

ASPECTS OF THE SURFICIAL GEOLOGY AND PERMAFROST
CONDITIONS, KLONDIKE GOLDFIELDS AND DAWSON
CITY, YUKON TERRITORY

by

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Frontispiece.

Klondike placer miner at the time
of the gold rush 1898-1900. (U.S.G.S.
photo)

Abstract

This thesis documents the stratigraphy and facies of Tertiary and Quaternary age gravels found in the Klondike area, central Yukon Territory, and presents observations upon the permafrost, ground ice and organic silt (muck) deposits of younger age.

The White Channel Gravel is generally structureless with indistinct bedding. Clast size varies from silt/clay to large boulders. The most common facies are massive, poorly bedded gravel with rare planar and trough cross bedding. Fines include dominantly horizontally laminated sands and low angle cross stratified sands with rare shallow scours. Facies analysis suggests deposition in a proximal position, characterized by relatively continuous deposition in a high energy environment. Yellow Gravel facies are similar to those of the White Channel Gravel but planar and trough cross bedded sands are more abundant. This facies change is accompanied by a decrease in imbrication, possibly the result of waning currents and the reworking of the White Channel Gravel clasts.

The Klondike Gravel was deposited contemporaneously with, or immediately following deposition of the White Channel Gravel. Facies and structures suggest a more distal

position, possibly reflecting the receding ice margin, and variations in sediment supply and discharge. Based on observations of facies and structures, four informal members are proposed. Member A is dominantly imbricate, clast supported gravel; member B thickly bedded sands and gravel; member C is characterized by gravel channel fill structures; and member D is composed of larger, shallow channels.

During either the Reid or McConnell glaciation, permafrost and ice wedges formed in valley fill deposits consisting of creek gravels and predominantly muck. These wedges are now relict, and a distinct thaw unconformity 2-3 m below the surface truncates the ice wedges and reflects a period of climatic warming possibly during the post-glacial climatic optimum. In later Holocene time, permafrost aggraded into the finer sediments of the Yukon River. The apparent truncation of segregated ice lenses and ice wedges 1 m below ground level in Dawson City reflects the current depth of seasonal thaw.

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1. Background and Setting

1.1 Introduction

The Klondike area is important to studies of the Quaternary history of the Yukon Territory because many post-glacial climatic, drainage and landscape changes are represented in the surficial deposits. Throughout the Quaternary, the area remained unglaciated, and relict permafrost is widespread. Numerous faunal remains preserved within the permafrost indicate the southeastern limit of the Bering Refugium.

The recent rise in placer mining activity in the Klondike enables access to good sections in gravel and permafrost. The Territorial Arctic Land Use Regulations normally prevent the stripping of large areas: since mining claims are exempt from these regulations, many sections are being exposed now for the first time.

1.1.1 Aims and Objectives

The objective of this study is to determine the nature, depositional history and subsequent reworking of late Tertiary and Quaternary placer gravels in the lower Klondike Valley and its south bank tributary Hunker Creek, central Yukon Territory. A second objective is to document, wherever possible, the nature of the permafrost conditions

of the area.

1.1.2 Study Area and Climate

The study area (figure 1) is located in the central Yukon Territory, near Dawson City (lat. $64^{\circ}03'N.$; long. $139^{\circ}25'W$). The sites selected for field investigations are located at Jackson Cut, Hunker Creek and Gold Bottom (figure 2, sites 1, 2, 3, 4 respectively). In addition, the surficial geology and permafrost conditions of the materials underlying the townsite of Dawson city (figure 2, site 5) were examined briefly when sewer and municipal services were installed in a series of trenches early in the summer of 1980.

The climate of the Klondike area is subarctic continental, with short summers and long winters with periods of intense cold, low winds and light snowfall and rain. Figure 3 shows the temperature and precipitation range of the area as recorded at the Dawson City airport over a 30 year period. Weather stations in the Yukon Territory are sparsely located, and almost all are situated in valley bottoms. Mountain areas receive more snow, especially on west slopes, and have a greater temperature range. Thus, the climatic data for Dawson are not necessarily characteristic of the Klondike area. Green (1972) gives data from Elsa as representative of the Dawson area since the station is not located in a deep valley bottom. Orographic effects are present in the study area, however, affecting both

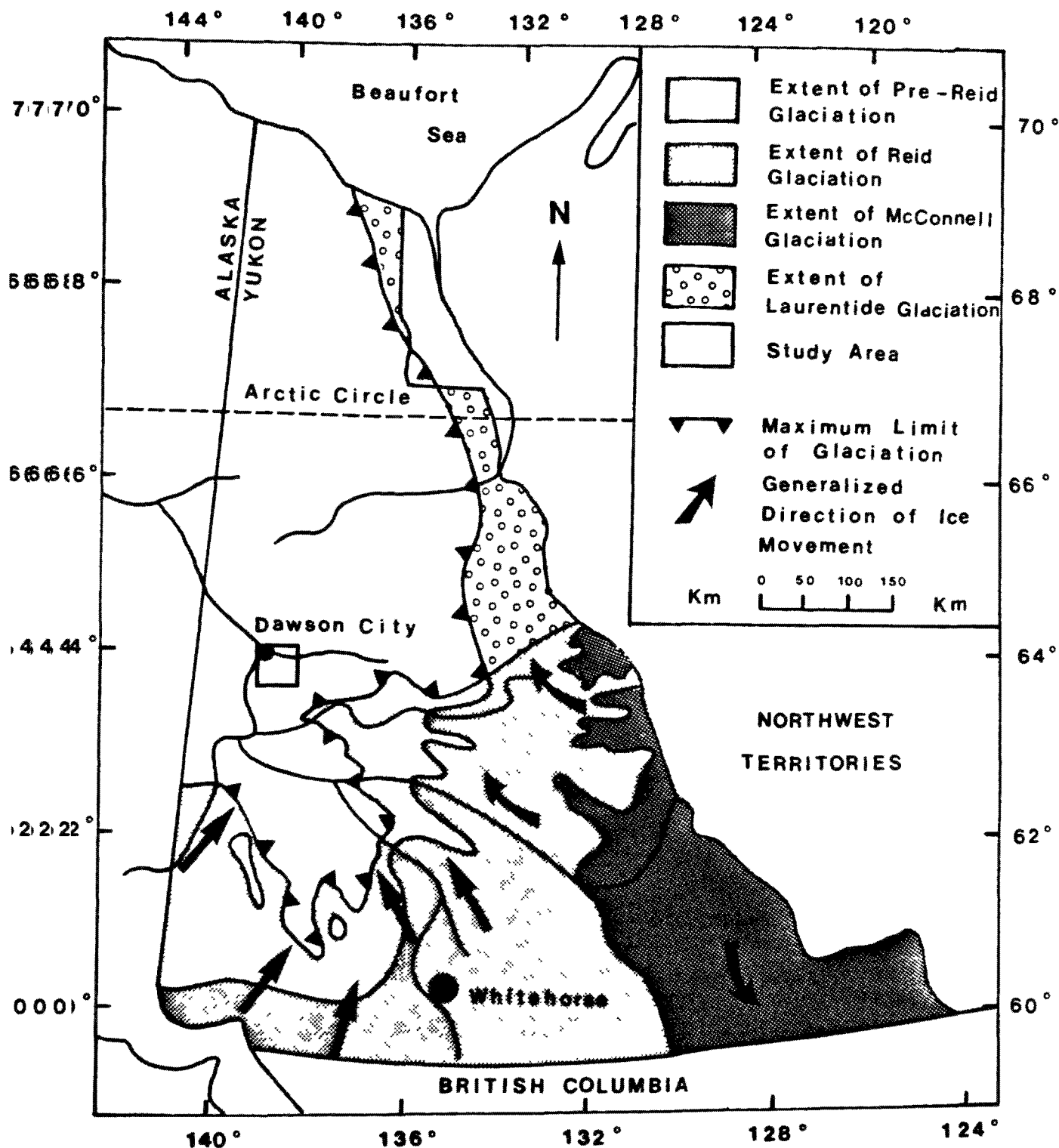


Figure 1. Location of the study area with respect to known glacial limits in the Yukon Territory, glacial limits generalized after Hughes (1969) and Rutter, Foscolos and Hughes (1976).

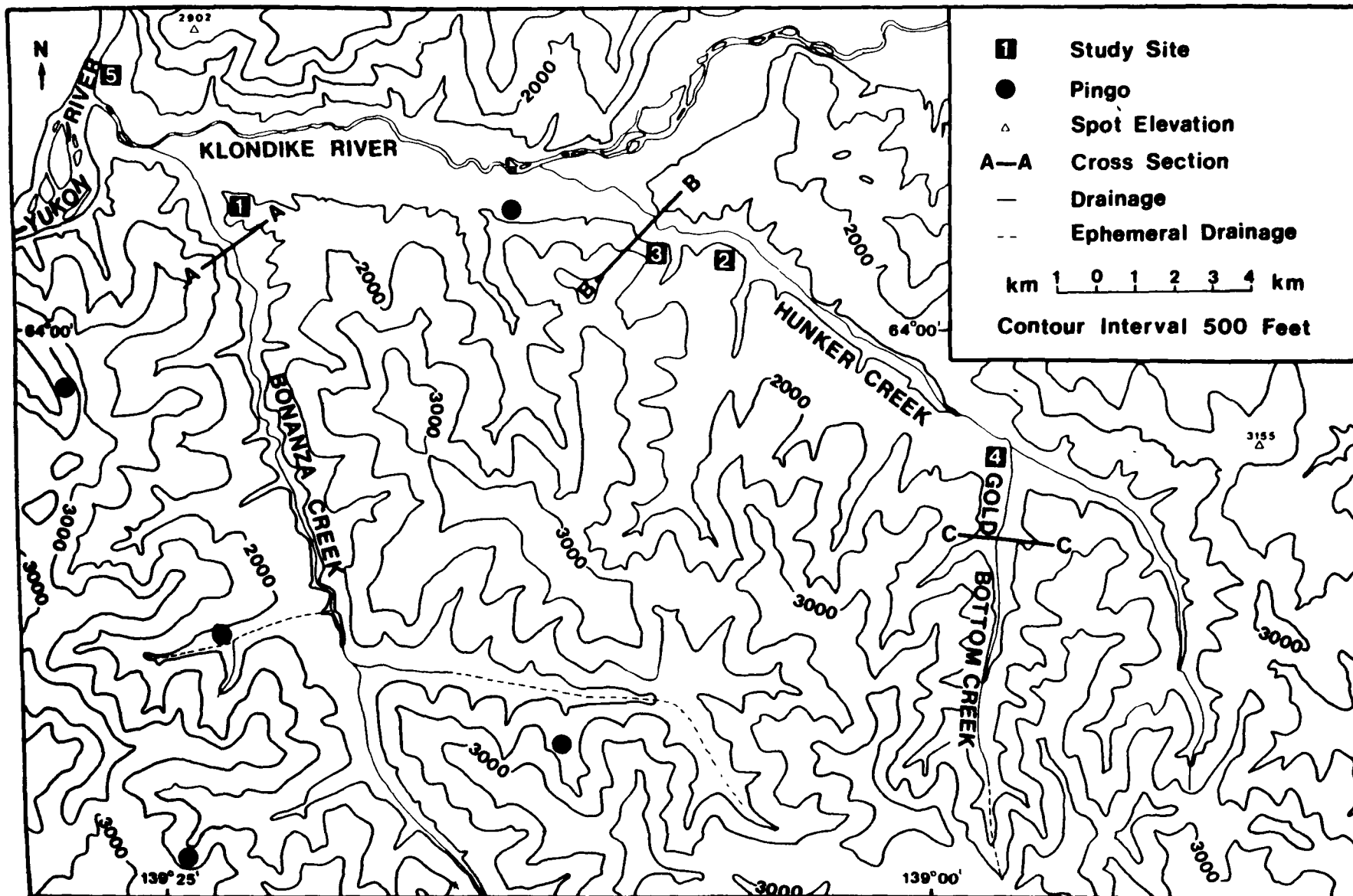


Figure 2. Klondike gold fields.

rainfall and snowfall. Although mean annual precipitation is uniform over much of the Yukon, ranging from 23 cm to 43 cm, precipitation for Dawson (elevation 500 m) and Elsa (elevation 1,000 m) differs significantly. One of the most important factors determining local climatic conditions is temperature range, given in figure 3.

1.1.3 Fieldwork

Placer gravels and permafrost conditions were examined in exposures created by placer mining operations between May 15 and September 15, 1980. The identification of major lithostratigraphic units was undertaken, and sections were mapped at an approximate scale of 1 cm = 1 m of exposure. The vertical and lateral extent of terrace gravel along Hunker Creek was recorded using an aneroid barometer accurate to ± 1.5 m. Particular attention was paid to the interfingering of White Channel, Yellow and Klondike Gravels. Gravel fabric, structures and facies type were noted and described, using the facies types of Miall (1978) and Rust (1978), shown in table 1.

The degree of reworking of these terrace gravels from high to intermediate levels was examined using the roundness, sphericity and form indices of Krumbein (1941), Wadell (1932, 1935) and Zingg (1935).

Muck deposits, where present, were mapped at an approximate scale of 1 cm = 1 m of exposure and ice content

Table 1
Facies Types of Miall (1978) and Rust (1978)
Used for Mapping and Facies Models.

Facies			
Code	Lithofacies	Sedimentary structures	Interpretation
Gms	massive, matrix supported gravel	none	debris flow deposits
Gm	massive or crudely bedded gravel	horizontal bedding, imbrication	longitudinal bars, lag deposits, sieve deposits
Gt	gravel, stratified	trough crossbeds	minor channel fills
Gp	gravel, stratified	planar crossbeds	linguoid bars or deltaic growths from older bar remnants
St	sand, medium to v. coarse, may be pebbly	solitary (theta) or grouped (pi) trough crossbeds	dunes (lower flow regime)
Sp	sand, medium to v. coarse, may be pebbly	solitary (alpha) or grouped (omikron) planar crossbeds	linguoid, transverse bars, sand waves (lower flow regime)
Sr	sand, very fine to coarse	ripple marks of all types	ripples (lower flow regime)
Sh	sand, very fine to very coarse, may be pebbly	horizontal lamination parting or streaming lineation	planar bed flow (l. and u. flow regime)
Sl	sand, fine	low angle (<10°) crossbeds	scour fills, crevasse splays, antidunes
Se	erosional scours with intraclasts	crude crossbedding	scour fills
Ss	sand, fine to coarse may be pebbly	broad, shallow scours including eta cross-stratification	scour fills
Sse, She, Spe	sand	analogous to Ss, Sh, Sp	eolian deposits
Fl	sand, silt, mud	fine lamination, very small ripples	overbank or waning flood deposits
Fsc	silt, mud	laminated to massive	backswamp deposits
Fcf	mud	massive, with fresh-water molluscs	backswamp pond deposits
Fm	mud, silt	massive, desiccation cracks	overbank of drape deposits
Fr	silt, mud	rootlets	seatearth
C	coal, carbonaceous mud	plants, mud films	swamp deposits
P	carbonate	pedogenic features	soil

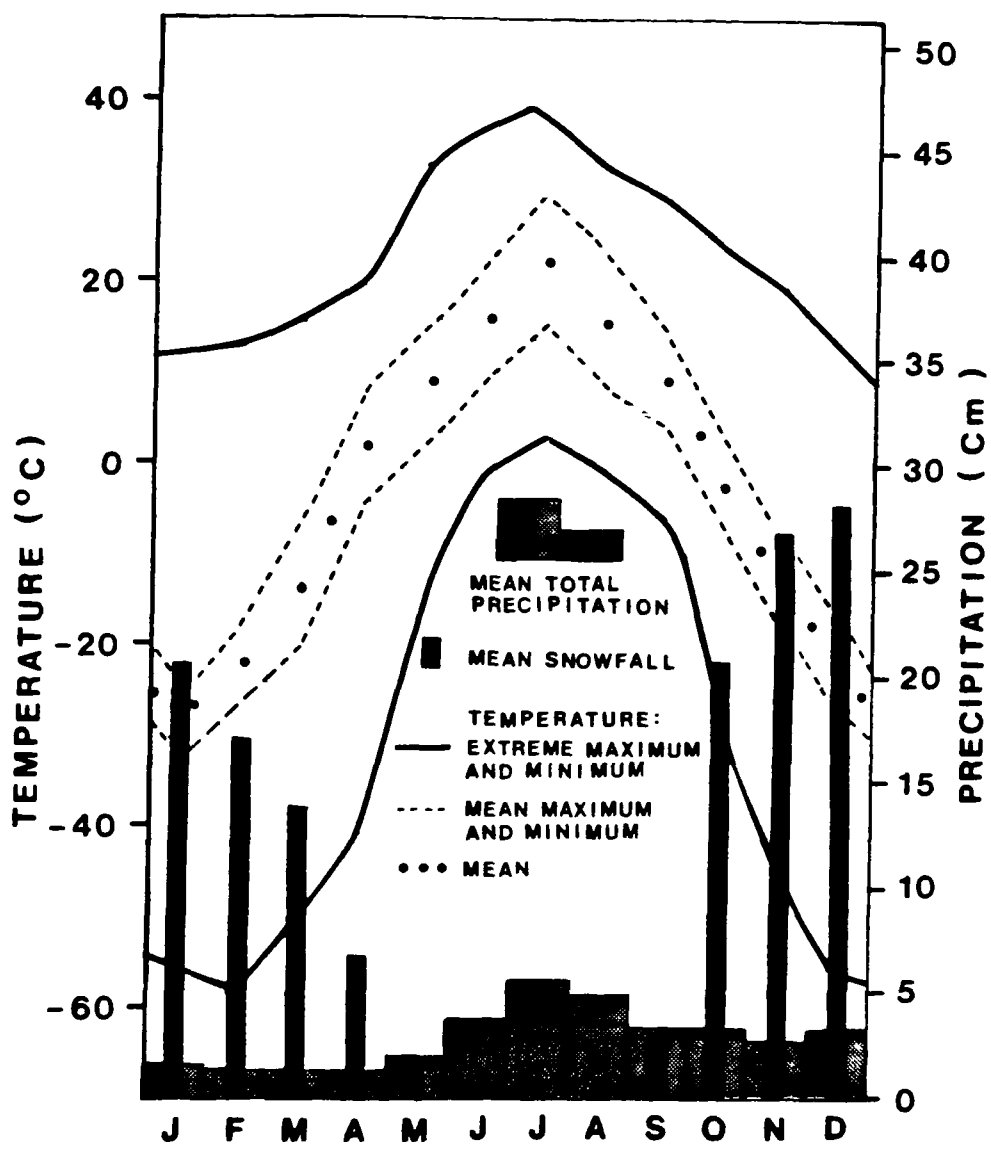


Figure 3. Climatic data for Dawson City, Y.T., 1941-1971. (Atmospheric Environment Service, Department of Environment).

(by weight) and ice type (Pihlainen and Johnston, 1963) described, as shown in table 2. The nature of the enclosing sediments was examined by the identification and description of colluvium types and any macrofossils. Recording of ice foliation attitudes, spacing and orientation of wedges, changes in sediment character and the identification of thaw unconformities assisted in the interpretation of the history of permafrost growth.

Attention was focussed upon exposures revealed at the following placer mining operations:

Site 1: Jackson Cut (64°01'N; 139°21'W):--Site 1 is located north of Lovett Hill near the junction of Bonanza Creek and the Klondike River (see figure 2, plate 1). The site had been previously mined, but not extensively. Current mining activity is restricted to hydraulic mining.

The site is important to the Quaternary stratigraphy of the Klondike since it is one of the few areas where Klondike Gravel overlies White Channel Gravel. Hughes, Rampton and Rutter (1972) note a bedrock terrace at 427 m, overlain by 40 m of White Channel Gravel and 56 m of Klondike Gravel. The Klondike Gravel thins out along Bonanza Creek, and is not exposed on Cripple Hill, 1.9 km south of site 1. At Trail Hill, the Klondike and White Channel Gravels are interbedded, suggesting that at one time,

Table 2
 Descriptive Field System for Ground Ice Proposed
 by Pihlainen and Johnston (1963)

Main group	Sym- bol	Subgroup description	Sym- bol	Field identification
Ice not visible	N	Poorly bonded or friable	Nf	Hand examination
		Well bonded	Nb	Thaw sample to determine excess ice (supernatant water)
		No excess ice	Nbn	
		Excess ice	Nbe	
Visible ice--less than 2.5 cm thick	V	Individual ice crystals or inclusions	Vx	Visual examination. Observations upon: location orientation thickness length spacing size shape pattern or arrangement hardness structure colour
		Ice coatings on particles	Vc	
		Random or irregularly oriented ice formations	Vr	
		Stratified or distinctly oriented ice formations	Vs	
Visible ice--greater than 2.5 cm thick	ICE	Ice with soil inclusions	ICE+ soil type	Visual examination Observations upon: Hardness--hard, soft structure--clear cloudy, porous, candled, granular, stratified colour admixtures
		Ice without soil inclusions	ICE	



Plate 1. Jackson Cut, July 1977. Lovett Hill is in the center of the photo; Bonanza Creek in the lower left corner. (EMR, Ottawa, A24704-179)

deposition of the upper White Channel Gravel may have been contemporaneous with deposition of the Klondike Gravel (Hughes, Rampton and Rutter, 1972).

Unusual and problematic structures are present in the White Channel Gravel. O. L. Hughes (personal communication, 1980) notes thrust bedrock interbedded with the gravel. Likewise, Gleeson (1970) observes shear zones on Bonanza and Hunker Creeks. The faults are of low angle, contain clay gouge and broken bedrock and have offset the high level gravels. Such offsetting may account for many of the anomalous gold values of McConnell (1903).

Fabric, structure and facies studies of the Klondike and White Channel Gravels were conducted at site 1, as well as muck descriptions.

Site 2: Stutter Operation, Hunker Creek at Dago Hill (64°00'N; 139°05'W):--Site 2 is located on the southwest side of Hunker Creek between Last Chance Gulch and Dago Gulch, comprising most of Dago Hill. As shown in plate 2, two types of mining have been conducted in this area: dredging and hydraulic. Earthen dams and hydraulic channels from the old workings are common in the upland areas. Mechanical operations are now being used for this part of Dago Hill.

Hydraulic mining has exposed White Channel Gravel on the high level terrace of Dago Hill. Gravels change



Plate 2. Stutter operations, Hunker Creek, July 1977. Old workings are in the lower right corner, new hydraulic workings in center, left. Dredge tailings in Hunker Creek are clearly visible (EMR, Ottawa A24704-98)

from white to yellow at the summit, forming the Yellow Gravel, a sub-facies of the White Channel Gravel. Klondike Gravel is not present at this locality.

The early miners reported mastodon teeth from these sections. However, few organics are present today, and thus little or no permafrost occurs at this site to aid in preserving fossil remains (see section 1.4.4).

Fabric structure and facies studies of the White Channel Gravel and the Yellow Gravel were conducted at this site, including the documentation of the inter-fingering of the White Channel and Yellow Gravel. Where present, muck and colluvium types were described.

Site 3: Mayes Operation, Hunker Creek (64°01'N; 139°07'W):--Site 3 (plate 3) is located downstream from Last Chance Creek on Hunker Creek, in close proximity to site 2. A low bedrock terrace lies against the steep valley wall on the left limit of Hunker Creek, overlain by auriferous gravels which are covered by a wedge of muck that attains a thickness of 15 m or more at the junction of the terrace and the valley wall.

Permafrost, muck and colluvium were studied at site 3.

Site 4: Gold Bottom Creek (63°59'N; 138°58'W):--Site 4 is located at the junction of Gold Bottom Creek and Hunker Creek, shown in plate 4. The site comprises the first

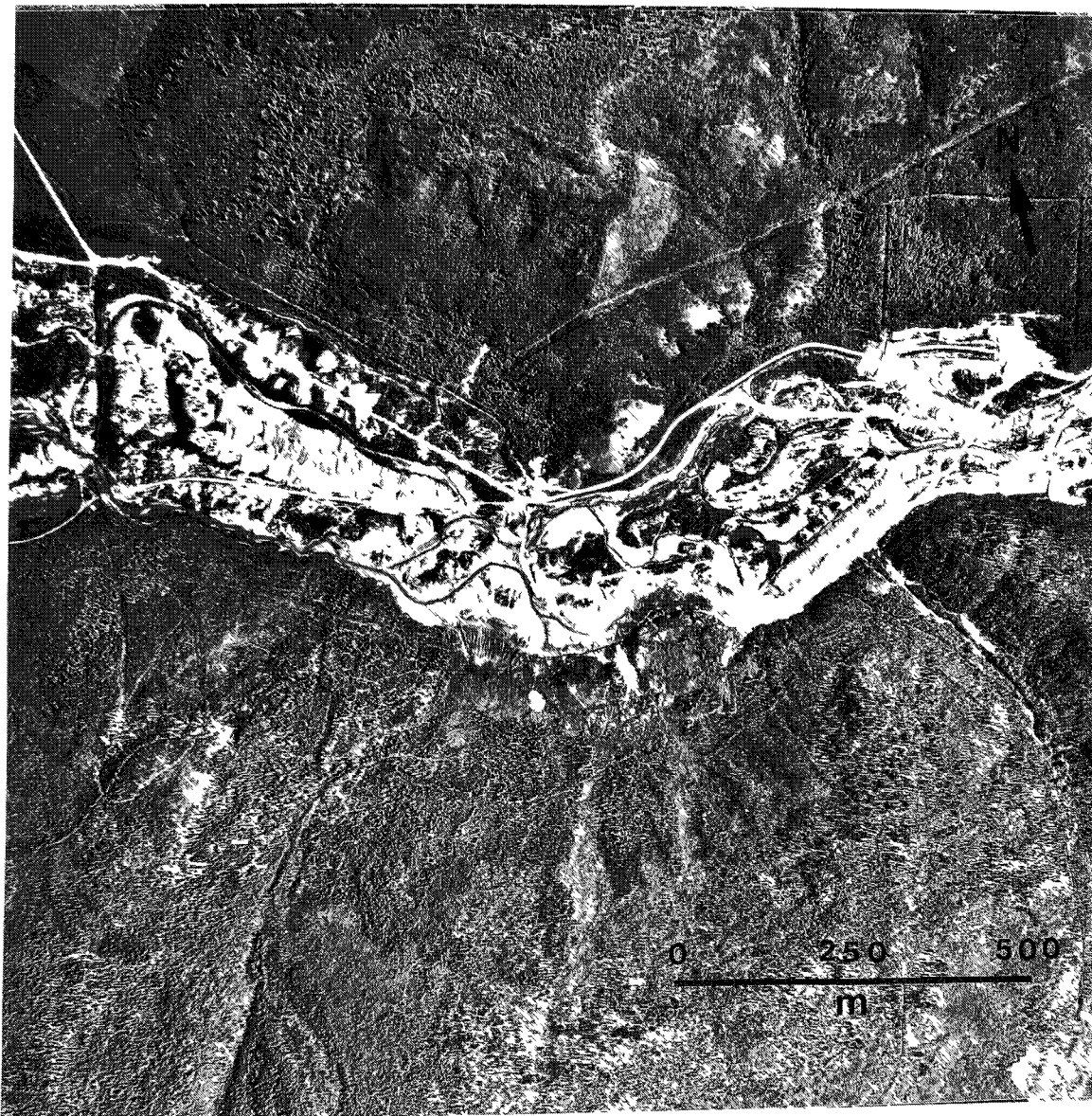


Plate 3. Mayes Operation, Hunker Creek, July 1977.
(EMR, Ottawa A24704-96)

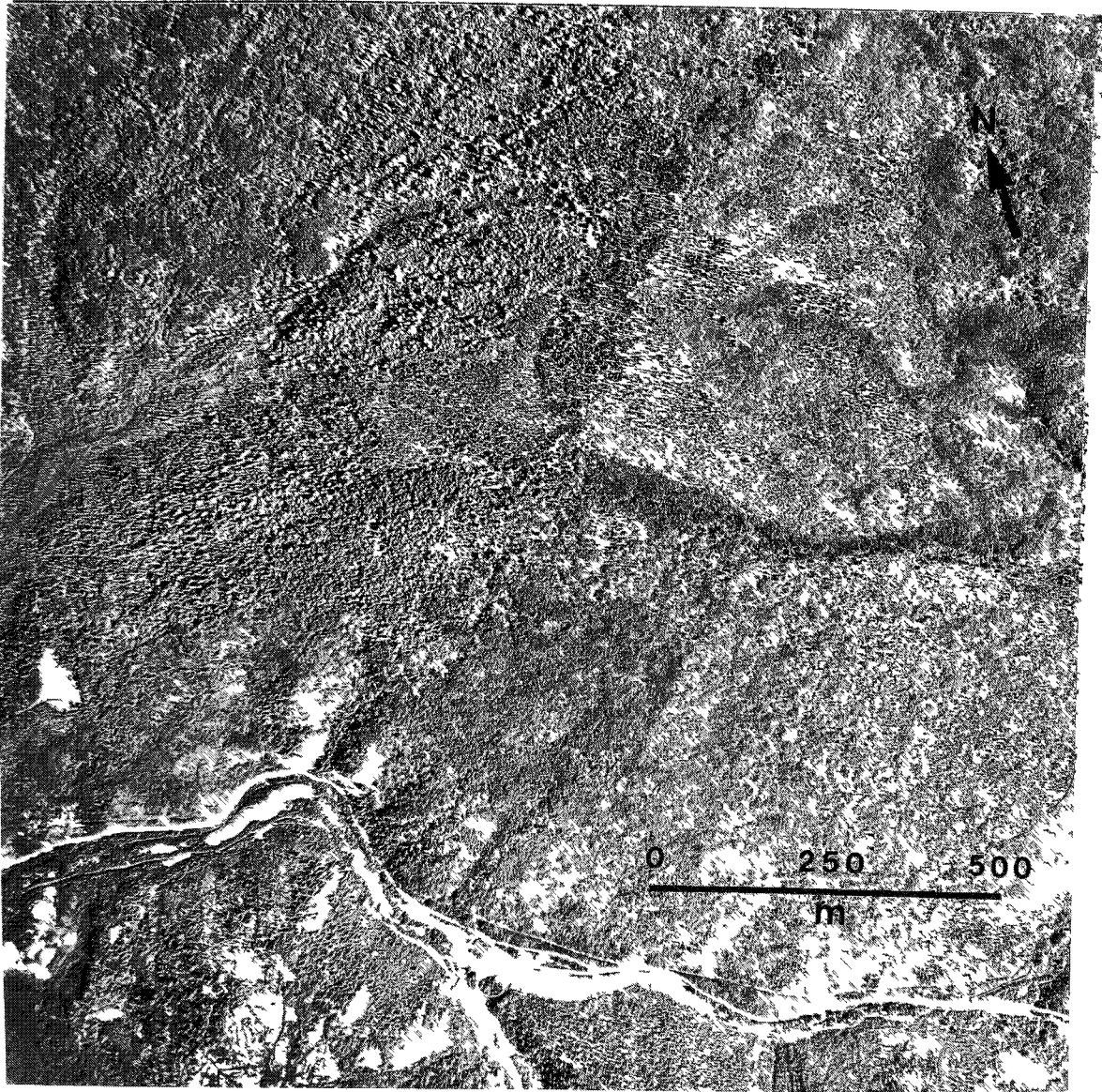


Plate 4. Site of Gold Bottom, at the junction of Gold Bottom Creek and Hunker Creek, July 1977. (EMR, Ottawa A24704-106)

few claims on Gold Bottom below Hunker Creek. This locality is important to the stratigraphy of the area because it is the lowest section available for study. The contact between creek gravels and bedrock is visible, overlain by slopewash interfingered with fluvial sediments.

Mining at this locality is done entirely by mechanical methods.

Fabric, structure and facies observations of creek gravels, muck and colluvium types were undertaken at this locality.

1.2 Regional Geomorphology

The study area is located within the Klondike Plateau portion of the Western Yukon Plateau (Bostock, 1948) (figure 4). This plateau is dissected by valleys to an average depth of 200 m (plate 5). Profiles reveal a characteristic V-shaped cross-section, often with a high level bench or terrace, suggesting a history of multicyclic valley development (figure 5). The intervening ridges possess uniform elevations, and are presumed to be remnants of an old uplifted erosional surface (Tempelman-Kluit, 1980); only the Dawson Range and the Tintina Trench form distinct major features in the area. The ridges converge into domes or groups of relatively smooth-sloped mountains. Two prominent domes occur in the study area: the Midnight Dome (figure 2) and the King Solomon Dome, approximately

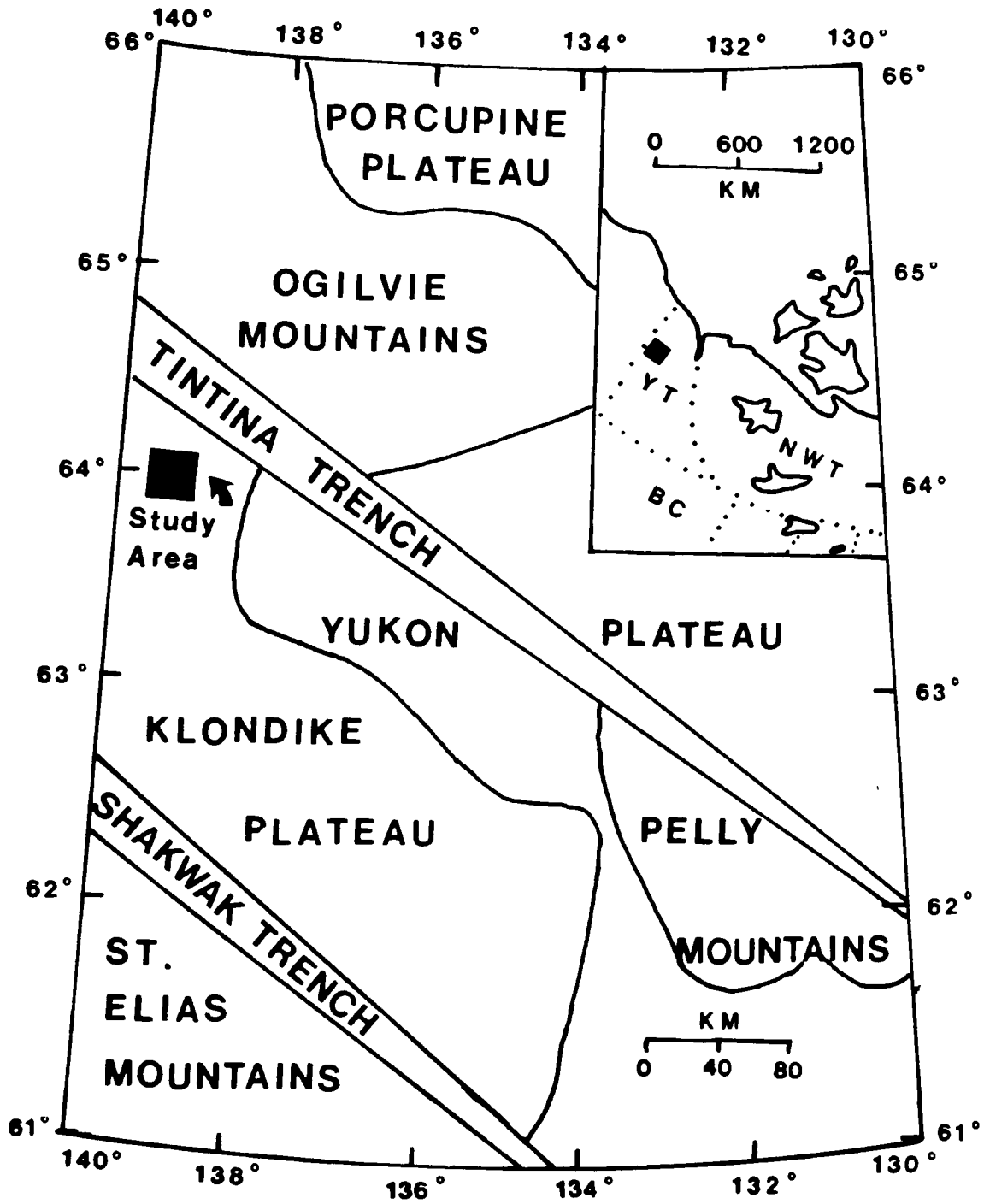


Figure 4. Physiographic map of central Yukon showing study area. (After Bostock, 1948)



Plate 5. View looking north from the King Solomon Dome. Penneplain remnants of the Klondike Plateau are dissected by tributary streams to Hunker Creek (center). Mountains visible in the background are the Southwest Range of the Ogilvies.

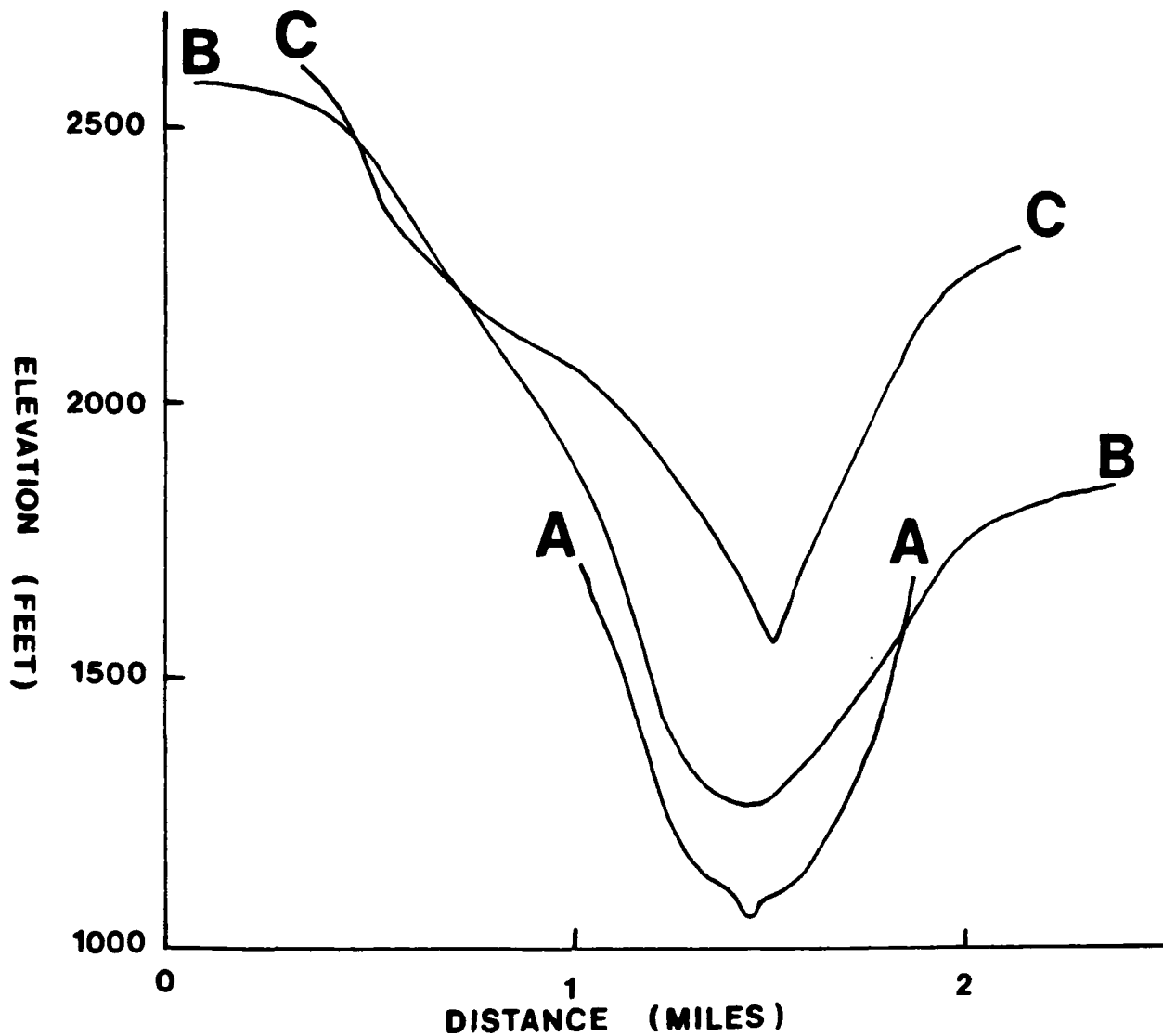


Figure 5. Cross-profiles of Bonanza (A), Hunker (B) and Gold Bottom (C) Creeks. Location of sections is shown on figure 2, vertical exaggeration 10X. Note the similarity of Hunker and Bonanza Creeks and the youthful nature of Gold Bottom Creek.

25 km southeast of Dawson City.

The rivers which fashioned the upland peneplain surface are represented today by the White Channel Gravel, probably of Pliocene age. Evidence of changes in drainage is shown by the levels of bedrock terraces beneath the White Channel Gravel, and its equivalents. These elevations indicate that the Proto-Yukon River from the vicinity of present day Dawson City to Fort Selkirk may have flowed southward as late as Pliocene time. Tempelman-Kluit (1980) demonstrates that old bedrock terraces slope southeast, opposite to the gradient of the present streams (figure 6). The present patterns of the Sixtymile and Indian Rivers also suggest that these streams were once tributaries to a south-flowing Yukon River. Additional evidence is given by the misfit nature of streams such as the Takhini and Dezadeash Rivers. In contrast, the Yukon and Stewart Rivers are relatively large for their present valleys, suggesting that the valleys have only recently contained large volumes of water.

A similar erosional history of downcutting in late Tertiary/early Quaternary times is found in interior central Alaska (e.g., Péwé, 1975; 1977): the lower Yukon, Tanana Rivers and particularly the Fairbanks area possess terrain and surficial deposits which are similar to those of the central interior Yukon. Like the Klondike region, this

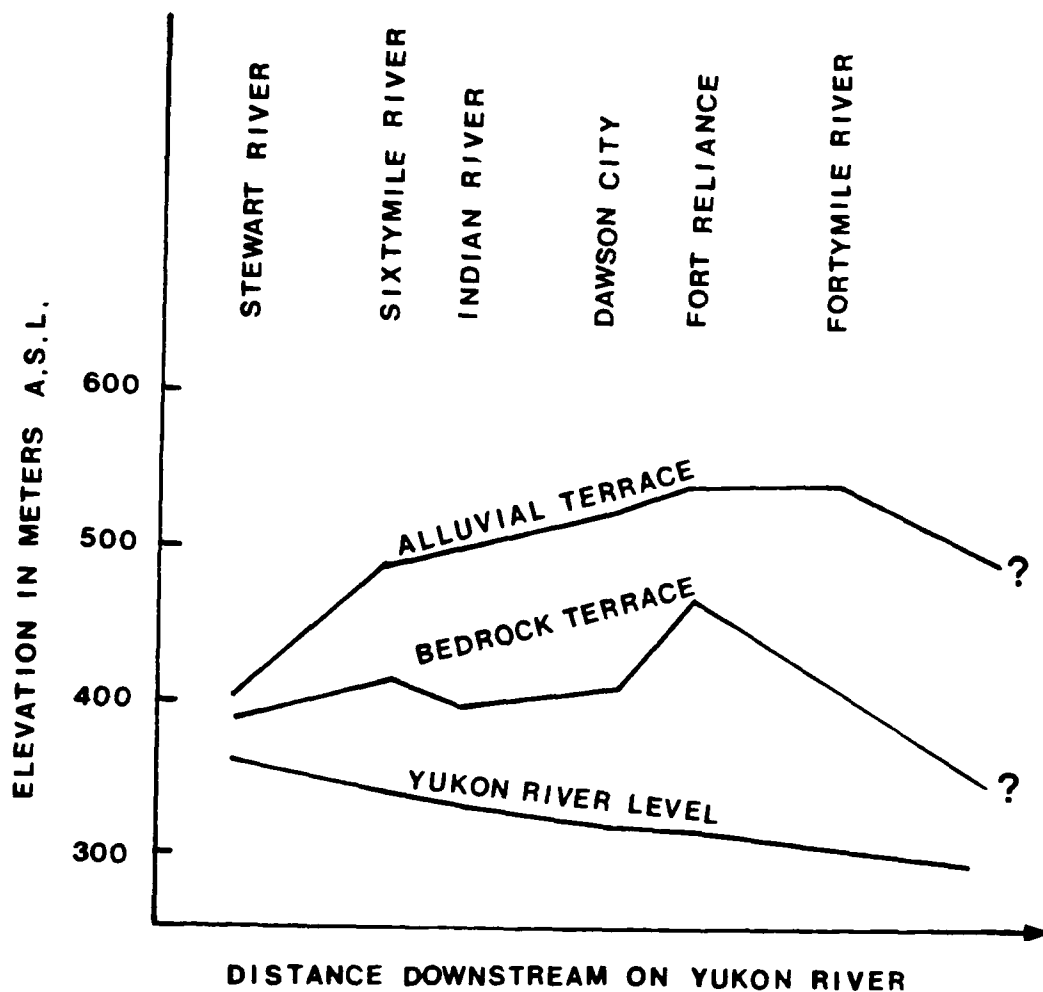


Figure 6. The plotting of elevations of the paleo-surfaces of the bedrock terraces and alluvial surface of the Yukon River relative to the present river surface shows that in the valley now occupied by the Yukon, there may have been two streams which flowed in opposite directions. The jump in elevation in the Dawson-Fort Reliance area is a result of uplift (of the Swede Dome area). Data from Hughes *et al.*, 1972.

area has escaped Quaternary glaciation, and analogous valley cross-profiles and deposits of gold-bearing gravels are found, as shown in figure 7.

1.3 Surficial Geology

1.3.1 Introduction

Surficial geology of the Klondike area has, with the exception of placer mining areas, been overlooked. The only study is by Vernon and Hughes (1966), who map the surficial geology of the Dawson, Nash Creek and Larsen Creek mapsheets. More recently, Hughes, Rampton and Rutter (1972) and Hughes and Van Everdingen (1978) describe aspects of the Quaternary geology and geomorphology of the central Yukon in field excursion guidebooks.

By contrast, the gravels of the region have long attracted attention because of their auriferous nature. McConnell (1903, 1905) was the first to map and classify the gravels of the Klondike region. Gleeson (1970) has since modified the classification:

Valley and Creek Gravels

- i) Gulch Gravels
- ii) Creek Gravels
- iii) River Gravels

Terrace Gravels

- i) Low level
- ii) Intermediate level
- iii) High level

A typical association of valley, creek and terrace gravels is shown in figure 8.

Recent placer mining activity is an asset to the study of these gravels. Previously, the sparcity of sections, particularly where permafrost existed, prevented serious efforts to study surficial materials. Also, as found by Vernon and Hughes (1966), evidence of the older glacial limits is not well preserved, nor is the relationship of periglacial features to these limits well known (e.g., Hughes, 1969).

1.3.2 Quaternary History

Bostock (1966) found evidence of four glaciations. These are termed (from youngest to oldest) the McConnell, Reid, Klaza and Nansen glaciations. On figure 1, the Klaza and Nansen glaciations are mapped as Pre-Reid--the McConnell advance is considered to be of main Wisconsin age, the Reid advance of early Wisconsin or Illinoian age (Hughes, Rampton and Rutter, 1972). Pre-Reid deposits in the form of outwash gravel which interfingers with White Channel Gravel on lower Bonanza Creek may be of earliest Pleistocene age (Hughes and Van Everdingen, 1978), or as early as late Pliocene (McConnell, 1905).

Although the Klondike area remained unglaciated through the Quaternary, the Pre-Reid glaciations probably provided source material for the White Channel and Klondike

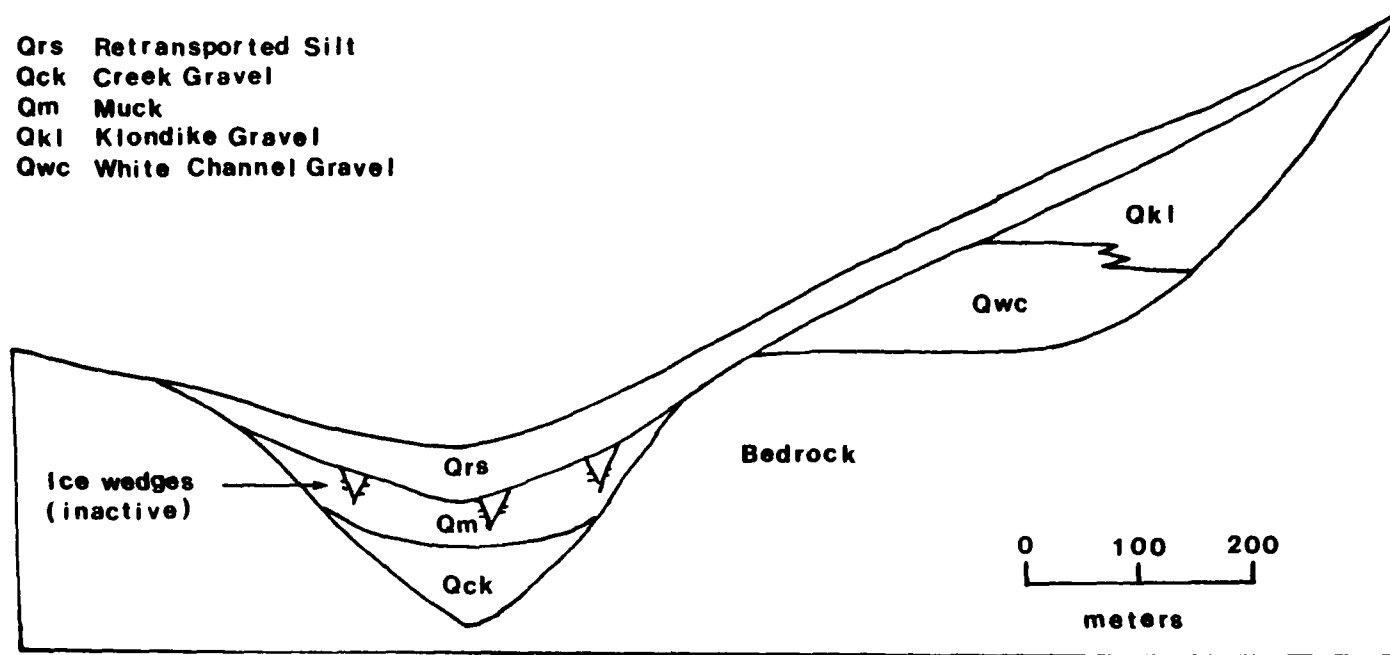


Figure 8. Typical distribution of valley, creek and terrace gravels in the Klondike area. Terrace gravels occupy upper benches, while valley and creek gravels occupy the lower, smaller valleys.

Gravels, and also a source for the wind-blown silt which later became incorporated into the ice-rich muck deposits which cover the valley and creek gravels.

1.3.3 Valley and Creek Gravels

These auriferous gravels are the easiest to mine, since they occur in valley bottoms to depths of 1-3 m, often overlain by several meters of frozen organic silt. The early miners worked these deposits extensively. The muck often contains a wide variety of fossil mammal remains (see section 4.2.4). The faunal richness of the valley bottom deposits is partly due to the fact that the valleys served as a terminus for reworked and soliflucted terrace gravels and colluvium.

It is sometimes useful to distinguish between gulch, creek and river gravels. Gulch gravels occur in the upper portion of main creek valleys and smaller tributary valleys. The gravels contain almost unworn schist from the nearby slopes and appear coarser and more regular than the creek gravels. The latter rest on bedrock of broken schist to a depth of 1-3 m, in places overlain by 1-10 m of muck. These gravels are composed of disc-shaped well rounded schist and subangular to rounded quartz pebbles and boulders. The pebbles are loosely stratified, with a matrix of coarsely bedded red sand. Compared with the creek gravels, the river gravels are harder and better

rounded. They are composed of quartzite, slate, granite, diabase and other rock types.

1.3.4 Terrace Gravels

Terrace gravels were deposited at intervals during the deepening of valleys. Low level gravels are restricted to the Indian River drainage system; intermediate and high level gravels (White Channel Gravel and Klondike Gravel) occur in the Klondike River drainage system. The gravels vary in thickness, and in general are similar in texture and fabric to the creek gravels.

Low level terraces are best developed on Dominion Creek, from near its head to below Larsen Creek, on Quartz Creek to just below Calder Creek and at the mouth of Gold Bottom Creek, where it joins Hunker Creek (Gleeson, 1970). In these areas the creeks have been deepened slightly, leaving bedrock terraces 1-15 m above the present valley bottom. In the lower parts of the creeks, recent creek gravels overlie white gravel similar to the White Channel Gravel.

Intermediate rock terraces occur with irregular distribution along Bonanza and Hunker Creeks and contain reworked upper level gravels.

The high level gravels represent remnants of early deposits laid down in wide, flat bottomed valleys. The basal unit of the high level gravels is the White Channel

Gravel. This is composed of quartz pebbles and rounded to subangular and wedge-shaped quartz boulders. The compact matrix consists of small, clear, little worn quartz and scales of sericite. The colour is characteristically white or light grey because of high quartz content and the leaching of iron. Thicknesses may vary from a few meters to 50 m, and width ranges from 30 m to 1 km or more. The deposit is stratified but does not occur in distinct beds.

Overlying the White Channel Gravel is a sub-facies, the Yellow Gravel. This is more distinctly stratified and has a rusty colour. It is not as widely distributed as the White Channel Gravel, and occurs in channels or pockets.

The highest of the high level gravels is the Klondike Gravel, which overlies the White Channel Gravel. Klondike Gravel is present along the Klondike River, and on stretches of Bonanza and Hunker Creeks and the intervening upland surface. McConnell (1905) and Gleeson (1970) consider these gravels to be fluvial, deposited by the Klondike River when it occupied a much wider, higher level valley than at present. Hughes and Van Everdingen (1978), however, believe the gravels are glaciofluvial in origin.

The Klondike Gravel has a more varied lithology than the White Channel Gravel, consisting of quartzite, slate, chert, granite, diabase and conglomerate in a matrix of grey to brown sand.

1.4 Permafrost Conditions

1.4.1 Extent and Distribution of Permafrost

Although mapped by Brown (1978) as discontinuous permafrost, relatively little is known about the permafrost conditions of the central Yukon. Permafrost conditions vary widely throughout the Yukon, with the central region acting as a transitional zone between the zone of continuous permafrost to the north, and the zones of sporadic, alpine or no permafrost to the south. In addition, the presence of relict permafrost greatly complicates the situation.

Permafrost is thickest under north-facing slopes and often absent from south-facing slopes. Thicknesses are highly variable, depending on the host materials, slope configuration, aspect and vegetation. As a general guide, Brown (1967) and EBA (1977, 1978) report permafrost depths of roughly 60 m in the Dawson area.

Milner (1976) reports thicknesses of 60 m in the White Channel Gravel at Lovett Hill, and 70 m below Eldorado Creek. At Jackson Cut, permafrost was observed in Klondike and White Channel Gravel to a depth of over 85 m.

1.4.2 Relict Permafrost

Since the study area was never glaciated during the Pleistocene, the main valleys experienced repeated infillings by clastic sediments whose amounts and physical

characteristics fluctuated with climatic cycles. Because of the cold climate conditions prevailing at the time, permafrost aggraded into these sediments and massive icy bodies formed, especially ice wedges. In some localities, these ice-rich silty colluviums contain abundant fossil mammal remains which frequently overlie the auriferous gravels of late Tertiary or early Quarternary age.

1.4.3 Permafrost Hydrology

The presence of discontinuous and relict permafrost gives rise to a number of important hydrologic problems and characteristics. Permafrost presents a relatively impermeable barrier which is temperature-dependant. Groundwater flow is restricted to unfrozen zones or taliks. The latter are classified as being supra, sub or intra permafrost in nature (Ferrians et al., 1969; French, 1976, p. 46). Where topographic gradients are encountered, it is possible for substantial exterior or hydrostatic head to develop. Moreover, in placer operations in areas of relict permafrost, the flow of water into the suprapermafrost talik may be responsible for groundwater icings.

In the study area, the unusual nature of groundwater flow is shown by the disrupted drainage in the Dawson City

townsite (see chapter 4), and by the presence of several open system pingos in the Klondike goldfields (see figure 2). The latter are some of several hundred pingos identified in the central Yukon and interior Alaska (e.g., Hughes, 1969; Holmes, Hopkins and Foster, 1968).

1.4.4 Relationship to Surficial Materials and Vegetation

In areas of discontinuous permafrost, there is often a close relationship between permafrost occurrence, surficial materials and vegetation cover. Vegetation influences ground surface temperatures and therefore the presence or absence of permafrost. Aspect is also important in hilly areas since south-facing slopes tend to be warmer, while north-facing slopes tend to be cooler. Thus, relationships between vegetation, surficial materials and permafrost are complex.

Usually, permafrost is present under north-facing slopes, at higher elevations and in valley bottoms where thick organic deposits provide insulating cover. Permafrost is absent from south-facing slopes and well drained areas.

Vegetation usually reflects these differences. In areas of permafrost, Black Spruce (Picea mariana), Tamarack (Larix laricina) and Dwarf Birch (Betula glandulosa), a shrub layer and ground cover of lichen, feather mosses and

sphagnum are found. In areas of little or no permafrost, White Birch (Betula papyrifera), Poplar (Populus sp.) and Alder (Alnus rubra) are present.

In the Dawson area, it is particularly important to note that the present vegetation assemblage is a result of regrowth since gold rush time. During the period 1896-1903, nearly all of the Klondike area was cut for lumber, and while the species distribution was not significantly affected, a stable community has still not developed.

An even more important factor influencing vegetation distribution is fire. Fire causes destruction of trees, thickening of the active layer and produces fire climax vegetation which may have cycles as short as 100-150 years (Zoltai and Pettapiece, 1973, p. 16). The most notable change is from Black Spruce to White Spruce (Picea glauca). On the upland areas, fire climax results in destruction of the trees, and a change to tundra tussock community (e.g., Eagle Plains, Swede Dome etc.). The thickening of the active layer and sudden release of water also causes significant slumping, adding large volumes of material to the valley bottom colluvium, and in turn increasing permafrost thicknesses in the valley floors.

2. Klondike Placer Mining

2.1 Introduction

The Klondike is unique in Arctic North America since virtually every square kilometer has been subjected to disturbance by man following the gold rush. Thus, the study of the surficial deposits of the Klondike cannot be undertaken without a knowledge of the technicalities of the placer operations and a historical perspective. Moreover, the nature of modern placer mining has changed considerably from the early days. This chapter provides some background to the development of placer mining in permafrost and the current methods which have provided the sections studied.

2.2 Early Mining and Exploration Methods

The Klondike gold rush of 1896-1898 represents the first major Canadian attempt to mine in the north. Thus, many techniques were developed to deal with the problems associated with frozen ground.

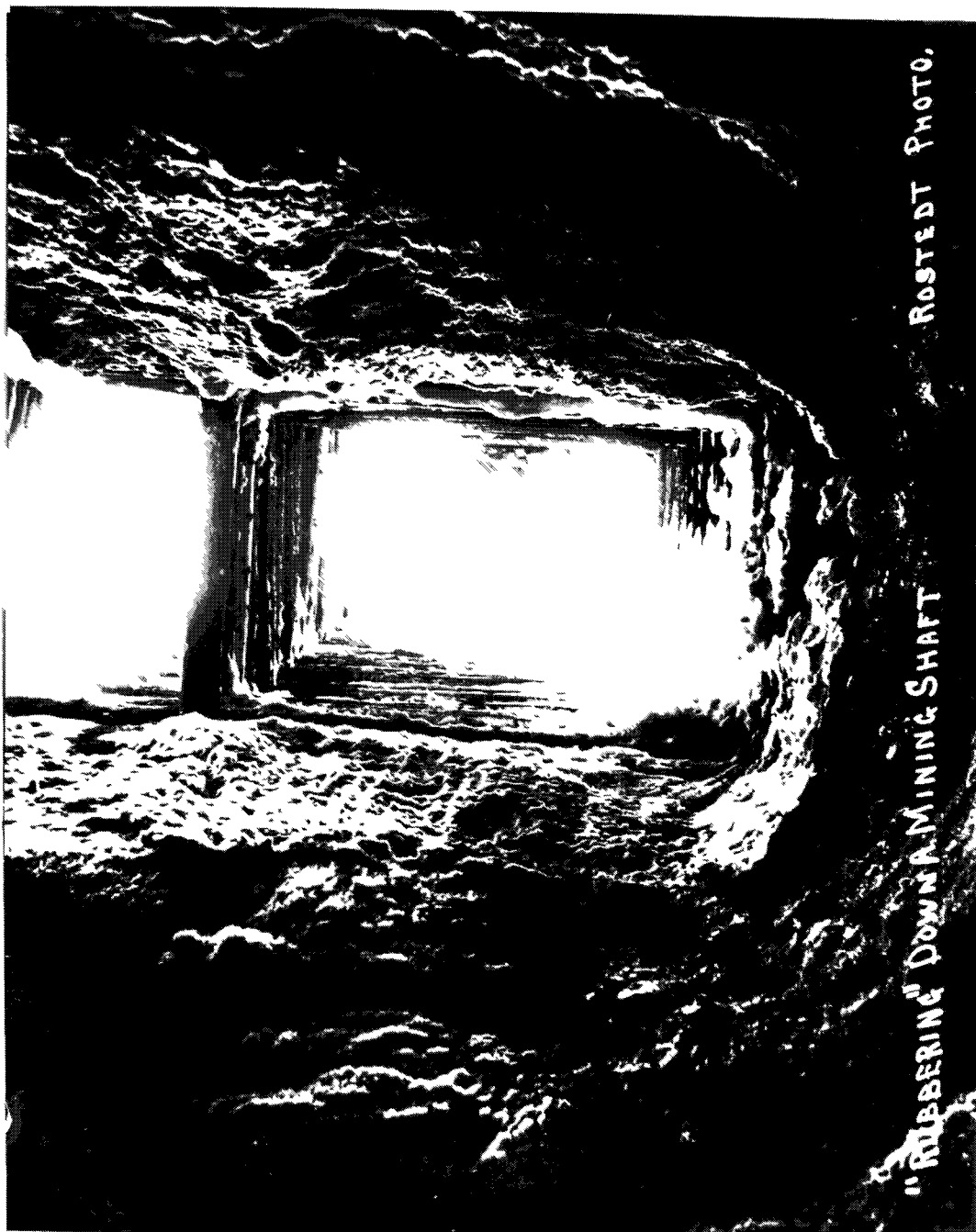
The first mining was conducted on the bars and banks of streams where flowing water kept the gravels unfrozen. At the time, it was considered impossible to reach bedrock where "less frost prevailed" (Ogilvie, 1913). As

exploration continued, prospecting methods were devised to remove the permafrost and dig to bedrock. McConnell and Tyrrell (1898) describe some of the early prospecting methods. Typically, a fire was built on the surface of the earth, thawing the ground. By removing this material, bedrock could then be reached. Perret (1912) calls this method "frost prospecting," and credits the Russians of the Ural Mountains with its development.

The sides of a shaft sunk in this manner (plate 6) usually remained frozen and solid. To obtain greater depths, and during summer, heated stones were thrown down the shaft which was covered with brush to prevent the heat from escaping. The stones would thaw the gravels to a depth of 15-20 cm overnight, and thawed material could then be removed.

One factor which greatly aided the Klondike gold rush was that a great deal of profit could be made with a small investment of manpower and materials. Early mining methods consisted of separation by rocker and sluice box.

Rockers, shown in plate 7, were used for bar and bank deposits, where a pair of men could clear from $1\frac{1}{2}$ to 4 cubic yards of gravel per day. Sluice boxes, shown in plate 8, were used to increase the hydraulic gradient enough to allow stream water to carry away the sand and gravel, and leave the gold behind. This was trapped by riffles,



ROSTEDT PHOTO.

"RUBBERING" DOWN A MINING SHAFT

Plate 6. Frozen prospector's shaft in Klondike, circa 1900.
(Photo courtesy of Yukon Archives, Vancouver
Public Library Collection)



Plate 7. Separation of placer gold from gravel using a rocker. Dominion Creek Claim, 1898. (Photo from Kirk, 1899)

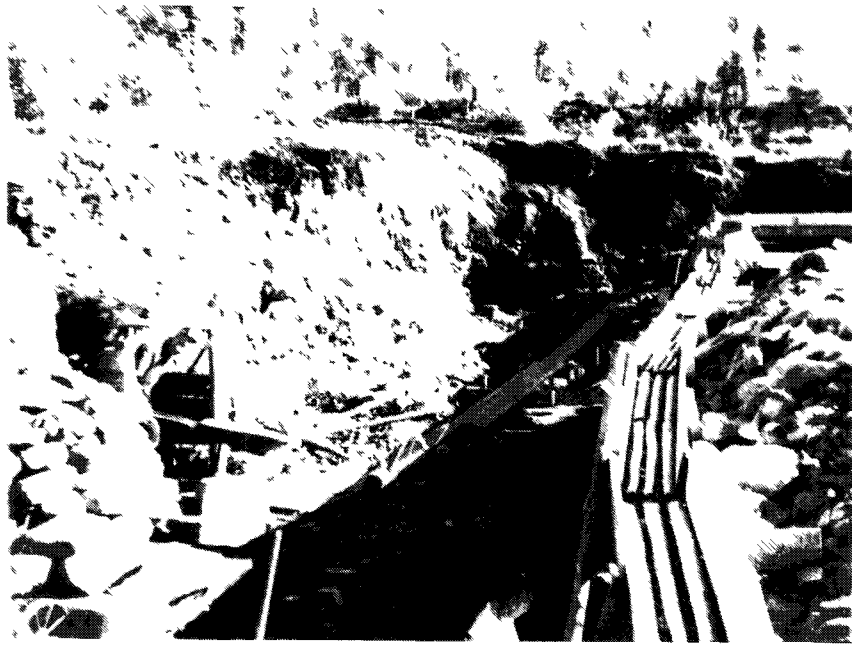


Plate 8. Sluice boxes with longitudinal riffles to trap gold. (G.S.C. photo, H. S. Bostock 88563)

or the finest material by coco-matting stretched across the riffles (Ogilvie, 1913). With a gradient of one in four or five, the sluice boxes could be used to greater advantage than the rockers, and many times the gravel volume could be washed, provided a plentiful water supply was available. Sluice boxes were not useful for mining along the bars and banks of streams, so they were mainly employed at the confluence of streams or in the deep channel areas.

2.3 Development of Thawing Techniques

In order to increase the yield of gold, it became necessary to mine the frozen gravels. Methods similar to those used in prospecting were developed to thaw the frozen ground.

McConnell and Tyrrell (1898) described the most economic method of working the creek claims--by open cut. The frozen muck overlying the gravels was removed by damming up the stream and then diverting it across the claim in several channels. The frozen muck readily thawed and was completely removed within a few weeks. The underlying gravels were then thawed in a similar manner and then shoveled into sluice boxes. McConnell and Tyrrell suggested that if the gravel were removed as it thawed, the rate of thaw could proceed at 5-10 cm per day. This method is known as "natural thawing."

While natural thawing was used on many large operations, smaller claims used fires to thaw gravel on river bars. Firing the bars in spring during the period of lowest water made the richest deposits available. However, Ogilvie (1913) pointed out several inefficiencies of this method. Since the fires were unconfined, the method was often wasteful of fuel. Fires often thawed more ground than held pay, greatly reducing the yield. Pay streaks were often not more than 1 m deep, while thawing could penetrate up to 3 m. The main advantage was that the method could be made inexpensive. Miners could cut timber during the winter and begin burning early the following spring. As a result of intense mining activity, many small creeks were almost completely deforested before 1900 (Ogilvie, 1913).

During the winter of 1897, many discussions were held to improve the methods of firing. Two suggestions evolved: (1) thawing by steam and (2) thawing by coal oil or gasoline fires. Of the two, steam was considered to be more cost effective. In addition, compared to steam thaw, gas operations were slow and localized in their effect.

C. J. Berry discovered the efficiency of steam thawing in 1898 in Alaska (Min. Sci. Press, 1922). While using a steam driven churn drill, he noted that steam escaping from the exhaust had thawed a hole in the frozen mud. This gave him the idea of applying steam through a pipe to the

ground, thus inventing the steam thawing point. From 1898 to 1916, steam points were used widely, with great success. Purington (1905, p. 90) highly recommended their use:

The direct application of jets of dry steam to the gravel bank through the agency of driven pipes has been found to be the most efficient method in general practice for thawing of frozen gravel.

This remained the general opinion of steam thawing until 1916. That year, J. H. Miles conducted several experiments while working for the Alaska Mines Corporation at Nome, Alaska. A section thought to offer the greatest resistance to thaw was chosen. This was a sequence of fine gravel, clay, quicksand and muck, as shown by figure 9. This combination is difficult to thaw with steam because of its compact (fine grained) nature. Clays baked around the points in previous attempts, preventing heat from escaping from the pipes.

The first experiment (A) used superheated steam, and was most unsatisfactory. The ground around the pipe began to sink and formed a pool of hot water. Little heat reached the depths below, as the water acted as a heat sink. As a result, the thawed area formed in the shape of an inverted cone. The second experiment (B) used saturated steam. This proved to be very similar to the supersaturated steam tests, with thaw cones slightly narrower and deeper. The third test (C) used hot water. This was more efficient at thawing

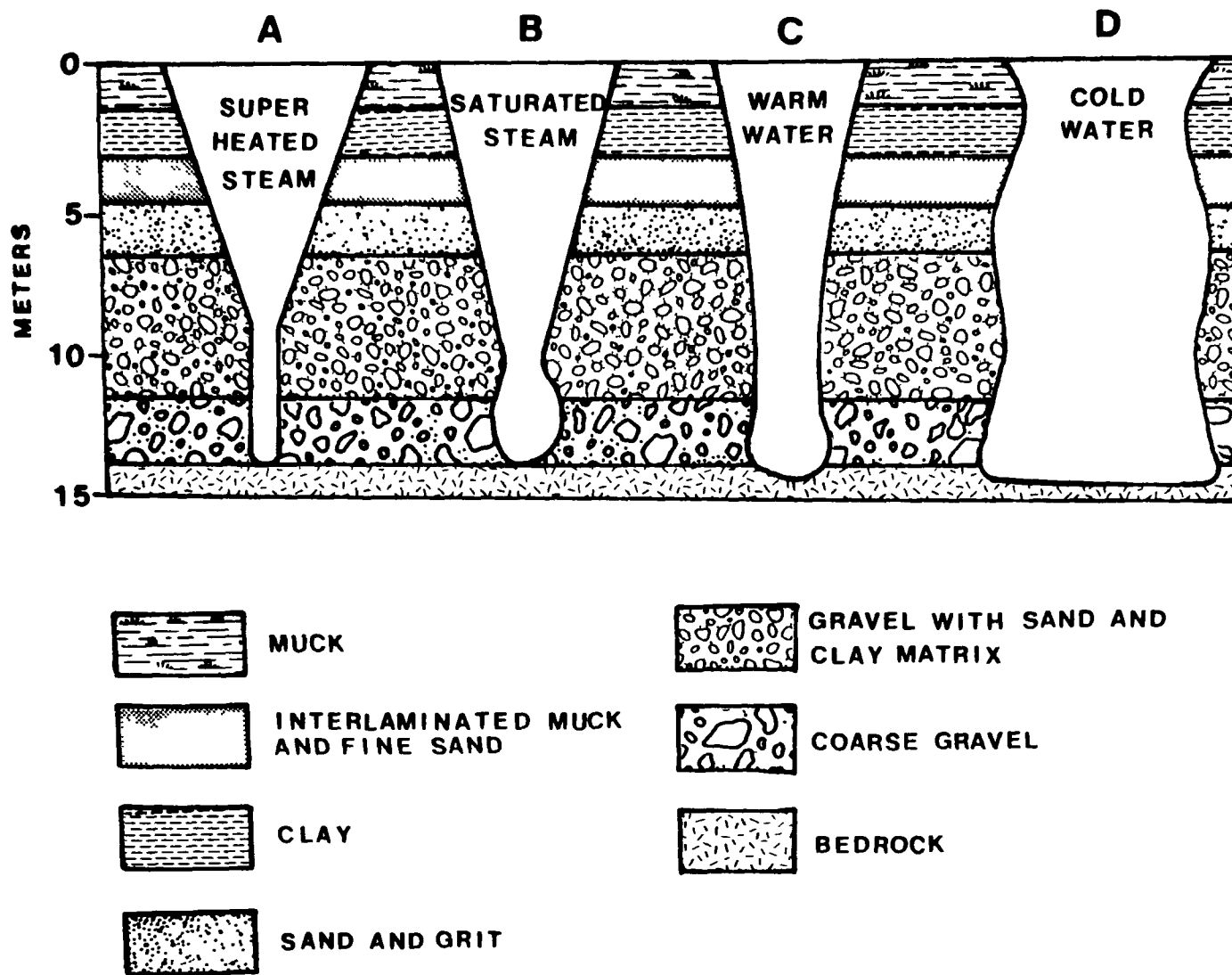


Figure 9. Thaw bulbs in placer gravels. (After Weeks, 1920)

ground, producing a nearly vertical thawed zone. Unfortunately, as in the first test, much heat was lost at the surface. The final experiment (D) used cool surface water. Here, the walls of the thawed zone were nearly vertical, and a much larger area thawed.

Subsequent studies have shown that maximum efficiency is achieved when the volume of water is just high enough to keep the temperature of the outgoing water slightly above freezing. For example, Weeks (1920) calculated the efficiency of Miles' thawing methods, and showed that the efficiency of cold water thawing was 57%, hot water 12%, saturated steam 6% and superheated steam 4%. Weeks strongly recommended the use of cold water thawing for greatest efficiency and cost effectiveness.

2.4 Modern Mining Methods

2.4.1 Dredging

Associated with steam and cold water thawing in river channels were various dredging operations (plate 8). Dredging in the Klondike lasted for a long period, from 1898 to 1966.

The first dredge to be used in the Yukon was built by the Lewes River Mining and Dredge Company, for use on the Cassiar bar of the Lewes River. The dredge was subsequently moved to claim 42 below Discovery on Bonanza Creek. There, the gravels were not frozen to bedrock

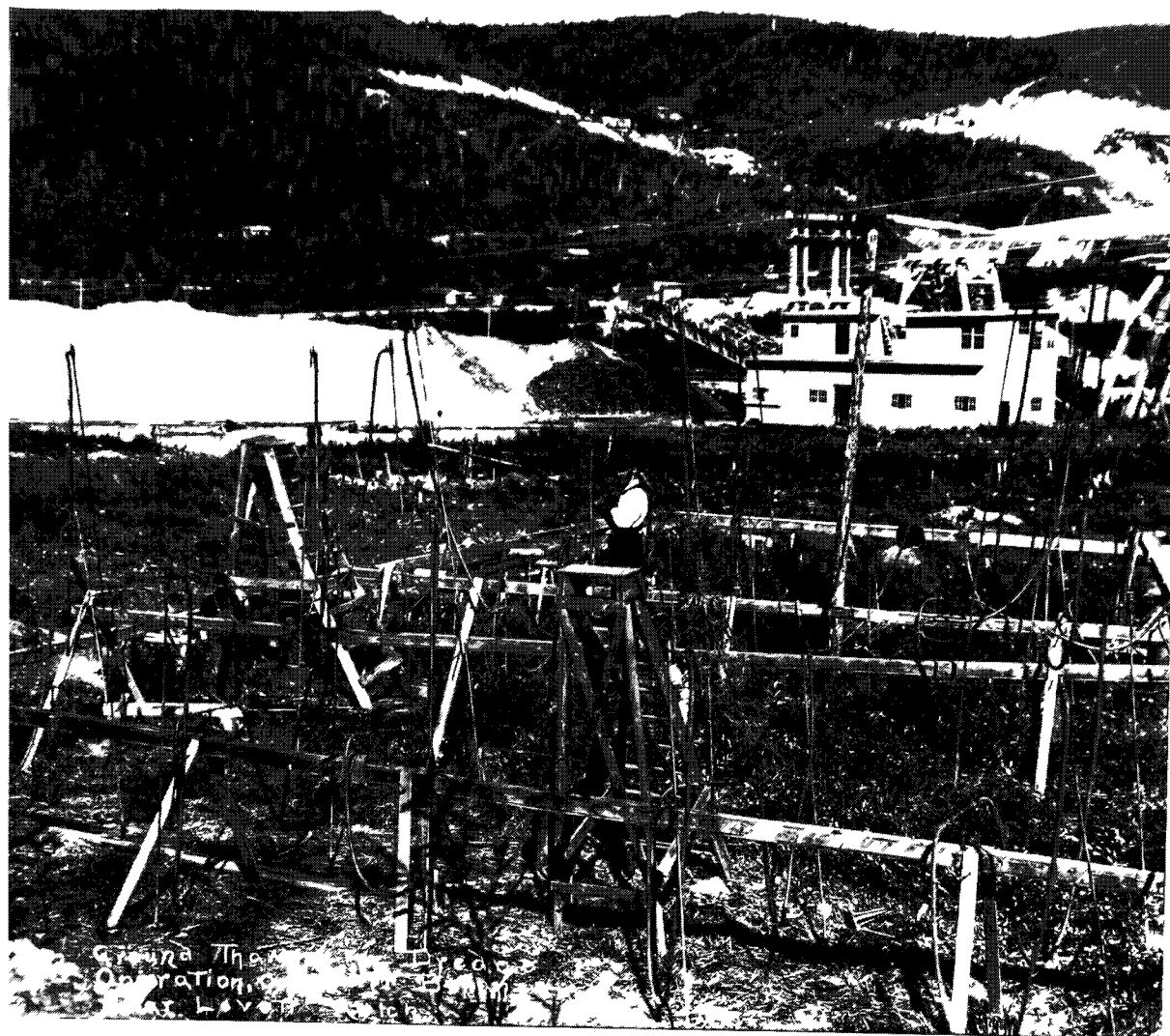


Plate 9. Ground Thawing for Dredge Operation on Lower Bonanza Creek near Lovett Gulch. (Photo courtesy of Yukon Archives, E. Telfer Collection)

and up to 5,000 cubic yards of gravel per day could be extracted, more than 1,000 times the volume that an early miner could extract with a rocker.

By 1915, many dredges were in operation, with varying results. Rickard (1908) describes 65 dredges built and operated in the Yukon and Alaska. Of the dredges described, 35 were described as "things to avoid" because they were mechanical eccentricities; of the 30 remaining, 18 failed because of faulty construction, frozen ground or lack of gold. Thus, out of 65 dredges, only 12 could be considered a success on either financial or technical grounds.

With the formation of the Yukon Consolidated Gold Corporation in the early 1930's, dredging increased to large scale operations as described by McFarland (1939). Dredging continued almost unchanged until ceasing completely in 1966.

Since then, two methods have dominated: hydraulicing and bulldozer (cat) mining. Cat mining is usually conducted in the low level terrace and creek gravels and hydraulicing in the high level terrace gravels.

2.4.2 Hydraulic Mining

Hydraulic mining is virtually unchanged from the method used in California 125 years ago. Several problems occurred in the early Klondike operations. Lack of water often restricted workings to low level gravels in preference to high level gravels. Similarly, lack of head confined

mining to the low terrace and river or creek gravels. The solution to this water supply problem in the Klondike was the "Yukon ditch," a wooden aqueduct system which provided the needed water to early placer mining operations.

Modern hydraulic operations, however, are easier with ample power to build hydraulic head. Water is supplied to high pressure monitors by diesel pump or gravity. The stream of water from the monitor is then used to dislodge gravel and to wash it into sluices (plate 10). Thus, bench and terrace gravels previously unworked may be mined.

Although the auriferous White Channel Gravels are almost always frozen, their low moisture content (dry permafrost) means that permafrost is not a hindrance to mining. At low elevations, water may be used to remove the top layer of muck, aided by natural thawing and further hydraulicing to expose the gravels beneath.

A typical operation is that of Miben Mining (1975) Ltd. of Dago Hill. Water is supplied to the monitors from nearby Hunker Creek through diesel pumps. Water and tailings are discharged over the edge of the terrace, upstream of the pumping station, allowing recycling of the water. As the mining progresses, it becomes more difficult to maintain grade and the present operators have initiated a mechanical operation whereby cats push gravel into a shaker and tailings are removed by trommel. In a similar operation at Jackson

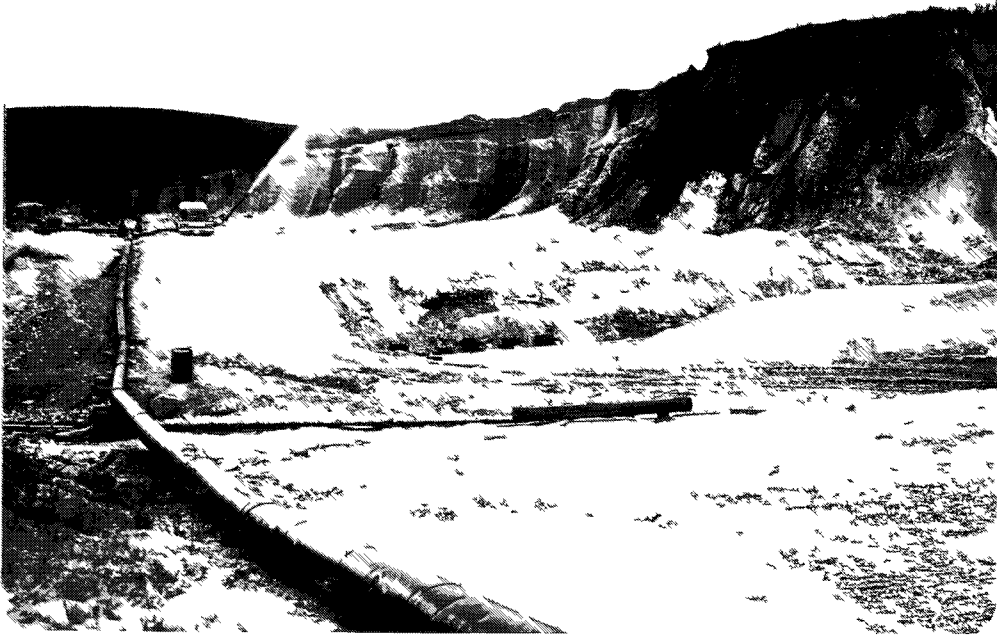


Plate 10. Modern hydraulic mining operations at Dago Hill, Hunker Creek (H. M. French).

Cut, Arctic Rim Operators Ltd. wash gravels into a holding area, where they are pushed into a shaker/slucice system, shown in plate 11.

2.4.3 Cat Mining

Bulldozer (cat) operations are currently being used by many small operations in the Dawson area. The technique is similar to that described by Schmidt (1961). Areas are stripped of muck by simple hydraulizing or natural thawing using water or natural thawing using water from the nearby stream. Gravel is then moved by cat into sluice boxes set up on inclined earth ramps (plate 12). Water is then pumped into the sluice boxes and the gravel washed.

2.5 Distribution of Placer Gold

The richest placer deposits are usually the result of the interaction of source rocks, geomorphic history and bedrock control. This appears to be the case in the Klondike, although the location of the source rock can only be speculative. Multi-cycle valley cutting in the Klondike has led to a complex history of placer development whereby gold from the upper and intermediate level terrace elevations is concentrated in the creek gravels. These have been most productive in the past (Gleeson, 1970) and are still good producers as shown at Gold Bottom and lower Hunker Creek locations. Current levels of Klondike placer activity are shown in table 3, which lists placer gold production



Plate 11. Mechanical operations at Jackson Cut. Gravel is pushed into a shaker (top) which removes the coarsest gravel and passes fines on to sluice boxes (bottom left). Tailings are carried away by trommel (front) to disposal area.



Plate 12. Cat mining operations on Hunker Creek. The cat guides gravel towards sluice box where it is washed.

Table 3
 Klondike Placer Gold Production 1898-1968
 (Gold Values in Ounces, data from
 Canadian Mining Statistics,
 Statistics Canada)

Year	Ounces	Year	Ounces	Year	Ounces
-	-	1921	65,994	1946	45,283
-	-	1922	54,456	1947	47,679
1898	483,750	1923	60,144	1948	60,606
1899	774,000	1924	34,825	1949	81,970
1900	1,077,553	1925	47,817	1950	93,339
1901	870,750	1926	25,601	1951	77,504
1902	701,437	1927	30,935	1952	78,519
1903	592,594	1928	34,364	1953	66,080
1904	507,938	1929	35,892	1954	82,208
1905	381,001	1930	35,517	1955	72,201
1906	270,900	1931	44,310	1956	71,736
1907	152,381	1932	40,608	1957	73,709
1908	174,150	1933	39,493	1958	67,745
1909	191,565	1934	38,798	1959	66,960
1910	211,091	1935	35,707	1960	78,115
1911	224,197	1936	50,358	1961	66,107
1912	268,447	1937	47,982	1962	54,805
1913	282,838	1938	72,368	1963	54,184
1914	247,940	1939	87,745	1964	56,712
1915	230,173	1940	80,458	1965	43,292
1916	212,700	1941	70,959	1966	41,983
1917	177,667	1942	83,246	1967	8,586
1918	102,474	1943	41,160	1968	8,897
1919	90,705	1944	23,818		
1920	72,778	1945	31,721		

from gold rush times to the present.

All alluvial placers are formed by either mechanical traps or hydraulic concentration. Traps are formed by bedrock irregularities and coarse gravel found in scouring stream beds. Bedrock structures on river bottoms are important to the development of both primary and secondary pay streaks (Milner, 1976). Ribbed bedrock formed by alternating hard and soft beds, if perpendicular to the flow direction, will act as natural riffles. Similarly, well developed joints or broken bedrock will also trap gold. This is borne out by the highest gold values being found near bedrock, as shown at Gold Bottom.

White Channel Gravel gold values are the result of two factors: initially high erosion which caused trapping of large gold particles on the bedrock channel floor, and subsequent deposition of large clasts which provided natural riffles to trap gold. In contrast, the Klondike Gravel is considered nearly barren, and is mined only when found overlying more economic deposits. In the past, these gravels have been mined on a bench on the south side of the Klondike River at its mouth (Lousetown Bench?) and on the north bank opposite Bonanza Creek. More recently, a low bench of Klondike Gravel has been mined on the south bank of the Klondike River near Germaine Creek (Gleeson, 1970). The lower gold values of the Klondike Gravel are due to two factors. First,

much of the gold had already been deposited in the White Channel Gravel, and second, natural riffles such as bedrock irregularities or coarse bedload in the stream channel had been covered by the White Channel Gravel.

3. Nature and Depositional Environment of Gravels

3.1 Introduction

This chapter gives a systematic description of the geomorphology and sedimentology of the placer gravels of the Klondike. Standard descriptive geological techniques are used to document the stratigraphy, structure, fabric and facies of the gravel units, and their morphology. Such a description has not been attempted before, and may assist in the interpretation of the depositional environment(s) of the gravels, which has long puzzled geologists and placer miners.

3.2 White Channel Gravel

3.2.1 Stratigraphic Position

The stratigraphic position of the White Channel Gravel and its equivalents is relatively well known, but the depositional history is less certain. The gravels are believed to have been deposited during a stillstand in the initial uplift of the Klondike Plateau, and are deposited along well defined terraces of the lower Stewart River and adjacent parts of the Yukon River (see section 1.2). Temporally, the gravels are bracketed between the last

movement of the Tintina Trench (late Tertiary) and deposition of the Klondike Gravel which interfingers and overlies the White Channel Gravel (early Pleistocene).

McConnell (1905) and Bostock (1964) consider the White Channel Gravel to be of Pliocene age. In the study area, the gravels overlie (unconformably?) bedrock of Tertiary age. Between the Klondike and McQuestor Rivers, the Eocene sediments of the Tintina Trench are overlain (unconformably?) by gravel mapped as the Flat Creek beds by McConnell (1905). Bostock (1966) correlated these as being equivalent to the White Channel Gravel. This is overlain by the Klondike Gravel which is contemporaneous or slightly younger than the White Channel Gravel.

3.2.2 Physical Characteristics

The White Channel Gravel consists of a nearly monomineralic assemblage of quartz, quartzite and chert with other minor components. Unlike the creek gravels, or the overlying Klondike Gravel, clast size varies greatly (plate 13). A very fine matrix of quartz silt and clay makes the gravel very cohesive. In contrast, large boulders are found in the lower parts of the sections near bedrock, where clast size approaches 1 m, as shown in plate 14. The clasts are very friable, and physical disintegration of the clasts, apparently through abrasion, is a major factor in the supply of fines to the gravel. This reflects



Plate 13. Dago Hill section DH1 showing cobbles in fine matrix of the White Channel Gravel. Although usually polymictic, this section reveals highly diamictic gravel with cobble sized clasts supported in a matrix of silt.



Plate 14. Boulders recovered from the basal section of White Channel Gravel at Dago Hill (DH2). Although smaller clasts are very worn, the largest boulders show little signs of abrasion, possibly reflecting rapid transport and deposition. (The axe is 44 cm long.)

the highly weathered nature of the gravel and contrasts with the relatively unweathered state of the overlying Klondike Gravel.

3.2.3 Facies, Structures and Fabric

White Channel gravels are generally structureless, with indistinct bedding and more distinguishable bedding in the fines. As shown in figure 10, the most common facies is massive, poorly bedded gravel (Gm). Also present are minor amounts of horizontally laminated sands (Sh), and sand with low angle cross stratification (Sl). In rare cases, broad shallow scours are visible within the fines (Ss). A section showing some of these facies is illustrated in plates 15 and 16. These fines show a strong resemblance to those creek gravels found at Gold Bottom (see section 3.5.3), and may reflect a low flow stage of deposition. The fine facies form only a fraction of the White Channel gravels, as shown schematically in figure 11.

An unusual structure in the White Channel Gravel is the apparent occurrence of ice wedge casts (Hughes, personal communication, 1980). These casts apparently occur in the central part of the section and are roughly 1-2 m long and up to 1.5 m wide. They were not observed during the 1980 field season, but if they are indeed ice wedge casts, they point to the occurrence of permafrost in the early Pleistocene in this part of the Yukon.

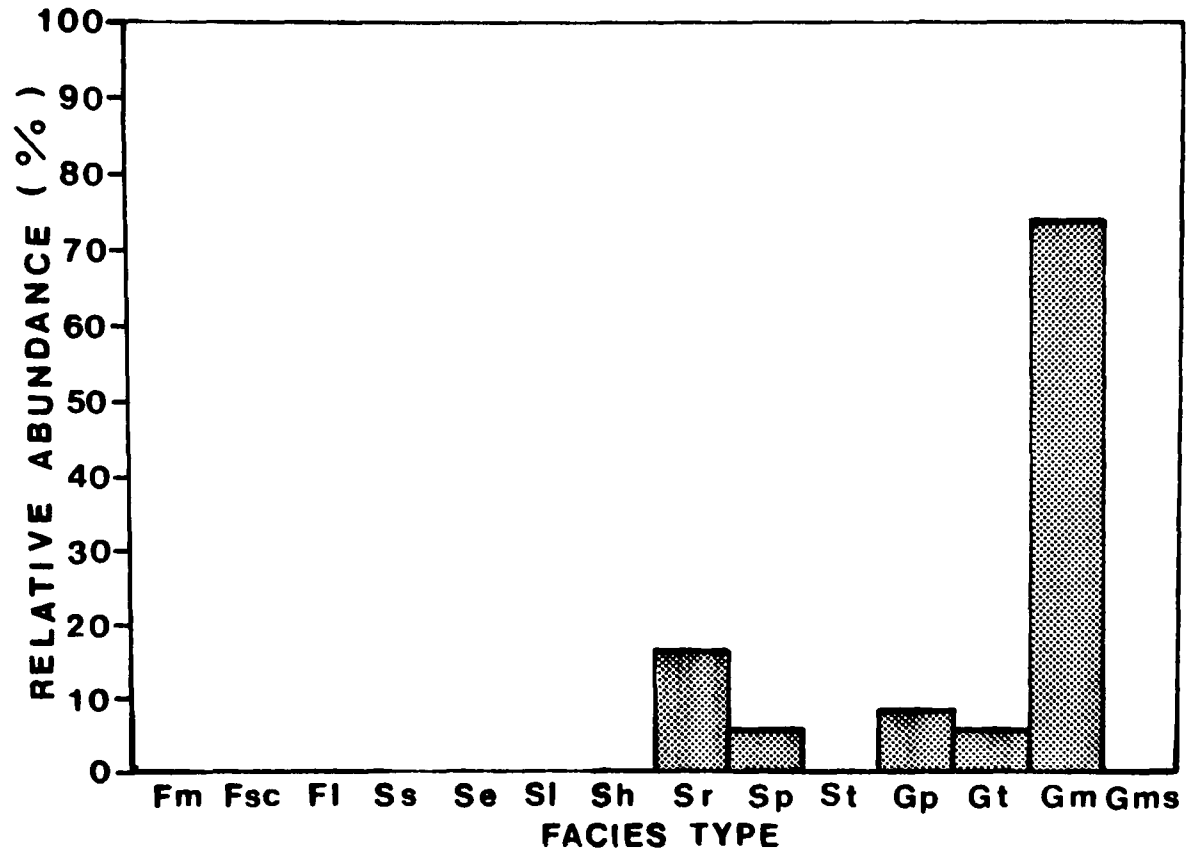


Figure 10. Relative abundance of facies types in the White Channel Gravel. Facies after Miall (1978) and Rust (1978).

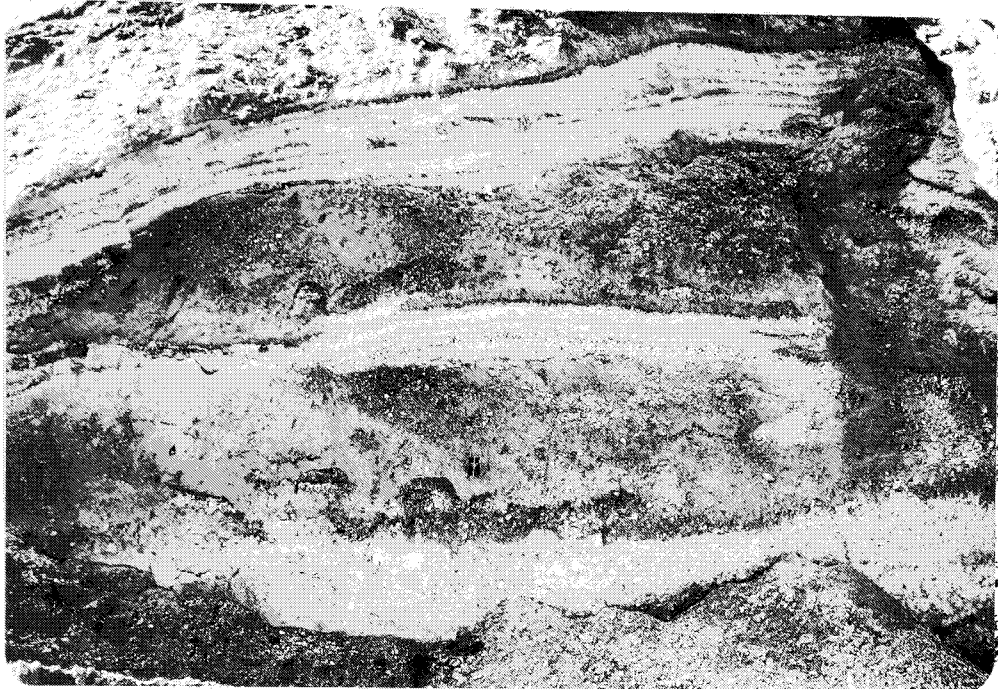


Plate 15. Fine facies at base of White Channel Gravel at Jackson Gulch, 10 m above bedrock. (Notebook is 15 cm long.)



Plate 16. Detailed view of fining upward sequence shown in central portion of figure above.

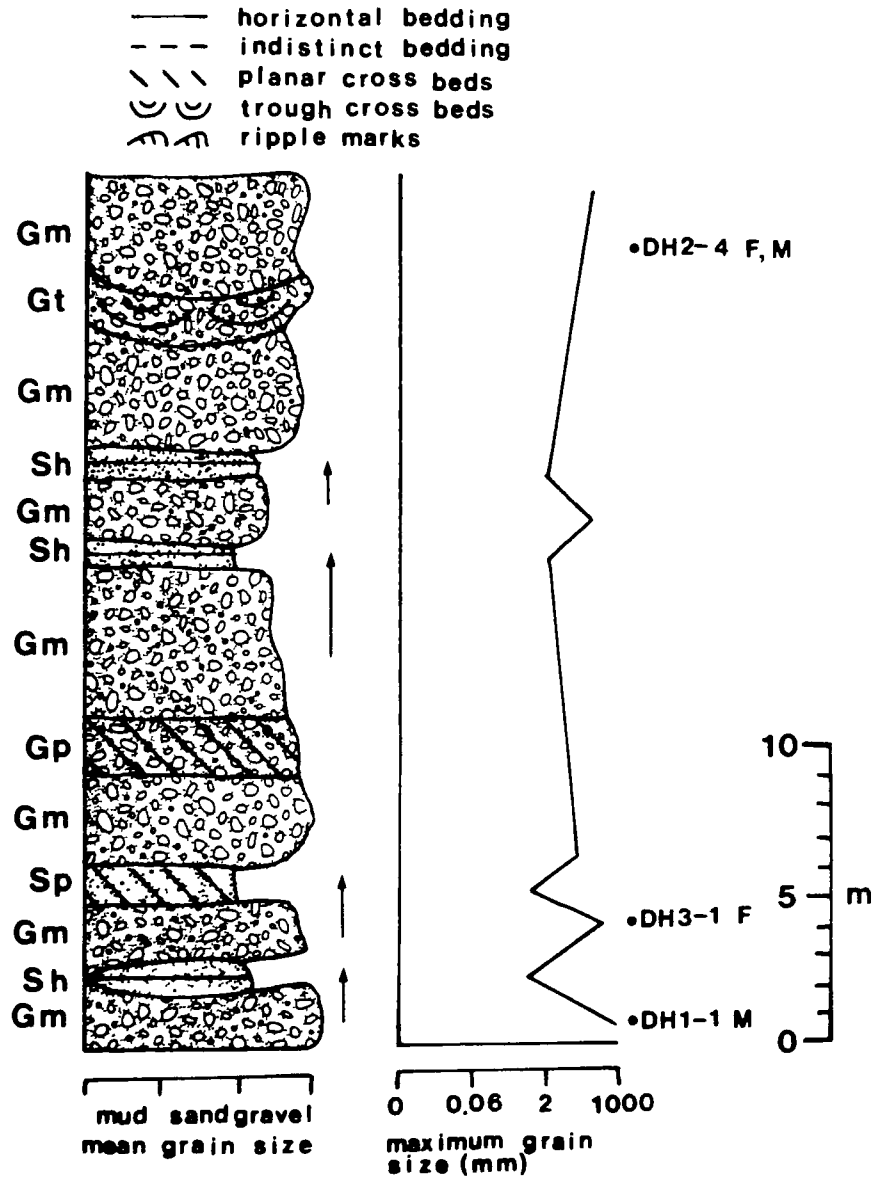


Figure 11. Vertical facies model for White Channel Gravel. Arrows indicate small scale fining upward sequences. Facies codes according to Miall (1978); sample points: F, fabric; M, morphology. Structures as in legend, where no structures are shown, beds are massive.

Several large thrust bedrock slabs have been observed in the basal section of the White Channel Gravel (see section 1.3). These may result from post-tectonic shifting to adjust to movement along the transcurrent fault forming the Tintina Trench, or may result from frost thrusting or downslope movement of exfoliated slabs.

The gravels have a high degree of clast/clast contact, giving rise to a preferred orientation of the AB plane of discoidal-shaped pebbles. Hence, fabric measurements indicate the orientation of the AB plane in space, and show imbrication where it exists. All fabric measurements were made within what appear to be uniform sedimentary beds, using the minimum outcrop area required to give a satisfactory number of measurements. Generally, the required area was confined to a zone roughly 60 cm by 120 cm in size.

Fabric studies (figure 12) show a fairly high degree of imbrication, which should be expected in the proximal reaches of a braided stream. This is characteristic of outwash areas, as demonstrated by Rust (1972a, 1972b, 1975) and Williams and Rust (1969).

3.3 Yellow Gravel Subfacies

3.3.1 Relationship to the White Channel Gravels

Yellow Gravels were first recognized by McConnell (1903), who divided the White Channel Gravel into two

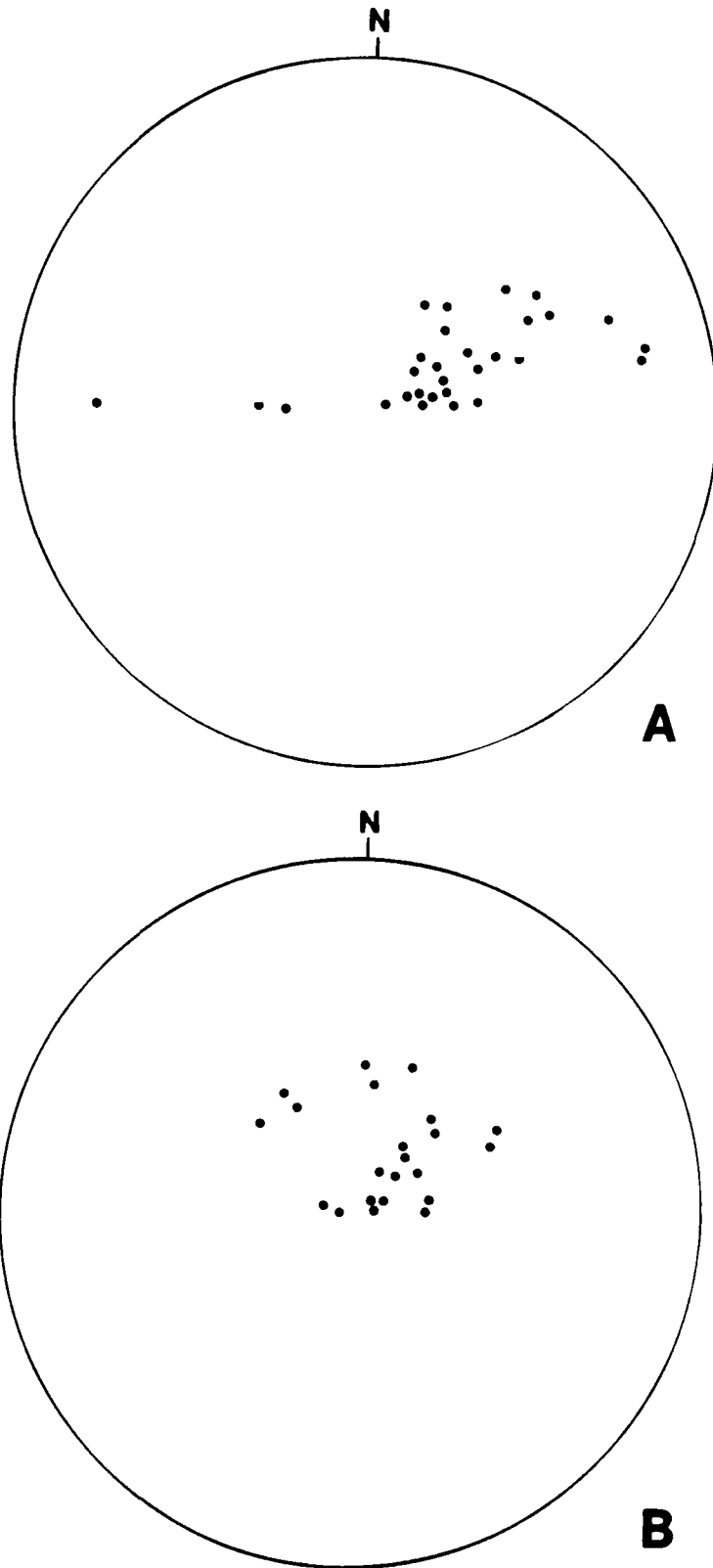


Figure 12. Fabric of White Channel Gravel at the base (A) and middle (B) of measured sections DH3-1 and DH2-4. Fabric plotted as poles to the AB plane of blade- and disc-shaped clasts.

subgroups, one of which was the Yellow Gravel. McConnell described the gravels as loosely stratified flat schist pebbles lying in a coarse sandy matrix. Quartz pebbles and boulders are also present, but not in the abundance of the White Channel (White) Gravel.

Yellow gravels were exposed at Dago Hill when Miben Mining (1975) monitor attack produced a prominent horizontal bench in the upper portion of the White Channel gravels, shown in plate 17. The less cohesive, stained upper gravels and the more cohesive lower gravels are both frozen, and have no sharp contact. Elsewhere, on Lovett Hill, the contact is gradational except for the degree of cohesion. Green (1966, p. 93) notes a similar difference in resistance at Cripple Hill, where Yellow Gravel lies 17-24 m above bedrock.

3.3.2 Physical Characteristics

The Yellow Gravel appears to have a higher concentration of fines than the White Channel Gravel, not reflecting a higher percentage of fines, but a segregation of fines into restricted beds. Clast size is generally finer than that of the underlying gravels. This may indicate a waning of currents, and combined with the iron staining, suggests periodic subaerial or shallow water exposure. An alternate hypothesis is that these gravels represent a warm period where groundwater percolation was possible through the gravels, thus resulting in their stained appearance.

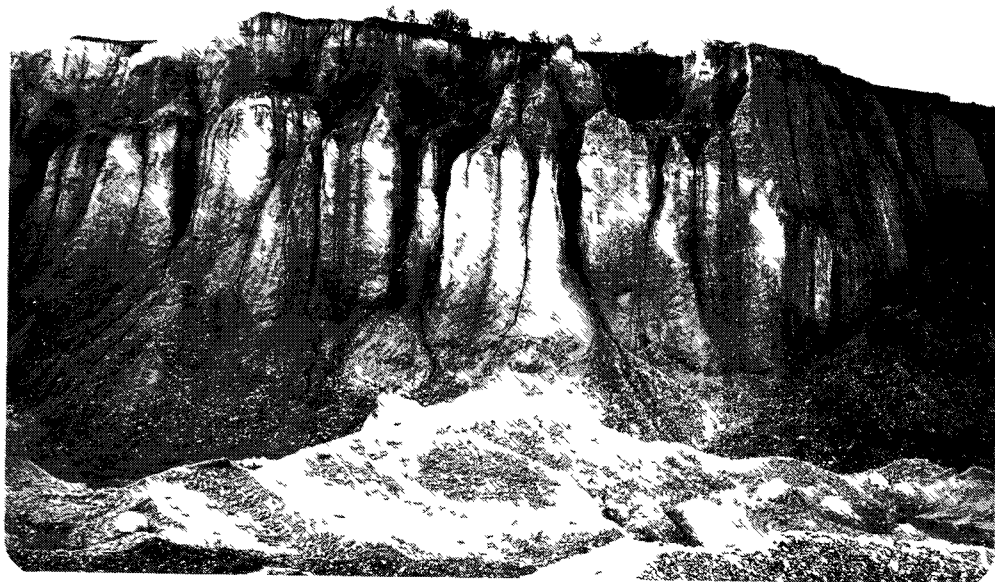


Plate 17. Contact between Yellow Gravels and White Channel Gravels at Dago Hill. Less resistant Yellow Gravels are eroded, leaving more resistant White Channel Gravels below.

The coarser underlying gravel clasts are identical in nature to the White Channel Gravel clasts.

3.3.3 Facies, Structures and Fabric

The Yellow Gravel consists of interbedded sand, silt and gravel structures which form high-angle cross stratification (plate 18). Within the sands and silts, planar cross-bedding (Sp) is evident. Gravel (Gm) is more clast-supported than the underlying polymictic gravel (Gm), and is well sorted. As shown in figure 13, there is an increase in finer grained facies within the Yellow Gravel, suggesting a shift from the proximal reaches of the White Channel Gravel to a slightly more distal portion of an outwash stream, but still within a proximal environment.

In contrast to the well imbricated fabric of the White Channel Gravel, the Yellow Gravel shows a less ordered fabric (figure 14). The lack of imbrication is likely due to the waning current being unable to induce a structured orientation of clasts. Although the gravels are high in the section, it is doubtful that this random fabric is due to the introduction of solifluction material, since no structures of this type are found in the Yellow Gravel.



Plate 18. Interbedded sand, gravel and silt in the Yellow Gravel exposed at Dago Hill. Note the crossbedded fines (Sp, St), interbedded with gravel (Gm).

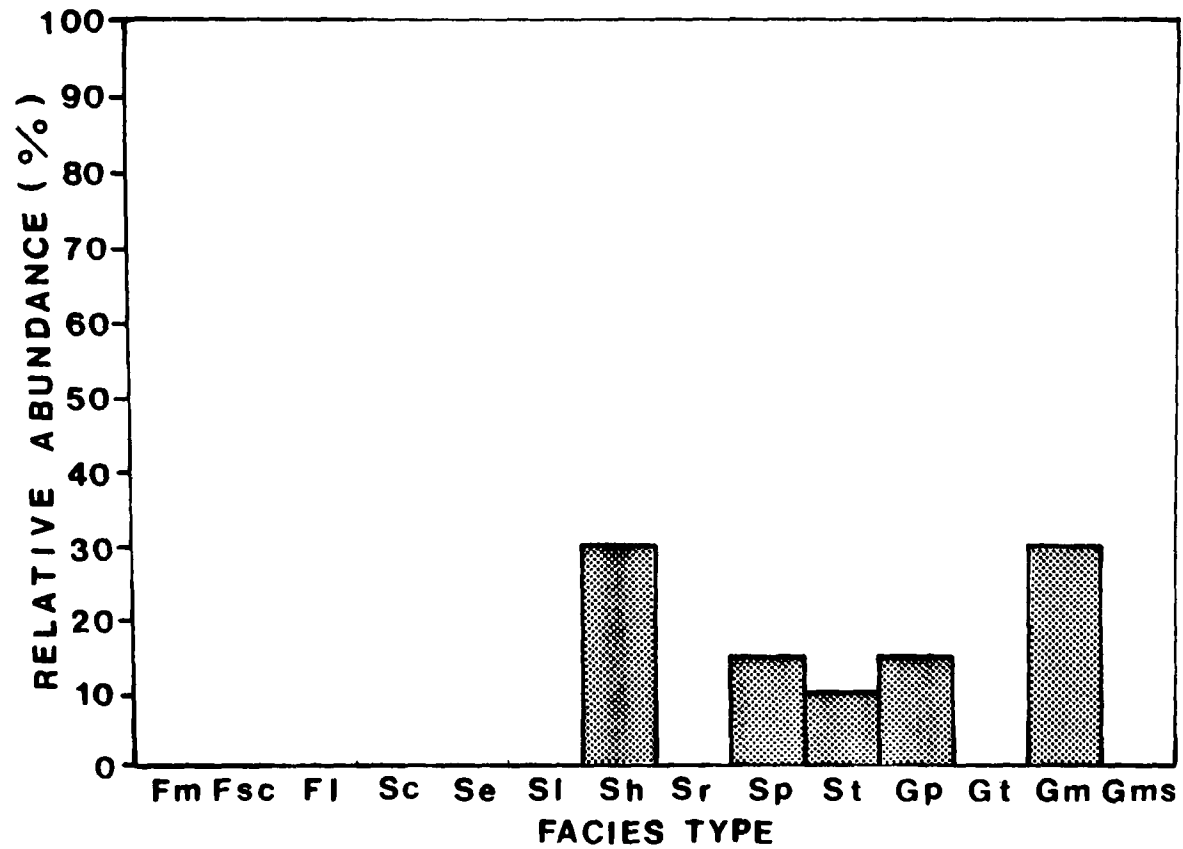


Figure 13. Relative abundance of facies in Yellow Gravel.

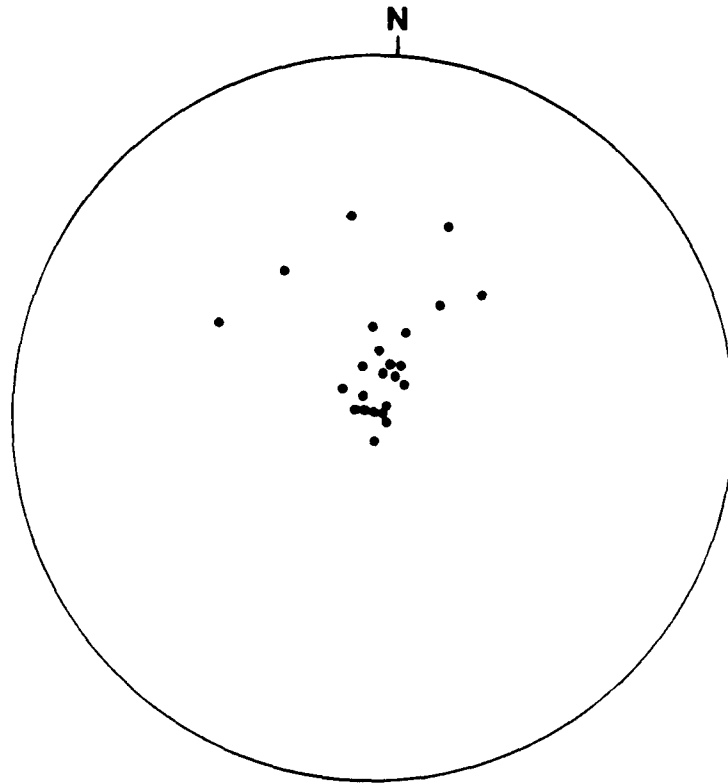


Figure 14. Fabric of Yellow Gravel measured at sample point DH2-5d. Fabric plotted as poles to the AB plane of blade- and disc-shaped clasts.

3.4 Klondike Gravel

3.4.1 Stratigraphic and Geomorphic Setting

The Klondike Gravel overlies the White Channel Gravel, and is the highest of the high level terrace gravels (chapter 1.3.4). In the study area, the Jackson Cut site (figure 4) is the only locality where the Klondike Gravel is exposed. Barometer measurements show a thickness of 48 m overlying the White Channel Gravel.

As shown in chapter 1.1.4, the Klondike Gravel thins out along Hunker Creek, and is interbedded with the underlying White Channel Gravel at Trail Hill, suggesting that Klondike Gravel deposition may have been contemporaneous with that of the White Channel Gravel (Hughes, Rampton and Rutter, 1972).

3.4.2 Physical Description

Unlike the White Channel Gravel, the Klondike Gravel is a heterogeneous mixture of lithologies forming a clast-supported gravel with a lower proportion of fines in the matrix. Typical sections (plate 19) show clast supported gravel and beds of sand and silt.

3.4.3 Facies, Structures and Fabric

During the summer of 1980, several sections of the Klondike Gravel were measured to assemble a composite section. Because of the vertical nature of the gravel

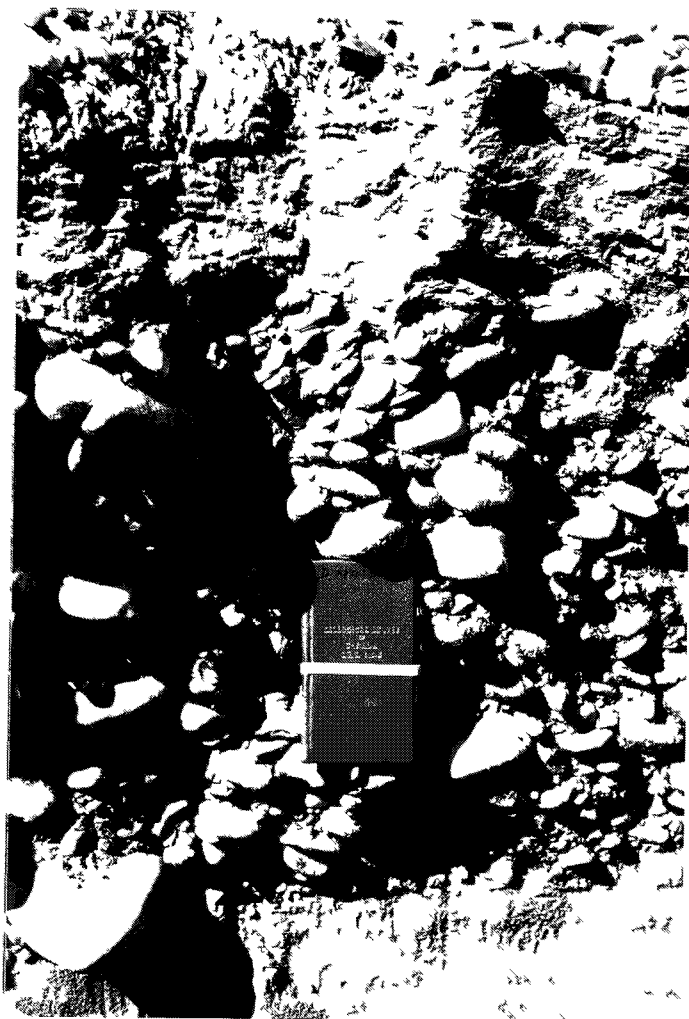


Plate 19. Coarse clast supported gravel (Gm) from Klondike Gravel member A. (Notebook is 17 cm long.)

facies and the intervals of talus cover, access was limited but 40% coverage was attained.

For descriptive purposes, the Klondike Gravel has been divided into (informal) members A, B, C and D which correspond roughly to the measured sections designated JC1, JC4, JC3 and JC2 respectively. These are shown in figure 15, which shows a generalized composite section of the Klondike Gravel with members, sample points and relevant mining features indicated.

Member A (JC1) is composed of imbricate clast supported gravel (Gm) with beds and lenses of structureless coarse silt and sand (F1) As shown in plate 20, indistinct parallel bedding is present in the gravel facies.

Member B (JC4) is composed of thickly bedded sand and gravel, shown in plate 21. The beds of silt and sand are horizontally laminated, or massive, and are the thickest found in the Klondike Gravel, ranging up to 2 m in thickness.

As the gravel of this member thaws, blocks up to 75 cm in diameter fall from the face. The finely laminated silt and sand has a marbled texture, similar to that associated with the melt of numerous small segregated ice lenses (Williams, 1980, p. 7).

Similar structures and facies are found in section JC5, located 10 m above JC1 and 10 m below JC4. The structures are intermediate in size and character between those

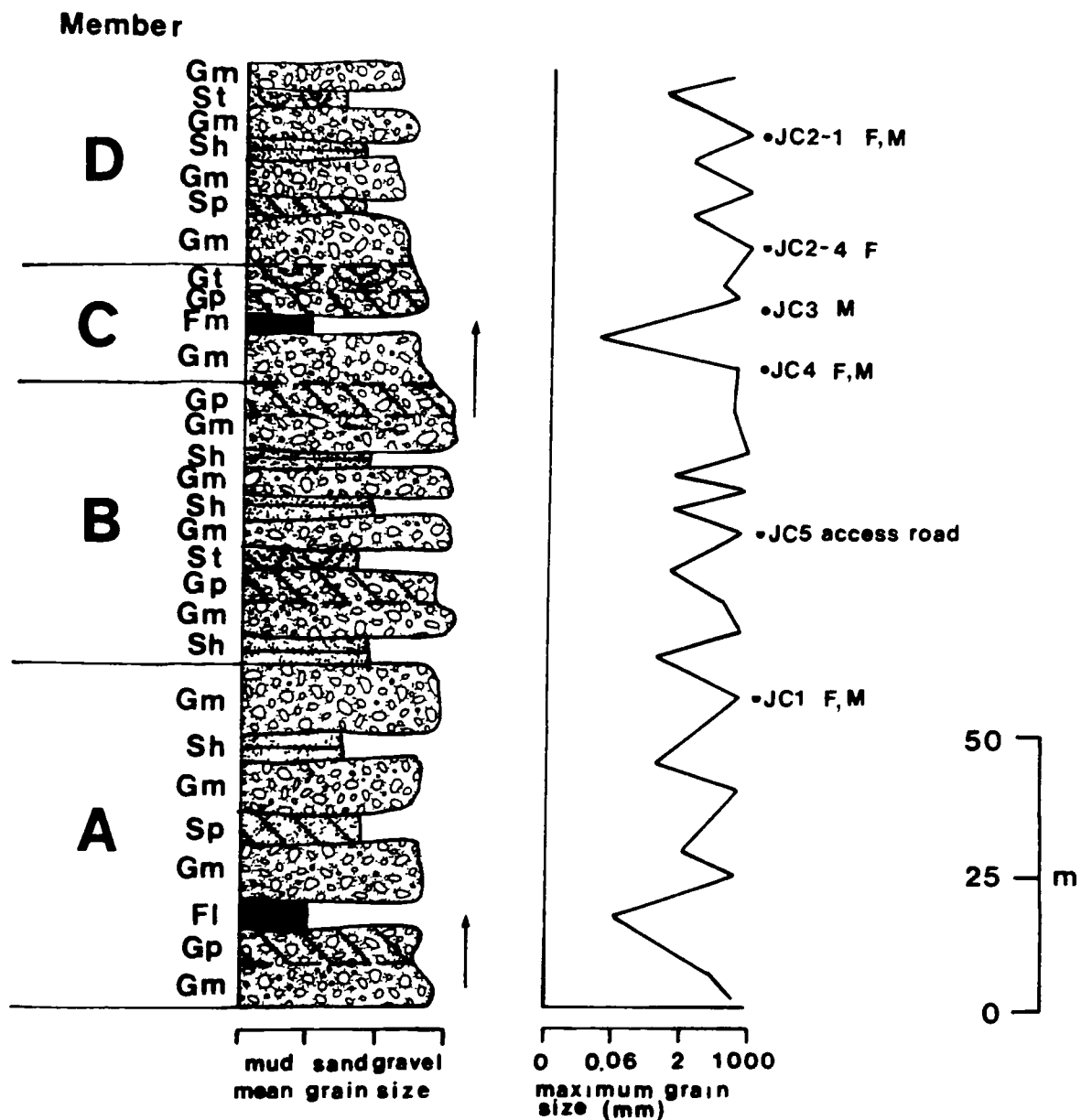


Figure 15. Vertical facies model for Klondike Gravel showing members measured and sample points. (Note beds are diagrammatic, only member thickness is true scale.) Internal structure as shown in figure 11.

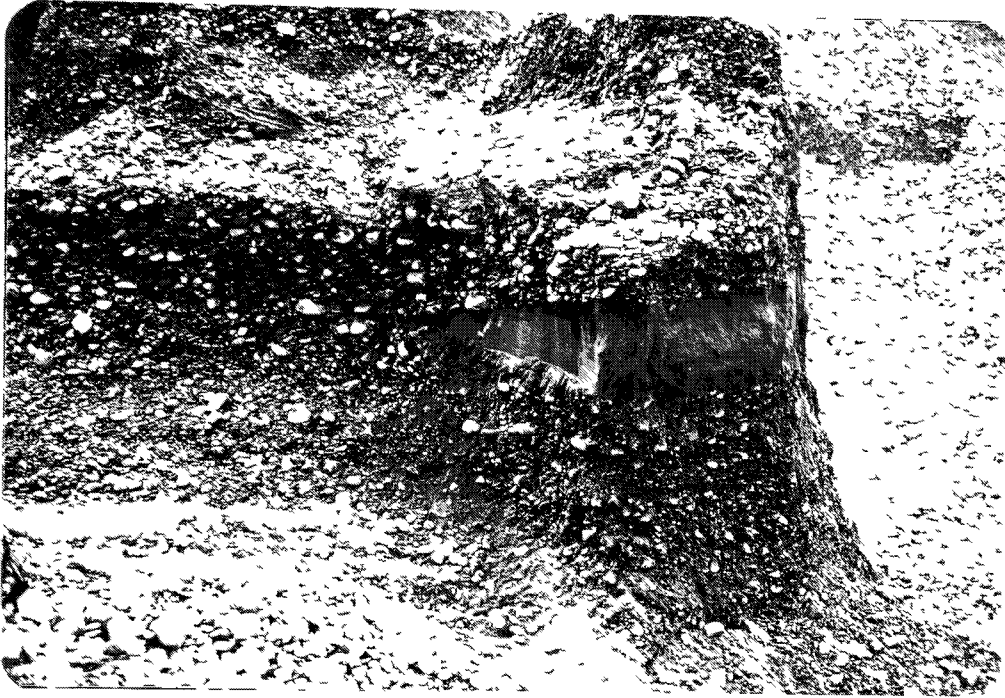


Plate 20. Facies of member A of the Klondike Gravel are shown here in section JCl. The bar shown was produced by monitor attack on the permanently frozen gravels. Facies F1, Gm and Gp are present.

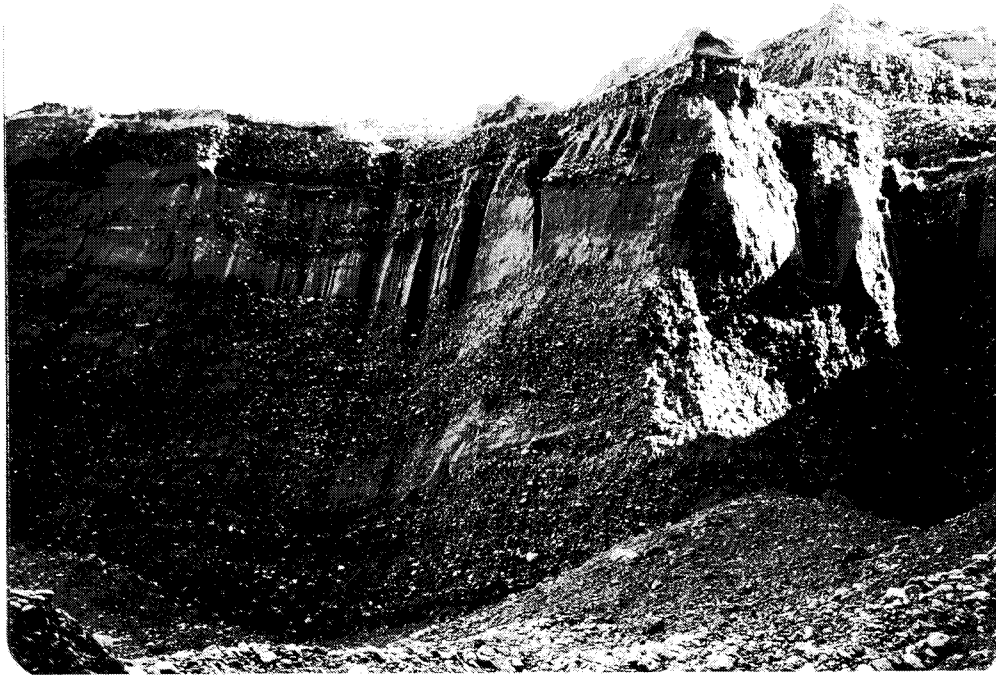


Plate 21. Upper section of Klondike Gravel JC4 where measured section was undertaken, showing member B facies. Note interbedding of sand and gravel.



Plate 22. Section JC5 showing structures intermediate in size and nature between members A and B. (Ice axe head is 25 cm long.)

of member A and B, and indicate a progressive increase in the magnitude and/or duration of fluvial events (plate 22).

Member C (JC3) is characterized by gravel channel fill structures. Facies present include cross-bedded gravel (Gp, Gt) (plate 23), clast supported sometimes highly imbricate gravel (Gm) and fine sand and silt drapes (F1, Fm) shown in plate 24. Small disrupted laminae and convolutions are present within the drapes; these may be fluid escape structures triggered by the weight of the overlying gravel. Although the gravel is frozen, these structures are not similar to cryoturbations. In places the drapes enlarge to form silty beds with an upper oxidized horizon (plate 24), or thin out to form discontinuous lenses up to 0.5 m long.

Small scale channels are present throughout member C. The channels vary in size with an average width of 3-4 m and depth of 1 m. Plate 25 illustrates a channel-fill sequence enclosing a bed of highly imbricate matrix supported gravel (Gm, Gt) resulting from channel migration.

Member D (JC2) is the highest section of the Klondike Gravel. Plate 26 shows a typical section of this member, with large scale shallow channels of sand and gravel and low angle cross stratified sand and gravel. Channels are 1-2 m deep and 10-15 m wide giving width/depth (W/D) ratios between 5 and 15. This would suggest that the



Plate 23. Planar cross bedded gravel (Gp) and fines (F1, Fm) in member C of the Klondike Gravel (JC3).

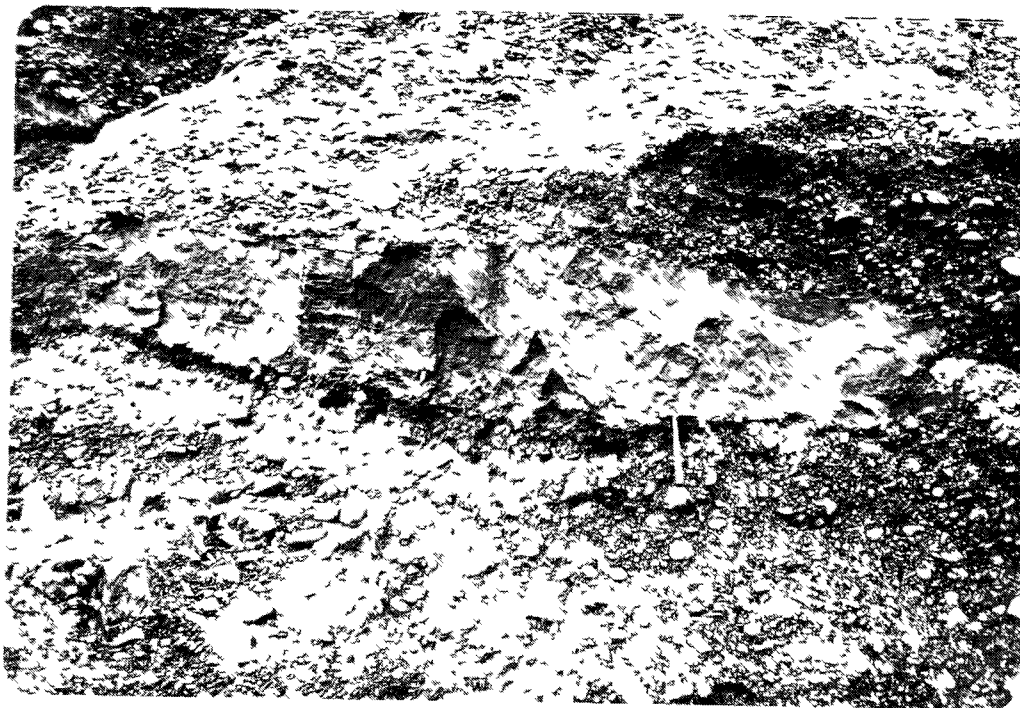


Plate 24. Silt drapes in member C often enlarge to form continuous beds of fines which have an upper oxidized horizon up to 20 cm deep.

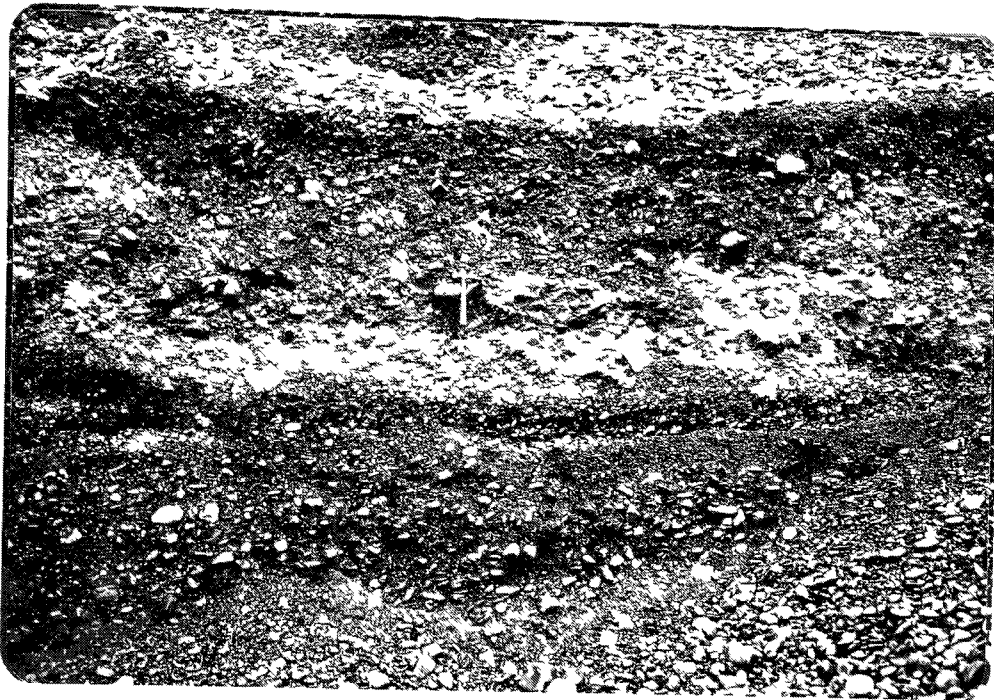


Plate 25. Gravel section at member C/member D boundary showing typical channel cut and fill structure.

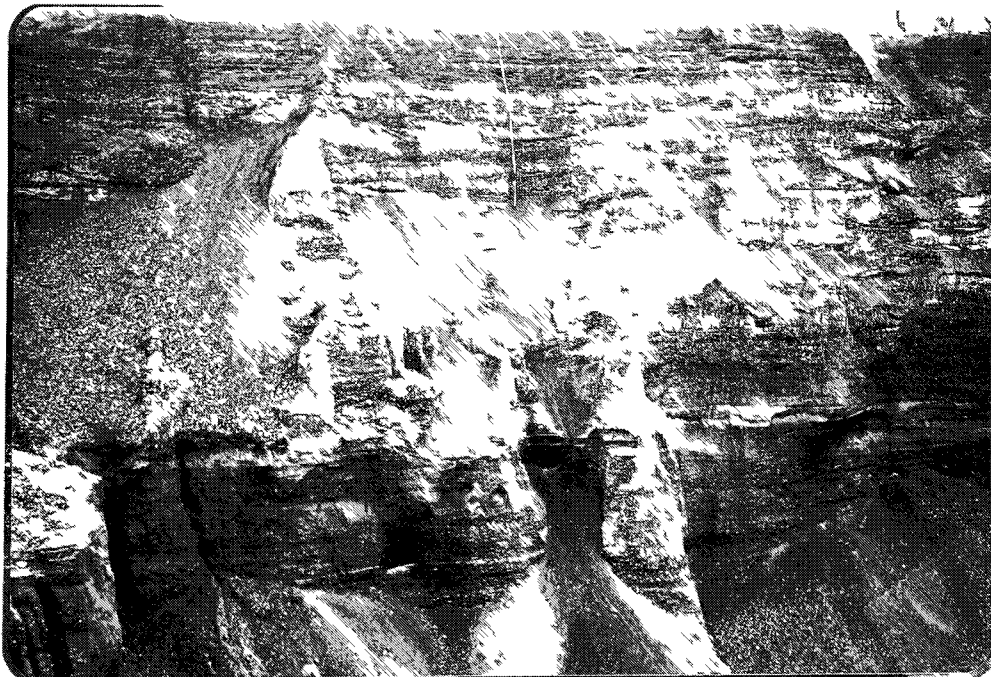


Plate 26. Member D, the highest elevation of Klondike Gravel, shown at JC2. Note interbedded sand and gravel in channels and coarse planar cross stratified sands. Red and white strip is divided into meters.

channels were formed in proximal to distal outwash position (cf. Williams and Rust, 1969).

Associated with these channel fill sequences are stratified gravels (Gm), coarse planar cross stratified sands (Sp) and low angle cross stratified sands and gravel (Sl). Beds of iron stained granules indicate periodic sub-aerial exposure, or periods of groundwater fluctuation. The vertical spacing of these beds is close to that of the cut and fill channel structures, suggesting that the two features are associated in a larger sequence of flooding and subaerial exposure.

Fabrics were examined at two positions within the Klondike Gravel: at the top of member D and at the base of the section throughout member A. In all cases, the gravel shows a well-developed imbrication. Fabrics measured in member A increase in strength as grain size decreases from JC1-1 to JC1-3 (figure 16). This is an apparent contradiction to the general pattern of strongly imbricated large clasts. The weakest imbrication is found at the top of the section in member D (JC2-1) shown in figure 16. This probably reflects the diminished influence of the waning current which deposited the upper reaches of the Klondike Gravel.

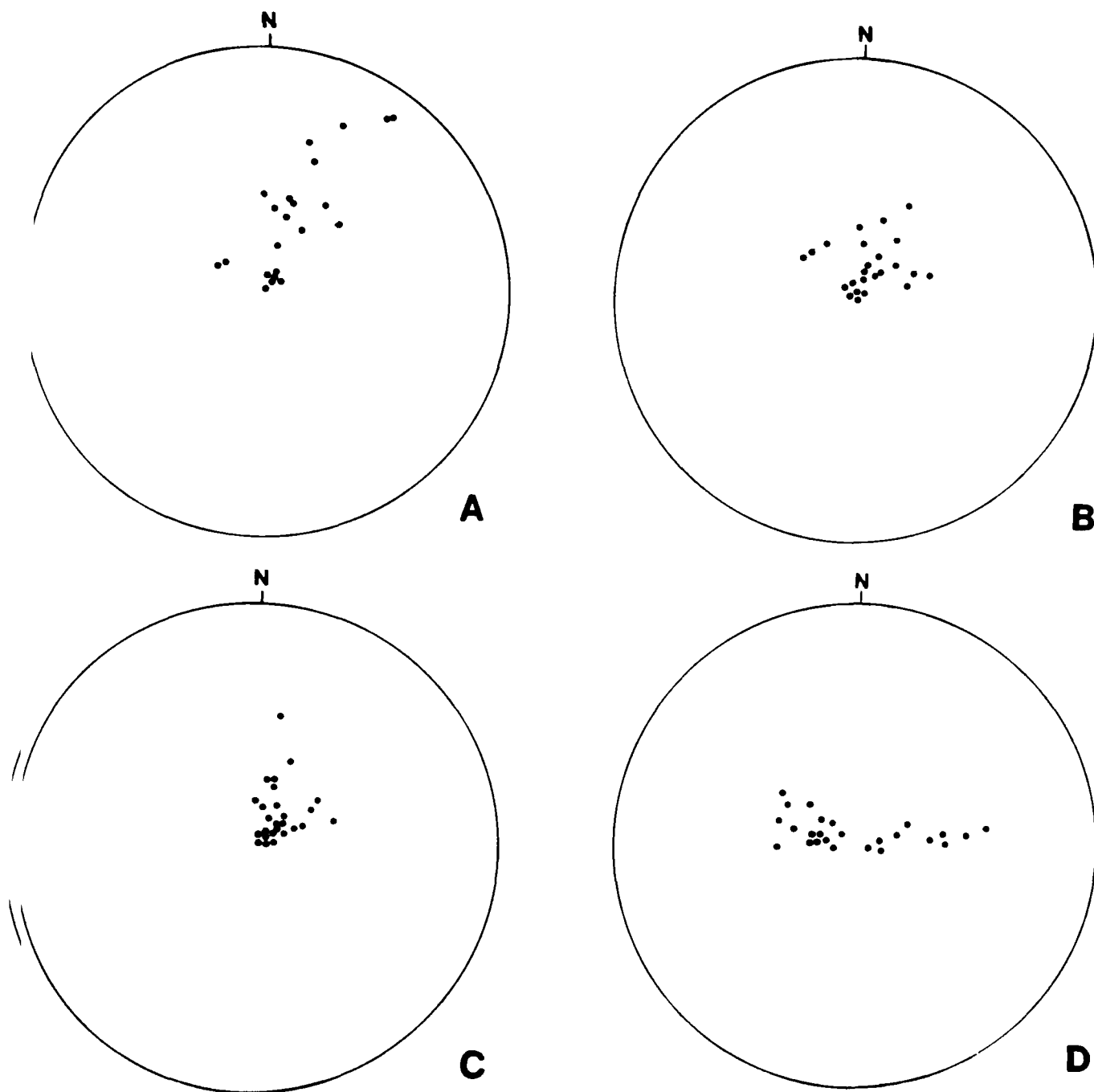


Figure 16. Fabric of Klondike Gravel in members A(A,B,C) and D(D). Fabric plotted as poles to the AB plane of blade- and disc-shaped clasts.

3.5 Creek Gravels

3.5.1 Stratigraphy and Geomorphic Setting

The creek gravels studied at Gold Bottom (chapter 1.4.1) occupy the lowest position geomorphologically of any surficial deposits of the Klondike area, and may occur at various stratigraphic positions since their deposition has been sporadic over time. Mass wasting (solifluction) processes play an important role in providing material for the creek gravels. Large amounts of organic matter as well as fine sand and silt, are incorporated within the gravels.

Creek sediments may be frozen or unfrozen, depending on the organic matter content, depth and thickness of organics, and aspect. At the Gold Bottom locality portions of the north-facing banks are nearly always frozen while south-facing banks remain unfrozen. Solifluction lobes are common on the north slopes of Hunker Creek and on the east slopes of Gold Bottom. Slope failure is also common along the banks of Gold Bottom.

3.5.2 Physical Description

It is not surprising that creek gravels are the most variable of all the gravels studied with respect to their morphology, clast size, bedform and structures. Source material for the gravels is highly variable: local bedrock, slopewash and solifluction materials, and reworked

terrace gravels from higher elevations all contribute to their diversity.

The great variety in fluvial deposits is also due undoubtedly to fluctuating river discharge. Sediments range from structureless silt and clay drapes to highly imbricate gravels.

Within the gravel fraction, clast size ranges from large cobbles (20 cm) to grit, with much imbrication of the pebble to cobble sized material. Other gravels are apparently without imbrication, or have poorly developed fabric resulting from the mixing of fluvial imbrication and fabric created by downslope movement. In some places, a gravel diamicton exists, 2-10 cm in size, within a grit matrix. This is likely colluvium, since many clasts are nearly equidimensional and have very low sphericity, in contrast to the flat, discoidal fluvial clasts.

In places the creek gravels are intimately associated with organic matter. There are at least two origins for this material: (1) slopewash or solifluction material moved into place from the surrounding hillsides and (2) in situ overbank deposits. Section 1 displays horizons of fibrous peat, peaty organic silt (muck) and roots. The presence of these organic beds and roots indicates periods during which plant successions had time to develop along the river banks. Fossil remains are sometimes associated

with the muck, but none were observed in the 1980 season at this locality.

3.5.3 Facies, Structures and Fabric

Creek gravels were examined at two locations in upper Gold Bottom Creek. At the first site, sections on the right (GB1) and left (GB2) limit were measured and described. Section 1 (GB1) contains interbedded sand, gravel and organics, shown in plate 27; section 2 (GB2) fines upwards from coarse clast supported gravel (Gm) to fine organic silt (Fr). Unlike the first section, these deposits are overlain by organic muck and solifluction deposits.

A third section (GB3) is located further downstream near the junction of Hunker Creek on the left limit. At this point the valley walls are shallower than at sections 1 or 2 and a well developed bar system is present in the creek. Gravels in this section are more fluviially dominated since slope processes play a lesser role in the supply and movement of sediment in the valley.

Section GB1 displays a general fining upward pattern from coarse, basal imbricate gravel (Gm) to the overlying organic muck (Fr), shown schematically in figure 17A. The majority of the section is composed of interbedded non-fossiliferous organic silt and gravel. In the central area of the section, the muck contains a fibrous, silty brown peat horizon, distinctly different from the surrounding

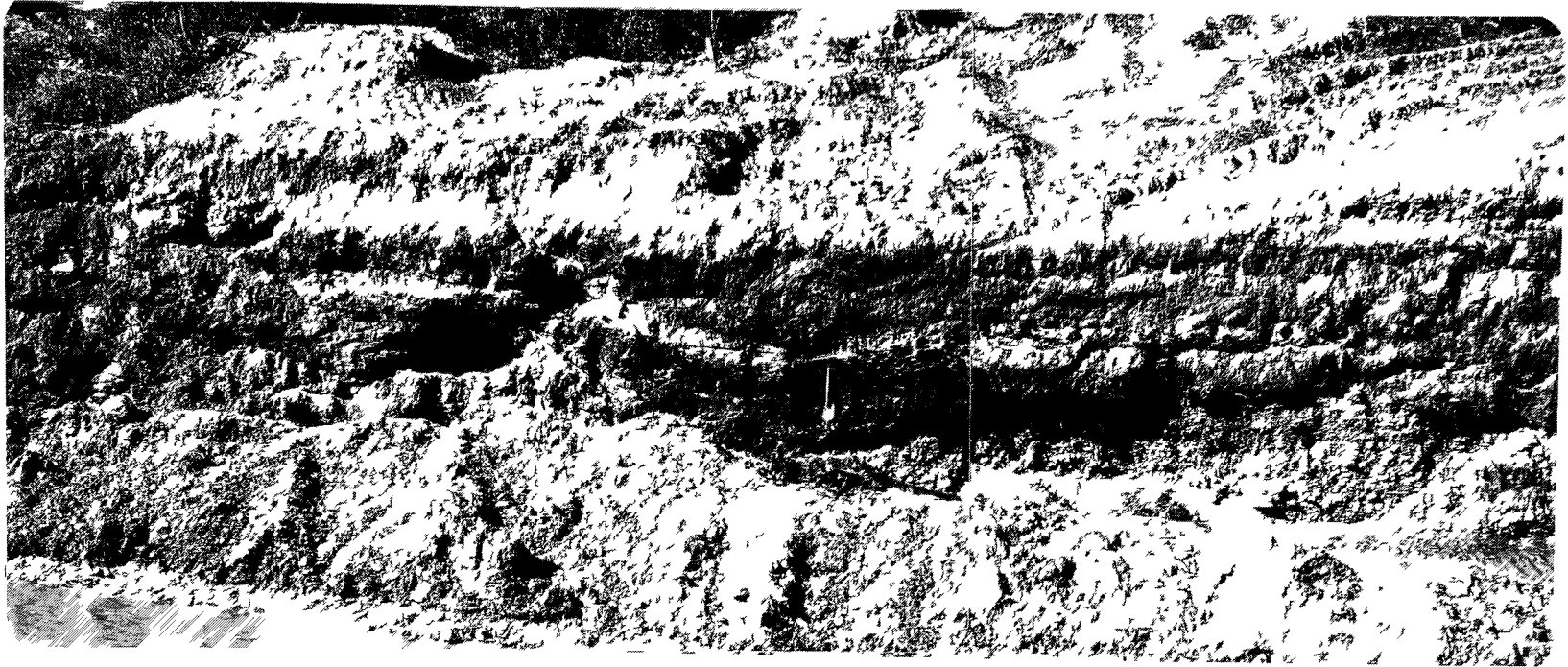


Plate 27. Gravel section at the right limit of Gold Bottom Creek. Thick peat bed is above contorted sand bed directly above shovel. Fabric measurement taken from coarse gravels shown in lower right corner. (Shovel is 65 cm long.)

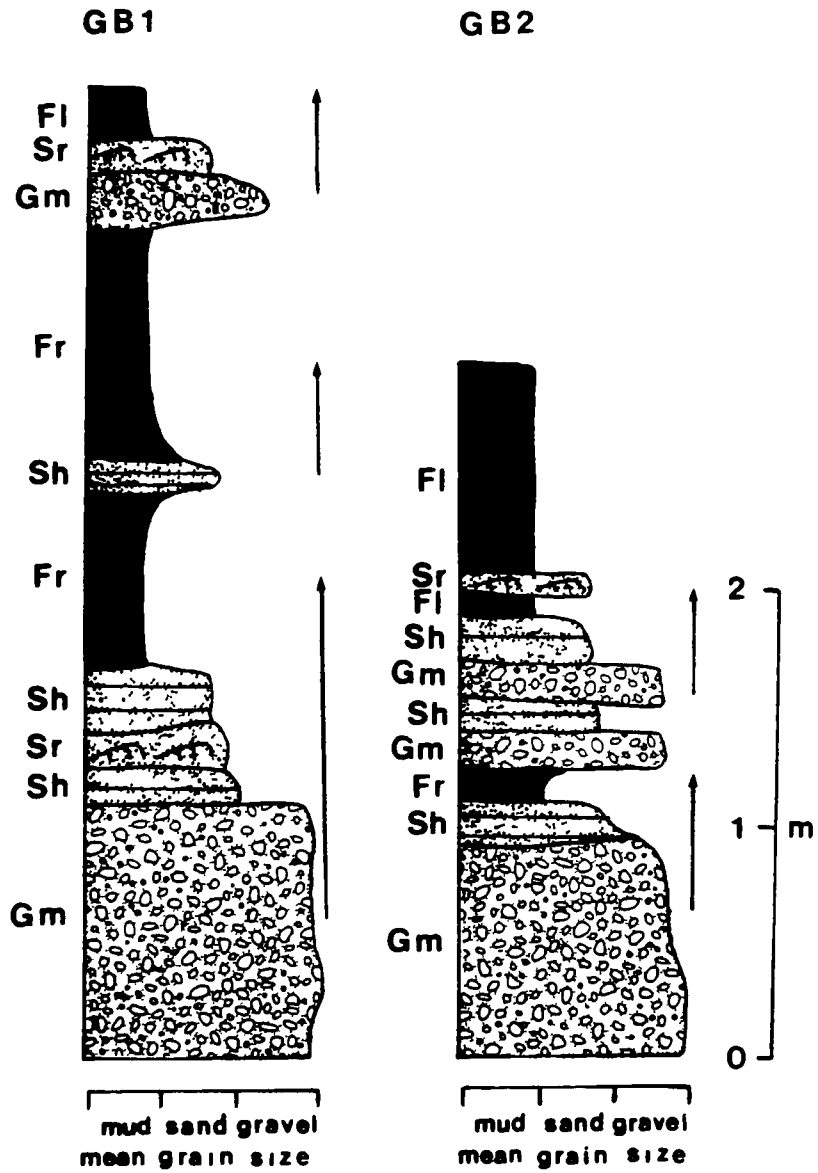


Figure 17. Facies in creek gravels on right and left limits of Gold Bottom Creek. Internal structures as shown in figure 11.

muck. Upper and lower contacts with the muck are sharp and uniform, suggesting a sharp change in depositional environment. Directly overlying this unit is a highly undulatory sand bed (plate 28) which varies greatly in elevation and thickness through the section. These sands are composed of laminated sand and silt with small rootlets, possibly indicating overbank deposition. Unlike sections further downstream, there are no cut and fill structures and most deposition is a combination of mass wasting and coarse fluvial gravel.

Section 2 (GB2) is located on the opposite west-facing bank where permafrost is present and mass wasting is more active. A distinct fining upward sequence is present (figure 17B) from coarse gravel (Gm) to fine organic silt (Fr). All contacts are sharp and conformable. No contacts are abrupt or erosional, but indicate one continuous, but sporadic deposition. Large organic fragments, mostly roots, are present within both the gravel and muck but are transported as opposed to the rootlets found in situ at GB1.

Fabrics were measured for the right and left limits of Gold Bottom (figure 18), where the gravel appeared to be the coarsest and most imbricate of the section studied. Both sections show a high degree of random orientation. A minor degree of preferred orientation is associated with the development of point bars in the braided system of Gold Bottom Creek, shown by the central cluster of points

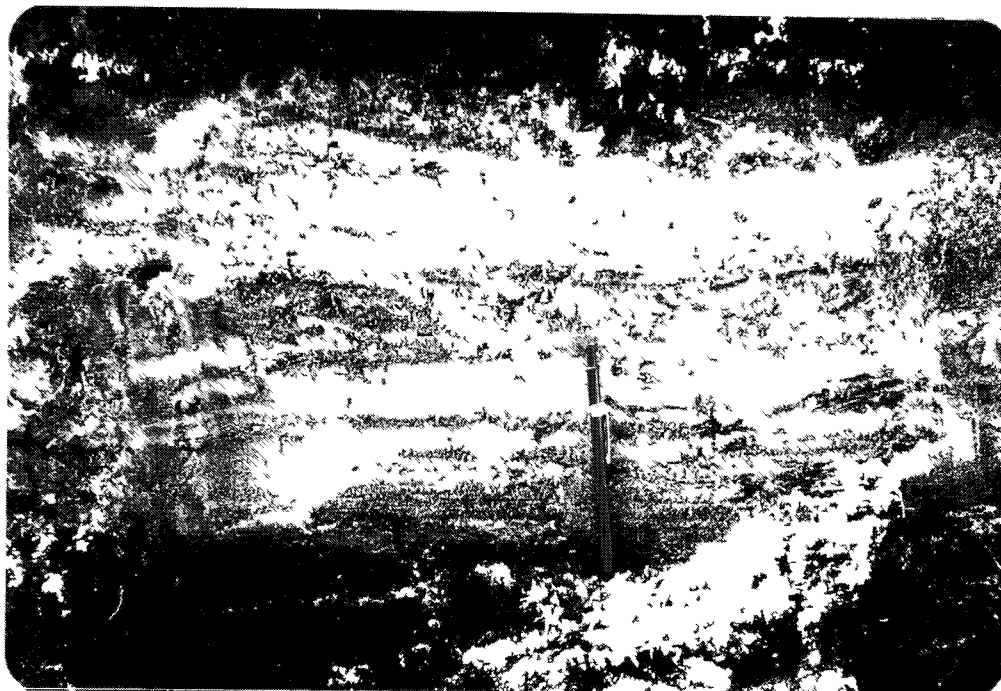


Plate 28. Undulatory sand and silt beds in center of section on right limit of Gold Bottom Creek. Note roots above pencil. (Pencil is 15 cm long.)

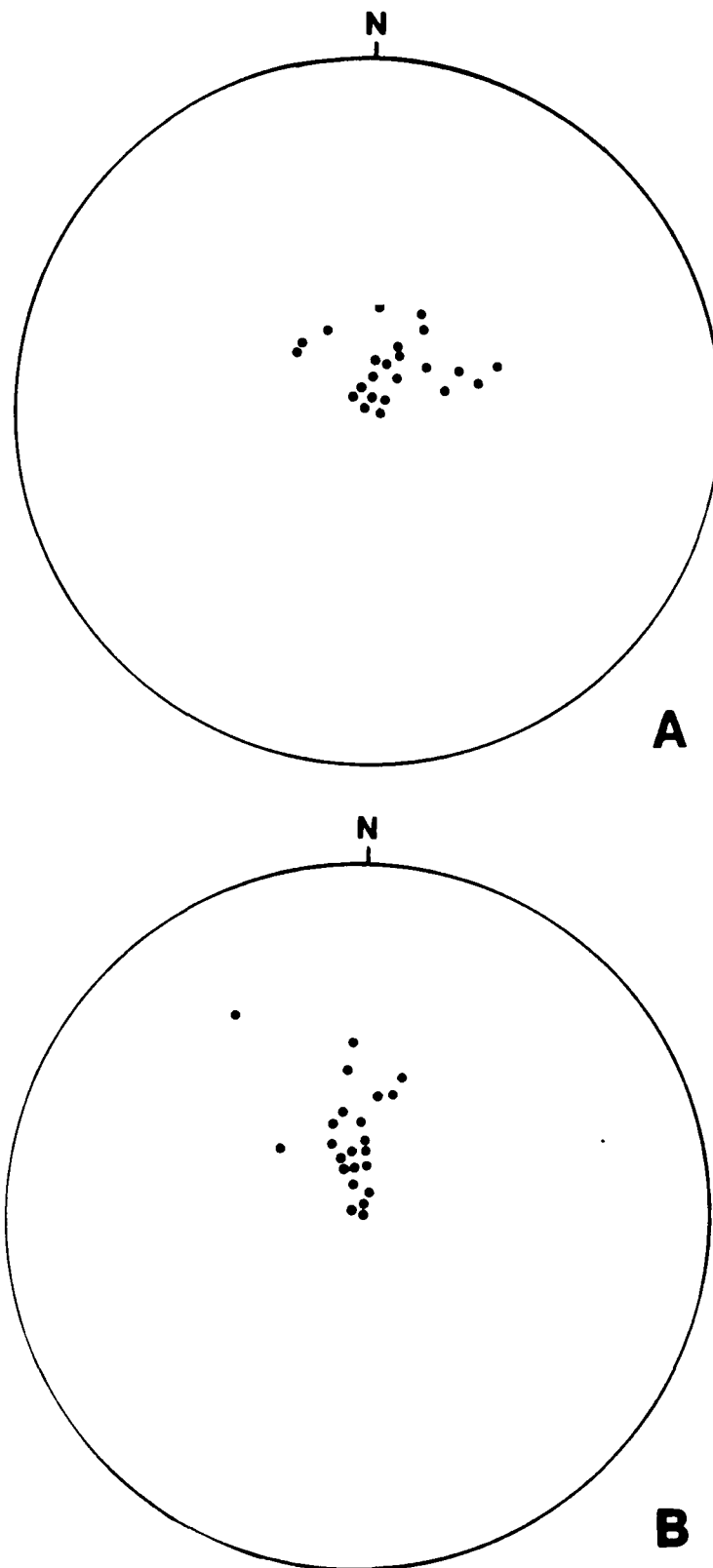


Figure 18. Fabric of creek gravels on right (A) and left (B) limits of Gold Bottom Creek. Fabric plotted as poles to the AB plane of blade- and disc-shaped clasts.

at the left and right limit. The dominant fabric element, however, seems to be a random factor probably introduced by the addition of mass-wasted material and the subsequent reworking of the gravels. If downslope movement of gravels had occurred en masse, there should be two distinct fabric elements present: a fluvial imbrication and a downslope orientation associated with slopewash and/or solifluction. The high degree of randomness in the fabric indicates that as colluvium reached the valley bottom, fluvial reworking destroyed most of the parent fabric. The rather simple fabric of solifluction deposits (e.g., French, 1971; Benedict, 1970) is missing. There is some element of organization in the fabric, however, which suggests a downslope dipping of the clasts towards the center of the valley.

3.6 Gravel Morphology

In order to document morphological change from high to low elevation terraces and reworking of terrace gravels into creek deposits, measurements of roundness, sphericity and form (section 1.1.3) were made at selected sites of Klondike, White Channel and Creek Gravels. Wherever possible, these indices were measured on clasts taken from the same bed, and if distinguishable, from the same structure to eliminate unnecessary variables.

The Klondike Gravel occupies the highest bench elevation, and shows a wide range of roundness and sphericity.

Measurements were made in members A, C and D, and are summarized in figure 19. Roundness varies from 0.4 to 1.0 and sphericity from 0.2 to 0.9 with even scatter between end values. This scatter probably reflects the rapid deposition of the gravel and the resulting lack of mechanical disintegration on transport.

Zingg indices were also measured at the same sample points (figure 19). These data are typical of coarse fluvial clasts, with 52% discs, 24% rods, 14% spheres and 10% blades. The large proportion of disc and rod-shaped clasts makes imbrication common, since clast shape favours preferred orientation.

The White Channel Gravel and its sub-facies the Yellow Gravel were also studied. Since there is little internal variation in the structure of the White Channel gravels, measurements were restricted to two points at the bottom and top of the gravels. Figure 20 summarizes roundness and sphericity characteristics of the White and Yellow Gravels. Roundness varies from 0.3 to 0.9 for the White Gravel and from 0.3 to 1.0 in the Yellow Gravel. Sphericity ranges from 0.4 to 0.9 and 0.4 to 1.0 respectively. Yellow gravels have a slightly higher index of sphericity, and appear to have a closer cluster of points. The most apparent difference, however, is found in form as shown in figure 20. As sediments change from White to Yellow Gravel there

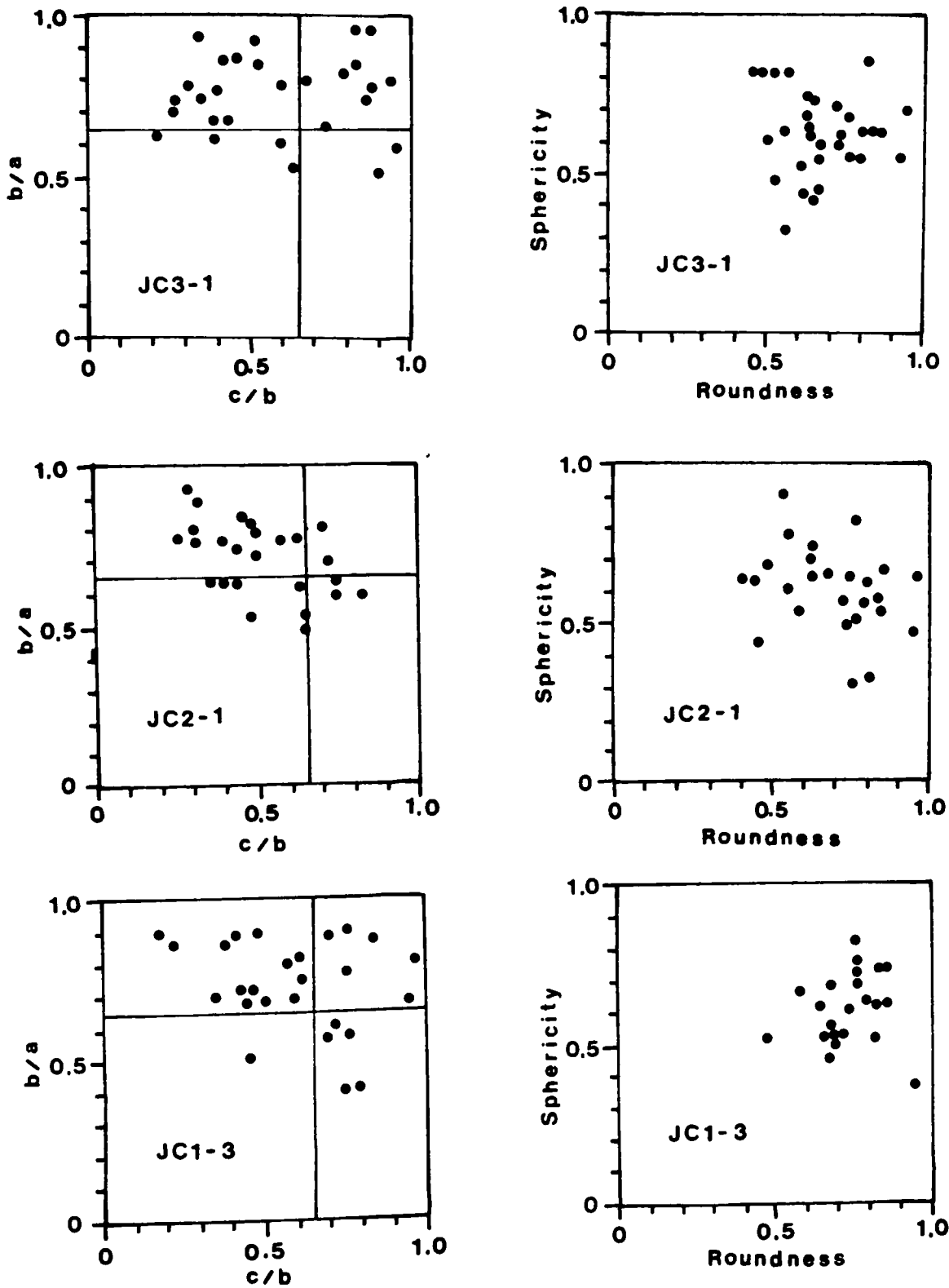


Figure 19. Roundness, sphericity and form indices of clasts in Klondike Gravel members A, B and C sampled at sites JC1, JC2 and JC3.

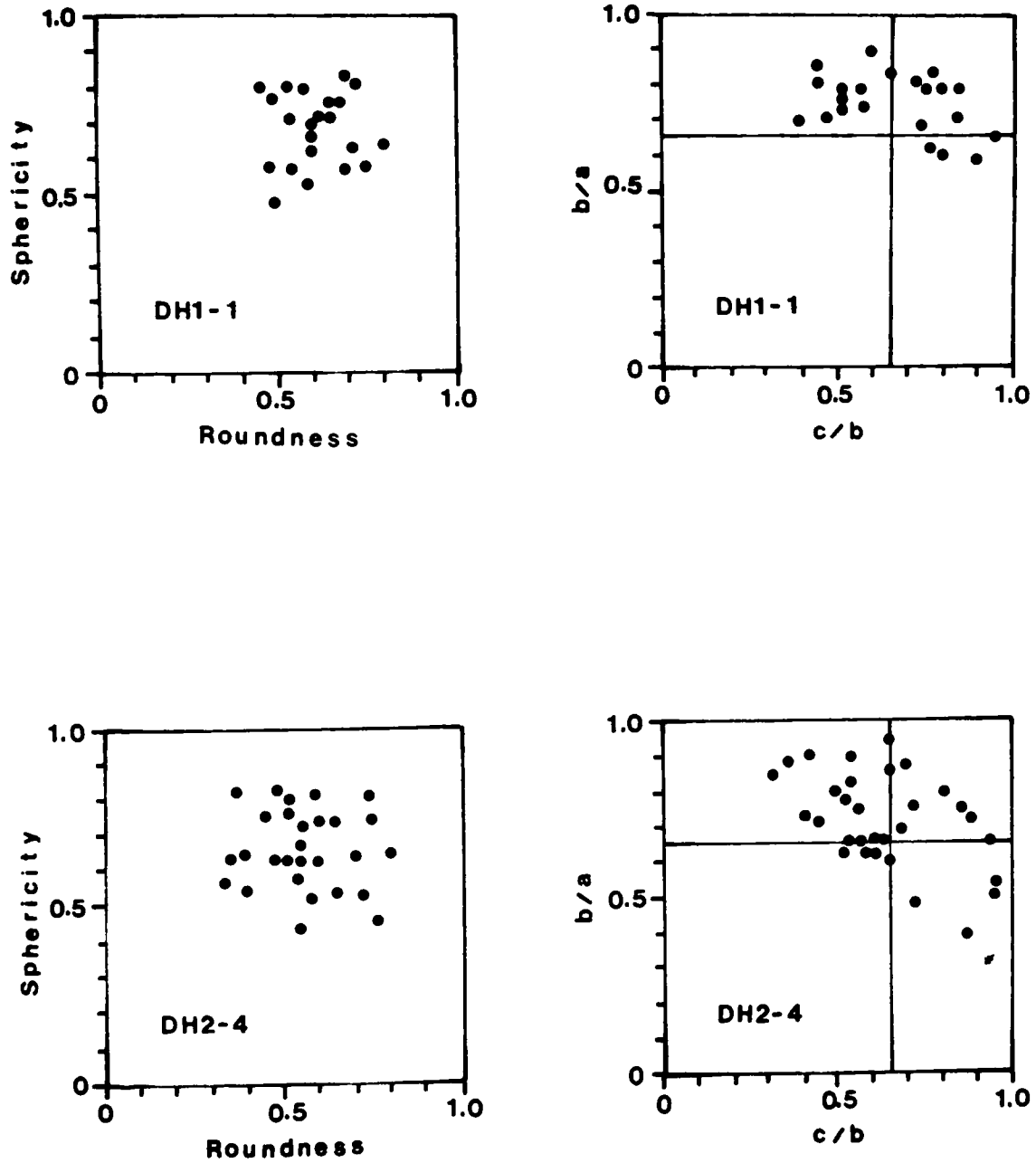


Figure 20. Comparison of roundness, sphericity and form of clasts from White Channel Gravel and Yellow Gravel.

is an abrupt increase in the proportion of disc and rod-shaped particles at the expense of spherical clasts, while the proportion of blade-shaped clasts remains constant. White Channel Gravel is 47% discs, 34% spheres, 14% rods and 5% blades whereas the Yellow Gravel is 54% discs, 24% spheres, 17% rods and 5% spheres.

The creek gravels show the widest variety of all. Roundness varies from 0.3 to 1.0 and sphericity from 0.1 to 0.9. Although these boundaries show very high limits, there is a great deal of scatter as shown in figure 21. The form of the creek gravels is also uncommon, as shown in figure 21. There is a very high percentage of blade-shaped clasts compared to the terrace gravels, indicating a large proportion of mass wasted material in the colluvium. This is also suggested by the very low roundness and sphericity indices of some clasts, indicating short distances of transport.

3.7 Depositional Environments

The deposition of creek gravels is relatively well understood, and is time-transgressive. Thus, the study of modern deposition and interpretation of past events is relatively straight forward. Gravels from higher terrace elevations are carried down into the present valleys by any of several mass wasting, active layer or fluvial processes. These all contribute to the accumulation of

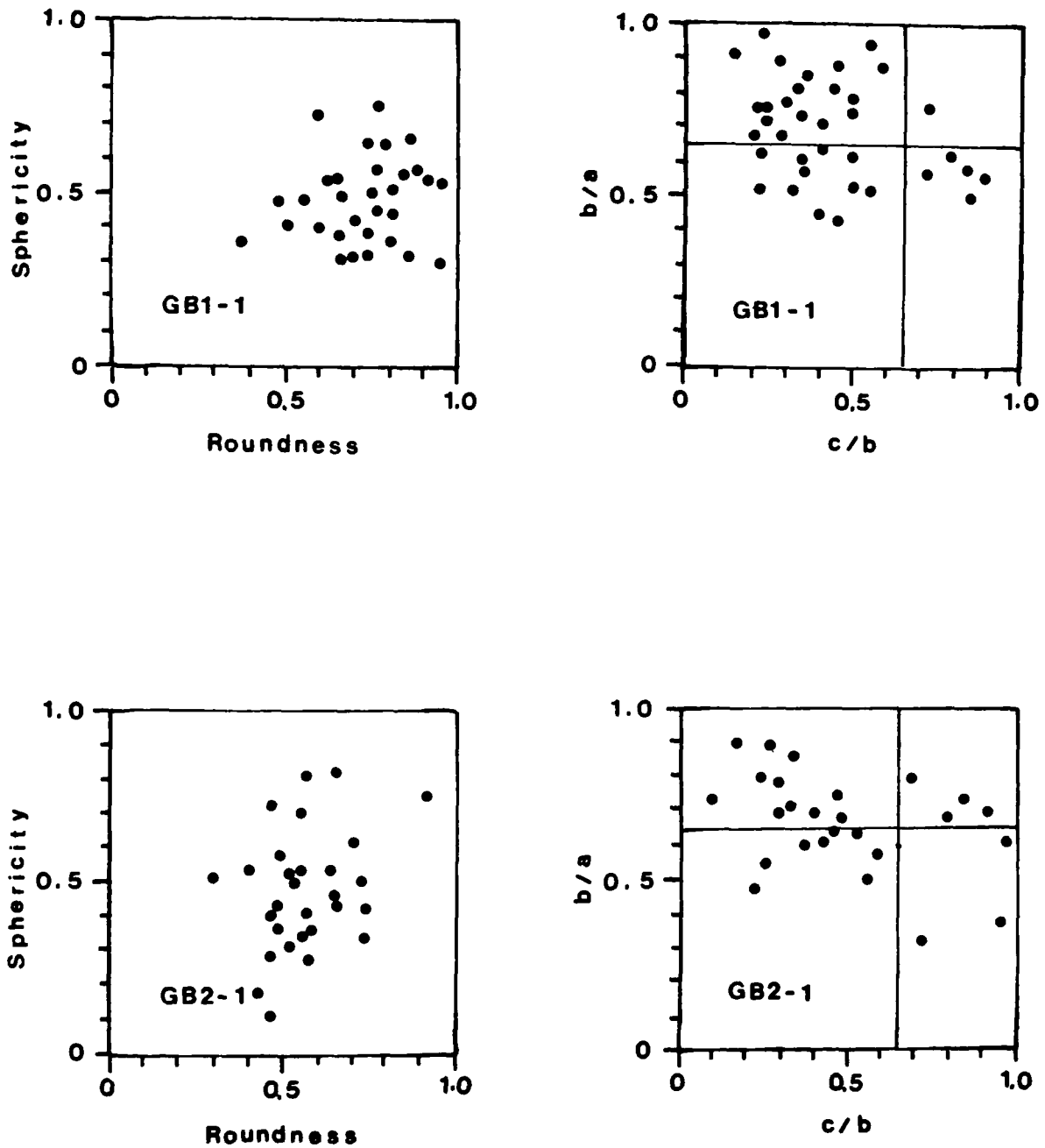


Figure 21. Roundness, sphericity and form indices for the creek gravels, Gold Bottom (sites GB1 and GB2).

material which eventually becomes part of the valley bottom colluvium which contains the valley and creek gravels. By comparison, the events surrounding the deposition of the terrace gravels are not as clear, and are discussed below in greater detail.

The White Channel Gravel which forms the basal outwash unit has a facies composition very similar to the Scott model of Miall (1978). The White Channel Gravel has a lower proportion of fines (St, Sp, Sh facies) than the Scott, but also has significantly less debris flow material (Gms) than more proximal models. Thus the Scott model is a close analogy to the depositional environment of the White Channel Gravel with a slightly more proximal position suggested. This is confirmed in the sections by the large proportion of poorly defined horizontal bedding with internal fabric in the massive gravel suggesting deposition on subhorizontal surfaces. Thus, the interpretation of fluvio-glacial gravel by Hughes and Van Everdingen (1978) is favoured rather than a fluvial origin as suggested by McConnell (1905) and Gleeson (1970).

The Klondike Gravel is found interfingering with the White Channel Gravel, suggesting contemporaneous deposition at the onset. As shown by the varied lithology and roundness, sphericity and form indices, physical and chemical weathering has been less intense than the White

Channel Gravel, possibly reflecting their rapid deposition. The Klondike Gravel resembles the Scott model more than the White Channel Gravel, where there are alternations of massive to horizontally bedded gravel (Gm) and sand (St, Sh, Sr) facies which are interpreted as being formed under progressively decreasing levels during flood stages. This is particularly well documented in members B and C. The relatively high proportion of fines and the relatively shallow channels in the upper portions, particularly member D, suggest a more distal position than the underlying White Channel Gravel, reflecting the retreat of the ice front.

As shown in the following section, there are several channel fill sequences in the Klondike area which are cut into the White Channel Gravel. These suggest an episode of valley cutting between the deposition of White Channel Gravel and the onset of Klondike Gravel deposition.

4. Permafrost Conditions

4.1 Introduction

In the Klondike, relic and modern permafrost is present in the placer mining localities and at the townsite of Dawson City, respectively. The study of muck and relic ground ice bodies provides valuable information regarding the paleoenvironments of the Bering Refugium, and specifically the presence and/or movement of certain Pleistocene flora and fauna, and related climatic events. The study of modern permafrost conditions is particularly useful at the Dawson City townsite where the unusual nature of the permafrost and associated groundwater movement causes a variety of geotechnical problems.

4.2 Muck Deposits

4.2.1 Origin and Nature of Muck

Much of the permafrost of the Klondike area occurs in highly organic silts, locally known as "muck". Although these muck deposits are widely distributed, they have not been intensively studied, and are generally regarded as a hindrance to mining activity. From a Quaternary geology viewpoint, however, they are important since the permafrost has resulted in the preservation of organic remains, and the stratigraphic study of ground ice is sometimes useful

in paleoenvironmental reconstruction.

Muck was first described in detail by Tyrrell (1917), who attributed its origin to refugia during glaciation of the surrounding area. Mosses such as Sphagnum and Hypnum dominated, with sticks, tree limbs, leaves and other plant debris being common. The inorganic component consisted of a large quantity of sand and silt.

The muck was thought to have originated as a thin blanket deposit of wind-blown silt, similar to loess, which was deposited on the surrounding hillsides during the colder periods of the Pleistocene. During warmer and wetter periods, much of the silt moved downslope under gravity processes, where it mixed with coarser fluvial sediments forming colluvium. Thus, much of the Klondike muck was deposited in its current position by processes either no longer active, or more rapid in the past.

Once deposited in the valley bottoms, permafrost quickly aggraded through the sediments, thereby preserving any fossil vertebrate remains (see section 4.1.2).

Not all of the muck is loess derived, however, as shown by peat occurrences at Gold Bottom (GB1). Beds of peat are traceable over long distances, with bedding clearly indicated. This lateral continuity and the presence of large tree fragments suggest a relatively long period of stability during which organics could develop

in situ. Thus, the muck of the smaller valley bottoms may have represented, before disruption by mining activity, the most complete record of valley fill deposits. They are unlike the valley bottom deposits of the larger valleys where foreign material may be incorporated into the sequences.

Various approaches have been used in the study of muck deposits. For example, Campbell (1952) described the palynology, and associated the floral remains with climatic events. He noted that the muck changes character from bottom to top. On bedrock the sediments are coarse and sharp. Higher in the section they appear finer and contain larger amounts of organic matter. In the upper levels, several prominent organic layers contain large tree stumps in growth positions.

The muck sections described by Campbell are similar to those at Fairbanks, Alaska, described by Péwé (1975). The Dawson Cut Formation, commonly called the Dawson muck, is found overlying auriferous valley bottom Fox Gravel and underlying the Gold Hill Loess, the oldest unit of the Fairbanks Loess. The Dawson muck has a similar faunal record as the muck at Hunker Creek, and the overlying Gold Hill Loess closely resembles the fine muck at the top of the Hunker Creek sequences.

4.2.2 Muck Types and Distribution

For the purposes of mapping, six general muck and colluvium categories are recognized, generally following the work of Campbell (1952) and Milner (1976).

1) Blocky muck:--this is found on oversteepened inner valley slopes and on most terraces and downstream sides of the spurs of Bonanza and Hunker Creeks. It consists of openwork block talus or diamicton.

2) Stoney muck:--This is found at the foot of slopes underlain by homogeneous well jointed bedrock, usually overlying valley bottom gravels. It consists of angular clasts with subtle, parallel bedding dipping towards the valley center. Charcoal present in the muck suggests this may be a distal mudflow deposit resulting from fire-induced active layer slides. It is similar in morphology to the Tanana Formation of Péwé (1975).

3) Gravelly muck:--this is distinguished from stoney muck by the presence of waterworn but angular clasts. It occurs in colluvial muck fans at the base of sections adjacent to minor tributaries of lower Hunker Creek. It appears similar to the Goldstream Formation of Péwé (1975).

4) Blocky sand:--this forms a sandy colluvium of sericitic quartzite, which is not of wide extent.

5) Micaceous (silty) muck:--possibly reworked loess, this unit often contains organic laminae. It is similar

to Engineer Loess and Ready Bullion Formation of Péwé (1975).

6) Icy muck:--fine grained muck may have ice contents 30%. It is commonly overlain by humified peat. Similar to type 5, it may also contain large organic and faunal remains.

4.2.3 Field Observations of Muck Sections

In addition to the muck sections studied at Hunker Creek, sections were studied at the northeast corner of Jackson Cut, the east end of Dago Hill, and the central portion of Dago Hill. In contrast to the blanket covering of muck found in the modern valleys, these elevated sites show patchy distribution of sediments reflecting the geometry of old channels and terrace slopes. They are thought to be channel fill deposits, and differ from the muck deposits for the following reasons: a) a lack of organic and faunal remains; b) crudely stratified heterogeneous diamicton of mineral rather than organic soil, and c) generally no permafrost because sites are well drained.

Where old terraces have been excavated, tongue-like wedges of muck and slopewash occur. For example, during the summer of 1980, Miben Mining excavated what is apparently an old channel in the mechanical mining area of Dago Hill. M. Stutter (personal communication, 1980) exposed an area roughly 20-50 m wide and 100 m long

containing muck. This channel runs apparently along the strike of underlying shallowly dipping bedrock. An unusual feature of this section is that it is surrounded by White Channel Gravel.

A typical section is shown in plate 29. The muck varies dramatically from nearly black (Munsell 5YR 2.5/1) fine organic silt to a mottled mixture of peat and inorganic silt with abundant stone inclusions up to 1 m in diameter. In contrast to the surrounding muck which was frozen on both sides (Nbn), the clay-rich black muck was not frozen when excavated (M. Stutter, personal communication, 1980).

Similar fine grained but ice-rich frozen deposits were found on the flanks of the hill at Jackson Cut, where muck is enclosed by Klondike Gravel.

Further information as to the nature of these elevated valley fill deposits was obtained at Dago Hill, where White Channel Gravel is overlain at one point by a complex sequence of muck and slopewash sediments (figure 22). Unlike the previous two localities, slope failure and active layer processes play a more important role in the transport and subsequent incorporation of sediment into the sequence. This is largely a result of two factors. The southwest facing slope has a thick active layer, and the silty colluvium at the surface (2.0 m thick) is subject to mass wasting.

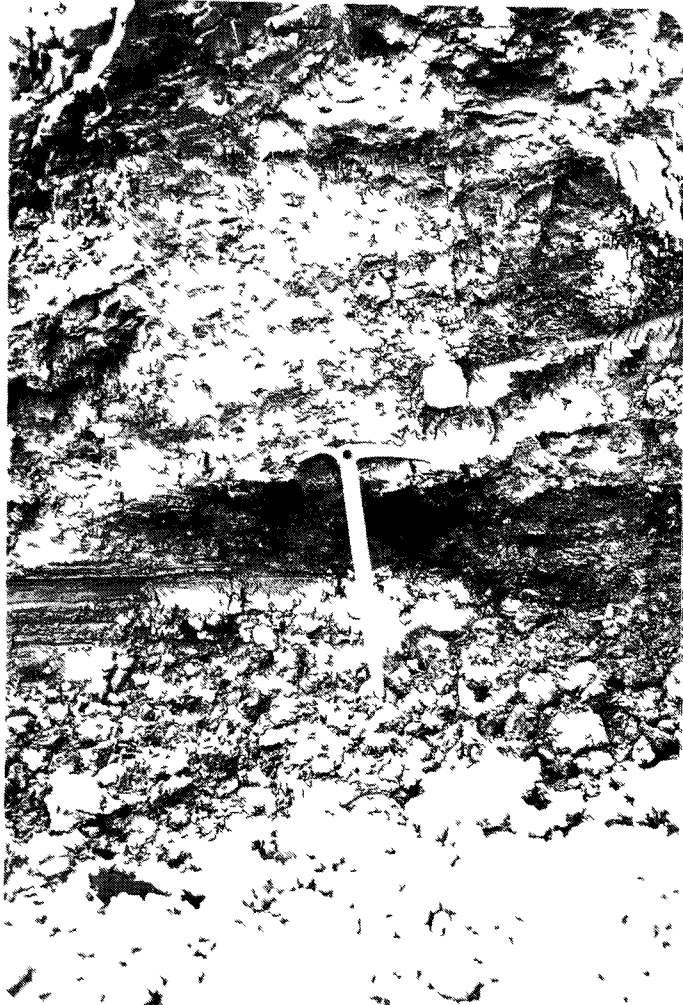


Plate 29. Channel fill deposits found in the White Channel Gravel at Dago Hill.

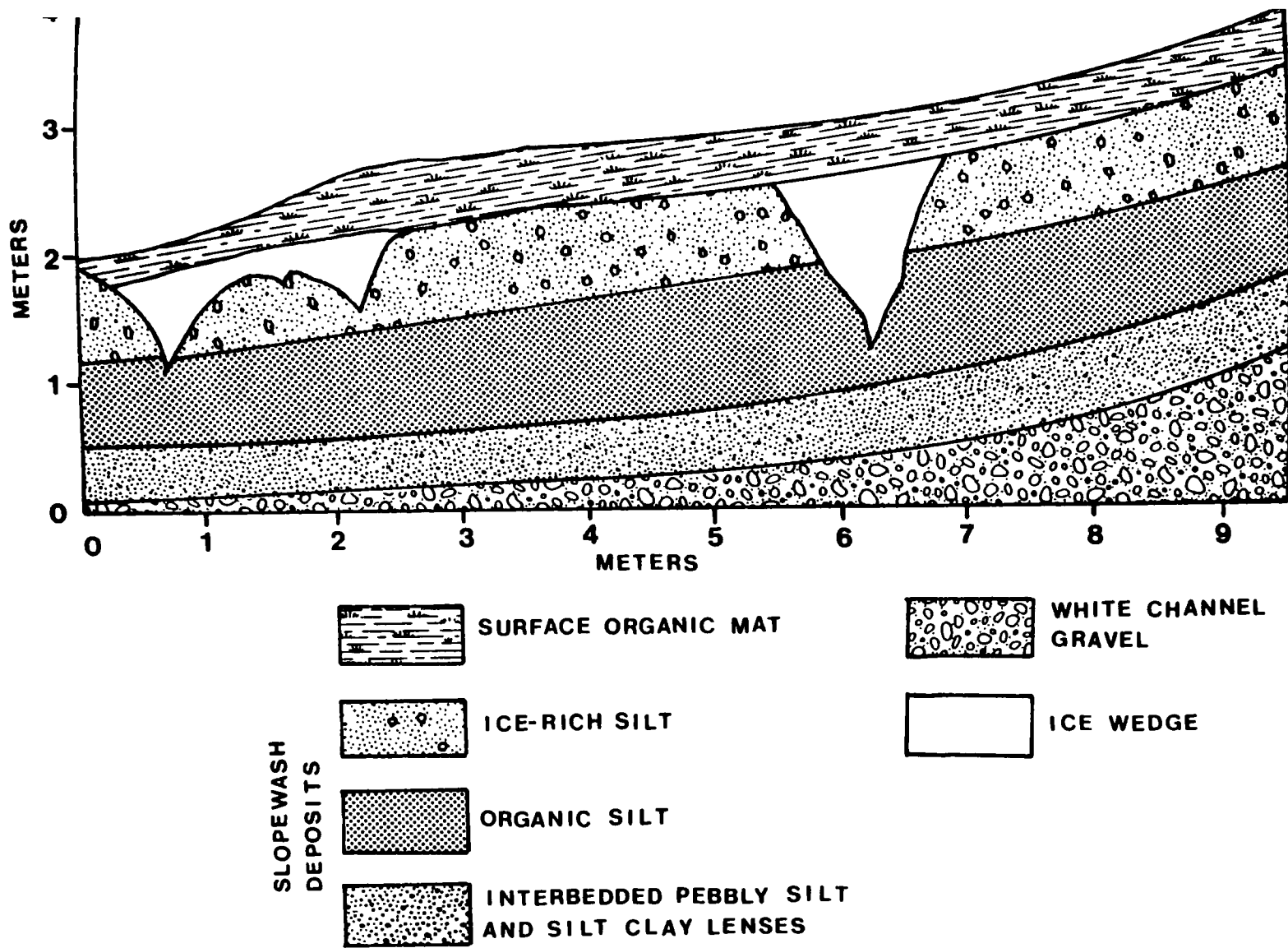


Figure 22. Slope sediments, SW Hunker Creek, May 1980.

4.2.4 Faunal Remains

The remains of several species of extinct Pleistocene mammals have been found in the muck of the Klondike area. The most common of this fauna include the American mastodon, woolly mammoth, tundra caribou, large horned bison and extinct species of muskoxen and horse.

Mammal remains were first described in the Klondike area by Dawson (1894), who recorded a fossil mammoth. With the onset of the gold rush, remains were frequently discovered in placer mining claims as shown in plate 30. With the continuing of placer mining, it became possible to systematically document the Quaternary fauna of the Klondike.

Several localities near Dawson City, Yukon Territory, have been documented by Harington (1965, 1980), Harington and Clulow (1973), Choquette, Harington and Archibald (1975) and others. These sites include Gold Run Creek, Dominion Creek and Quartz Creek. Faunal lists for each locality are shown in table 1. Similar findings have been documented in central Alaska by Guthrie (1967) and Whitmore and Foster (1967).

Since the Klondike and central Alaska remained unglaciated during the Pleistocene and is considered to be the southeastern extremity of the Bering refugium, Klondike mammalian studies are important to both Pleistocene paleogeographical reconstruction and to paleoecology.



Plate 30. Mastodon tusks (ivory) recovered from gold mining claim on Eldorado Creek. Photo: National Museum of Canada.

Repeated migration of mammals took place from Asia into North America, across a Bering isthmus which appeared and disappeared several times. Sardova (1961) demonstrated, using benthonic foraminifera in the bottom sediments of the Bering Sea and the North Pacific, that synchronous uplift of the ocean floor and lowering of sea level during glaciations brought the Bering land bridge into existence at least three times, beginning in Kansan time. During times of emergence it is assumed that the bridge was an area of wide plains with low hills and sparse woodlands (Flerow, 1967). These environmental influences are borne out by the faunal record.

Woolly mammoth, caribou, bison and the American lion probably occupied a cool grassland or parkland habitat, while the woolly mammoth and caribou suggest a tundra influence, possibly alpine tundra. Bootherium sp., the Yukon wild ass, the kiang-like horse and particularly the badger are indicative of a well drained grassland. The presence of moose and American mastodon suggest that smaller areas of wet parkland or boreal forest existed in selected areas such as the valleys and lower areas. Considering the abundance of wild asses, large horned bison and woolly mammoth, it is evident that vast areas of upland must have existed as cool steppe-like grassland during the late Pleistocene.

A major difficulty in studying Quaternary fauna is that most of the interior Yukon and Alaskan vertebrate remains have little or no known stratigraphic context. Fossils are most readily seen when the enclosing sediments have been washed away, so the majority of remains have been found lying loose on river banks and at disrupted placer mining sites. Detailed stratigraphic studies of the Yukon and Alaska were not initiated until the late 1940's and 1950's, so that even when fossil remains were collected in situ, no conclusions could be drawn as to the age of the sediments.

Harrington (1967) and Harrington and Clulow (1973) have made extensive studies of the remains in Gold Run Creek, Quartz Creek and Dominion Creek (table 4). Late Pleistocene mammal remains are usually found in stratigraphically similar situations throughout the region. As shown in figure 23, most specimens were derived from muck near the surface of the underlying gold-bearing gravels. In August 1972, a pair of bison horn cores and a few fragments of mammoth bones were found in situ at Gold Bottom Creek, partly exposed between 4 m of overlying brown, highly micaceous muck and at least 1-2 m of the underlying oxidized auriferous gravels. Bison alaskensis remains were also found at this locality and are evidently older than the other specimens found, since they were located in a deep sink in the creek bed. Radiocarbon dating yielded ages

Table 4

Quaternary Mammal Faunal Remains, Klondike Region.

1. Gold Run Creek. 2. Dominion Creek.

3. Quartz Creek.

Linnean Name	Common Name	Age
1.		
<u>Canis lupus</u>	wolf	
<u>Arctodus simus yukonensis</u>	short faced bear	
<u>Taxidea taxus</u>	badger	
<u>Panthera (leo) atrox</u>	lion-like cat	
<u>Mammut americanum</u>	American mastodon	
<u>Mammuthus primigenius</u>	wooly mammoth	32,250±1750
<u>Equus (Asinus) lambei</u>	Yukon wild ass	
<u>Equus cf. E. (Asinus) kiang</u>	Kiang-like horse	
<u>Alces alces</u>	moose	
<u>Rangifer tarandus</u>	caribou	
<u>Bootherium sp.</u>	extinct muskox	
<u>Bison alaskensis</u>	Alaskan bison	> 39,000
<u>Bison crassicornis</u>	large horned bison	22,200±1400
2.		
<u>Spermophilos undulatus</u>	ground squirrel	
<u>Mammuthus primigenius</u>	wooly mammoth	
<u>Equus sp.</u>	small horse	14,870± 260
<u>Alces alces</u>	moose	
<u>Rangifer tarandus</u>	tundra caribou	
<u>Bison crassicornis</u>	large-horned bison	
<u>Panthera (leo) atrox</u>	lion-like cat	22,680± 300
3.		
<u>Canis sp.</u>	wolf	
<u>Mammuthus primigenius</u>	wooly mammoth	
<u>Equus sp.</u>	small horse	
<u>Rangifer tarandus</u>	tundra caribou	
<u>Bison crassicornis</u>	large horned bison	30,300±1850

Source: Harington (1967) and Harington and Clulow (1973).

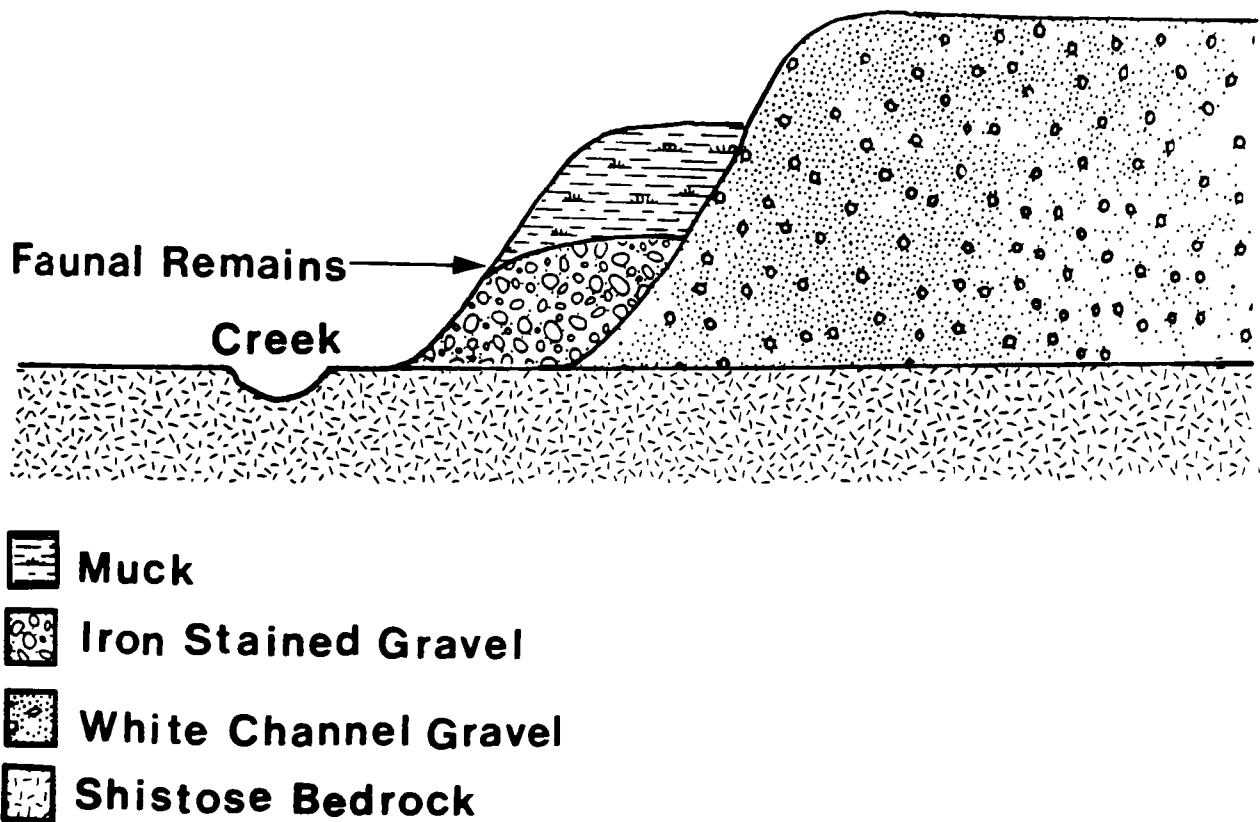


Figure 23. Stratigraphic location of faunal remains in Klondike placer mining localities. (After Harington, 1973.)

of $22,200 \pm 1,400$ BP (Bison crassicornis) and $32,250 \pm 1,750$ BP (Mammoth bone) while the Bison alaskensis yielded a date in excess of 39,000 BP. In addition, other material has been dated from the Dominion Creek and Quartz Creek localities. A small horse (Equus sp.) and a lion-like cat (Panthera atrox) from Dominion Creek yielded dates of $14,870 \pm 260$ BP and $22,680 \pm 300$ BP respectively. An additional specimen of Bison crassicornis from Quartz Creek has been dated at $30,300 \pm 1,850$ BP.

A horn core of Saiga tatarica (Saiga antelope) was found in organic silty muck on an alluvial terrace on lower Hunker Creek in May 1980 (plate 31). The presence of the skull within the permafrost is best explained by the downslope movement of colluvium and the aggradation of permafrost into these fine grained sediments. Harington (1973) believes most of the mammal remains were washed down with large masses of loess from a former grassland during a period of increasingly rapid erosion about 11,000 BP. They were deposited most frequently near the top of the creek gravels and at the base of the overlying muck deposit. This sequence of events is corroborated by Mathews (1974) who gives a similar sequence of events for muck deposition in the Isabella Basin (Fairbanks, Alaska) where core material from 39,900 to 4,510 BP has been radio-carbon dated and stratigraphically analyzed.



Plate 31. Horn core of Saiga tatarica discovered on Lower Hunker Creek, May 1980. (H. M. French)

4.3 Ground Ice Bodies

4.3.1 Associated Sediments

Permafrost, ground ice and associated muck deposits were studied in detail at the Mayes claim (site 3, section 1.1.4). The majority of the sections exposed in this operation consisted of varieties of muck (plate 32). These organic silts are ice-rich, and display randomly oriented ice lenses or veins (Vr). A second typical muck section is shown in plate 33, where organic silt and peat are finely interbedded with thin segregation ice lenses. Interspersed throughout the peat horizons are rootlets up to 0.5 cm in diameter.

4.3.2 Ice Wedges and Thaw Unconformities

One of the largest permafrost exposures occurs near the pumping station at the upstream end of the Mayes claim. This section was first observed by Hughes and Van Everdingen (1978), and is illustrated by figure 24. Approximately 2 m of silty sandy colluvium overlies 5 - 10 m of ice-rich silty and organic beds. Towards the bottom of the section, the frozen organic silt grades into ice with silt inclusions. The silt contains ice which varies from Vr to Vs, forming lenses up to 5 cm in thickness.

The excess ice and cryotexture character of these muck (organic-rich) and mineral-rich silts are documented



Plate 32. General view of MA-2 section. Note highly organic horizons containing tree fragments in frozen silty gravel, and refrozen slumped overburden.



Plate 33. Details of frozen muck included in relic ice wedge system at the center of section MA-1.

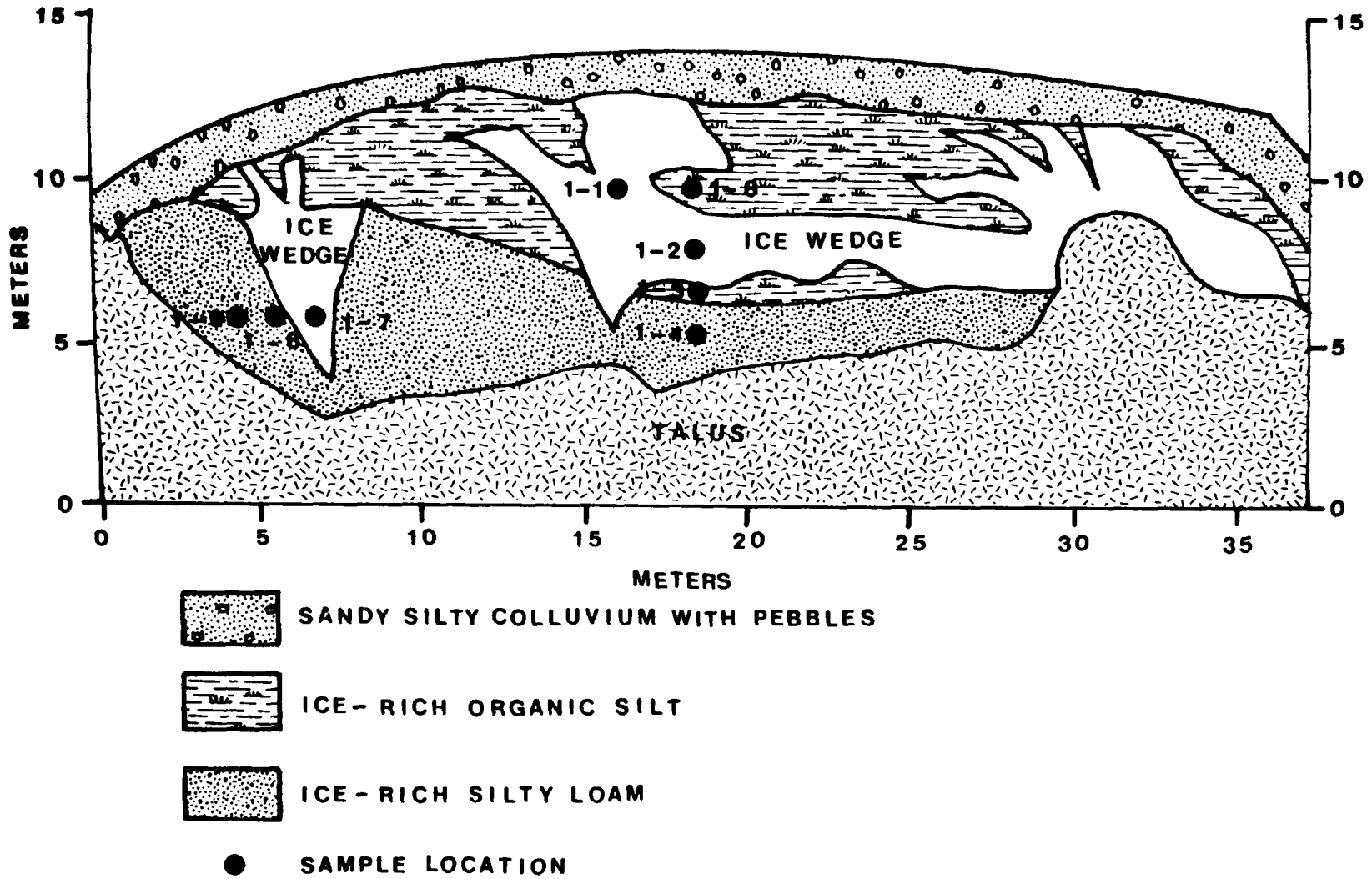


Figure 24. Permafrost section, Hunker Creek, August 30, 1980.

in table 5. Ice contents of the organic beds are relatively constant, ranging from 2% to 29%, with similar cryotextures. The mineral silts have a wider range of both ice content and cryotextures. This difference is most likely due to the nature and sorting of materials which comprise the silts.

Massive ground ice, in the form of large, inactive ice wedges, comprises 40% - 50% of the exposed face. The active layer consisted of 0.5 cm of unfrozen silt.

The proportion of ice to organic silt is exaggerated by the orientation of the face with respect to the geometry of ice wedges. In both natural and artificial sections, most wedges are seen obliquely. This exaggerates the proportion of ice observed (e.g., Mackay, 1977). During May 1980, and subsequently, as the muck and permafrost section was cleared for mining and melting took place, observations regarding the three dimensional aspects of the ice wedges were made. Since only one wedge was observed in normal section (plate 34), the interpretation of ice wedge geometry is difficult. The wedge shown is approximately 4 m high and 2 m wide at the top. 1-2 m from the top of the wedge, smaller wedges branch from the larger wedge. A polygonal wedge system exists, with wedges separated by a distance of 10-15 m.

Table 5
Ice Contents and Cryotextures of Permafrost
at Mayes Site MA-1

Sample Number	Excess Ice Content (%)	Cryotexture
<u>Ice-rich Silty Loam</u>		
1-1	6	Vr silt (med)/med.-coarse sand Vx/ silt-clay Nbe
1-4	38	Silt with Vs ice, some ice with soil inclusions.
1-6	14	Silt in Vr lenses 2-3 cm thick, randomly oriented sand and grit inclusions.
1-7	43	Wedge ice horizons bubble track.
	$\bar{x}=25$	
<u>Ice-rich Organic and Silty Sediments</u>		
1-2	29	Wedge ice, oblique bubble trains, ice with silt inclusions.
1-3	22	Interbedded organic silt, clay Vx- Vr ice.
1-5	23	Interbedded organics and silt, Nbe ice.
	$\bar{x}=25$	

(See figure 24 for sample locations.)



Plate 34. Ice wedge shown in nearly normal section. Wedge shown is roughly 3 m long with a second wedge joining the flank at the upper right hand side.

The complex geometry of the obliquely oriented wedges is demonstrated by plate 35, which shows ice wedges from the north end of the section. Branching ice wedges are common, and large volumes of included sediments are contained in the ice wedge network. All wedges observed appear to be inactive. No signs of thermal contraction at the terrace surface are noticeable, and the ice wedges appear truncated at a depth of 2 m from the top of the section. Since it was not possible to determine the maximum depth of summer thaw, which is probably at least 1 m, it is unclear whether this truncation merely reflects the base of the active layer, or is a thaw unconformity.

Thaw unconformities may be recognized by one of the following criteria:

- 1) Truncation of ice wedges and veins or other ground ice bodies;
- 2) changes in the ice content of sediments above and below the suspected unconformity;
- 3) different cryotextures above and below the suspected unconformity; for example the presence of fluid escape structures (microstructures) above the suspected unconformity, and the distribution of organic matter suggesting melting and release of water.

Other, less reliable, methods include:



Plate 35. Oblique view of ice wedge system at north end of Mayes claim, Hunker Creek. Several branching ice wedges contain large cavities filled with organic and ice-rich silts.

- 4) Increase or decrease in organic matter or the presence or absence of fossil material, indicating a change in depositional environment;
- 5) changes in the geochemistry of ice above and below the suspected unconformity.

Indicators such as conductivity, specific cation levels (Na^+ , Ca^{++} , Fe^{+++} , etc.) and oxygen, sulphur or deuterium isotopes may be used with varying success. For example, Sellmann (1967) has shown a correlation coefficient of 0.98 between concentration and conductivity, which is easily measured in the field; however, contamination of groundwater is a problem. Hughes (1974) noted the difficulty of tracing groundwater movement in permafrost regions, and the introduction of foreign ions into the groundwater system is likely. Since there is a significant amount of mass wasting in the study area, method 4) is of little value since the material in question may not be in situ. This leaves the first three methods for the recognition of thaw unconformities in the study area.

The suspected thaw unconformity in the section studied is shown by the truncation of ice wedges across the entire section. As seen in May and August, the same level of truncation appears, thus precluding the identification of an unconformity due to a geometrical coincidence.

Support for this interpretation is provided by Campbell (1952, p. 60) who states that ". . . at some time in the past the ground has been thawed to a depth of about three feet below the present upper level of permafrost, for all large ice veins end abruptly at this level and the muck shows definite signs of caving over the top of them into a cavity left by their melting."

4.4 Dawson City Townsite

4.4.1 Introduction

The nature of recent permafrost conditions was investigated at the townsite of Dawson City (lat. 64°03'N; long. 139°25'W). The townsite is situated on a floodplain at the confluence of the Klondike and Yukon Rivers. The central portion of the city is level floodplain, but the housing section to the east is situated on a moderately steep slope where coarse grained talus from the bedrock exposures above overlies and interfingers with fluvial deposits.

During late Quaternary times, the Yukon River probably occupied the entire valley, leaving a coarse alluvial fill in the valley bottom. At the confluence with the Klondike River, fine sand and silt was deposited over the underlying gravel, forming a terrace upon which the townsite is now located. Borehole data obtained by EBA Consultants Ltd. (1977, 1978) have verified that a contact

is present between the base of the Klondike deltaic sediments (organic silt) and the gravels. Thus, the south end of the townsite occupies a portion of the Klondike River delta where coarse grained sand and gravel has been built up contemporaneously with the river terrace (figure 25). The rest of the townsite is underlain by silts from the Yukon River terrace.

4.4.2 Permafrost Distribution

In the townsite, permafrost conditions are variable, depending on the nature and age of the underlying alluvium. The permafrost is thought to be modern (i.e., related to present climatic conditions). EBA (1977) notes variations in the occurrence and thicknesses of permafrost and relates this to a slough (plate 36) which separates frozen from non-frozen ground underlying the city. The boundary separating the two zones is inferred from borehole data, and roughly coincides with the boundary between deltaic sediments of the Klondike River and fine grained terrace sediments of the Yukon River.

4.4.3 Geothermal Conditions

As shown in figure 26, permafrost temperatures at the Dawson townsite are warm and thus the permafrost is very thaw sensitive. Figures 27 and 28 illustrate ground thermal conditions in frozen and unfrozen areas of town,

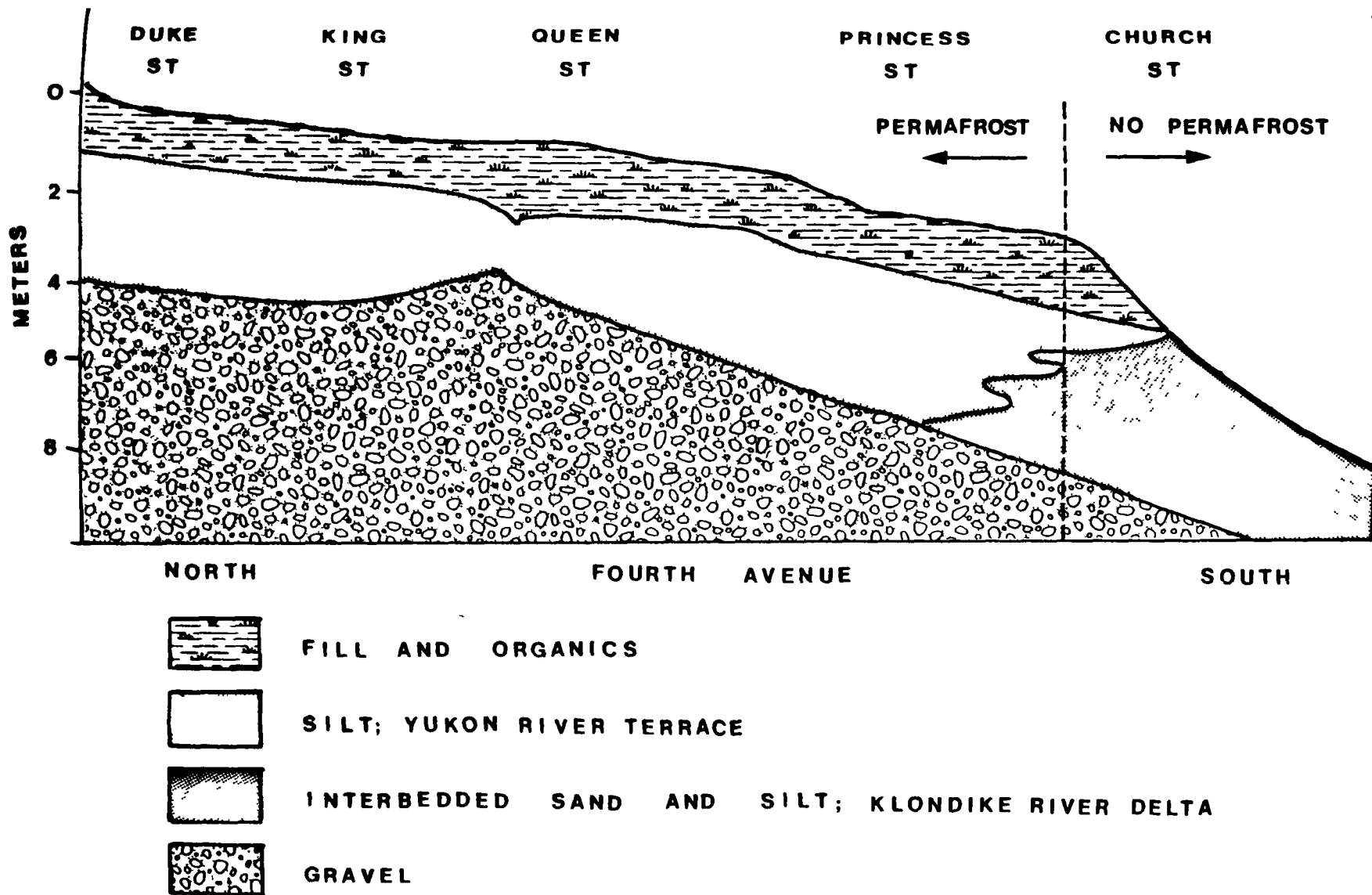


Figure 25. Cross section along Fourth Avenue showing sediments underlying Dawson City, June 1977. (EBA, 1977)



Plate 36. Townsite of Dawson City, Y.T., August 1974. Slough location is shown in black, and EBA borehole locations marked with X. Frozen zone is to the northeast of the slough; unfrozen zone to the southwest. (EMR, Ottawa, A23905-38)

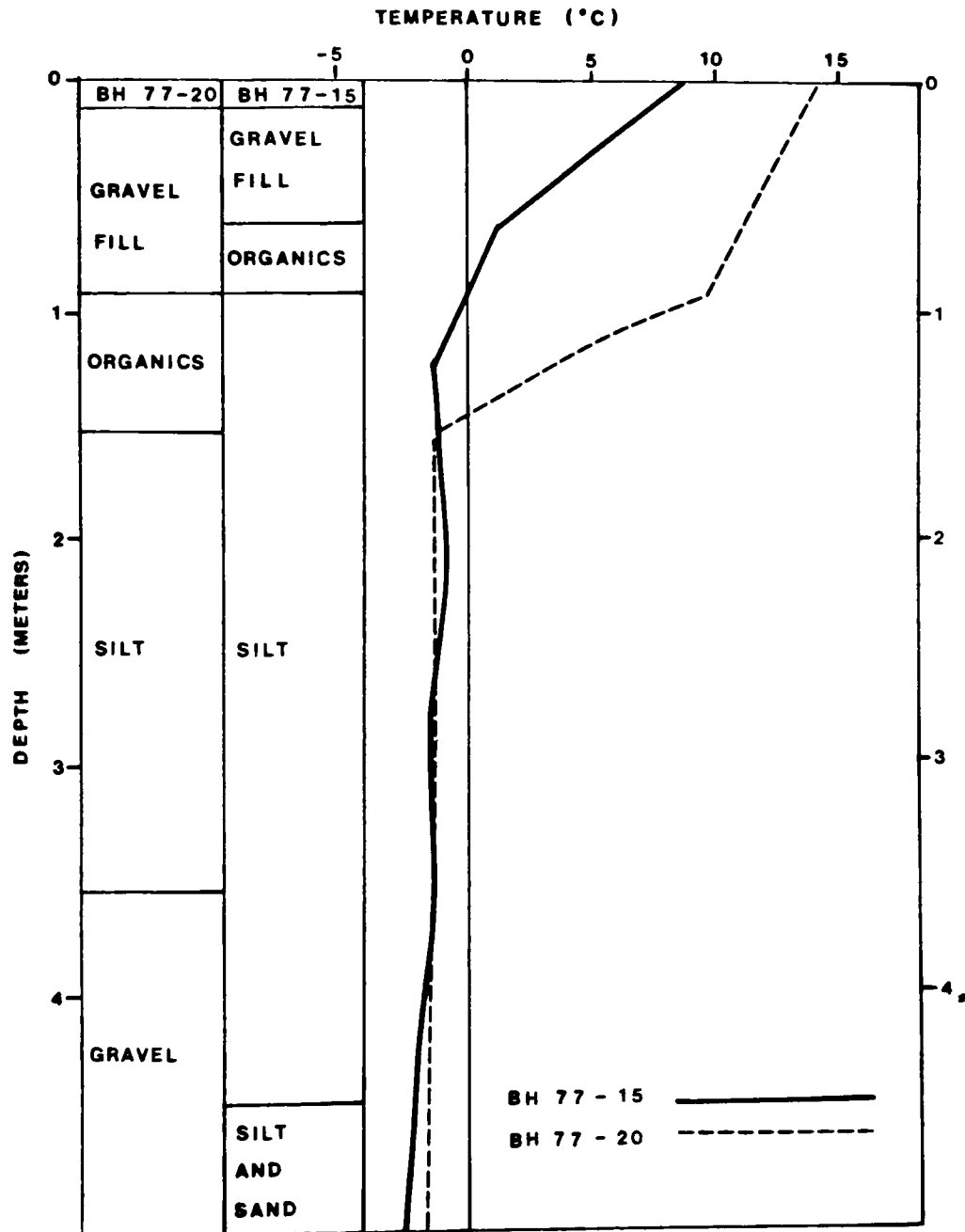


Figure 26. Subsurface temperatures, Dawson City, June 1977. (After EBA, 1977)

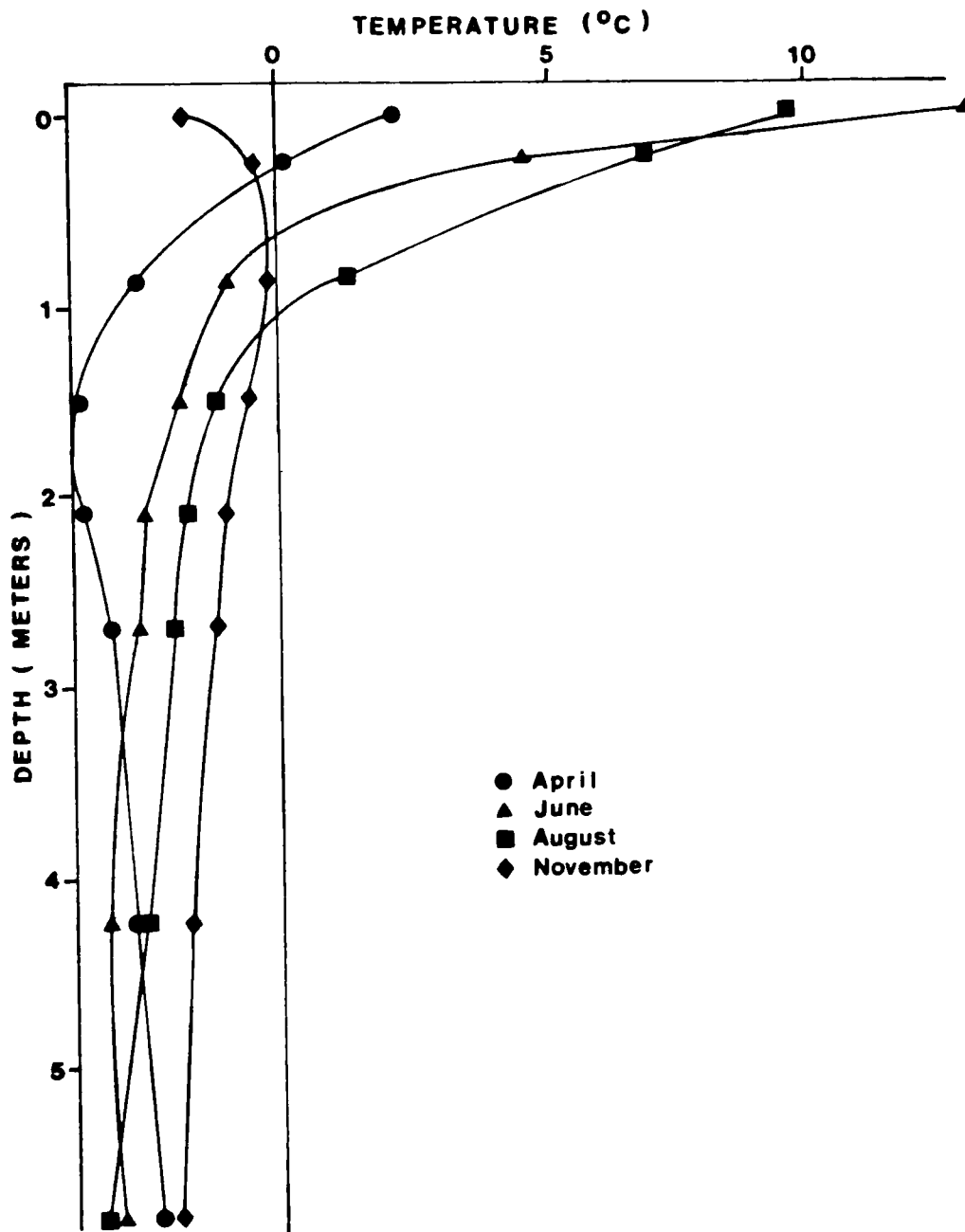


Figure 27. Ground temperature profile, Red Feather Saloon, Dawson City, Y.T. in Frozen Zone (BH 72-5).

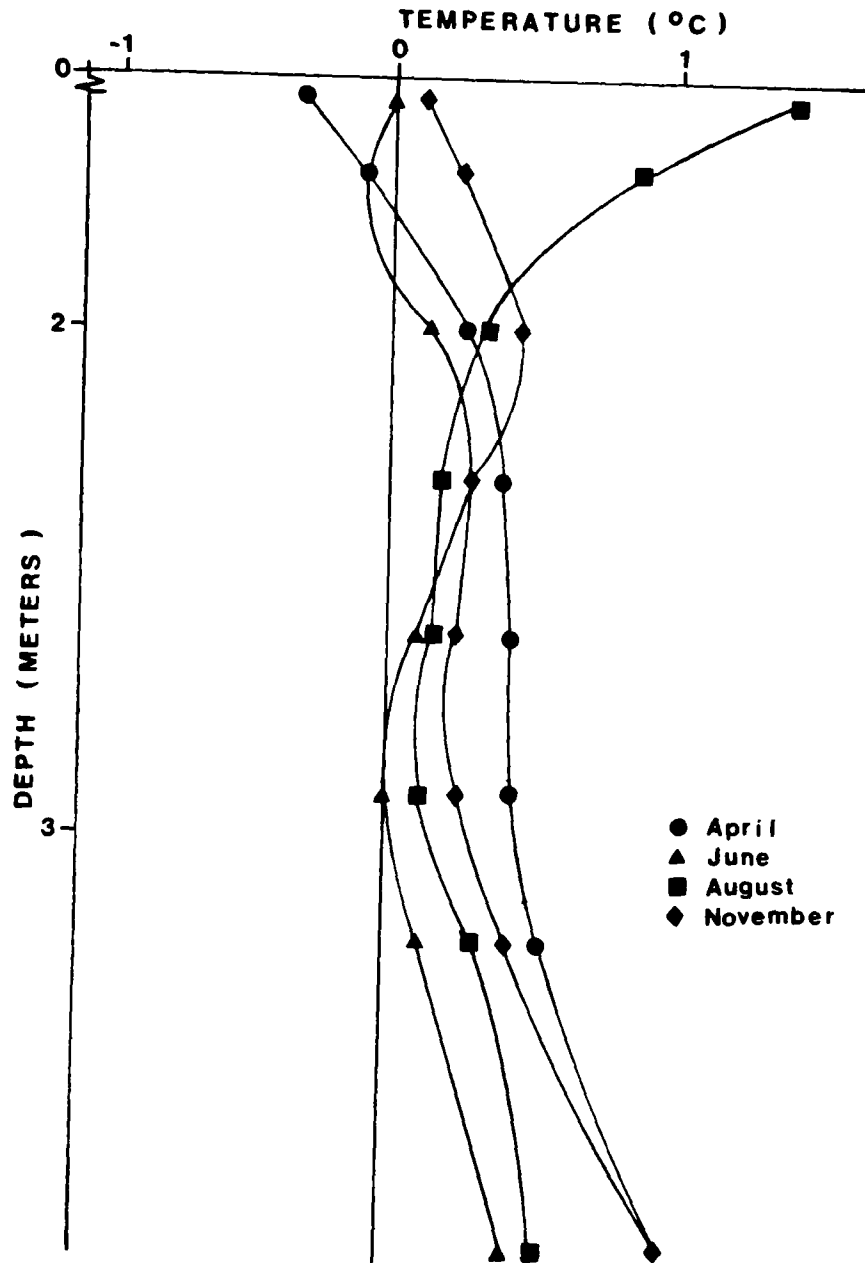


Figure 28. Ground temperature profile, commissioner's residence, Dawson City, Y.T. in Unfrozen Zone (BH 72-9).

respectively, throughout the year. The variations and trends recorded are similar to those at other localities (e.g., Inuvik; Heginbottom, 1973). Several seasonal fluctuations are clearly visible. For example, there is a significant lag time between maximum and minimum air temperatures (figure 3) and maximum and minimum ground temperatures (figure 27). Mean monthly minimum air temperatures occur in February, but minimum ground temperatures do not appear until April. Similarly, although monthly maximum air temperatures occur in June and July, it takes until September or October for the ground to warm up to maximum temperatures. A whiplash effect is present in figure 28 where cool October and November temperatures increase with depth as a result of the absorbed summer heat retained in the ground.

Active layer depths vary greatly over the townsite. Within frozen zones, the average depth is between 1 and 2 m. Where muck accumulations are thick, the active layer is thinner. For example, during May 1980, the permafrost table was interpreted to occur at a depth of 1 m at sewer trench excavations along Fourth Avenue. In the unfrozen zones (figure 28) the depth of seasonal freezing varies from 2-4 m with an average frost penetration of 3 m. This difference evidently results from the different thermal conductivities of the coarse sand and silt and the organic silt.

4.4.4 Stratigraphy and Ground Ice

At the townsite, permafrost apparently formed with, or subsequently to, the deposition of fluvial sediments. Both segregated ice lenses and ice wedges are present.

A typical permafrost section is shown in figure 29, as exposed by sewer excavations May, 1980. The section shows an interesting history of sedimentation and permafrost aggradation. Segregated ice is present in the organic-rich silts (plate 37) and occurs as highly stratified or randomly oriented lenses (Vs/Vr ice). The lenses are approximately 4-5 cm thick and may be continuous for 0.5-1.0 m. In places, the segregated ice gives a layered appearance (plate 38), termed "ice gneiss" (Mackay and Black, 1973). These sediments commonly have excess ice contents of 30-90% (by volume). In addition to segregated ice lenses, ice wedges are common in the silts. These are all of the same general size (and age) and are all truncated approximately 1 m below the surface. Wedges range in width from 50-70 cm at the top and 1-2 m in depth (plate 39).

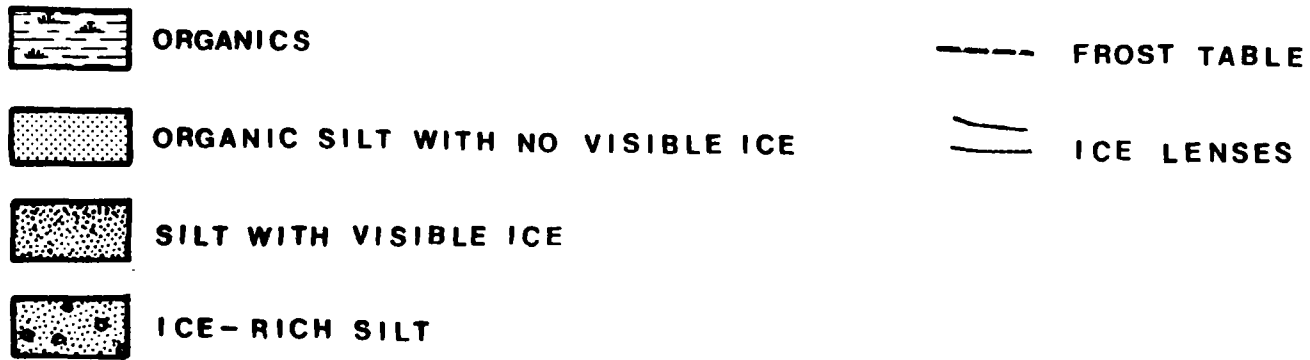
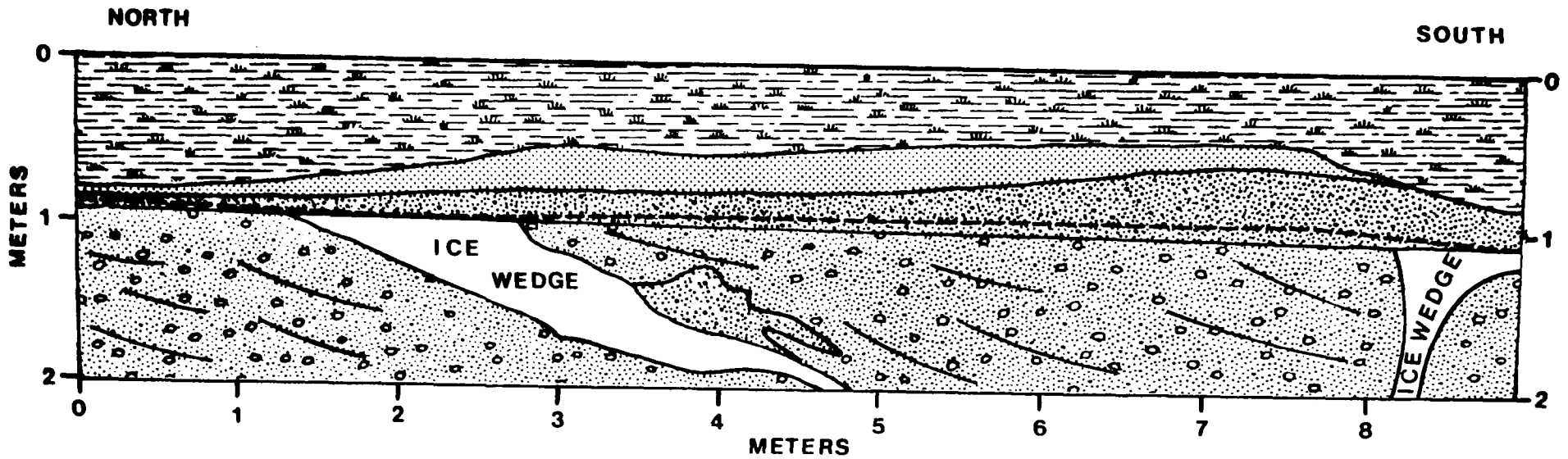


Figure 29. Section exposed near Robert Service School, Dawson City, May 19, 1980.

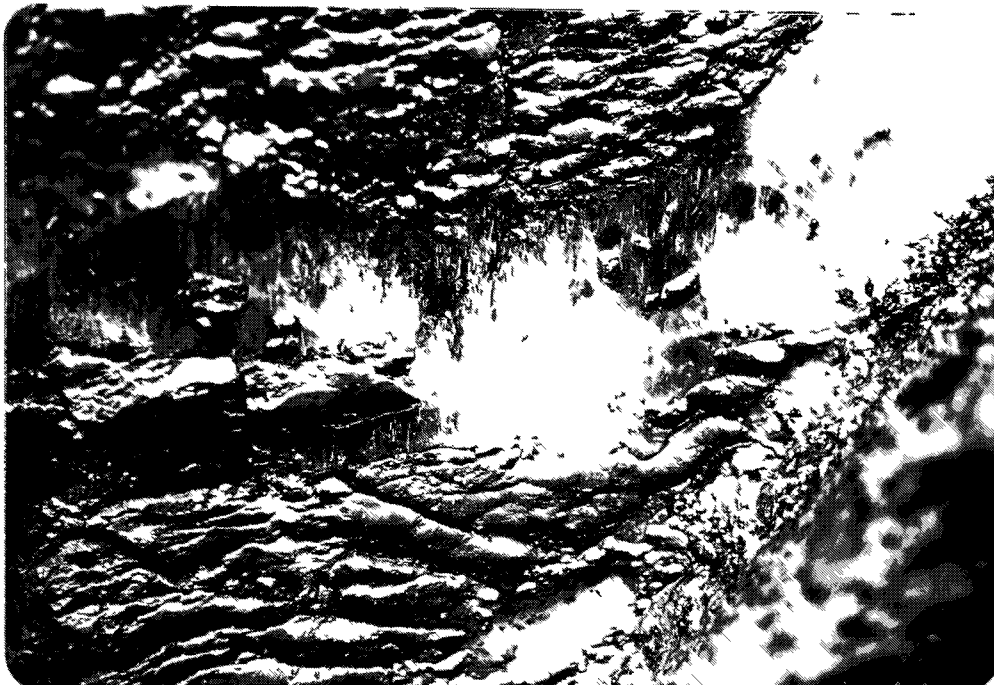


Plate 37. Segregated ice with silt inclusions exposed in sewer trenches, May 1980. Bubble trains in segregated ice are oriented normal to the freezing plane.

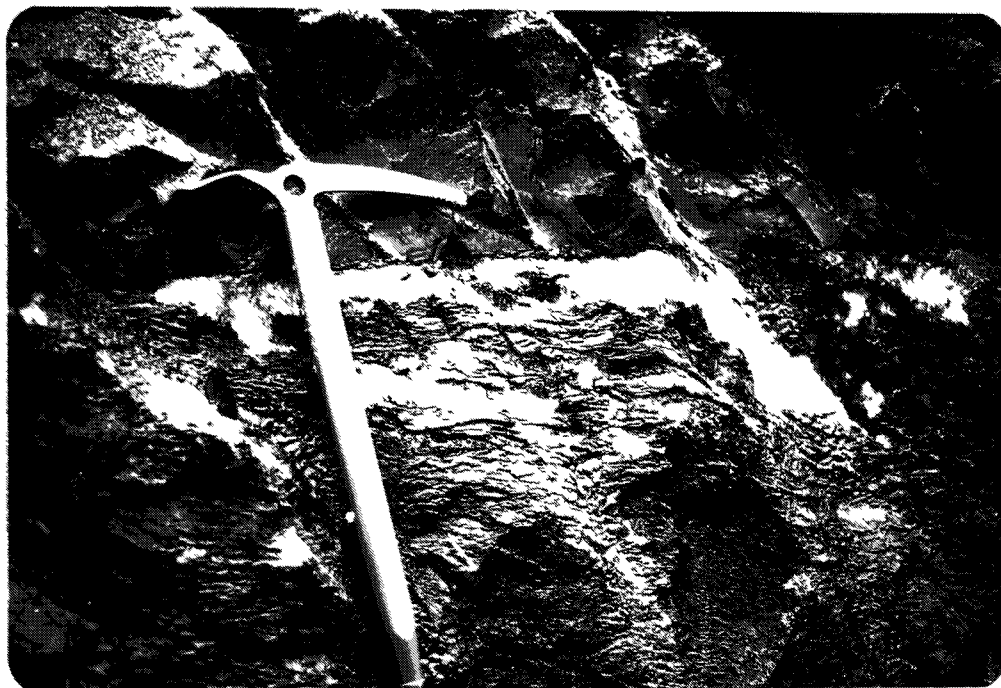


Plate 38. "Ice gneiss" exposed in sewer trench at Dawson City, May 1980. The upper unit is blue-grey organic silt with very low visible ice content (Vr). The lower unit (gneiss) is blue-grey silt with random and oriented segregation ice lenses (Vr-Vs). The abrupt ending of segregation lenses indicates the maximum depth of the active layer. The head of the ice axe indicates the approximate level of the frost table.



Plate 39. Ice wedge exposed in approximate cross-section in Dawson City sewer trenches, May 1980. (Ice axe is 55 cm long.)

5. Conclusions

5.1 Introduction

The fieldwork carried out in the summer of 1980 was of a reconnaissance nature, and thus is insufficient to make any but the most tentative conclusions about the geomorphology and Quaternary history of the Klondike. However, it would appear that this area has undergone a series of complex and interrelated events as evidenced by the Quaternary deposits of the area.

5.2 Depositional History of the Gravels of the Klondike

The earliest surficial deposits examined are the White Channel Gravel, of late Pliocene or early Pleistocene age. Facies studies undertaken in this thesis suggest that the gravel was deposited in a braided fluvial environment. A period of channel cutting followed, in which the Yellow Gravel and several smaller channel fill units resembling muck were deposited. Both the White Channel Gravel and the Yellow Gravel are highly weathered. Roundness and sphericity values are relatively high, and show a small scatter, reflecting their similar lithologies and resistance to abrasion. The sharp increase of disc and rod-shaped clasts in the Yellow Gravel may reflect

renewed fluvial action where previously deposited White Channel Gravels were reworked in more recent, smaller channels within the original alluvium. This is shown also in the facies of the Yellow Gravel which contain an abundance of fines compared to the White Channel Gravel. This suggests a more distal position than the relatively proximal White Channel Gravel. The heavy iron staining of the Yellow Gravel is a product of intense oxidizing, a possible result of a warming climate.

The interfingering and other contact relationships (section 3.4) with the Klondike Gravel suggests that this unit was deposited contemporaneously with, or immediately subsequent to the deposition of the White Channel Gravel. The relatively wide scatter of roundness and sphericity values for the Klondike Gravel are a function primarily of the varied lithologies, although rapid erosion and transport of the clasts may be important also.

A marked change in source, weathering and/or depositional environment occurs between the White Channel Gravel and the Klondike Gravel. Since the earliest (Pre-Reid) glaciations were the most extensive of all Pleistocene glaciations in the Yukon, it is unlikely that different source areas are responsible for the varying lithologies found. A wide range of bedrock occurs in the glaciated

areas, and any of these lithotypes could be expected in the outwash gravels. Thus, weathering and depositional environments must have differed.

The clast type (i.e., lithology, roundness, sphericity and form) of the White Channel Gravel suggests a long period of weathering prior to deposition. This must have been in Miocene or earlier time. This hypothesis is supported by high placer gold values in the White Channel Gravel, suggesting some period of weathering. By contrast, the Klondike Gravel is considered economically barren, and contains only residual placer gold from White Channel Gravel deposition.

The White Channel Gravel contains a high proportion of matrix supported gravel, which is structureless, compared to the well-bedded Klondike Gravel. At the same time, the fine facies found in the upper members of the Klondike Gravel are absent from the White Channel Gravel, and the large boulders found in the lower sections of White Channel Gravel are not found in any unit of the Klondike Gravel, where maximum clast size is generally smaller. These characteristics, along with the abundance of separate fine grained facies, are indicative of waning currents and/or channel migration and a more distal position for the Klondike Gravel.

5.3 The Late Quaternary Environment

During Reid and earlier glaciations, eustatic lowering of sea level exposed the Bering land bridge and at the same time during Reid glaciation, a large portion of the Bering Refugium inhabitants crossed the bridge from Eurasia. The numerous fossil megafauna found in the Klondike muck deposits have radiocarbon dates from 15,000 to >39,000 BP. Thus, at some time during this period, the Klondike area was inhabited by a boreal forest/steppe-tundra community representing the eastern limit of the Bering Refugium. In the study area, this association is evidenced by remains such as the Saiga tatarica horn core found in May 1980 at Hunker Creek.

The relict ice wedge system found beneath the fossiliferous muck must have developed during either the Reid or McConnell glaciation, when cold periglacial conditions characterized the unglaciated Klondike region. Similar muck and ice wedge systems are found throughout the unglaciated central Alaska area, and have been documented by Péwé (1974, 1977). The distinct thaw unconformity found in the section MA-1 is likely the result of the climatic optimum following McConnell glaciation, and occurs at a similar depth to unconformities found along the western Arctic coasts and in the Mackenzie Delta (e.g., Mackay, 1971, 1975; French, Harry and Clarke, 1981).

After the McConnell glaciation, the high flow of the Yukon River subsided and the main Yukon River terrace, on which Dawson City is located, formed. As the Klondike Delta prograded onto the terrace, permafrost aggraded into the finer sediments. Ice wedges as observed in the May 1980 sewer excavations also formed. In all probability, the apparent truncation of ice bodies 1 m below ground level in Dawson City simply reflects the present depth of seasonal thaw. However, wedges truncated at 2-3 m depth and exposed at the Mayes claim, are better interpreted as inactive ice wedges which were truncated during the post-glacial climatic optimum.

5.4 Recommendations for Future Study

Because of the reconnaissance nature of this study, detailed analysis was not possible in many instances. Many opportunities exist for future study of the Klondike surficial deposits. For example, weathering profiles and pollen analyses could give an indication of the climate and time involved to produce the quartz assemblage of the White Channel Gravel, and might help to clarify the temporal relations between the White Channel Gravel and the Klondike Gravel. Similarly, these studies would also help typify the environment at the time of renewed channel cutting when the Yellow Gravel and correlative valley fill sequences were deposited. Geochemical studies of the Yellow Gravel would determine

if the coloration is indeed due to iron oxides, or to other sources which may be climatically related.

Recognition and mapping of the ice wedge casts reported by O. L. Hughes from the White Channel Gravel would help to define the periglacial environment subsequent to the deposition of the gravels.

In order to further elucidate the permafrost history of the Klondike, radiocarbon dating of the muck together with palynological and coleoptera studies might prove useful. Present studies indicate that the valley bottom muck deposits are composed partly of residual materials (e.g., stumps, mosses and other locally derived weathering products). Muck found higher in the valleys and stratigraphically above the valley fill deposits appear to be partially of wind-blown origin. To differentiate muck units, SEM techniques might be employed to distinguish between locally derived muck (i.e. silt from slopewash or in situ weathering of organic material) and wind-blown silt similar to the loess found in central Alaska. Identification of surface textures indicative of aeolian processes would greatly aid in the identification of these units. Frosting, chatter marks, micro-striations and identification of micro-ventifacts in the mineral components of muck would indicate aeolian origin. Ventifacts have been found in other south-central Yukon localities (e.g., McQueston and Carmacks) and, if present in the Klondike, should be found in the upper muck deposits.

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