving can occur in the frost susceptible matrix of fines, thereby thrusting the stones back to the surface. If sedimentation is greater than the rate of frost heaving, surface accumulations of well sorted silt will remain. Surface concentrations of stones may therefore be tentatively related to the differences between the rates of surface sedimentation and frost heaving.

On talus foot slopes the reverse situation occurs. Adjacent to the break in slope angular talus gravels predominate whilst downslope surface and sub-surface stones decrease in frequency until the regolith consists of predominantly fine material containing some gravels. Clearly a major source of stones will be the talus slopes and this satisfactorily accounts for the decrease in stone counts downslope. Frost heaving still operates and existing stones will be heaved vertically and horizontally in response until the frost deposits are thoroughly intermixed.

Such processes, operating in conjunction with frost sorting and solifluction could lead to an extensive disruption of any surface accumulations of fresh silts.

Conclusions:

A dichotomy has been shown to exist between the fresh 'single season' deposits and the regolith which receives the results of slope sedimentation. Fresh sedimentary features deposited on steep gravel or talus slopes are subject to fluvial disruption and transport, whereas those deposited on the low angle fines rich slopes rarely form any appreciable concentrations of homogenous sediments. In addition the 'single season' deposits contrast significantly with subsurface fines from low angle slopes. The latter were shown to possess higher clay and sand percentages and consequently sorting was relatively poor. On talus foot-slopes samples showed that downslope, mean grain size of the fines decreased, but such trends were ill defined.

The regolith, however is dynamic and frost sorting, turbation and frost heaving probably lead to rapid incorporation of the 'single season' deposits into the pre--existing regolith. The high clay percentage could be due to inheritance from pre-existing fines, rich materials, or from subsequent mechanical weathering of 'single season' deposits as such processes can operate on material down to 0.002 mm. diameter.

CHAPTER VII

THE STRUCTURE OF THE SEDIMENT TRANSPORT SYSTEM AND CONCLUSIONS

The drainage and sediment transport system under consideration was complex. Basically, water from melting snow, melting permafrost ice and rainfall drained from the land surface in the form of interflow, overland flow and supranival flow. Throughput of drainage waters was rapid due to the presence of the impermeable permafrost table.

Much emphasis was placed on sediment transport in rills flowing across talus foot slopes and raised beach terraces. Bed material load and suspended load (wash load) were difficult to differentiate in such small rills and both contributed to the sediment discharge recorded (S.D.R) from sediment traps. These traps, placed in the bed of rills, possessed values of S.D.R. up to 140 gm./day. S.D.R.s greater than 5-10 gms/day usually corresponded to the deposition of sediment from large inputs of suspended load. Suspended loads recorded in p.p.m. (max. 1640 p.p.m.; mean 621 p.p.m.) yielded high sediment transport rates of up to 3 gms per sec. (rill D 23/7/70), although 1 gram/sec. was more common (rill G). Unless rill velocities were exceptionally high, suspended sediment was deposited downslope in a zone that oscillated depending upon the prevailing hydrological conditions.

The presence of suspended load was related to the supply of sediment. In certain rills, flowing from talus slopes, turbidity could be traced up to the break of slope, but in most rills, turbidity was not prevalent, usually only occurring during periods corresponding to the final decay of rill head snow patches. At such times, the silt laden layers of basal ice were exposed in snow patches and the included fines then washed into rills. Snow patch sediments included gravels and sands focusing upon inlet tunnels which channelled water from the interflow zone into the snowpatch. On this evidence the immediate source of fines was inferred to be in the interflow zone, or upslope. Tubular deposits of relatively well sorted fines similar to rill sediments and washed strands of vegetation provide direct and indirect evidence of wash within the interflow zone.

The main components of the system were examined in the following order:

a) low angle slope sedimentation from overland flow.

b) break of slope sedimentation from snow patches.

c) interflow sediment transport and deposition.

Such a sequence of study developed naturally from the original main topic of sediment movement in overland flow and enabled the main structure of the sediment transport system to be outlined as shown in Fig. 7:1.

Certain components of the sediment transport system studied received greater emphasis during the study, these are indicated

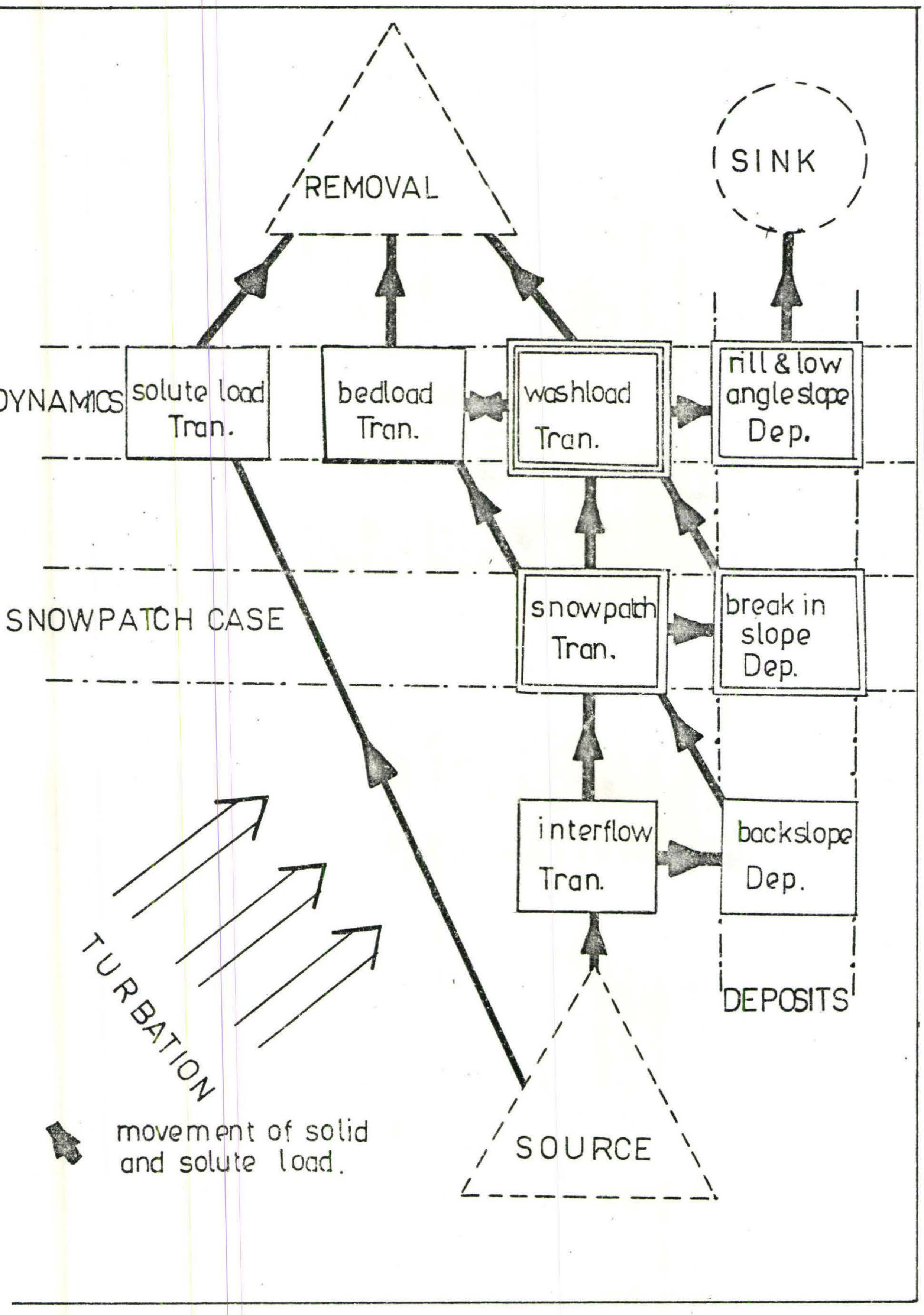


Fig. 7:I Structure of the sediment transport system.

by more pronounced boundaries in figure 7:1. Arrows tentatively show the generalized scheme of movement from the source of fine materials to their removal out of the system or deposition within the system (the sink). Material is either removed straight through the system, as in the case of solution load, or can be deposited in stages, the residence time being greater on low angle slopes than on steep back slopes. At the present stage of research little information exists on the movement of sediment across the plateau surfaces, although a significant amount is transported during the early thaw season as bedload in overland (rill and polygon margin flow)and supranival flow.

For the sediment transport system outlined (fig. 7:1) the initial conditions are:

a) Source of fine materials. This was not studied, but talus slopes, fines-rich plateau surfaces, tills and mechanical weathering of bedrock could provide abundant fines.

b) The movement of water through and across the regolith.

c) The existence of turbation processes. These include frost sorting, heaving, rain drop action and mass movements which keep the system rejuvenated with fines.

Water movement in small channels flowing across the permafrost table on gravel and talus slopes apparently transported fines in large quantities. Deposition occurred occasionally as demonstrated by small tubes and spheres of fines occurring on talus and back slope gravels within the interflow zone. These deposits were unstable and had short residence times in any one place.

Interflow transport washed such fines straight into rills or break of slope transverse snow patches. In the former case no evidence could be found of transport within the interflow zone and usually little evidence of significant sediment transport could be ascertained by rills supplied in such a manner.

Frequently interflow channels flowed into snow patches and in such cases, fines became trapped in basal ice voids and remained to be deposited in situ or washed into rills. Once in rills, either deposition occurred downslope on the low angle slopes, or the materials were removed from the system into rivers, lakes or the sea (fig. 7:1).

Within the 'sink','single season' deposits (those sediments deposited within the prevailing thaw season) differed markedly from fines occurring on low angle slopes. The former possessed Inclusive Graphic Standard Deviation (Folk & Ward 1957) between 1 and 2 Ø with mean diameters in the coarse silt grade, whereas the low angle slope fines formed a matrix in a framework of stones and gravels.

Standard deviations of between 2 - 4 Ø with mean diameters in the medium silt range showed these deposits to be significantly poorer sorted and finer than single season deposits.

Such a difference is provisionally explained by mechanical weathering, frost action and turbation occurring in the regolith.

Such processes could well mix 'single season' deposits with pre-existing fines derived from other sources (e.g. tills). In addition, mechanical weathering could diminish particles sufficiently in size to render such deposits unrecognisable after several years. Gravels and stones from the talus slopes or pre-existing raised beaches may then be injected into the small increments of'single season'deposits.

The sediment transport system has been shown to operate on a variety of terrains, and on each terrain type fluvial processes vary and deposits differ in morphology and mode of formation. The final link of the chain, that of explaining the difference between 'single season' and existing slope sediments has yet to be substantiated.

REFERENCES

Arctic Summary, Meteorological Branch, Department of Transport, Toronto (yearly).

Arnborg, L., Walker, H.J. and Peippo, J., "Suspended load in the Colville River, Alaska 1962", Geog. Annr., 49, pp. 131-44.

Atlas of Canada, 1957. Department of Mines and Technical Surveys Geographical Branch, Ottawa.

Balchin, W., in McCabe, L.D. 1939. "Nivation and corrie erosion in West Spitzbergen." Geog. J. v 94. pp. 447-65.

Bird, J.D., 1967. The Physiography of Arctic Canada. Johns Hopkins Press. 336 pp.

Bögli, A., 1960. "Kalklösung and Karrenbilding", Z. Geomorph. Suppl. 2. pp. 4-21.

Bones, J.G., 1971. Process - morphology Interaction on Arctic Debris Slopes, S.W. Devon Island, Canada. Unpubl. MSc. thesis McMaster University.

Cogley, J.G., 1971. Observations on a High Latitude Drainage Basin. Unpubl. MSc. thesis McMaster University.

Cook, F.A., 1967. "Activity of rivers in the Canadian High Arctic," Geog. Bull. 9 (3) pp. 262-8.

Cook, F.A., and Raiche, V.G., 1962a. "Simple transverse hollows at Resolute, N.W.T.," Geog. Bull. 18 pp. 79-85.

Cook, F.A., and Raiche, V.G., 1962b. "Freeze-thaw cycles at Resolute, N.W.T.," Geog. Bull. 18 pp. 64-78.

Czeppe, Z., 1965. "Activity of running water in S.W. Spitzbergen," Geog. Polonica, 6 pp. 141-150.

Czudek, T., 1964. "Pereglacial slope developement in the area of the Bohemian Massif in northern Moravia," Buil. Periglac. 14 pp. 169-195.

Dinely, D.L., 1954. "Investigations in Vestspitzbergen," J. Glaciol v. 1. pp. 379-383.

Dylik, J., 1960. "Rythmically stratified lslope waste deposits," Buil. Peryglac. 8 pp. 31-41.

Eakin, H.M., 1916. The Yukon-Koyukuk Region, Alaska. U.S. Geol. Surv. Bull., 631 88 pp.

Einstein, H.A., 1964. "River Sedimentation" in: Handbook of Applied Hydrology. Chow V.T. McGraw Hill section 17. II.

Embleton C., and King, C.A.M., 1968. Glacial and Periglacial Geomorphology. Edward Arnold.

Emmet, W., 1970. The Hydraulics of Overland Flow on Hillslopes. U.S. Geol. Surv. Prof. Paper 662 H 68 pp.

Folk, R.L., and Ward, W.C., 1957. "Brazos river bar: a study in the significance of grain size parameter." J. Sed. Pet. 27 pp. 3-26.

Fortier, Y.O., et al 1963. Geology of the N. Central part of the Arctic Archipelago, N.W.T. (Operation Franklin). Memoir 320. Can. Geol. Surv. 671 pp.

Fristrup, B., 1952. "Wind erosion within the Arctic deserts," Geog. Tidsk. Copenhagen Bd 52 pp. 51-65.

Galehouse, J.S., 1971. Sedimentation Analysis in: Proceedings in Sedimentary petrology: Carver R.E. Wiley-Interscience.

Hopkins, P.M., and Sigafoos, R.S., 1951. "Frost action and vegetation patterns on Sevard Peninsular Alaska," U.S. Geol. Surv. Bull. 974C 51 pp.

Jackson, R.H., 1970. Observations on Some Arctic Soils of Southwest Devon Island, N.W.T. Canada. Unpublished MSc. thesis McMaster University.

Jahn, A., 1960. "Some remarks on evolution of slopes on Spitzbergen," Z. Geomorph. Sup. 1 pp. 49-58.

Langbein, W.B., and Schumm, S.A., 1958. "Yield of sediment in relation to mean annual precipitation," Am. Geoph. Un. Trans. v. 39 pp. 1076-1084.

Lewis, W.V., 1936, "Nivation, river grading and shoreline development in Southeast Iceland," Geog. J. v. 88. 431-47.

Lewis, W.V., 1939. "Snowpatch erosion in Iceland," Geog. J. v. 94 pp. 153-161.

Maarleveld, G.C., 1960. "Glacial deposits in the Netherlands transformed under Periglacial conditions," Buil peryglac. 8 pp. 13-20.

McCabe, L.H., 1939. "Nivation and corrie erosion in S.W. Spitzbergen," Geog. J. 94 447-65.

Miller, D.E., 1971. "Formation of vesicular structure in soil," Soil, Sci, Soc, Amer. Proc. v. 135 no. 4 635-37.

Nichols, R.L., 1963. "Miniature Nivation cirques near Marble Point, McMurdo Sound Antarctica," J. Glaciol. 4 477-9.

Pecsi, M., 1969. "Genetic classification of slope deposits", Buil peryglac. 18 pp. 15-28.

Pissart, H., 1967. "Les modalites de l'ecoulement de l'eau sur l'île Prince Patrick" Buil Peryglac. 16 pp. 217-24.

Rapp, A., 1960a. "Recent developements of Mountain slopes in Karkevagge and surroundings, N. Scandinavia," Geog. Annr. v. 42, pp. 65-200.

Rapp, A., 1960b. "Talus slopes and mountain walls at Templefjorden, Spitzbergen," Norsk Polar Ins. Skv 119 96 pp.

Rudberg, S., 1969. "Distribution of small scale Periglacial and Glacial geomorphological features on Axel Heiberg Island, N.W.T., Canada," in Pewe: The Periglacial Environment 1969 McGill-Queens University Press, pp. 129-161.

Ruxton, B.P., 1958. "Weathering and subsurface erosion in granite at the piedmont angle, Balos, Sudan. Geol. Mag. v 95 no. 5 pp. 353-77.

Schwarzenback, G., 1957. Complexiometric Titrations. trans. H. Irving (London).

Snow Hydrology 1956. Summary Report of the Snow Investigations. U.S. Army Corps of Engineers. N. Pacific Division, Portland, Oregon.

Starkel, L., 1960. "Periglacial covers in the Beskid Wyspowy (Carpathians)", Buil Peryglac. 8 pp. 155-169.

Tedrow J.C.F, and Cantlon, J.E., 1958. "Concepts of soil formation and classifications in Arctic regions," Arctic 11, pp. 166-79.

Tedrow, J.C.F., 1966. "Polar desert soil," Soil, sci, soc. Amer. Proc. 30 pp. 199-204.

Te Punga, M.T., 1956. "Altiplanation terraces in Southern England," Buil. Peryglac. 4 pp 331-38.

Thorsteinsson, R., 1958. Cornwallis and Little Cornwallis Islands District of Franklin, N.W.T. Geol. Surv. Canada. Mem. 294 134 pp.

Tricart, J., 1969. Geomorphology of Cold Environments. Macmillan St. Martins Press 320 pp.

Van der Hammen, H., and Maarleveld, G.C., 1952. "Genesis and Dating of the Periglacial Deposits at the E. Fringe of the Velum (Netherlands)," Geol. e Mijnbouw v. 14, pp 47-52.

Watson, E., 1965. "Periglacial structures in the Aberstwyth region of Central Wales," Proc. Geol. Assoc. Land. 76 pp. 443-62.

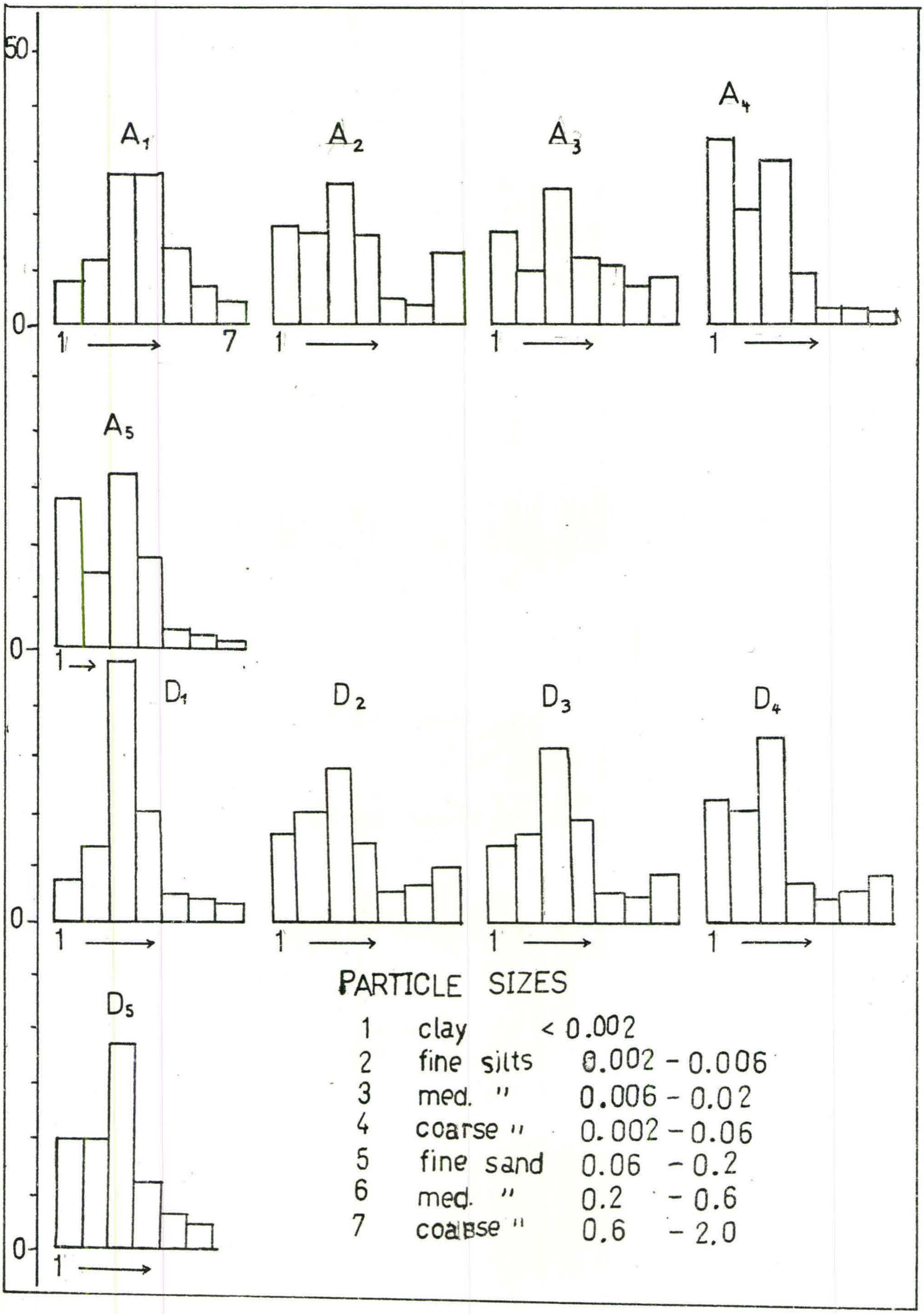
Watson, E., and Watson, S., 1967. "Ther periglacial origin of the drifts near Morfu-Bychan near aberystwyth," Geol. J. 5 (2) 1967. pp 419-40.

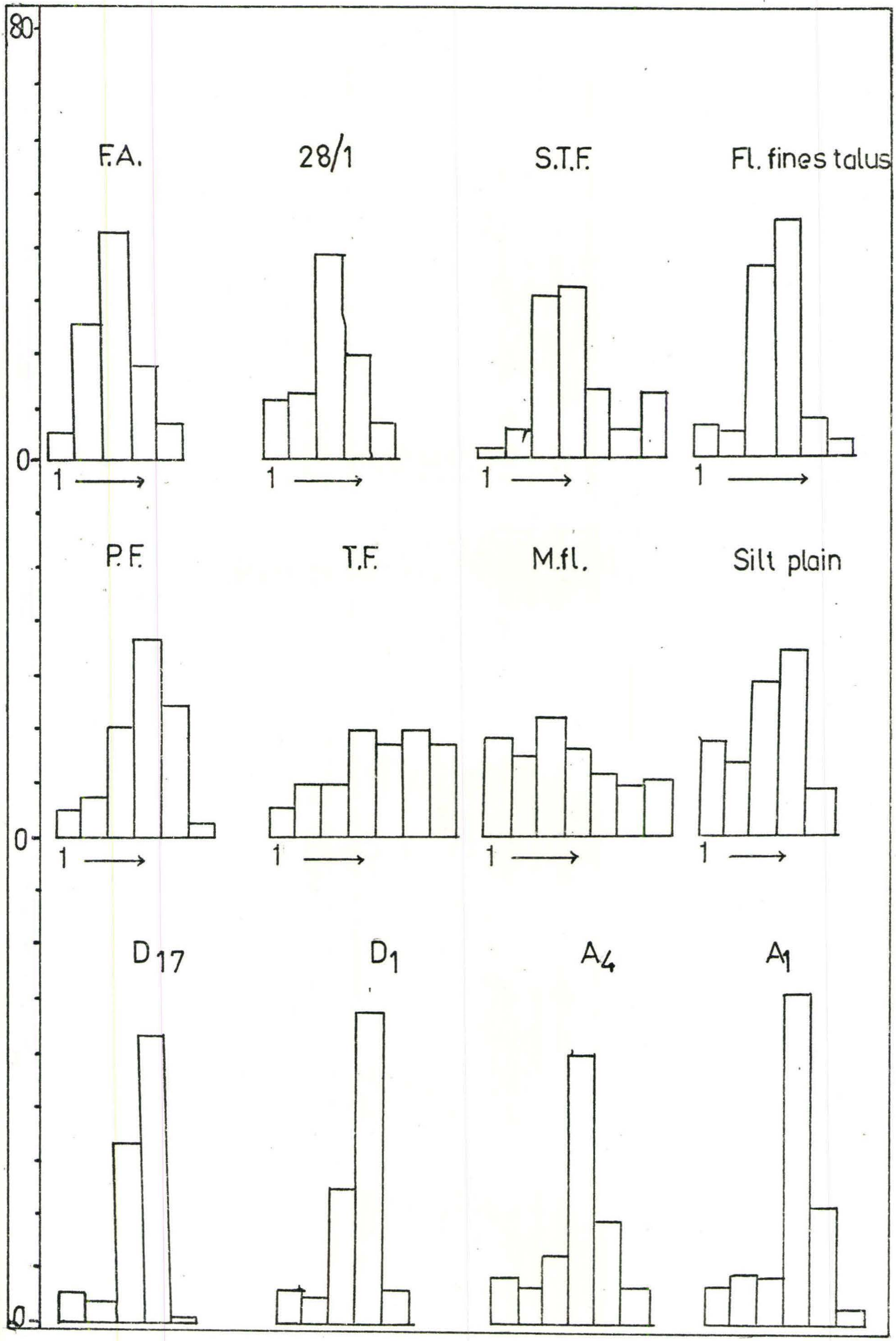
Waters, R.S., 1962. "Altiplanation terraces and slope development in Vestspitsbergen and South-west England," Buil. Peryglac. 11. 89-101.

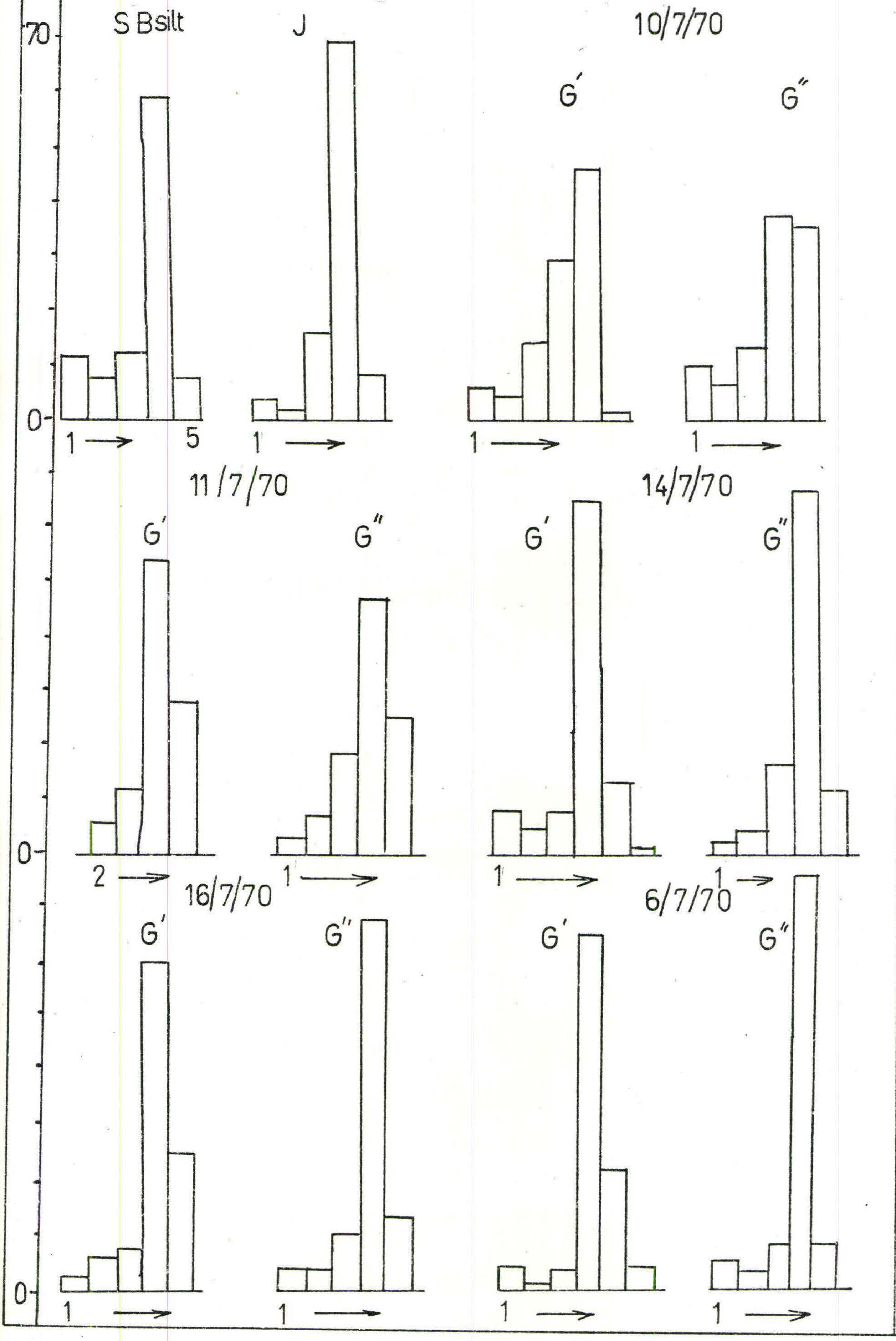
Vries, D.A. de, 1963. Thermal properties of soils pp. 210-35. In Physics of Plant Environment N. Hilland publishing company. Amsterdam.

APPENDIX A

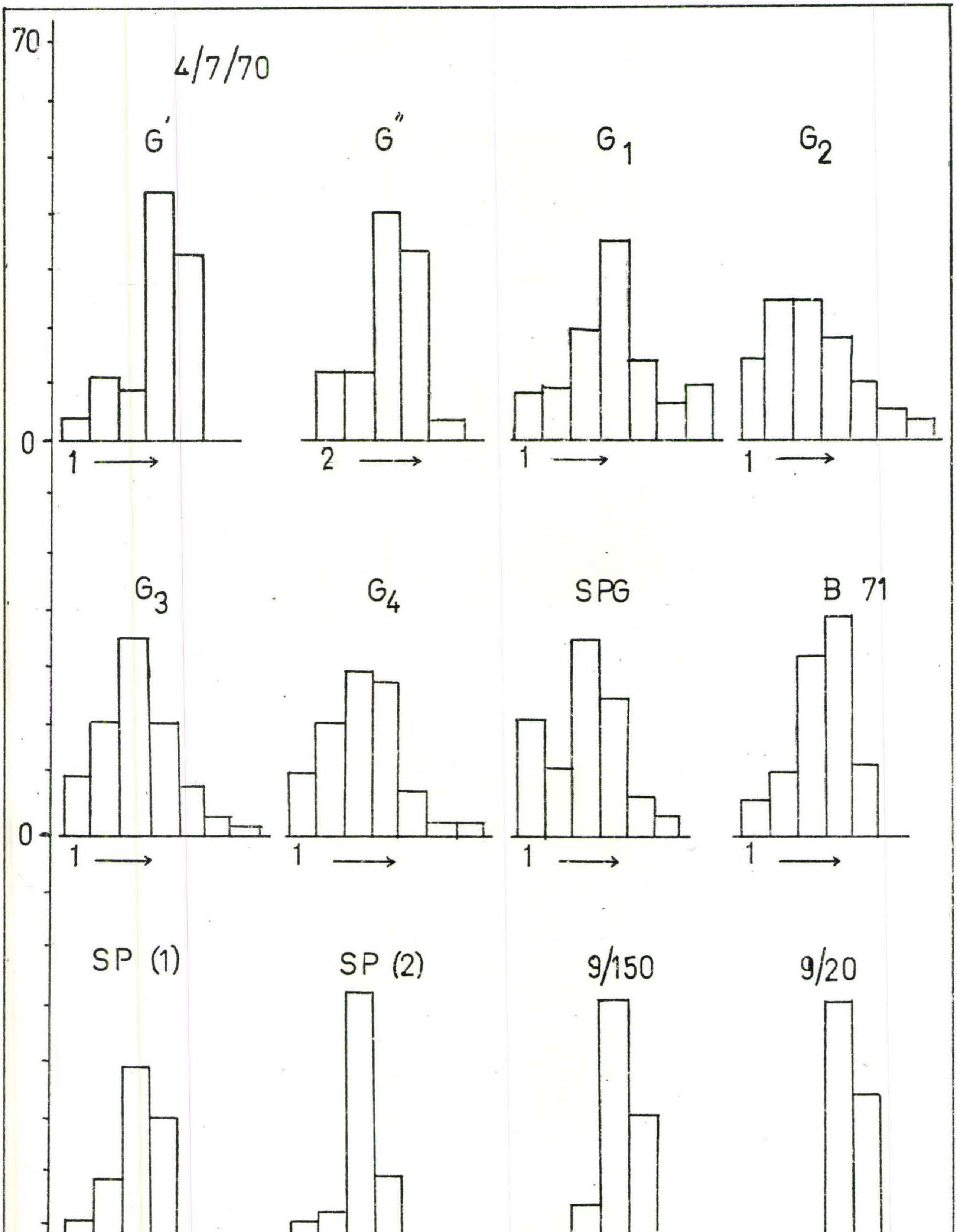
Histograms for single season and slope deposits.
I970 and I97I

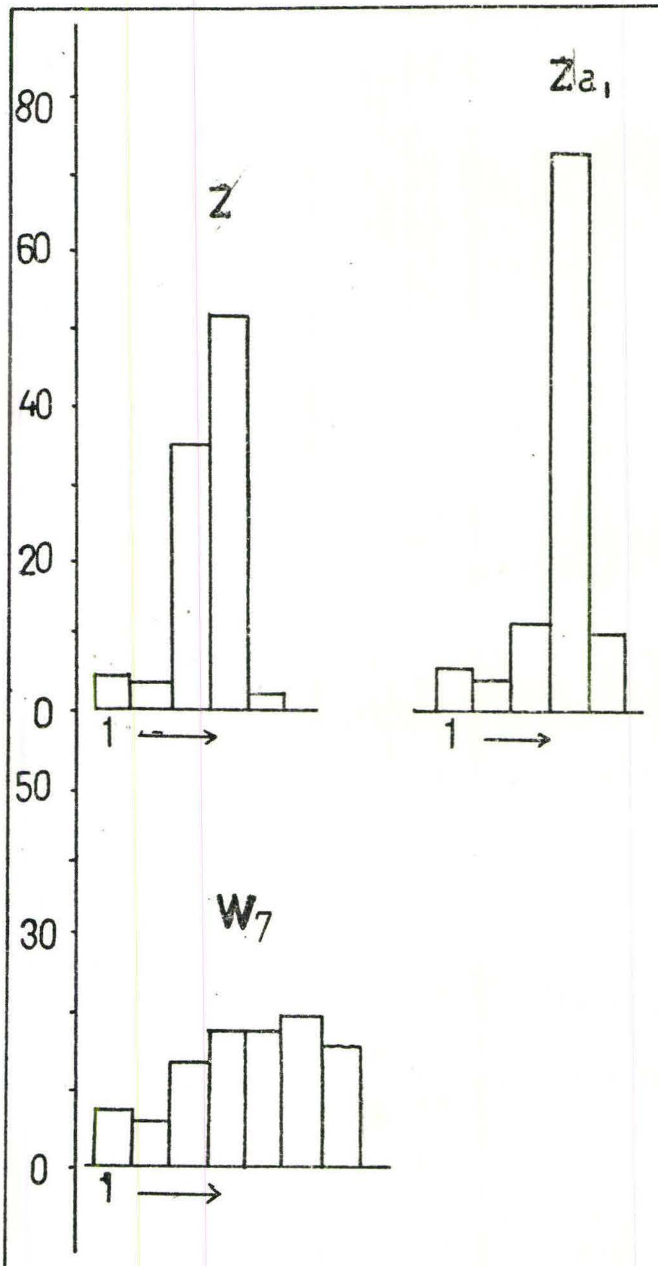

50
0
A1
A2
A3
A4
A5
D1
D2
D3
D4
D5
1
7
PARTICLE SIZES
1 clay < 0.002
2 fine silts 0.002 - 0.006
3 med. " 0.006 - 0.02
4 coarse " 0.002 - 0.06
5 fine sand 0.06 - 0.2
6 med. " 0.2 - 0.6
7 coarse " 0.6 - 2.0


80
0
0
0
F.A.
28/1
S.T.F.
Fl. fines talus
P.F.
T.F.
M.fl.
Silt plain
D 17
D1
A4
A1
1



70
S B silt
J
10/7/70
G′
G″
0
1
5
1
1
1
11/7/70
14/7/70
G′
G″
G′
G″
0
2
1
1
1
16/7/70
6/7/70
G′
G″
G′
G″
0
1
1
1
1


70
4/7/70
G'
G''
G_1
G_2
0
1
2
1
1
G_3
G_4
SPG
B 71
0
1
1
1
1
SP (1)
SP (2)
9/150
9/20
0
1
1
2
1



80
60
40
20
0
50
30
0
Z
Za1
W7
1
1
1