Geomorphology of the Klondike Placer Goldfields, Yukon Territory

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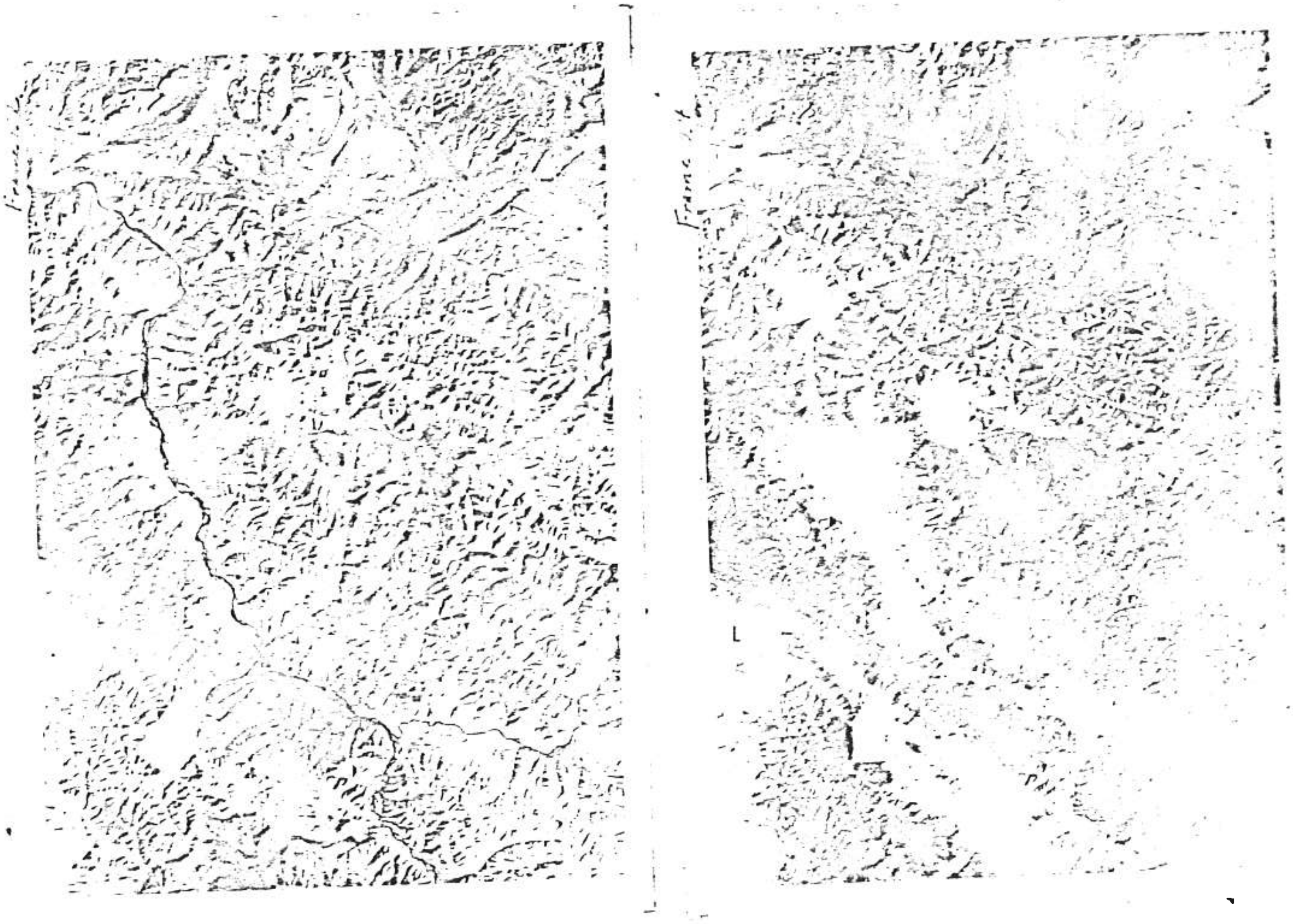

FRONTISPIECE - Parts of Landsat Images, Klondike region

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CHAPTER I

INTRODUCTION

Purpose and scope.

The Klondike Goldfields are situated between Indian River, to the south, and the Klondike River, to the north, both westerly flowing tributaries to the Yukon River. The area lies between latitudes 63°30' and 64°10' north and longitudes 138°30' and 139°30' west and is a few miles southwest of Dawson, Yukon Territory, Canada (Fig. 1).

The "Klondike" was one of the richest known concentrations of placer gold. No adequate explanation of its origin has appeared; no known lode gold occurrences could have released the amount of placer gold mined from the creeks and alluvial terraces. The purpose of this study is to assemble all available information and to interpret the geomorphic history of the goldfields; to identify possible bedrock sources of the gold; to describe processes of weathering and gold release in the source area, modes of transportation on slopes, and mechanisms of transportation and concentration in streams; and to identify geomorphic principles relevant to the location of, and prospection for, placers in the Klondike and other similar areas.

Both bedrock and surficial materials exert a strong control on topography. The positions of some terraces and the widths and configurations of valley floors are related to specific rock types. The understanding of landforms, drainage patterns, stream gradients, slope forms and geomorphic processes in the Klondike requires comprehensive knowledge of the bedrock. Much of the bedrock information

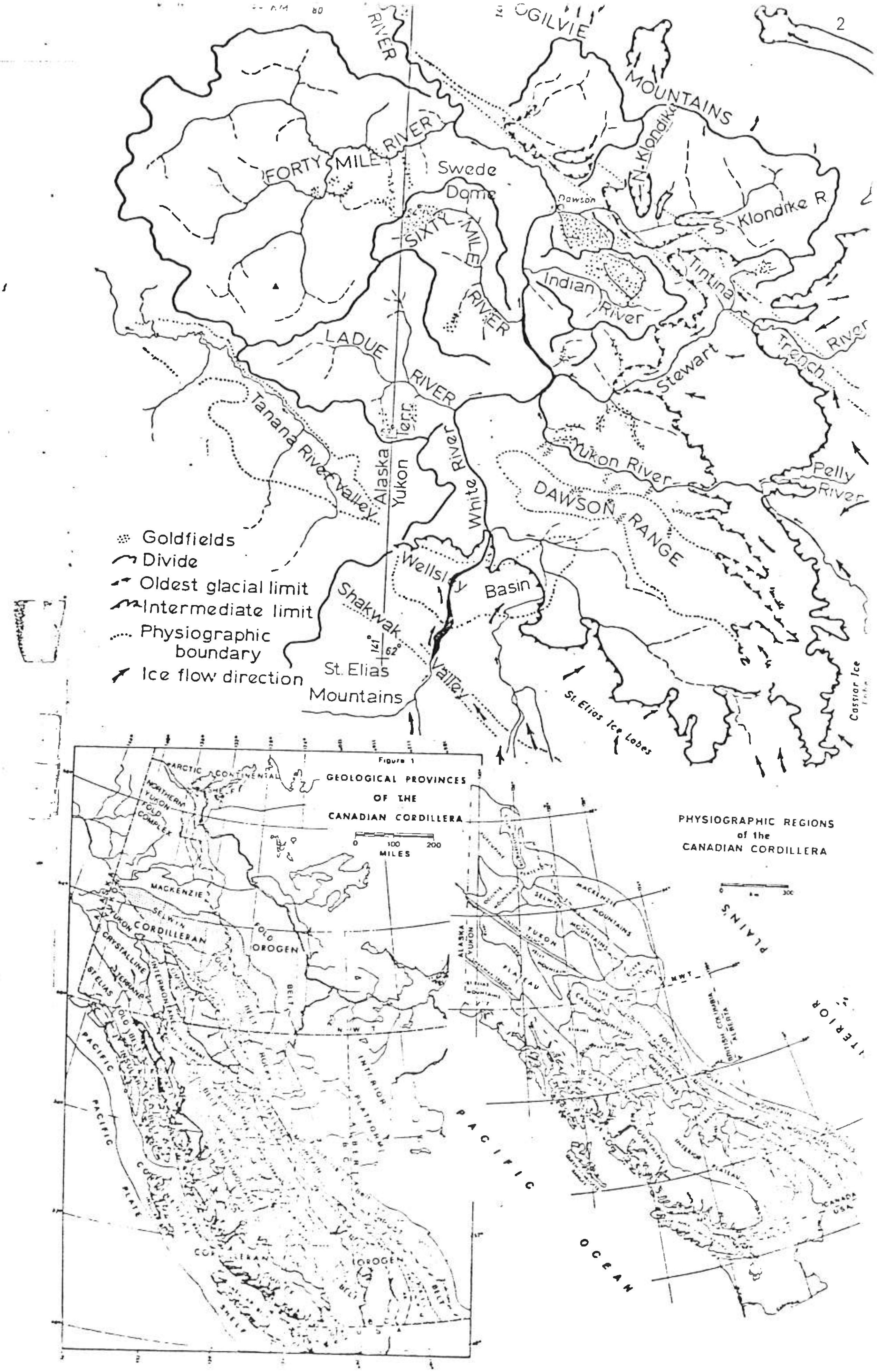

FIGURE 1. Location maps.

is available only on a reconnaissance scale. Pebble shapes and the mineralogy of sands are both indicators of provenance and both influence fluvial concentration. The physical and chemical maturity of sediments and the weathering of source rocks and alluvium are strongly influenced by lithology. Sedimentary textures as indicators of modes of transport also vary with lithology. Hence, because of its importance to this study, bedrock geology receives strong emphasis.

Surficial materials encountered in present day mining operations include overburden that impedes some mining techniques. Colluvium also obscures the terrace geometry of the placer deposits and is therefore included in the study.

The characteristics of placer gold particles give information on metallogenesis, provenance, and on the possibility of secondary enlargement. Such enlargement *in situ* could result from regional metamorphism, from supergene enrichment in the source rock, from agglomeration during transport, from diagenetic growth of gold particles in the creeks; or possibly a combination of these.

Thus the scope of this study is wide and encompasses the genesis of placer gold deposits, and their recycling in a periglacial environment.

Previous work and source of data.

Bostock (1957) reprinted most of the reports of the work done by the Geological Survey of Canada in the Yukon Territory prior to

1933. In 1878, G. M. Dawson reported on mineral occurrences in the northern Canadian Cordilleria and together with R. G. McConnell and William Ogilvie led the "Yukon Expedition of 1887-88". The latter two passed Deer Flats, which became the site of Dawson City in 1897, named after G. M. Dawson, son of Sir William, principal of McGill University. Tyrrell and McConnell visited the area again in 1898 and reported on the activities in the developing Klondike Goldfields. McConnell returned in 1900 and again in 1903 when he completed the first map of the bedrock geology of the Klondike area. In 1906, McConnell evaluated the gold-bearing high level gravels. Cairnes visited the area briefly in 1911 to examine lode gold prospects in the Klondike; this work was continued in more detail in 1913 by MacLean (1914). Cockfield, in 1929 and 1930, reported on the mining activity in the Yukon Territory including the Klondike. Bostock continued to write annual mining reports until 1941. More detailed mining reports were published by the Geological Survey of Canada from 1960 to 1968 and these have been continued by the Department of Indian and Northern Affairs from 1969 to 1974.

Bostock (1942) mapped the area south of the Klondike River (N.T.S. 115-0, Stewart River map sheet then referred to as Ogilvie, G.S.C. Map 711A at the scale 1:253,440) including some revision of the southern part of the Klondike previously mapped by McConnell at the scale 1:126,720; Green and Roddick (1962) and Green (1972) mapped the area to the north (N.T.S. 116B-116C E/2, Dawson) at the scale 1:250,000.

Campbell (1952) studied the paleobotany of the overburden (muck, colluvium) and Harington and Clulow (1973) reported on vertebrate fossils in the surficial material overlying the auriferous gravels. Harington has continued to collect these fossils in this "muck" annually since 1966 as a project of the National Museum of Canada.

Gleeson (1970) carried out heavy mineral studies in 1962 with the goal of outlining sources and reserves of placer gold and of identifying possible by-products of placer mining in the Klondike.

Vernon and Hughes (1966) mapped surficial geology north of the Klondike area and Hughes *et al.* (1972) present a summary and reinterpretation of the geomorphology of the goldfields. Hughes (1969) reported evidence of Pliocene-Pleistocene thrusting and crustal arching in the area.

Much unpublished information is used in this study. The Yukon Consolidated Gold Corporation, the only large mining company active from *ca*. 1930 to 1966, deposited most of its records with the National Archives in Ottawa, where they are held in a restricted category. The Yukon Territorial Archives, in Whitehorse, has collected photographic negatives recording some mining operations in the Klondike. The Royal Canadian Mint, in Ottawa, has records of gold deposits and contained gold and silver for individual shipments - these were made available for purely statistical purposes. These records, government mineral industry reports from 1960 to the present and Dawson Mining Recorder records from 1950 to 1960, have been useful in constructing the later history of the creeks, the approximate grade of gravel being mined then and the locations from which gold shipments were derived.

CHAPTER II

BEDROCK GEOLOGY

GEOLOGICAL SETTING

The Klondike Goldfields are in the Yukon Crystalline Terrane (Gabrielse, 1976) which is the result of Triassic regional metamorphism (Green, 1972), southwest of the Tintina Trench. The Tintina Trench is the topographic expression of a Mesozoic right lateral fault of some 250 miles displacement (Templeman-Kluit, 1966; Roddick, 1967). Shear zones parallel to the Tintina Trench occur in the Klondike area (Gleeson, 1970; Aho, 1959) and major lineaments and faults with similar trends occur in and southwest of the Klondike area (Fig. 3).

McConnell (1903) classified rocks of the area into older schistose rocks, comprising the Klondike Series and the Nasina Series; igneous rocks; and unaltered, lower Tertiary sedimentary rocks. Newer information suggests an age framework for his units.

PREMESOZOIC BASEMENT ROCKS

KLONDIKE SERIES

The Klondike Series of McConnell and his subdivisions, Klondike Schist and Pelly Gneiss, are used for their descriptive values only; the sedimentary and metamorphic genesis for these and similar rocks of Green (1972) is more generally favoured over McConnell's theory of igneous origin.

The geomorphic significance of the main rocks of the Klondike Series follows.

FIGURE 2. Geological map of the Klondike area (after Bostock and Green) (see Fig. 17 for creek names)

Klondike Schist

Quartz-sericite schist. The most common rock within the Klondike Schist is quartz-sericite schist. It varies from a sericite schist to a sericitic quartzite, a common clast lithology in the auriferous gravels. In general it is geomorphically neutral and is seldom naturally exposed; but the more quartzitic, structurally and geomorphically competent varieties outcrop and produce coarser debris on slopes and in streams. Schistose phases tend to weather recessive so as not to produce outcrop or coarse float. Marble (Gleeson, 1970, p. 31), as well as dark graphitic phases, occurs sparsely within the rock type.

Quartz-eye schist. Commonly with blue quartz grains, quartz-eye schist appears most abundantly in the area of Eldorado and lower Bonanza creeks associated with a more quartzitic variety of quartz-sericite schist. This association tends to be more competent than the quartz-sericite schist and forms ridges. Physical weathering processes tend to produce large blockey fragments on slopes and in streams. This rock supports relatively well exposed ridges but it may weather into slabby, flaggey, or even shaley material depending on the thickness of the more competent bands in the schist. This rock type, although characteristic of the Bonanza Creek area, also occurs on Sulphur Creek near Friday Gulch. A variety, quartz-feldspar-eye schist, is on ridges west of the Bonanza-Eldorado area (McConnell in Bostock, 1957, p. 74).

Chlorite schist phase. The Klondike Schist contains a chloritic variety which is a source rock for gold (Gleeson, 1970) is mainly in two belts (Fig. 2), one along the ridge between Gold Bottom and Hunker creeks through King Solomon Dome and Dominion Mountain and down Gold Run Creek, and a second east of upper Bonanza Creek. This phase is here subdivided into quartz-magnetite-chlorite schist, quartz-carbonate-chlorite schist, and amphibole-quartz schist.

Quartz-magnetite-chlorite schist occurs within the chlorite schist phase of the Klondike Schist along the crest of the ridge north of King Solomon Dome near the Mitchell Vein (Fig. 19); it is probably the cause of the weak magnetic lineament that parallels the chlorite schist phase (Geological Survey of Canada aeromagnetic map 7868G), and is probably the source of the abundant magnetite in the gravels of Caribou Creek as well as some of the magnetite in Hunker Creek.

Quartz-carbonate-chlorite schist outcrops near the confluence of Gold Bottom and Hunker creeks. It appears as pebbles and cobbles in Gold Bottom Creek and as colluvial clasts on the east side (right limit)*. Because magnetite sand is more abundant in Upper Hunker Creek east of the westerly dipping chlorite phase belt and distinctive quartz-carbonate-chlorite schist pebbles occur only in Gold Bottom Creek, on the west, it is assumed that the carbonate-bearing schist occurs west of the ridge in the chlorite phase belt and structurally above the

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* The right limit is the right bank of the channel looking downstream, the geographic term right fork refers to a branch view as if walking upstream.

magnetite-bearing schist, on opposite sides of the Hunker-Gold Bottom divide (Fig. 2). The aeromagnetic anomaly which also indicates a westerly dip, is slightly to the east of, and parallel to the major ridge in the chlorite schist phase. Local and regional banding and schistosity dips to the west.

Amphibole-quartz schist, an uncommon variety of crystalline rock, occurs in gravels of Caribou Creek and Friday Gulch, on opposite sides of the ridge that coincides with the chlorite schist phase.

Amphibolite. A distinctive white and green, coarse grained amphibolite, probably originally a dike, trends across the ridge between Gold Bottom Gulch and upper Bonanza Creek and forms cobbles and pebbles seen only below Gold Bottom Gulch, and in dredged bedrock on Sulphur Creek.

Granitic rock. A coarse-grained homogeneous "granite", occurs as blocky colluvium high on the right slope of the head of Right Fork, Hunker Creek, opposite the Mitchell Vein. Minor dikes cut the country rocks. In airphotographs frost river blocks of "granite" appear light toned because they support a floor of caribou moss. This lithology is represented in Hunker Creek gravels by scattered, relatively large rounded boulders.

Pelly Gneiss

Gneissic granite. A coarse grained, massive to schistose quartzo-feldspathic rock, occurs in the southeast of the area. It occurs as a resistent rock, forming ridges west of Quartz Creek mouth, and east of lower Dominion Creek, where there are prominent tors. Elsewhere it seems to form valleys such as lower Quartz and Sulphur creek valleys. Green (1972, p. 118) describes a similar lithology in the Sixty Mile River area south of Swede Dome (Fig. 7). Very likely the geomorphic response on ridges is due mainly to cold climate geomorphic processes of the present and Pleistocene time, whereas the valleys are the result of chemical weathering in a former, warmer, late Tertiary climate.

Mylonite. Small occurrences of mylonite, a common variation of the Klondike Series, are ubiquitous.

Age and Correlation of Klondike Series.

The Klondike Schist has been compared by Green (1972) with his unit 3, which is the "grit unit" of several authors, in the Yukon and British Columbia and probably represents arkosic sediments of Cambrian age of earlier. However, Templeman-Kluit and Wanless (1975, Fig. 4) suggest a younger, Devono-Carboniferous age for rocks in the Klondike and Sixty Mile regions. Further support for Green's tentative correlation is the presence in the Klondike Schist of marble, of iron carbonate (the quartz-carbonate -chlorite schist lithology) and of abundant magnetite in some parts, all of which resemble features in the grit unit. The chlorite phase of the Klondike Schist is probably related to Green's unit C, greenstone, which interfingers with his unit B, Klondike Schist, and which has a correlative in the grit unit. This correlation of greenstone units in Klondike Schist and grit unit contradicts Roddick's (1967) designation of upper Paleozoic for this unit.

The amphibolite dike could be related to the chlorite schist unit.

The granitic rock at the head of Hunker Creek may be part of the Pelly Gneiss. If so it sheds new light on the origin of that rock. It appears to be igneous and relatively fresh with intrusive relationships to the surrounding schist. If the basis of Green's gradational contact between the Pelly Gneiss and the Klondike Schist (p. 114) is bedrock exposure and dredged bedrock fragments in tailings on lower Sulphur Creek, and if that part of the creek is a fracture zone as suggested (Fig. 3) in this report, then the contract is not gradational and the Pelly Gneiss does not represent regionally metamorphosed Klondike Schist, as Green proposes. Rather the Pelly Gneiss is a granite intrusive into sediment, both of which were sheared and metamorphosed in the Triassic. Pelly Gneiss and Klondike Schist as Mertie and Cockfield believed (Green, 1972, pp. 119, 114), as well as Green's model, are shown in schematic cross section of Figure 2. Gleeson (1972, pp. 33, 36, 48) favours an intrusive origin on the basis of the metamorphic minerals, garnet, kyanite and staurolite in streams near the contact.

NASINA SERIES

The Nasina Series of McConnell has "alternating shales, flags, quartzites, and limestones". Five main lithologies are here recognised: graphitic phyllite, black quartzite, black carbonate phyllite, marble, and banded quartz rock. The Nasina Series outcrops in the Klondike River valley and in the lower parts of Bonanza, Bear and Hunker creeks, in the lower section of Hunker Creek and in some parts of Last Chance Creek. It also is present in the south of the study area along Indian River and in Dominion Creek.

Graphitic phyllite. The most common lithology of the Nasina Series is a graphitic phyllite. It underlies much of the exceptionally wide segment of the Klondike River Valley below Hunker Creek. It appears on the lower part of Bonanza Creek and consists of narrow bands, possibly fault slices or recumbent folds, forming recessive and irregular slopes when adjacent to more competent rocks on Lovette Hill and in the lower part of Bear Creek. The presence of this rock type below the Eocene (?) unconformity on Hunker and Last Chance creeks - also on Indian River - and its coincidence with the very wide Pliocene (?) valley of Hunker Creek from below Gold Bottom Creek, as well as the present inner valley of Hunker Creek mentioned above, attests to the topographically recessive geomorphic role character of this lithology has played in a variety of morphogenetic environments.

The rock is well exposed in a fault zone visible in the old bedrock drain from the north end of Dago Hill. It is also seen on the mined bedrock terrace, on the upstream end of Dago Hill, on Paradise Hill and on Nugget Hill.

A garnetiferous variety of black, interbanded phyllite and quartzite underlies the broad valley of Dominion Creek below Portland Creek.

Isolated, relatively thin bands of black phyllite occurs on the north side of Temperance Hill near the mouth of Gold Bottom Creek. A similar, wider band crosses Bonanza Creek through Boulder Hill where it is exposed on the bedrock terrace and in the bedrock drain, under Bonanza Creek, as indicated in dredge tailings, up the right inner valley wall where it is eroded to form an asymmetric theater (discussed later), and outcrops again in an overflow gully from the Bonanza Creek ditch system in Queen Gulch.

Black quartzite. Relatively minor in distribution, black quartzite is best exposed on the upstream end of Paradise Hill, where it forms a very well preserved strath terrace. It also outcrops in the narrows on Hunker Creek below Paradise Hill and supports spurs at the narrows near the mouth of Hunker Creek. Theater slopes in the last location are presumably underlain by graphitic phyllite.

Black carbonate phyllite. This rock type underlies a wide section of Hunker Creek above Independence Creek, where in dredge tailings it displays sedimentary banding, moderate cleavage and abundant pyrite crystals.

White marble. Bands of marble with associated sacaroidal, white "quartzite" occurs in the oldest bedrock drain from Paradise Hill, on the right limit of Hunker Creek near Eighty Pup, on both sides of Wet Gulch opposite Last Chance Creek, and just above the narrows, on lower Hunker Creek, opposite Henry Gulch. Marble also occurs in thin bands and pods in schist above the mouth of Hunter Creek on Dominion Creek and, according to Bostock (1942), in an extensive area on Jensen Creek. It is very local in extent and has little geomorphic importance, but is a valuable marker bed for structural interpretation. It also is a source of of lime in the soil and, like the lime rich gneiss near Allgold Creek, promotes the development of local, striking limey soils on slopes which are useful in tracing marker beds.

Banded quartz rock. This is observed only as cobbles in the Pliocene (?) gravels of Last Chance Creek, and from tailings on a Pleistocene terrace on Hunker Creek below Independence Creek near Nugget Hill. The rock is probably a recrystallized chert. Milky white bands alternating with bluish grey bands are in tight drag folds suggesting deformation and recrystallization of a relatively competent rock. The banded quartz rock is thought to occur near the western margin of the Nasina Series of the Hunker-Last Chance area. The same lithology appears in conglomerate on MacKinnon Creek.

Age and Correlation of the Nasina Series.

The Nasina Series of McConnell is grouped with similar rocks to the west by Green; however, to the west there is more marble, some of which is fossiliferous. Also the western rocks are mainly quartzite with less schist than is usual in the Nasina rocks of the Klondike area. Green infers that the Nasina "Series", unit A, is older than the Klondike "Schist", unit B. Green does not attempt to correlate these rocks with similar rocks on the opposite side of the Tintina Trench. Templeman-Kluit (1974, Fig. 7) does not show Nasina rocks near the Tintina Trench probably because of the scale of his figure and

Templeman-Kluit and Wanless (1975, Fig. 4) do not indicate Nasina quartzite in the Klondike area either. The area of McConnell's Nasina Series is designated Klondike Schist, Pelly Gneiss, or a combined schist-gneiss unit by them. This may be due to generalization because of the small scale of their figure or the inclusion of those rocks as a facies of the Klondike Schist. These authors do recognise Nasina Quartzite west of Dawson in the area mapped by Green. They indicate that the Nasina Quartzite is older (Ordovician, Silurian, Devonian) than the Pelly Gneiss and Klondike Schist (upper Devonian and Mississippian).

A simple, regional, structural interpretation places the Nasina Series on lower Dominion Creek stratigraphically below the Klondike Schist with the chlorite phase near the base of the Klondike Schist and the quartz-feldspar-eye schist near the top of it as shown in Figure 2.

ULTRAMAFIC ROCKS

Ultramafic rocks in the Klondike area fall into three groups depending on the degree of alteration: peridotite, serpentinite, and steatite.

Peridotite. Alpine type peridotite (Green, 1972) occurs in zones parallel to the Tintina Trench forming some of the more prominent hills like Mount Leotta, on the divide northeast of Hunker Creek. These masses are partially serpentinised, perhaps more so near their margins, but are relatively large, prominently magnetic, and topographically positive features.

Serpentinite. It occurs in association with the Hunker Creek Fault (see Fig. 2). It is cut by brown carbonate and in places, also, talc and occurs along Hunker Creek beneath the bedrock terrace of Pliocene (?) age. It is, relatively unsheared, in the bedrock drain from the hydraulic cut between Paradise Hill and Eighty Pup and on Paradise Hill where weathered, soft, white talc and associated serpentinite occur in the downstream and the upstream bedrock drains. Serpentinite with carbonate veins and associated actinolite occur as float on the Gold Bottom Creek side of Temperance Hill and on the right bank of Hunker Creek opposite Gold Bottom Creek. On Dehli Hill massive serpentinite occurs in the bedrock drain in contact with quartz-sericite schist. This schist contains an apple-green micaceous mineral perhaps because of chromium metasomatism. A prominent magnetic anomaly crosses Hunker Creek below Dehli Hill; perhaps it represents a large magnetic serpentinite mass that may be continuous with the occurrence opposite Gold Bottom Creek. The presence of pebbles of the green actinolite in gravel in the mouth of Mint Gulch suggests a nearby ultramafic source. Distinctive carbonate-bearing talc occurs as rounded pebbles on the bedrock terrace on the left bank of Allgold Creek below Alexandra Creek and as angular colluvial fragments overlying the alluvium.

These occurrences on the Hunker Creek Fault are on or near a bedrock terrace, suggesting that they are geomorphically weak rocks;

however, the fact that these same rocks are exposed in the artificial openings of bedrock drains at the margin of the weathered, vulnerable bedrock terrace, suggest that they are relatively resistant to fluvial erosion as well as mass wasting, and protect or fortify adjacent weak rocks in the bedrock terrace. This "buttress effect" analogous to "defending bedrock ledges" in the alluvial terraces of Davis (1909, p. 549) applies to all intrusive rock types in the Hunker Creek Fault.

Serpentinite occurs on Last Chance Creek in the bedrock drain from the north end of Discovery Hill. There foliated serpentinite with minor carbonate veins forms the end of the bedrock drain beyond which the tailings fall several tens of feet into a gulley cut into Nasina phyllite.

An isolated piece of soapstone float found near Seven Pup, Victoria Gulch and together with the occurrence on Last Chance Creek may be related to a major fracture zone as discussed later.

A ledge of serpentinite appears through colluvium on the right limit of Gold Bottom Creek about two miles above its mouth and is a unique source of serpentinite cobbles as well as pebbles of green actinotite in a groundmass of talc.

<u>Steatite</u>. Talc carbonate rock with brown-weathering carbonate veins and pods occurs as float in a gullied bulldozer trench halfway up the left side of Right Fork, Hunker Creek, on the left side of Twenty-four Pup. A smaller but similar occurrence exists in a bulldozer trench on the slope between the ridge near the Mitchell Vein and Right Fork, Hunker Creek. In the bottom of the valley near this trench

soapstone occurs in some places showing talc after actinolite with associated coarse grained chlorite schist containing magnetite octahedra 1 cm on the side. Soapstone with associated serpentinite occurs on the right slope higher up the creek half way to the summit near the granitic rock described previously. These ultrabasic rocks, although not apparent on aeromagnetic maps, supply considerable magnetite to Right Fork, Hunker Creek.

Age and Correlation of Ultramafic Rocks.

These ultramafic rocks appear to belong to Green's unit E which appear to be "strung out through a belt parallel to the Tintina Trench and as much as 12 miles southwest of this feature", (Green, 1972, p. 125). However, the three classes of ultramafic rocks considered here suggest that those closest to the Tintina Trench are the most fresh and least related to lineaments while smaller serpeninized and altered masses occur in or near important lineaments. It would appear that the intensity of alteration of these rocks increases with distance from the Tintina Trench. Those not on lineaments have a crude age correlation below the chlorite phase of the Klondike Schist, and occur high on slopes. These may correlate with ultramafic bodies that are ... "associated with greenstone ... (unit C, or) occur as small lenses or sill-like bodies in the enclosed sedimentary rocks of unit A", (Green, 1974, p. 119). The possibility that some of these ultramafic rocks are flows seems real when considered in light of a 250 mile, right-lateral movement on the Tintina Fault which juxtaposes them with ophiolitic rocks near Francis Lake.

POST-MESOZOIC COVER ROCKS

LOWER TERTIARY SEDIMENTARY ROCKS

Unmetamorphosed sedimentary rocks occur in three basins associated with the Klondike Goldfields: MacKinnon Creek-Indian River area, Last Chance Creek-Hunker Creek area, and the Germaine Creek-Klondike River area.

MacKinnon Creek-Indian River area.

This area to the south of the Klondike Goldfields is underlain by poorly exposed quartz pebble conglomerate with white to grey orthoquartzite containing black carbonaceous wood fragments, shale and coal. These rocks are cut by and intercalated with igneous material of intermediate composition. These Tertiary rocks appear to have been deposited in extensive intermontane, possibly fault controlled basins. The conglomerate appears as frost heaved blocks on the left bank of MacKinnon Creek for much of its length, and also on steep banks on the right side near earlier shafts and adits, and in 1975 excavations and drilling. Coal outcrops on Ruby Creek where it was mined ca. 1902 (MacLean, 1914); it was encountered in drilling on MacKinnion Creek in 1975. At Coal Gulch, a right limit tributary of Ruby Creek, eight miles south of Indian River, the coal was traced in exposures for 1/2 mile along a northeast strike. The beds dipped 10° northwest, and were therefore folded, and were observed to be overlain by sandstone and carbonaceous shale.

The conglomerates are auriferous, were explored underground in the boom years of the Klondike, and are being explored now. Placer gold particles have been recovered from depth by drilling.

Last Chance Creek-Hunker Creek area.

In the north of the Klondike area, lower Tertiary sediments exposed by placer operations consist of a basal paraconglomerate (fanglomerate?) containing angular black phyllite clasts with some subround quartz and volcanic rock clasts in a matrix of brown coarse sand. On Discovery Hill, Last Chance Creek, where it is exposed in the bedrock drain, it grades upward into siltstone and tuff. This conglomerate appears to comprise five coarse horizons; the beds dip east under Last Chance Creek where andesite flows overlie the gently folded and faulted pyroclastics. Ascending in the stratigraphic succession at Preido Hill, opposite Discovery Hill on Last Chance Creek, more lavas and agglomerate occur within the tuffs. Agglomerate and flows displaying columnar joints outcrop near Eighty Pup on Hunker Creek, further east, where they overlie a thin veneer of sandstone resting on Nasina phyllite.

The southeast margin of the lower Tertiary outcrop is seen on the north end of exposed bedrock on Paradise Hill. A few decimeters of sandstone rests on serpentinite. Nearby, rubble of coarse sandstone and fine conglomerate occur, probably representing outcrop disturbed by mining. Siliceous, angular red jasper-like rubble apparently rests on the unconformity, and white to blue-grey chert concretions are in the sediments overlying the unconformity.

Germaine Creek-Klondike River-Tintina Trench area.

To the north of the Klondike area lower Tertiary sediment of "probable" Eocene age are well masked by outwash and colluvium. At Germaine Creek shale and sandstone appears as a veneer on a bedrock terrace covered by outwash and lacustrine silt. Exposed in 1962-4 and 1974 by placer mining operation on the left bank bench of that creek near the Klondike River valley (Green, 1965, p. 64), these sediments are probably continuous with the coal bearing sediments of the Tintina Trench that occur along the Klondike River below Flat Creek (Gleeson, 1971) and for 60 miles to the northwest and possibly 40 miles southeast to Bellview Bluffs on the McQuesten River. No volcanic rocks are known to cut the Tintina Trench sediments but rhyolite porphyry intrudes the base of the sediments on Germaine Creek.

LOWER TERTIARY IGNEOUS ROCKS

Scattered basic igneous dikes, basic to intermediate lavas in two areas of Tertiary sediments, and scattered acid plugs are not affected by the Mesozoic metamorphic event and appear related to Tertiary tectonism and sedimentation.

Basic dikes. Most common in the Bonanza Creek basin principally along Eldorado Creek, on Lower Bonanza Creek above Sourdough Gulch, and near the mouth of Bonanza Creek these dikes are rarely more than a meter wide. Also, coarse grained porphyritic basic dikes occur north of the Lone Star property (Fig. 19), (Gleeson, 1971). Basic dikes occur at the mouth of Ready Bullion Gulch and on the ridge between Bonanza and Gold Bottom creeks. They are also indicated on middle Sulphur Creek in an unpublished map by Yukon Consolidated Gold Corporation geologist.

Some of these dikes appear to be collinear with topographic lineamentsand coincident ultramafic bodies southeast from Sulphur Creek and from Bonanza Creek (Bostock, 1942).

Basic to intermediate flows and pyroclastics. Basic to intermediate igneous flows, agglomerates, and tuffs have been preserved in the Eocene sediments of the MacKinnon and Last Chance areas. The former is part of Bostock's (1942) basic-ultramafic zone trending 164° through Eldorado Creek, Haystack Dome and Pyroxene Mountain; the latter may be related to a 25° trending lineament discussed later.

Acid igneous rocks. "Porphyry" plugs occur throughout the area but are common in the Hunker Creek drainage basin and on the ridge to the northeast. Many of these bodies are associated with the Hunker Creek Fault and appear as outcrops on bends in the valley. They also form the buttressed terraces such as is seen on Whiskey Hill.

The lithology ranges from rhyolite through quartz-feldspar rhyolite porphyry to holocrystalline granitic rock. The rhyolite variety is most common near Tinhorn Gulch where it forms the ridge between Hunker and Germaine creeks. Gleeson (1971) considers the rock intrusive; Green (1972) maps it as extrusive.

Age and correlation

The sedimentary rocks including coal north of the Klondike area and in the Tintina Trench are late Eocene in age based on fossil leaves (Collier, 1903, p. 25); or latest Cretaceous-early Tertiary, early Tertiary-probably Eocene, and Paleocene to mid-Miocene, according to fossil leaf fragments and microfossils (Green , 1972, pp. 102-103). Green suggested a probable Eocene age; Hopkins et al. (1975) found further microfossil support for an Eocene age.

Similar coal bearing sediments in the Tintina Trench to the southeast of the Klondike area, near Ross River are considered Paleocene on fossil leaf evidence (Kindle, 1945). Sediments 50 miles to the northwest of Kindle's locations, but with overlying basic lavas, correlated lithologically with nearby similar lavas which are now dated radiometrically as Cretaceous (Lowden, 1963), were also considered Paleocene by Roddick and Green (1961).

Near Stewart Crossing, halfway between Ross River and the Klondike area, Bostock (1948) describes faulted and fractured sedimentary and pyroclastic rocks. They outcrop in disconnected areas on the southern margin of the Trench from Crooked Creek to Reid Lakes. Nearby volcanic rocks which he correlated lithologically with the Mount Nansen volcanics are now considered Eocene.

Lithologic correlation of sedimentary rocks in the northwest Tintina Trench with similar rocks to the south that are overlain by basic to intermediate volcanic flows and pyroclastic beds, has been made by Bostock (1942). However, Green (1972) avoids this correlation. He designates sediments similar to his "probable" Eocene, Trench sediments, immediately to the south of the Tintina Trench as lower Tertiary. His reasons are the absence of volcanic rocks in the Trench and the belief that the probable Eocene sedimentary rocks are "restricted both in source area and sedimentation to the topographic depression along Tintina Trench" (Green, 1972, p. 104).

The basic to intermediate volcanic rocks in the Klondike region have been correlated lithologically by Bostock (1942) and Templeman-Kluit (1974) with the Carmacks Group and are considered Eocene or younger.

Evidence for an Eocene or younger age for Carmacks Group exists in radiometric dates for the older Mount Nansen Group and in geomorphic observations in the Dawson Range. A sub-Mount Nansen Group erosion surface of low relief (in the order of 1000 feet) (Templeman-Kluit, 1974, p. 43 and Fig. 10) is radiometrically dated by an age of 50-60 m.y. (Eocene) on alaskite of the Mount Nansen Group (volcanics) - Nisling Range Alaskite suite (Templeman-Kluit and Wanless, 1975). The erosion surface in places truncates the alaskite and in places is also overlain by volcanics which are also intruded by alaskite (Templeman-Kluit, 1974, p. 43). The Carmacks Group in the Dawson Range, is on younger topography of high relief (greater than 3000 feet) and cuts the older, Mount Nansen Group volcanic terrain (Eocene). It is therefore younger than 50-60 m.y.; the amount of erosion required to produce the change in relief would suggest the passing of considerable time but the denudation may still have occurred within the Eocene (60-40 m.y.).

In the Klondike region, topography with relief of about 2000 feet with broad valleys containing lower Tertiary sedimentary rocks are disconformably overlain by rocks of the Carmacks Group which include feeder dikes.

On Germaine Creek the rhyolite porphyry cuts sedimentary rocks of Eocene (?) age which implies a Tertiary age for it; no cross cutting relationships between the acid and basic Tertiary rocks has been observed.

Quartz veins. These are wide spread, mainly in pre-Tertiary rocks. They tend to control ridge positions, as near Mitchell Vein (Fig. 19) but are also common on slopes. In one location on Sixty Mile River an auriferous quartz vein cuts basic lavas (Templeman-Kluit 1974, p. 75).

UPPER TERTIARY AND QUATERNARY SEDIMENTS

On the valley slopes adjacent the Yukon River unpaired bedrock terraces and alluvial deposits at various altitudes are related to the down cutting of the master stream (Bostock, 1942). Paired bedrock terraces are lowest and can be correlated along the Yukon River and its major tributaries. The altitude of this bedrock terrace system and the thickness of the alluvial fill on it increases down stream past the Klondike area (McConnell *in* Bostock, 1957; Hughes *et al*., 1972).

The alluvium on the terrace system in the northern part of the Klondike Goldfields is referred to as the High-level gravels. These gravels comprise the White Channel gravels, resting on the bedrock terrace; the Yellow gravels, an ubiquitous upper facies, or a channel deposit within the White Channel gravels; and High-level Klondike River gravels, a deposit which interfingers with the upper part of the White Channel gravels and overlies them.

Lower, unpaired terraces below the White Channel terrace and valley floors are covered by poorly sorted, immature clastic sediments and fine grained, mineral and organic "muck" deposits.

Age and Correlation.

The White Channel gravels were considered Pliocene (McConnell *in* Bostock, 1957, p. 84) because of their chemical maturity, which infers a pre-Pleistocene climate, and their bleached nature, which implies a long time of leaching by warm groundwater. The Yellow gravels are described as less physically and less chemically mature, suggesting a colder climate, and are cut by fossil, syngenetic (Czudek and Demek, 1970) ice wedges. The High-level Klondike River gravels probably correlate with the 600-foot thick Flat Creek Beds which contain till from a pre-Wisconsin glaciation in the upper part (Hughes *et al.*, 1972).

Valley floor gravels contain and are overlain by muck containing fossils representing extinct Pleistocene animals. Radiocarbon dates from the lower "muck" give ages from 20,000 to 50,000 years; dates from higher "muck" yield ages less than 10,000 years

TECTONIC SETTING

In the context of the Geological Provinces of the Canadian Cordillera (Gabrielse, 1976) the Klondike Goldfields are situated near the northern limit of the Yukon Crystalline Terrane and are separated, and tectonically isolated, from the Selwyn Fold Belt to the northeast by the Tintina fault (Fig. 1.).

Selwyn Fold Belt.

The Selwyn province is not important to the geomorphic history of the Klondike Goldfields in a tectonic sense. It was part of a block moving southeast with respect to the Klondike area, the southwest end of the Selwyn province was originally near this area, as indicated previously in the discussion on ultramafic rocks. Cretaceous sediments involved in the thrusting north of the Klondike Goldfields, in the Tombstone area, have correlative rocks in Alaska 250 miles to the northwest (Templeman-Kluit, 1966; Roddick, 1967).

Tintina Fault Zone.

The Tintina Trench, the topographic expression of a major fault zone (Green, 1972) is a major topographic feature. The right lateral displacement of the Tintina fault was determined as 260 miles based on the displacement of Precambrian sedimentary and metamorphic rocks (Roddick, 1967) and Cretaceous sediments (Templeman-Kluit, 1966). Roddick argues that 40 miles of this movement may have occurred before Carboniferous (?) because of the displacement of a belt of basic rocks. Still earlier movement on the Tintina-Rocky Mountain trench system is suggested by Gabrielse (1972).

Late stage transverse movement in the order of 15 miles is indicated by Roddick (1967) based on the displacement of a fault that is assumed to have been continuous across the Tintina fault zone.

Templeman-Kluit (1972) presents arguments for Triassic initiation of a fracture zone and injection of alpine ultramafic rocks along it, followed by early Triassic dip-slip movement on south dipping northern

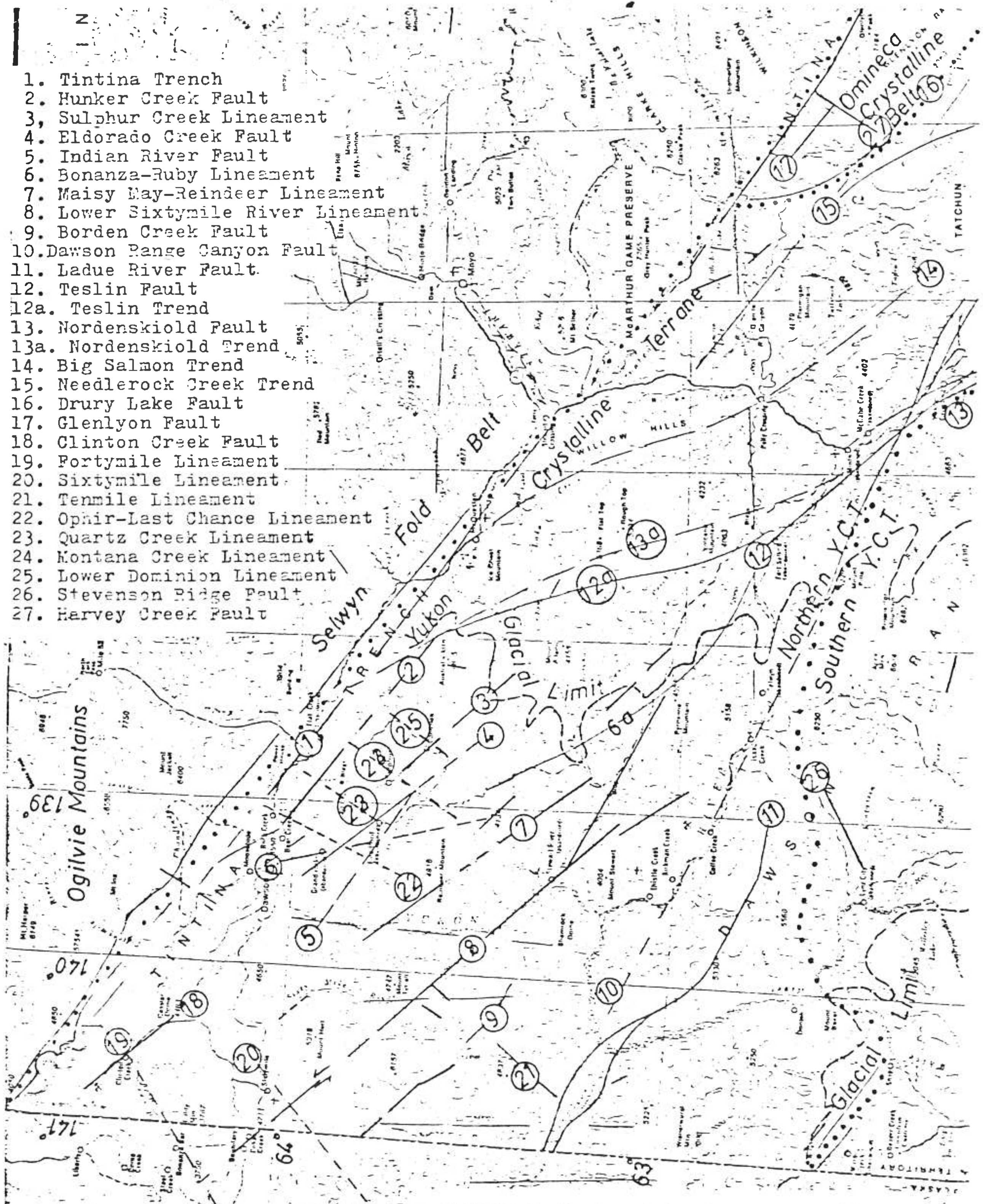


FIGURE 3. Regional tectono-geomorphic map of the central Yukon Terr.

splays of the fault, with mid-Cretaceous transcurrent movement followed by post-Paleocene (?) limited strike-slip and relatively minor dip-slip movement.

Most of the right lateral movement is generally thought to have occurred by the end of Mesozoic because of the presence of an unsheared, 66 m.y. (Paleocene) granodiorite batholith between two parallel splays of the fault system (Roddick, 1967) and because of the absence of deformation in Eocene and Paleocene sediments greater than that which would cause dips of less than 45° and minor, apparent dip-slip movement.

Later displacement is suggested by the following geomorphic relationships (see also Chapter III). The apparent right lateral offset of the Stewart River valley, which is presumed to have had a relatively straight south westward course before the mid-Tertiary reactivation of the fault, is in the order of 32 miles. (Roddick, 1967, considers this apparent offset to be an accident of glacial diversion.) Similar offsets of three other valleys and two mountain ranges in the central Yukon Territory are visible on the topographic map MCR 25 and on satellite images.

A similar Tertiary displacement can be seen in geological relationships. Campbell (1967, p. 69) and Kindle (1945) discuss the absence of granitic pebbles in Paleocene (?) sediments in the central Tintina Trench where potential present day sources for such clasts exist on mountainous terrain to the south. This could be due to post Paleocene (?) transverse fault movement. Paleocene (?) granite pebble conglomerate occurs about 30 miles southeast of the Harvey Creek location of Campbell (Roddick and Green, 1961) and supports the hypothesis of right lateral displacement of Tertiary landscape.

There is an apparent similar right lateral displacement of the Clear Creek Goldfield with respect to the Klondike Goldfield. If the gold was of early Tertiary genesis and related to northeast trending lineaments then this relationship would further document the Tertiary movement on the Tintina fault.

Most of the evidence for vertical displacement of topography (Aho, 1959) is explained by the 32-mile right lateral movement. However, vertical movement in the form of regional arching or doming may have occurred during the Miocene (?) development of modern topography prior to the later right lateral movement.

Templeman-Kluit (1972) does argue for normal faults displacing Paleocene (?) beds; this also may be due to apparent dip-slip movement on a fault having predominantly strike-slip motion during Miocene time.

Roddick's (1967) evidence against post-Paleocene movement would be more convincing if the 66 m.y. unsheared batholith cut across the fault zone. Numerous "anastomosing" shear surfaces could divert fault movement around the massive intrusion, leaving it unfaulted.

The argument that gently folded Tertiary sediments in this zone do not display important fault movement is weakened by lack of good exposure. Steeply dipping beds are recorded for exposures on Cliff Creek (Hopkins et al., 1975) and near Watson Lake (Milner and Craig, 1973). The structures may represent normal faulting and related graben development. Normal faulting could mark the end of transverse fault movement although this has not been proved. Green's boundary for these sediments is not a linear one as would be expected for a fault bounded basin; and if Roddick (1967) and Eisbacher _et al._ (1974) are correct in their models of master streams flowing along this lineament, then irregular valley widening could be expected and need not involve normal faulting.

Present day movement is suggested by lineaments in surficial materials but these could be due to differential compaction especially on gravels overlying lacustrine sediments, and bedrock response to stress relief. Several airphoto lineaments in the Klondike valley below Flat Creek presumably are related to faults on the southern margin of the Tintina fault zone. One, on the South Klondike River near the South Fork drainage ditch, apparently displaces a low alluvial terrace in a right lateral sense. Topographic maps show stream alignment in the Flat Creek gravels near McQuesten River.

Differential isostatic rebound resulting from deglaciation or of denudation may also play a role in the development of recent lineaments.

Yukon Crystalline Terrane.

In the area southwest of the Tintina Trench the bedrock geology is especially important to the understanding of the regional geomorphology because of its control of drainage and relief.

The northern part of the Yukon Crystalline Terrane, of Omineca

Crystalline Belt affiliations (LeCouteur and Templeman-Kluit, 1976; Templeman-Kluit, 1974, Fig. 7), is characterised by faults, and numerous fault-bounded, early Tertiary basins (Fig. 3). These basins contain coal occurrences and have volcanic centers; they are involved in folding (coal beds dip 10° in the MacKinnon River area, MacLean, 1914); other beds dip up to 35° (Bostock, 1942) and are folded or block faulted (Green, 1972, pp. 104, 122). The boundary zone between the northern and southern parts of the Yukon Crystalline Terrane continues from the end of the Intermontane Belt (Whitehorse Trough) along the Yukon and Ladue rivers into Alaska.

The southern part of the Yukon Crystalline Terrane, of Coastal Plutonic Complex and Intermontane Belt affiliation, (LeCouteur and Templeman-Kluit, 1976), is characterized by early Tertiary plutonic events. Similar volcanic centers to those in the north do not have extensive coal-bearing sediments and have not been folded or tilted, dips being depositional (Templeman-Kluit, 1974, p. 51). Faulting appears to be only of minor importance.

Northwest Trending Faults.

Teslin Fault. The glacially accentuated Teslin Lake and river valley, continuous with faults in British Columbia, is one of the most prominent lineaments in the central Yukon Territory and trends 141°. The Teslin lineament probably controlled the pre-glacial course of the Teslin and Yukon rivers (Roddick, 1967). The fault, trending toward the Klondike area and oblique to the Tintina Trench, appears to end near Minto where it may be covered by glacial debris. Its displacement is not known.

The abrupt termination of linear geochemical anomalies (Cathro, 1972) and the form of magnetic patterns at the Teslin "fault" (Templeman-Kluit, 1972) are evidence of some movement.

Lower Sixty Mile River Lineament. This feature is next most important to the Teslin Lineament. It is 30 miles southwest of the Klondike area and trends 137°. It is marked by a series of gravel-bearing wind gaps north of higher terrain, near Mount Stewart and Barker Creek. A fault farther south shown by Bostock (1942) may be related. This "relict" lineament probably represents a captured subsequent stream following a fault trace. Alternatively, the gravel-bearing windgaps could represent former alluvial fans adjacent to a fault scarp. The topography of this locality, as seen on topographic maps and in satellite imagery, has sharp textural contrast on opposite sides of the lineament. A similar contrast appears in the aeromagnetic pattern of the area, for this segment of the fault. A straight, although wide, reach of the Yukon River to the northwest and a straight section of the Sixty Mile River extend the lineament farther northwest. There, apparent displacement of Eocene (?) volcanic and underlying sedimentary rocks (Templeman-Kluit, 1974) suggests a left lateral displacement of six miles. Mineral occurrences including fluorite in quartz porphyry, chalcopyrite in skarn related to a batholith that abuts the north side of this lineament, gold in an Eocene (?) quartz vein and volcanics of PER claims, and placer gold and cinnabar in the goldfield of Miller Creek, extend this feature to the Alaska Boundary.

Dawson Range Canyon Lineament. This feature consists of more or less collinear segments of the Ladue River, Los Angeles Creek and the Yukon River. It may be continued southeast through Dark Creek and a valley north of Tatchun Lake. Bostock (1958, p. 69) draws attention to the canyon as a possible indication of superposition of Tertiary drainage from an earlier course northwest from Fork Selkirk; Roddick (1967) also suggests that this water gap was the site of glacial diversion of the Yukon River from a preglacial course north of Minto; however neither glacial ice nor alluvial cover is known to have extended that far. Earlier subsequent drainage along this lineament probably eroded an initial valley through which diversion took place at an altitude of less than 2500 feet.

Maisy May - Reindeer Lineament. As yet this feature has little associated geological information aside from the valley system of Maisy May, Reindeer and Galena creeks and a coincident kink in the north flowing Yukon River. The lineament does appear strong and passes through the goldfields of Henderson Creek and an ultramafic body at the head of Reindeer Creek, suggesting crustal weakness and permeability allowing for ascending magma and hydrothermal solutions. A granite contact parallels Reindeer Creek.

The collinearity of creeks separated by terrain with lode and placer gold occurrences almost seems to be a characteristic of the Yukon Crystalline Terrane.

Other probable lineaments with weak supporting geological evidence pass through Walhalla Creek, Deep Creek and Henderson Dome (Fig. 3).

Most of the tectonic breaks discussed here in the regional setting and in the Klondike area trend toward the Tintina fault and the area in Alaska where the Tintina fault zone appears to bend to the southwest. The postulated left lateral movement on the lower Sixty Mile River Fault would fit into such a tectonic model and represent adjustment in an area of compression on the south side of the bend.

Northeast trending fracture zones.

These features do occur in the region but are not well documented. Evidence for their existence is suggested by Gleeson and Brummer (1976), Cathro (1972) and Leary (personal communication, 1975). Northeast trending geochemical anomalies from regional surveys appear to be related to areas of stratiform copper occurrences and porphyry-type copper-molybdenum occurrences. In Alaska, Lathrum (1974), found that copper and molybdenum mineralization occurred where northeast trending fractures intersected northwest trending fractures.

Northeast topographic lineaments pass through the Forty Mile Goldfields along Wade Creek in Alaska and are common along the lower, Canadian section of the Forty Mile River. The upper Sixty Mile River lineament is a major topographic feature in Alaska and Canada, and has support in the northeast trending auriferous gold vein in Eocene (?) volcanic rocks on the PER claim (Templeman-Kluit, 1974; Cockfield, 1921, p. 52; and Green, 1966, pp. 26-28).

STRUCTURE OF THE KLONDIKE AREA

Faults and lineaments.

Northwest trending faults are of major importance in the area. Gleeson (1971, pp. 9, 16) refers to parallel faults adjacent the Tintina Trench. Aho (1959) and Green (1966, p. 104) describe gouge exposed in an Allgold Creek placer operation. Mylonite float appears on slopes to the west and is common in the more competent varieties of the Klondike Schist; coarse grained, strongly contorted sericite schist represents faults in the less competent varieties of the lithology.

Eldorado Creek Fault. First described by Gleeson (1971, p. 9) on upper Eldorado Creek, it trends 136°. Where seen in placer operations the fault zone is 100 feet wide and dips 60° southwest. Weak collinear, negative topographic lineaments to the northwest suggest that it passes through Mount Bronson. If this fault zone is a source of gold, then placer gold on the upper part of Chief Gulch, lower French Gulch, Skookum Gulch, and in Adams Creek below Stampede Gulch, may indicate its extension (*see* Fig. 19). A spring or pingo (Hughes, 1969) on Adams Creek suggesting groundwater flow in permeable ground (discussed later), a parallel quartz vein north of the mouth of Chief Gulch, and a quartz vein and associated porphyry at a local break in slope on the ridge west of Grand Forks, suggest permeability and structural weakness of long duration on this zone. A topographic lineament continues to the southeast curving to the east in higher topography because of the westerly dip of the fault and appears to coincide with an isolated magnetic anomaly (GSC Map 7868G) and associated geochemical anomalies

(Hilker, 1973). "Pingos"occur on this lineament and the parallel lineament of Calder Creek. The lineament continues down Nineteen Pup to Quartz Creek, where it marks the upper limit of modern, open placer workings on Quartz Creek.

Similar northwest trending shear zones are reported by Gleeson (1971) at Lone Star Mine, crossing Bonanza Creek near O'Neil Gulch, and near Gay Gulch.

These faults could be genetically related to the Teslin Lineament with which they are parallel or subparallel.

Hunker Creek Fault. A zone trending 126° is shown approximately by the course of Hunker Creek upstream from above Dago Hill (where a shear zone is exposed in the bedrock drain). Along this section of the fault up to Whiskey Hill numerous serpentinite masses, rhyolite porphyry plugs, and granitic plugs occupy the zone of structural weakness. From the dispersal of these anomalous rock types it would appear that the fault zone is wide or sinuous or that the ascending magmas diverged from the trend of the fault zone on subsidiary zones of weakness. The similar coincidence of negative topographic lineaments with ultramafic rocks occurs through Clinton Creek as mentioned earlier. The Hunker Creek Fault also appears to be the boundary for Eocene (?) sedimentary and volcanic rocks which suggests a downthrown block to the southwest. The fault can be extended to the southeast through negative topographic lineaments of Six Above Pup and Alexandra Creek. Soapstone occurs at the mouth of Alexandra Creek on Allgold Creek. To the southeast, a right limit tributary of Lucky Creek trends almost parallel to the lineament direction and contains a pingo. Another pingo appears further southeast on Minnie Bell Creek. Upper Jensen Creek is aligned close to this trend and the Nasina Series on Jensen Creek, allowing for the inaccuracy of early topographic maps, appears to terminate at this fault. Projected from Jensen Creek 20 miles at 127° through Pelly Gneiss, the fault crosses an ultramafic body shown by Bostock (1942) in a possible fault position offsetting a marble band 2 miles in an apparent right lateral movement. This zone of Bostock is occupied by an ultramafic body 2 miles long trending 145° and is used by Templeman-Kluit (1972) as supporting evidence for a splay of the Tintina Trench toward the Teslin Lineament (Fig. 3).

A fault zone parallel to the Hunker Creek Fault may exist to the northeast represented by the gouge of Green (1966) and Aho (1959) on Allgold Creek(above),mylonite on slopes to the west, and the strongly magnetic ultramafic rocks underlying topographic highs like Mount Leotta. Topographic expression of such a zone is lacking but ERTS tone contrast on either side of this trend appears strong.

Indian River Fault. Indicated by Templeman-Kluit (1972), it trends 123° and separates Nasina Series, ultramafic rocks, and Eocene (?) sediments to the south from quartz-eye schist and Pelly Gneiss on the north. This fault may end at the Eldorado Creek Fault; the south side appears to be downthrown.

Northeast lineaments

Ophir-Last Chance Lineament. Trending 25°, it has topographic expression in the two creeks after which it is named. The significance of widely spaced, collinear creeks such as on this and on the Maisy May - Reindeer lineament, is discussed later. Structural evidences of a fracture zone include a shear zone exposed in the bedrock drain north from Discovery Hill on Last Chance Creek, a foliated serpentinite mass therein, and the pre-Pleistocene, controlled course of Last Chance Creek. Soapstone float along this line north of the Lone Star mine also indicates crustal weakness in this zone. Several auriferous quartz veins occur near this lineament. The main ones are the Lone Star mine, the Violet shaft, and veins exposed in trenching near Gay Gulch and Victoria Gulch (Fig. 19). Lode Claims HF, staked on a ridge near CarmacksFork, and an isolated porphyry outcrop fall on this trend.

A possible model for this lineament and associated gold occurrences is a left lateral, tension fissure system. Also, because two apparently downfaulted Eocene (?) basins occur to the southeast of this lineament, adjacent the Hunker Creek Fault and the Indian River Fault, displacement had a dip-slip component, downthrown block on the southeast.

A similar northeast lineament could be drawn through the straight section of Quartz Creek above Calder Creek to the peridotite mass of Mount Leotta, along the positive topographic lineament of the ridge, between Quartz and Canyon creeks, through Mitchell Vein (Figs.3 and 19), and near the soapstone occurrences at the head of Hunker Creek.

A parallel, negative topographic lineament exists on lower Dominion Creek; it includes a prominent magnetic anomaly on Indian River possibly caused by ultramafic rocks.

Thrust faults

Ancient thrust faults may exist in the Hunker Creek area where soapstone occurs apparently stratigraphically related to the chlorite schist phase of the Klondike Schist.

Post Pliocene (?) thrusts have been described by Hughes (1969), Gleeson (1971, p. 9) and described by Green (1966, p. 95). These faults on Adams and Paradise hills cut pre-Pleistocene gravels displacing bedrock 30-40 feet over gravel on a fault plane that dips 20° to the west.

If these features are truly structural in origin then they represent anomalous tectonism, both from the age and direction of thrusting. However, their occurrence on terraces at the base of gentle, northerly facing slopes that were affected by permafrost causes one to speculate on surficial mass movement, perhaps involving creep of a slab of permanently frozen ground. This movement could be casually related to erosion of the White Channel gravels during the time of Yellow gravel incision during a preWisconsin glaciation or prior interglacial.

Folds

The broad structural interpretation of Bostock (1942) and also Templeman-Kluit (1974, Fig. 13) of a syncline with its axis west of the Klondike area with westerly dips from 20° to 50° remains unchanged although locally structure is complex with several directions of folding. The chlorite phase of the Klondike Schist has primary compositional banding that appears todescribe a marker zone, parallel to the synclinal axis dipping gently toward it. "Small scale and possibly large scale isoclinal folding with strong foliation, in places obliterating the bedding is described for the metamorphic belt south of the Tintina Trench" (Green 1972). Yukon Consolidated Gold Corporation geologists presented such a picture of northwest trending, southwest dipping recumbent folds.

The structure near the Klondike River northeast of Hunker Creek does not conform with the general picture; northeast strikes and moderate north and south dips of phyllite and marble horizons suggest northeast trending folds.

Metamorphism

The metamorphic grade in general is middle greenschist facies with widespread development of sericite schist, and graphitic phyllite with occasional coarse grained marble. Higher metamorphic grades are suggested for the eastern and southern parts of the area by abundant garnet in the Jensen Creek area of Dominion Creek and also along the Klondike Highway near Flat Creek. Kyanite is abundant in Dominion Creek below Sulphur Creek. Regional metamorphism of Triassic age is thought to mask earlier metamorphic events; however, kyanite and staurolite in association with Pelly Gneiss may be relict metamorphic minerals related to the metaigneous origin of the Pelly Gneiss suggested earlier by Cockfield and Mertie (Green, 1972, p. 119).

Eocene (?) alteration is evident in andesites of Hunker Creek (McConnell in Bostock, 1957 , p. 80). These Eocene (?) sedimentary rocks are gently folded, are cut by minor faults, and at Germaine Creek, are cut by quartz porphyry - the possible cause of the alteration of the andesites.

Hydrothermal alteration of unknown age is apparent in rocks north of King Solomon Dome and in other places bleached margins of veins are common. Ubiquitous soapstone derived from ultramafic rocks suggest abundant hydrothermal activity.

CHAPTER III

GEOMORPHOLOGY

GEOMORPHIC SETTING

The Klondike Goldfields are located in the Yukon Plateau Division of the Cordilleran Region (Bostock,1948, 1970). The Klondike region is characterised by drainage divides at about 3300 feet locally rising to about 4500 feet. These are crooked ridges separated by dendritic valleys and are drained by master streams from 1000 to 1500 feet above sea-level. A few summits, locally called domes, with altitudes of about 5000 feet occupy ridge intersections.

The Yukon Plateau geomorphic province occupies the central or interior Yukon Territory, on both sides of the Tintina Trench (Fig.1.). Ridge and upland altitudes from 3000 to 5000 feet are common in the Yukon Plateau Division (topographic map, Yukon Territory, MCR 25). The Division is bounded on the north by the Ogilvie Mountains where numerous summits are as high as 7000 feet.

The Klondike Plateau, unglaciated subdivision of the Yukon Plateau Division, extends southeast from Alaska in the west and is bounded by the Tintina Trench on the northeast and by glaciated plateau terrain on the south and east. In the north the upland surface is presumed to be defined by nearly horizontal accordant ridges; in the south remnants of it surround the Dawson Range which stands about 1000 feet higher.

The rolling upland surface of the Yukon Plateau physiographic province has been thought to be the dissected remnants of an uplifted, Tertiary erosion surface (Bostock, 1938, pp. 66-73 ; Templeman-Kluit, 1974, p.7). In the Klondike region it is considered to be a skeletal upland surface initially developed during mid-Tertiary time, which has probably been faulted, lowered by erosion, and warped in late Tertiary time and periglacially modified during Quaternary time.

To the north of the Tombstone Range, in the northern part of the Ogilvie Mountains, extensive unglaciated pediment surfaces of possible Tertiary or early Pleistocene age locally grade into valley floors at altitudes of about 1500 feet. These pediment surfaces appear to be warped (Hughes, 1972).

Evolution of the present drainage system.

Modern drainage has developed since the mid-Cretaceous Columbian Orogeny when mountains evolved to the northwest and southwest of the Yukon Crystalline Terrane. Changes in drainage occurred as a result of the late Cretaceous - early Tertiary Laramide Orogeny especially to the southwest of the Yukon Crystalline Terrane. Late Laramide crustal warping probably extended throughout the Yukon Crystalline Terrane.

Ogilvie-Selwyn mountain drainage. To the north of the Klondike area, on the north slope of the Ogilvie Mountains (Fig. 1) presumed antecedent streams such as the Blackstone and Hart rivers indicate drainage there has been northward since before late Cretaceous thrusting and intrusion in the Tombstone area. Uplift in the northern Ogilvie Mountains continued in early Tertiary time (Mountjoy, 1967) with the uplift, thrusting and folding of late Cretaceous - early Tertiary non-marine clastic sediments. The sediments of the Monster Formation were deposited in a basin 50 miles northwest of Dawson and are now folded into a northeast trending syncline. The Bonnet Plume Formation, in a basin 150 miles northwest of Dawson is also deformed. The deposition and deformation of these sediments suggest the nature of deformations of nearby older rocks and the amount of incision to be expected by antecedent streams. Incision by late Tertiary and early Quaternary streams during crustal warping in the northern Yukon Territory is suggested by Hughes (1972).

On the south slope of the Selwyn Mountains early regional consequent streams probably drained the basins of the ancestral Pelly, Macmillan and Stewart rivers. Some of this Cretaceous topography is preserved beneath Cretaceous lavas between the South Macmillan and Tay rivers (Roddick and Green, 1961). These streams flowed across the Klondike region to the southwest, perhaps initially on an alluvial cover, before the major right lateral displacement of the Tintina fault. Later, subsequent drainage evolved in the Selwyn Fold Belt and northwest subsequent stream eroded along the Tintina fault. The resulting valley drained northwest then northeast through the Peel Re-entrant, as suggested by Eisbacher *et al*. (1974), supplying sediment to the local nonmarine basin of the early Upper Cretaceous Eagle Plain Formation and the late Cretaceous - early Tertiary Monster Formation. Drainage through the Peel Re-entrant presumably was defeated by the folding later in the early Tertiary that created the Monster Syncline. The drainage patterns on the southern portion of the Selwyn Fold Belt, except for minor piracy and glacial diversion, have probably changed little.

Tintina Trench drainage. The Tintina valley originally could have been eroded by the late Cretaceous - early Tertiary "Tintina river". The river would have captured west flowing streams from the subsequent Selwyn drainage systems. As a result of Tintina fault movement, the fault-valley river would have captured faulted streams of Selwyn provenance at the lower ends of fault-valley streams. After these captures obsequent streams developed in the Yukon Crystalline Terrane occupying the valleys of the former southwest flowing stream. The modern analogy for the capture described above is the Klondike, through its tributary Flat Creek, capturing the Stewart River in the Tintina Trench at the bend below McQuesten. If this capture were to take place, the lower part of the Stewart River would then, through the development of a northeast flowing obsequent stream, become a major tributary valley of the new system. Such a major obsequent valley in early-to mid-Tertiary time could have lead to the development of the ancestral Yukon river south of Dawson. The original stream, prior to the Laramide Orogeny, may have carried drainage from the Selwyn Fold Belt to the Pacific Ocean. The now glacially deranged Willow Creek valley or ancestral Lewes river valley may have been part of this Pacific watershed.

The "Tintina river" may have been one of the depositional agents for the lower Tertiary sediments in the Tintina Trench. Alternatively a series of closed basins may have been filled by alluvial fan deposits from local streams. Normal faulting is suggested by Templeman-Kluit (1972) both before and after the main lateral movement on the Tintina fault; such movements would tend to produce graben or half-graben sedimentary basins along the fault. Also, horizontal movement juxtaposing terrain of different relief could produce apparent vertical displacements with related scarp deposits such as alluvial fans and local basin deposits such as lacustrine sediments along the fault. Another possibility is that transverse movement along a non-linear fault trace would result in gravitational adjustments within the shear zone that would produce graben. These hypotheses suggest the creation of insequent drainage and sedimentation directly due to tectonism as an alternative to the classical fluvial headward erosion and stream piracy along a zone of weakness.

There is very little direct evidence for the existence of the hypothetical, Cretaceous-early Tertiary "Tintina river" in late Tertiary time. The Trench near Dawson is covered with slumped lower Tertiary (Eocene?) sediments and Quaternary glacial deposits which are dissected by transverse streams. The area was extensively explored for coal as well as gold as the time of the Klondike gold rush and only one occurrence of preglacial White Channel-like sediment was found. Bostock (1947b) describes gravels like White Channel gravels overlain by brown gravels, like the high level Klondike River gravels, in a hydraulic cut near Clear Creek; these are probably related to the present Clear Creek valley. Yet, because a valley exists, McConnell, in 1902 (Bostock 1957, p.51), and Roddick (1967) indicate that the Trench was occupied by a master stream and that it was diverted southwest to the Yukon River during early Pleistocene time.

A broad cone sector with an apex near an altitude of 3500 feet, several hundred feet above the floor of the Trench, occurs near Fifteen Mile River. It is mapped as Tertiary sediment and is northeast of the general limit of these rocks in the Trench. This morphology resembles an alluvial fan. Nearby, gentle slopes grade down from the Ogilvie Mountains and the usually wide Trench floor at the head of Rock Creek suggests pediment surfaces. These features may be late Tertiary or Quaternary in age and do not support the hypothesis of a major preglacial river system within the Tintina Trench.

The importance of Tintina drainage to the Klondike Goldfields is threefold. First, if a "Tintina river" and a White Channel Strath river joined downstream from (northwest of) the Klondike area prior to glaciation and upstream from (southeast of) that area following glaciation then there would be changes in erosion rates and base levels which would affect terrace development in the goldfields. Second, if the "Tintina river" were present before glaciation then it would have intercepted sediment from the North Klondike and South Klondike rivers preventing discharge through the lower Klondike valley as at present. Preglacial, southeast drainage along the Flat Creek segment of the Trench is suggested by Hughes _et al_. (1972). Third , if the Tintina river drained Clear Creek and the northeastern goldfields of the Klondike area northwest along the Trench then placer gold might be found there. Conversely, the probability of placer deposits being preserved in terraces of the Yukon River below the Klondike area would be decreased.

Yukon Crystalline Terrane drainage. In the southern part of the Yukon Crystalline Terrane in the Dawson Range, Templeman-Kluit (1974) argues for an early Eocene terrain of low relief with a drainage pattern unlike that of the present (as discussed in Chapter II and below). He envisages a later (possibly Eocene) episode of erosion that developed topography and drainage similar to that of the present. In this area, in some places, low order streams of the present drainage coincide with and are incising Eocene or later valleys preserved under volcanic cover of variable thickness. In British Columbia relief during Miocene time is thought to be low, also early thinking on Yukon geomorphology called for Miocene peneplanation Local shifts in divides from Eocene time to the present are the only changes that are apparent in the Dawson Range. The drainage pattern and direction of flow of high order streams is unknown, but the abundance of Eocene valleys on the flanks of the Dawson Range and the higher altitudes there, suggest that it may have been a regional divide.

To the south of the Dawson Range the broad valleys of the Tanana River in Alaska and the adjoining Wellesley Basin, both containing deranged drainage, form an obvious westward course for some of the suggested former streams, such as the Nisling River, in the southern part of the Yukon Crystalline Terrane. The narrow valleys or gorges of the lower White River west of, and the Yukon River north of the Dawson Range suggests superposition or diversion, implied by Bostock (1957, p.69) or glacial diversion as shown, in the latter area, by Roddick (1967, Fig. 3). They may also be antecedent to late Tertiary crustal warping. Brooks (1906) envisages the ancestral Alsek river draining the upper Tanana River valley and the headwaters of the White River southeast via the lowlands near Kluane and Dezadeash lakes thence southwest through the valley of Mush and Bates lakes to the Pacific Ocean. He believes that the southwest flowing segment was antecedent during late Tertiary, Laramide uplift in the Pacific Orogen. Presumably the ancestral Alsek river lost part of its watershed to the extending Tanana River system. Undoubtedly the broad valley of the Takhini River played some role in draining the southern Yukon Territory in preglacial time.

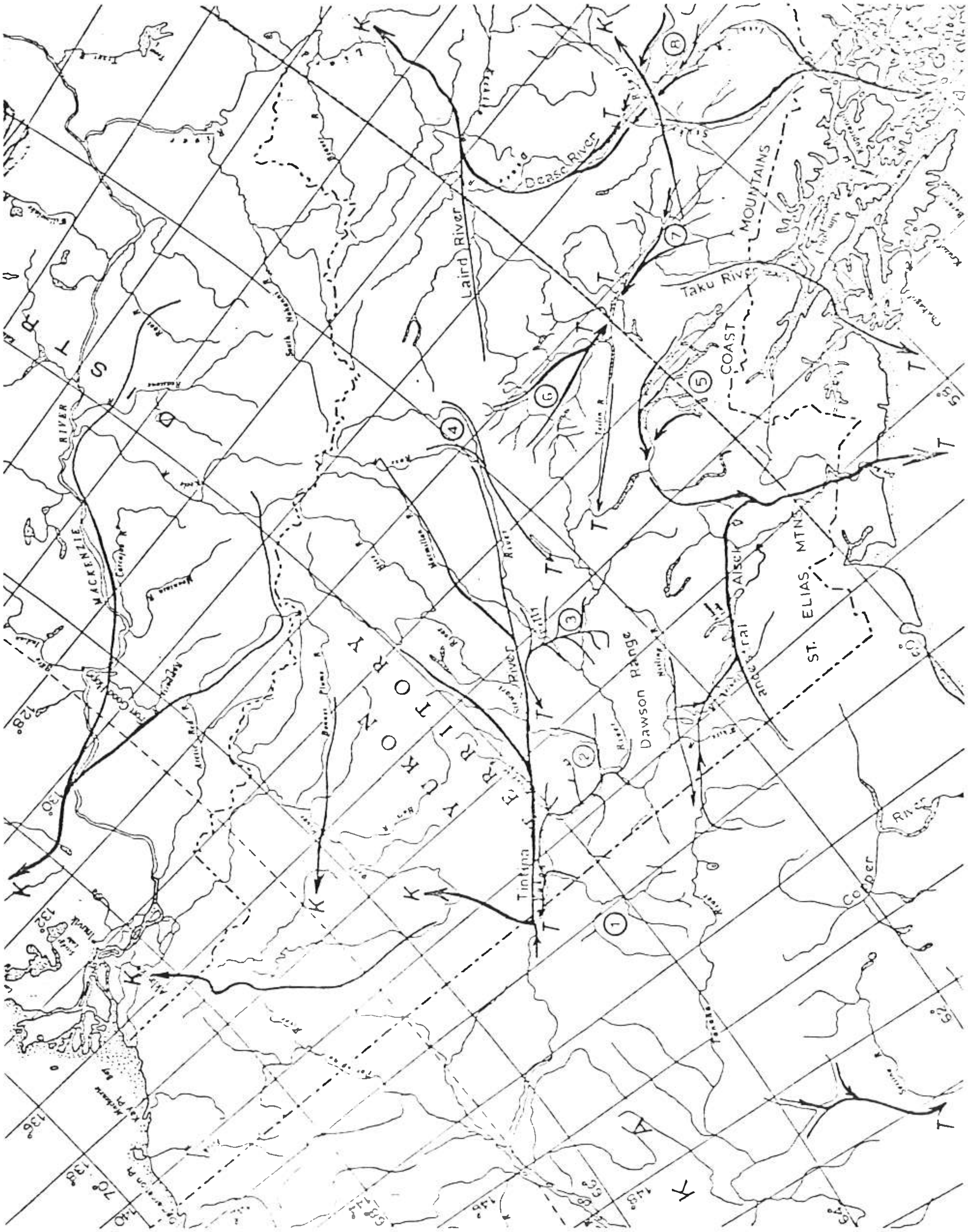
The timing of these drainage changes is not known but at least three possibilities exist. Diversions caused by uplift, crustal warping, and faulting happened during Eocene plutonism; river piracy, diversion or superposition took place during mid-Tertiary times of relative crustal stability or during late Tertiary uplift and alluviation; or diversion or superposition resulted from Quaternary or earlier glaciations or was caused by associated glacial outwash.

The importance of this drainage history to Klondike geomorphology is that during early Tertiary time some parts of the present Yukon River basin belonged to the Pacific and Arctic watersheds and the axial Yukon River or its predecessors were much less important then than now.

In the northern part of the Yukon Crystalline Terrane folded and faulted Eocene or younger sedimentary rocks with overlying volcanic rocks occupy valleys of that age possibly continuations of the valleys mentioned above on the north side of the Dawson Range. Both the low-order Eocene or younger valleys on the Dawson Range and the Eocene or younger basins to the north are mantled by volcanic rocks correlated by lithologic similarity with the Carmacks Group of Eocene or younger age. The unconformity below the sediments in the northern part of the Yukon Crystalline Terrane is tentatively correlated with the sub-Mount Nansan Group erosion surface in the Dawson Range discussed earlier. The detritus produced by the erosion in the Dawson Range may be the sediment in the basin to the north if the drainage pattern assumed in Figure 4 is valid. The distribution of maximum grain sizes in these sediments shown by Templeman-Kluit (1974) indicate north flowing streams; however, his clasts have local provenance suggesting simply relief decreasing northward. This Eocene or younger fluvial episode with associated coal swamps in the northern part was terminated by sedimentation, volcanism and resulting river diversion.

Present drainage presumably developed by adjustment through river extension or piracy during late Tertiary time; orogenic movements did not necessarily play a role. Drainage patterns and interfluves developed at this time continued to the present as the upland surface of the Yukon Plateau province.

In the Klondike region drainage is poorly integrated and has strong structural control. Such a pattern is evidence against inheritance of drainage pattern from an erosion surface of low relief and suggests that structural elements guided river development. The depth of incision below the possible surface of low relief combined with the structural dissection of the bedrock may explain the low degree of integration. Narrow valleys of master streams need not necessarily result from river



1. Forty Mile River system.
2. White Channel Strath system.
3. "Minto" river system.
4. Magundy river system.
5. Tagish river system.
6. Quiet-Wolf river system.
7. Sheslay river system.
8. Kinaskan drainage.

FIGURE 4. Paleodrainage map of the northern Cordillera

diversion but may represent local antecedent reaches related to local late Tertiary or Pleistocene crustal warping.

A number of distinct river segments can be identified that relate to this late Tertiary stage of river development and others that may have resulted from Pleistocene drainage diversion.

White Channel Strath drainage. The valley of the Yukon River containing the White Channel Strath and weathered alluvial fill upstream to a point above the mouth of the Stewart River marks the pre-Pleistocene position of the river system. This system includes the tributary valleys Forty Mile and Sixty Mile rivers on the west and Bonanza and Hunker creeks and Indian River on the east. The extensive strath terrace system discussed by McConnell (*in* Bostock, 1957, p.66) Cockfield (1921), Bostock (1942) and Hughes *et al*. (1972) represents a period of crustal stability that was terminated by uplift in the Swede Dome area in Pliocene (?) time.

Lower Stewart River The segment of the Stewart River below the Tintina Trench was probably the major contributor to the White Channel Strath drainage system. It occupies a relatively wide southwest trending valley below the Trench and a straight wide, probably fault controlled segment collinear with Walhalla and Scroggie creeks. The White Channel Strath is not readily traced upstream above the mouth of Scroggie Creek (Bostock, 1942). White Channel gravels are said to occur on the right bank of the Stewart River, near river level, opposite the mouth of Rosebud Creek. Continuation of the strath upstream is suggested by the width of the valley floor of the lower Stewart River. The lack of exposure above Scroggie Creek is due in part to glaciation and in part to the absence of uplift which tends to expose the strath as a terrace in the area to the northwest. This segment of the river system is approximately perpendicular to the direction of tilt and near the outer limit of influence of the Swede Dome uplift. The suggestion that this reach of the Stewart River is the result of glacial diversion of the "Tintina river" is negated by the presence of the preglacial strath.

Tertiary movement on the Tintina fault.

At least seven topographic and geologic features apparently match across the Tintina fault zone if a left lateral replacement of 32 miles is assumed. This implies a late stage of movement following a period of quiesence during which drainage patterns crossing the fault were developed–presumably on topography of low relief. Initial incision of the topography took place before further displacement. Before this displacement the valley of the Stewart River trended southwest with no offset along the fault. The valley in which the White Channel Strath was developed was continuous across the fault and intercepted northwest flowing streams in the fault zone.

Displacement of topography.

Upper Stewart River and related rivers. The wide, straight valley of Stewart River from above the fault to below Fraser Falls probably drains preglacial tributaries through the valley of Mayo Lake and possibly the Nadaleen River and the head of Stewart River above that. The parallel valley of Lansing River continued through the segment of the Stewart River between Lansing and Fraser Falls. It may have been a tributary to the upper Stewart River near Fraser Falls or it could have continued southwest through the valley of Nogold Creek across the Tintina fault and, prior to the last offset, through the valley of Lake Creek to the lower Stewart River valley.

Similarly, the valley of Macmillan River meets Crooked Creek or Willow Creek. In the same restoration position Lapie River valley

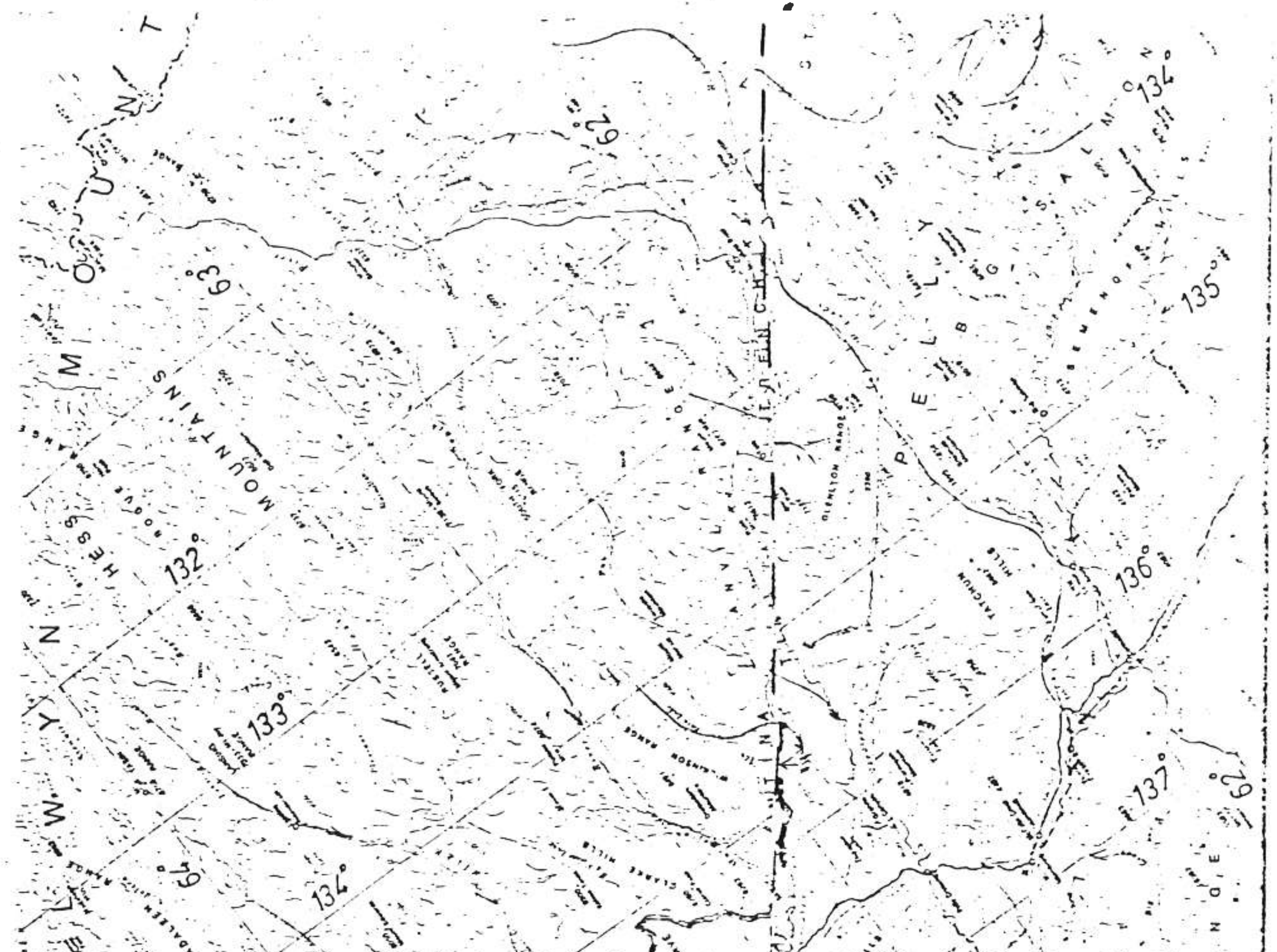


FIGURE 4a. Paleodrainage across the Tintina Trench at 30 miles left lateral fault restoration.

southwest of the fault facies the lower, northeast trending segment of Hoole River on the northeast side.

Ancestral Magundy river and Pelly Mountains. The Ross and upper Pelly rivers drain a large area bounded by the Anvil Range, the Selwyn Mountains and the St. Cyr Range of the Pelly Mountains. The Magundy River -Little Salmon Lake and river valley is a major topographic feature that divides the Pelly Mountains in two, and was probably eroded by a large through-going river system. The south wall of this valley, or the north slope of the St. Cyr Range, taken as a projection of the 5000 foot contour, accurately displays the 32 mile final displacement on the Tintina fault. This dissection of the Pelly Mountains could result from incision of an upland surface of low relief where the mountains represent resistant residuals of the upland, or the mountains could be due to crustal warping of topography of moderate relief to which the ancestral Magundy river was antecedent. The diversion of the Ross and upper Pelly rivers to the Tintina Trench may have been early Pleistocene glacial diversion or late Tertiary stream piracy by the fault-subsequent reach of Pelly River.

Anvil and Glenlyon ranges. In the northwest part of the Pelly Mountains, in the restoration position, the Anvil Range is more closely opposed to the Glenlyon Range. In particular, Rose Mountain and Glenlyon Peak face each other (Fig.4a.); this suggests that the two ranges were one which acted as a local drainage divide across the Tintina fault zone.

Displacement of Geological Features

Glenlyon Conglomerate. The presence of Trench conglomerate without granite clasts adjacent to batholiths of the Glenlyon Range at Harvey Creek has been considered due to either faulting or unroofing (Campbell, 1967). Faulting supports the present hypothesis (Chapter II). A more probable provenance for the granitic clasts is the convergent drainage of the lower tributaries of Glenlyon River that feed the northeast reach of that river. This is the most likely point of introduction of granitic clasts from the Glenlyon Range and possibly would have been a site of either an alluvial fan or the beginning of a train of indicator pebbles in a subsequent stream occupying the Tintina fault zone. The 32 mile left lateral restoration places this source adjacent to or only slightly northwest of the Paleocene (?) conglomerates with the granitic clasts of Roddick and Green (1961).

The northeast reach of Glenlyon River correlates with the Blind Creek lineament suggesting that a crosscutting structure was displaced by the fault. Sediment there dips vertically and strikes northeast suggesting folding due to Tintina faulting or possibly deformation along the northeast lineament.

Timing of the last stage of movement.

The length of the period of quiesence and the timing of the final 32 miles of movement is unknown. If the assumption made on the age of the granite pebble conglomerate and its provenance in the Glenlyon Range are valid, then the major part of the 262 mile movement had taken place by Paleocene time and the final 32 miles of displacement was later. Deformation of "probable" Eocene sediments farther northwest in the Trench suggests final movement was Eocene or later. If deductions made on the age and genesis of the Yukon Plateau upland are correct, then a Miocene or later age is necessary for the displacement of this topography.

Evolution of the Yukon Plateau upland surface.

An hiatus exists in the geological record of the central Yukon Territory during which the present valleys were established and the upland surface that characterises the Yukon Plateau province was developed. The Yukon Plateau physiographic province was extensively eroded following deposition of the Eocene or younger Carmacks Group and prior to the Pliocene (?) development of the White Channel Strath.

Early geologists considered the upland surface to be an uplifted dissected peneplain. Brooks (1906 , pp. 290-293)postulated a long period of crustal stability following the "Cordilleran" orogeny when the interiors of Alaska, Yukon Territory, and British Columbia were reduced to a peneplain. The major part of the peneplain is considered by Brooks to have been a broad shallow trough sloping from low marginal divides to the central, meandering, ancestral Yukon river. He postulated differential uplift, more on the flanks of the shallow trough than near its center. Cookfield (1921) retains this "broad trough" concept and describes the present average altitude of the erosion surface in the central Yukon Territory as decreasing from 4700 to 5200 feet near the bounding mountain systems to 4100 feet near the Sixty Mile area. In this location the upland surface is 3000 feet above the master streams.

Early Tertiary, postorogenic streams draining southwest to the Pacific such as the Alsek, Copper, Taku and Stikine rivers extend into the interior region. These streams probably antecedent during the later Tertiary uplift, have lost much of their drainage network to the Interior Plateau river systems; the Taku underwent Pliocene rejeuvenation(Fig.4).

Brooks (1906) implies that uplift of the peneplain took place in Miocene time contemporaneous with the deformation of "Eocene" sediments and that uplift was followed by the deposition of the unconsolidated, undeformed Miocene or Pliocene beds along the lower Yukon River in Alaska.

Late Pliocene or early Pleistocene differential uplift implied by such features as deformed terrace systems described by McConnell (<u>in</u> Bostock, 1957, p. 66) are recognised by Brooks (1906, p. 292).

More recent, concrete evidence exists in the northern part of the Yukon Crystalline Terrane. A bed of conglomerate 30 feet thick inter-

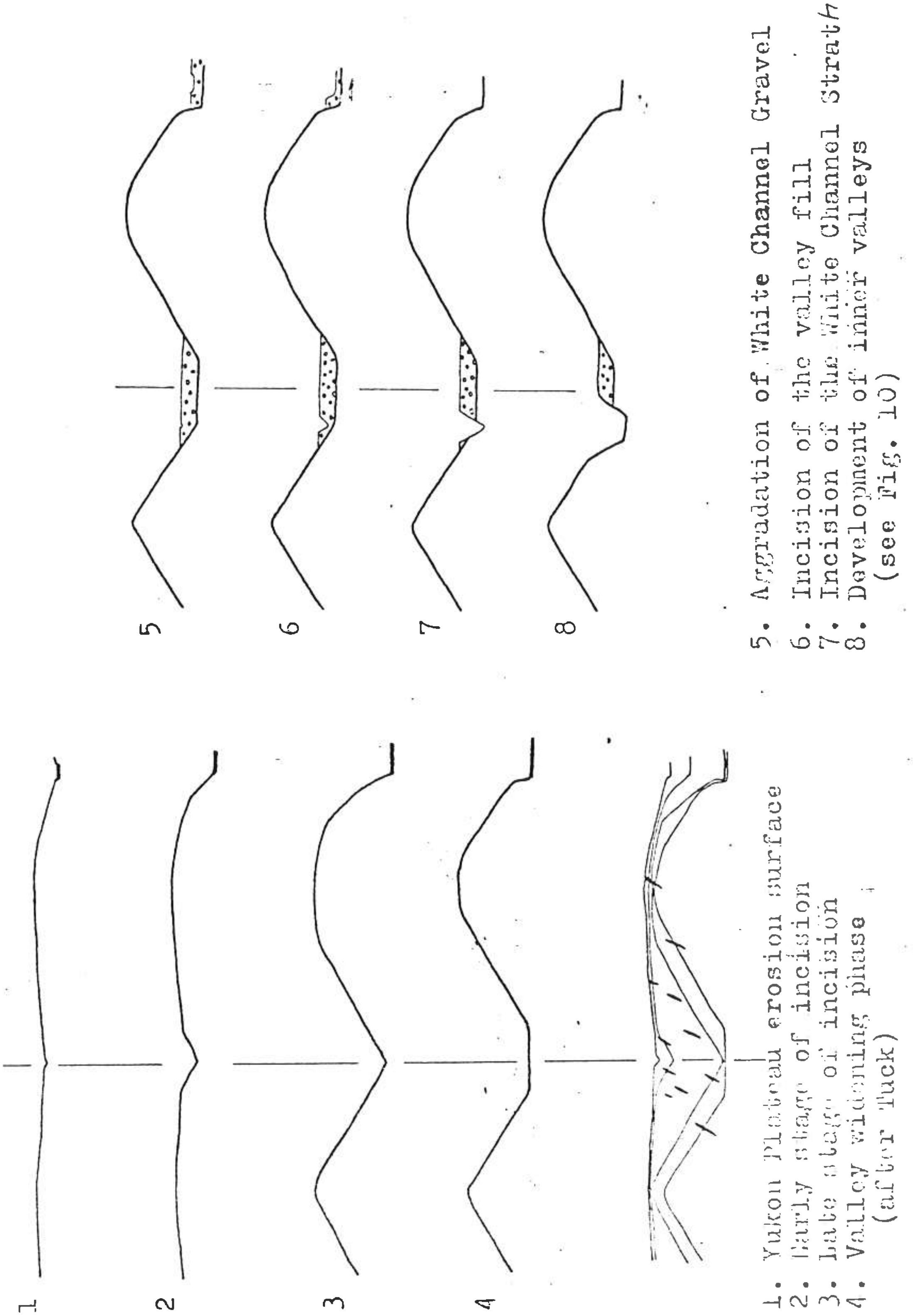


FIGURE 5. Classical model for geomorphic development of the Klondike Goldfields.

calated with basic lavas (Carmacks Group of Templeman-Kluit, 1974) on Mount Hart, 40 miles southwest of the Klondike area, is described by Cockfield (1921). These rocks are at an altitude of 4900 feet, 500 to 700 feet above Cockfield's upland surface. Pebble gravels derived from relatively low energy streams intercalated with volcanic rocks are mapped by Green (1972) to the northwest, north of the Sixty Mile Goldfields. These outcrop in cols at altitudes of 3000 to 3500 feet on ridges underlain by volcanic rocks that occur as high as 3800 feet, and in the valley to the south only 2200 feet above sea level. These scattered lowland deposits owe their present position largely to differential vertical movements or gentle deformation with an amplitude of about 3000 feet. No boundary faults have been recognised. Cockfield concludes that Mount Hart is an erosional remnant or monadnock and that these rocks were involved in structural movements prior to uplift and planation.

In the southern part of the Yukon Crystalline Terrane, 2000 to 3000 feet of volcanic rocks cover some divides in the Carmacks map-area (Bostock, 1938) and show little folding or faulting in the Snag map-area (Templeman-Kluit, 1974).

Lowland occupied the Tintina fault zone in late Cretaceous-early Tertiary time. Modern paleontological evidence from the Tintina Trench (Chapter II) indicates that deposits formerly assumed to be Eocene because of the presence of coal and a lithological correlation with the Kenai Series probably accumulated in separate basins at different times in the early Tertiary period. The abundant, local, coarse-grained fluvial deposits, lacking features in common such as coal beds and lacking diagnostic fossils described by Templeman-Kluit (1974) together with new evidence from fossiliferous coal-bearing rocks (Hopkins et al., 1976) may yet provide dates for tectonic events in later Tertiary time.

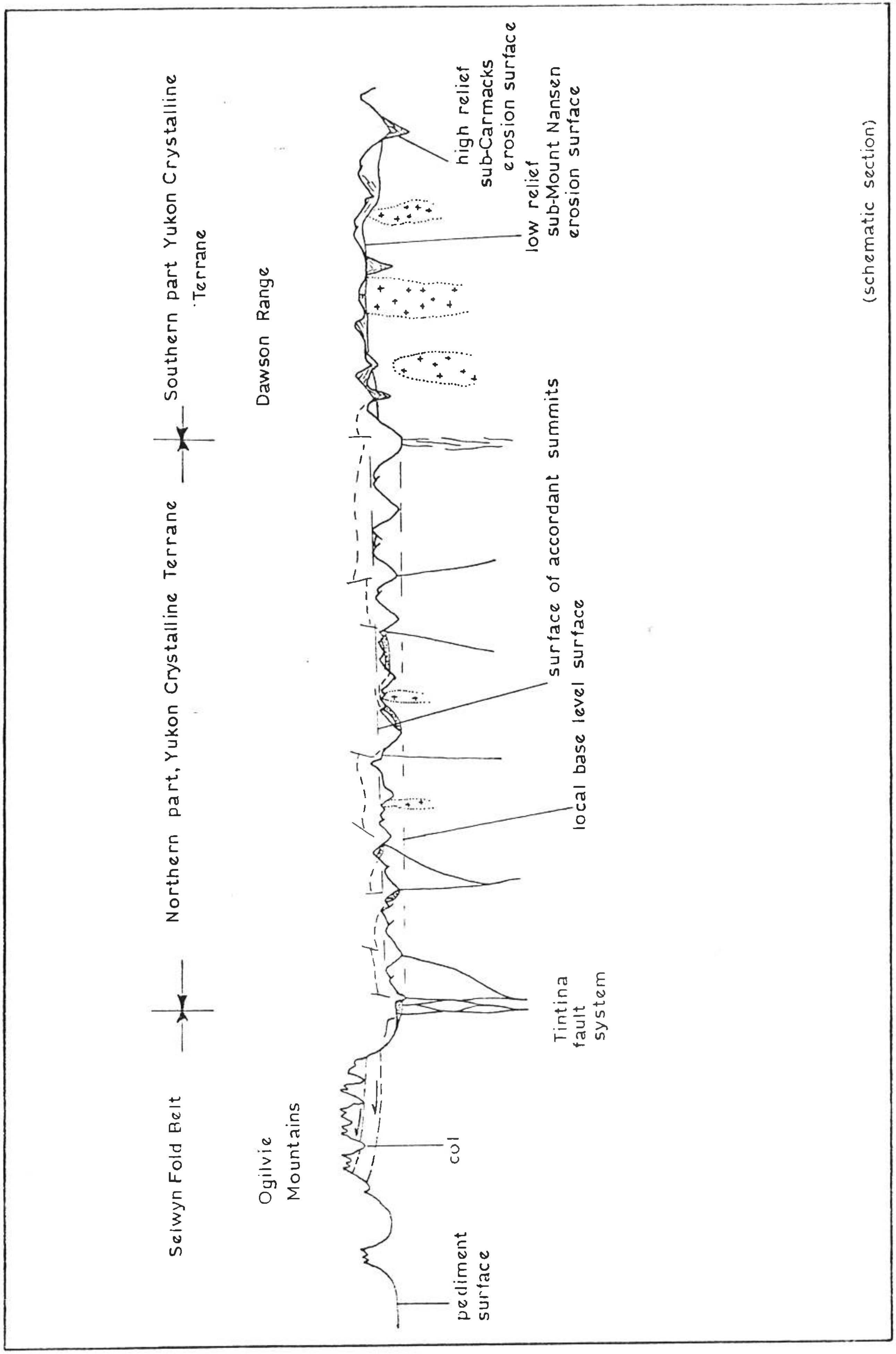


FIGURE 6. Dynamic equilibrium model for the Yukon Plateau

The sub-Mount Nansen Group erosion surface of low relief dated as Eocene in age (Chapter II) is preserved more or less undeformed in the Dawson Range and sets a maximum age limit for the Yukon Plateau upland which is younger. A still younger age for the Yukon Plateau upland surface is established by the truncation of the Eocene or younger Carmacks Group in these valleys of high relief which cut the sub-Mount Nansen Group surface. In places the upland surface probably coincides with and exhumes the early Eocene erosion surface.

If the present upland surface originated as a mid-to late Tertiary erosion surface of low relief, it must have developed from two or more contrasting topographies. In both, the apparent relief of unconformities was reduced by deposition of volcanic or sedimentary rocks. In the south, although Eocene topography in the Dawson Range was deeply incised, relief was generally reduced by volcanic accumulation. Also, this area was tectonically stable, presumably rendered rigid by Eocene intrusions and acid volcanism of the Nisling Range Alaskite-Mount Nansen Group suite. To the north sedimentation and volcanism also reduced the more moderate relief there, although later folding and possible block faulting caused deformation of lowland deposits with an amplitude in the order of 3000 feet. Some of this apparent movement may be due to early Pleistocene crustal warping.

It is highly probable that many of these processes or events were in part contemporaneous. An hypothesis is suggested consisting of regional uplift in the south coinciding with the intrusion of the high level Nisling Range Alaskite created the potential for erosion there. Synchronous warping promoted basin development in the north. The warping in the north accompanied and was succeeded by block faulting. This was followed by volcanism partly contemporaneous with sedimentation. In this hypothesis erosion was continuous; regional uplift in the south and deformation in the north were also continuous and kept pace with erosion so that relief never exceeded the amplitude of deformation. Regional aggradation of sediments from bordering mountains and local downwarping both may have contributed to the burial of interfluves and led to the development of the present drainage. Neither a peneplain nor a Miocene terrain of low relief (less than 500 feet) is necessary. This model involves dynamic equilibrium between uplift and erosion and could maintain an upland of accordant summits as a result of uniform drainage densities associated with more or less constant available relief in spite of continuous uplift(Fig.6). Cryoplanation or altiplanation also must play a role in the development of some accordant ridges (Chapter IV).

Tertiary climate.

Plant studies in the southern Canadian Cordillera and in nearby Washington and Alaska indicate a relatively warm early Tertiary climate (Rouse, 1976). A sub-tropical climatic optimum during Eocene time followed by a climatic collapse in mid-Oligocene time has been described from the coast of Alaska. Further cooling occurred in Pliocene time.

Climate is partly controlled by topography. The Pacific Orogin first developed relief that produced a dry interior in mid-Eocene time. Renewed uplift in the Pacific and Columbian orogens, which blocked arctic and maritime air masses, probably produced a drier climate in Pliocene time. Low relief believed to have existed during Miocene time permitted access of maritime air and resulted in an humid climate in the interior.

The climate optimum of Eocene age could have produced coal deposits in the Tintina Trench.

Tertiary weathering.

The chemical or physical nature and the depth of weathering in the Yukon Plateau are important to the genesis of gold placers. The deeply chemical weathered mantle of Tertiary age has generally been eroded in unglaciated areas. Fresh, unweathered material uncovered during rapid denudation, and local valley incision in the later periglacial environment generally underlies the present surface. However, granitic rocks exposed in roadcuts in the Tanana valley of Alaska are weathered to saprolite and disintegrated to gruss suggesting warm temperate conditions. Pediment slopes in the northern Yukon Territory and the desert dome-like form of Mount Fairplay in Alaska may be relict preglacial landforms. Weathering of granitic rocks and quartzite in the central Yukon Territory produces tors or castlated outcrops -- features that are common in both sub-tropical and periglacial environments.

Traditionally, deep chemical weathering is involked in the genesis placer gold deposits. Brooks (1908, p. 129) argues for secular, deep decay which liberated gold particles subsequently concentrated to form bedrock values in streams during cycles of erosion. Such a production of gold grains follows Tuck's (1968) model of valley and pay streak development. However, attrition of gravel in transport and weathering during temporary storage in terraces also could generate placer deposits, as well as weathering on slopes and uplands.

Deep oxidation is documented in the Keno Hill area by Boyle (1965) where late Tertiary weathering reaches depths of 400 feet. The position of the Tertiary "oxidation front" appears to have a uniform altitude (G. Partridge, pers. com.) suggesting that weathering was related to a former surface of low relief now dissectedby modern valleys. Deep weathering is apparent in the Williams Creek copper deposit and in the

Whitehorse Copper Belt where secondary minerals are common at considerable depths. In the Casino porphyry copper deposit of the Dawson Range, a supergene zone 250 feet thick occurs beneath a limonite capping up to 500 feet thick and is believed to be the product of Paleogene weathering (Godwin, 1976). The chemical weathering of sulphide deposits and the widespread production of leisgang banding in the Yukon Plateau province is, however, probably restricted to rocks rich in pyrite where agents of weathering are sulphuric acid developed from supergene decomposition of pyrite not to general chemical weathering.

Zones of chemical weathering may occur in the central Yukon Territory especially the unconformities of Eocene age below volcanic cover rocks. Some zones of weathering may be related to water circulation associated with Tertiary volcanism.

Saprolite occurs in the White Channel Strath and in terraces in the Klondike area. Secondary minerals are associated with sulphides on ridges, slopes and in the valleys of the Klondike Goldfields primary minerals also occur there but commonly within vein quartz where they are protected from weathering.

Swede Dome uplift.

The relative tectonic stability recorded by the regional development of the White Channel Strath ended when crustal warping caused a decrease in gradient and resulting aggradation in the Yukon River valley upstream from Forty Mile River. The White Channel gravels are up to 150 feet thick in the Klondike area and were subsequently weathered and possibly partly reworked. Climatic cooling to a mean annual temperature of less than -5°C, indicated by fossil ice wedges at various levels of the upper, Yellow gravels facies of the White Channel

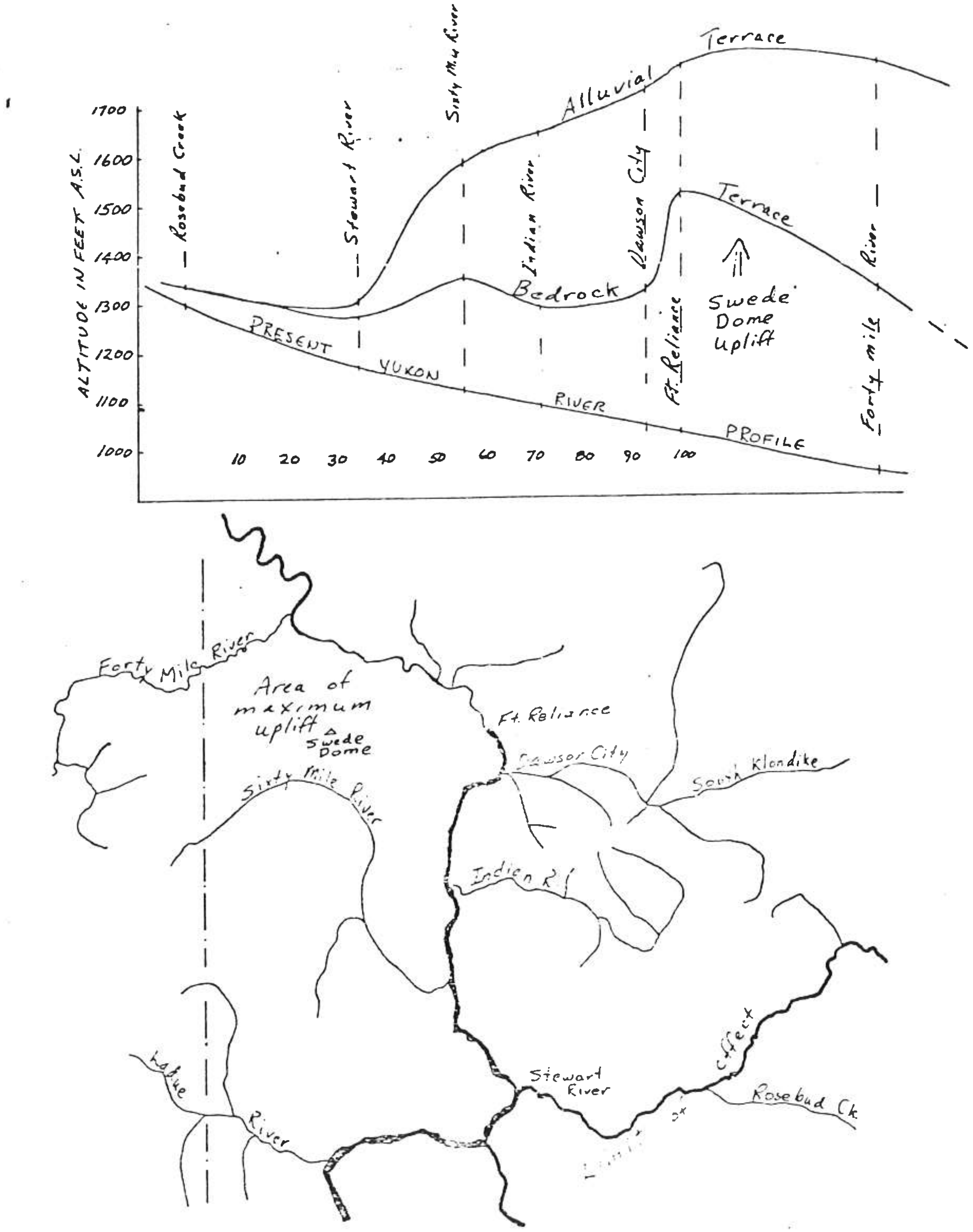


FIGURE 7. Swede Dome uplift (after Hughes)

gravels, coincides with an upward decrease in chemical and physical maturity of the gravel. Glacial outwash, without periglacial characteristics, interfingers with and overlays the Yellow gravels. Non-uniform differential uplift continued in sectors of maximum uplift and local incision commenced probably bevelling and possibly truncating the White Channel gravels in some sectors. The gravel now forming the surface fill is outwash of pre-Ried age (see below) from the White, Stewart, Indian and Klondike rivers as well as from streams draining the Ogilvie Mountains. This tilting model for the Klondike area (Hughes et al., 1972) is complicated by glacial diversion of drainage (see below).

Although the White Channel Strath is generally considered to be regionally continuous, the valley fill is not. Continuous differential uplift of the bedrock terrace suggests local erosion of valley fill at times. It seems likely that non-paired terraces developed during incision and may provide spureous data in Figure 7. In general the lowermost gravels above the White Channel Strath are like the White Channel gravels of the Klondike Goldfields. They are chemically more mature than modern stream gravels yet represent local bedrock. In the lower part of the borrow pit on the Clinton Creek road, southeast of the Forty Mile River is a grey quartzitic gravel derived from erosion of the Nasina Series. Quartzite is more abundant in the Forty Mile River watershed than in the Klondike area (Chapter II; Hughes et al., 1972, p. 31). Downstream from the mouth of Miller Creek on Sixty Mile River, thick bench gravels presumed to rest on the White Channel Strath are known, possibly because of the weathering of basic volcanic clasts derived from the Carmacks Group that occurs near there.

White Channel gravels.

The structure of the White Channel gravels in the Klondike Goldfields varies generally from coarse-grained, massive or structureless, poorly sorted gravels in the lower part, to fine-grained, bedded and crossbedded gravels in the upper part. Sparce boulders up to one meter in diameter occur high in the column; however, well sorted cobbles have a similar distribution, and fine-grained, cross bedded sand and gravel occur near the base. The subangular cobbles and boulders are quartz and fine clasts and matrix are largely quartz. Pale, leached sericite schist clasts are common and locally other bedrock lithologies as well as vein quartz appear. Very apparent weathering of clasts in the lower White Channel gravels on Dago Hill is due to the presence of rhyolite porphyry clasts there. In the lower three meters it is common to find clasts of the porphyry as well as chlorite schist completely weathered. Whereas at higher levels the same lithologies are less weathered or unweathered.

The contact between the White Channel gravels and its ubiquitous upper, Yellow gravels facies at Lovett and Dago hills appears to be gradational except for the degree of cohesion. At Dago Hill, in the first cut by Miben Mining during 1975, monitor attack produced a prominent horizontal bench in the middle of the White Channel gravels. The less cohesive, stained, upper gravel and the more cohesive, lower gravels were both frozen and except for the differences mentioned above they had no sharp contact. A similar difference in resistance to hydraulic mining is described by Green (1966, p. 93) 50 to 70 feet above bedrock on Cripple Hill.

The weathering has temporal significance: if sedimentation was continuous then weathering of the gravel probably occurred in a terrace environment possibly in interglacial times, and the deposition of the White Channel gravels and the uplift near Swede Dome must have occurred as recently as Pleistocene time. On the other hand the wide spread bleaching and chemical decay of the gravels and the chemical maturity of the clasts both mitigate against Pleistocene weathering and suggest an early Pliocene age.

Regional glacial geology.

The Klondike area was not covered by glaciers but received glacial outwash. Three glacial advances appear to be represented in the central Yukon Territory. The oldest and most extensive advance from the Selwyn lobe of the Cordilleran ice-sheet, known as pre-Reid was followed by the successively less extensive Reid and McConnell advances (Hughes et al., 1969). These are tentatively correlated with the glacial advances from the Ogilvie Mountains identified by "old", "intermediate", and "last" glaciations (Vernon and Hughes, 1966).

Similar glacial advances of the St. Elias ice lobe are recognised in the south (Fig. 1).

Dates for the "last" and McConnell advances are less than 14,000 years ago (late Wisconsin), the age of the "intermediate" and Reid advances are greater than 43,000 years ago (early Wisconsin or earlier), and the age of the "old" and pre-Reid glaciations are pre-Wisconsin (Hughes et al., 1972).

The limit of pre-Ried drift (Nansen drift of Bostock, 1966) in the Stewart River valley near Maisy May Creek is traced up the Stewart River valley past the Indian River windgap (see below) to the Tintina Trench. In the Trench the Flat Creek beds consist of alternating beds of silt, sand, clay, and gravel 8 to 15 miles wide, and extend from the Chandindu (Twelve Mile) River in the northwest to the Stewart River in the southeast (McConnell *in* Bostock, 1957, p. 78). The lower 300 feet of these beds are composed of glaciofluvial sediments. The upper 400 feet are outwash from a presumed piedmont glacier that occupied the Trench near the confluence of O'Brien Creek and the North Klondike and South Klondike rivers. Two gravel-rich till horizons occur in the outwash which is presumed to be pre-Ried in age (Hughes *et al.*, 1972, pp. 42, 43).

Terminal moraine from the "intermediate" glaciation is mapped by Vernon and Hughes (1966) in the lower North Klondike River valley; an outwash fan grades from this toward the South Klondike River at the base of the 600 foot escarpment formed by the Flat Creek beds. The terminal moraine and outwash fan are within the valley of the North Klondike River which, with the valley of the South Klondike River, is entrenched in the gravels that underlie the high level surface generated by early piedmont glacier(s) and infers a much older age for them (Hughes *et al.*, 1972).

Glacial diversions.

There are four glacial diversions that effect the fluvial history of the Klondike area.

Indian River windgap. A meltwater channel at an altitude of 2300 feet near the head of Indian River (Fig. 8) correlates with the pre-Ried (Nansen drift) glacial limit and marks the point of entry of gravels foreign to the Klondike Goldfields (Bostock, 1942, 1966). These gravels with abundant black chert clasts, perhaps are derived

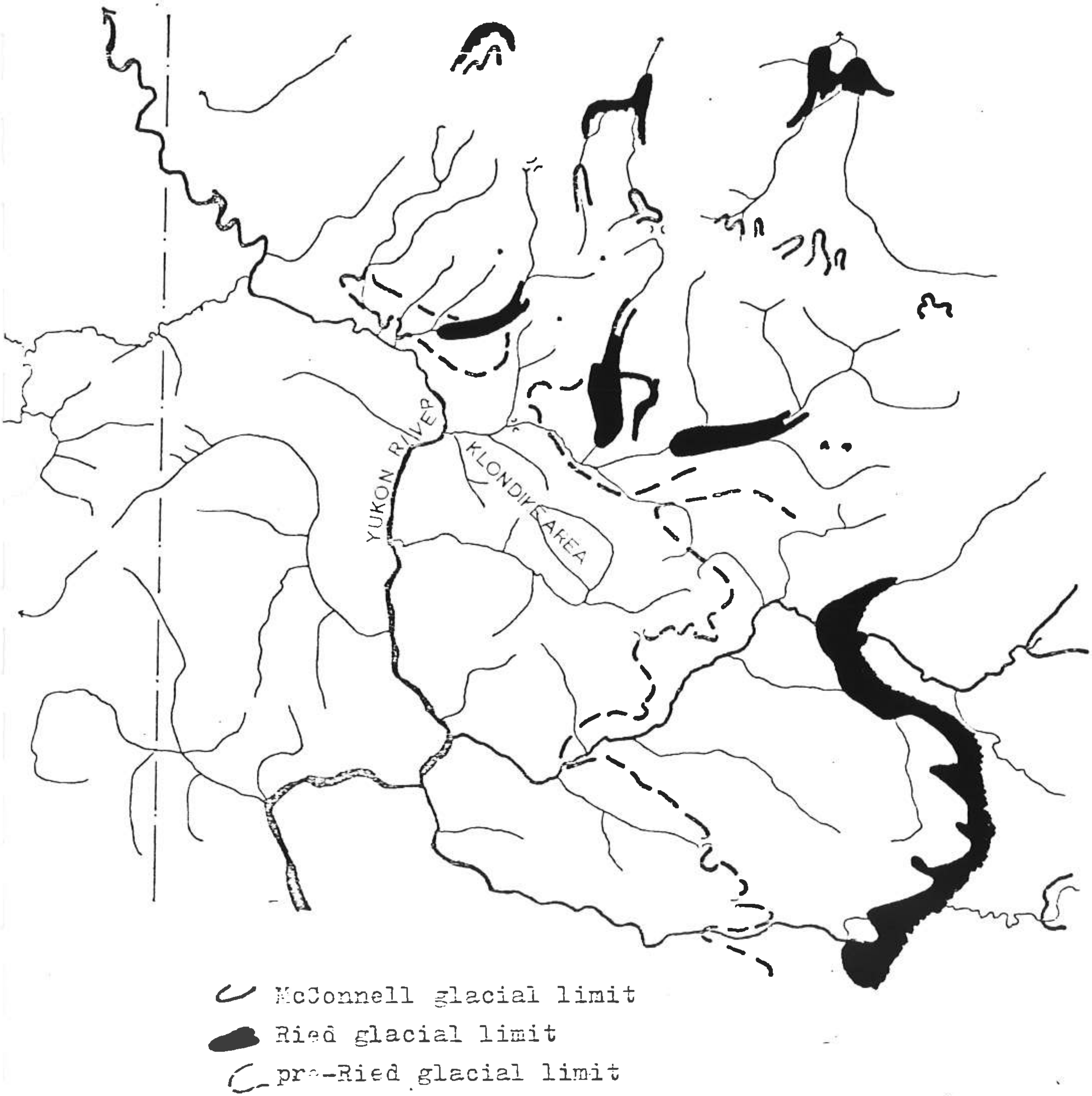


FIGURE 8. Glacial limits near the Klondike area.

from the Ogilvie Mountains, and occur as terraces on the south side of Indian River near Eureka and MacKinnon creeks. The effect of the accumulation of outwash on the Indian River system would have been to raise local baselevels for Dominion, Eureka, and Quartz creeks. This may be the explanation for the differences in color and possible other characteristics between the upper and lower parts of White Channel gravels in Quartz Creek and the presence of an alluvial terrace on the south side of Dominion Creek at Granville.

Ancestral Flat creek. The presence of lacustrine deposits beneath outwash and till, implies that a glacial lake was formed in the Tintina Trench near Flat Creek. Either damming of a northwest flowing stream by Ogilvie Mountain glaciers or outwash, or of a southeast flowing stream, by the Selwyn ice lobe are the two possible causes of this sedimentation. McConnell (*in* Bostock, 1957, p. 217) argues that during the time of deposition of White Channel gravels the Klondike River headwaters discharged into the Stewart River or into the Twelvemile River (Chandindu River). The presence of a watergap at Rock Creek on the Klondike River, where that river leaves the Tintina Trench, suggests the second hypothesis is the more likely as indicated by Hughes *et al.*(1972, p. 33) also Campbell (1952, p. 118). The North Klondike and South Klondike rivers uniting to form the southeast flowing ancestral Flat Creek in this situation would fill a "Flat Creek lake" and then extend an outwash plain over it until the altitude of a col at Rock Creek was attained. Further aggradation would explain the 200 feet of outwash represented in the high level Klondike River gravels. The incision of the valley fill related to the Swede Dome uplift which includes younger glacial drift, and the entrenchment into the Rock Creek pass, maintain the continued course of the Klondike River.

Lacustrine silts overlying outwash gravels on the unpaired intermediate terrace 70 feet above the mouth of Germaine Creek probably indicate local ponding contemporaneous with aggradation during the "intermediate" glacial advance. Lower alluvial terraces without related bedrock straths or lacustrine deposits are common in the Klondike River valley.

Chandindu - Fifteen Mile rivers diversion. A piedmont glacier similar to that proposed by Hughes *et al.* (1972) for the Klondike forks must have formed in the Tintina Trench near these two rivers. End moraine of the "intermediate" advance is mapped in the lower Chandindu River valley (Vernon and Hughes, 1966), and a boundary for glacial and alluvial deposits (including some of McConnell's Flat Creek beds) is shown by Green (1972) in a pattern suggestive of a piedmont glacier there. Outwash from the Ogilvie Mountains and slumped Tertiary deposits there would tend to obscure evidence of the "oldest" glaciation(s). One can speculate that the Yukon River, prior to the pre-Ried glaciation, followed the Trench below this location, as shown by Roddick (1967), and that glacial or outwash diversion could have occurred. Terraces uplifted to an altitude of 2000 feet, directly north of Swede Dome, indicate the position of the river at the time of diversion. The pass at an altitude of 2650 feet, presumed to be formed by end moraine or outwash, represents the former glacial dam in the Trench. An earlier high level surface or bahada appears to be represented in the Trench by flat topped ridges which slope away from the Ogilvie Mountains toward the alluvial terrace at the

Yukon River.

This damming of the Yukon River by a glacier seems improbable as one sees it today. However, during the pre-Reid maximum the watershed of the Yukon River was largely ice; the unglaciated portion of the river system above this point would have yielded little runoff. During the winter when glacial advance by Ogilvie Mountain glaciers would be greatest, glaciers, permafrost, aufeiss, and river ice would reduce the flow of the Yukon River to a trickle. Diversion could have occurred during spring breakup perhaps from a glacial lake. A southeast draining tributary valley marked by barbed drainage in the present position of the Yukon River between the mouths of the Chandindu and the Forty Mile rivers may represent this lake. Diversion may also have occurred during the peak summer runoffs from an outwash plain.

<u>Ancestral Lewes river</u>. The idea of the diversion of the Yukon (formerly called Lewes River above the mouth of Pelly River) was first suggested by Cockfield (1921, p. 39), expanded by Bostock (1936), and accepted by Roddick (1967). The original course followed the Klondike Highway north from Minto along the Willow Creek valley to the Tintina Trench near Stewart River Crossing. This course seems reasonable in view of Bostock's 500 foot high bedrock terrace system in the Yukon River and Big Creek valleys and the similar altitude of the "Highway valley" (less than 2000 feet above sea level). The well integrated, dendritic drainage pattern of the Tatlmain, Needlerock, lower Pelly, little Salmon rivers and Frenchman's and Tatchum lakes strengthens the argument (Fig. 4).

Glacial erratics occur on the ridge 15 miles southwest from the mouth of the Pelly River, at altitudes of 3300 feet. Probable spillways exist at altitudes less than 2500 feet in deranged left bank tributaries of the Yukon River and less than 2000 feet on either side of the ridge with erratics, and a watergap exists on the Yukon River to the north where the river enters the canyon at 1400 feet above sea level, on the north slope of the Dawson Range.

A possible, older windgap, now dissected and covered with glacial debris, exists northwest of the mouth of the Pelly River at an altitude of less than 2500 feet.

White river. Early adjustment could be of Tertiary or Pleistocene age as described above; the time and nature of any diversion here is uncertain. Reversal from the ancestral Alsek river (see above) was probably early as suggested by the gradients involved; the diversion from the Tanana River valley northward to the Yukon River may have been due to pre-Ried outwash although there is no evidence. Damming of the Tanana River valley by the alluvial fan at Tok may have raised water levels to an altitude of 2000 feet. The pass on the Taylor Highway into the Forty Mile River watershed is at an altitude of 2500 feet.

Holocene, glacially induced alternation of drainage from Kluane Lake between Pacific Ocean and Bering Sea drainage is presented by Bostock (1969).

Incision of the Swede Dome uplift and related alluvium.

Entrenchment of the Yukon River through the outwash, valley fill, and differentially uplifted bedrock progressed rapidly. The river probably first encountered bedrock below Fort Reliance during local uplift there, before incision began in the Klondike Goldfields. This bedrock presumably acted as a local baselevel for the region.

Younger bedrock terraces, intermediate in position between the White Channel Strath and the present valley floor, occur in the canyon below Fort Reliance, downstream from Dawson; on the Klondike River of Germaine Creek; and in the north flowing streams of the Klondike Goldfields. Thicknesses of gravel in the order of 20 feet on some intermediate terraces as at the Archibalds' bench on Bonanza Creek below Mosquito Gulch and Schnider's bench on Hunker Creek below Last Chance Creek, suggest later episodes of aggradation during downcutting. Superposition from a valley fill appears probable at Harry Leamon Gulch on Bonanza Creek where gravels surround a bedrock high that rises 30 feet above creek level. This aggradation of streams draining the Klondike Goldfields may be the result of aggradation of the master streams which act as a local base level during the Ried or McConnell glaciations.

Superposition of Bonanza and Hunker creeks and the random incision of the White Channel Strath and its medial pay streak reconcentrates gold on the intermediate terraces and on the present valley floor.

A valley-in-valley form in Bonanza and Hunker creeks is the result of the Pleistocene incision (Hughes _et al_., 1972, p. 30; McConnell _in_ Bostock, 1957, p. 81). Outer valley slopes are graded to the White Channel gravels and have slopes in the order of 1 in 10 (6°); inner valley slopes are graded to the present valley floor and have slopes of about 1 in 5 (12°) (Figs. 5, 9, and 15).

The outer valley is straight as indicated by the outer valley slopes which are symmetrical and straight, the projected limits of the White Channel Strath, and the medial position of the paystreak

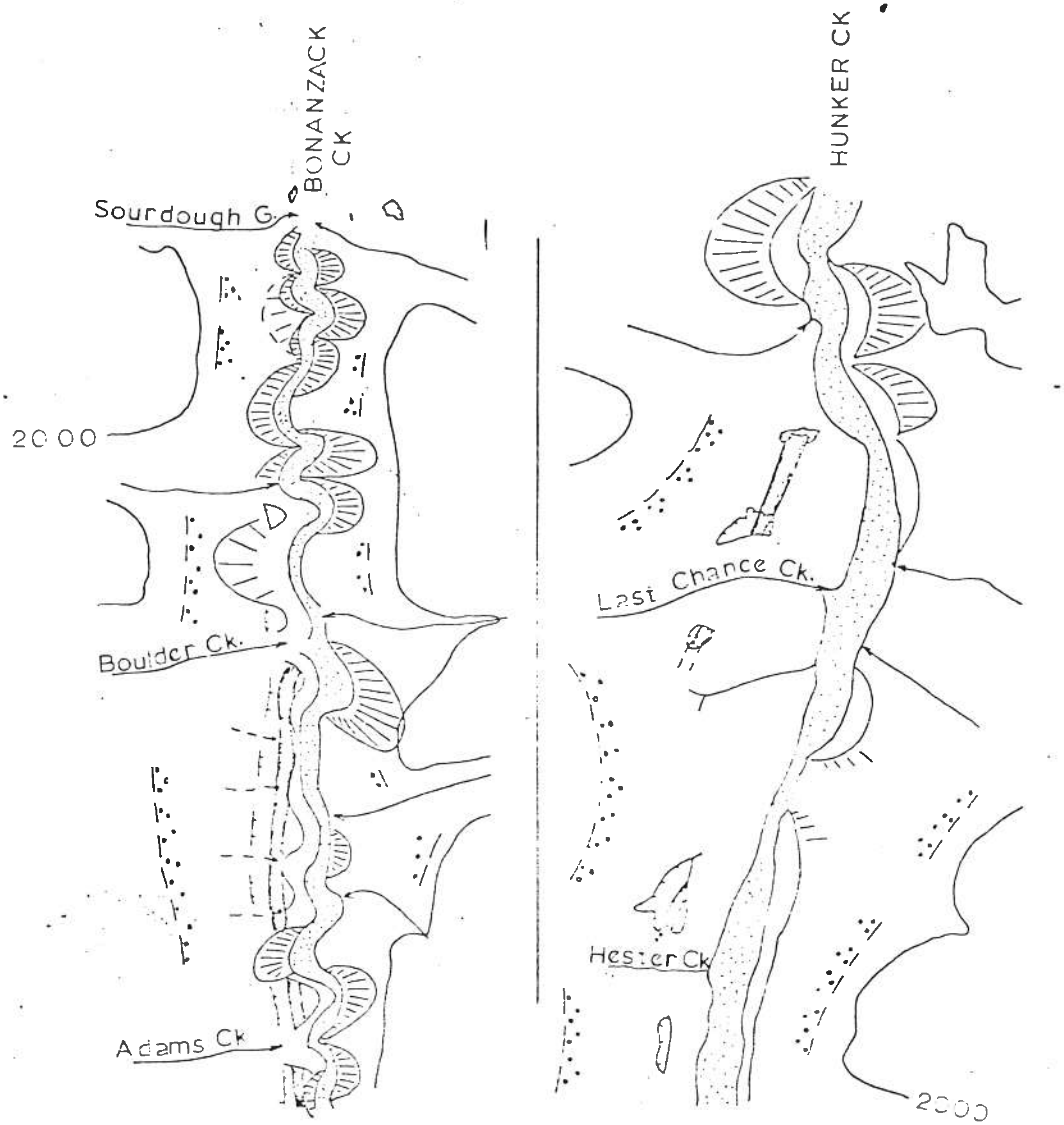


FIGURE 9. Pattern of incision of inner valleys showing sinuous inner valley bottoms and related theaters, White Channel paystreak and lateral limit, and pit margins in White Channel Gravels.

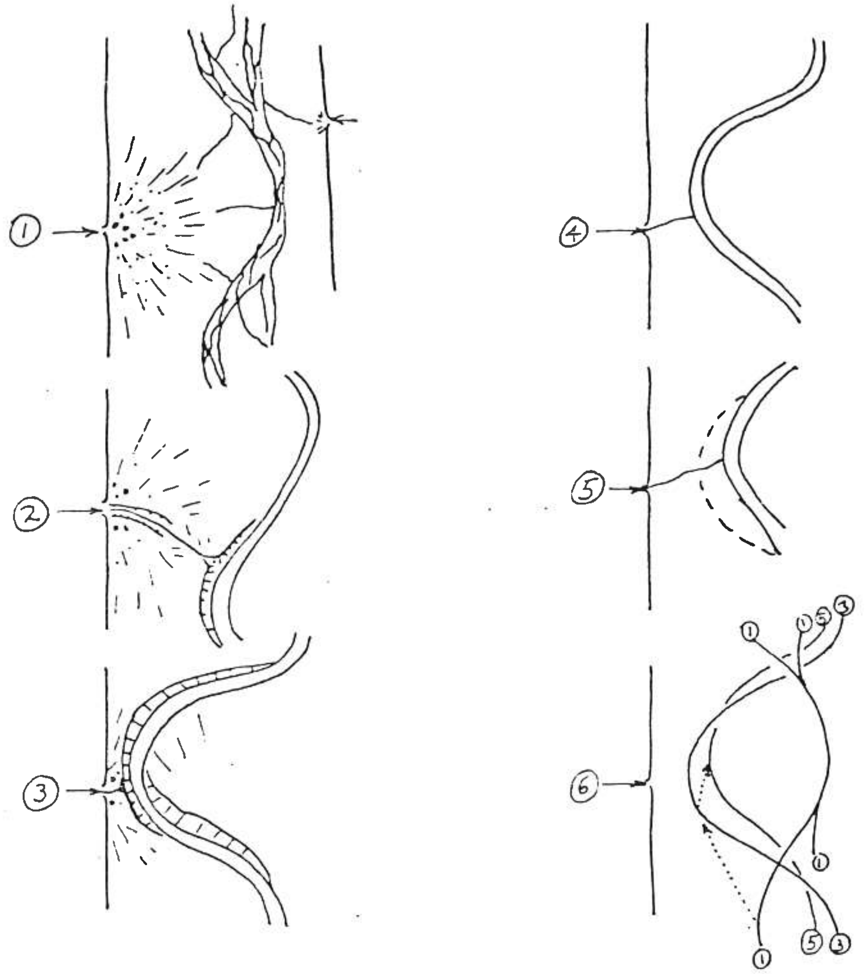
in the White Channel gravels which is straight (see Chapter V).

The inner valley bottom is a sinuous feature as shown by the pattern of dredge tailings. It has prominent asymmetrical spurs which protrude from the inner valley wall and separate theaters cut by river bends. The spurs are undercut on the upstream side and have no terraces. Intermediate terraces are preserved on the abandoned, downstream side of spurs. Terraces are also found on the outsides of bends and presumably may be found at the base of theater slopes under talus. Tributary streams commonly join the master stream on the outsides of bends.

An hypothetical model of incision for north flowing streams in the Klondike Goldfields is presented in three stages: 1) Sinuous preglacial, perhaps periglacial, braided streams and alluvial fans at the mouths of tributary valleys developed in master valleys with contemporaneous decrease in gradients of White Channel streams flowing towards the Swede Dome uplift. The alluvial fans deflected the master stream and controlled their sinuosity by their position and frequency. 2) Entrenchment of these streams through the White Channel gravels followed breaching of the Swede Dome uplift. Lowering of base level, increase in stream gradient and an increase in potential sinuosity resulted (Schumm and Khan, 1972). The incision of the less cohesive upper part of the White Channel gravels generated braided sinuous patterns rather than meandering channels. Continued incision into the more cohesive lower White Channel gravels caused an increase in the sinuosity of streams.

3) The bedrock below the White Channel Strath was less cohesive than the overlying gravels, possibly due to physical weathering in a periglacial

1. Tilting phase: decreasing gradient causes the position of the braided stream to be controled by alluvial fans at low order tributaries.
2. Shallow incision of the White Channel Gravels: tributaries rework alluvial fan facies and downstream shift of meanders reworks braided stream facies.
3. Deep incision of the more cohesive lower White Channel Gravels causes an increase in the sinuosity and downstream shift of maanders reworks terrace gravels.



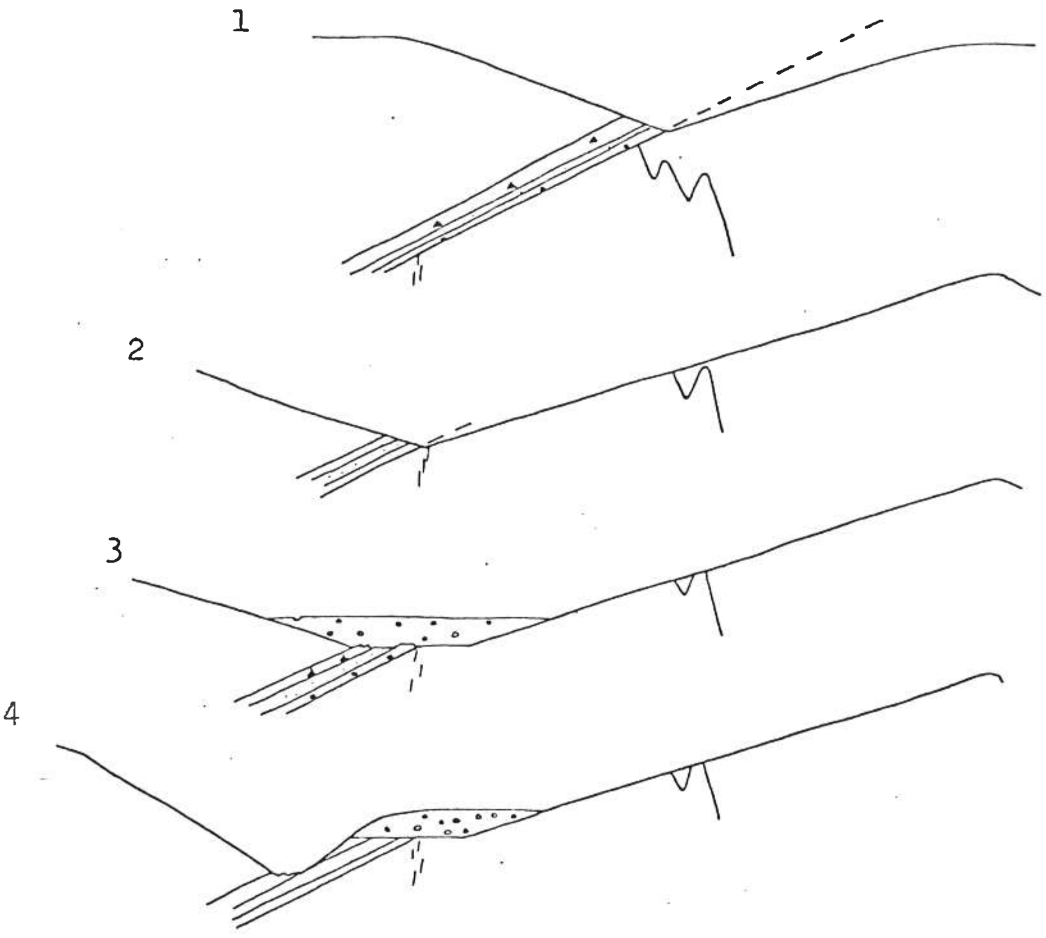
4. Incision of White Channel Strath: thedecrease in cohesiveness of the stream load causes inner valley straightening.
5. Downstream shift of meanders and valley streightening promote preservation of intermediate terraces.
6. Post incision: tributaries control the position of inner valley bends but in the opposite sence from the initial phase.

FIGURE 10. General model of incision by sinuous inner valleys of northwest flowing streams.

environment. The decrease in the cohesivity of the stream load and banks, together with decreasing stream gradients during the later stage of incision resulted in a decrease in sinuosity or a straightening of the inner valley bottom. The downstream shift of meanders combined with the decreasing sinuosity caused terraces to be abandoned on the downstream side of spurs and in some river bends. The downstream shift of bends appears to have been about one half wavelength of the sinuosity. The same tributaries that initiated the sinuosity through fan development at the onslaught of periglacial conditions, later, as unloaded streams, fixed the position of the bend.

In south flowing streams, especially the lower, southeast flowing reaches of Sulphur and Dominion creeks, an open valley form exists without inner valleys. This is in part due to decreasing uplift away from the Swede Dome area and to the limited amount of incision in this part of the watershed about 40 miles from the mouth of Indian River. In the headwaters of Sulphur and Dominion creeks a type of inner valley or valley incision has occurred because of increase in stream gradient because of the tilting effect of the regional uplift (Hughes et al., 1972, p. 33; Louis, 1969). This deepening of the headwaters was accompanied by a valley shift to the southwest producing terraces on the northeast. The master valley of Quartz Creek, being perpendicular to the direction of tilt was unaffected by this type of valley deepening and was only entrenched because of a decrease in baselevel resulting from incision in Indian River.

In the Indian River watershed the White Channel Strath can be traced upstream from the Yukon River. At the confluence of the two rivers it is preserved in an alluvial terrace and is incised by facing south-upstream



1. Vertical incision to the level of the unconformity overlain by lower Tertiary pyroclastics and sediments.
2. Lateral shift along the unconformity during erosion and establishment of control by the fracture zone.
3. Valley widening and aggradation.
4. Incision and superposition of the stream into the lower Tertiary rocks.

FIGURE 11. Lithologic control during incision of Last Chance Creek.

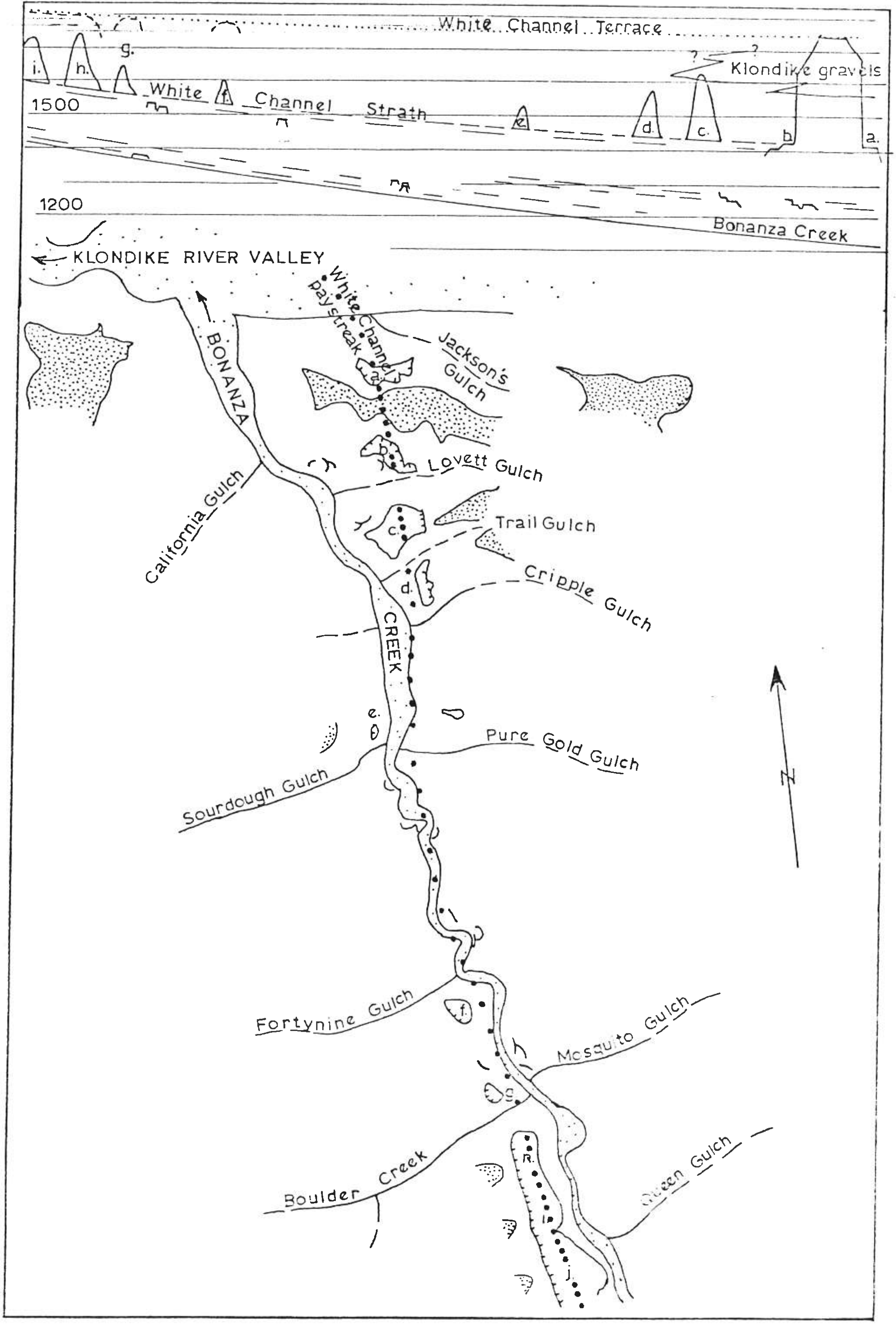
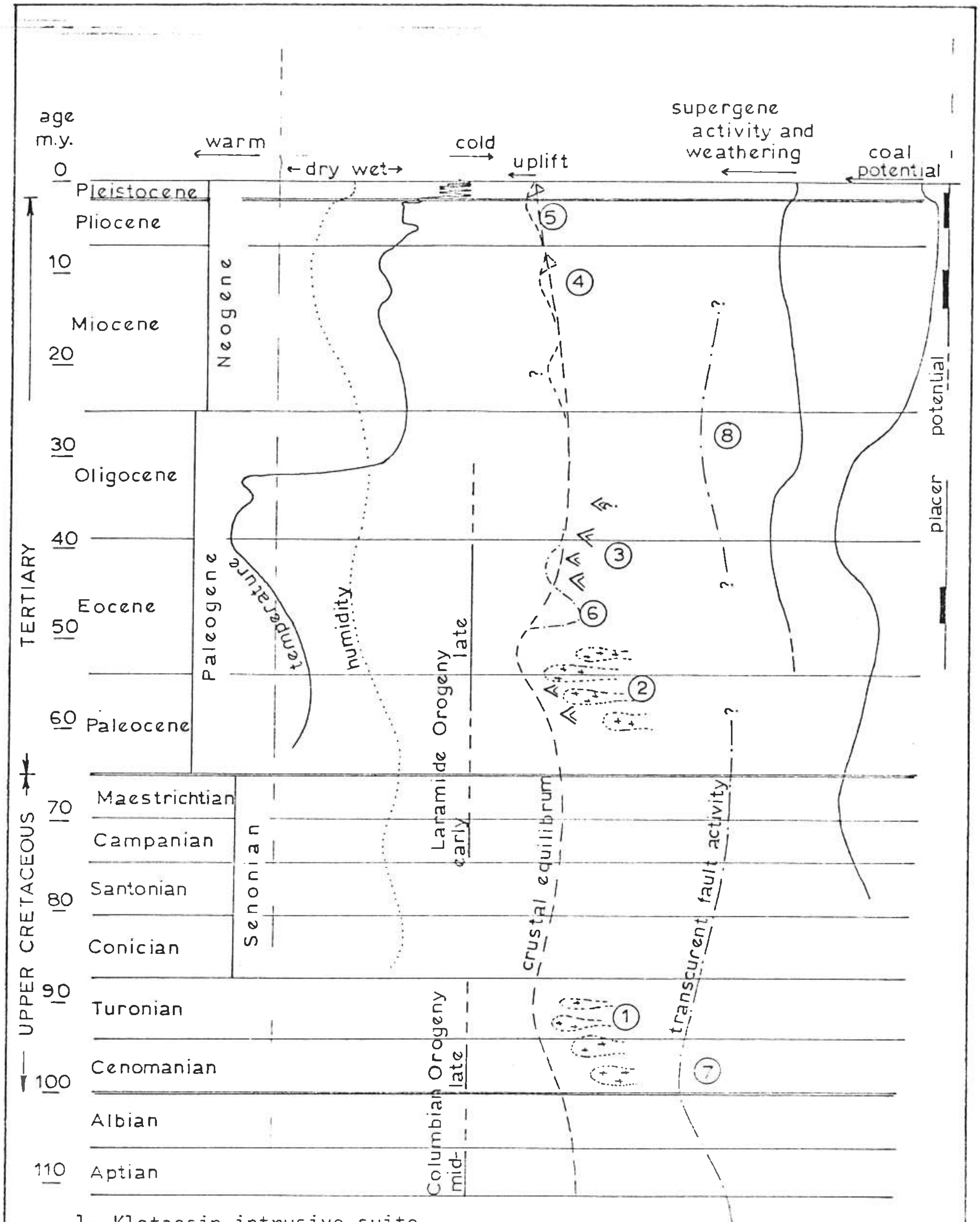


FIGURE 12. Plan and profile model of terrace development.



1. Klotassin intrusive suite
2. Nisling Range-Mount Nansen suite
3. Carmacks volcanics
4. King Solomon uplift
5. Swede Dome uplift
7. Major activity on the Tintina fault zone and in the northern YCT
8. Late, 32-mile displacement on the Tintina fault zone
6. incision following uplift

FIGURE 13. Historical geomorphic chart.

Indian River. In Quartz Creek, above Calder Creek, it is exposed by mining and stands above creek level. In lower Dominion and Sulphur creeks the Strath and White Channel gravels underlie the broad valley floor.

The present Indian River flows in a narrow inner valley consisting of ingrown meanders downstream from the confluence with Ophir Creek, entrenched to a depth of 200 feet (Hughes *et al.*, 1972). Above the mouth of Ophir Creek, Indian River meanders across a broad valley bottom cut below the outwash terrace on the south side.

CHAPTER IV

GEOMORPHIC PROCESSES AND FORMS

Environmental factors.

Present climate.

A continental climate prevails in the Yukon Plateau physiographic province. Winters are cold with temperatures commonly below -40°C and summers are warm with temperatures in the order of +20°C. The mean annual temperature at Dawson is -5°C. Annual precipitation in the region is 25 to 30 cm, 35 to 50 per cent of which falls in the summer (Bostock, 1972).

Strong departures from climatic norms are the rule. Wet months with adequate water for present day placer mining are sometimes followed by dry ones. Intense local thunderstorms commonly flood one creek while an adjacent watershed may have inadequate water for mining. Northerly winds and clear skys associated with high pressure systems cause very cold weather commonly bringing snow in August.

Warm Pacific air masses from the south produce temperature changes of 20°C or more causing midwinter thaws.

For example, the autumn of 1972 was clear and cold and the ground froze without preceding precipitation. Many of the miners' sluice boxes were frozen before the final cleanups. The following autumn was unusually wet late in the season and there was little snow cover when freezing occurred. The absence of an insulating snow cover and the rapid conduction of heat by wet soil caused deep cooling and perhaps, later, after removal of latent heat of fusion, the prograding of permafrost. The abundance of water was apparent in the spring of 1974; *aufeis* or "road glaciers" were more extensive in the creeks then than possibly in the last 20 years and they lasted late into the summer. Normal spring floods combined with *aufeis* frozen to channel bottoms, causes some erosion at unusually high levels in streams. This tends to produce widening of valleys.

During the winter of 1973-74 deep freezing occurred in the dredge tailings of the Klondike River valley. Placer miner Gus Heitman pump-tested the pond closest to his hydraulic claim on Jackson's Hill in the following summer and found the pond isolated; recharge did not occur until at least much later in the season. During dredging there about 1945 in unfrozen ground permafrost was encountered at the southern margin of the valley. The ground adjacent to the dredge and early hydraulic tailings was still frozen in the winter of 1971-72 when Heitman sank a shaft to test the valley bottom deposit. According to local miners, dredged ground will not freeze permanently (*also* Hughes, 1969, p. 6) and frozen ground covered by hydraulic tailings will thaw as a result of groundwater flow. Perhaps, rare cold autumns coinciding with high soil moisture and late snowfall may cause progradation of permafrost in dredge tailings located in areas without groundwater flow.

Vegetation.

North facing slopes having low insolation and dominated by permafrost are forested with white spruce and occasional birch. In some areas stunted spruce, sphagnum, labrador tea and dwarf birch form the dominant vegetation. Warm south facing slopes, largely without permafrost, are forested by poplar, spruce and some birch. Poplars in autumn foliage display brilliant clone patterns on ridges and large southern exposures. Dwarf birch predominates near tree line at altitudes about 3700 feet.

Some windswept south facing slopes and ridges are grass covered. Poplars tend to dominate on other similar sites and because clones are most distinct with sharp boundaries, they are probably the areas of most recent afforestation. Areas of speckled clones or mixed poplar and spruce as well as south facing valleys may not have been grass covered in the recent past.

Late autumn tree colors are due to tree bark and reveal red tints of young birch bark distinctly different from olive-green poplar bark. Birch streaks on hardwood slopes appear to be associated with rocky, well drained soil.

Although natural afforestation of grassy areas in the Klondike region is quite possible, succession of poplar following forest fires and woodcutting may be happening. Kojima (1975, written communication) also Rowe et al. (1974) find poplar to be an indication of fire in

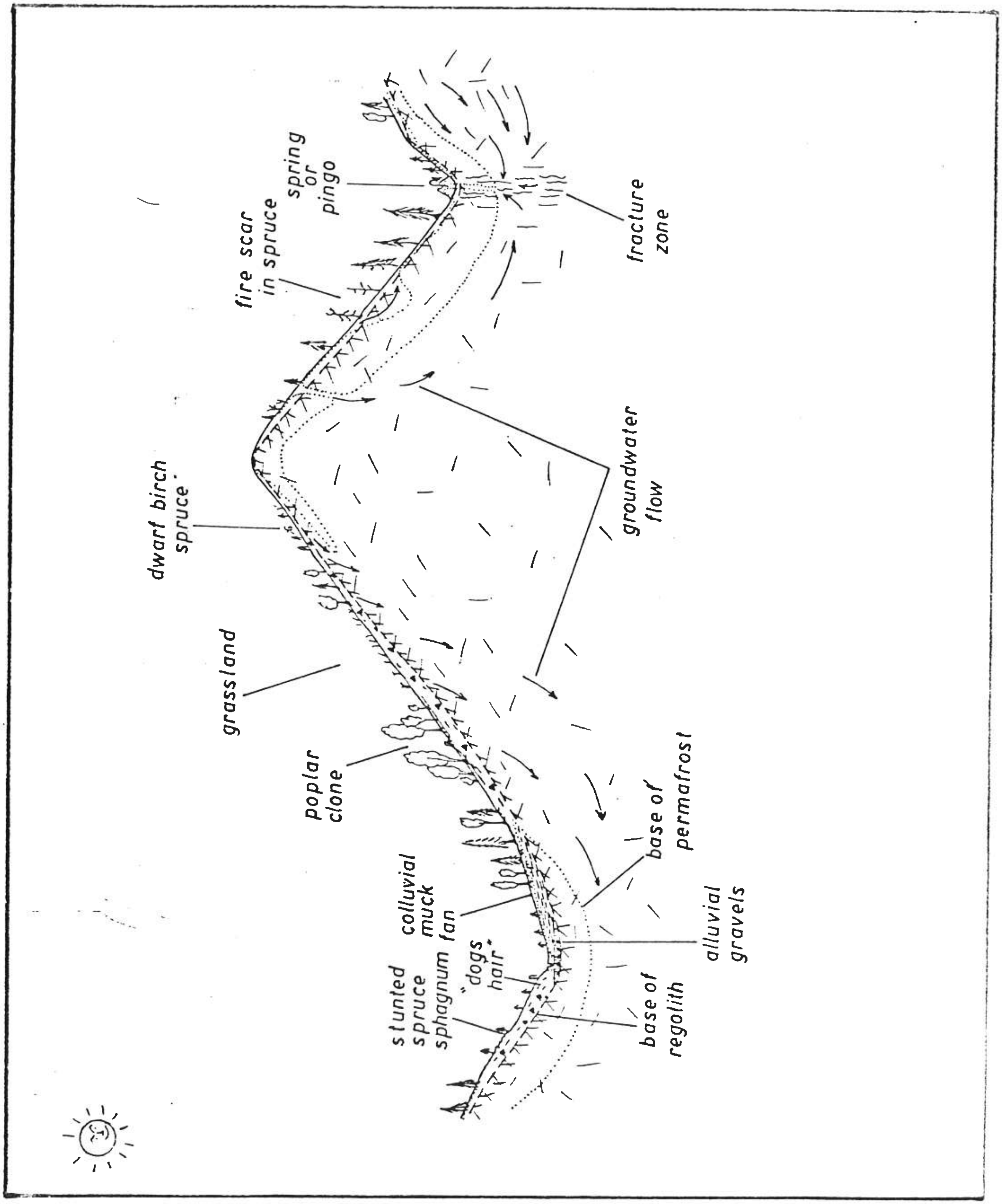


FIGURE 14. A topographic model for hillslopes in the Klondike Goldfields.

areas in the Ogilvie Mountains and the Mackenzie River valley. Poplar propagates by root spreading in areas burned in quick succession.

Fire.

Forest fire is a common phenomena in the Klondike area (Fig. 14a) and in other boreal areas. Standing snags from the 1967 fire, clad in charred bark, are common in the area between Allgold and Hunker creeks. In some places burning was incomplete, killing only some trees. Blanched skeletons from the fire about 1950 still stand on the ridge between Sulphur Creek and Indian River. Charred, standing stumps of young spruce near Victoria Gulch indicate fire about 1920. Scattered, charred stumps from before 1910(?) lie on the slope above Gay Gulch result from fallen snags or soil erosion. Charcoal burned 70 years ago, according to the 4 inch diameter spruce growing there, is common in the moss covering sorted, frost-heaved blocks on a northeast facing slope above French Gulch. Charred wood fragments occasionally appear in the paleosols in colluvium at the base of slopes. Campbell (1952, p. 98) mentions evidence of fire in woodland paleosols within muck deposits of Hunker Creek valley that are up to 9000 years old (Fig. 16).

Fire scars are apparent in early photographs in the Klondike Goldfields and mining operations then used charred logs in construction. Library research on the fires in the area was being directed in 1975, by E. Nyland, Yukon Forestry Service.

Regional studies on the effects of fire on permanently frozen ground are being conducted in the Mackenzie River valley (Rowe et al., 1974). Relevant to Klondike geomorphology are their conclusions that:

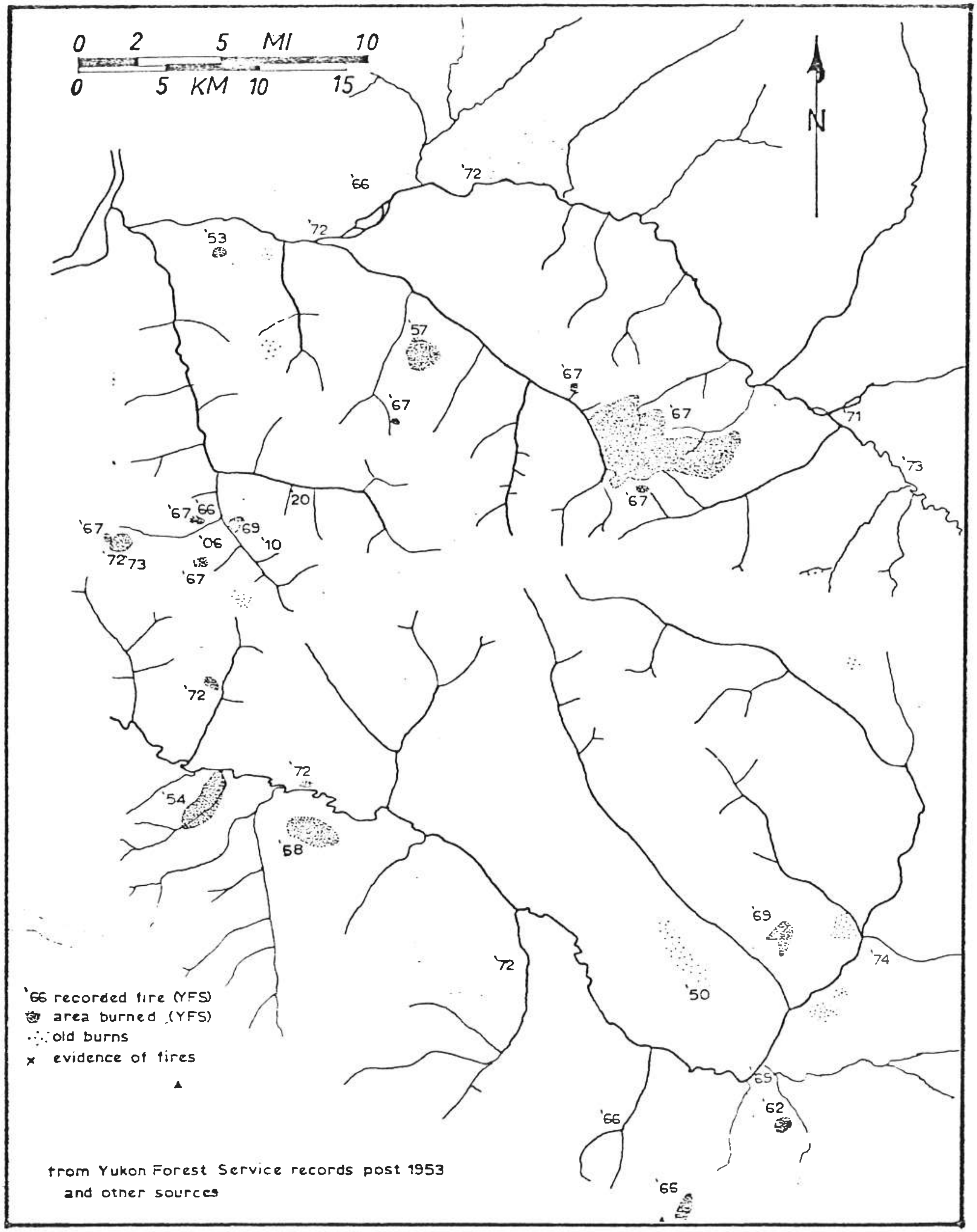


FIGURE 14a. Fire patterns in the Klondike area.

a) air mass weather rather than frontal situations is dominant in lightening ignition of fires;

b) fire recurrency intervals vary from about 25 years for well drained seasonally frozen sites to about 100 years in areas of permafrost;

c) north facing slopes tend to have crown fires while south-facing slopes commonly have groundfires; and

d) the type of burn varies with maturity and uniformity of vegetation, storm tracks, and relief.

The short term effect of fire is both the elimination of the insulating organic cover and the decrease in albedo of the burned terrain. The direct heat of the fire is of minor importance. Subsequent rapid depression of the permafrost table and deep seasonal frost results in accelerated frost weathering in the active zone. The long term effects are erosion, a change in texture and a mixing of soil horizons caused by frost sorting, cryoturbation, and windthrow of large, fire killed trees. This leads to asymmetry of slopes and increased production of colluvium.

On some gentle slopes ice rich layers above receding permafrost will melt and cause active layer detachment slides often in the same year as the fire (Rowe _et al_., 1974, p. 55). However, rising of the permafrost table in stable terrain occurs with plant colonization and the development of organic mat insulation in succeeding years (Zoltai and Pettapiece, 1973, pp. 16, 38).

Permafrost and groundwater.

Permafrost is discontinuous under valley floors of large streams. Dredging patterns in the Klondike River valley are in part governed by sporadic permafrost (Hughes *et al.*, 1972, p. 34). This is due to movement of groundwater or river water or both, or to related vegetation cover. Permafrost is thick under north facing slopes. In the White Channel gravels of Lovett Hill it is 175 feet deep (McConnell *in* Bostock, 1957, p. 66) and it occurs below Eldorado Creek to a depth of 221 feet (Tyrrell, 1903; Brown 1970, p. 790). To generalise, south facing slopes have deep active zones and may be entirely talik (Fig. 14). Patches of permafrost occur on some gentle south facing slopes underlain by alluvium. Muck covered alluvial terraces are commonly deeply frozen; however, some gravels may be dry frozen beneath impermeable frozen muck caps. The contrast in slopes of different aspect and permafrost content tends to produce asymmetrical valleys (*see* below).

Open system pingos are present, the largest example is at the base of the slope at the south side of the Klondike River valley (Hughes *et al.*, 1972). It is decadent; a central pond is drained by a stream, and subsidence cracks are apparent in the rim. Smaller pingos (Hughes, 1969) or spring-like water filled depressions some in mounds, and mounds alone, both occur in creeks and are commonly associated with faults or fracture zones (Chapter II). Hughes (1969, p. 4) points out the possible influence of bedrock geology on the distribution of pingos inferring movement of subpermafrost water through relatively permeable fault or fracture zones. These springs may represent subpermafrost water under hydraulic head, moving through ground thawed from below by groundwater or from above perhaps following fire (*see also* Brown, 1970, Fig. XIII-16).

An artificial situation involving confined subpermafrost water possibly analogous to pingo development is documented on Eldorado Creek. In November, 1902, "Deep-hole Thompson" and Dr. A.T. Hayden sank a shaft in the bottom of Eldorado Creek valley to explore for a deep lead of which they reportedly penetrated two (Baird, 1963). At a depth of 205 feet Tyrrell (1903) describes a fault breccia composed of slightly oxidized, slickensided mica schist fragments frozen in finer comminuted material. They encountered artesian water at a depth of 221 feet flowing at 1000 gallons per minute (Tyrrell, 1903; Brown, 1970, p. 790). The flow was considered permanent by Tyrrell and the inhabitants of Grand Forks feared that a "road glacier" might engulf the townsite according to Baird, and $6000. of government funds were spent to grout the hole. The valley bottom has since thawed because of more recent surface mining and no one has succeeded in duplicating either the artesian water or deep leads. Ascending groundwater is probably common in mined creeks and poses a mining problem on Gold Bottom Creek near Soda Pup.

Other hardrock shafts (MacLean, 1914) reveal hydrologic conditions. The Violet shaft 150 feet deep on the crest of the ridge between Eldorado and Ophir creeks at an altitude of 3150 feet was open for about 70 feet and dry in midsummer 1975, while shallower pits and shafts contain water or ice. McConnell, (in Bostock, 1957, p. 66) describes this shaft penetrating unfrozen ground at a depth of 60 feet. Mitchell shaft is 84 feet deep and situated on the ridge crest between Hunker and Gold Bottom creeks at an altitude of 3550 feet. It had been flooded by 1911 and was filled with ice in 1975.

Upland and Slope features.

Cryoplanation (altiplanation) terraces. Cryoplanation terraces as such are not present in the Klondike area although Reger and Péwé (1976, Fig. 5) show this area as having well preserved "sharp" cryoplanation terraces. Inactive but distinct cryoplanation terraces are described by Hughes et al. (1972, p. 28) at altitudes about 3200 feet west of the Yukon River near the Alaska boundary. Although no terraces exist, rounded, gently plunging ridges in the Klondike area have long horizontal segments suggesting relict or skeletal forms resulting from erosion of former sharp-featured terraces. These landforms are probably identical to the "stepped but rounded crests ..." representing former terraces now "... greatly modified" (Reger and Péwé, 1976, p. 102).

Statistical analysis shows a modal altitude of ridge crests at about 3300 feet for the Klondike area and also for the Forty Mile - Sixty Mile area (Appendix I). If the ridge geometry was inherited from a Tertiary erosion surface and if Swede Dome uplift effected the uplands as well as the White Channel Strath then the correlative features should be several hundreds of feet higher. Summits appear higher near Swede Dome but the most frequently occurring shoulders occur at similar altitudes suggesting a post uplift altiplanation process. On the other hand if cryoplanation terraces are the cause of the 3300 foot altitude mode, then extrapolation of Reger and Péwé's similar cryogenic features predict that it should be about 200 feet lower near the Alaska boundary. Conversely, sharply defined terraces should occur at about 5000 feet altitude in the Klondike. Alternatively, these inactive sharply defined terraces in Alaska and the relict terraces in the Klondike hills may be the same age (McConnell advance) but affected by more active surficial processes. The action of cryoplanation on these ridge systems renders uncertain the existence of an upland, or projected upland surface representing a Tertiary erosion surface. The terraces on the ridges in the area of the Swede Dome uplift indicate the importance of upland planation although these features were known and the process of equiplanation (altiplanation) was understood by peneplanationists such as Cairnes (1912).

"Cryotruncation". Triangular facets terminate ridges of main and tributary valleys in places producing straight "V" shaped valleys and locally pyramidal hills. Mass wasting tends to remove fine grained colluvium on slopes surrounding more massive, geomorphically resistant bedrock. As the soil cover thins due to differential mass wasting, the bedrock highs, still under soil cover with its ambient moisture, are exposed to more intensive freeze-thaw activity. Frost weathering attacks bedrock highs preventing them from forming outcrops, tors, or spurs. Probably straight spurless valleys in permafrost terrain are caused by this bedrock truncation.

Tors. The ridge east of Dominion Creek underlain by Pelly Gneiss has abundant tors but they do not occur within the Klondike area. In other areas to the west tors are found roughly 500 feet lower than cryoplanation terraces (Hughes *et al.*, 1972, p. 29; Rampton, 1969).

Solufluction lobes. Thin recumbent solufluction lobes are common on north facing slopes in the Forty Mile - Sixty Mile area at altitudes of about 4000 feet. In the Klondike area similar lobes occur sparcely, near tree line (3700 feet). Upright lobes of sphagnum filled with ice and sometimes mineral soil, on lower slopes are associated with "J" shaped, stunted spruce rotated by the motion of the lobe.

Solufluction terraces. At intermediate altitudes on northward facing slopes, horizontal rows are formed of open work, slaby and blocky material (solufluction terraces of the stone bank type, Benedict, 1976) mantled by a thin organic cover in spruce forest. The relief is roughly a meter and the spacing is about 10 meters. The dry open work nature of the blocky soil at crests and the insulating effect of dry organic cover there must retard frost shattering. West of Victoria Gulch various terraces seemed to be of different lithologies suggesting a very limited movement downslope. Regolith exposed in bulldozer trenches there, is in the order of a meter thick.

Block talus. Both oversteepened theater slopes of about 30°, and inner valley slopes of about 10° on Bonanza and Hunker creeks, and outer valley slopes in areas of more competent rocks near tree line, are commonly covered with blocks. Block fields are not observed on ridge crests. Outcrop at the tops of talus covered inner valley and theater slopes have no free faces from which clasts could fall. Grain size appears to be coarsest along the center line of talus tongues.

Outcrops at the inflections between higher and lower slopes suggest this moisture is supplied from the active zone of the regolith upslope. A combination of freeze-thaw and frost heaving may be in effect.

A steady state model for this talus would be more or less continuous production of blocks at the top of the slope and movement down the slope in a block stream. Alternatively, episodic winnowing of

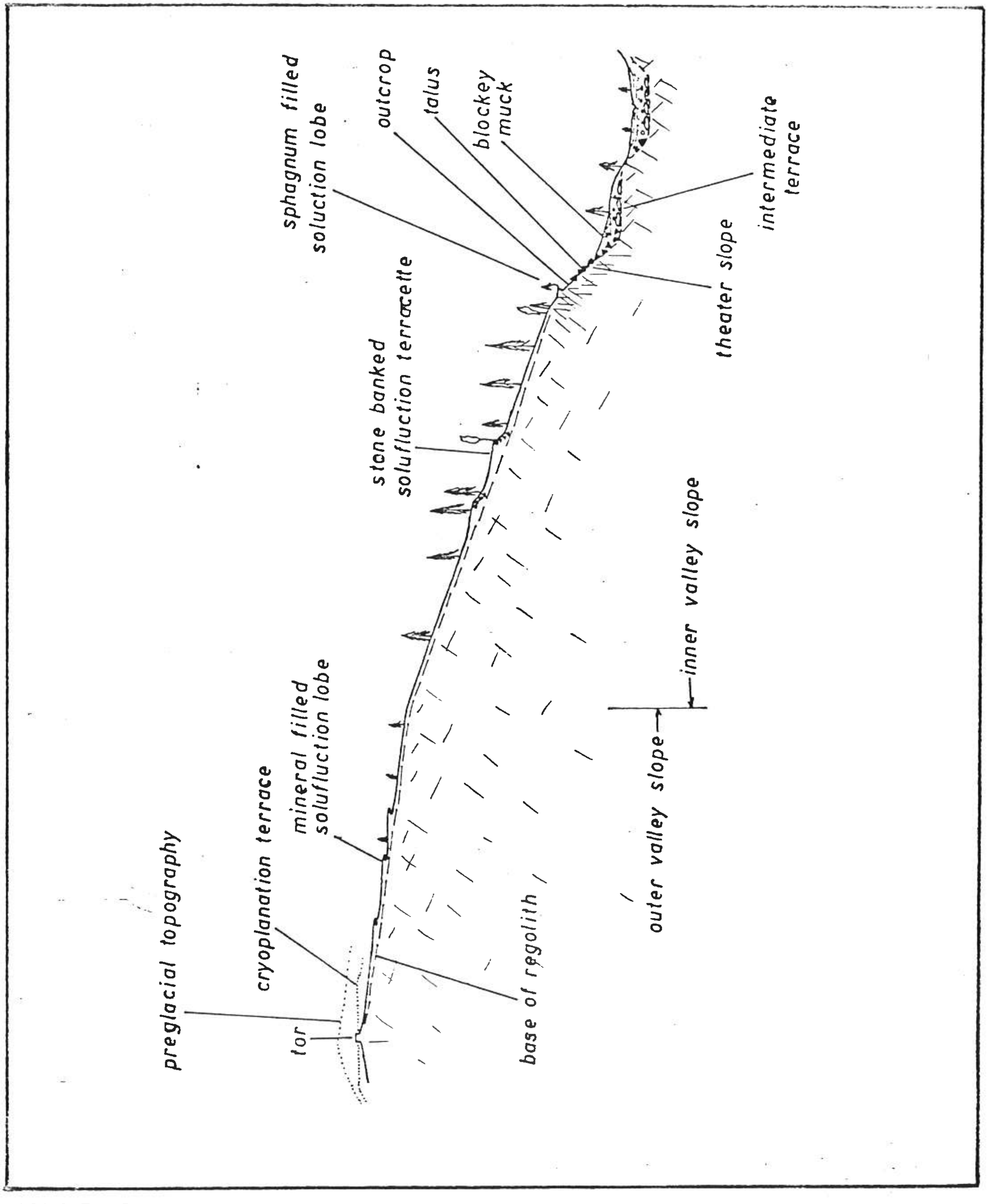


FIGURE 15. A mass wasting model for Klondike hillslopes

fines from the coarse textured regolith after fire could generate such block covered slopes. Blocks would result from erosion after recurring fires, with formation of new soil between fires. There is evidence of fire on these slopes and the re-establishment of permafrost is suggested by vegetation patterns (see Fire. above). The latter hypothesis is more compatible with block slopes (White, 1976) that have no visible rock source such as a cliff or ledge; and which have slopes in the order of 30°. Fabric studies indicate they owe their origin to soil creep in the periglacial active zone environment and are subsequently exposed by erosion (Benedict, 1970).

Mass movement. Surficial mass wasting involves active layer processes Deeper, slow mass movement involving the whole permafrost zone (less than 60 meters thick) would tend to have a locus of movement at the base of permafrost, especially in coincidence with permeable zones of weakness. If the artesian conditions that existed under Eldorado Creek in 1903, were common below permafrost in lower slopes, then hydrostatic pressure would promote creep or "permafrost zone detachment slides" similar to block glides and analogous to active layer detachment slides of Hughes et al. (1973, p. 16). These would occur during initial establishment of permafrost and during stream entrenchment which would cause thawing of permafrost at the foot of slopes. Such a mechanism could explain thrusts cutting the White Channel Strath (Chapter II); however, Hughes (1970) states that there is "general agreement that the thrust structures resulted from tectonic movement, rather than local gravity movement or permafrost activity".

Valley floor features.

Muck, an informal, placer miners' term for fine grained overburden, is mainly silty organic rich soil developed in valleys containing underfit streams. It probably developed by aggradation on a vegetated surface during erosion of higher slopes. The muck is colluvium, a general term including alluvium transported by unconcentrated surface runoff, and also soil material or rock fragments resulting from solufluction, earthflows, and rockslides. Near centers and on southern sides of valleys the muck grades into fluvial and bog deposits. Muck may also contain reworked and primary loess as indicated by Harington and Clulow (1973) and Hester (1970), who place undue emphasis on this component of the soil.

Muck facies are described under the following headings: blocky muck, stoney muck, gravelly muck, blocky sand, icy muck, micaceous muck, grass roots muck, peat, and woody peat.

Blocky muck. Oversteepened, inner valley slopes produce large blocks (cobble and boulder size) which may be an openwork block talus or a diamicton. Blocky silt is present on most terraces on the downstream sides of spurs on Bonanza Creek. Similar lithology and size of clasts occur in underlying gravels indicating that colluvium of this type has been introduced into streams (*see* Chapter V).

Stoney muck. A stoney-silt colluvium with cobble and pebble size clasts may be found below moderate slopes that are underlain by homogeneous, well jointed bedrock. It has very angular clasts and subtle, parallel layering which dips toward the valley center, and overlies the auriferous valley bottom gravels. This type of muck was well displayed in the downstream end of John Erickson's 1975 hydraulic cut opposite Mint Gulch on Hunker Creek.

A stoney muck lense about 30 meters long and one meter thick was exposed by Art Fry, in 1973, beneath 3 meters of fine grained muck on the right bank bench of Bonanza Creek at Grand Forks. Charcoal fragments were common at both ends of the lens suggesting that this is a distal mudflow deposit and resulted from a fire initiated, active layer detachment slide.

Gravelly muck. Coarse grained tongues and sheets of angular gravel in colluvial muck fans, radiate from mouths of minor tributaries into master valleys. It is distinguished from stoney muck by the presence of waterworn but angular clasts. In the upstream end of Erickson's 1974 cut (center of 1975 cut) angular, poorly sorted gravel, first appearing as beds, was later exposed as tongues radiating from a former channel of May Pup. Similar, "sharp" gravels are described by Campbell (1952) at the base of the muck sections adjacent minor tributaries on lower Hunker Creek.

Stoney muck and gravelly muck may contain some anomalous, subround to subangular clasts where terrace gravels higher on the hillslope have been incorporated as at Gold Bottom and on Eldorado Creek opposite Golden Gulch.

Blocky sand. Very friable, sericitic quartzite weathers to form very sandy colluvium. In a borrow pit near Six Above Pup, Hunker Creek, a sandy blocky colluvium contains this type of material that probably occurs on Left Fork, where sand forms the bed of the creek. The lack of placer workings in this part of Hunker Creek and the apparent absence of placer gold may be due to simply an absence of clasts which tend to retain gold in placer concentrations - a principle demonstrated by Mertie (1975).

Icy muck. A fine grained-olive grey muck containing about 30 per cent ice is common at the base of freshly exposed muck columns. The ice occurs in thin, horizontal layers apparently conformable with bedding. Shells of the terrestrial snails Succinea were found in this muck in Erickson's cut in 1975 within one meter of the auriferous gravel and with peat structures suggestive of climbing bogs or thermokarst ponds. A 10 centimeter layer of humified peat overlay the shelly, icy muck and included occasional bones of extinct mammals. Shells of this sort were also discovered by Ian Hamilton in icy muck at his claim on upper Dominion Creek. These deposits may correlate with calcareous silt, bearing aquatic moss on Lower Hunker Creek in Campbell's (1952) layer 6.

When exposed to warm air or sunlight it "weeps" and erodes to form deep caves during stripping by monitor and groundsluicing methods.

Micaceous muck. A common, greyish brown muck contains abundant mica, schist fragments, and horizons of weathered schist. The term is used by Harington and Clulow (1973, p. 698), probably representing their reworked loess. Organic horizons are common as are variation in the color of the muck which are commonly due to a variation in carbon content.

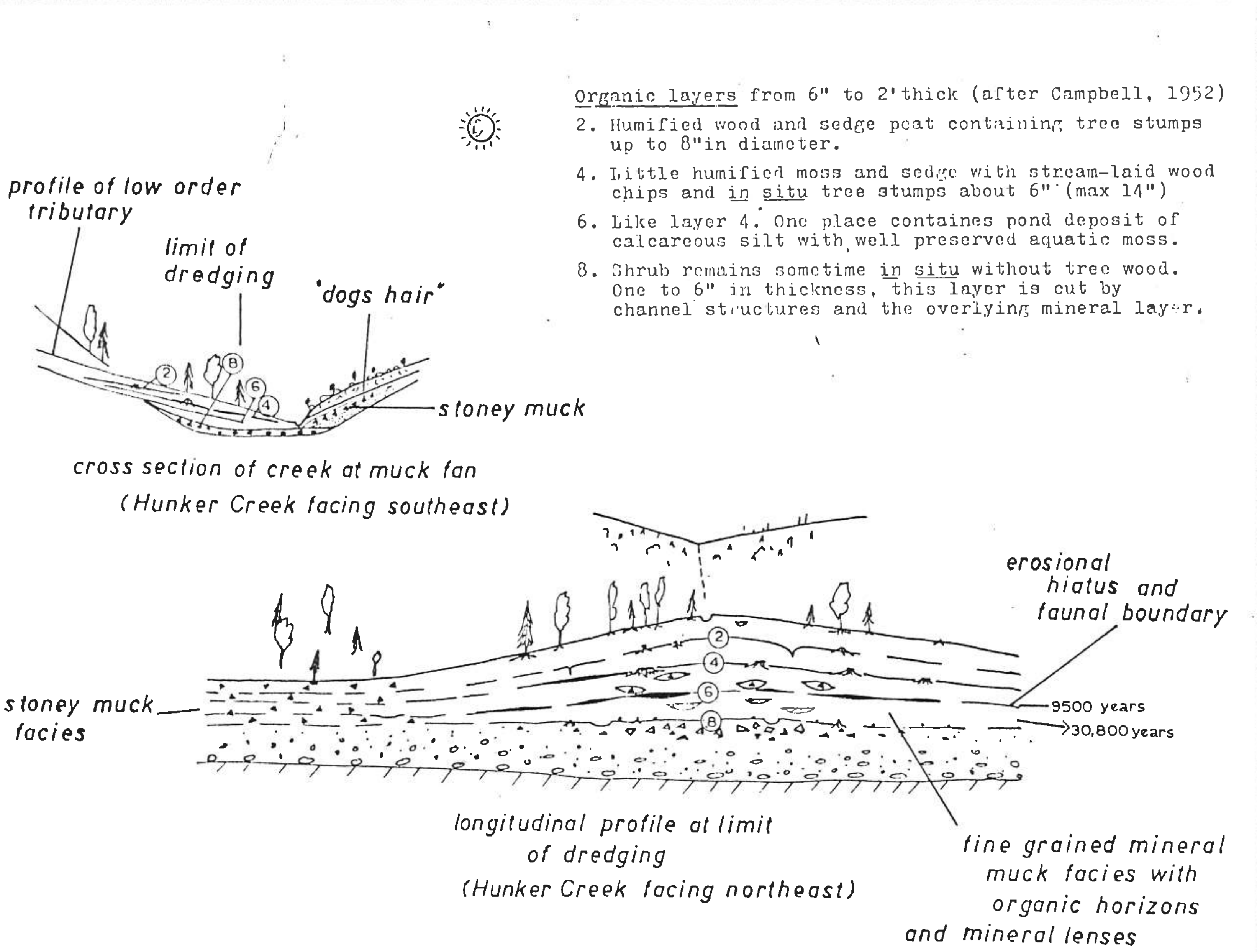
A distinctive, decomposed schist-fragment horizon served as a stratigraphic marker in the muck in Art Sailor's, 1972-75 cut on Dominion Creek. It had a fan form, the apex of which is situated near the unnamed gulch by his cabin.

Grass roots muck. Rootlets are exposed in some horizons during hydraulic stripping in olive-gray mineral muck commonly below a dark brown muck. This composite soil rarely contains woody fragments and appears to represent an aggrading grassland soil.

Stripping of this muck has been done recently using conventional sprinkler systems, less expensive than bulldozer or monitor stripping (Schmidt, 1964; Green and Godwin, 1964, pp. 54-56). This indicates how high rainfall and sheet wash following fire can erode material of this sort.

Peat. Four distinct peaty or organic horizons, sometimes contain tree trunks up to about 25 centimeters in diameter, were traced by Campbell (1952) for 1/2 mile along the northeast side of lower Hunker Creek (Fig. 16). These horizons, exposed at the limit of dredging, were less than one meter thick and usually consisted of humified material only.

Fresh peat about seven meters deep outcrops for about 1/2 mile above the mouth of Independence Creek or Hunker Creek, at the southwest limit of dredging. This sphagnum peat exposed in 1938-39 contains occasional wood. Campbell (1952, p. 107) describes the faintly stratified bog deposit having no other apparent variations with depth except for a spruce root horizon



<u>Organic layers</u> from 6" to 2'thick (after Campbell, 1952)

2. Humified wood and sedge peat containing tree stumps up to 8"in diameter.
4. Little humified moss and sedge with stream-laid wood chips and <u>in situ</u> tree stumps about 6" (max 14")
6. Like layer 4. One place containes pond deposit of calcareous silt with well preserved aquatic moss.
8. Shrub remains sometime <u>in situ</u> without tree wood. One to 6" in thickness, this layer is cut by channel structures and the overlying mineral layer.

FIGURE 16. Colluvial muck fan stratigraphy (after Campbell and Hughes)

at a depth of about 5 meters (14 feet) which may represent a "recurrence surface". The more abundant birch and alder pollen above this surface, he correlates with a warm period possibly the climatic optimum. The fresh peat overlies "sharp gravel" and humified peat at the base (Campbell, 1952, pp. 76, 77) and represents the only place on this reach of Hunker Creek where the stream did not follow the left limit of the valley. The absence of mineral matter in this section only 30 meters from the limit of the valley is unusual.

Woody peat. A chaotic mixture of sphagnum and spruce roots blankets north facing valley slopes and valley bottoms. Known as "dog's hair" (Green 1966, p. 101) by some placer miners, it was exposed in 1975 on upper Dominion Creek at Ian Hamilton's and on Eldorado Creek at Chief Gulch, where Joe Lamontagne had exposed a face about 8 meters high. It probably is mainly organic colluvium resulting from gelefluction on north facing slopes with depauperized vegetation.

This material is difficult to strip compared to mineral muck because of its insulating properties, strength, and ice content.

Fluvial silt. If overbank and point bar deposits existed, they have been removed by mining since 1900.

Landforms within valley muck.

The various muck facies represent the equilibrium between erosion, deposition of colluvium, and soil development during climatic changes following the Ried and

McConnell glacial advances. The fan forms are associated mainly with first- and second-order tributaries to third-or fourth-order valleys with underfit streams. Fan morphology manifests itself in basal gulch gravel, intermediate paleosols in colluvial muck, and the pre-mining surface form.

A facies model for muck fans incorporating Campbell's (1952, pp. 74-76) stratigraphy and Hughes' (see Dyck and Fyles below) stratigraphy and radiocarbon dates is shown in Figure 16.

Pleistocene climate.

Pollen studies in nearby areas and the character of sediments (Chapter III) indicates climatic cooling at the end of Tertiary time. Decrease in chemical and physical maturity in the Yellow gravels, and the fossil ice wedges about 3 meters long cutting both the Yellow gravels and the enclosing White Channel gravels at various levels, record climatic cooling, decrease in drainage density (see Drainage density below), and the establishment of permafrost in fluvial environments. Ice wedges are believed to indicate a mean annual temperature colder than -6 to -8°C (Pewe, 1973)*.

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*Open system pingos form where mean annual temperature is between -1 to -6°C (Washburn, 1973) and the lowest sharp featured cryoplanation terraces occur where lowland mid-day summer temperatures average from +2 to +6 and lowland mean annual temperatures are about -12°C (Reger and Péwé, 1976). The mean annual temperature in Dawson is -3°C.

Glacial outwash without fossil ice wedges overlying the White Channel gravels expanded into the lower Klondike River valley interfingering with and covering the White Channel gravels after filling "Flat Creek lake" (Chapter III). Subsequent aggradation of high level Klondike River gravels probably records outwash from an early Pleistocene, pre-Ried glacial advance.

Overbank deposits on an Intermediate terrace formed at the beginning of incision of inner valleys contain a distinctive tephra horizon (MWM9) that may provide a lower age limit for this pre-Ried advance. These sediments show no ice wedge features suggesting a warmer or interglacial climate or that no permafrost was present of that location during the meandering phase of incision (see Chapter III). Lower intermediate terraces have no structures diagnostic of climate; wood does appear more abundantly in lower terraces. Bones in the lower terraces may have been in reworked gulch deposits inset into terrace gravels.

Reworked bone deposits found in muck above auriferous valley bottom gravels range in age from greater than 40,000 years to 15,000 years and many of the same species became extinct about that time (Harington and Clulow, 1973). They suggest that these bones were transported from grasslands during erosion there that accompanied loess deposition about 11,000 years ago.

The vertebrate fossil assemblage for the southern Klondike

Goldfields according to Harington and Clulow are those of "dry open grassland or prairie, planes or parkland; and spruce woodland, and tundra or cool parkland." South facing grassy slopes and ridge may have been the "dry open grassland" environment of the badger, American lion, Alaskan and large-horned bison, Yukon wild ass, Kiang-like horse, and wooly mammoth. North facing slopes, ridges and valley bottoms could have been the spruce woodlands and tundra environment of mastadon, caribou, moose, and muskox. Wolves and short faced bears were also present. The grassland habitat implies either a dryer climate or a warmer climate (higher evapotranspiration) than at present (see Vegetation).

The greatest concentrations of bones are in the basal muck near the contact with the underlying gravelly muck opposite minor tributaries according to Campbell. A "bone placer" model is suggested by Harington and Clulow (1973, p. 743) for bones in this position. Adjacent to these deposits are barren stoney muck aprons (Fig. 16).

Paleobotanical evidence developed by Campbell (1952, pp. 74-76) for the lower muck indicates that shrubs grew in the organic horizon (8) directly above the basal fan gravels and stoney muck. He describes scour channels that cut this horizon and which may have transported bones from grasslands. The absence of tree roots and the presence of lime concretions in the organic horizon indicates a shrubland environment and a dry climate. Deposition of silt above this organic horizon results from erosion of soil higher on slopes that has abundant fine grained material presumably produced by frost weathering.

Thus a muck fan similar in texture and genesis to the boreal alluvial fan described by Legget et al. (1966) was produced.

The lower muck contains plant detritus dated at 30,800 years (Dyck and Fyles, 1964, p. 172), and radiocarbon dates on bones ranging from about 40,000 to 15,000 years for species that are now extinct, indicates a pre-McConnell interstadial or interglacial age for the colluvium and fossiliferous grassland soil. The episode of erosion postulated by Harington and Clulow at 11,000 years agrees with scour features cutting Campbell's paleosol horizon (8) and with Hughes' erosional hiatus somewhat less than 30,800 years ago (I(GSC) 181, GSC-88) and prior to 9,500 years (I(GSC) 196; GSC-73, 57); it correlates with the McConnell advance (Fig. 16).

Organic soil with calcareous pond deposits (Campbell, 1952, p. 75) and wood dated at 9,500 years (Dyck and Fyles, 1963, p. 52) postdates Hughes' hiatus (McConnell advance time) and was buried by aggrading grassland, silty soils and spruce-sphagnum forest soils. During the latter part of Holocene time the climate was dry enough for forest fires to burn south facing slopes. Organic colluvium and bog deposits accumulated at the base of northern exposures and the warm climate, indicated by Campbell's pollen spectrum for the Independence peat bog, probably correlates with forest paleosols which contain spruce stumps up to 35 centimeters in diameter (Campbell, 1952, p. 75).

Volcanic ash horizons are preserved in the muck and are stratigraphic markers that may be valuable chronostratigraphic units. The most common ash layer occurs within one or two meters of the surface and is tentatively correlated with the White River Ash deposited in this region 1900 or 1400 years ago (see Hughes et al., 1972, Fig. 4). A rarely exposed tephra layer (MWM5) occurs at the base of muck on top of gravels at Eighty Pup that are penecontemporaneous with Hunker Creek valley bottom gravels. This tephra layer may correlate with a volcanic ash above Ried drift enclosing wood greater than 42,900 years old (Hughes et al., 1972; Lowden and Blake, 1968, p. 228). A much older ash (MWM 9) occurs in a silty clay above a basal gravel and below thick alluvium on a high intermediate terrace (Archibalds' bench) at about the altitude of the White Channel Strath on Bonanza Creek.

Drainage patterns.

Drainage patterns in the Klondike Goldfields are generally dendritic with local pincer or arcuate patterns on upper Dominion and Sulphur creeks and, on a smaller scale, in Right Fork and Left Fork, Hunker Creek and also on Little Blanche Creek. Streams crossing the northwest grain of the terrain such as Quartz or Portland creeks are dendritic.

The drainage pattern has a bilateral symmetry about a northwest trending axis from near Gold Run Creek through King Solomon Dome to Dawson. The arcuate patterns of master streams such as Sulphur and upper Dominion creeks mirror each other as do the patterns of Quartz and Allgold creeks, Eldorado and upper Hunker creeks, and also upper Bonanza and either Gold Bottom or Last Chance creeks. Quartz and Allgold creeks lie along a northeast trending, secondary axis of symmetry. Northwest trending divides are skewed towards the major axis of symmetry. A vague trellis pattern (or asymmetric pinnate pattern in the sense of von Engeln) are suggested, with master streams

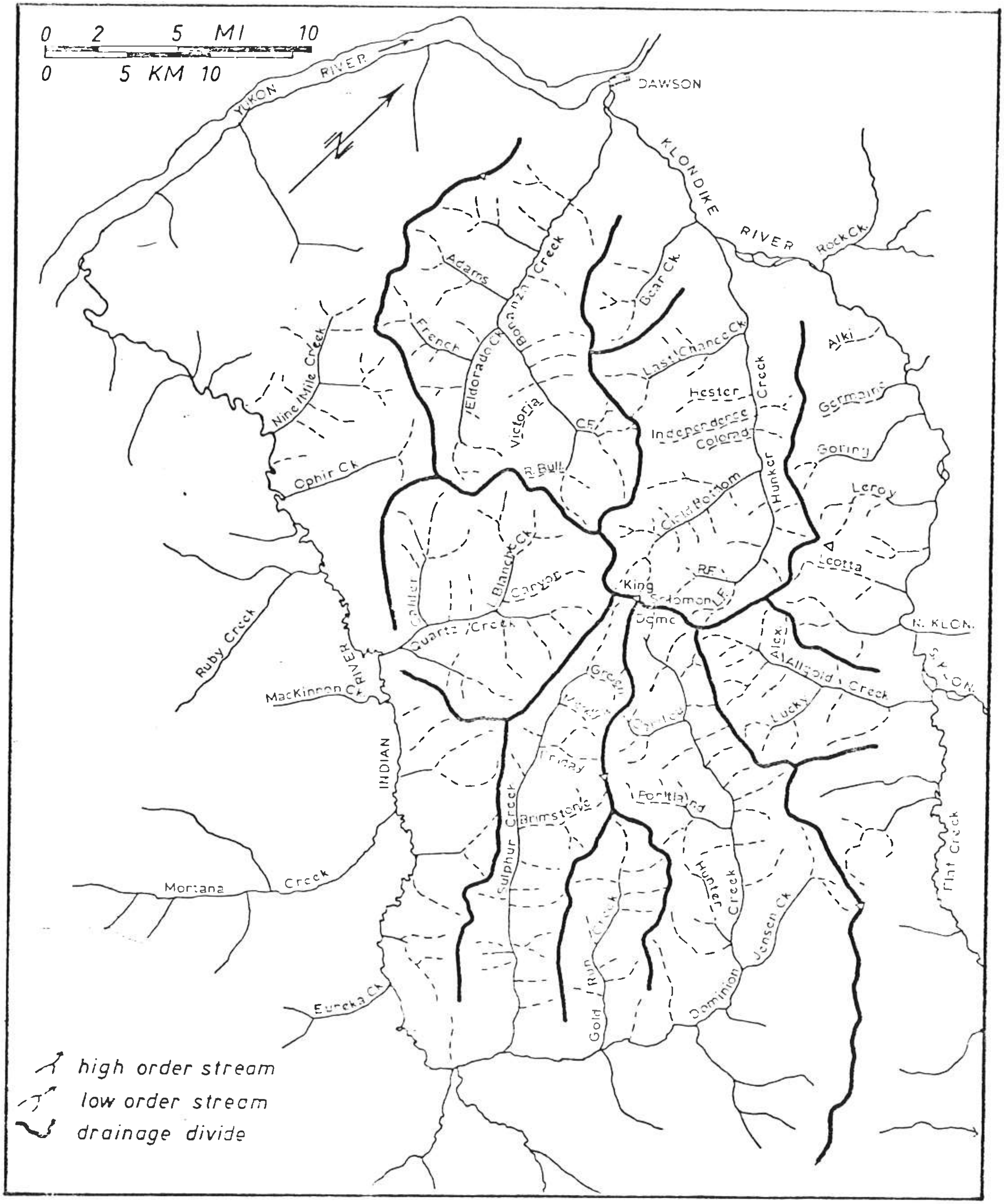


FIGURE 17. Drainage pattern in the Klondike Goldfields.

or "subsequent" stream generally parallel to the major axis of symmetry. The use of trellis pattern is descriptive only; known structure agrees with the pattern only on Sulphur Creek (Chapter II). The "trellis" pattern is especially apparent in the southern, arcuate streams where "resequent" tributaries Green, Meadow, Friday and Brimstone gulches flow southwest to Sulphur Creek and other "resequent" tributaries Caribou, Portland, and Hunter creeks, flow northeast to Dominion Creek. Similarly, Last Chance, Hester, Independence, Colorado, and Gold Bottom creeks flow northeast to Hunker Creek and Alkie, Germaine, Goring, Leroy and Allgold creeks flow northeast from the ridge east of Hunker Creek. Numerous short, unnamed "obsequent" streams enter the master "subsequent" streams from the opposite sides to those named above, flowing towards the major axis of symmetry which the "resequent" streams flow away from that axis. This pinnate or trellis asymmetry is reversed on lower Bonanza Creek.

The symmetry suggests doming of a basement arch despite the lack of convincing geological evidence in cover rocks. The asymmetry of the trellis or pinate pattern in this scheme is due to tectonic increase in relief and increase in gradients of outward flowing streams - not superposition of an earlier pattern from cover rocks. The pincer pattern in crystalline terrain indicates stress release (von Bandat 1962, p. 41) which may be caused by erosion during domming. The "trellis" pattern could result from adjustment of drainage during uplift. Streams in resequent positions would undergo extension or lengthening as their gradients were increased, and streams in obsequent positions would be shortened both by the encroachment of "resequent" streams and by destruction of lower valleys the outward lateral shift of the "subsequent" streams of the trellis. This hypothetical King Solomon Dome uplift is mid-to late Tertiary in age; the incision may coincide with the incision of the Yukon Plateau upland surface in post-Miocene time and was completed before the time of the Swede Dome uplift. The outward shift of master streams has implications for pay streak development. In some places the shift caused them to occupy fault lines.

Drainage density. If all drainage lines shown or inferred from contours on available topographic maps are included, the drainage density is about one mile per square mile. Higher densities exist locally on some slopes being undercut by streams, for example north of Indian River. Also minor but distinct variations in drainage density occur on presumably contrasting rock types on both sides of Last Chance, Too Much Gold and Allgold creeks. The anomalously low density is due to a combination of vegetation canopy and infiltration capacity of the soil. Frozen ground enhances spring runoff. The deep permeable active zone below poplar on south facing slopes, with its high infiltration capacity and the sphagnum, with its storage potential on north-facing slopes, retards control summer runoff.

In a warm temperate, arid climate such as that which may have existed in Tertiary time, runoff would have been much greater and might have produced a drainage density in the order of 10 miles per square mile. As a result, transportation of detritus during Tertiary times of high drainage density would have been predominantly by streams, in contrast to storage in and transportation on slopes by mass wasting, during Quaternary times of low drainage density. This is at least part of the explanation for the higher chemical and physical maturity of the White Channel gravels as compared to the immature gravel of the valley bottom. The absence of organic detritus in White Channel gravels except for rare carbonaceous fragments, and the braided channel structure of that sediment, strengthens the argument for near desert conditions, low infiltration capacities, and higher drainage densities during White Channel time. Direct evidence of more abundant first order streams of Tertiary age has been removed by mass wasting on higher slopes and possibly buried by colluvium on lower slopes.

A special case of fire initiated high drainage density exist for northfacing slopes. Abundant drainage lines are visible on air photographs near the heads of gulleys where normally precipitation and meltwaters are stored in sphagnum cover, in the active zone, or as aggrading permafrost. Subsequent melting of this water following early summer fire can produce high rates of runoff and erosion, and may develop new channels as shown by Brown (1975, lecture at McGill University) for permafrost terrain of low relief.

Bedrock control. Linear reaches of Eldorado, Hunker, Sulphur, lower Bonanza, Ophir, and Last Chance creeks, have been used as evidence of faults and fracture zones (Chapter II). Banding or schistosity appears to control Bonanza Creek between Carmacks Fork and Ready Bullion Gulch, most of Gold Bottom, and some reaches of Sulphur, Dominion, and Gold Run creeks. Straight valley segments making small angular deflections at their junctions, as well as curved segments, occur on middle Gold Run, upper Dominion, and upper Sulphur creeks and are common in other areas in the Klondike Plateau subprovince suggesting a permafrost or a periglacial origin (see "Cryotruncation".)

Control of low order streams is expressed by a collinearity of streams on both sides of divides. A second-order, straight tributary to Carmacks Fork is aligned with a first-order tributary of Bear Creek to the north. The divide separating them shows no depression or notch as one might expect if a fault, fracture, or a set of closely spaced joints were present. A similar reappearance of a lineament occurs on two second-order tributaries in Allgold Creek and is used as evidence for the extension of the Hunker Creek Fault (Chapter II). Alexandra Creek flows southeast along the fault to the master stream and there is no topographic representation in the ridge to the southeast. Further southeast however, a second-order right bank tributary to Lucky Creek is almost parallel to it. The Ophir-Last Chance Lineament (Chapter II) has auriferous quartz veins as supporting evidence for its existence in the watershed of Bonanza Creek which separates the collinear streams.

Some reasons for the intermittent control could be that the structure is locally healed by metamorphism, silicification, or intrusion; or that there is only minor selective erosion of weak zones and that surficial processes tend to mask them.

Cryoplanation on ridges could bevel notches and the dispersal of detritus on slopes would mask minor lineaments. However, on slopes a combination of non-channeled mass wasting and the infiltration of runoff into surface materials, could limit all but a few drainage lines to positions without structural control.

Structural control, perhaps by joint sets, is expressed by paired, approximately opposed tributaries.

Valley shift.

Four causes of displacement of streams could exist in the Klondike Goldfields:

1) Outward shift from the hypothetical King Solomon Dome uplift in Tertiary time.

2) Northward shift caused by the ease of erosion of south facing, warm slopes compared to north facing, permafrost slopes during incision of competent streams in Pleistocene time.

3) Southward shift caused by crustal tilting in late Tertiary to early Pleistocene time.

and 4) Southward shift resulting from colluvial encroachment on valleys of underfit streams in Holocene time or warm Quaternary times.

The first type discussed above would tend to disrupt pay streak development except in Bonanza Creek where entrenchment seems to have been vertical and unaffected by valley shift (Fig. 5).

The second type is the corollary of the principle of asymmetrical slopes due to aspect. Although northfacing slopes produce colluvium at slower rates than the more dynamic, southfacing hillsides, competent streams tend to shift northward because of the absence of permafrost and the presence of more erodable material there. As a result, colluvium and permafrost prevent undercutting of north-facing slopes, the colluvium of which covers alluvial deposits. These form terraces as the stream shifts to the north while it incises the valley and undercuts the southfacing slope. Examples of this are on upper Dominion Creek where colluvium masks gravels on the right limit of the southeast flowing stream (Green, 1966, p. 91). Also, on upper Livingston Creek northward shift of the stream during

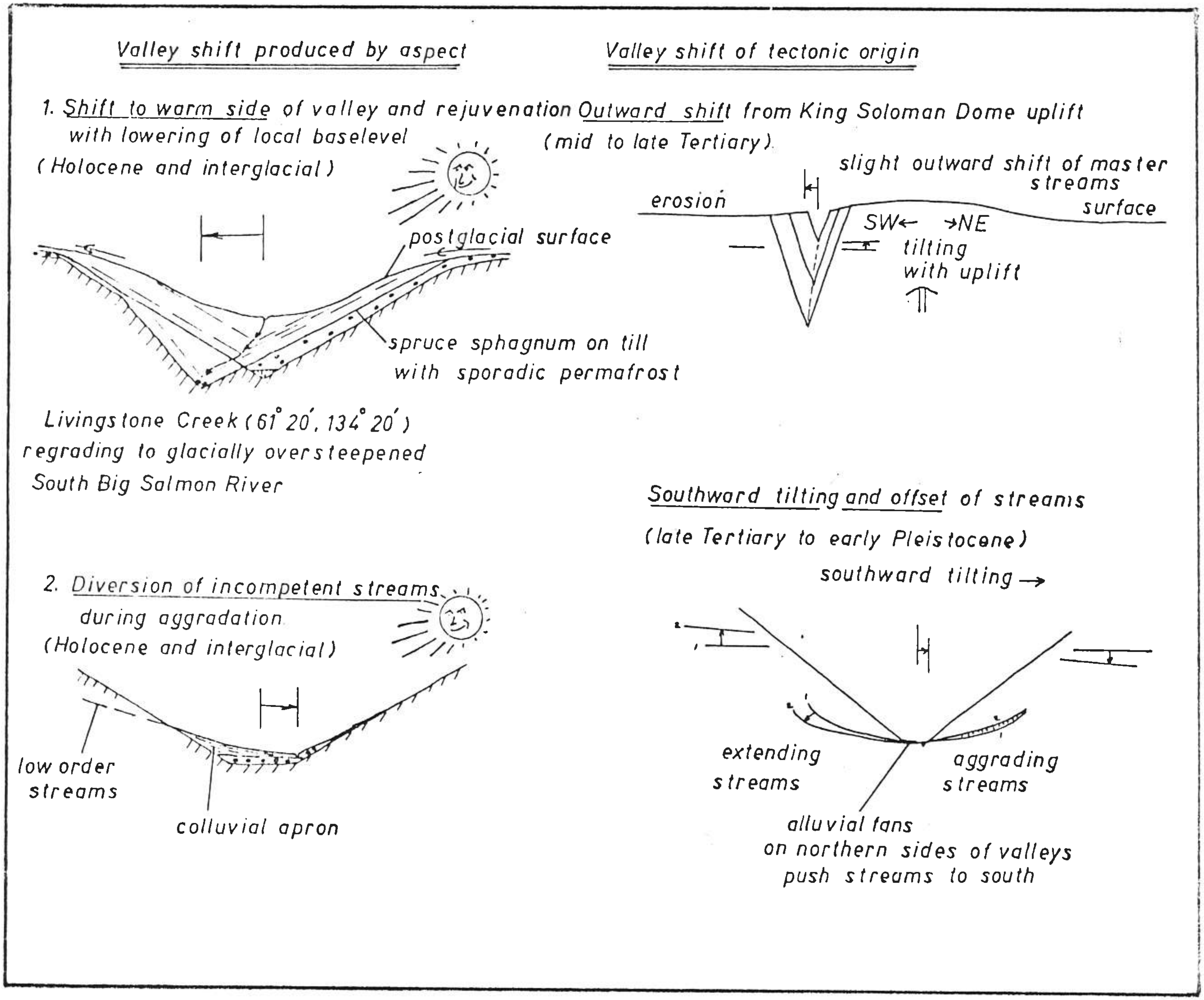


FIGURE 18. Valley shift models for asymmetrical valleys and terraces.

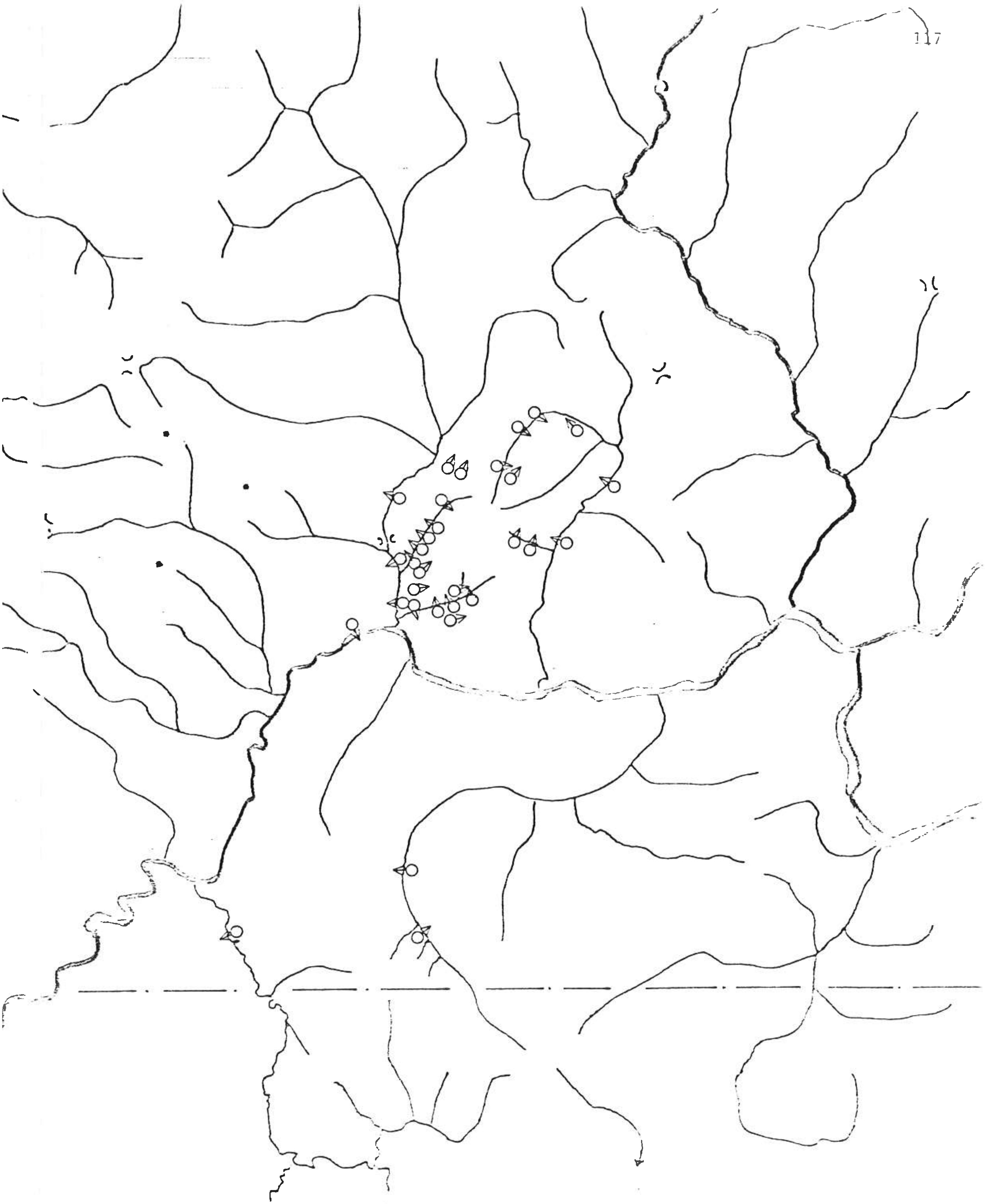


FIGURE 18a. Direction of valley shift.

superposition from glacial till, explains the buried channel on the south side of the valley and the oversteepened bedrock slope on to the north side (Bostock in Bostock, 1957, p. 623). A similar situation exists on Dubin Gulch. Sixty Mile and Indian rivers also show extensive, gentle north facing colluvial slopes including terraces, opposing steep, unforested, south facing slopes.

The third type of valley shift could have happened during inner valley incision and southward tilting. The majority of the high level terraces lie to the north of inner valleys as shown in Figure 18 and may be directly due to crustal tilting south-southeast from the Swede Dome uplift (Hughes et al., 1972, p. 33) or west-southwest from late Pliocene or early Pleistocene crustal movements perhaps related to tectonic activity along the Tintina Trench (Hughes, 1970), or a southward tilt caused by a slight uplift to the north (Hester, 1970, p. 60).

The southward shift of master streams may result from displacement by colluvial or alluvial fans which in turn are partly due to incision. The increased gradient on south facing valleys of south flowing tributaries is produced by tilting and causes incision. The resulting debris cannot be accommodated by the master stream transverse to the direction of tilt. Later, incision in the lower reaches of the drainage system lowers local baselevel and causes the displaced streams to be superposed from alluvium at the southern margins of valleys. This results in inner valleys southward from former valley deposits.

The fourth type of valley shift results from the greater production of colluvium on warm southfacing slopes and the crowding of the incompetent streams across broad valley floors toward the north facing slopes. This model is derived from Hunker and Dominion creeks and is discussed above. Campbell (1952), by implication, assumed this type and Currey (1964) presents similar processes for asymmetry of periglacial valleys.

CHAPTER V

PLACER GEOLOGY

Sources of gold.

Eldorado and Bonanza were the richest creeks. The best paystreaks and the coarsest gold were on Eldorado Creek below Gay Gulch.

The grade of the creek bottom gravels dropped abruptly above Gay Gulch and the gravels of Gay Gulch were auriferous suggesting that the important source of gold is in the terrain to the east. Similarily, the placer gold on upper Bonanza Creek appeared to come from Victoria Gulch which contained angular gold in its headwaters. Partly decomposed slide rock contained visible gold and covered the surface of the hill below outcrop of the same material (McConnell *in* Bostock, 1957, p. 106). Around 1900, numerous quartz veins were uncovered on the divide between the two creeks (Fig. 19) but only the Lone Star Mine on the Victoria Gulch side produced lode gold.

In 1961 and 1962, Klondike Lode Gold Mines discovered new auriferous quartz veins on both sides of the ridge (Gleeson, 1970, p. 51; Western Miner, 1960). Geological mapping and heavy mineral studies by Gleeson established that gold also occurred in more

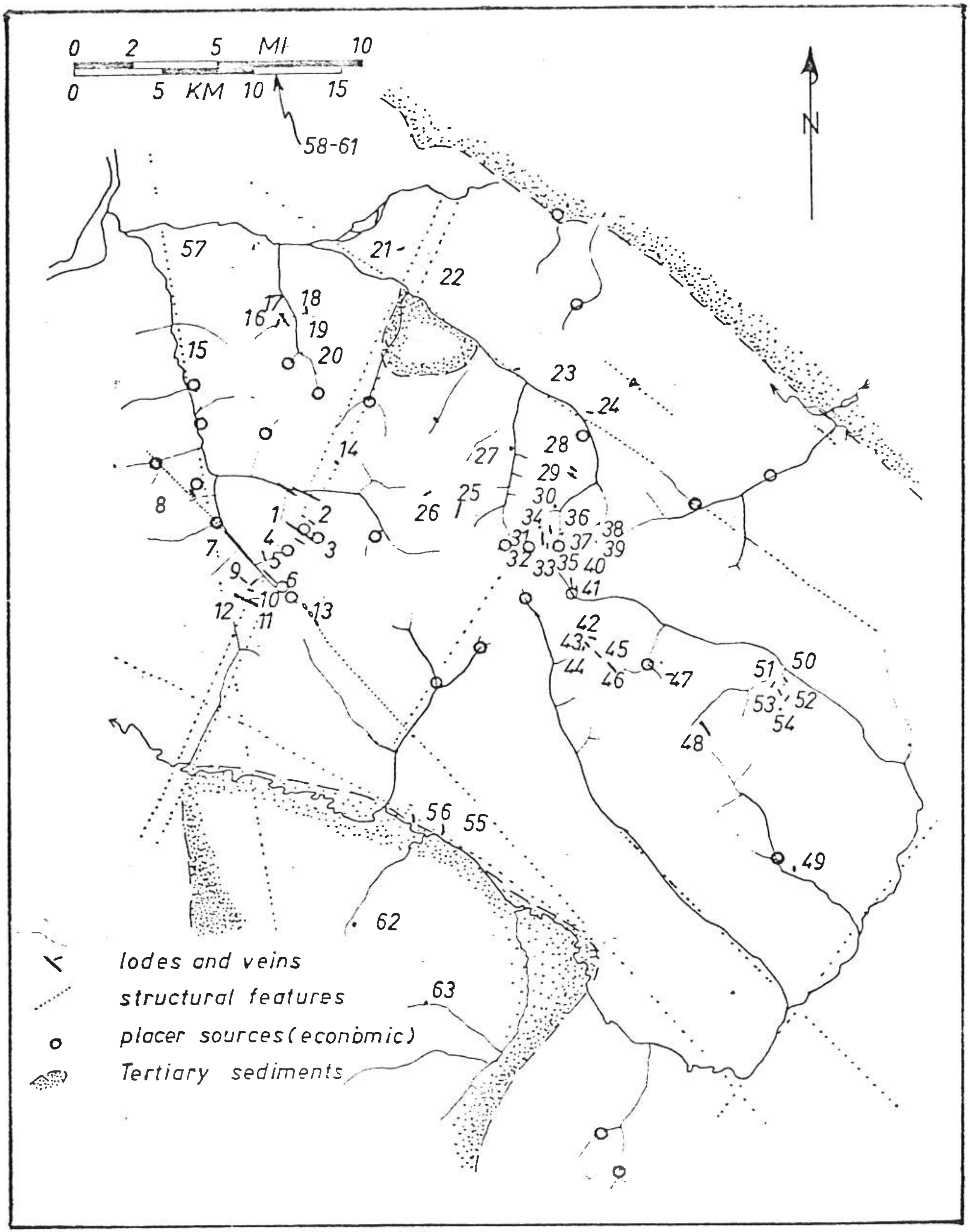


FIGURE 19. Lode gold occurrences and other sources

GOLD AND BASEMETAL OCCURRENCES

1. Boulder Lode
2. Victoria Gulch lodes
3. Eldorado Dome Lode
4. Robin Vein
5. Gay Gulch Lode
6. Joe Vein
7. Eldorado Creek Lode
8. Gold Hill showing
9. Peacock Lode
10. Homestake Lode
11. Gleeson's Vein
12. Violet Lode
13. Hilker's anomaly
14. HF Vein
15. Bonanza sphalerite
16. Jean Vein
17. Virgin Stringer zone
18. Gordon Lode
19. Bear Creek occurrences
20. Ludlow Vein
21. California Vein
22. Unexpected showing
23. Hunker Road Vein
24. Six Pup Veins
25. Jack Pot Vein
27. Goldbottom copper
28. Hillsborough Lode
29. Brandon Lode
30. Alphonse Vein
31. Castle Vein
32. Mitchell Vein
33. Portland Fair Vein
34. Syndicate Vein
35. Tractor Vein
36. Nose Vein
37. Thurber Vein
38. MacKay Lode
39. Fournier showing
40. Summit Lode
41. Dome Lode Vein
42. Tiger Vein
43. Yellow-jacket Vein
44. Yellow-jacket Lode
45. Cousin Jack Vein
46. Mary Lode
47. Patterson Vein
48. Pioneer Vein
49. Goldrun showing
50. Good Faith Barrel Lead
51. Jumbo Vein
52. Clara Vein
53. Baker Vein
54. Huron Vein
55. Raven Lode
56. Esperanza Stringers
57. Golden Age Vein
58. Rose showing
59. Great Eastern Vein
60. Mary McD. showing
61. Billy Button showing
62. Britannia-Thistle conglomerate
63. Eclipse-Doly comglomerate

schistose phases of the Klondike Schist and that it occurred in association with barite in northwest trending shear zones. Many lode gold occurrences are on the northeast trending, Ophir-Last Chance Lineament especially where it crosses northwest trending shear zones as at the Lone Star Mine (Chapter II). The Eldorado Creek Fault may be auriferous as outlined in argument for its extension northwest and southeast and may be responsible for some of the coarse gold in Eldorado Creek.

In the eastern part of the Klondike Goldfields placers were much less rich than on Bonanza and Eldorado creeks. Right Fork of Hunker Creek and upper Dominion Creek which head in a col east of King Solomon Dome, and Gold Bottom and Upper Sulphur creeks which drain the col west of the Dome were the main producers. About 1900, weakly auriferous quartz veins were located on the ridge between Right Fork and Gold Bottom Creek and on the ridge east of King Solomon Dome, and other prospects were developed to the south near the heads of Dominion and Sulphur creeks (Fig. 19).

Trenching about 1967, mainly north of King Solomon Dome, located other quartz veins.

The auriferous veins are fault fissure fillings associated with the chloritic phase of the Klondike Schist trending along the ridge system through Dominion Mountain and King Solomon Dome (Gleeson, 1971, pp. 15, 17; Chapter II).

Quartz and Allgold creeks were relatively unimportant producers; the source of the placer gold in them is unknown.

Genetic models.

Several theories are presented for the genesis of the lode gold of the Klondike area; very likely more than one type of occurrence exists.

Hydrothermal emplacement. Probably most of the lode gold occurrences in Eldorado, Bonanza, Quartz, Last Chance, and Bear creeks are the hydrothermal type. Zones of high permeability in northwest and northeast trending fractures, and at their intersection, acted as channels for ascending auriferous solutions. Some fractures may have remained open longer than others because of regional stress patterns or could have been reopened during the time of gold mineralization.

No suitable igneous rocks are exposed that could have produced either the hydrothermal solutions or the gold, or that could have acted as an adequate heat source for hot, meteoric water convection systems. Rhyolite porphyry plugs and dikes, older granitic rocks and ultramafic and basic masses are neither closely associated with the source areas of placer gold nor large enough to account for the amount of gold. Deep hydrothermal sources of Tertiary age could exist in the Klondike by analogy with the Sixty Mile area which has similar geology. There, a northeast trending auriferous quartz vein cuts lower Tertiary volcanic rock indicating that at least some gold mineralization is of mid-Tertiary age (Chapter II).

Source bed model. The most suitable model for lode gold genesis in upper Hunker, Gold Bottom, Dominion and Sulphur creeks involves the source bed concept (Knight, 1957). The chloritic phase of the Klondike Schist is the lithology common to the auriferous creeks in the eastern

Klondike Goldfields and probably contains high background values of gold. The known auriferous quartz veins may represent local remobilization of this gold and quartz and deposition in fault fissures. Other background values and local concentrations in non-quartz rock recrystallized by metamorphism, both in the chloritic phase, probably exist and may have yielded much of the gold in these creeks. Metamorphic growth of gold in a schistose host rock during metamorphism of Triassic age could help explain the abundance of scaley or flaky gold on lower Dominion Creek.

The chloritic schist source bed, described as a source of placer gold by Gleeson, gathers some support from the exhalitive volcanic or iron formation model for gold deposits (Ridler, 1970).
The abundance of magnetite and the magnetic character of the chloritic phase, the iron carbonate, chlorite, and amphibolite schist represent metamorphosed iron-rich sediments. Conformable talc carbonate masses suggest associated ophiolites and favour syngenetic ore genesis (see Chapter II).

In the Sixty Mile Goldfields the presence of Klondike Schist and perhaps its favourable, lower chloritic phase near the contact with the Nasina Series and transecting fracture zone strengthens the source bed model and local remobilization of the gold. The same situation may exist on Henderson Creek (see Maisy May - Reindeer Lineament).

In the Klondike area, the chlorite schist phase dips west and appears to be on the eastern limb of a regional syncline (Chapter II). It must be present at depth in the western part of the Klondike area where it is intersected by fracture zones and may have been leached of its gold by fluids ascending from even greater depths.

Alternatively, a deeper source related to the zone of basic and ultramafic dikes of Eldorado and Bonanza creeks and southeast (Bostock, 1942) and on Sulphur Creek (Chapter II), may be the site of some lode gold. Several hundred feet of diamond drilling was done near the Eldorado Creek Fault (Western Miner, 1960) near Bostock's zone of dikes indicating economic interest in such a source below the creek bottom.

Ultramafic source. Locally, on Hunker and Allgold creeks and Victoria Gulch, there is a close spatial relationship of serpentinite and talc-carbonate rock with source areas for placer gold. Lineaments southeast from Hunker, Sulphur, and Eldorado creeks with basic dikes and ultramafic bodies on them (Chapter II) strengthens this argument. The coincidence of very spherical placer gold particles, found only on the Hunker Creek Fault at the confluence of Alexandra and Allgold creeks, and the talc carbonate rock there implies this type of source. Similar gold nuggets occur in the Atlin Mining District (Boyle, 1976) where ultramafic rocks are abundant.

Similar, carbonatized ultramafic rocks are related to some gold deposits in Ontario (Pike, 1976).

Heat engine or convection-leaching model. The rhyolite porphyry stocks of Tertiary age may have been the source of heat that caused circulation of water which altered ultramafic rocks and basic lavas of lower Tertiary age. Probably cassiterite (Mulligan, 1975, pp. 67-70) as well as some gold was deposited in conjunction with the emplacement of the porphyries and associated fumarolic activity.

Recycled placers of Tertiary age. Placer gold occurrences in conglomerates overlain by volcanics of Tertiary age on Upper MacKinnon Creek were developed about 1905 (McConnell, ibid., p. 78; MacLean, 1914, pp. 62-66) but no production is recorded. Conglomerates on Last Chance Creek overlain by similar pyroclastic rocks appear to contain placer gold particles. Small pockets of rich ground on Eighty Pup mined on the unconformity below columnar lava could represent early Tertiary bedrock placer values. The only known souce of deeply weathered placer gold (see below) is near this unconformity on Last Chance Creek suggesting recycled early Tertiary placer gold. A scheme for valley shift along the unconformity and paystreak development on Last Chance Creek is suggested in Figure 11. Similar recycled gold may exist on Eureka, Hunker, and Germaine creeks and also in the Sixty Mile area.

Description of lode gold.

Gold in quartz veins is commonly associated with pyrite, limonite in weathered specimens, galena and chalcopyrite (MacLean, 1914) and with barite (Gleeson, 1970). The visible gold appears at the margins of veins both in quartz where it is commonly crystalline and in adjacent schist (McConnell, ibid.,p. 107; Cairnes, 1912; MacLean ,1914; and Gleeson, 1970, p. 16). Gleeson (pp. 32, 37) finds a sympathetic variation of pyrite, and goethite after pyrite with eluvial and alluvial gold on Eldorado and Bonanza creeks, and (p. 45) an antethetic relationship between pyrite and magnetite in sericite schist. He suggests that hydrothermal solutions introduced pyrite and gold but some pyrite formed at the expense of magnetite.

Known auriferous quartz veins are lean and an erratic distribution of the gold is common (MacLean, 1914). Milling at the Lone Star Mine during its limited production about 1912 showed mining grades of $3.60 to $3.90 (ca .18 oz) per ton while assay grades ran only $.50 to $1 (.03 oz) per ton, an indication of the erratic distribution and richness of some pockets. McConnell (*ibid*., p. 106) considering the volume of quartz in the district suggested an average grade of less than a few cents per ton for the quartz eroded from the country rock to explain the known placer gold.

Fineness ratios $\frac{Au}{Au + Ag} \times 1000$ derived from gold and silver assays of vein quartz, which tend to be spureous because of the inclusion in the assay of argentiferous galena, vary from 667 to 843 for the Mitchell Vein, and from 300 to 500 with some values between 600 and 800 for the Lone Star occurrences. Values from samples containing chalcopyrite, in general, were less than 100.

Description of eluvial gold.

The original hydrothermal or metamorphic character of the lode gold is probably preserved in eluvial gold, or particulate gold in the regolith, as well as in alluvial gold. Supergene features in gold acquired in oxidized veins (*see* Boyle, 1976) and in pyritiferous schist during Tertiary weathering are not recognised but probably are present on a minor scale. Pedological processes may also effect eluvial gold; gold is mobile and subject to geochemical concentration in organic soils (Shacklette, *et al*., 1970), suggesting that chemical accretion of gold particles in the soil environment may also take place.

Illuvial or physical concentration of eluvial gold in the upper few decimeters of soil produced by the turbation of rain drops, sheet erosion, and frost action (*see* *Cryoplanation terraces*) have not been described but is presumed to be represented in auriferous soils on ridge crest eluvial samples.

Gleeson describes heavy minerals in soils including eluvial gold. Fine grained, yellow, flaky gold, angular in form, is commonly attached to or intergrown with sericite grains on slopes near the Lone Star Mine; flaky gold occurs in soils on the ridge near Violet shaft (pp. 48, 50). Spongy looking shots or pellets of gold (and minor amounts of native copper) tend to occur in soils on the ridge near the Mitchell Vein (p. 49). Fine grained, flaky gold, usually with a black coating occurs along the ridge between Bonanza and Hunker creeks (p. 45).

Rapid mass movement such as mudflows are rare and are unimportant in placer development. Large scale mass movements of intermediate rates, such as solufluction, transport gold particles, a phenomen stressed by some Russian authors described by Miller (1970). The high viscosity of the transporting medium prevents settling of eluvial gold. Talus placers, on the other hand, may develop on slopes where talus creep surpasses solufluction in importance and, presumably due to the open-work nature of talus, allow liberated gold particles to accumulate at the base of the regolith (Miller, 1970, p. 114).

In the Klondike Goldfields the primary placers are Tertiary in age; solufluction and talus phenomen are more important geomorphic processes in Pleistocene time and no primary placers are correlated with them.

Distribution and character of alluvial gold.

The largest nuggets and the richest claims in the Klondike Goldfields were on Eldorado Creek below Gay Gulch. The Bonanza Creek watershed contained a greater amount of placer gold than any other creek suggesting more favourable sources and optimun placer conditions in that area. Hunker Creek, followed by Dominion, Sulphur, and Quartz creeks were of lesser importance (McConnell, ibid.,p.18).

Possible explanations for the richness of Bonanza Creek placers are the nature of the source rocks, the geomorphic history, and bedrock control. The hydrothermal lode gold may be coarser and more abundant, and is situated nearer to the master stream of Bonanza and Eldorado creeks. The anomalous orientation of the trellis or pinnate drainage pattern, possibly controlled by the structural break along the creek, may be the result of the lack of valley shift during Tertiary time on Bonanza Creek; this could explain the well developed White Channel pay streak on Bonanza Creek. The resistant bedrock of Bonanza Creek, on which the White Channel Strath was developed may have been a much more favourable placer surface than the country rock of other creeks; it also dominates the inner valley and the generation of secondary placers in it.

Coarse particles of gold tend to occur near headwaters where stream gradients are about 150 feet per mile and where hardrock sources are nearby. Nuggets weighing up to 5 troy ounces (200 grams) have been recovered in recent years from Eldorado, upper Bonanza, upper Dominion and Caribou creeks and on Friday Gulch. The largest nugget found in the Klondike Goldfields was 85 ounces (7 pounds or 30 kilograms) in 1907, on Eldorado Creek below Gay Gulch (Mining

Journal, Nov., 1907).

The form of nuggets varies. Gastrolith or potato shapes are common with abraided and rounded corners, and angular quartz inclusions are frequently present. Some nuggets and more often finer grains on Bonanza and Eldorado creeks, have crystalline forms of simple and modified octahedra. Occasionally negative hexagonal forms as well as inclusions of quartz crystals indicate original deposition in cavities within quartz veins. Rarely particles of gold in Bonanza Creek are attached to, or contain, geothite after pyrite, schist, and magnetite. Anomalously round gold nuggets (one gram), and smaller grains, with frosted surfaces occur on a bench at the confluence of Allgold and Alexandra creeks These and other types of nuggets are considered by Boyle (1975) to be concretionary or accretionary particles formed in oxidized grains and in creeks.

Smaller, flatter grains occur in lower reaches of streams where gradients are about 50 feet per mile. These grains have been winnowed from gravels higher up the creek because of their size and shape. During transport the smaller grains not only have been abraided but also, more important, hammered by clasts during transport so that they have a characteristic matted surface and flat round outlines.

Larger heavier particles of gold may be transported in quartz pebbles. A subangular quartz pebble with a vein of gold protruding from it, and a round granular quartz pebble containing a boxwork of gold foil partly exposed by decrepitation of the granular quartz were recovered from Dago Hill by Mike Stutter in 1974 and 1975.

Wire gold with an open "frame" structure that was apparently neither weathered nor deformed was recovered by Dave Johnson on Eldorado Creek below Gay Gulch along with nuggets. Wire gold is reported by McConnell (ibid.,p. 106) "from Eldorado and other Klondike creeks" and is considered to be a chemical deposit formed in the creek.

Chemical weathering of gold.

Native gold is a natural alloy of gold and silver as well as other trace elements. Fineness of Klondike placer gold varies from 880 on Gold Run Creek to scattered low values about 690 on Adams, Eldorado and lower Hunker creeks. Last Chance, Eureka, Quartz, Eldorado, and Gold Bottom creeks are uniformly low probably because of the nature of the lode gold sources (see Fig. 20). The average fineness for Klondike gold mined in 1905 was 775.

Differential solution of silver from placer gold has been the explanation for increase in fineness with increase in distance of transport (Lindgren, 1911; Browne, 1905). The decrease in size and the resulting increase in surface area presented to the weathering solution is the accepted mechanism for this phenomen which can be seen in several places on Figure 20. Silver depleted surfaces of nuggets are demonstrated by McConnell (ibid.,p. 223). Higher gold values are reported for shipments of gold containing smaller sizes than those containing coarser gold at one placer mine on Gold Bottom (Ole Lunde, pers. com.).

The removal of silver is not a simple leaching process that would develop a porous gold margin but rather a phenomenon similar

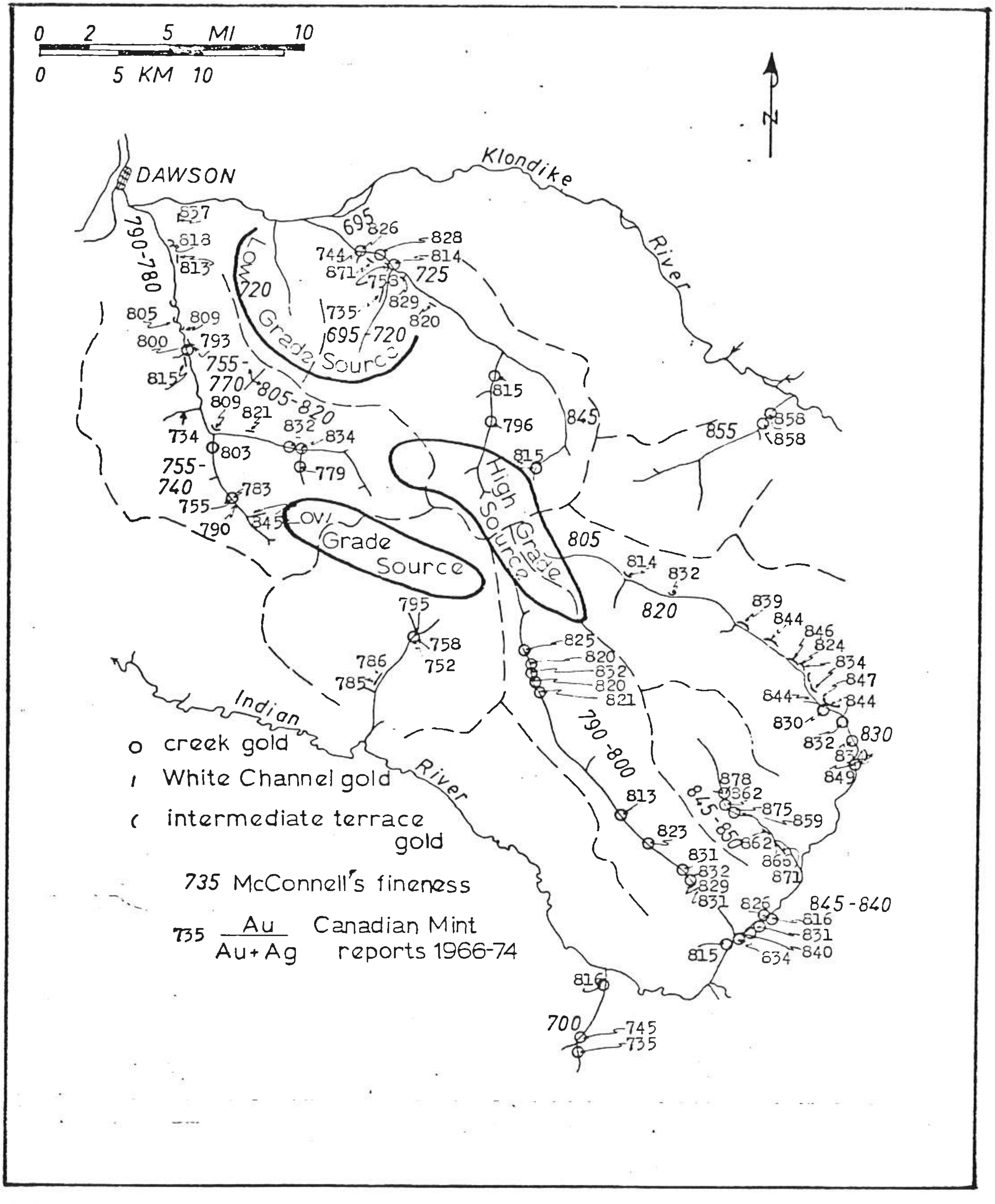
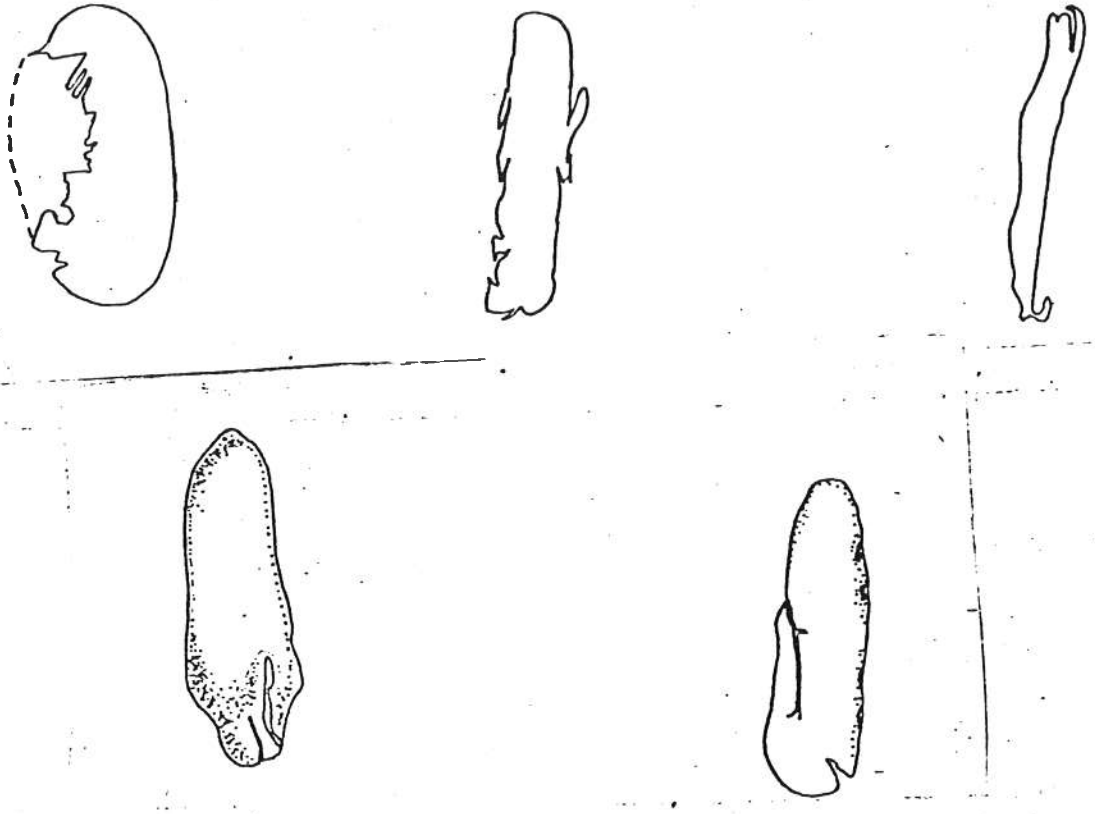


FIGURE 20. Fineness variation of Klondike placer gold.

to electroplating. Mustart (1965) argues that gold and silver are ionized in water, the silver remains in solution and the gold deposits on the surface of the alloy producing a dense, pure gold skin which has the yellow color characteristic of unstained placer gold. Black, brown, or reddish stains may develop on the surface but the true color of the alloy, which may vary with silver, copper or other minor elements, is obscured by the pure gold veneer. The color of the alloy appears on surfaces that have been recently worn or scratched and on areas protected from weathering solutions by mineral grains. The true color of the gold is also seen on abraided and polished surfaces of nuggets carried in miners' pockets.

Shallow weathering of gold grains seems probable because of the self arresting nature of the process but it may be many microns deep. In polished section the gold rim is usually only a few microns thick and its inner margin is sharp. Electron microprobe analysis show an almost pure gold margin with constant gold silver ratios for cores of individual grains. Solid state diffusion, through time, or cold working (Boyle, 1976) during recycling may augment the depth of weathering.

Deep weathering is apparent in gold grains from White Channel gravels on and below lower Last Chance Creek and in valley bottom gravels there. In polished section, this gold displays the pure gold rim surrounding a zone containing non-relective dendritic embayments into the core. Canals appear to penetrate the gold rim in polished section and deep tunnels are apparent under the scanning electron microscope. The development of these features may be analogous to anode pitting, a phenomen of electroplating (Wise, 1964). Pits,



a) Smooth, round outline with vein quartz imparting a crystalline boundary-homogeneous interior.

b) Hackley, rectangular outline-homogeneous interior.

c) Smooth, lenticular outline with embayments and "hooks" near the edge-homogeneous interior.

d) Smooth, lenticular outline with narrow embayments-pure, dense gold margins with "dendritic" porous interior.

e) Lenticular to round, smooth outline with narrow embayments-"dendritic" porous margin.

FIGURE 21. Placer gold morphology.

or other flaws, act as canals through which gold and silver ions are transported out of the inner margin past the outer cathodic gold plate surface which receives the deposit of gold. A laminar crystalline structure visible under the scanning electron microscope strenghtens the argument that gold is deposited on this surface.

Gold displaying internal dendritic structures was first described by Mustart (1965) for samples from Discovery Hill, Last Chance Creek and the structure interpreted by him as evidence of colloidal precipitation of the original lode gold. Identical samples come from north Dago Hill. Similar structures with incomplete gold rims occur on gold from Ken Tatlow's 1974 operation on Hunker Creek valley bottom, downstream from Dago Hill. These relationships suggest abrasion during reworking of a train of particles from Last Chance Creek. The deep weathering is considered to be of early Tertiary age; however, it may be restricted to gold having low fineness.

Wire gold appears unweathered and unworn and could represent new gold liberated from weathered bedrock or a weathered pebble. McConnell's arguments for chemical deposition of wire gold in the creeks, and the silver content implied by its color suggest deposition of a silver-gold alloy involving different conditions to those above.

Agglomeration or secondary growth.

In various gold mining camps the large size of placer gold particles compared to those found in nearby lodes caused people to postulate the enlargement of gold in streams.

Lindgren (1911) cites occurrences coarse lode and eluvial gold contrary to this theory. Also, Liversidge did much work on this problem in Australia, about 1900, and found evidence for only minor secondary growth. Uglow also etched polished sections of gold nuggets and found that they commonly have internal crystalline structure indicative of lode gold. Mustart (1965) reached similar conclusions in the Yukon Territory.

Nuggets and smaller grains commonly have rounded, knobby parts distal to the center of the grain, apparently abraded; and hackley, irregular proximate hollows, apparently are unworked, original placer surfaces. These grains represent poorly rounded particles either transported only a short distance from the source or newly liberated from a pebble. The distal knobs have the weathered gold color and are smooth; the proximal surfaces are pale, fresh and rough. Further, crystal structure in etched polished sections continue to near the edge of the grains. Also, no variations in silver content appears in the cores of grains. Nothing suggesting an annular structure was observed.

In order for this gold to have precipitated or agglomerated the gold-silver ratio had to be the same as that of the nucleus in various particles of different compositions and the grain had to enlarge in the same crystallographic orientation as the core. Alternatively, the growth could have been random in crystal orientation and high in silver as suggested by the wire gold, followed by diffusion and recrystallization. Relict, buried, weathered rims could have been erased by diffusion.

No rounded sedimentary particles appear as inclusions in polished section nor are sedimentary particles (except the magnetite, geothite, schist and quartz described above as original polylithic clasts or as inclusions) are cemented by gold. Only the wire gold of Colorado and other creeks and angular, dendritic gold apparently grown in the upper surface of a rounded boulder in Miller Creek represents gold deposited from solutions in a fluvial environment (McConnell, ibid., pp. 45, 106).

Placer concentration.

Alluvial placers are of two types; mechanical traps and hydraulic concentrations. The first is formed by the rough bedrock and coarse gravel bottoms of a scouring stream. It is analogous to the riffles in a sluice box and is the cause of bedrock values in placer deposits as well as some higher concentrations in or beneath coarse gravel horizons.

The second type is a sedimentary concentration involving grain size and density differences of particles (hydraulic factor) and flow conditions that exist in shifting streams and rivers. It is responsible for heavy mineral concentrations in sandy sediments and for bar gold on sand and fine gravel bars.

The pay streak is a belt of rich gravels that usually occupies the central third of broad valley floors. The width of the primary pay streak in the Klondike Goldfields expands from a few feet at valley heads to several hundred feet in the downstream portions of broad valleys; the gold content per unit length of valley diminishes downstream except in a few isolated cases where ground is richer near the mouth (Nordale, 1946, p.90).

The "youth-maturity" model of placer and pay streak genesis of Tuck (1968) calls for the incision of deeply weathered terrain by youthful, straight streams produced "V" shaped valleys that concentrated gold in placer deposits. These concentrations were "let down" through the topography as the valleys were deepened by the vertical incision of streams. At the end of initial valley incision the stream had concentrated most of the gold on the valley floor that had once occurred within the triangular prism of rock now represented by the valley. At the termination of downcutting the valley floor contained weathered gold particles from sources many of which may have been destroyed by erosion. The gold particles had been shifted downstream toward the master stream. The coarsest particles, while being "let down" through the topography moved only by gravity and erosion perhaps only as much horizontally as vertically, away from their source (<u>see</u> McConnell, <u>ibid.</u>, p.224) while some finer particles moved further by hydraulic action.

At equilibrium or "grade" the stream widens the valley floor by meandering and strath development - in the Klondike Goldfields the White Channel Strath system (Chapter III). The pay streak that accumulated during the primary phase of incision is only slightly reworked remaining at or near bedrock in the position of the bottom of the "V" shaped valley. Lode gold liberated during valley widening would be relatively unweathered and therefore have a low fineness compared to that of the weathered gold of the pay streak. The volume of the triangular prism of bedrock eroded during incision is greater than that of the trapezoidal prisms eroded during a similar interval of valley widening therefore the amount of gold in the center part of the valley floor is greater than that on the margins.

During recycling that accompanies later rejuvenation and inner valley incision, relicts of the original pay streak are "let down" into the new valley system and shifted slightly downstream (McConnell, ibid, pp. 219-224, 228, 236; Hester, 1970). Some parts of the original pay streak are mobilized; weathered and unweathered alluvial gold is removed by abrasion. The result of the remobilization is to produce secondary pay streak trains of a lower fineness than the primary one, or its "let down" relict following inner valley incision. This modification of Tuck's pay streak model explains variation in fineness across valley floors and in inner valleys (Fig. 20) without necessarily invoking local sources of lode gold.

Tributary inner valleys that cut the White Channel paystreak were rich downstream from the primary paystreak as were the main valleys immediately below the mouths of these tributaries, whereas reaches of the inner valley away from the paystreak and without rich tributaries were lean (McConnell, ibid., p. 224). Between Boulder and Cripple hills the inner valley coincided with the position of the White Channel Strath and the inner valley bottom was rich (McConnell, ibid., p. 187; Hester, 1970).

These relationships, best displayed on lower Bonanza Creek, also hold on Hunker Creek. On Quartz Creek the pay streak, presumed to coincide with most extensive mining, probably occurs on the right limit bench of upper Quartz Creek, where bedrock slopes north toward the road, across Little Blanche Creek below Canyon Creek, where creek gravels are rich because of the let down pay streak. It continues on the right limit bench below Little Blanche Creek where tailings from underground mines are reported to contain larger boulders than where the strath outcrops to the southeast. It continues below Nineteen Pup where it has been mined recently by open-cut methods and the pay streak swings into the inner valley where dredge mining recovered the gold. Below Calder Creek the White Channel Strath has been destroyed. The inner valley of Little Blanche Creek below Canyon is relatively rich and the grade of the inner valley gravels decrease downstream, according to Rasmuson and Lacross, in 1975, and only submarginal values are found in their bedrock drains.

A similar situation may exist in Gold Run Creek where White Channel gravels occur also in a right limit bench.

The role of bedrock structure on the creek bottoms as a "placer surface" is important to the development of both primary and secondary pay streaks. Ribbed or "rippled" bedrock formed by alternating hard and soft layers, if oriented perpendicular to the direction of flow, tend to act as riffles or traps which concentrate the gold on the bedrock in basal gravels there and in crevices (McConnell, ibid., p. 224). Similarly abundant open joints or blocky or slabby bedrock will act as traps and concentrate gold in the fashion of block riffles. Ribbing parallel to stream flow, and compact but soft, wide schistose zones will tend to erode and allow scour to remove any temporary concentrations there. Wide soft zones will produce broad hollows in bedrock separated by humps of more resistant rock, similar to the pool and riffle system of fluvial geomorphologists. Unlike the sluice box analogy, the gold is concentrated on the bedrock highs not in the bedrock lows. Examples of this are known in the Klondike Goldfields from both dredge and bulldozer mining in valley bottoms, and also in Alaska. The bedrock high acts as the placer trap because it is composed of at least some resistant rock that forms a rough surface. Efficient flow in pools and inefficient flow on riffles may explain the "scour" that removes gold from pools and concentrates it on riffles.

On lower Allgold Creek areas underlain by fresh bedrock were rich while adjacent patches of clayey material formed of decomposed country rock and volcanic rocks (or fault gouge, Green, 1966, p. 104) were lean. The early shafts uncovered by bulldozer mining appear to be directed at the solid bedrock (Green, 1964, p. 66). This could be on example of pool and riffle effect.

Potholes are poor traps of gold because of the milling action of gravels in these features and the soft maleable nature of gold (see Kindle in Bostock, 1957, p. 133).

Deep scour reworks some gravels during aggradation as argued by Cheney and Patton (1967) who, reported a sawn plank at depth in the valley fill of the Colorado River. They postulated that the development of bedrock values below lean gravels was due to scour. Infrequent scour during floods on a non-meandering thalweg could produce a pay streak inthe central scour path as scours shift downstream. Scour on the outside downstream reaches of bends during meander and point bar development, and the placer concentration implicit in the basal lag gravels, is probably more common on straths. Scour very likely does play a role in placer development.

Very coarse basal gravels with massive clasts lodged on bedrock acts as a placer surface in zones of resistant, massive bedrock and in physiographic settings where gravity transports large blocks directly to streams. On lower Bonanza Creek block talus and block muck (see Chapter IV) has been added to the inner valley alluvium both on the present valley floor and on intermediate benches. The gigantic tabular clasts are usually water worn on both sides and probably were introduced to the top of the alluvium by mass wasting processes, transported downstream by undermining during scour, and lowered by scour to the base of the alluvium where they become obstructions to further scour. The size of the clast in the basal gravel is a measure of its permanence and of the value of the placer gravels. On lower Bonanza Creek terraces, gravels with 600 lb clasts yield about $3 per cubic yard while those with 20 lb clasts average 50¢ per cubic yard (Clive Nickelson, 1975, pers. com.). Very likely boulder-armored surfaces were partly responsible for the retension of the gold in the "canyon" of Lower Bonanza Creek.

Brooks (1908, p. 133) describes similar phenomen of talus in Alaska.

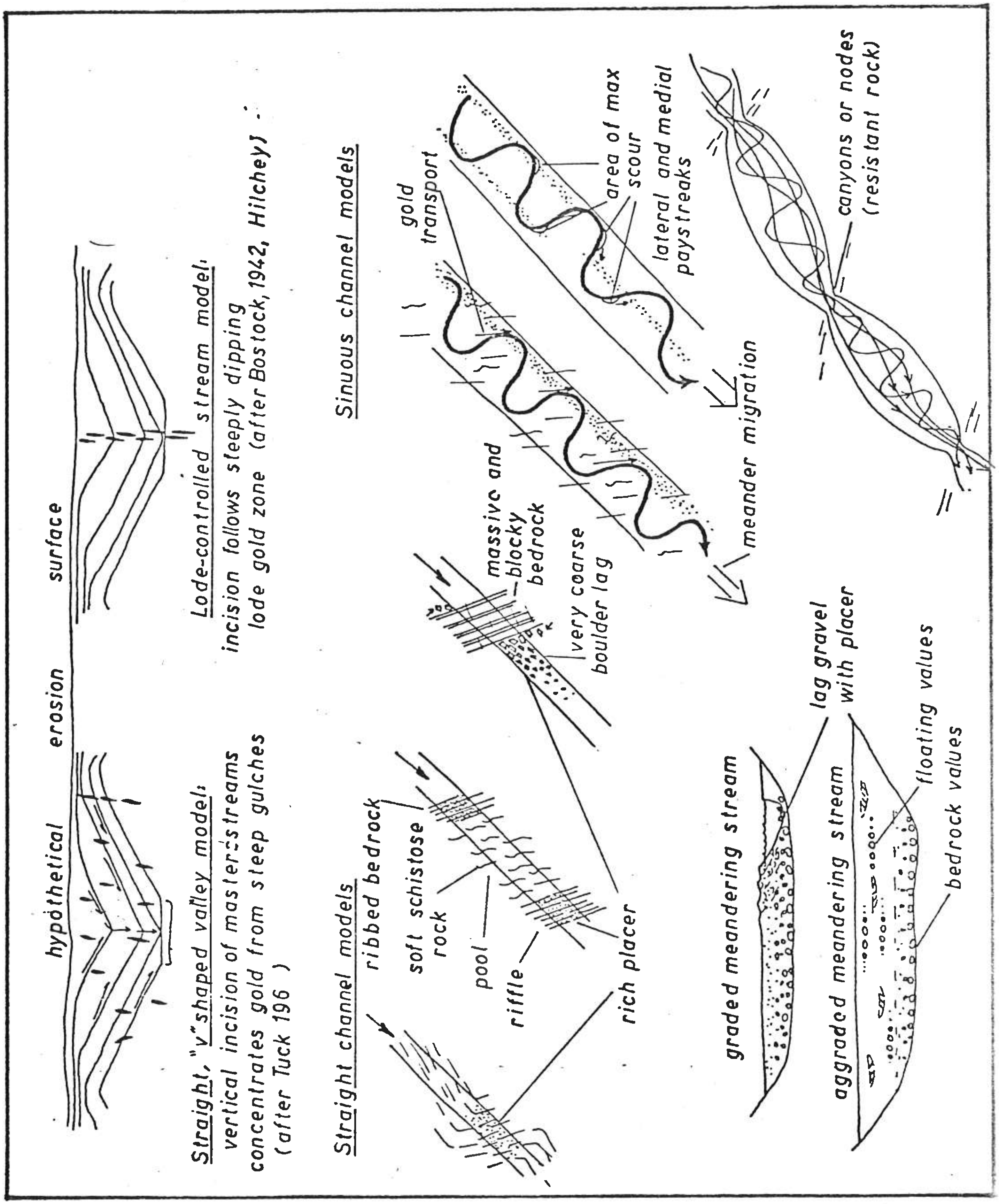


FIGURE 22. Paystreak models.

SUMMARY AND CONCLUSIONS

There are no signs of chemical weathering in the Klondike hills such as thick residual soils concomitant with a warm Tertiary climate; no evidence of deep secular decay related to a mid-Tertiary peneplain, pediplain or other erosion surface exists in the Yukon Plateau geomorphic province. However, weathered gravels of late Tertiary age, deposited in an arid climate, and the underlying chemically weathered bedrock, are preserved. Tectonically induced alluviation in the late Tertiary and early Pleistocene time followed by superposition of drainage during incision in late Pleistocene time provides a mechanism for preservation of these features.

Intensive masswasting during Holocene and Pleistocene time has obliterated any other surficial features of late Tertiary age. Inner valley slopes, theaters cut into them, and colluvium masking these features are the result of periglacial, fluvial erosion and related slope transported in response to crustal warping. Solufluction terracettes and lobes are recent slope phenomen possibly promoted by earlier cryoplanation which, during Pleistocene time, beveled ridges. Outer valley slopes and ridge altitudes reflect Tertiary landforms to some degree but are wasted by frost action and these solufluction processes. This masswasting obliterated drainage lines of Tertiary age causing the present low drainage density.

Fluvial erosion was important in Tertiary time when sparce vegetation and thin soils promoted high drainage density. Active transport and erosion some time in the Pleistocene occurred when sinuous streams carved inner valleys. Fluvial erosion was minimal during Holocene time and probably interglacial times when underfit streams in wide valleys transported silt from the abundant, eroding frost-weathered colluvium.

Sedimentation of the White Channel gravels of Pliocene age was induced by crustal uplift to the north. Braided channel deposits with alluvial fan facies accumulated during uplift. The periglacial Yellow gravels and reworked White Channel gravels were contemporaneous with early Pleistocene outwash in the final stages of uplift. More humid conditions during Pleistocene incision produced sedimentary deposits now preserved on terraces and in valley bottoms. These have some elements of meander channel deposits including boulder pavements generated near very coarse colluvium.

The geological history of the area includes Paleozoic or earlier sedimentation of a source bed of iron formation affinity, metamorphosed in Triassic time to a chlorite schist. Transecting fracture zones acted as channels along which ascending solutions transported gold from source areas into earlier northwest trending lodes. The time of gold emplacement could be as young as Miocene.

Bedrock features commonly control surficial features and broader elements of the geomorphology. Buttressed benches involving the formation of terrace gravels on and preservation of placer gravels by the stronger, nonfoliated, intrusive rock, the locus of which is in turn controlled by fault or fracture zones, are important in present day placer prospection, although not quantitatively important in the Klondike. Controlled ridges do occur in areas of abundant and persistant quartz veins. Collinear valleys are common and together with intervening ridges reflect an equilibrium between channeled mass-wasting or erosion and colluvial deposition. "Cryotruncation" and straight periglacial valleys are related to this type of masswasting.

Pingos, expressions of groundwater flow from below the permafrost zone, have strong correlation with faults and lineaments.

Faults, lineaments and fractures control positions, patterns and gradients of streams in the Klondike Goldfields and regionally in the northern part of the Yukon Crystalline Terrane. This relationship tends to maintain a homogeneous pattern of master streams and a low regional baselevel. Locally in the Klondike Goldfields these planes capture shifting streams during incision and arrest drainage development that would otherwise result from local crustal warping.

Late phase fault displacement of 32 miles on the Tintina fault system displaced topography near the Tintina Trench starting in Miocene time.

Crustal warping in the Pelly Mountains, the King Solomon Dome uplift in Miocene time and of the Swede Dome uplift in Pliocene time possibly related to the late stage movement on the Tintina fault system. Stream adjustment to the King Solomon Dome uplift caused a pinnate-trellis drainage pattern in the Klondike, modified by fault control. This uplift caused greater depths of incision than in other areas. The Swede Dome uplift caused tilting of the Klondike area to the southeast in accordance with Hughes' synthesis and is probably related to strain on the Tintina fault system.

The Yukon Plateau surface of accordant summits probably was not a peneplain, but rather an accordant surface in the sense of a trend surface, in dynamic equilibrium with the drainage and climate An incising, uniform network of fault controlled master streams and tributary valleys maintain ridges at similar altitudes through the Tertiary.

These ridges were eroded as rapidly as they were weathered in late Tertiary time and were further modified by altiplanation during glacial episodes. The last phenomen alone removed any residual, chemically weathered soils as well as supergene deposits of Tertiary age. Such features may occur in this terrain below unconformities of Paleogene age where they occur on ridges or in valleys.

Other goldfields similar to the Klondike and Sixty Mile goldfields may yet be found where the iron-rich source beds of the lower Klondike Sreies is cut by northeast fracture zones and related northwest trending shears. Streams controlled by auriferous shears would be rich. Symmetry and pinnate drainage patterns should be useful in locating ancient uplifts where more deeply incised terrain would have greater potential for placer concentration. Stream shift should help locate areas of deposition of sediments and late phase recycling. Conversly knowledge of tilt direction could aid terrace location and outer valley pay streaks.

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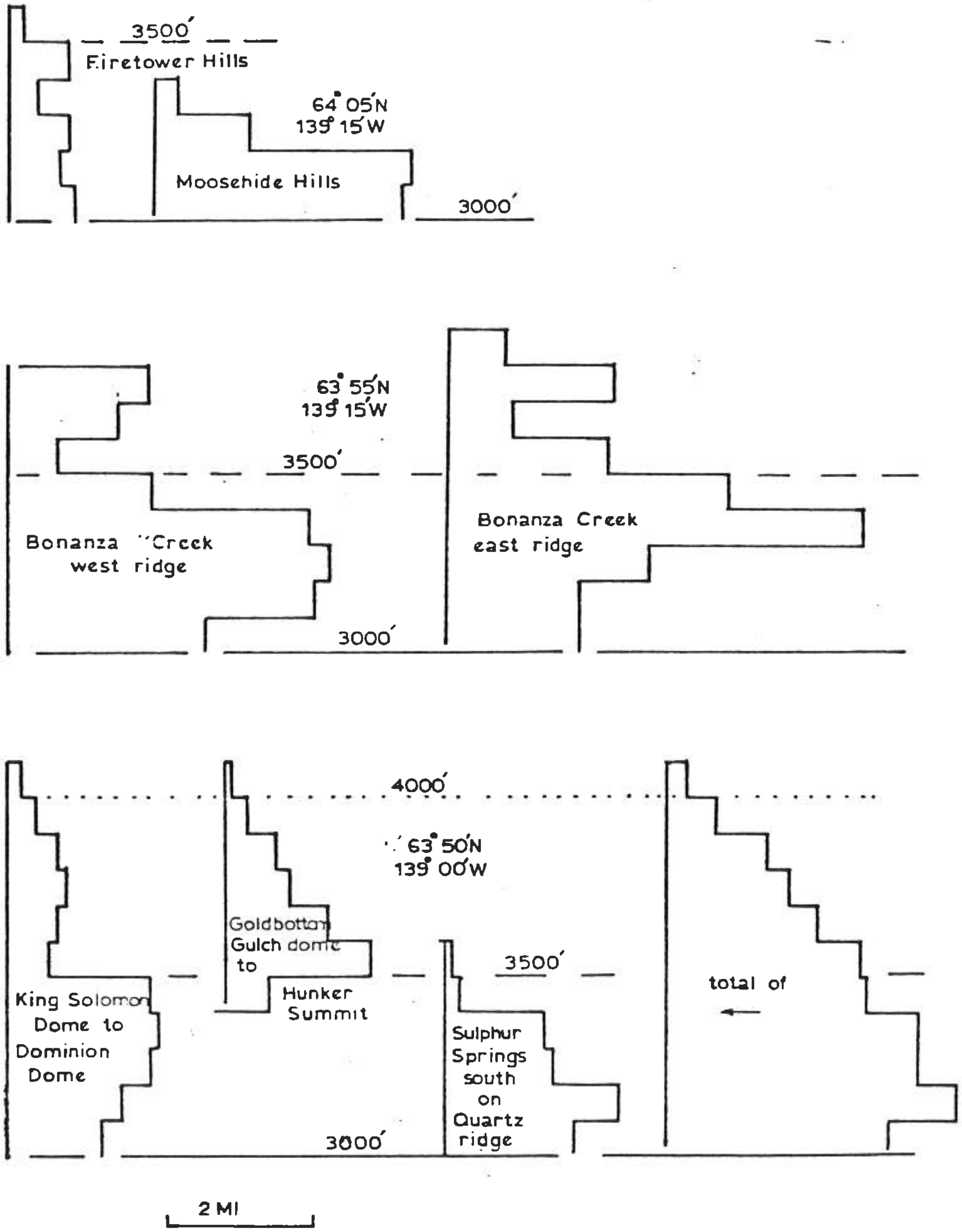
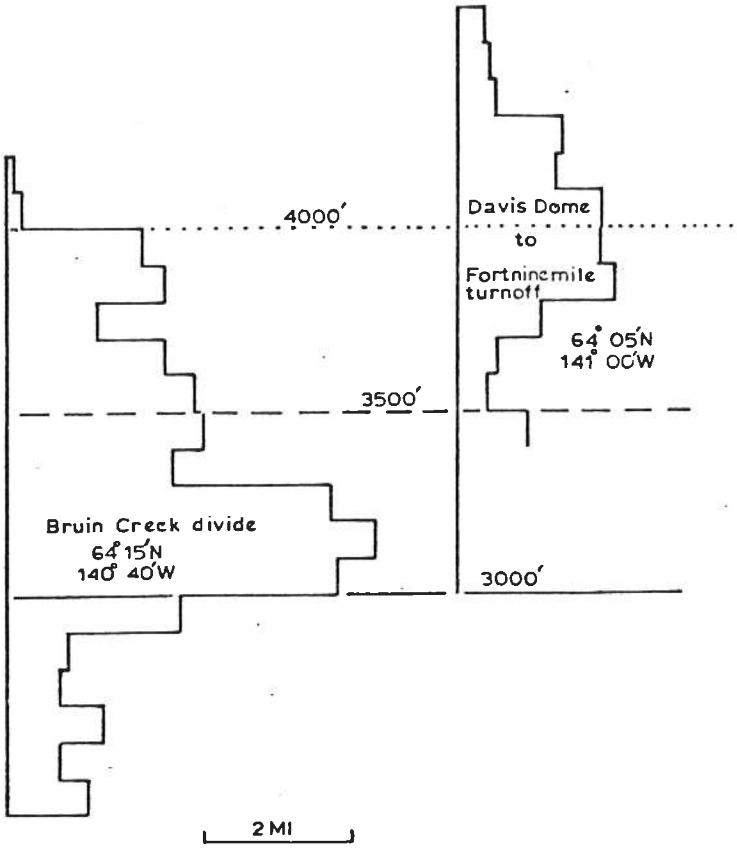
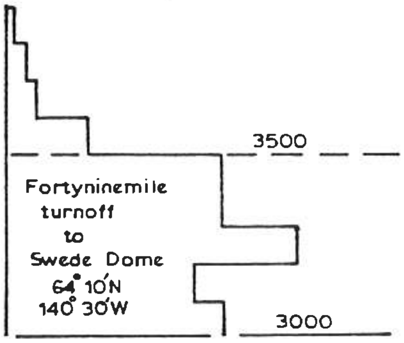
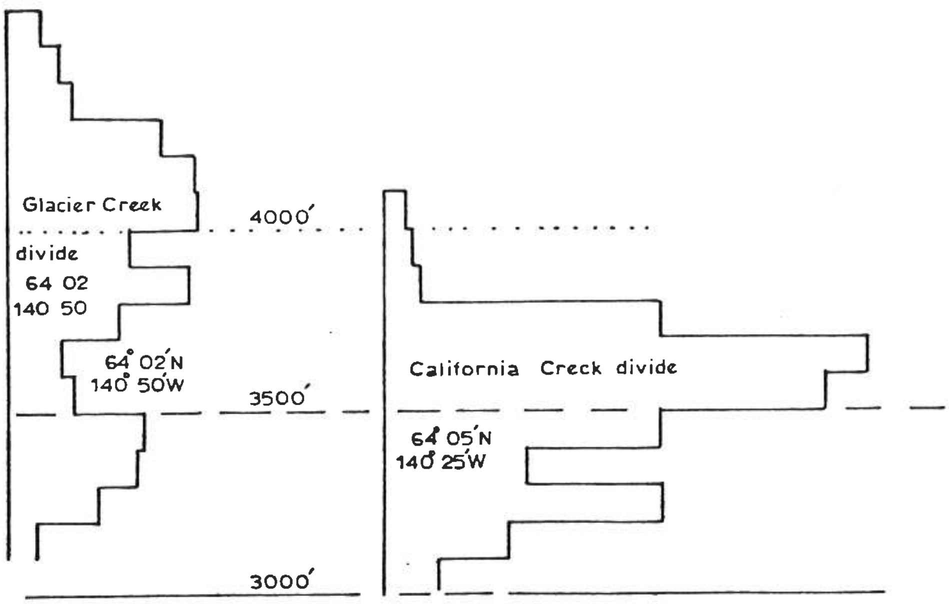
APPENDIX I

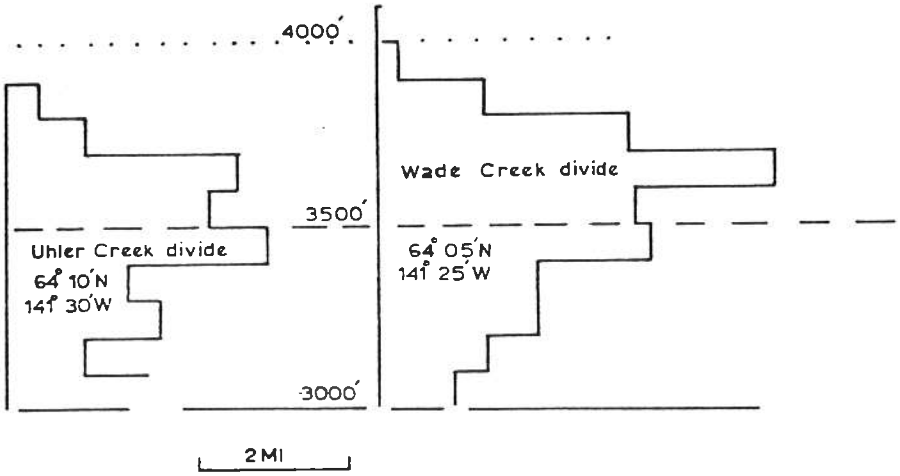
Ridge altimetry

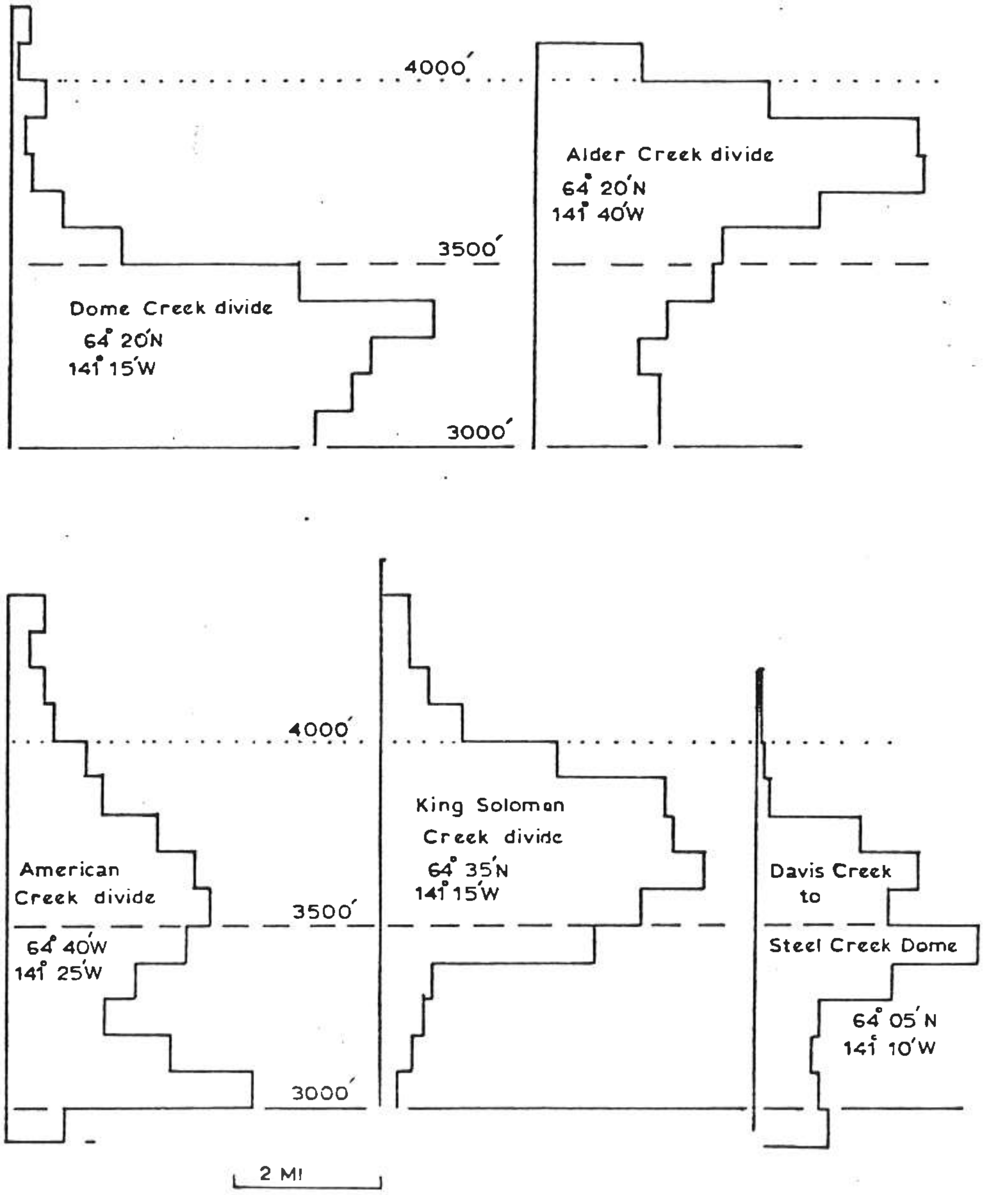

3500′
Firetower Hills
64° 05′N
139° 15′W
Moosehide Hills
3000′
63° 55′N
139° 15′W
3500′
Bonanza Creek
west ridge
Bonanza Creek
east ridge
3000′
4000′
63° 50′N
139° 00′W
Goldbottom
Gulch dome
to
Hunker
Summit
3500′
total of
King Solomon
Dome to
Dominion
Dome
Sulphur
Springs
south
on
Quartz
ridge
3000′
2 MI


4000′
Davis Dome
to
Fortninemile
turnoff
64° 05′N
141° 00′W
3500′
Bruin Creek divide
64° 15′N
140° 40′W
3000′
2 MI


3500
Fortyninemile
turnoff
to
Swede Dome
64° 10′N
140° 30′W
3000


Glacier Creek
divide
64 02
140 50
64° 02'N
140° 50'W
4000'
3500'
3000'
California Creek divide
64° 05'N
140° 25'W


4000'
3500'
3000'
Uhler Creek divide
64° 10'N
141° 30'W
Wade Creek divide
64° 05'N
141° 25'W
2 MI


4000´
3500´
3000´
Dome Creek divide
64° 20´N
141° 15´W
Alder Creek divide
64° 20´N
141° 40´W
4000´
3500´
3000´
American Creek divide
64° 40´W
141° 25´W
King Solomon Creek divide
64° 35´N
141° 15´W
Davis Creek to Steel Creek Dome
64° 05´N
141° 10´W
2 MI