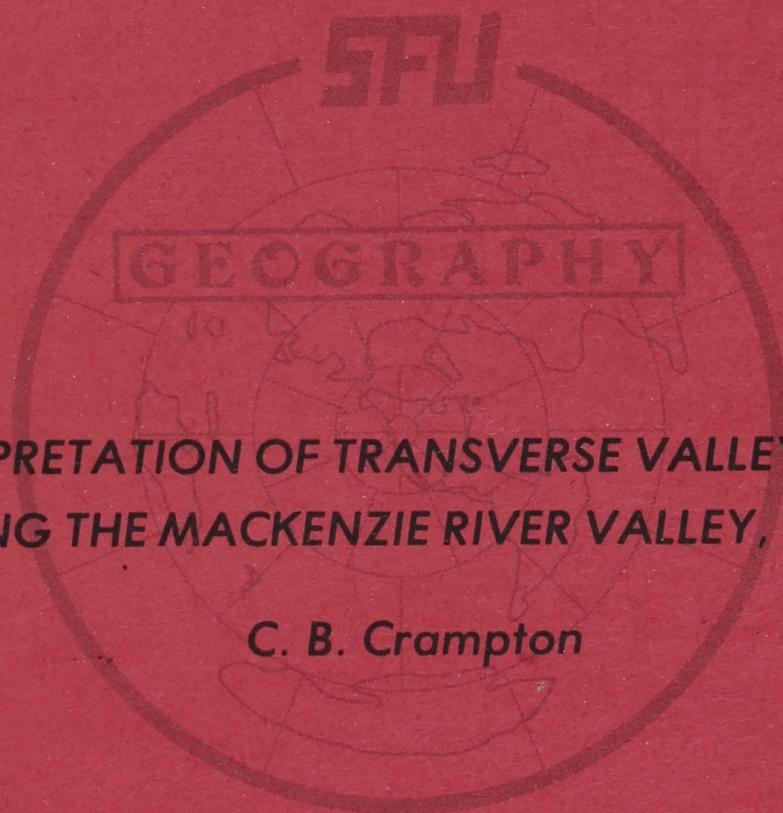


**DEPARTMENT
OF GEOGRAPHY
DISCUSSION
PAPER SERIES**



**AN INTERPRETATION OF TRANSVERSE VALLEY-PROFILES
ALONG THE MACKENZIE RIVER VALLEY, N.W.T.**

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An Interpretation of Transverse Valley-Profiles
Along the Mackenzie River Valley, N.W.T.

by

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Comments are invited.

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INTRODUCTION

This paper interprets glacial and periglacial processes within the Mackenzie River valley on the basis of the delineation of transverse valley-profiles. The Mackenzie River courses from Great Slave Lake in the southwest to the Mackenzie Delta on the Arctic coast in the northwest of the Northwest Territories.

Section A is a discussion of the general principles involved in such processes within the Canadian north.

In Section B these processes and associated landforms are utilized as the basis of an interpretation of the distribution of asymmetry in the transverse valley-profiles of Mackenzie River tributaries.

Section C is a discussion of the textural-ice distributional relationships.

In Section D these relationships are used to support an interpretation of the presence or absence of permafrost within transverse valley-profiles of Mackenzie River tributary slopes with different aspect.

In Section E the stability of one common glacial successional sequence is interpreted for a transverse valley-profile across a Mackenzie River meander.

A. GLACIAL AND PERIGLACIAL PROCESSES

Examination of sedimentary layering within ocean bottom cores reveals a progressively more severe colder-warmer oscillation as the Pleistocene has developed, with the last glaciation being the most intense. The ultimate and penultimate glaciations are listed below.

<u>North American</u>	<u>European</u>	<u>Siberian</u>
Wisconsin (ultimate)	Weichsel (glaciation)	Valdai
Illinoian (penultimate)	Saale (glaciation)	Dnepr

At its maximum extent about 13,000 years ago the Wisconsin Laurentian Shield ice sheet extended to the southeast into Hudson Bay, Davis Strait and the Labrador Sea, southwards beyond the Great Lakes into the United States, and southwestwards into the Mackenzie River valley to abut against the Mackenzie Mountains along the western side. The Mackenzie Range and other western mountains spawned glaciers, but west of the Mackenzie Mountains in Yukon and Alaska there were extensive unglaciated areas. Hence, the study area, the Mackenzie River valley (Fig. 1) was situated under the western and southwestern edges of the Laurentian ice sheet.

The heavy accumulation of ice on land during a continental glaciation first removes sufficient water from the world's oceans to lower the sea level, exposing parts of the continental shelf. Secondly, the land is slowly depressed, parts of it to below sea level. Thus, today the massive Antarctic ice sheet, over 4,000 m A.S.L. on its dome, has depressed parts of the continent to 300 m below the surrounding sea level. If the ice

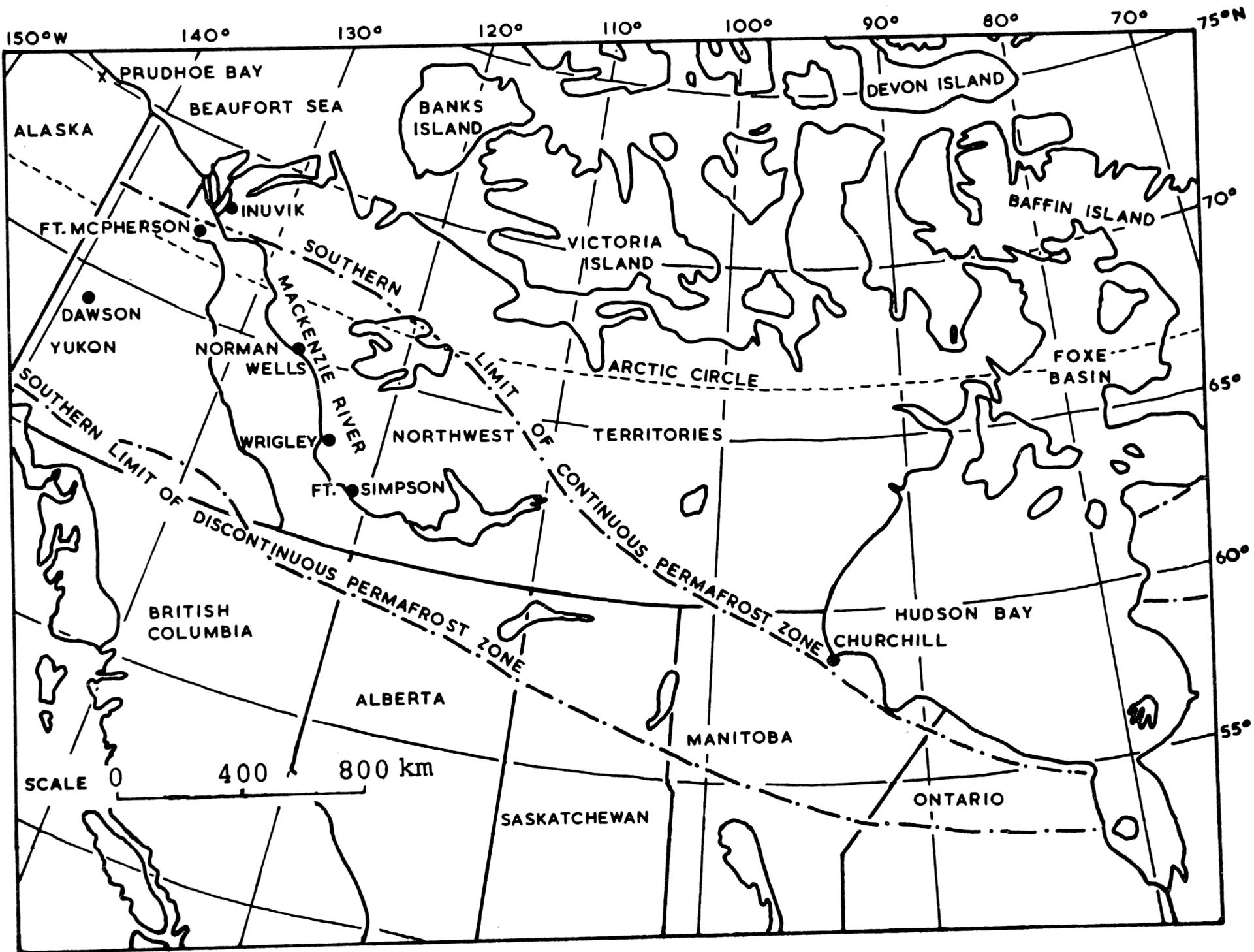


Fig.1. Location of the Mackenzie River study-area within Canada, showing the southern limits of the Continuous and Discontinuous Permafrost Zones.

sheet was to melt, the immediate effect would be to raise the sea level, to form a large inland embayment covering central Antarctica (Sugden and St. John, 1976). Isostatic rebound following removal of the weight of ice would be a much slower process, progressively lifting the continent above sea level. This process is discontinuous, beaches forming during each hiatus in uplift. As a glaciation ameliorates further, periglacial conditions associated with extensive permafrost take over. Thus, today in the Canadian north, remnants of the once extensive Wisconsin ice sheet remain only on Baffin and Ellesmere Islands, and a periglacial environment extends across much of the northern continent which is still undergoing discontinuous uplift, with the formation of parallel or concentric beach lines.

Permafrost forms at about where the mean annual temperature isotherm of 0°C tracks across the North American continent, the southern limit of the Discontinuous Permafrost Zone (Fig. 1). Northwards, the mean annual temperature declines and the permafrost penetrates deeper into the earth. Hence at Fort Nelson in northeastern British Columbia permafrost extends downwards less than a metre. Near Fort Simpson in the southern Mackenzie River catchment it penetrates the earth to about 6 m; at Norman Wells in the central catchment to about 60 m, to about 450 m on Melville Island on the northwestern periphery of Fig. 1. The seasonal variations at the surface decline to a mean temperature at about 9 m, below which there is a temperature gradient towards the base of the permafrost at 0°C .

Within an ice sheet there is a similar temperature gradient, the excessive cold at the surface ameliorating with increasing depth, to

near 0⁰ C at the ground surface (Sugden and St. John, 1976). In this way an ice sheet, to some extent, protects the ground from the excessively cold temperatures associated with a glaciation. Away from the edge of an ice sheet the cold penetrates deeply into the ground throughout the glacial and interglacial periods. Around unglaciated Dawson City in Yukon with a current mean annual temperature of -5⁰ C there is about 60 m of permafrost, whereas around glaciated Thompson in Manitoba with a similar current mean annual temperature, there is only about 5 m of permafrost. The Mackenzie River valley was situated under the edge of the Wisconsin ice sheet, and so was protected from the worst of the glaciation cold.

Within the periglacial environment the northernmost Continuous Permafrost Zone includes terrain which is mostly permanently frozen, although there are always scattered pockets of unfrozen ground. To the south occurs the Discontinuous Permafrost Zone in which there is a complex of frozen and unfrozen terrain, the extent of unfrozen ground increasing southwards towards the southern limit of occurrence of permafrost. These two zones are skewed southeastwards (Fig. 1), as are all temperature-related zones. Warm ocean currents bathe the western North American continental coast, bringing a warmer climate to this coast. Cold ocean currents bathe the eastern continental coast, bringing a cooler climate to this coast. A maritime climate with its small seasonal temperature range contrasts with the great temperature range associated with a mid-continental climate. A combination of these different effects produces the southeasterly skewing of the permafrost zones. Thus,

the Mackenzie River valley within the western subarctic lies mostly within the Discontinuous Permafrost Zone, entering the Continuous Permafrost Zone near its delta.

Although permanently frozen ground appears solid and impervious, the smallest substrate pores always contain unfrozen water, due to increased pressures and salt concentrations created during the freezing process. In silty soils as much as one-third of the water may be unfrozen several degrees below 0°C . This unfrozen water moves, albeit slowly, through apparently frozen ground towards a freezing surface. Therefore, the accumulation of ice in permafrost involves not only the 9 percent increase in volume on freezing, but also the additional volume increase as water is drawn in from adjacent substrate.

Transverse valley-profiles were levelled, alignment mosaics prepared, and drilling undertaken by the Department of Public Works and Foothills Pipeline Company across eastern tributaries of the Mackenzie River (Fig. 2), for intended construction of the Mackenzie Highway extension (now delayed), and for pipeline construction (now started), respectively. Terrain evaluation by the author in the Mackenzie River valley (Crampton, 1975 and 1981) allowed access to many unpublished alignment surveys. This study is an interpretation of these transverse valley-profiles, in terms of separate advances by the ice sheet during the Wisconsin Glaciation, and of the periglacial environment that developed during the interstadials between advances. Smaller valleys 500 to 1,000 m across have been utilized for the study of valley asymmetry, while larger valleys 2,000 to 4,000 m across have been utilized for the study of the relationships between icy permafrost, aspect and latitude.

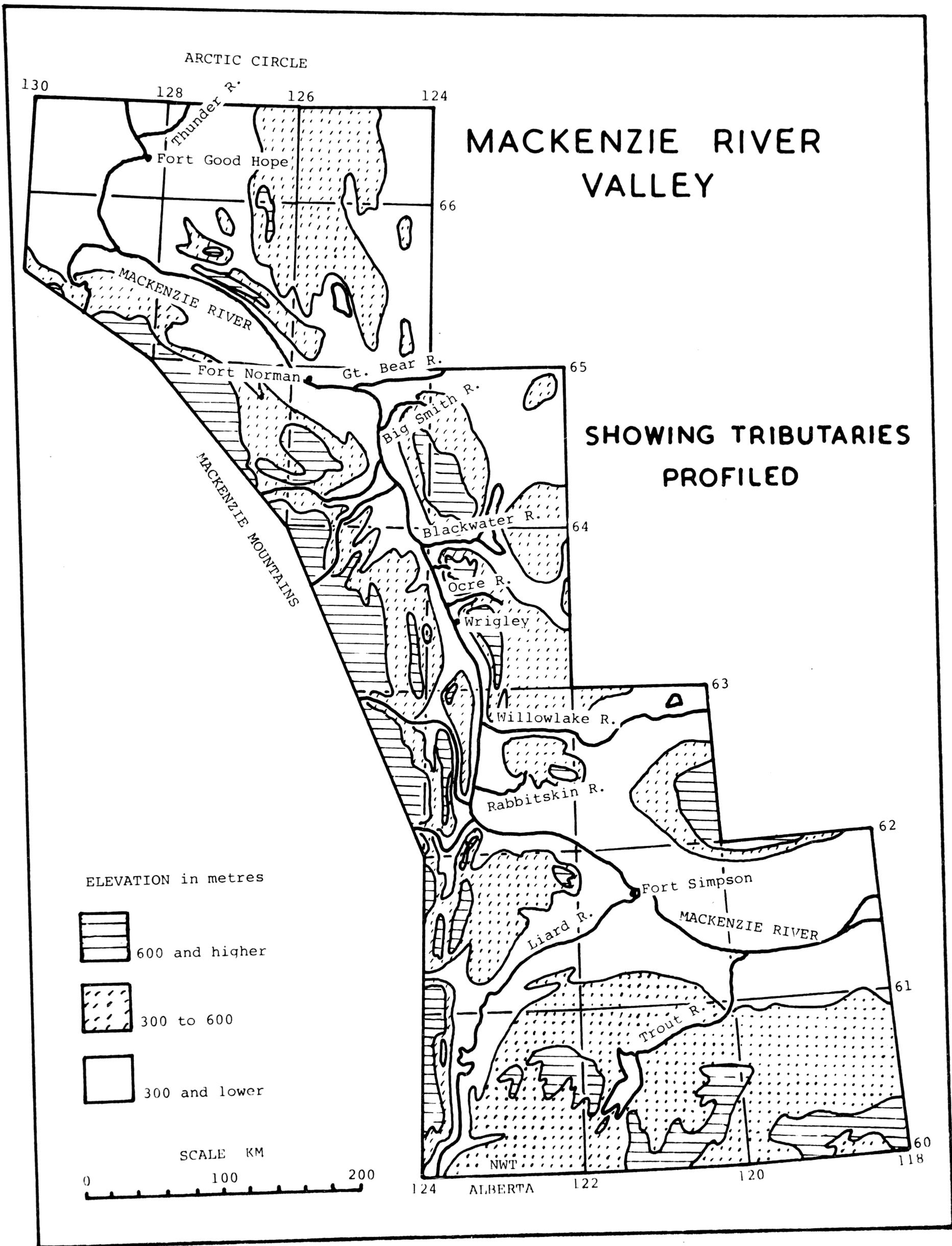


Fig.2. Relief of the Mackenzie River valley, showing the tributaries across which transverse valley-profiles have been levelled.

B. ASYMMETRIC VALLEYS

Introduction

In contrast to the mountainous western side of the Mackenzie River, to the east of the river the relief is much more subdued. The area was glaciated by at least two advances of the Wisconsin Laurentide ice-sheet from the east (parallel to many minor tributaries of the Mackenzie River, partially infilling but not destroying their form), to abut against the Mackenzie Mountains. Isostatic readjustment following deglaciation has produced differential uplift to the north and east, and beach lines formed around Glacial Lake McConnell in the region of the Mackenzie River are now inclined upslope, about 380 mm/km (Craig, 1965).

Procedure

Levelled, transverse valley-profiles of the lower reaches of 335 tributaries of the Mackenzie River flowing from the east have been examined and compared, especially with respect to any asymmetry of the (more or less) N- and S-facing slopes. Tributaries graded to the Mackenzie River are mostly asymmetric in transverse valley-profile. The general trends in asymmetry were examined, and three transverse valley-profiles were selected to illustrate these trends.

Other Work

Valleys with steeper SW-facing slopes have been reported at several localities in now-temperate latitudes (Dylik, 1956; Ollier and Thomasson, 1957; Crampton and Taylor, 1967), and have been described as fossil

periglacial features. In areas with permafrost today in the Canadian arctic, valleys with a similar asymmetry have been reported by French (1971), while Bronhofer (1958), Presniakov (1955) and Gravis (1969) have reported asymmetric valleys with steeper NE-facing slopes in the Canadian and Siberian arctic. In the area of the Mackenzie Delta, Kennedy and Melton (1972) found that in upper valley areas of more severe climate and low relief the N-facing slopes were steeper, whereas in areas of milder climate and deeper valleys the S-facing slopes were steeper. On this basis, compared with the arctic, the area between Fort Simpson and Fort Norman (Fig. 2) could be categorized as milder and with deeper valleys, characterized by steeper S-facing slopes. The study area has more in common with now-temperate areas containing asymmetric valleys, presumably once on the fringe of an active periglacial environment.

In the now-temperate climate of South Wales terraced solifluction deposits normally accumulated at the foot of SW-facing slopes where they were thought to have helped create a backslope steeper than NE-facing slopes (Crampton and Taylor, 1967). Concerning fossil solifluction phenomena in SE England, Ollier and Thomasson (1957) also proposed maximum erosion on SW-facing slopes, with lateral movement and erosion by the river having helped to further steepen the SW-facing slopes.

Results

The valleys were about 15-30 m deep. Many valley-profiles were asymmetrical, the S-facing slope (inclined at about 10°) being steeper than the other (inclined at about 7°), referred to as simple asymmetry

and illustrated in Fig. 3 by a transverse profile across a creek situated between the Blackwater and Ochre Rivers north of Wrigley. Some had lower, more prominent, and upper, less prominent slopes of different inclination (by about 2°), referred to as composite asymmetry and illustrated in Fig. 4 by a transverse profile across the Rabbitskin River situated between Fort Simpson and Wrigley. In the composite valley-profiles a slope inflection separated a lower, deeper profile with a steeper S-facing slope, from an upper, generally wider and shallower profile with a steeper N-facing slope, shown by the Rabbitskin River, but very pronounced in the transverse profile across Big Smith River south of Fort Norman, illustrated in Fig. 5. These slope inflections on either valley side have been joined by a broken line.

Of all the valleys observed in the study-area, 64 percent had steeper slopes facing south (the more prominent lower slopes in composite valley-profiles), 23 percent had steeper slopes facing north, and 13 percent were symmetrical in transverse valley-profile. The great preponderance of valleys with steeper slopes facing the maximum insolation is consistent with studies of fossil periglacial features elsewhere (e.g., Dylik, 1956). The rivers had eroded through the thin drift mantle, deeply into the rock. It was clearly observed that slopes with frozen substrate in summer, whether inside or outside river valleys, were mostly facing north (e.g., Fig. 4). Summer ice remnants were particularly associated with N-facing slopes in the deeper valleys, also reported by Brown and Johnston (1964).

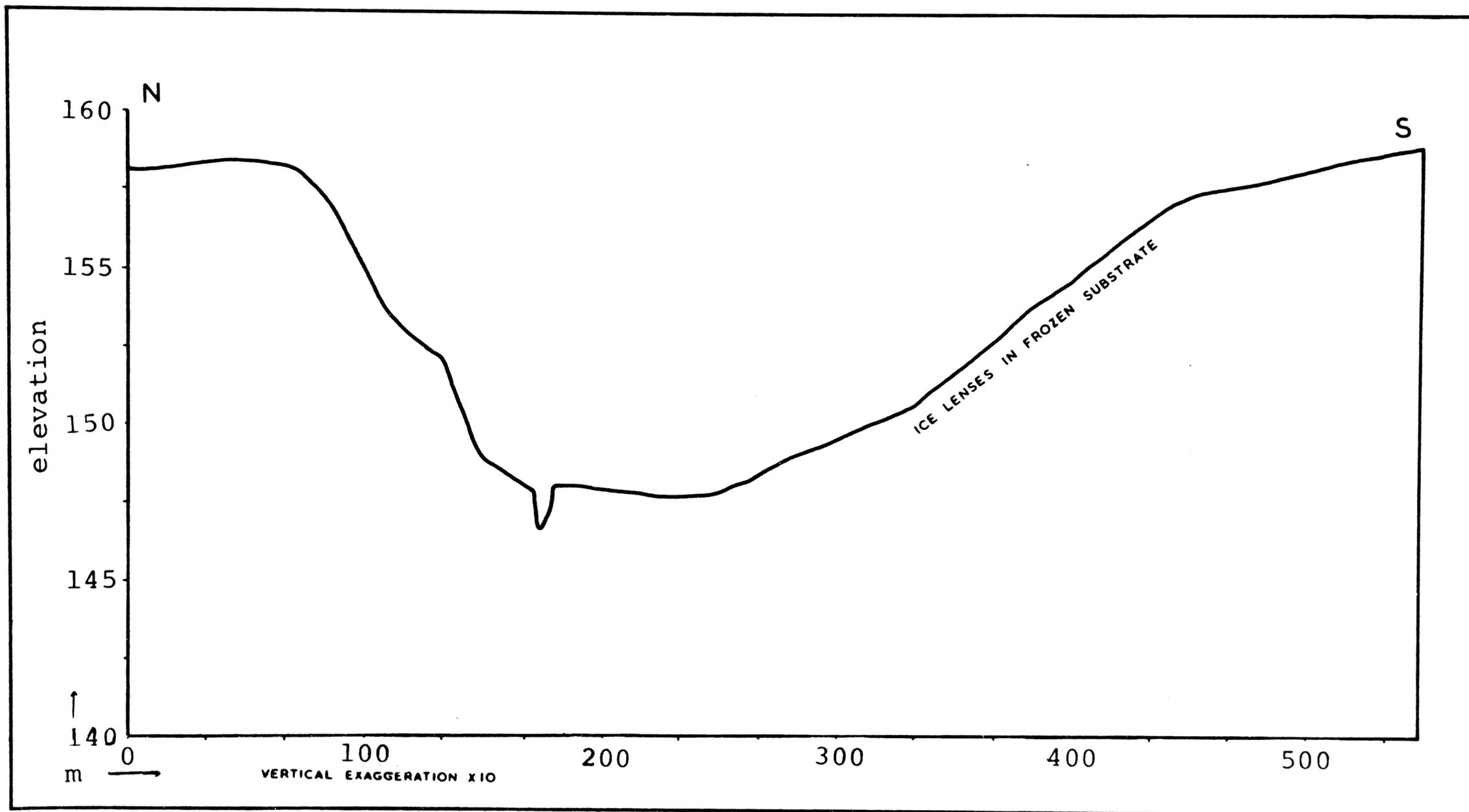
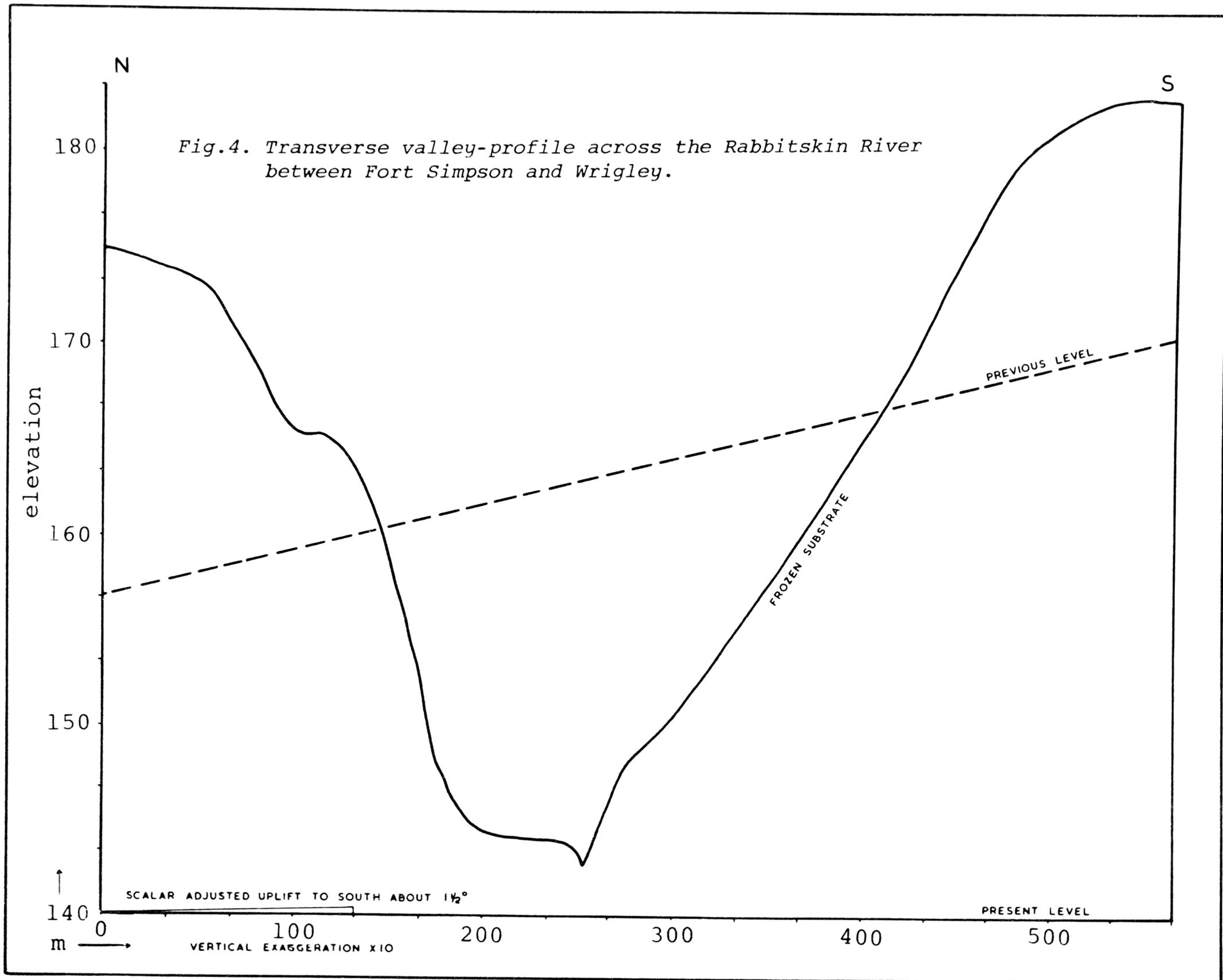
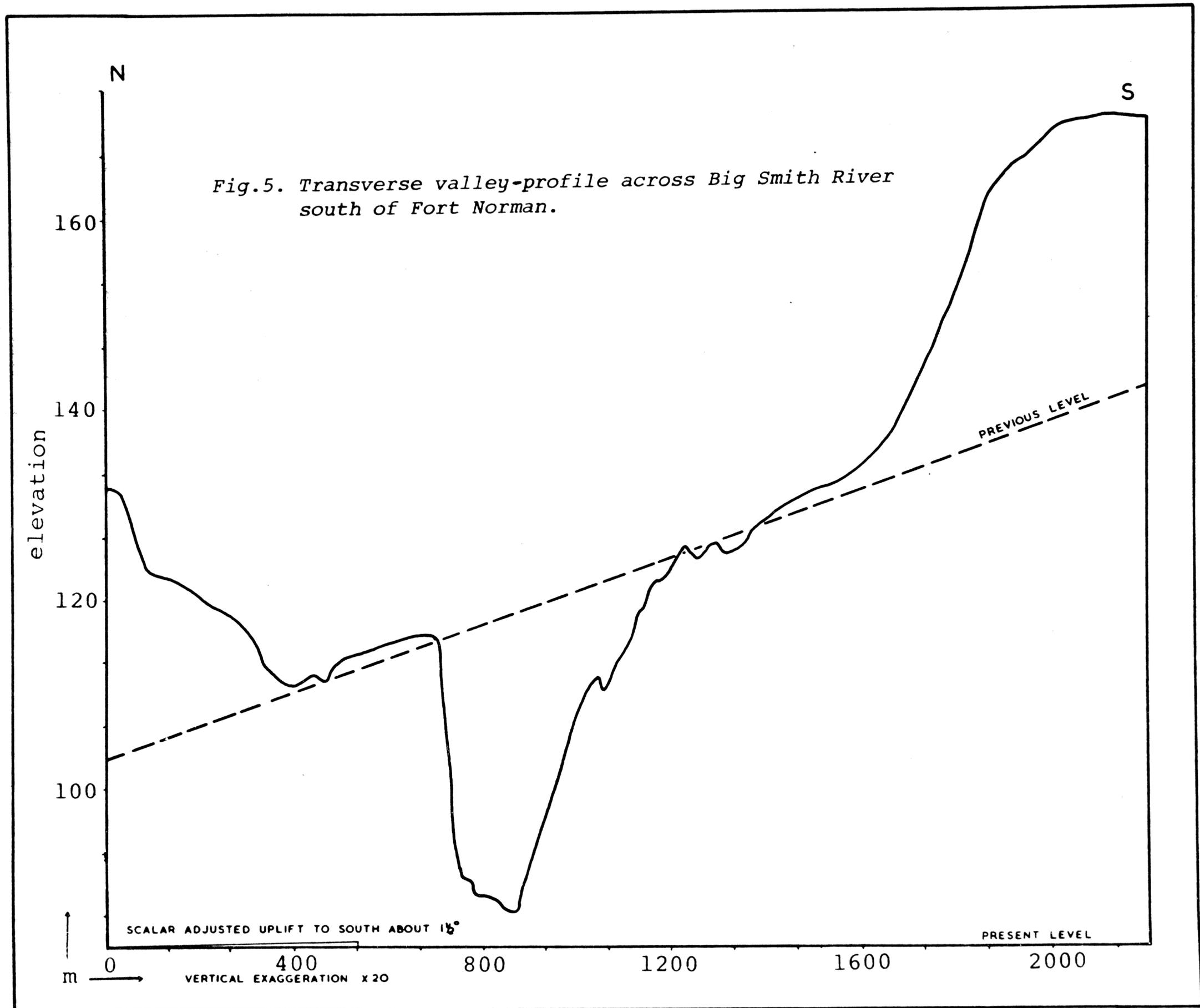


Fig.3. Transverse valley-profile across a creek between Blackwater and Ochre Rivers north of Wrigley.





Discussion

Since many of the N-facing slopes of the examined Mackenzie River tributaries remained frozen during summer, especially in deeper valley parts, they have probably been erosionally inactive. S- or W-facing slopes with maximum insolation usually thawed seasonally, and so a seasonal movement of water-charged, slurried material should be more pronounced down these slopes, causing a faster valley-side retreat. Unless the footslope accumulations were very thick, lateral river movement and erosion would enhance steepening of S- and W-facing slopes.

A comparison of the study-area with work by Kennedy and Melton (1972), and with asymmetric valleys in now-temperate regions suggests that periglacial activity in the Mackenzie River valley was subarctic rather than arctic. This proposal would help account for the differences between reported asymmetry and explanations for the Mackenzie valley area, and for today's arctic periglacial landscapes.

In composite valley-profiles the changes of slope on each side of the valley separating the upper (first-formed) and lower (last-formed) profile forms of opposite symmetry lie within a plane inclined downwards and northwards (called "Previous Level" in Figs. 4 and 5). The plane containing these slope inflections was probably horizontal at one time, and has since been displaced, possibly by downwarping to the north. When a composite valley-profile is oriented such that this plane is horizontal, the S-facing slope of the upper (older) profile form becomes the steeper, consistent with the symmetry of the lower (younger) profile form before adjustment was made for possible downwarping.

Scalar adjustment of the postulated downwarping yields a generally northern angular rotation of the landscape through $1\frac{1}{2}^{\circ}$. This represents a tilting down to the north of about 26 m/km, or a close resultant thereof which, because of the amount of downwarping, must have been horizontally discontinuous.

Conclusions

Craig (1965) reported evidence suggesting at least two advances of the ice sheet across the study-area during the Wisconsin Glaciation. Between advances a periglacial climate would have prevailed, just as such an environment prevails in the area today. The older, upper valley-profiles could have formed within the interstadial periglacial environment, the S-facing slopes experiencing greater solifluction and steepening, with many of the N-facing slopes remaining permanently frozen throughout the summer. The last advance, which achieved its maximum extent about 13,000 years ago, would have depressed the land by its weight, primarily to the north and east, changing slope inclinations and making N-facing slopes the steeper. The younger, lower valley-profiles would have formed during the current periglacial environment, with solifluction once again preferentially steepening S-facing slopes which receive maximum solar irradiance and surface thawing. Isostatic rebound since the last glaciation is still continuing, beach lines are still forming, and uplift has not yet offset the original land depression under the weight of the Wisconsin ice sheet. If differential insolation during interstadials produced valley assymetry, recent uplift has not had the time to noticeably disturb older, upper valley-profiles, or younger, deeper valley-profiles.

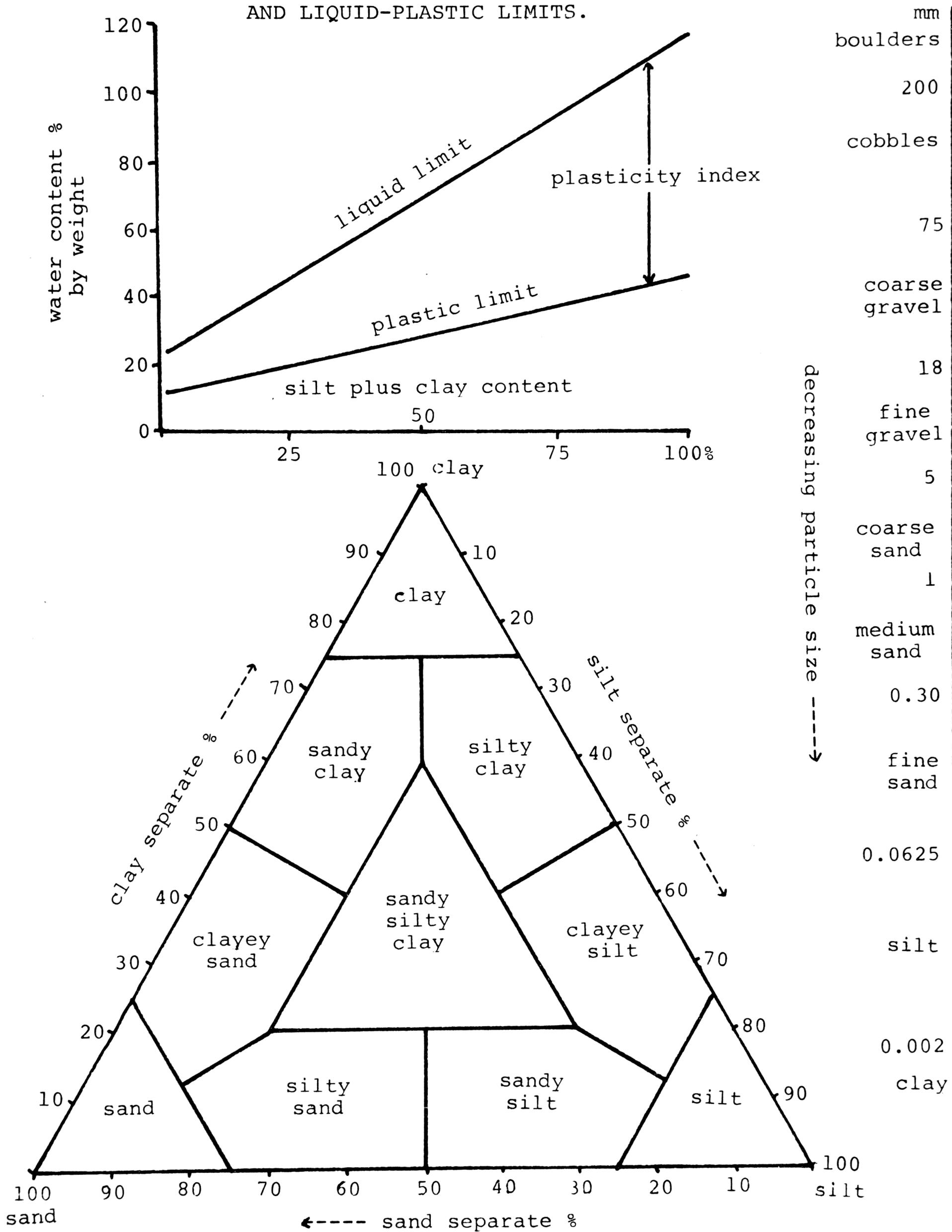
C. CLASSIFICATION OF TEXTURES AND ICE DISTRIBUTION

Unlike pedologists who classify soil textures according to subjective, but relevant field experiences, engineers classify substrate textures systematically, as in Fig. 6. This allows reasonable assessment of the influence of sand, silt or clay on important properties such as the range of moisture contents within which the substrate remains plastic, deforming continuously under pressure, rather than becoming hard (associated with low water contents), or forming a slurry without any strength whatsoever (associated with high water contents). Low contents of "fines," silt plus clay, concomitant with high contents of sands, particularly fine sand (Fig. 6), allows a substrate to slurry or flow with only about 25 percent of water by weight. Such a fine sandy substrate is said to exceed its liquid limit (Fig. 6).

The pressure of water in substrate pores, the pore pressure produced by the head of water within any overlying sediments, also influences the tendency for a substrate to slurry. Where permafrost exists, sands hold little water as ice, and so a frozen sandy substrate remains moderately porous and an effective head of water can develop in any overlying sediments. It has been observed by many (e.g., Brown and Johnston, 1964) that silts and organics hold more water as ice than clays, and much more water as ice than sands. However, even a frozen silty soil remains porous to a small extent because water in the smallest pores between particles never freezes.

Fig.6.

UNIFIED SYSTEM FOR
PARTICLE SIZES, TEXTURES,
AND LIQUID-PLASTIC LIMITS.



Sands absorb more heat in summer than the fines, and so the "active layer," the surface thickness of substrate through which thawing penetrates each summer is greater in sands than in silty or clayey substrates. Summer fires that regularly (and naturally) sweep across many northern landscapes remove the insulating vegetative and, sometimes, organic cover and change the albedo, increasing the depth of summer thawing and the amount of free water that percolates through surficial sediments.

Even where frozen, sands are more porous than silts and clays. In the Discontinuous Permafrost Zone where substrate temperatures are often only just sub-zero, any free water tends to move through sandy substrates, particularly as pore pressures build up (a process which depresses the freezing point), until percolation is sufficiently impeded by a layer of silt or clay to encourage freezing. Some of these relationships are discussed in Williams (1979). The distribution of frozen water as non-visible ice, for example in sands where it binds the substrate, needs to be differentiated from the often observed, and reported (e.g., Mackay, 1972) visible accumulation of ice in lenticles, for example in silts underneath sandy sediments. The National Research Council has developed a classification of ice distribution, described in Fig. 7.

D. PERMAFROST IN VALLEY SLOPES

Procedure

Levelled, transverse profiles across four selected E-W tributaries of the Mackenzie River, Trout River south of Fort Simpson, Ochre and Blackwater Rivers between Wrigley and Fort Norman, and Thunder River north

Fig.7.

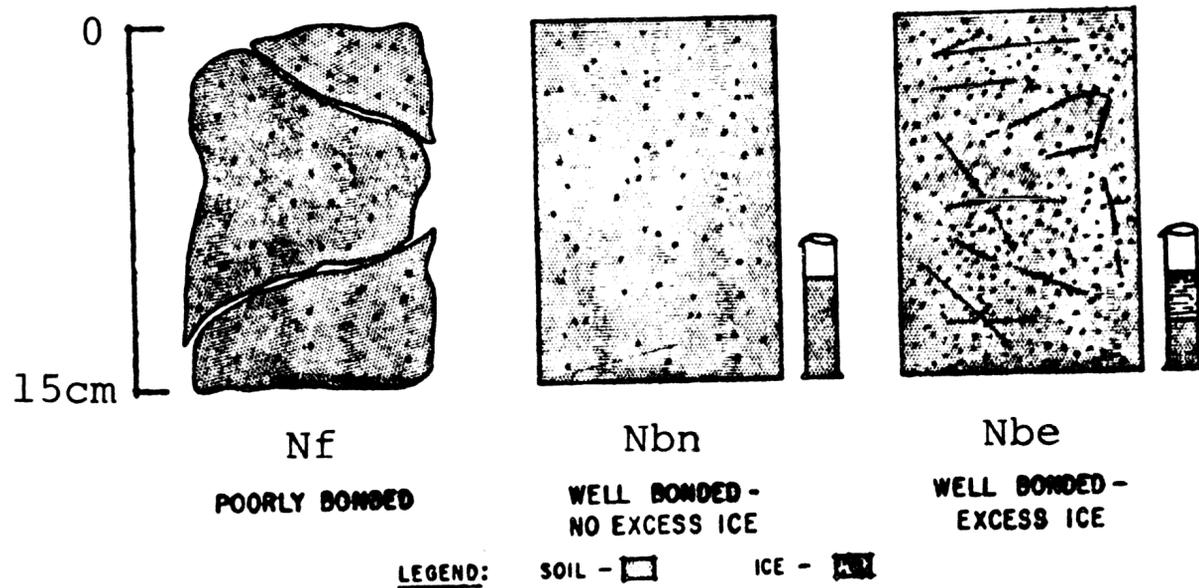
DESCRIPTION OF ICE DISTRIBUTION: NATIONAL RESEARCH COUNCIL

Pihlainen, J.A. and Johnston, G.H. 1963. Guide to a Field Description of Permafrost for Engineering Purposes.

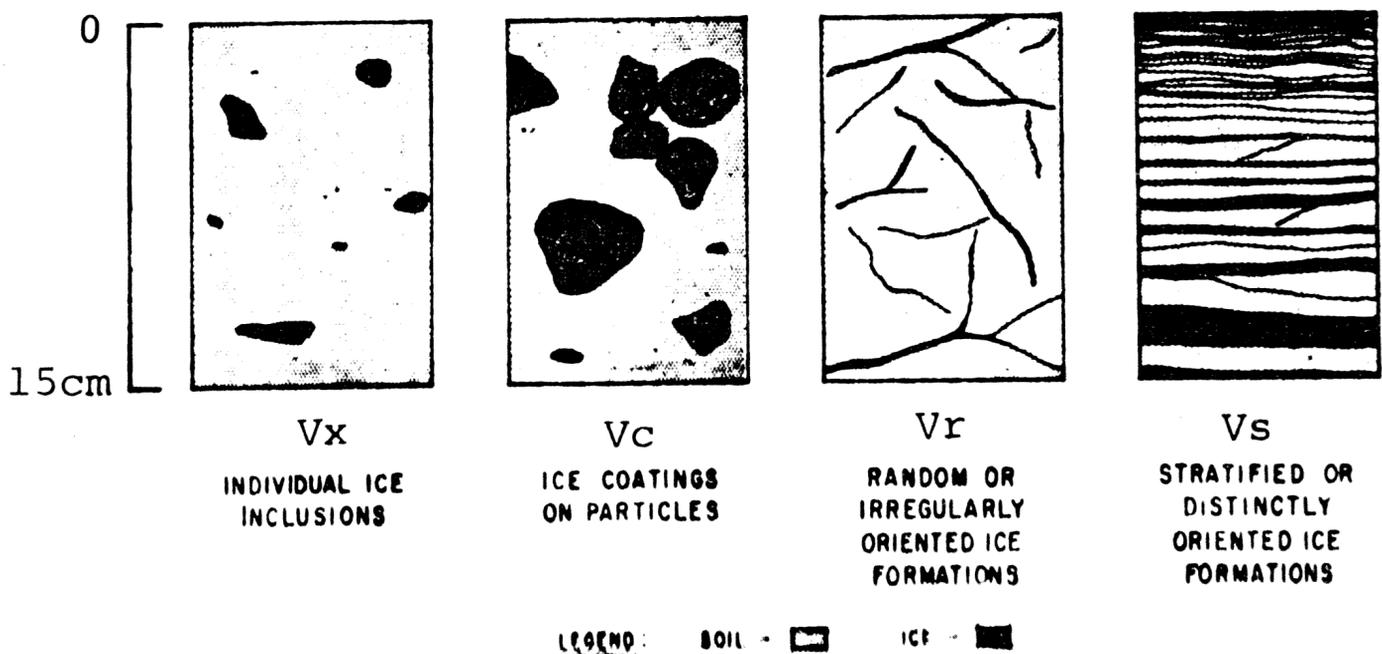
(a) *Frozen soils in the N group may, on close examination, indicate presence of ice within the voids of the material by crystalline reflections or by a sheen on fractured or trimmed surfaces. The impression received by the unaided eye, however, is that none of the frozen water occupies space in excess of the original voids in the soil. The opposite is true of frozen soils in the V group.*

(b) *When visual methods may be inadequate, a simple field test to aid evaluation of volume of excess ice can be made by placing some frozen soil in a small jar, allowing it to melt, and observing the quantity of supernatant water as a percentage of total volume.*

ICE NOT VISIBLE



VISIBLE ICE LESS THAN 25MM THICK



of Fort Good Hope (Fig. 2) were used to study the differential distribution of permafrost in N- and S-facing slopes, at increasingly higher latitudes. Drilling to 5 m had been undertaken across the valleys as part of a terrain evaluation for proposed pipeline construction, in order to determine the distribution and nature of permafrost, associated with different textures (analyzed using the hydrometer technique) and slope positions. The amount of ice, or water present in the substrate was determined by weighing a sample of substrate, drying and reweighing. Drilling was undertaken with as little disturbance as possible to the natural vegetation, usually on already cut seismic lines.

Landscapes

At all four of the selected valley sites, the slopes and shoulders were mantled with fine-textured till deposited from the melting Wisconsin ice sheet, whereas valley bottoms were often covered by recently deposited, coarser-textured alluvium. The river valleys tended to be symmetrical in cross-section. The vertical exaggeration of the transverse profiles was great and, in fact, the valleys were wide and had gentle slopes, such that the shoulders of the N-facing slope did not shield the opposite slope from the sun.

Trout River is situated in the Discontinuous Permafrost Zone, and Thunder River in the Continuous Permafrost Zone, with Ochre and Blackwater Rivers being situated within the transition between the two permafrost zones. Forests mantle valley slopes in the Discontinuous Permafrost Zone, although the trees become increasingly more stunted northwards through the transition

between the two permafrost zones, especially on the colder N-facing slopes. Across the valley shoulders, forests on the slopes generally give way to a scrubby vegetation beyond the shoulders, often associated with ice-cored, low, raised peat flats. The trees are white spruce with trembling aspen in the south, with balsam poplar in the north. The scrub flora on icy peatlands includes rich lichenous crusts (much of it caribou moss), with such species as dwarf birch and labrador tea, with sphagna and cotton grass sedge in scattered depressions.

Results

South of Fort Simpson, the Trout River valley slopes are covered with silty clays and clayey silts, while alluvial cobbly sands have been deposited along the valley floor. Drilling revealed no permafrost, whatever the texture or slope aspect of this most southerly valley in the study-area. The water content of the substrate decreased with increasing depth, especially where the textures are fine on S-facing slopes (Fig. 8).

Drilling along the transverse profile across the valley of Ocre River north of Wrigley revealed permafrost extending down to below 5 m of silty clays and clayey silts on the shoulders and upper N-facing slopes, and to about only 1 m in alluvial silty sands and sandy silts on the lower N-facing slopes. The fine-textured substrates were well bonded near the land surface, with excess ice on the shoulders, where the ice was distributed as scattered inclusions below about 3 m. The coarser-textured substrates were poorly bonded by icy permafrost.

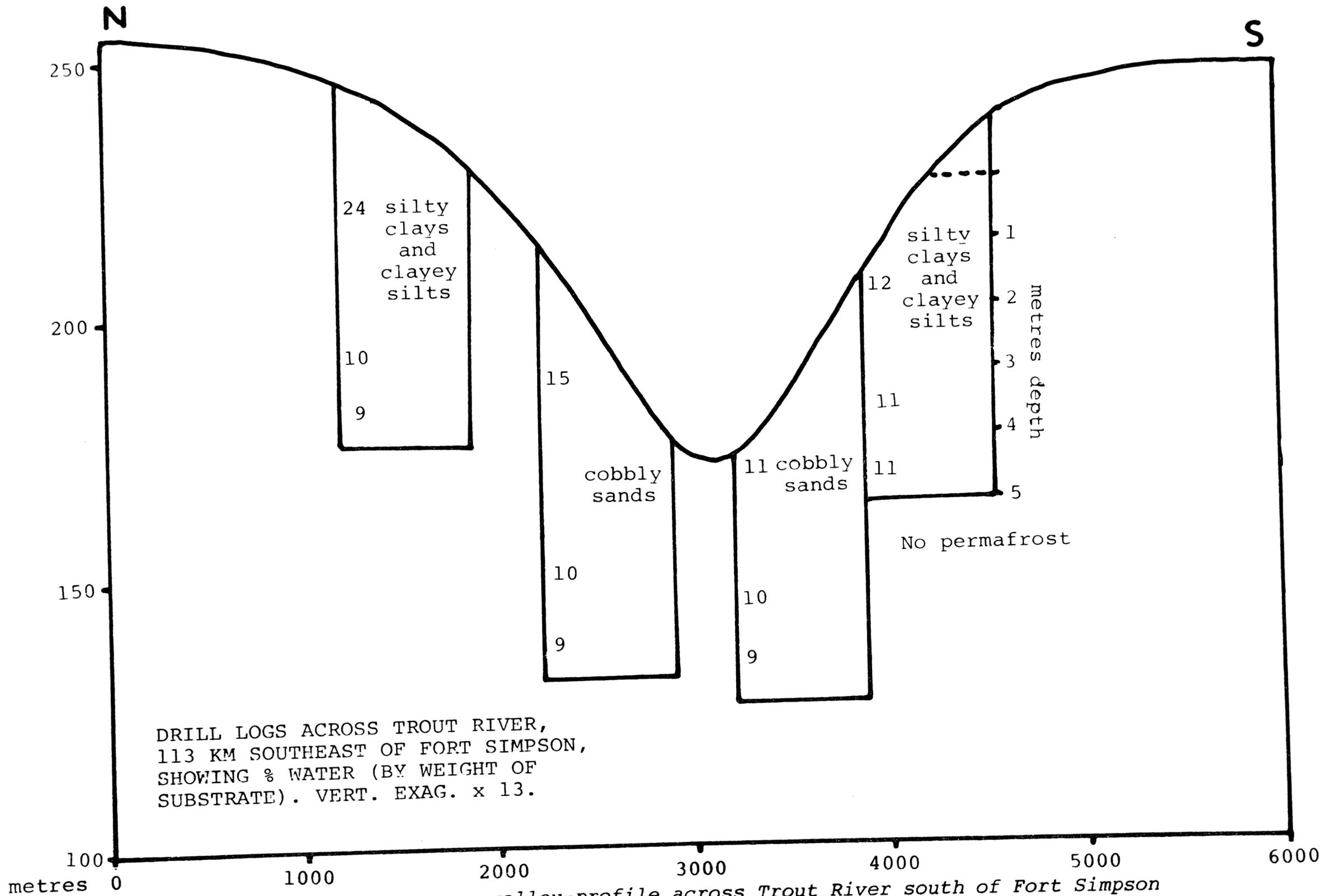


Fig.8. Transverse valley-profile across Trout River south of Fort Simpson showing the location of drill logs (at the centre of each column) illustrating the distribution of water (% by weight of substrate)

Regardless of whether the water was frozen (as on middle and upper N-facing slopes), or unfrozen (as on all of the S-facing slopes), the water content decreased with increasing depth, particularly in the finer-textured substrates on the slopes, whereas on the shoulders where the forests gave way to scrubby, icy peatlands, the water content increased with increasing depth (Fig. 9).

Blackwater River is situated further north, and closer to the Continuous Permafrost Zone. The valley shoulders, slopes and bottom were mantled with silty clays and clayey silts. Drilling revealed permafrost extending down into the substrate to at least 5 m on both valley shoulders, and in the N-facing slopes. Near the surface the substrate was well bonded by the frozen state, and at greater depths excess ice was expressed in the form of scattered ice crystals, except on the lower N-facing slopes where the ice remained invisible. The lower S-facing slopes associated with the most dense white spruce and balsam poplar forests were unfrozen. In the forested valley slopes the water content, frozen or unfrozen, decreased with increasing depth, whereas on the more open, scrubby shoulders the water content (as ice) increased with increasing depth (Fig. 10).

Thunder River is situated within the Continuous Permafrost Zone and all parts of the transverse profile contained permafrost extending to below 5 m. Tills of silty clays and clayey silts mantled the valley shoulders and slopes, and alluvium of sandy silts and silty sands floored the valley bottom. Near the surface the ice was visible as coatings around substrate particles, except on the lowermost S-facing slopes

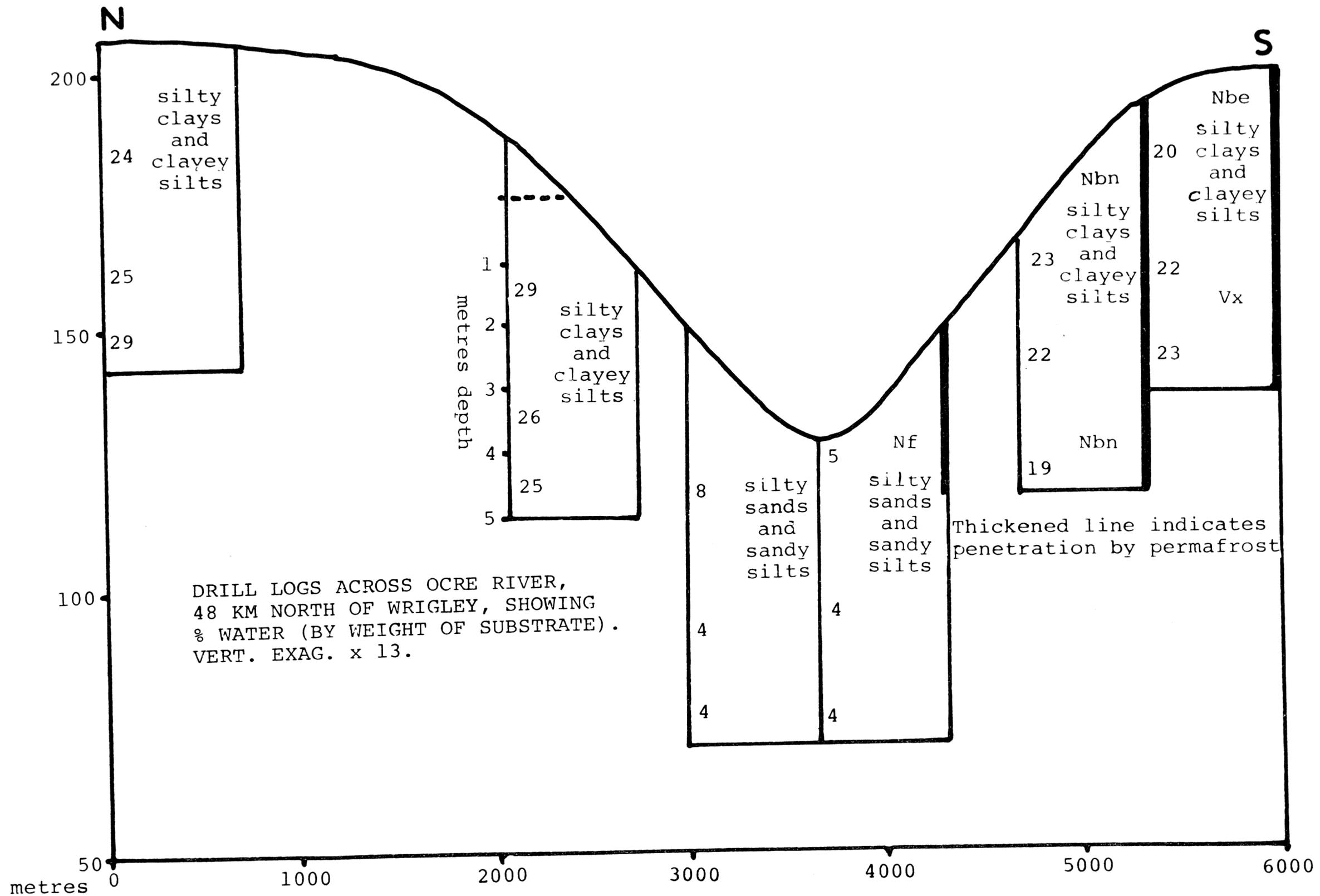


Fig.9. Transverse valley-profile across Ocre River north of Wrigley showing the location of drill logs, illustrating the distribution of free water and ice (% by weight of substrate) and textures with depth.

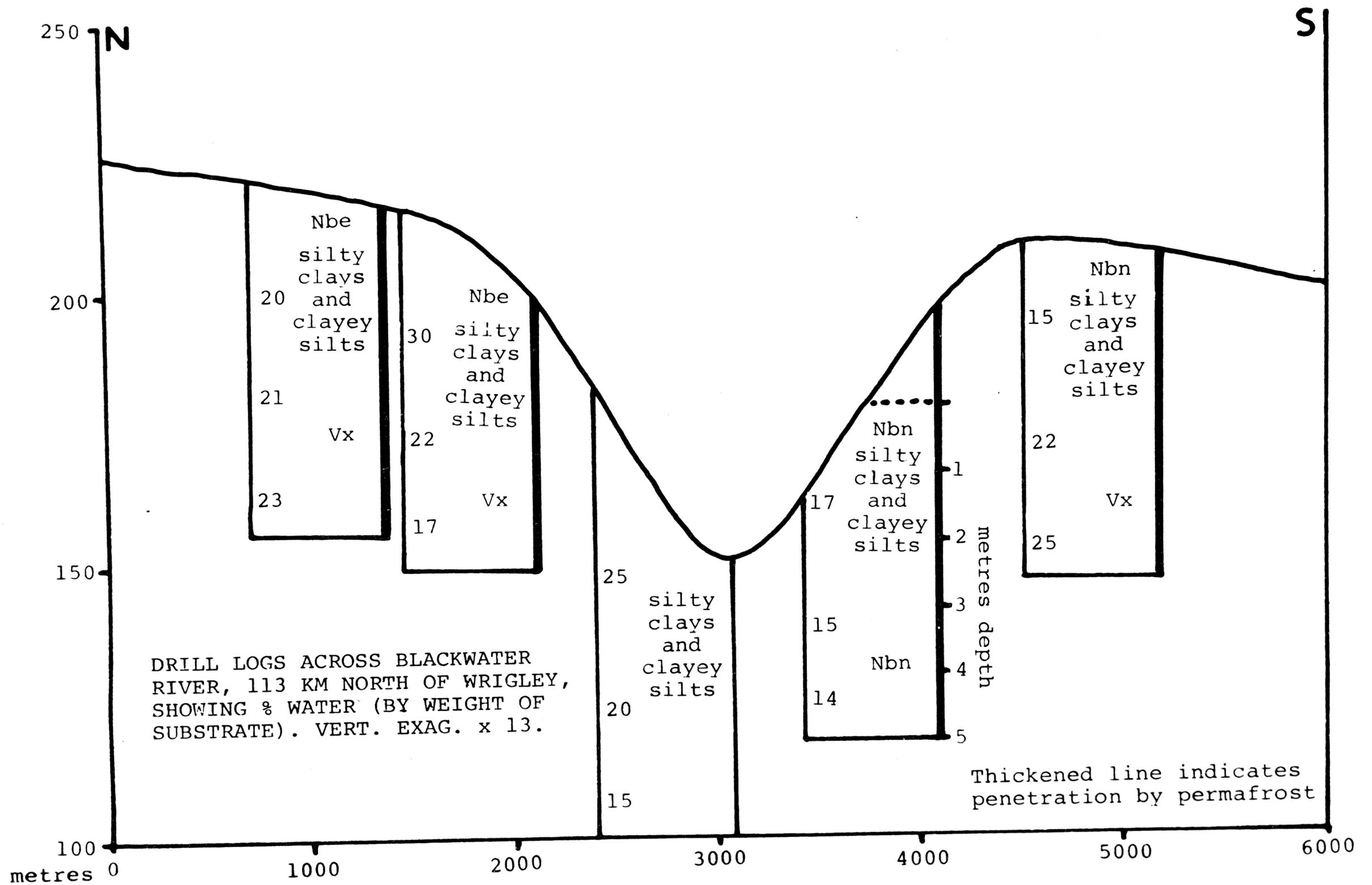


Fig.10. Transverse valley-profile across Blackwater River north of Wrigley showing the location of drill logs, illustrating the distribution of water, ice and textures with depth.

where the ice occurred as scattered crystals. At depth on the shoulders the ice occurred as lenticles or as irregular accumulations. At depth in the valley slopes or bottom the substrate was mostly well bonded without visible ice separations. As for the other transverse profiles, the water content (always as ice in the Thunder River valley-profile) decreased with increasing depth in the valley slopes and bottom, and increased with increasing depth on the shoulders, more substantially in the case of Thunder River, the most northerly valley studied, than for the other river valleys studied (Fig. 11). On the slopes the trees were becoming stunted, especially on the N-facing slopes, grading into icy peatlands over the shoulders.

Discussion

In the transition from south in the Discontinuous Permafrost Zone, to north in the Continuous Permafrost Zone, permafrost was observed first in upper N-facing slopes, extending downslope at higher latitudes. At still higher latitudes permafrost was also observed in upper S-facing slopes, extending downslope with increasing latitude, until the whole valley profile contained permafrost. The forests became increasingly more open and stunted, and lichen more abundant over the valley shoulders where permafrost was first observed, especially on N-facing slopes. Permafrost more slowly penetrated the lower, more densely forested slopes, especially those facing south. The occurrence of permafrost thus appears related to an interaction between aspect, latitude and vegetation.

Since the valleys studied are wide and gently sloping, the greater radiation received by S-facing slopes, over the shoulders of the N-facing

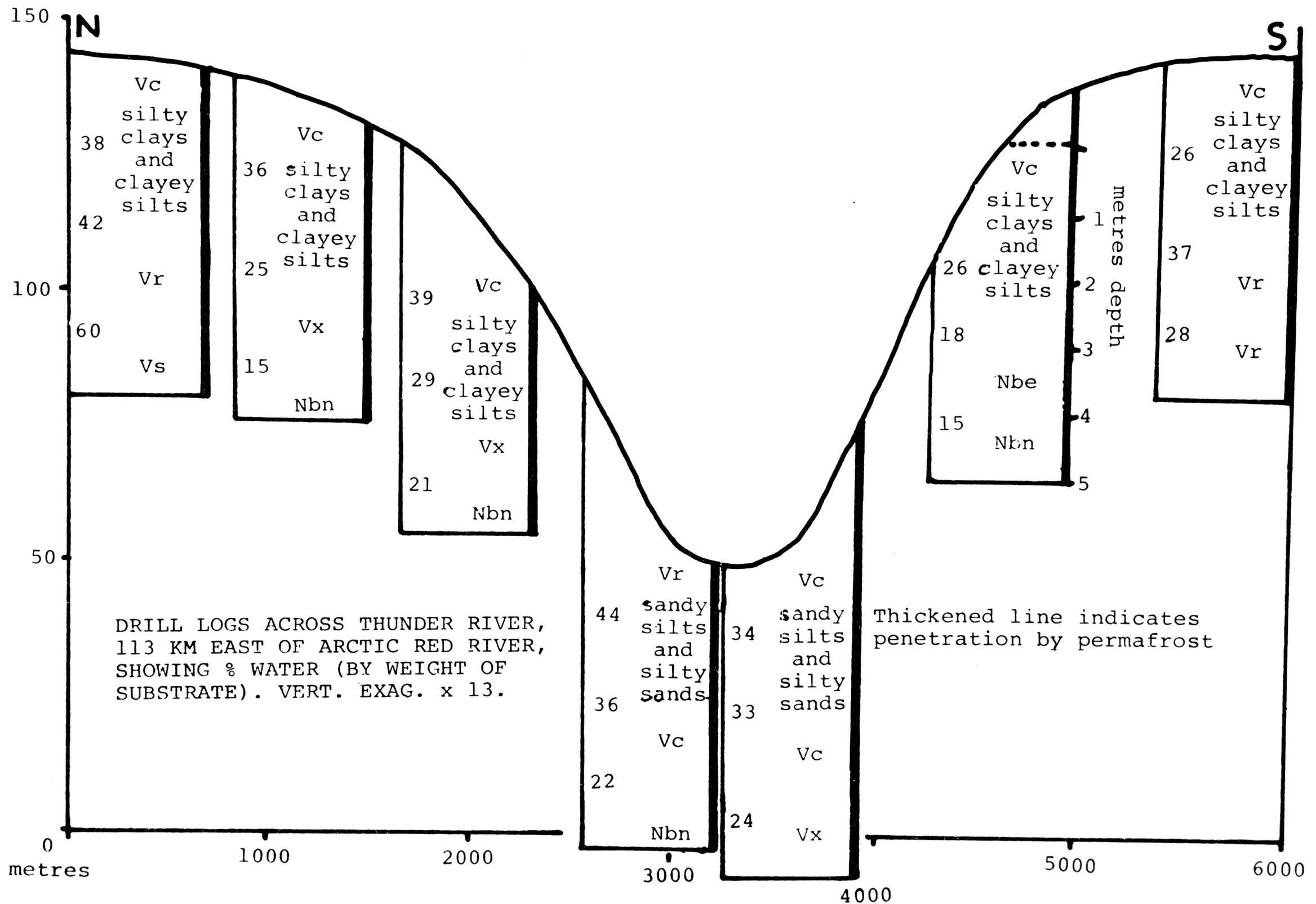


Fig.11. Transverse valley-profile across Thunder River north of Fort Good Hope showing the location of drill logs, illustrating the distribution of ice and textures with depth.

slopes, presumably warms the S-facing slopes each summer sufficiently in the Discontinuous Permafrost Zone to keep them relatively free of permafrost, at higher latitudes compared with N-facing slopes which receive only reflected radiant energy. The southernmost river valley studied, Trout River, contained no permafrost. At higher latitudes and increasingly more oblique insolation, the amount of radiant energy declines and permafrost becomes more extensive, until within the Continuous Permafrost Zone the Thunder River valley contains permafrost in all parts. The degree of forest development on different slopes, at different elevations is presumably related to the same interaction between aspect and latitude that appears to influence the distribution of permafrost, tree growth responding to greater warmth, permafrost to greater cold. However, icy peatlands on valley shoulders are extensively covered by white caribou moss (lichen) which, unlike dark forest colours, effectively reflects much solar radiation, keeping the land cool during summer, discouraging tree growth and encouraging the accumulation of ice in the organic layer.

In valley slopes and bottoms the water content generally decreased with increasing depth into the substrate, whereas on the shoulders the water content generally increased with increasing depth. Since these changes occurred whether the water was frozen or unfrozen, the processes responsible for them are probably unrelated to the formation of permafrost. In the Canadian north, precipitation is small, about 380 mm in the south, decreasing to about 250 mm in the north of the study-area. On the thinly vegetated flats and shoulders much of this water settles and percolates,

slowly down through the fine-textured substrates associated with these flats and shoulders, very slowly, but still percolating down through the small-pore network of frozen silts and clays, sometimes producing high ice accumulations at depth. On the slopes run-off is great which, apparently, is not significantly impeded by the forest, and so percolation is much less important and less water is held at depth, particularly where the alluvium is coarse-textured.

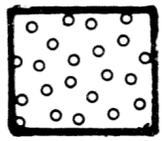
Conclusions

The distribution of permafrost in northern river valley landscapes is, in part, the result of an interaction between aspect, latitude and, to a certain extent, vegetation. The distribution of water within the substrates is probably mostly a result of the slope of the land. On flatter land either side of river valleys, locally ice can accumulate at depth.

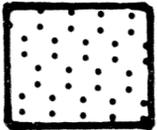
E. STABILITY IN MACKENZIE VALLEY SURFICIAL MATERIALS

Introduction

The site of the transverse profile, Fig. 12, dissected one of the outer meander courses of the Mackenzie River north of Fort Simpson, showing the pool against the outer bank created by the main current being thrown against it and eroding it. The slip-off slope rose gently towards the inside bank. A succession of drill logs, each taken to about 90 m depth, revealed that river bottom sediments consisted of a thin cover of alluvial cobbles and gravels, overlying glacial sediments that could be



Alluvium of cobbles in gravel



Lacustrine sandy silt and silty sand varves



Till of bouldery sandy clay except for silty clay in NW

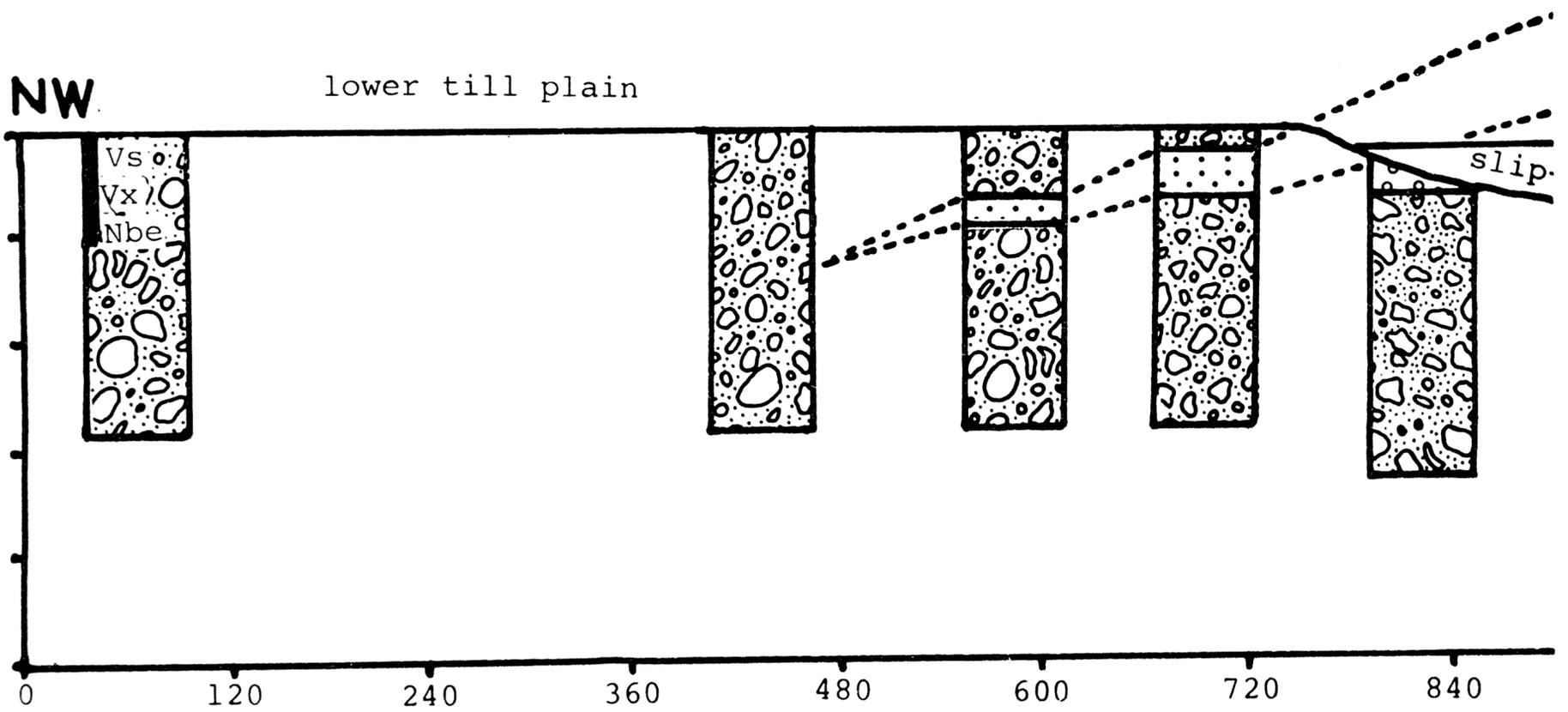
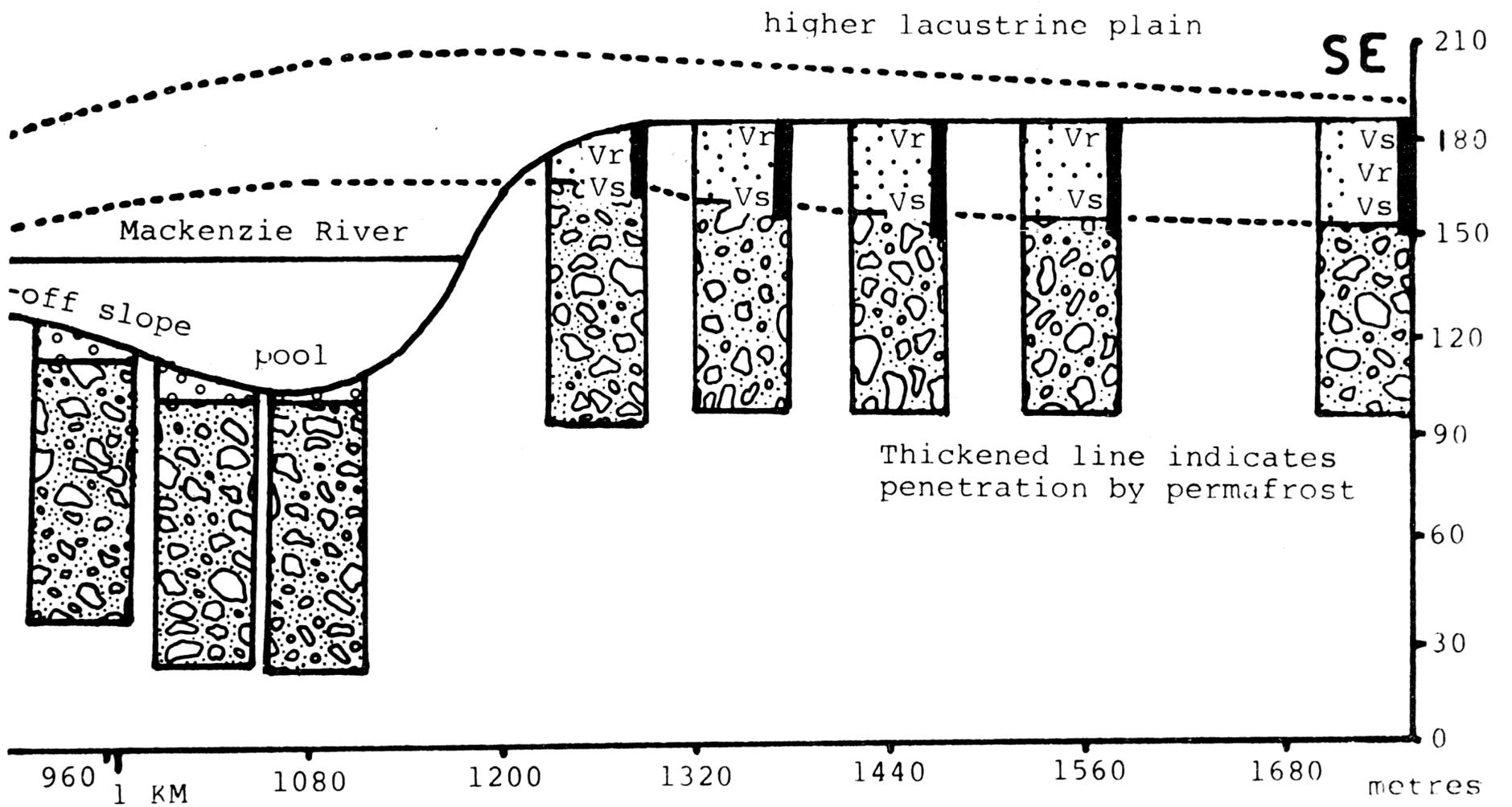


Fig.12. Transverse profile across the Mackenzie River north of Fort Simpson showing

DRILL LOGS ACROSS MACKENZIE RIVER, 30 KM NORTHWEST OF FORT SIMPSON, SHOWING THE DISTRIBUTION OF PERMAFROST IN SURFICIAL MATERIALS. VERT. EXAG. x2.



the location of drill logs, and illustrating the distribution of ice and surficial materials.

better examined where they crop out on either side of the river. These glacial sediments consisted of morainal sandy clay tills dropped by the melting Wisconsin ice sheet, and lacustrine fine sands and coarse silts deposited in a temporary lake impounded by a retreating ice sheet against some local prominent relief feature. These glacial lakes were not only short-lived, but they also changed their shape and location according to changing ice fronts relative to the local relief. The site is within the Discontinuous Permafrost Zone, and the occurrence, the depth to which permafrost penetrates into the substrate, and the nature of the distribution of ice were shown by the drill logs. The till plain on the northwest side of the river was 40 m lower than the lacustrine plain on the southeast side of the river, the side being eroded by the main river current which created a high, relatively steep outer meander bank.

Procedure

The distribution of surficial materials is used to speculate upon the glacial history of the site. The nature of this distribution, and of river erosion is interpreted in terms of bank stability. For one stratigraphical succession the liquid limits for different layers were estimated (Fig. 13). Each estimate was made by drying a sample, to which incremental additions of water were made, the sample being tested after each addition. In this way the range of water contents through which the sample remained plastic (like plasticine) could be estimated and, of special importance, the amount of water needed to take the sample out of its plastic range, beyond its liquid limit, into a state of slurry.

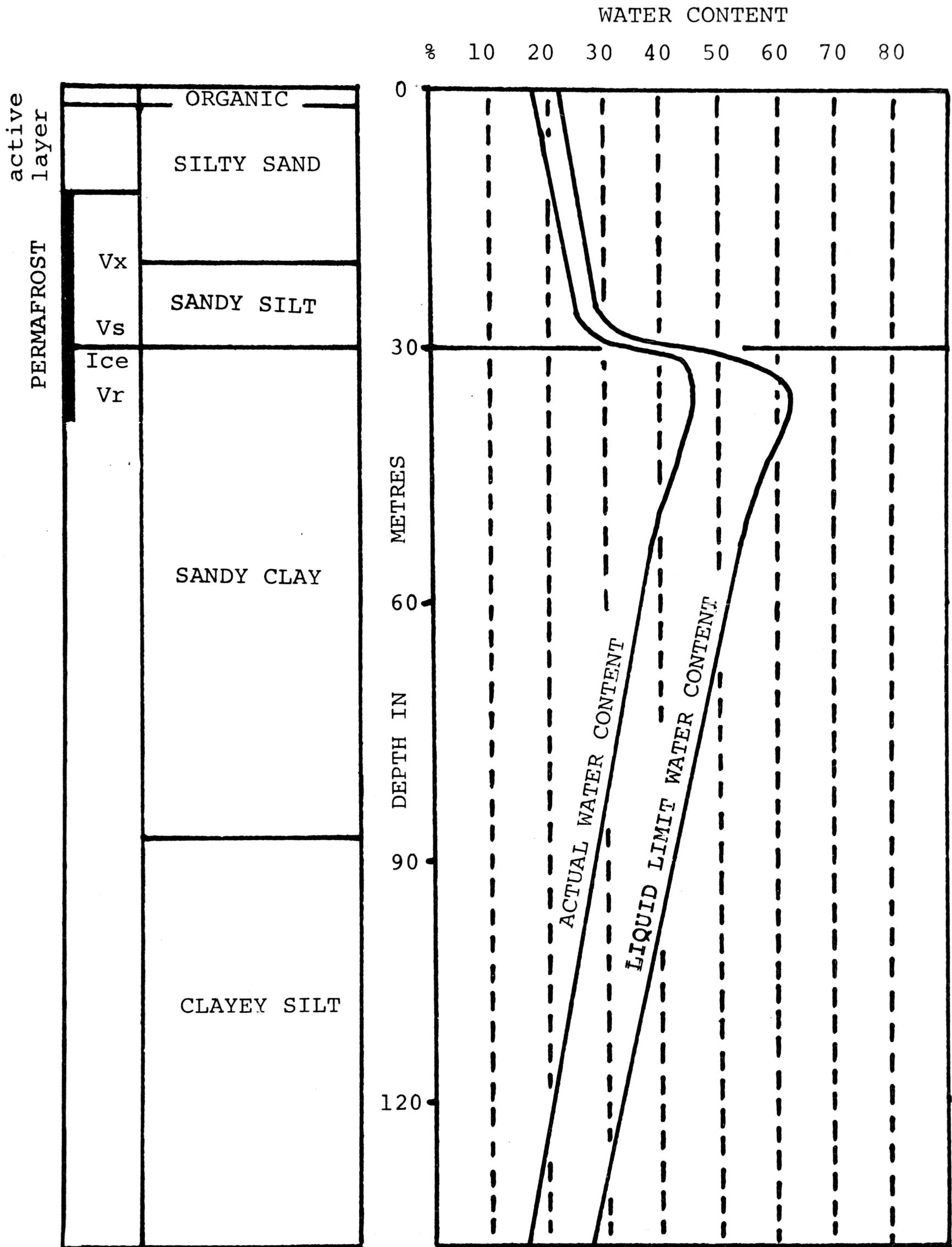


Fig.13. Stratigraphical and physical data (Isaacs, 1974) for a drill hole through glacio-lacustrine sands over morainal clays in the central Mackenzie River valley.

Results

The lower till plain on the northwest side of the river (Fig. 12) contained permafrost only at the most distant location on the transverse profile where icy peat (Vs) had accumulated over silty clay till frozen (Vx and Nbe) to a depth of about 30 m. Elsewhere on this lower plain the till was a sandy clay and permafrost had not developed. Presumably, within the Discontinuous Permafrost Zone sufficient heat had been conducted into this non-silty ground to raise the mean temperature to above zero. About 400 m from the river, within the till a diachronic, lacustrine, sandy and silty wedge widened towards the river bank, and rose through the till, representing deposition within a glacial lake that became more extensive while its shoreline shifted southeastwards with the passage of time.

The Mackenzie River has eroded through this lake deposit, but it could be seen capping the high banks on the southeast side of the river. About 35 m of lacustrine sands and silts mantled the high plain on the southeastern side of the river, at a higher level than on the opposite river bank, indicating that the lake continued to become more extensive and shift its shoreline southeastwards with the passage of time. Permafrost had penetrated this silty substrate to about 35 m depth, down to near the junction with the non-silty till. Within this permafrost the ice was distributed mostly as irregular ice formations, but lenticular ice became prominent within the lowermost lacustrine sediment and uppermost till.

Discussion

Permafrost appears to be associated with silty substrates in this part of the Discontinuous Permafrost Zone. Water can percolate slowly down through the small-pore network of frozen silt, and the sand content of the lacustrine sediments will further improve their porosity. Although the amount of precipitation in the area is small, and although the rate of percolation will be slow, over time percolating water has accumulated either side of the junction between the coarser-textured lacustrine sediment and the finer-textured till as ice lenticles. The water contents in frozen substrates can often exceed their liquid limits (Code, 1973; McRoberts and Morgenstern, 1973). Because of its nature, basal permafrost is near zero temperature. If pore pressures generated near the junction of lacustrine and till substrates become great enough, they can depress the melting point. Any slight change of the physical environment around this junction in this way might release sufficient water to exceed the liquid limit of coarse silty-fine sandy substrates, making the junction a plane of weakness.

Fig. 13 shows the distribution of actual water content and estimated liquid limit water content through a junction at 30 m depth of sandier over clayier sediments, situated below one bank of the Mackenzie River. Massive ice has accumulated along the junction. At this junction the two water contents are so close that any slight change in the physical environment could cause melting of the thick ice accumulation, the sandier lacustrine sediments to exceed their liquid limit, and the supra-junction sedimentary block to fail and slide over the slurry thus created. Strang

(1973), Code (1973) and McRoberts and Morgenstern (1973) have all observed that many slides occur where there are lacustrine sandier sediments over clayier sediments. Fig. 14 shows a rotational slide that has occurred in the high banks of the Mackenzie River north of Fort Simpson, a failure that was undoubtedly started by the slurring of lighter-coloured, coarser-textured lacustrine sediments which had exceeded their liquid limits, over darker-coloured, finer-textured tills which had held the accumulation of ice, and then water close to the junction.

Conclusions

Icy permafrost accumulates mostly in silty substrates. Where coarser-textured sediments overlie finer-textured sediments, and especially where the base of the permafrost occurs at about the depth of the junction between the two types of sediments, ice can accumulate along the junction. Because of its nature, the base of the permafrost is at a critical temperature, and any slight change of the physical environment, for example an increase in pore pressures because of changes in the head of unfrozen water, the ice concentration at this level can melt. Melting can release sufficient water to cause adjoining, sandier sediments to exceed their liquid limit and slurry, allowing the overlying sedimentary block to slide if there is no lateral support, as in a high river bank.

SUMMARY

Transverse valley-profiles have been used as an aid to interpreting differential uplift along the Mackenzie River valley, for interpreting the distribution of permafrost within opposing slopes of tributary valleys, and to help interpret river bank slides.

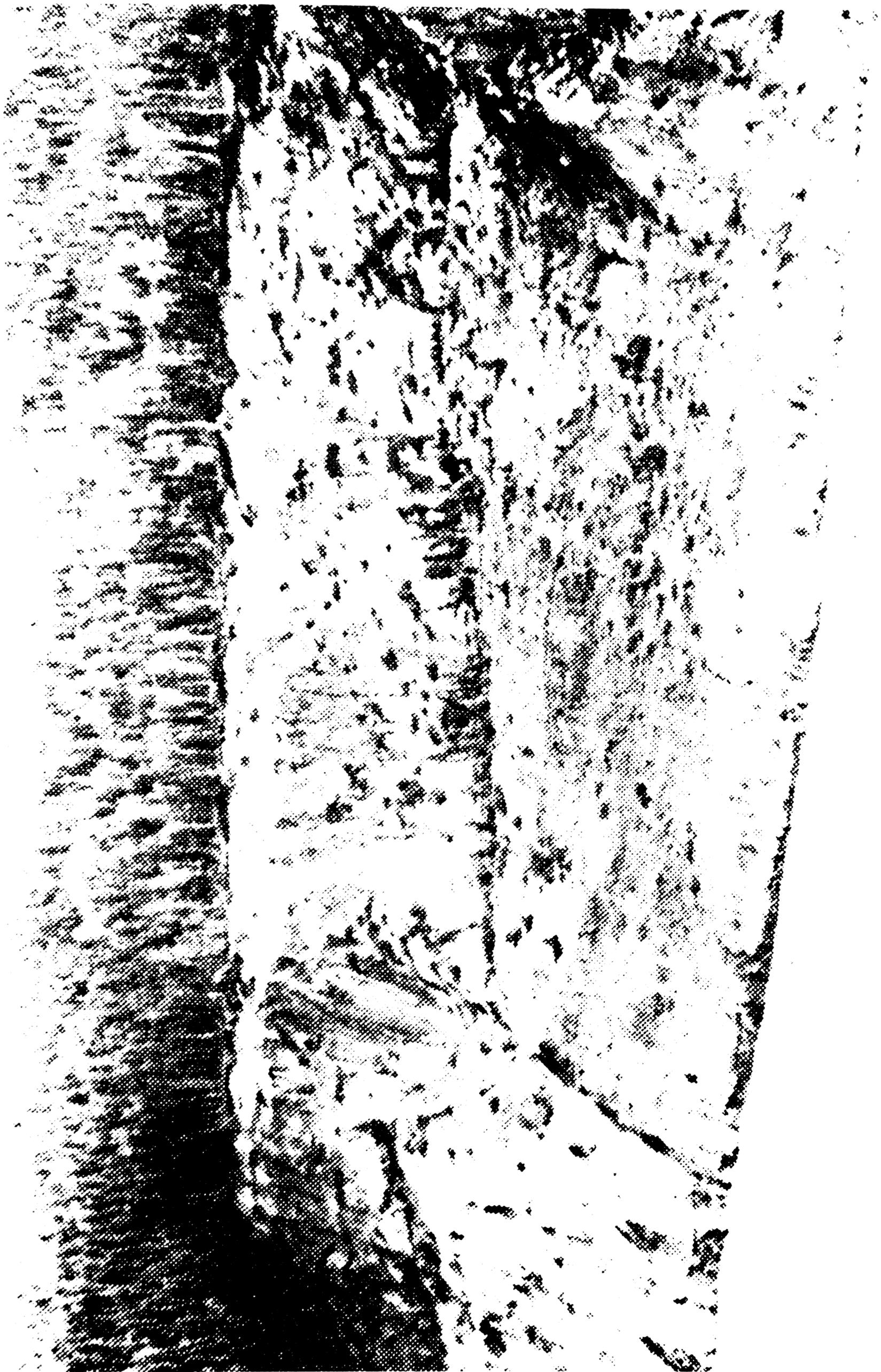


Fig.14. Rotational slide on outer meander bank north of Fort Simpson, showing surficial, lighter, lacustrine sands, over darker, morainal clays and silts, the junction being the probable failure layer.

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