Frontispiece.

HUNKER CREEK in the KLONDIKE.

- Three Levels of Erosion:
  the Ridges, the High Benches
  and the New Valley.

The PALAEOBOTANY and STRATIGRAPHIC SEQUENCE of the PLEISTOCENE KLONDIKE "MUCK DEPOSITS"

by

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THESIS

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Abstract

THE KLONDIKE MUCK DEPOSITS

The Klondike Districtof Central Yukon Territory around Dawson City is particularly advantageous for the study of the sequence of the Pleistocene epoch because it was never glaciated and therefore has never lost its fossiliferous superficial deposits.

This paper presents a pollen diagram from a Sphagnum peat bed, which was the youngest deposit discovered, and pollen floras from different ages back to the Pliocene. The peat bed flora shows fairly steady climatic conditions little different from the present; the Pliocene flora shows a distinctly warmer climate; and all the others appear to show colder climates.

The paper also presents a theory of correlation of geological events in the district with world-wide climatic variations:

- cutting of very broad creek valleys; climate warm	- Earlier Tertiary
- deposition of the oldest gravels; climate warm	- Pliocene
- deposition of oldest unweathered gravels; climate cold	- Nebraskan Glaciation
- rapid cutting of narrow lower creek valleys	- Three Major Interglacial Ages
- major interruptions of valley cutting; climate cold	- Kansan and Illinoian Glaciation
- deposition of thick valley - bottom muck; climate cold	- Wisconsin Glaciation
- erosion of valley - bottom muck; climate warmer than the present	- Post-Glacial Climatic Optimum
- deposition of Sphagnum peat bed; climate same as today	- Recent Time

1. INTRODUCTION

1. Foreword and Acknowledgements

The only part of Canada of any great size that escaped glaciation by the four successive ice ages of the Pleistocene epoch was the west-central plateau country of the Yukon Territory. Here is to be sought the best fossil and stratigraphic record of climatic changes while the rest of the country was buried under ice.

By far the most accessible and best known part of this plateau is the Klondike Gold Field around Dawson City, the old capital of the Yukon. The writer has spent two summers, 1950 and 1951, in the Klondike region, mostly at the mining camp on Hunker Creek, fifteen miles from Dawson, collecting from the extensive Pleistocene deposits along the creeks for a study of the fossil plants and pollen grains contained in them.

This paper presents what appears to be the first pollen **diagram** worked out for the central Yukon region, and, as the result of field observation and laboratory examination, a newly formulated chronology of Pleistocene events in the Klondike.

The work was carried on under the direction of Dr. M. V. Roscoe, chairman of the Department of Botany, McGill University. The field season of 1951 and the work of the following winter were supported by the Arctic Institute of North America under contractual arrangements with the United States Office of Naval Research. I wish to thank Dr. Roscoe and the Arctic Institute as well as the following people, for criticism, encouragement, and help: other members of the staff of the Department of Botany, McGill University, especially Dr. R.D. Gibbs; Dr. Jacques Rousseau, Mr. Marcel Raymond, and Mr. James Kucyniak, of the Montreal Botanical Garden; Dr. H. S. Bostock of the Geological Survey of Canada who introduced me to the Yukon; Mr. A. E. Porsild, Chief Botanist of the

National Museum of Canada; the officers of the Yukon Consolidated Gold Corporation at Dawson City; research workers at the University of Alaska, especially Dr. Ivar Skarland and Mr. Otto William Geist; Dr. N. Polunin; and my fellow graduate students in the Department of Botany at McGill University.

2. The Problem

The Klondike district is a rectangle 25 to 40 miles across, of rolling upland culminating in a central prominence called "the Dome". From this Dome radiate the deeply cut stream valleys that drain the district into the Klondike River on the north and the smaller Indian River on the south, both of which run westward into the great Yukon River. It is part of the Western Yukon Plateau which, alone of all Canada, was never glaciated during the Pleistocene ice ages. More than once the glaciers of the Ogilvie Mountains and the ice sheet of the Mackenzie Mountains far to the eastward pushed to within twenty miles, but they never rode over the district.

Yet then as now the Klondike was a region of intense cold in winter and heat in summer, a region of continuing drought; so that now the valleys and hills are covered with an almost continuous mantle of residual frozen gravel and muck, the northern equivalent of soil, which has been accumulating in some places since before the Pleistocene. Here is an excellent place to trace the changing climates of the ice ages in the remains of plants and animals preserved in the frozen mantle.

Beside this, the district has a history that has greatly increased its value as a field of study, for it was the focus of the famous Klondike Gold Rush of 1898. That human flood established systems of transport, built permanent towns in the wilderness, and searched the whole area for gold. Today Dawson, served by a regular plane route, offers the conveniences of any small town. Since the gold that caused the rush is placer gold, it is part of the superficial mantle and the search for it has left a legacy of detailed data on the conformation of gravels and the location of deposits. The extensive mining operations that have been going on ever since the Rush have served to expose the deposits for study and collection in a way that no scientific worker could ever afford.

So for completeness of geologic record, for the worker's personal convenience and for ease of access, the Klondike district is unsurpassed as a sort of test-tube for the study of the Pleistocene Epoch as it affected the Boreal regions of Northwestern America.

3. History and Literature of the Region.

The recorded history of the central Yukon begins in 1843 when Robert Campbell, a servant of the Hudson's Bay Company crossed the Frances Lake divide from the Liard River country, and descended the Pelly River to the point where it joins the Yukon, where in 1848 he founded Fort Selkirk. But the Company lost Fort Selkirk to Indian trade rivals in 1852, and lost its only other Yukon River post, Fort Yukon, to Americans in 1869, and from then on played no part in the history of the country. American traders have dominated there ever since the purchase of Alaska from the Russians by the United States in 1867. Short accounts of this early period are given by Leechman (1950) and the pamphlet of the Canadian Department of Resources and Development (1950).

Lieut. Frederick Schwatka of the U.S. Army conducted the first scientific survey of the region in 1883 when he drifted down the Yukon River on a raft from its source to its mouth. And about this time, geologists of the United States Geological Survey, working across the border in Alaska, recognized the fundamental fact that this far northern country, the basin of the Yukon River, alone in all the northern half of the continent, had never been glaciated.

In 1887, Dr. G. M. Dawson of the Geological Survey of Canada initiated geological exploration when he descended the Pelly River to its mouth at old Fort Selkirk, ascended the Yukon to its source, and crossed the 20-mile pass that separates the river's head from tidewater where Skagway now stands. His report (Dawson 1890) is a very complete account of the country he saw, for it contains descriptions of the natural history and natives as well as of the geology and topography.

In the same year and the following, R. G. McConnell of the Geological Survey of Canada carried out one of the most extensive survey expeditions ever undertaken in the Yukon. Alone or with local help, he descended the Liard River and wintered at Fort Providence. The next year he descended the Mackenzie River almost to its mouth, ascended the Peel River and crossed the mountains to the Yukon basin. He descended the Porcupine River into Alaskan Territory, went up the Yukon to its source and finally crossed the pass to tidewater the same way Dawson had travelled the year before. Altogether he covered over 4000 miles on foot, by dog-sled, by canoe and by poling-boat; more than once he had to halt long enough to build a boat or some other equipment from the materials the country provided. All the way he kept notes on the geology and topography, vegetation, inhabitants, and events that raise his report (1891), in interest, far above the ordinary. Subsequently he was to become the authority on the geology of the central Yukon.

The fur trade brought the first white men to the Yukon, but gold opened the country and made it known. Less than 25 years after the first great North American gold rush in California, the advance guard of the wave of gold-seekers that rolled northward through the Cordillera from one rush to the next, found enough of the stuff to raise their hopes in the Yukon. And almost 25 years after that, when there were already several hundred prospectors searching the unglaciated country below the Stewart River, on August 17, 1896, George Carmack and two Indian partners discovered coarse gold in the gravel of Bonanza Creek, a small tributary of the Klondike River.

In the rush that followed, the outlying creeks and workings were abandoned, the local miners all staked fabulously rich claims, unbelievable hordes of strangers from all the lands of the earth groped their way over the Chilkoot

Pass and down the long Yukon River, and Dawson City, the little district's river-landing named for the explorer, changed overnight from one man's farm and trading post into a rowdy masculine city of twenty to forty thousand miners.

In 1900 and subsequent years, the Geological Survey of Canada sent back R. G. McConnell to investigate the source of this activity. His extensive work, published in 1903, 1905, 1906 and 1907 forms the foundation of our knowledge of the geology and geomorphology of the Klondike mining district. He was succeeded in the following decade by D. D. Cairnes and in the 1920's by W. E. Cockfield. Since the early 1930's, Dr. H. S. Bostock has carried out, for the Survey, general area mapping of the geological formations from the Klondike region south to the Lake Laberge country and east beyond the town of Mayo.

Botanical exploration in the central Yukon begins with G. M. Dawson who made voluminous notes on the tree growth, shrubs and general vegetation on his trip in 1887, and collected a few plants as well. After the gold rush, many collectors visited Dawson City and made it one of the best botanized localities of the north country. Notable among these was John Macoun, botanist of the Geological Survey of Canada, who made a large collection in 1902, and in his 1906 report, gave an early account of the ecology of the Yukon and its climate. A list of botanical explorations in the Yukon up to 1948 is to be found in Porsild's "Botany of the ...Yukon..." (Porsild, 1951). In 1949 a party from the Dominion Experimental Farm at Ottawa including several botanists, spent the summer at Dawson. The results of their extensive collections have not yet been published.

The synthesis into a single Flora of many of these collections together with collections from the Alaskan mainland and the Aleutians, has been accomplished in masterly fashion by Dr. Eric Hultén of Stockholm, Sweden. His "Flora of Alaska and Yukon" begun in 1941 and completed ten years later is the taxonomic authority for the whole country at present. Prof. J. P. Anderson of the University of Iowa has constructed keys to the species described by Hultén, in his "Flora of

Alaska and Adjacent Parts of Canada". In 1951, A. E. Porsild, chief botanist of the National Museum of Canada, Ottawa, published his "Botany of the South-eastern Yukon Adjacent to the Canal Road", which is really a summary of taxonomic knowledge of the whole Yukon Territory, together with many new records and discussions of the ecology of the glaciated country far to the east of our area.

4. The Klondike Placer-Mining Industry.

Since the placer-mining industry of the Klondike district has made possible most of the observations and collections which form the basis of this study, a description of its methods will aid in understanding the investigation. Bostock (1932 & ff.) and the Geological Survey of Canada (1947) present accounts of the evolution and re-organization that have occurred in the industry.

In the early days after the gold rush, production-mining of the richest placer deposits required only a small capital investment for axes, picks, and wheelbarrows, a certain amount of ingenuity in the construction of simple devices, and a strong back. But since the exhaustion of the rich "streaks", production now depends on the larger deposits of lower value, and methods of extraction must be immensely more efficient and, consequently, on a far larger scale and more costly. Most of the gold production of today comes from eight large dredges, owned by the Yukon Consolidated Gold Corporation, which sit in little ponds of their own digging in the various creek valleys that radiate from the Dome. But beside this, a small regular production comes from individual miners operating with sluice box and monitor or bulldozer in the discontinuous deposits of the hillsides.

The basic implement in placer-mining is the sluice box, a long trough with a corrugated bottom, through which the material of the placer deposit is run by a good rushing stream of water. The agitation of the rushing water and the action of gravity cause the heaviest materials such as metallic oxides and gold to accumulate in the corrugations while the slightly lighter gravel is transported over top. With this simple device, wonderfully efficient recoveries of gold can be made. The individual miners often set up a long wooden sluice box in a creek bed and push the gravel into the upper end with a bulldozer, letting the creek water do the rest. If their claim consists of older gravel in a cliff away from any present creek, they set up their sluice box at the foot of the cliff and wash the gravel into it using a jet of water from a large high-pressure water-gun or "monitor" which is kept supplied by a system of pipes. The cut-bank so formed is the best place to collect material for the study of this older gravel.

Essentially, a gold dredge is a sluice box mounted on a barge with suitable machinery for digging gravel, presenting it to the sluice box and disposing of it after it has been stripped of its gold. The dredge floats on a pond which it is constantly enlarging ahead of itself and filling in behind. Only enough outside water is required to keep the dredge-pond full, for the large pumps on board frequently force through the sluice boxes a larger volume of water than the creek discharges; they just use it over and over again. By swinging back and forth on its anchor cables, by digging shallow and deep, and by inching slowly forward, the dredge works over the gravel of the whole area bearing gold. In the Klondike district, the dredges are operated by hydroelectric power produced by a large plant on the upper Klondike River. They are thus able to operate very cheaply. Still, a dredge cannot efficiently work over an area that is far from level or ground that is frozen solid; and the creek bottoms are usually both.

To thaw the ground, thin pipes or "points" are driven down through it to bedrock at twenty-foot intervals, and cold creek water is pumped through them continuously for about six weeks. The slight warmth in the water is sufficient to thaw all the ground between the points. To level the ground a series of monitors with their elaborate system of feeder pipes is set up so as to wash the soil from a whole area and so reduce it to the flattest possible level, referred to by miners as the "grade". This operation, called "stripping", is moved slowly downstream leaving behind a row of low cut-banks on either side of the valley which are ideal places to collect samples for a study of the valley-bottom deposits, or at least of those deposits above the grade level. Those below the grade are only exposed when they are dug up by the dredge, and then they are usually so churned about as to be surely contaminated.

At any rate, the placer gold mining industry provides an opportunity to examine the superficial mantle of the Klondike district at least in part. Certainly the permanently frozen condition of all the deposits presents a grave obstacle to examination by more conventional means such as boring; and an open cut-face gives a much better picture of stratigraphy than a blindly collected drill-core even under the best of circumstances.

II THE WORLD IN THE PLEISTOCENE EPOCH

1. The Age in Outline

The age of glaciation, the Pleistocene, was the shortest of all the geological periods that we recognize and, geographically at least, the most important. During that time the continents assumed their present shape, plants and animals achieved their present distributions, and rivers, lakes and mountains received their moulding; all as a result of changes which in many cases still proceed. The Pleistocene is the best-known of all periods, for the recency and vast quantity of its continental deposits present us with a far greater wealth of geological data than we have for any earlier time.

The Pleistocene epoch as defined by Flint (1947) began with a radical cooling of climate that brought to a close the previous epoch, the Pliocene, and continues up to the present time. Post-glacial time varies greatly in length with locality and, in fact, has never existed in central Greenland and Antarctica. Geologically, the Pleistocene was short, yet it is generally believed to have been about one hundred times as long as the interval since the last glacier retreated from the southern Great Lakes region, or about one million years in all.

The general chronology of the period has been arrived at by correlation of separate chronologies worked out by a very great number of different studies. Flint (1947) in America and Zeuner (1950) in Britain have made recent compilations of information from the different sources. Flint, discussing mostly the geological and geomorphological record, is very wary of attempts to assign definite dates to the period, but Zeuner, whose interest is in the history of man in the Pleistocene, frankly attempts to assemble the most reliable estimates of date into an absolute chronology.

2. Geological Evidence

The deposits left by the glaciers themselves have been intensively studied in many parts of the world, especially in central and northern Europe, and in the Great Lakes and eastern Plains regions of North America. Flint (1947) has brought together the literature on the glacial geology of the Great Lakes region with its confusing evidence of moraines, tills, lake-silts, beaches, crustal warpings and changed drainage channels. Chapman and Putnam (1951) writing on the Physiography of Southern Ontario, provide a good example of the detailed study involved. Here the authors, by assembling a vast array of information, have worked out in detail the history of a small area during a very short period in the retreat of the last glacier.

In the Great Lakes area, several successive ice-sheets advanced from a rather indefinite and always shifting centre somewhere in the region of Hudson Bay. Each advance overrode the deposits laid down by its predecessors. The great weight of the ice depressed the land surface so that large lakes often formed in front of the glacier and laid down sediments there. In the western Cordillera, mountain ice-caps grew, spread and fused to form continuous sheets which filled many of the great basins and spread eastward to meet the Hudson Bay ice; all the evidence shows this happened more than once. Everywhere, the various deposits laid down by the ice, when finally exposed, were deeply weathered by the processes of soil formation; in deposits buried by later ice advances, the depth of weathering is a measure of the length of time between the glaciations.

A significant feature of central North American glaciation is that each of the successive ice-advances followed roughly the same paths and reached roughly the same limits. The outer margins of the different glaciations are, considering the great area and time involved, remarkably uniform. Flint, (1947) deduces from this that the causes of ice advance and the conditions of advance were the same in all of the ice ages.

Zeuner (1950) and Flint (1947) both summarized the European evidence which, because of the smaller area involved, the denser population and consequently better accessibility, and the longer period of study, is more detailed than the evidence from North America. The Alps of Switzerland, the major European centre of mountain glaciation, were the first to be studied intensively. The evidence there, which is incomplete because of the great amount of erosion that occurs in mountain regions, consists for the most part of sheets of outwash that can often be traced up the valleys in which they are found, to sheets of till.

Of greater extent and importance were the continental ice sheets of Europe. Ice from the major centre in Scandinavia spread so that at various times it coalesced along the east coast of England and Scotland with ice from the large minor centre in Great Britain. The edges of the Scandinavian sheet have yielded the best record of the retreat of the last glaciation, as well as details on previous advances.

Much of the study on the last retreat has been done by Gerard de Geer of Stockholm who invented and perfected the technique called "varve analysis". Pro-glacial lakes, those formed by damming of melt-water at the edges of a glacier, deposit silt which consists of annual layers whose thickness varies with the weather of the year. De Geer (see Flint, 1947, and Zeuner, 1950) was able to correlate layers (which he called "varves") in one lake with those in another and thus actually count the number of years each lake was in existence and, by addition, to count the number of years from the present time back to any given glacial feature. On this basis, he and his students constructed an elaborate chronology of the glacial retreat from Denmark to the existing isolated glacierettes in the mountains of northern Sweden. Antevs (see Flint 1947 and Zeuner, 1950) worked out a similar chronology for eastern North America from Long Island to James Bay, but the gaps in his records and the guesses he made to fill them in render his work considerably less reliable than de Geer's.

The radical climate changes of the Pleistocene epoch which caused the advance and retreat of the glaciers, were felt pretty well all over the world, and left evidences of one sort or another far beyond the actual area of glaciation. Flint (1947) summarized the observations in North America and Zeuner (1950) described the best of the elaborate studies which correlate Pleistocene deposits and human occupation in Britain, France, and the Mediterranean region.

Four peri-glacial features should be mentioned here: outwash, loess, solifluction and stream-variation. The melting edge of a glacier regularly debouches vast quantities of rock material which may be of any size but includes a large amount of finely crushed silt termed "rock flour". The rock material may be dropped by the melt-water streams anywhere in their course away from the glacier, but most of it forms great beds, called "outwash fans", directly in front of the ice.

In an arid continental climate these outwash fans, typically devoid of vegetation, are attacked by strong dry winds which carry away the flour and deposit it over large areas of land to leeward. Thus great beds of uniform fine-grained sediments called "loess" have accumulated in the central part of North America and in eastern Europe, where the climate is, and presumably always has been dry. Loess is rather rare in western Europe where the climate has almost always been moist enough to keep wind from picking up silt; and it is notably absent from eastern North America where the outwash was usually trapped in pro-glacial lakes and protected from the wind. Tuck(1940) has shown that the very deep "muck" deposits at Fairbanks, Alaska, were originally loessial in nature, though he ascribes them to a warm dry period rather than to a cold dry one.

The process of solifluction, best described by Taber (1943) is the frozen-ground equivalent of sheet erosion. It consists in the downhill movement of muck and rock fragments caused by the alternate freezing and thawing of the large amounts of water invariably included in the muck. Often whole surfaces with the vegetation riding on top move gradually downhill. Vegetation may then be caught ahead of the sheet damming the flow and causing a "turf-banked terrace" (Taber 1943). Overriding of the dam causes the scroll-shaped patterns which identify solifluction in deposits; bursting of the dam can overwhelm a large animal and account for many of the spectacular animal fossils of northern countries.

Solifluction has been frequently recognized in recent years in the periglacial deposits of England and France (Zeuner 1950). Very often a zone of solifluction is seen to grade upward into a bed of loess. Zeuner attributes this to a change from cold wet to cold dry conditions. Tuck (1940) showed that the "muck" of the Fairbanks region, while originally loessial, had often been subsequently displaced by solifluction so as to engulf the many organisms found in it.

The correlation of archaeological with glacial sequences in western Europe has depended largely upon the study of changes in beach levels and stream courses. (Zeuner 1950). The piling up of ice on the continents removed water from the sea and significantly lowered the sea-level, and the weight of the ice itself depressed the continents and allowed the formation of high level beach-lines. The interaction of the two factors raised and lowered the base levels of streams and so decreased and increased their gradients. Thus many streams have intricate histories of alternate deepening of channel and filling with alluvium corresponding to the changing climates. One of the best-studied streams from this point of view is the Thames of England.

Beside this, streams with constant base-levels erode their channels at different rates in different climates. In a cold climate, chemical weathering is at a minimum and the products of erosion must be carried away mechanically as solid particles. In a warm climate, much more material can be carried in solution so that a stream need not flow so rapidly to carry away all the material dumped into it. Thus a stream flowing to a constant base-level will erode its channel in a warm period and aggrade it when the climate becomes colder. The result of this is a series of terraces above the stream level, each with an alluvial capping.

3. Sequences Derived from Geological Evidence

By the use of various geological methods, several sequences of the Pleistocene have been independently worked out in various places. All of them agree that there were, during the epoch, more than one major ice-age, and that each major ice-age was marked by minor fluctuations.

In the north-eastern Alps, the earliest region to be intensively studied, Penck and Brückner in 1909 (see Flint, 1947, and Zeuner, 1950) recognized four major glacial periods, each with minor fluctuations, and three interglacial periods, and Eberle in 1930 (see Flint 1947 and Zeuner 1950) recognized several glacial periods earlier still. The sequence and the names applied to them are:

Würm Glaciation	Substage 111
	Substage 11
	Substage 1
Riss-Würm Interglacial	
Riss Glaciation	Substage 11
	Substage 1

Mindel-Riss Interglacial ("Great" Interglacial)

Mindel Glaciation	Substage 11
	Substage 1

Günz-Mindel Interglacial

Günz Glaciation	Substage 11
	Substage 1

Donau Glacial stages and earlier stages

As mentioned earlier, the study of the Scandinavian and North German glacial area has concentrated on the waning phases of the last glaciation. But both Flint (1947) and Zeuner (1950) present a sequence including four major ice-advances and definite substages in at least one:

Fourth Glacial	Fennoscandian Recessional Moraines.
	Pomeranian Moraines
	Brandenburg Moraines
	Warthe Moraine
Saale-Warthe Interglacial	
Saale Glacial	
Elster-Saale Interglacial	
Elster Moraine	
Pre-Elster Moraine.	

In North America the record is best worked out in the central region. Flint (1947) presents the details of evidence used to trace the retreat of the last ice-sheet in the Great Lakes region and the advances of the earlier sheets farther west. The sequence worked out is elaborate but rather less confused than the European schemes:

Wisconsin Glaciation	Cochrane Deposits
	Mankato Moraine
	Two Creeks Interval
	Cary Moraine
	Tazewell Moraine
	Peorian Interval
	Iowan Glaciation

Sangamon Interglacial

Illinoian Glaciation

Yarmouth Interglacial (longest interglacial)

Kansan Glaciation

Aftonian Interglacial

Nebraskan Glaciation

Attention should be drawn to the "Two Creeks Interval" and the Mankato moraine. Here in the waning phase of the Wisconsin glaciation, a re-advance of the ice rode over top of a well established forest of spruce, pine and birch extending over at least 500 square miles in northeastern Wisconsin.

These sequences all agree, as mentioned above, in having four major glaciations in the Pleistocene separated by three interglacials of which the second is by far the longest. And further than that they all agree that the first substage of the last major stage was more extensive than the following substages and separated from them by a considerable ice retreat; in fact in North America, that first substage was for a while described as a separate glaciation followed by a major interglacial period.

This coincidence of detail leads to the suggestion that all the sequences are parallel and that the glacial maxima in them were contemporaneous. Thus we may feel justified in making the following correlation:

North America	Alps	Northern Europe
Wisconsin-Later Moraines	Würm - Substages 11 111	Fourth - Later Moraines
-(Peorian)		
-Iowan	- Substage 1	- Warthe
(Sangamon)	(Riss-Würm)	(Saale-Warthe)
Illinoian	Riss	Saale
(Yarmouth)	(Mindel-Riss)	(Elster-Saale)
Kansan	Mindel	Elster
(Aftonian)	(Günz-Mindel)	
Nebraskan	Günz	Pre-Elster
	Donau and earlier	

In different parts of the world, attempts have been made to determine the relative ages of the glacial stages and the interglacials. The better guesses, based mostly on degree of weathering of soils, are that all the glacial stages were roughly several times the length of so-called "post-glacial time" while the interglacial periods, of which the longest was the second, were eight to fifteen times as long. (Flint 1947)

Taber (1943), studying the deep mucks of the Fairbanks region of Alaska, found evidence of two cold periods, cold enough to keep the ground frozen to great depths, separated by a period warm enough to thaw the frozen ground to a depth of four or five feet. He theorized that the warm period was the Yarmouth interglacial, and that the two other major interglacial periods had not affected Alaska. While both Capps (1931-32) and Bostock (1936, 1947, 1948) have demonstrated the existence of several major ice-advances in the central Yukon and Alaska, and have tentatively correlated the most recent of these with the

Wisconsin sheet of central North America, only Taber has attempted to correlate any evidences with specific earlier periods.

4. Pleistocene Archaeology

In Europe and in Asia, the study of the Pleistocene has been closely linked up with the study of ancient man. Zeuner (1950) in fact merely presents his detailed discussion of the epoch as a background to his main interest in archaeology. But North America, where the density of population never was very great until historical times, has yielded few rewards to students of ancient cultures; and no discoveries here can match the age of the oldest relics found in Eurasia. There the earliest "hand-axe" impliments made by unknown creatures in eastern England date from the time of the earliest glaciation or before. But in America, the oldest known human evidences date from the time of the Wisconsin glaciation.

It is generally accepted that the earliest immigrants to this continent must have come across Bering Strait on winter ice or glacial land-bridge, up the open Yukon Valley, and over into the Central Plains. Flint points of Wisconsin age have been discovered in the central States, but no earlier human evidences have been found. Skarland (unpublished thesis) believes that at various times during the ice-advance, the Cordilleran ice sheet lost contact with the Hudson Bay sheet, opening a temporary ice-free passage, the "Mackenzie Corridor", down the east side of the Mackenzie and Rocky Mountains from the unglaciated Peel River country in the north to the Great Plains region of the United States. Hansen (1949-b) has found fossil evidence in bogs of the Edmonton district in support of this idea.

Of late years, considerable attention has been given to the archaeology of the central Alaskan region, but except for studies of the most recent native inhabitants, the Kutchin and the Eskimo, the results have been meagre and discouraging. Skarland and Giddings (1948) have published a small list of pre-Kutchin stone implements found in the region, but admit they have been unable to determine even the relative ages of the various objects.

The writer picked up a well-made chert blade from the muck in the stripping operations at Hunker Creek near Dawson City. It was about five inches long, flattish and slightly dished, and sharpened carefully all around the edges. Its position in the muck was unknown ; Dr. Skarland of the University of Alaska identified it as "pre-Kutchin". It is now in the museum of the University of Alaska, Fairbanks.

5. Botanical Evidence

The study of animal fossils in Pleistocene deposits has yielded spectacular discoveries. Especially in northern unglaciated countries, large and imposing extinct mammals such as giant bison and woolly mammoth have been found in remarkable stages of preservation. But the fact that they are extinct, that we don't know how they lived, makes them rather useless for determining the conditions of the times. We must fall back on the plants of the country, both living and fossil, for since they are seldom extinct, their ecological requirements are generally known, and they are much more responsive to environmental variation.

Botanical evidence of Pleistocene sequence will be described under four main categories: Dendrochronology, Phytogeography, Palaeobotany and Pollen Analysis. The last of these, Pollen Analysis, is really a sub-division of Palaeobotany, but its recent refinement has made of it such a specialized tool, so useful for studying the later phases of the epoch, that it will be considered separately.

Dendrochronology.

Tree-ring analysis, or Dendrochronology, is a botanical method for the study of recent history. In it the annual rings of trees are counted and correlated from one tree to another by comparing relative widths in much the same manner as in de Geer's "varve analysis". By this method Douglass and his students (see Zeuner 1950) have been able to construct a chronology for Pinus ponderosa in Arizona back about 1500 years, and to use it for dating various archaeological finds made from the wood of this tree. Hustich (1947) has constructed a short chronology for Pinus sylvestris in northern Scandinavia, and Giddings (1941) and Oswalt (1950) have worked out two parallel chronologies for Picea glauca in central Alaska going back several hundred years. Giddings also used the method to prove that many pieces of wood buried in the ancient muck deposits of the Fairbanks region differed considerably in age, so that they very likely came to rest where found as a result of reworking older deposits.

The method is of limited use in Pleistocene study, but this last proof is good evidence in support of Tuck's (1940) theory on the much-discussed problem of the origin of the Fairbanks muck deposits.

Phytogeography.

The study of living plants, their taxonomy, and their distribution in detail, has yielded in the hands of Prof. Eric Hultén of Stockholm remarkable clarification of the history of the modern Flora (Hultén 1937). And Raup (1947) has used a similar method to determine the history of the flora of a small isolated area on the southern Mackenzie-Yukon border. Briefly the method consists in plotting the total distribution of as many species of plants of a district as possible on a map of the whole continent or of the whole Arctic, and then classifying the plants as to distribution pattern. Given distribution patterns in the light of known geological facts can be explained as the results of certain migration-histories. The "ecological amplitude", or tolerance to range of conditions, of the species must be known, and also something of the geological history of the area in question. Geological theories deduced from the facts of plant distribution, such as Fernald's theory of "nunataks" or unglaciated little peaks in northeastern North America (Fernald 1925) have too often been proved incorrect (cf. Wynne-Edwards 1939). Porsild (1950) has recently theorized the presence of unglaciated peaks in Mackenzie District and the Arctic Islands on similar grounds; geologists have offered no verdict on this theory as yet.

However, certain facts of plant distribution needing explanation have lead to theories subsequently proved by other methods. The northern limits of many plants are not sharp and continuous, but diffuse, ending in a broad zone in which the plants are scattered in small groups often so isolated that the plant's methods of migration could not jump the gap. One is forced to the conclusion that, in this belt, conditions, mostly climatic, which are now unsuitable for the plant in question except in very isolated spots, were once suitable for continuous distribution but have since changed; that is, the climate was once warmer than it is now.

A good example of this is the distribution of the Lodgepole Pine, Pinus contorta, in the Klondike region. A large isolated patch exists on top of a very broad gravel mesa in a broad valley to the east of the region, and an extremely small grove grows on the warm slope of a gulch running into Hunker Creek about 20 miles west of the first grove; those are the only known occurrences of pine in the region of the Klondike.

Paleobotany

The identification of plant fossils in a deposit gives the surest guide to the ecological conditions that existed at the time of deposition, and in Pleistocene sediments one very seldom meets with forms now extinct whose requirements are unknown. But identification, which depends on detailed morphology, is often difficult since the fossils are frequently fragmentary and poorly preserved. And a laboratory sample of a deposit cannot contain the larger fossils in anything like representative quantities. Where precise determination of ecological conditions depends on statistical data, study of the larger fossils is of very little help.

Yet macrofossil study has yielded numerous valuable results. (see Jessen 1949). Steenstrup as early as 1841, and later in the century Kinahan, Geikie, Blytt, and especially Sernander laid the foundations for our modern concepts of post-glacial climatic changes using only the macrofossils observable in peat bogs. Jesses (1949) studied the macrofossils of the bogs of Ireland to round out his post-glacial flora-history of that island. And Chaney (1938 a) made check-lists of many small macrofossil floras from western United States in order to follow in outline the large-scale climatic changes which have occurred in the Pacific coast regions of North America and Asia during the Tertiary Era.

Macrofossils are valuable subjects of study in Pleistocene work, but they cannot give any but the roughest data on relative frequencies of the forms present. To avoid this difficulty there has arisen the modern study of Pollen Analysis.

6. Pollen Analysis

Pollen grains, the "male" gametophytes or microgametophytes of seed plants, are formed in the anther or pollen-sac of the flower. The inside of the anther consists of a mass of sporogenous cells, the pollen-mother cells, each of which undergoes meiosis to form a tetrad of pollen grains. This elementary fact governs the morphology of the resulting grains. They may stick together in composite grains or, more likely, they may fall apart showing seams and ridges which result from the close association in the tetrad; in either case, pollen grains may usually be identified as to genus or even species on the basis of the pattern formed in the tetrad.

The pollen grain consists of a central living mass surrounded by two concentric layers or walls. The inner wall, the "intine", is made of cellulose as is a normal cell wall; it is subject to rapid disintegration as soon as the cell dies. But the outer wall, the "exine", is formed of one of the most resistant organic materials known. It is so resistant that it has been shown to have persisted, occasionally, chemically unchanged, since Carboniferous times in coal deposits; and Faegri and Iverson (1950) report it can be heated to 300°C or treated with strong acids or bases without disintegration. As a result of its durability the composition of this substance (or substances) is largely unknown. Zetzsche (cited in Erdtman, 1943) isolated substances which made up 20 to 25 percent of the weight of fresh Lycopodium spores and conifer pollen. He called these substances "sporonines" and "pollenines", and suggested that they are terpenoid in nature. At any rate, because of this resistance to destruction, the spores and pollen grains of many species of plants are easily preserved in geological sediments. They exist in all unweathered continental deposits of cool climates, often in great numbers.

Flowering plant species may be classified on the basis of the method of dispersal of their pollen grains into two groups: "entomophilous" or insect pollinated, and "anemophilous" or wind pollinated. Grains of entomophilous species are almost invariably large, heavy and few in number. Only rarely do they escape the insects that collect them and fall into sediments where they are preserved, and then they are only deposited very near the plant that produced them. Anemophilous species on the other hand produce vast numbers of pollen grains that are light and, except in the conifers, quite small; these grains are spread far and wide by the wind and deposited evenly over the country, roughly in proportion to the number of plants of their species present in the country. By a happy coincidence many of the dominant plants of cool climates, especially the trees and grasses, are anemophilous and therefore well represented in sediments, while most of the ecologically subordinate species are entomophilous. The pollen-flora of northern sediments is thus mostly a record of dominant species.

This fact, coupled with the great numbers of pollen grains shed by many plants, their durability and their small size make them excellent fossils on which to base the sort of statistical-ecological calculation for which macrofossils cannot be used.

History

The idea of "Palaeo-ecology" was developed in the latter part of the nineteenth century by Steenstrup, Geikie, Blytt, Sernander, and others, and the morphology of pollen grains had been studied since late in the eighteenth century by Bauer, Von Mohl and Fritzsche. It was Lagerheim who first brought together these two lines of thought when in 1905 he identified pollen grains in peat and calculated percentages; and it was his student, Lennart von Post, who, in 1916, introduced the new sub-science of pollen analysis. Von Post was a geologist interested in post-glacial time in southern Sweden and anxious to quell the bitter feud which had developed between the two factions of macrofossil palaeo-ecologists under the leaders Rutger Sernander and Gunnar Andersson. He succeeded in introducing a more rational view of the problem and providing a standardized technique for the study of climatic changes.

Since that time, especially among the students of von Post in Scandinavia, pollen analysis has come of age. The technique has spread. Godwin developed a flourishing school in England, and Auer (1927, 1930) introduced the method to North America where Cain, Deevey, Hansen, Sears and others have taken it up. Some years ago, Hyde and Williams coined the term "Palynology" to refer to pollen analysis (see Erdtman 1948) and subsequently some enthusiasts have tried to consider it a sort of separate science.

Methods.

Von Post's original method of pollen analysis was simplicity itself. He placed a pinch of dry peat on a glass microsope slide, soaked it in 10% NaOH, heated this to boiling several times over an alcohol flame, covered with a drop of glycerine and a cover glass, and examined under a microscope. He counted several hundred pollen grains, identifying each one, and on the assumption that only forest-tree species were dominant in northern Europe, he expressed the species-composition as percentages of the total tree-pollen present.

In recent years many refinements and improvements have been proposed, not all of them useful, and several reviews and texts have been written on the subject (Cain 1939, Erdtman in Wodehouse 1935, Erdtman 1943, Faegri and Iverson 1950, Godwin 1934, 1951). It has now been recognized that there are two main objectives in preparation of sediments for pollen analysis: first, the separation of the pollen grains from the particles of sediment to which they invariably adhere; and second, the elimination of non-pollen particles so that it is reasonably easy to find grains to count. (Cain 1939). For the first objective, McCulloch (1939) proposed a mechanical dispersion method, and Geisler (see Cain 1939) proposed the use of alcohol. But most workers prefer the general method implicit in von

Post's original technique, chemical deflocculation.

In 1936, G. Erdtman, a student of von Post, published directions for the method of preparation which has now become more or less standard. It consists of treating the pollen-bearing sediment in a test-tube, first with nascent chlorine to oxidize the lignin fraction, and then with an acetolysis mixture of acetic anhydride and sulphuric acid to hydrolyse the polysaccharide fraction. (Erdtman 1936, 1943). Assarson and Granlund (1924) had already presented a method of removing the mineral fraction, when present in considerable quantities, by the use of hot hydrofluoric acid. Faegri and Iverson (1950) point out that while pollen exine can stand any amount of acid treatment, it is mildly attacked by violent oxidation. They therefore advocate a return to the use of hot sodium or potassium hydroxide instead of nascent chlorine for getting rid of the lignin fraction. Godwin (1945) had already published much the same method. Several ways of avoiding the use of hot hydrofluoric acid, one of the most dangerous of reagents, have been tried. Radforth's laboratory at McMaster University uses cold hydrofluoric acid standing overnight, with good results (personal communication). Frey (1951) used the method of Knox, in which the sediment is suspended in bromoform. Organic material floats while mineral particles sink.

Mounting is usually done in a drop of glycerine under a small coverslip. Wodehouse (1935) who is chiefly interested in pollen morphology and hayfever, advocates the use of glycerine-gelatine with a trace of basic fuchsin or methyl green to stain the grains. However, fossil grains are always stained brown by "humates" in the deposits and require no extra coloring. The laboratory of Dr. N.D. Radforth at McMaster uses a very satisfactory method of mounting which is unpublished so far as the author is aware. A pinch of prepared sample is placed on a glass microscope slide in a drop of 50 percent commercial corn syrup, then thoroughly stirred with a needle, spread evenly and thinly and allowed to dry for several hours into a glassy film which requires no covership. Slides so prepared may be examined under oil immersion or stored in any position as long as they are kept dry, yet a pollen grain may be rolled over for closer examination by softening the film with a tiny drop of water.

Since the original impetus to pollen analysis came from curiosity about North European peat bogs, it has been traditional to look upon peat as the regular object of investigation. But the hydrofluoric acid method of Assarson and Granlund opened up the possiblilty of studying more mineral sediments as well. Faegri and Iverson (1950) have pointed out, moreover, that bog peats provide much less reliable pollen counts than lake or pond sediments formed far from sources of pollen. The future will probably see more work done on these deposits as methods of collection are improved.

Up to now however, peat bogs, at least in northern Europe, have been the most convenient places to make collections since fuel-cutting operations frequently expose vertical sections of a whole bog, and in the absence of a good cut, the friable nature of peat makes it easy to bore with a suitable core-cutting tool. Mineral deposits require sturdier borers, and lake sediments require elaborate equipment to get vertical series of samples from under water. Erdtman (1943) and Faegri and Iverson (1950) fully discuss collecting equipment, and the difficult problem of avoiding contamination.

Whatever the method of collection used, samples must be obtained in a vertical series from bottom to top of the deposit at close intervals. Care must be taken to determine the exact position of each sample in the series relative to the other samples, for strata in sediments are frequently contorted enough to place older material above or on the same level as younger. For this reason, when samples are collected blindly with a borer, it is best to make only one hole. Sediments laid down by solifluction are particularly confusing to sort out; the scroll-pattern produced by the movement of turf-banked terraces frequently puts older layers above or even inside of younger strata.

The interval between samples depends on the rate of deposition of the sediment. Rapidly deposited material will show relatively little change in fossil composition through considerable depths, while slow deposition may lead to radical change in flora inside very thin layers.

Pollen counting is done with a mechanical stage and a magnification of 400X to 600X. Identification of grains requires mostly a fair personal familiarity on the part of the observer with grains of those species of plants he is likely to see. Several keys for identification of pollen grains, and many catalogues of illustration have been published (Erdtman, 1943; Faegri and Iverson, 1950; Sears, 1930; Wodehouse, 1935) but these are only a very incomplete substitute for personal observation of known pollen grains. Each worker or laboratory needs to have a set of "type slides" of pollen from known plant species.

European workers including Jentys-Szafer (see Erdtman 1943) make counts in genera whose species are distinguished only by a slight difference in size by using size-frequency curves. Cain (1940) has applied the method to eastern North American species of <u>Pinus</u>, and is now working on a similar approach to American species of <u>Picea</u>.

Statistical treatment of completed counts has received very little study. Von Post's original method of counting and identifying from each sample a given number of tree species pollen grains and all the grains of other species seen at the same time, and expressing the counts as percentages of the tree-pollen total, has been most generally followed. But when the sample being studied was deposited in an unforested region, percentages of herbaceous pollen may reahh astronomical sizes. For this reason, composition should be calculated as percentages of all the species present or of all the species that are ecologically significant in any or all samples of the vertical series. (Faegri and Iverson, 1950). In any case the results from all the samples in each vertical series are presented as percentage-time graphs for each species either superimposed or arranged side by side for comparison. It is conventional to draw the graphs with time as the vertical axis so that when, as usually happens, the exact age of a sample is not known, its depth below the present ground level can be substituted logically. In cases where the vertical series records a change from tundra to forest conditions or from grassland to forest, a graph of total non-arboreal-pollen ("N.A.P.") expressed as a percentage of the total pollen count gives a valuable picture of the variation; or a graph of the ratio of total forest-tree species pollen (Arboreal Pollen = "A.P.") to the N.A.P. can give the same picture.

Faegri and Iverson (1950) discuss the technical problems of several sources of error in pollen analysis; the most important one, and the only one that need concern us here, is over-and under-representation of species. In north Europe, the classical difficulty of this type is the fact that _Pinus sylvestris_ the Scots Pine, which is the dominant sub-arctic tree there, produces far more pollen than any other plant. A single pine tree growing nearby enormously, and quite falsely, raises the pine-percentage in a sample. _Alnus_ and _Corylus_ act the same way to a lesser extent. For this reason, Faegri and Iverson advocate concentration on the study of lake sediments which were deposited far enough from the sources of pollen to avoid erratic over-representation; and they also advocate division of the pollen-count of each species by factors roughly proportional to the amount of pollen produced by those species.

The genus _Populus_ causes errors of the same sort but in the opposite direction. The aspen, _Populus tremuloides_ is immensely important ecologically across North America, but it is practically never represented in pollen counts. Its pollen grains, while produced in very great numbers, and spread widely by the wind, have only disconnected flakes of exine material scattered over the surface of the intine, so that the grains disappear completely when the cellulose intine disintegrates.

Post-Glacial Climatic Sequence based on Pollen-Analysis.

In the 1870's, Kinahan in Ireland and Geikie in Scotland (see Jessen 1949) examined cuts in peat bogs in unforested regions and noticed that there were regularly two layers of stumps and wood debris with layers of moss-peat above each. The lower stump-layer contained oak-wood, and the upper contained pine. Geikie theorized that post-glacial time could be divided into four periods:

(youngest)	Upper Turbarian;	humid climate, time of peat-bogs, continues up to the present time.
	Upper Forestian;	dry and warmer than the preceding, though not as warm as the Lower Forestian time of pine forests.
	Lower Turbarian;	humid and cool, time of peat bogs.
(oldest)	Lower Forestian;	dry and quite warm, time of oak forests.

In 1893, Blytt (see Zeuner 1950) published a similar scheme from his examination of Norwegian bogs. He proposed new names for Geikie's periods, and these names are still used to a certain extent. His scheme was:

Sub-Atlantic

Sub-Boreal

Atlantic

Boreal

Sernander, in his interpretation of the bog evidence, added an earlier "Pre-Boreal" or tundra phase to the scheme and codified it into a rather rigorous dogma. In its defence, he entered into a long series of quarrels with Andersson (see Sears 1947)

Lennanrt von Post of the Department of Geology of the University of Stockholm, Sweden, was the man who restored order to the study of post-glacial climate-history, for he introduced pollen-analysis as a standard method of attack. He soon found that during the late "Atlantic" and early "Sub-Boreal" phases of the Blytt-Sernander hypothesis, southern Sweden was invaded by forests of Oak, Elm and Linden, trees which are now rare or extinct in Sweden. From this evidence he deduced that post-glacial time had seen a gradual warming of the climate up to a maximum ("optimum" he called it from the typical northerner's attitude towards warmth) followed by a moderate cooling down to the present. He buttressed his theory by using it to explain the presence of isolated communities of warm-climate plants in northern regions. Thus for the arbitrary climate-alternation scheme of Blytt and Sernander, he substituted a flexible concept of gradual change.

As fully developed by von Post and his students (see von Post 1946) the theory of post-glacial climate succession in Scandinavia begins with a period of arctic-like tundra, the "Dryas-time", interrupted by a short period called the "Allerød oscillation" after its place of discovery, when sub-arctic tree-birch forests were dominant. The following Dryas-time was succeeded by a period dominated by mixed forest of birch and pine, and this in turn was followed by a period of oak, elm and linden forests, evidently a warm period, the "climatic optimum". After that, the climate cooled off so that in recent time the dominant forest tree in Denmark and southern Sweden is the beech.

The following table compares the old and the new systems:

Sub-Atlantic	Beech forests	
		cooling down.
Sub-Boreal	Oak-Elm-Linden	(climatic optimum)
Atlantic		
		warming up
Boreal	Pine-Birch	
	Younger <u>Dryas</u>-time	
Pre-Boreal	Allerød	
	Older <u>Dryas</u>-time	

This system has been widely accepted in principle, though, of course, the indicator species are different for different districts. Godwin (1940) has proved its applicability in England, and Jessen (1949) found that it fitted the evidence from Ireland. An increasing number of American workers in the field of pollen-analysis have shown that in its broad outlines, the scheme holds for this continent.

The first reference to pollen analysis in the American literature is a review of the method by Fuller in 1927. In the same year Auer (1927, 1930) a student of von Post, studied 34 peat bogs in eastern Canada from Nova Scotia to the Niagara Peninsula and found a sequence of climatic changes that seemed to fit von Post's scheme. Some subsequent workers (Voss, 1934, and McCulloch, 1939) at first found no support for the idea of a climatic optimum. But Sears, who was the first to study the morphology of American fossil pollen grains (Sears, 1930), in a long series of reviews (Sears, 1932, 1935, 1947, 1948, 1951) upheld the view of fluctuating climate. Deevey (1943) has shown a definite climatic optimum in Connecticut where the oak-hickory climax was present though now replaced by a slightly cooler, wetter oak-chestnut climax. In a masterly study of the Puget Sound region Hansen (1947) was able to date the periods he recognized quite closely, but found that climatic changes were masked by the humidity of the country. However, working in the dry region of Alberta (Hansen, 1949a, 1949b, 1952) he has found some evidence of a post-glacial warm, dry period. It is notable that no one in America has found undisputed evidence of a tundra phase following the glacial retreat, such as the Europeans describe.

In 1947, Sears discussed the evidence for one warm dry period. In 1948, he stated that geological records indicate at least six ice fluctuations from the Tazewell maximum of the Wisconsin Glaciation to the present, (Tazewell, Cary, Mankato, Agassiz, Cochrane, Recent or historical) each followed by a warm period;

and that pollen analysis has found evidence of four of these. He therefore felt that post-glacial climatic history has been characterized by oscillations, not by the steady rise to the "optimum" followed by a decline to the present, that von Post at first suggested. However he does feel that the warm period following the Cochrane re-advance was quite the warmest, and could be correlated with the European "optimum"; and he arrives at a scheme in which there are smaller fluctuations superimposed on von Post's major climatic cycle.

Thus in widely scattered areas, we find general support for von Post's concept of the "Post-glacial climatic optimum". The resulting question, whether it is contemporaneous all over the world, has just recently been solved in a very remarkable way by the use of a newly developed technique, the Radioactive Carbon-14 age determination method.

7. Carbon-14 Age Determination.

Arnold and Libby (1949) published the account of a method of determining the age of any organic substance not more than 12 or 14 thousand years old. It is based on the fact that in the ionosphere of the upper atmosphere, nitrogen is constantly being converted into a radioactive isotope of carbon called carbon-14 because of its atomic weight. This heavy carbon is found as CO_2 in the lower atmosphere at a constant and very low concentration because of the equilibrium between its production and its radioactive decay. Photosynthetic plants and the animals that directly or indirectly eat them take up radioactive CO_2 in this constant proportion and deposit it in their structural and storage substances in the same proportion.

The radioactive carbon disappears from the organic materials at an ever-decreasing or parabolical rate based on the fact that its half-life (the time it requires to reduce its weight to half what it was at the beginning of the period) is 5568 years ≁ / - 30 years. By measuring the concentration of Carbon-14 in the total carbon content of an organic object, the age of the object can be estimated within a margin of error. Since the original concentration of Carbon-14 is very low, and approaches zero with age, and since the margin of error increases geometrically with age, the limit of determinable age is at present about 13 or 14 thousand years, and even great refinements of technique will not push this back very far.

The general principle has been used for many years to date igneous rocks containing high concentrations of Uranium and its degeneration-products. Using this technique, ages up to 1,985 <u>million</u> years have been estimated with a reasonable certainty of accuracy. (Zeuner 1950). But since radioactive carbon has a much lower concentration in nature and a much shorter half-life, its use in age determination has had to wait on the development of particularly sensitive methods of analysis. The Uranium methods have a rather limited though very important applicability. They may only be used on those rather rare igneous rocks that contain Uranium and its degeneration products, and they are not nearly sensitive enough to date events in the Pleistocene.

From the first, the Carbon-14 method was allied with archaeology. It was standardized using ancient Egyptian relics of known age as well as chunks of wood from the heart of <u>Sequoia</u> trees. But it soon was used to date plant fossils from post-glacial peat beds. Two laboratories have been set up, one at New Haven, Connecticut under W.E. Libby, the other in New York under Kulp and his associates (Kulp, Feely, Tryon, 1951, Libby, 1951) for routine age determinations of objects of scientific value in programs of archaeology, paleontology and geology; from time to time these laboratories publish lists of objects which they have dated. (Arnold and Libby 1951, Libby 1951, Kulp et al. 1951)

Two facts stand out as a result of Carbon-14 age determinations of post-glacial material: first, the almost complete vindication of De Geer's lately discredited chronology for northern Europe based on his varve analysis; and second, the proof that certain similar evidences of post-glacial climatic fluctuation in Europe and North America were, indeed contemporaneous. The first and most important of such proofs of contemporaneity came when the age of the much-discussed European "Allerød oscillation, a warm phase between two tundra phases, was set at 11,000 to 10,000 years, and the age of the very well marked Two Creeks warm interval between the Cary and the Mankato ice advances in the western Great Lakes region of North America was set at about 11,000 years (Flint 1951). It is interesting to notice that the Allerød oscillation was discovered purely by pollen analysis, while the Two Creeks interval was explored by geologists. A log from an ocean-flooded forest on the submerged platform of Bermuda, which must have grown while the ocean level was lowered during the glacial age, was determined as slightly over 11,000 years in age. Thus the oceans did not reach their present level until sometime after Allerød time.

The following table presents a correlation of a few interesting dates and periods.

Age in years	European phases		America	Archaeological
present				
	Sub-Atlantic			
3000				
	Sub-Boreal	"climatic optimum"		1st dynasty Egypt
6000	Atlantic		Pine forests in Maine	Ur of the Chaldees
			Pine forests in Connecticut	
9000	Boreal		Pine forests in West Va.	
	Allerød		Two Creeks	oldest American Man.
12000				
Too old to determine			Cary, Tazewell.	

Most of the age-determinations so far have been correlations with known geological or archaeological sequences. But more and more the method is being used to determine the stratigraphic position of discoveries. Frey (1951) working on a "bay" lake in the coastal plain of South Carolina, dated a period of hemlock-beech-hickory-oak maximum at 10,000 years, i.e. Two Creeks age, and deduced that a pine-spruce maximum just below it must be Mankato in age. On a basis of rate of sedimentation, determined at one inch per 730 years, he judged that the lake is between 40,000 and 100,000 years old.

Attempts have recently been made to date the muck deposits of

Fairbanks, Alaska, by the Carbon-14 method. Ages ranging from 12,600 years to "greater than 20,000 years" have been found. The youngest sample, submitted by the Museum of the University of Alaska, was said to have been associated with bones of "extinct mammals", but its stratigraphic position is unknown.

The proof that the established post-glacial sequences in Europe and North America, and, in fact, throughout the world, are essentially synchronous does not prove that the earlier Pleistocene sequences that have been worked out are synchronous also. But it increases a hundred-fold the probability that they are. The actual proof of that, though, will have to await development of age-determination methods based on elements intermediate between Carbon-14 and Uranium in sensitivity.

111 A STUDY OF THE KLONDIKE REGION

1. The Country

a. Geography

Dawson City and the Klondike district form part of the larger area which Bostock (1948) in his "Physiography of the Canadian Cordillera..." calls the "Klondike Plateau". This is the northwestern part of what he calls the "Yukon Plateau", a broad general region extending from the St. Elias Mountains in the south to the Ogilvie Range in the north, and from the Selwyn Mountains in the east, westward to the Alaska border and far beyond. Cutting diagonally northwestward across the Yukon Plateau is a remarkably straight narrow valley over one thousand miles long called the Tintina Valley. The area of the Klondike Gold Field lies directly adjacent to this valley where it forms the boundary between the Yukon Plateau and the Ogilvie Mountains.

The Klondike district is a roughly rectangular area over 40 miles from east to west and 20 miles north to south. It is bounded on the north and south by the Klondike and Indian Rivers respectively and extends from the Yukon River on the west to the Tintina Valley on the east.

Like the Klondike Plateau generally, the Klondike district is an area of very large, high, smoothly rolling hills and narrow regular valleys betraying its unglaciated nature. The highest point, the Dome, is a rounded knob 4250 feet high, protruding several hundred feet above timberline, and the lowest point is Dawson City at the mouth of the Klondike River in the valley-bottom of the Yukon River at 1,100 feet elevation.

Dawson is the river port and commercial centre of the region, a town of about 800 permanent residents, with streets, sidewalks (wooden) public buildings and civic utilities hardly to be expected in such a remote place. From Dawson the roads radiate east and south to the gold creeks where seasonal workers imported from "outside" operate the dredges. Fifteen miles east of town lies the airport for the twice-weekly plane that is the chief link with the outside at the present time. A road past the airport up the Klondike Valley may soon connect with the Alaska Highway in Canada to replace the precarious car-track that now runs westward from the Yukon ferry for 60 miles along the mountain ridges at or above timberline to the Highway in Alaska.

The map on the following page, traced from the National Topographic Series sheets "Klondike" and "Fort Selkirk", 8 miles to the inch, shows the general plan of the district. The gold creeks are those that roughly radiate from "the Dome" which is the highest point between the Klondike and the Indian Rivers. The gold creeks are Hunker Creek, Dominion, Sulphur and Quartz Creeks, and richest of all, Bonanza Creek and its tributary, Eldorado Creek. All of these flow in relatively narrow deep valleys which they themselves have carved; but they drain into either the Klondike River on the north or the Indian River on the south, which are streams of medium size flowing in very broad misfit valleys. The valley of the Indian River is broad and relatively shallow, but that of the Klondike below where it breaks out of the Tintina Valley, is a broad, deep trench in places two miles wide, with walls rising steeply for 2000 feet or more.

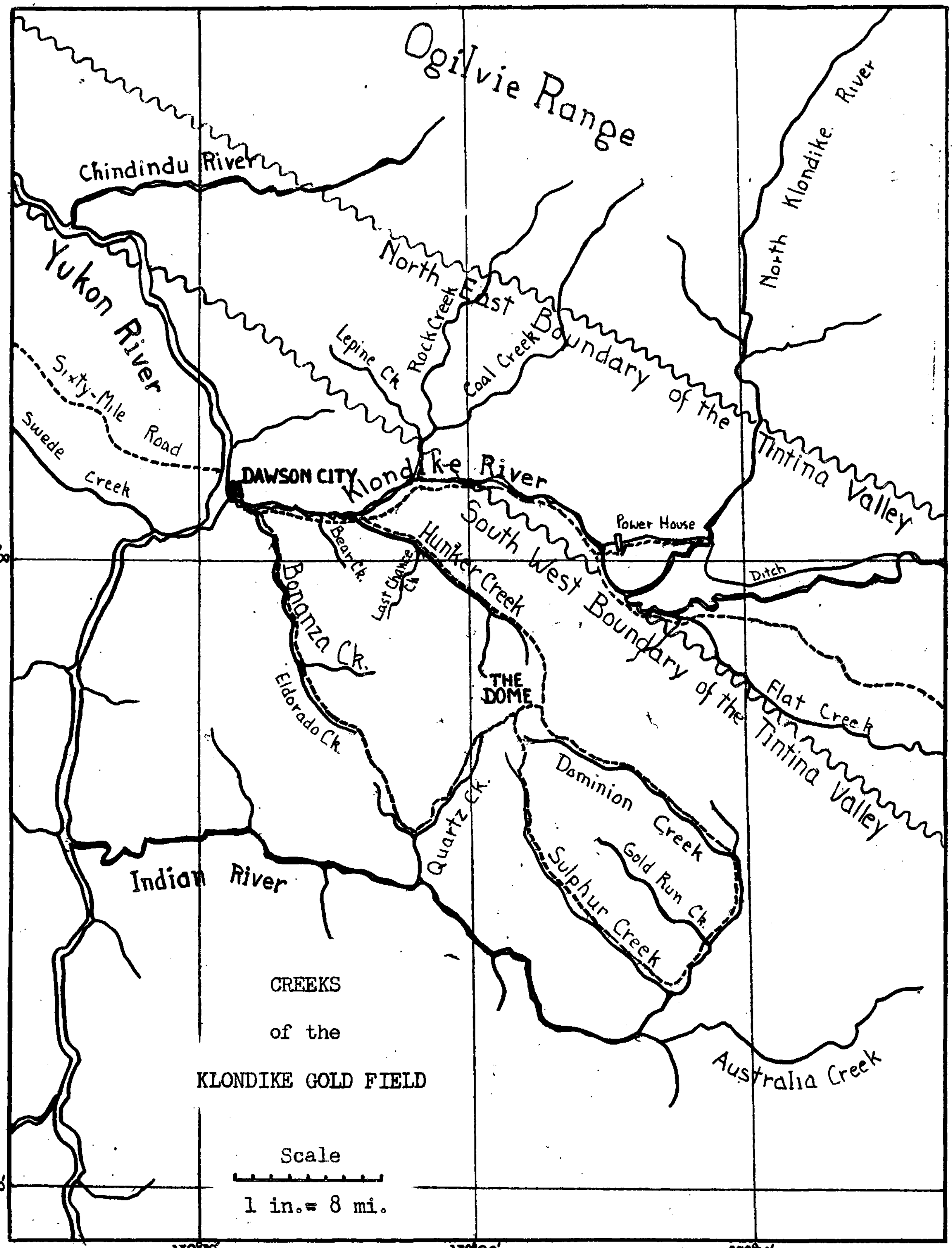

Ogilvie Range
Chindindu River
North East Boundary of the Tintina Valley
North Klondike River
Yukon River
Lepine Ck
Rock Creek
Coal Creek
Sixty-Mile Road
Swede Creek
DAWSON CITY
Klondike River
South West Boundary of the Tintina Valley
Power House
Ditch
Bear Ck.
Last Chance Ck
Hunker Creek
Bonanza Ck.
Eldorado Ck.
THE DOME
Flat Creek
Dominion Creek
Quartz Ck.
Gold Run Ck
Sulphur Creek
Indian River
Australia Creek
CREEKS
of the
KLONDIKE GOLD FIELD
Scale
1 in.= 8 mi.
64°00
63°30
139°30'
139°00'
138°30'

Figure 1.

The Tintina Valley is a major topographical feature of the central Yukon, of unknown origin. It was first recognized by R.G. McConnell (1906) who believed it to be an ancient drainage course. Certainly it was that at one or more times in geological history, but fundamentally it is structural in origin. In our region it is a strip of rolling gravelly lowlands underlain in places by Eocene coal measures and in other places by Pre-Cambrian rock, and bounded on either side by very distinct upland or mountain fronts. In the region just southeast of Flat Creek it attains its maximum width of ten miles or more; and here it is floored by a flat bed of sand and gravel 500 or more feet thick above the present creek and river level; this bed extends for 45 miles southeastward to the Stewart River. In the region of Coal Creek north of the Klondike River, the valley is choked with rough gravel hills that rise 2000 feet above the level of the streams.

On the northeast side of the Tintina Valley rises the Ogilvie Range of mountains, which for all its nearness to Dawson, is one of the least known areas of the Yukon. Aerial photographs taken of it in 1951 will provide the first maps we have ever had of the area. Cockfield of the Geological Survey of Canada, ascended the North Fork Klondike River almost to its source in 1919 and reported on it in 1920; but the map he drew has never been published except in reduced form as part of the "Klondike" sheet, National Topographic Series. Bostock (1943a) and the late Livingstone Wernecke of the Treadwell Yukon Mines entered the eastern end of the range in the upper Mc Questen River area, but Cockfield has supplied the only report for the region above Dawson. The front of the range sweeps up majestically and smoothly to the nearest peaks which are 6000 or 7000 feet high, but beyond this front, the range appears from a distant view to be exceptionally choppy and rugged. Few peaks appear to be higher than the front peaks. Bostock (1948) believes the mountains consist of sedimentary and intrusive rocks. The pointed shape of most of the peaks shows that alpine glaciation was very active during the Pleistocene. In the interior, ice may have formed local ice-fields, but did not extend beyond the south borders; no present glaciers are reported (Bostock 1948).

b. Climate, Ecology and Botany.

Macoun (1906) was the first to report on the climate of the Yukon, but did so only from personal observations during a single summer, and from hearsay. Since that time meteorological data have been recorded practically continuously at Dawson, making it one of the best documented stations in the Canadian north. The "Climatic Summaries" (Canada, Dept. of Transport, Met. Div.) of 1948 give data based on observations of 41 years. Only three other stations are listed from the Yukon, all far from the Klondike district, and all recording observations for a much shorter time.

The climate of the Klondike is extreme in temperature and dry. The average yearly precipitation is very low, about 12.61 inches, distributed fairly evenly throughout the year with a slight increase in the three summer months. Quite a bit of this comes as thundershowers; snow is never very deep. The recorded extremes of temperature in 41 years are 95°F. high and -73°F. low. Diagrams in the pamphlet "Climate of Canada" (Canada, Dept. of Transport, Met. Div. Air Service) show that while the mean for July has varied very little over a period of 39 years, remaining quite close to 59°F., the mean for January over the same period has varied rather spectacularly from -44°F. to + 8°F. The average frost-free period is 74 days, but again this is rather variable.

Probably the most satisfactory system of climate classification so far proposed is that by Thornthwaite (1948) replacing his own earlier system (1931) although even the more recent one is still by no means completely rational as Thornthwaite himself hastens to point out. Halliday (1937) worked out a forest classification for Canada based partly on the older system in which he roughly described the forest of the Yukon and placed the area in the "Climatic Province" $\underline{CdD'd}$ indicating a sub-humid climate with slightly insufficient moisture. Sanderson (1948a and b) using the new system, has recently published a climatic classification for Canada in which she states that the Mackenzie River valley is a region of definite water deficiency.

Although she does not publish figures for the Yukon, it appears from her maps that she believes the region about Dawson is also an area of water deficiency. Apparently she puts it in the new category $C_1C_1'dc_2'$. The writer has recalculated the data and arrived at the following indices:

adjusted P-E	46.3 cm
% deficiency	42.0
% surplus	10.8
Moisture Index	-15.1

Large seasonal moisture variation, summer is dryest
(season

Summer conc. P-E 73.5%

Hence the station seems to fall in the category $C_1C_2's_2c_2'$ or considerably drier than Sanderson indicates and with no maritime influence at all.

Below is the climate graph for the station of Dawson City, based on calculations following Thornthwaite's recommendation that the correction for P-E at stations in latitudes higher than 50° be made using his correction factors for 50° N.

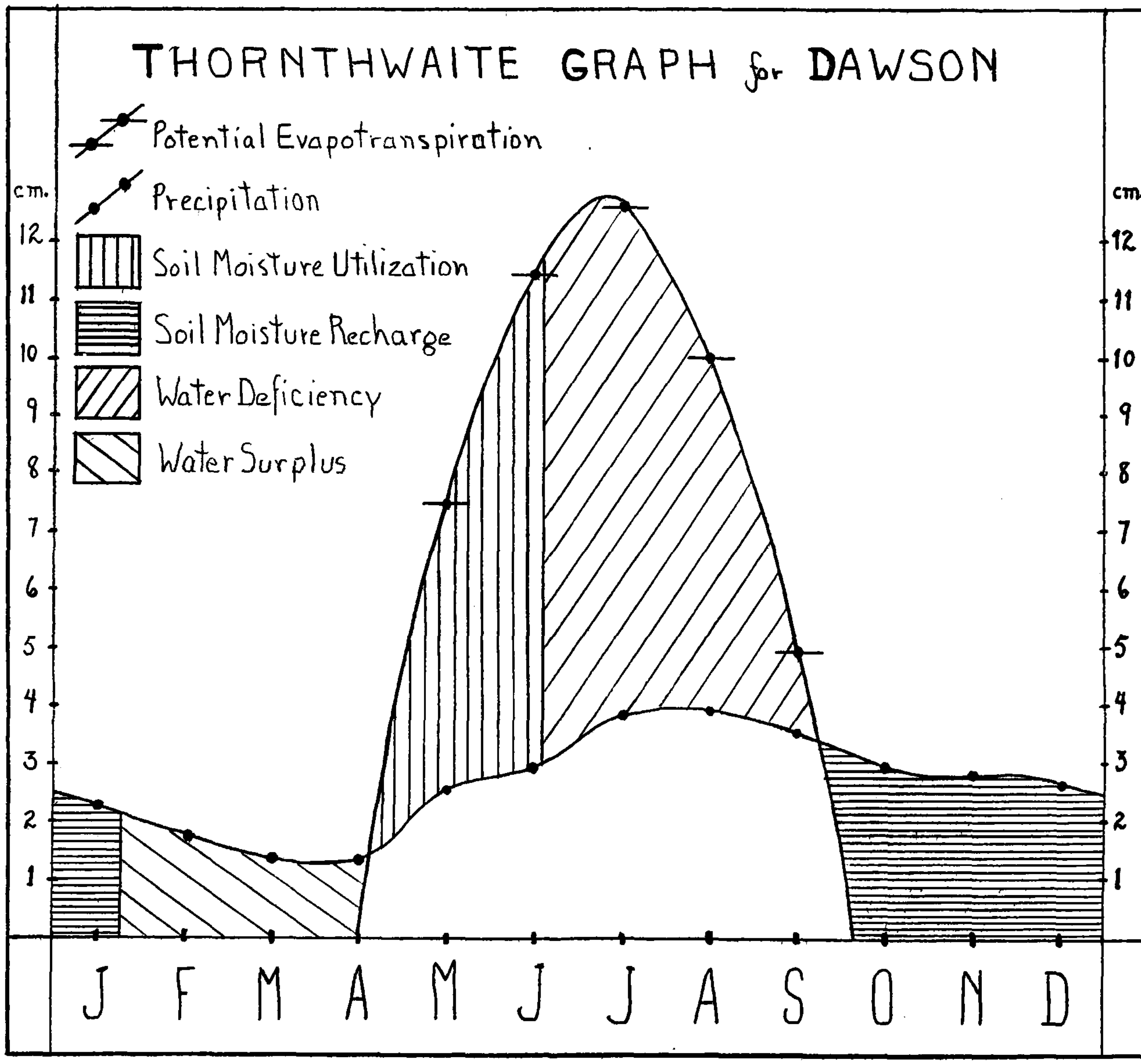


Fig.2

But the summer day-length at Dawson is almost 24 hours because the town lies at 64° N, and consequently summer insolation is far more active than Thornthwaite's 50° N. lat. correction factors suggest. Therefore new correction factors have been approximated by extrapolation on curves; the resulting calculation indicates a higher P-E, 57.8 cm., a higher annual deficit, 31.2 cm., and the category $DB'_1dc'_2$, indicating an essentially warm, dry, extreme climate. In any case however, Thornthwaite feels that the whole system may not work for regions so close to the Poles.

It must be noticed that these calculations are only applicable with certainty to the town of Dawson itself, for in the surrounding country there are a great many local climates. The rolling topography causes channelled convection currents and accumulations of cold air in the valleys. The climate varies widely with the great relief which varies from 1,100 feet at Dawson to 4,200 feet at the Dome. The angle at which the sun's rays in summer strike a ground surface, at right angles on a steep south-facing slope, obliquely on a flat, and scarcely at all on a north-facing slope, controls the intensity of insolation, and hence, the ground temperature. High peaks such as the Dome and Moosehide Mountain just behind Dawson have frequent thunderstorms on their southwest faces which raise the total annual precipitation on that side and leave a noticeable dry zone on the northeast side. Thus the climate varies sharply over very short distances. The frost-free period of summer is said to average a week and a half longer on top of the 300-foot-high bench that rises behind Dawson than in the town itself.

All this local variation in climate expresses itself in an equally great variation in vegetation. At the highest elevations, above 4000 feet, there is a zone of purely alpine flora dominated by dwarf willows, dwarf birth (Betula glandulosa), ericaceous shrubs, and herbs of many kinds. Below the treeline the character of the vegetation depends on the topographical aspect and the recency of the last denudation.

Over most of the Klondike district, fire and wood-cutting have at one time or another destroyed the forest trees and made way for the various seral stages which now cover the country. Therefore the following notes are based largely on observations made by the writer while on survey with the Geological Survey of Canada in 1948 in essentially similar country that has not been deforested, about 100 miles southeast of Dawson.

Immediately below timberline on warm south-facing slopes, the commonest subclimax stage is a sort of scattered brush of large willow trees often up to 30 feet high. At lower elevations in similar situations, the sub-climax is aspen (Populus tremuloides) and grasses. Both of these give way eventually to a sort of climax consisting of open stands of white spruce (Picea glauca) and white birch (Betula papyrifera) with an understory which varies with elevation from grasses and willow shrubs at low elevations to dwarf birch and dry lichens towards timberline. A few slopes of various aspects, with a good supply of ground water and enough drainage to prevent permanent freezing, bear a very similar stand of very large white spruce and white birch with an understory of alder, rose bushes and mosses.

North-facing slopes, except those few with good drainage, present a very different appearance. They, like all poorly drained wet places, have a sub-climax of mosses, grasses and willow shrubs which develops into a sort of climax with the suppression of grasses and the addition of cyperaceous tussocks, dwarf birch, ericaceous shrubs and very much stunted black spruce (Picea mariana) growing widely spaced. The ground under this assemblage is permanently frozen and the ground-cover forms a thick springy mat in which the little spruces lean drunkenly. In the back country, beyond the range of man-set forest fires, this is probably the commonest association.

In middle and lower altitudes, the extremes of local ground temperature are indicated by two associations which form isolated patches throughout the country. On exceptionally steep south-facing hillsides where the ground is unstable and completely mineral, expecially at lower levels, there is an association of low heat-loving, drought-resisting plants remindful of the grasslands of the intermontane basin regions of southern British Columbia and Washington. It consists of low sage-brush (Artemisia frigida) and various bunch-grasses with a scattering of a very large number of kinds of heat-loving plants representing such groups as Juniperus, Zygadenus, Anemone, Leguminosae, Arnica and Solidago. At the other extreme are the narrow meadows found in the bottoms of many of the steep-sided little valleys in high country. They consist of a dense mat of sod-forming grasses, various caryophylls, and a few other plants such as Delphinium and Rumex. Apparently they form in those places where cold air accumulates during summer nights as a result of convectional flow, and where consequently, frost may be expected any night of the year.

There are two widely differing associations found on level ground, one on rich well-drained alluvial river bottom-lands, the other on dry level upland. The first begins its ecological succession with a stand of very large well-formed cottonwood trees (Populus balsamifera) up to two feet in diameter and 120 feet tall that gives way to a densely packed stand of equally large, equally well-formed white spruce. Such stands can only develop where the ground is permanently thawed and where a river provides a sort of natural irrigation to supplement the meager rainfall of the country. The second association begins with willow-brush and develops into an open park-like stand of small spruce, both black and white, with a dense low growth of dwarf birch and a ground cover of dry whitish lichens. Probably this is to be regarded as the true climax of the region, for it grows in those places where topography has little or no effect, where the vegetation must get along on what moisture and sunshine the climate brings it.

The alpine vegetation, also, can be subdivided into assemblages mostly governed by topography. Porsild (1951) has listed eight subdivisions recognized by him along the Canol Road in southeastern Yukon in the glaciated country:

1. Alpine "gardens" or herbmats,
2. Alpine heaths,
3. Lichen heaths,
4. Alpine snowflush herbmats,
5. Rocky slopes, cliffs, ledges, ravines,
6. Unstable screes and stone creeps,
7. Subalpine outwash fans,
8. Xeroseres: gravel-plate screes on south-facing mountain slopes.

Porsild (1951) gives the most recent treatment of the Taxonomy of the Yukon. He makes extensive use of Hultén's monumental work on the Flora of Alaska and Yukon (Hultén, 1941-1951) but differs with it in many places and adds several species to the known list. Porsild's list totals 894 species and sub-species of vascular plants native to the Yukon plus about 60 recently introduced weeds and garden escapes; the list includes 38 Pteridophytes, 9 Gymnosperms, 234 Monocotyledons, and 613 Dicotyledons.

Hultén divided the Territory into three generalized and somewhat tentative floristic provinces, but Porsild (1951) suggests seven fairly well-defined provinces. His number 4 is "the western or central Yukon Plateau...(which)comprises the upper Yukon Basin which lies north of Aishihik Basin, west of Glenlyon and McArthur Mountains and south of the Ogilvie Range. It is believed to have escaped the Wisconsin glaciation, and its flora is rich in species of endemic or disrupted range. Since Dawson City and the famous Yukon Goldfields are in this province, its physiography, flora and fauna are better known than are the other parts of the Yukon" (Porsild, 1951).

c. Geology and Geomorphology

Bedrock

McConnell (1903 1905) was the first to report on the geology of the Klondike district, and Bostock (1943 b) has re-examined it. The oldest rocks in the area are immensely thick clastic sedimentary schists of Pre-Cambrian age which Bostock calls the Yukon Group. They form the foundation of the countryside although they are visible in the gold-field area only along Hunker and Dominion Creeks. They appear to be down-warped to form a major syncline which trends North-Northwest and crosses the Indian River just above its mouth. The Yukon Group is intruded by vast granite-schist bodies also of Pre-Cambrian age,called Klondike Schist by McConnell, which underlie most of the gold field. The whole mass is shot through with gold-bearing quartz veins which, though of very low value, have been shown by McConnell (1905) and Tyrrell (1912) to be quite rich enough to account for the phenomenal placer deposits of the Klondike creeks.

On the north side of the Tintina Valley there are a few exposures of Palaeozoic marine sediments which may be indications of the rocks in the Ogilvie Mountains. Several massive unaltered granite bodies in the Indian River watershed are believed to be of Mesozoic age. Large assemblages of clastic rocks containing coal measures, probably Eocene in age, occur in two localities: in the Tintina Valley north of the Klondike River, and near the syncline which Bostock (1943 b) describes south of the Indian River.

Creeks and Benches.

The Klondike district is a plateau thoroughly dissected by stream valleys; its erosional history is best recorded in the structure of the valleys of Hunker and Bonanza Creeks. Each of these has, in fact, two valleys, a younger narrow steep-walled trench cut two to three hundred feet into the floor of an older broad valley. The effect now is of a narrow stream valley bordered on each side by a continuous row of high and very regular terraces or benches. The steep walls of the younger valley bear irregular small intermediate terraces. The valley bottom, the high terraces and the intermediate terraces all are covered by great quantities of stream-laid or solifluction deposits.

Below, to show the relative size of the two valleys, is a cross-section of Hunker Creek drawn with vertical and horizontal scales equal.

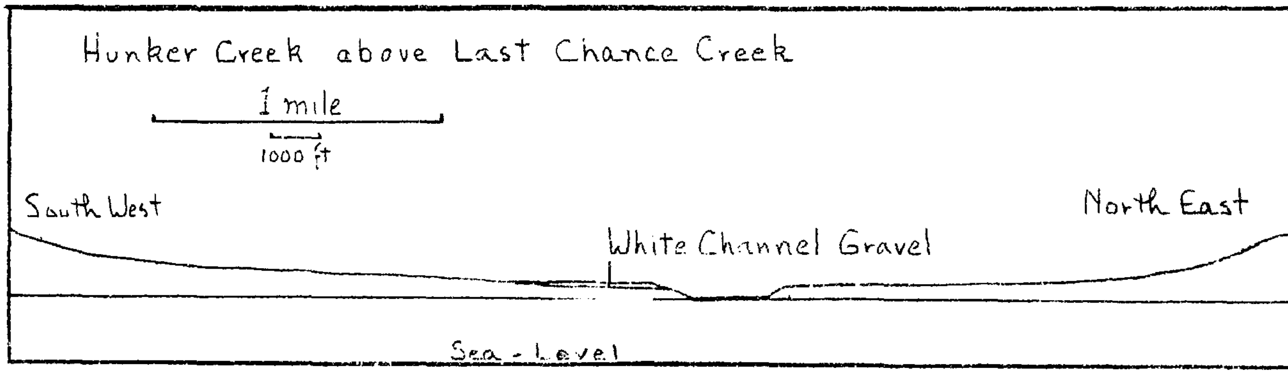


Fig. 3

The older valley is here about 1300 feet deep and three miles wide, while the younger is about 300 feet deep and one-quarter mile wide. Since the drainage basin of Hunker Creek must have had the same area when the broad valley was cut as it has now, and since any conceivable rainfall could not have been radically different, it follows that the length of time involved in cutting the broad valley is immensely greater than that involved in cutting the new one. It should be noticed that all the hills on either side of the broad valley rise to much the same height, about 3000 feet above sea-level; they are the remnants of an erosion surface much older than the broad valley. And the Dome sticking up 1000 feet higher still is roughly the same height as quite a few other similar rounded knobs in the region; they are remnants of a still earlier erosion surface. The history of the area, then, may be represented by the following diagram:

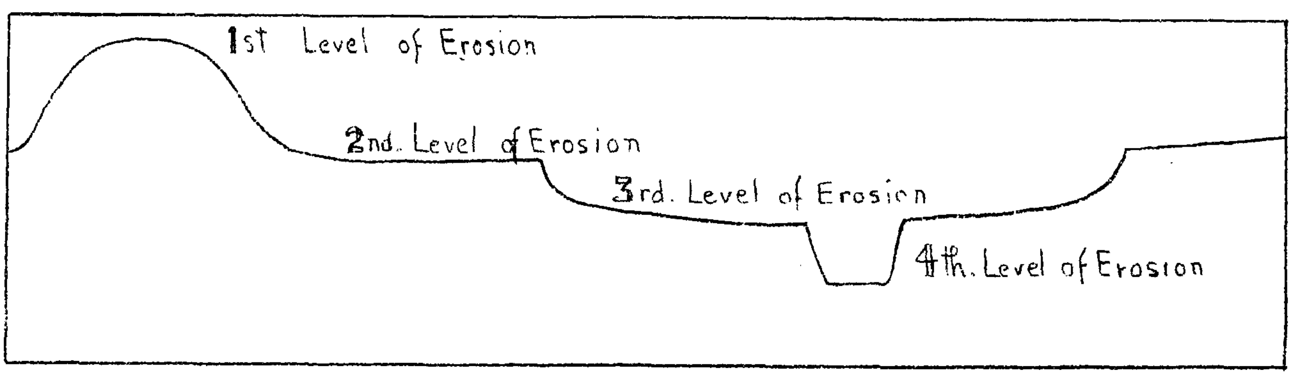


Fig. 4

The floor of the older valley, the high bench along the creek, bears deep deposits of gravel laid down when the creek was at that level. They are much the oldest gravels of the district, definitely pre-glacial and probably Pliocene in age (McConnell, 1903, 1905). Invariably these gravels consist of pure white quartz boulders and pebbles in a fine matrix of white, or occasionally reddish quartz and sericite; from the predominantly white color they derive their common name "White Channel" gravels. They are 50 to 150 feet thick, deepening downstream, and they contain large amounts of gold. Individual miners are able to exploit them using the monitor-cut and open sluice-box method, for the boxes can be placed below the gravels which now cap the terraces along the creek.

McConnell (1905, 1907) made extensive studies of these "high-level gravels". He found they differ from ordinary stream deposits of the country in their compactness and white color, and their imperfect sorting and bedding. The compactness and white color are due to the almost complete weathering away of the great mass of schist from which they are derived, leaving only cobbles of vein quartz and tiny plates of sericite. Therefore he suggests the gravels were deposited under somewhat peculiar conditions which allowed exceedingly slow accumulation in small streams with easy grades and slack currents.

He was able to support this suggestion from observations on the distribution of gold in the White Channel gravels. Practically all the gold lies at the bottom of the gravel on top of the bedrock which is weathered to a depth of about 15 feet. And it is not spread evenly across the whole width of the deposit, but concentrated in a relatively narrow band parallel to the valley, the "paystreak". The miners found that whenever there was a paystreak in the bench gravels, there was very little gold in the valley bottom. This led McConnell to the conclusion that valley bottom gold was derived entirely from destruction of the White Channel paystreak. Furthermore, from plotting paystreaks in the bottom of the broad Klondike valley, he was able to say:

"The White Channel deposits are remarkable in this respect, that, even when completely destroyed their former position is marked by a trail of gold. They are traceable in this manner from the present mouth of Hunker, Bear and Bonanaa Creeks far out into the present valley of the Klondike, showing that the old valley was small, smaller than that of Hunker Creek, and unlikely to have contained a large rapid river such as the Klondike."

At the mouths of Hunker and Bonanza Creeks, the White Channel gravels are overlain by beds of quite different gravels to a depth of about 100 feet. These have coarse smooth unweathered cobblestones derived from the Ogilvie mountains and laid in place by rapid water. McConnell took this to indicate that the Klondike River at some time broke, or was forced from an older channel in the Tintina Valley into the valley of the little creek of White Channel times, and suddenly dumped the coarse gravels there. These he called the "Klondike River gravels".

Below the level of the high benches there are, as mentioned above, many very short, narrow intermediate benches of ddeply weathered bedrock bearing thick deposits of gravel and, frequently, small gold streaks. McConnell (1905) reports that this gravel is frequently overlain, sometimes to great depths, with muck similar to that which floors the present valley. He explains these benches as simply remnants of former valley bottoms left during the excavation of the newer valley; they are irregular in distribution and occur at all levels below that of the main terrace.

The details of high and intermediate benches may be summarized in the diagrams presented below, which represent cross-sections of the creeks. Figure 5 represents Hunker or Bonanza Creek a mile or so above its mouth where there are no Klondike River gravels; while figure 6 represents the creek just above its mouth where those gravels are present.

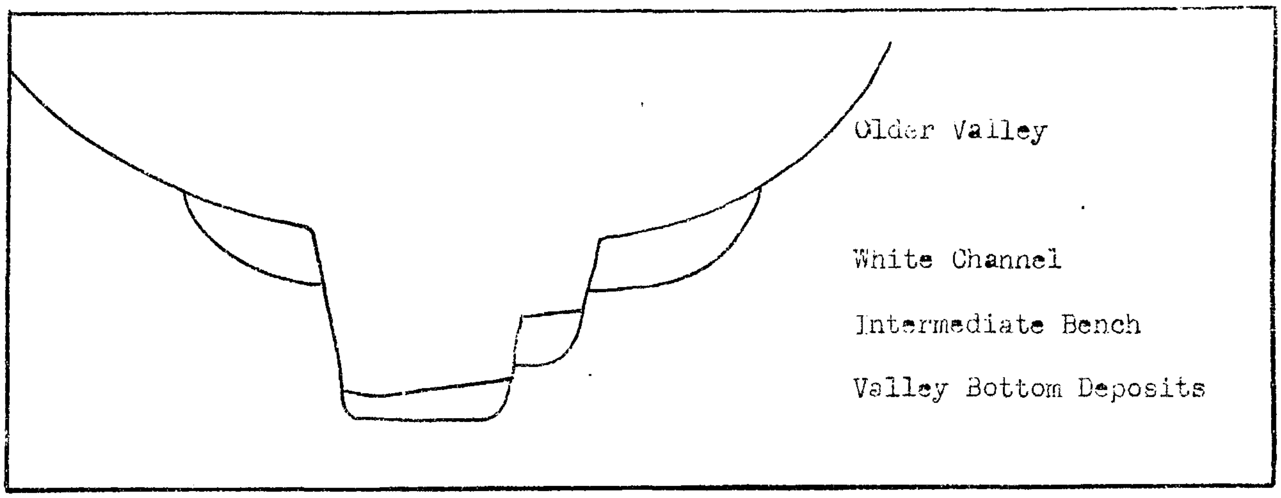


Fig. 5

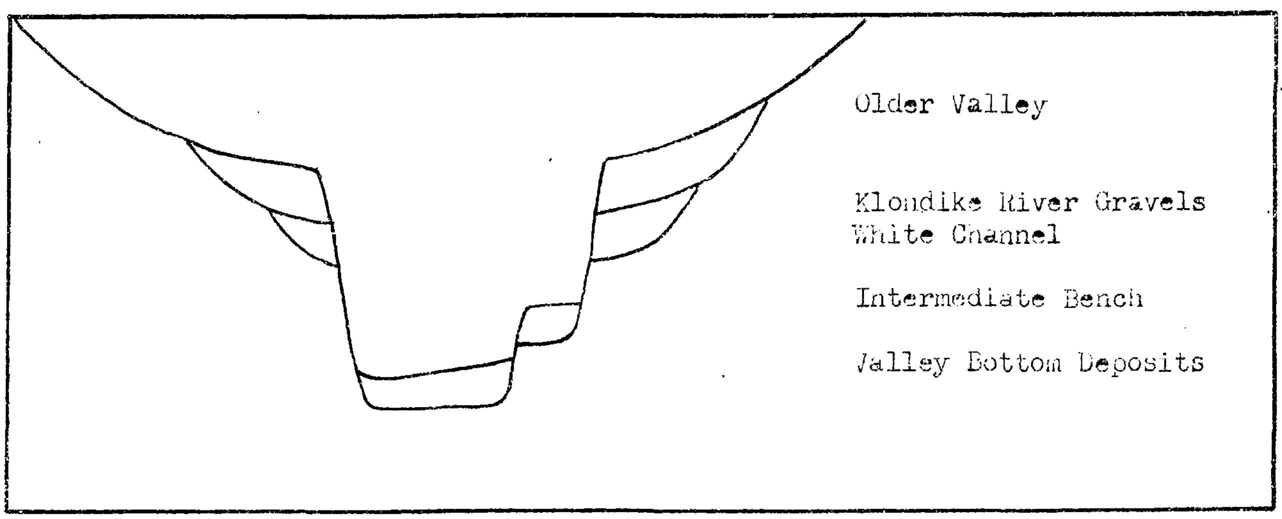


Fig. 6

The high benches of Hunker, Bear and Bonanza Creeks, in spite of erosional interruption in the Klondike Valley, are easily traceable to the prominent rows of benches that line the Yukon on either side at Dawson. All of them agree in elevation and appearance, and all of them increase in height downstream. One mile below the source of Hunker Creek and twelve miles above its mouth the benches are first noticeable; they rise rapidly, or rather the stream cuts down into them rapidly, so that they are about 300 feet high at the mouth. At the mouth of the Klondike River, twelve miles farther downstream, they are also about 300 feet high, and at the mouth of the 40-mile River some 50 miles farther down the Yukon, they are about 700 feet high (McConnell, 1905). On the Yukon, they persist upstream some distance above the mouth of the Stewart River where they are 60 to 100 feet high (Bostock, 1948). They continue up the Stewart River and up all the small tributary streams near its mouth (D.D. Cairnes, 1917, Bostock, 1943 b).

On Kirkman Creek which flows into the Yukon about 25 miles above the mouth of the Stewart, Cairnes (1917) traced the benches, which here are very low, upstream about five miles to where they merge with the present valley floor. Above that point the gravels of the age of bench deposits are under the most recent deposits (D.D. Cairnes, 1917). On the Indian River, the southern drainage of the Klondike district, the benches persist upstream above its mouth about 40 miles to the forks where Dominion and Australia Creeks unite to form the river. Above that, the creeks and their newer gravels and mucks lie over top of the older gravels. Quartz Creek, which enters the Indian River below the forks, has benches capped with White Channel gravels in the same manner as Hunker and Bonanza Creeks; but in Sulphur, Gold Run and Dominion Creeks, the White Channel gravels are to be sought on the bedrock floor of the valley, and benches are lacking (McConnell, 1905). The situation, however, is somewhat complicated. In the first place, trenches have been cut into, though not through, the White Channel gravels, and subsequently filled by later deposits. (McConnell, 1905). Besides, there have been some changes of stream course which were masked by more recent deposits. (Bostock, personal communication).

Thus we see a whole river system with an old level of erosion standing above a newer level which has a much steeper gradient. There must have been at some time in the past, a radical lowering of the base-level of erosion to cause rejuvenation and renewal of cutting. But the cutting has not yet completely reached the headwaters of all the streams. Upper Kirkman Creek and the creeks of the upper Indian River watershed are still flowing in essentially the same valleys they occupied before the lowering of the base-level of erosion.

Valley Bottom Deposits

In the terraced creeks of the Klondike district such as Hunker and Bonanza, the youngest deposits lie on the bedrock floor of the lower valley bottom. They are derived partly from reworking of the older gravels and partly from erosion of the local bedrock. In the creeks of the upper Indian River drainage, they lie for the most part on top of the older gravel deposits.

In the terraced creeks, the bedrock floor is chemically weathered like the bedrock under the White Channel deposits; but whereas the latter is weathered to a depth exceeding 15 feet, the former is only weathered three or five feet deep. Since the placer gold frequently has worked its way down into this "rotten" bedrock, the dredges dig about two feet into it, bringing it up as a black, sticky, almost bituminous-appearing mass.

Miners and the older writers (McConnell, 1905, Tyrrell, 1912, 1917) distinguished two layers in the valley bottom deposits. These are first, the gravel, lying on bedrock, consisting of coarse pebbles, sometimes rounded sometimes quite angular; and second, the "muck", lying on top of the gravel, consisting of very fine-grained silt with large quantities of included vegetable matter such as roots, tree stumps and layers of peat. McConnell placed figures on the depth of each layer, and Tyrrell (1917) assumed the muck to consist almost entirely of remains of mosses. However the writer believes that this distinction is unjustified. Certainly the bottom deposits are of a different character from the upper ones, but the layers in between show a gradation rather than a sharp division.

The sediment below the "grade" level, and lying on top of the bedrock, is coarse and gravelly or sandy. Much of the gravel is rounded and derived obviously from the older gravels, but much of it, especially in certain localities, is very angular and sharp, and derived by mechanical erosion directly from bedrock. At higher levels, about the "grade" level, the sediment is generally finer though many rough lenses of coarse material are found. Above that, in the layers shown in the cut-banks left by the stripping operation, there is no coarse material at all; the sediment consists largely of a very fine silt (never fine enough to be a clay), with much included plant material and many prominent flat-lying layers made up entirely of peat and wood. The finer deposits frequently have their strata contorted by solifluction scrolls, while the coarse deposits show cross-bedding and lenses as though they were fan-deposits. The depth of the valley-bottom deposits varies considerably. On Hunker Creek, the dredge usually digs between 15 and 22 feet below "grade" level to reach bedrock, while the stripping operation has to remove between 10 and 45 feet to get down to "grade". Thus the deposits there are between 25 and 65 feet deep.

The writer considers that the gradations or obvious relationships amongst all these beds, in Hunker and Bonanza Creeks at least, speak for an essential homogeneity, and warrant lumping everything under the single term used by the miners, "muck". In the creeks of the upper Indian River drainage, where the White Channel gravels lie under the muck, there is, of course, a definite distinction between the two.

At Hunker Creek, the bones of the large extinct mammals are found only at middle and lower levels. Remains of certain moose-like animals are found in the lowermost silt beds a little bit above "grade", while Pleistocene horse, and some forms of giant bison and musk-ox appear in the region of interspersed coarse beds. At grade level a few remains of mammoth are found and in the levels dug by the dredge below grade, considerable amounts of ivory are recovered, often in good condition. Mastodon remains are very rare in the Klondike, having been recovered only once or twice and then from mucks of doubtful position. Apparently that animal became extinct before the mammoth did.

Tuck (1940) and Taber (1943) have written descriptions of superficial creek-bottom deposits from the region of Fairbanks, Alaska where the material called "muck" lies in depths up to 150 feet. The writer has examined two of the Fairbanks creeks, and feels that they are not homologous with Hunker and Bonanza Creeks of the Klondike. For one thing, there are no high-level gravel benches; the few benches that do occur, as at Gold Hill, are of muck, not of gravel and bedrock. For another thing, the inorganic part of the muck consists entirely of fine silt, very uniform in size, much like the upper layers at Hunker; there is no gravel mixed with this as at Hunker, and there is little or no recognizable stratification. Tuck (1940) considered this silt to be a wind-blown deposit, but Taber (1943) disagreed. At any rate, the creeks seem to resemble Dominion, Gold Run and Sulphur Creeks of the Klondike in having the oldest gold-bearing deposits more or less undisturbed and covered over with subsequent sediments.

However, the creeks of the Fairbanks district resemble those of the Klondike in one important respect. In both regions, the temperature of almost all the valley bottom muck and gravel is, at the present time, below freezing, and all the contained water is in the form of ice. Muller (1945, reprinted 1947) writing from the point of view of an engineer, proposed for this condition the term "Permafrost", which is now the accepted designation, in spite of the fact pointed out by Bryan (1946) that the frozen condition is often far from permanent. Thawing to considerable depths can be brought about by removal of the vegetation by fire or clearing or agriculture, and re-freezing occurs with re-growth of the cover. Taber (1943) proposed the accurate though rather awkward term "Perennially Frozen Ground."

The difficult problem of the origin of permafrost and its characteristics is discussed by Taber (1929, 1943), Muller (1945, 1947), Jenness (1949) and Washburn (1950), and is outside the scope of this study. But two resulting phenomena, themselves poorly understood, contribute to the observed structure of the valley bottom mucks. These are ice veins and solifluction.

Ice veins are of unknown origin, though as early as 1904 Tyrrell proposed a theory for their structure which has much to recommend it. Taber (1929, 1943), relates them to the phenomenon of crystal building in the course of frost-heaving. The observable facts, both at Fairbanks (Taber 1943) and at Dawson (Tyrrell 1904, 1917) are that clear or almost clear ice is formed in all fine-grained sediments that are well supplied with ground water. The ice takes the form of vertical sheets often as much as three feet thick at Dawson and thicker at Fairbanks, which cut all the sediment beds and intersect each other to form a giant honeycomb or reticulate pattern in ground plan; there are frequently also horizontal sheets closing over the top of the honeycomb. This pattern is much better developed at Fairbanks where the sediments are uniformly fine and very deep.

At both Fairbanks and Dawson it is apparent that, at some time in the past, the ground has been thawed to a depth of about three feet below the present upper level of permafrost, for all the large ice veins end abruptly at this level and the muck shows definite signs of caving over the top of them into a cavity left by their melting. Taber (1943) noticed that, in the creeks at Fairbanks, the present surface of the sediments is an erosion surface bevelling the rough strata of the muck; yet the upper ends of the big ice veins are a constant distance from the present surface, and the ground above is refrozen except for a thin layer of annual freeze-and-thaw. He therefore reasoned that the melting back of the ice veins occurred at the same time as the erosion, at a period warmer than now between two cold periods. This period of warmth he assumes to be the Yarmouth or longest interglacial. At Dawson the writer has observed a similar erosion surface and parallel truncation of the ice-veins, but feels that neither the original veins themselves nor the period of erosion are nearly as old as Yarmouth times.

Solifluction or soil creep is the commonest process by which surface debris is transported downhill in regions of permafrost and as such has been chiefly responsible for the deposition of the muck of the valley bottoms. For this reason it should be mentioned again although already discussed amongst the evidences of Pleistocene glaciation. Taber (1943) has exhaustively discussed it and explained it as resulting from excessively high water content of frozen ground (up to 80 percent) coupled with alternation of freezing and thawing of the surface layers. The typical scroll-shaped contortions of strata caused by solifluction, enclosing irregular lumps of organic matter, can be seen everywhere in the muck, in the Klondike and at Fairbanks. Apparently all the Fairbanks muck and at least the upper Klondike muck was deposited in its present position mostly by solifluction on a far greater scale than can be seen at the present time. Solifluction scrolls are very well developed and common on the north side of Hunker Creek valley even at the foot of steep south-facing hillsides which today bear an Artemisia -- bunch grass association on warm dry rocky ground where solifluction is impossible. The process today may be commonly observed only on those steep cold north-facing hillsides bearing a stunted black spruce-moss association.

The Glacier Front.

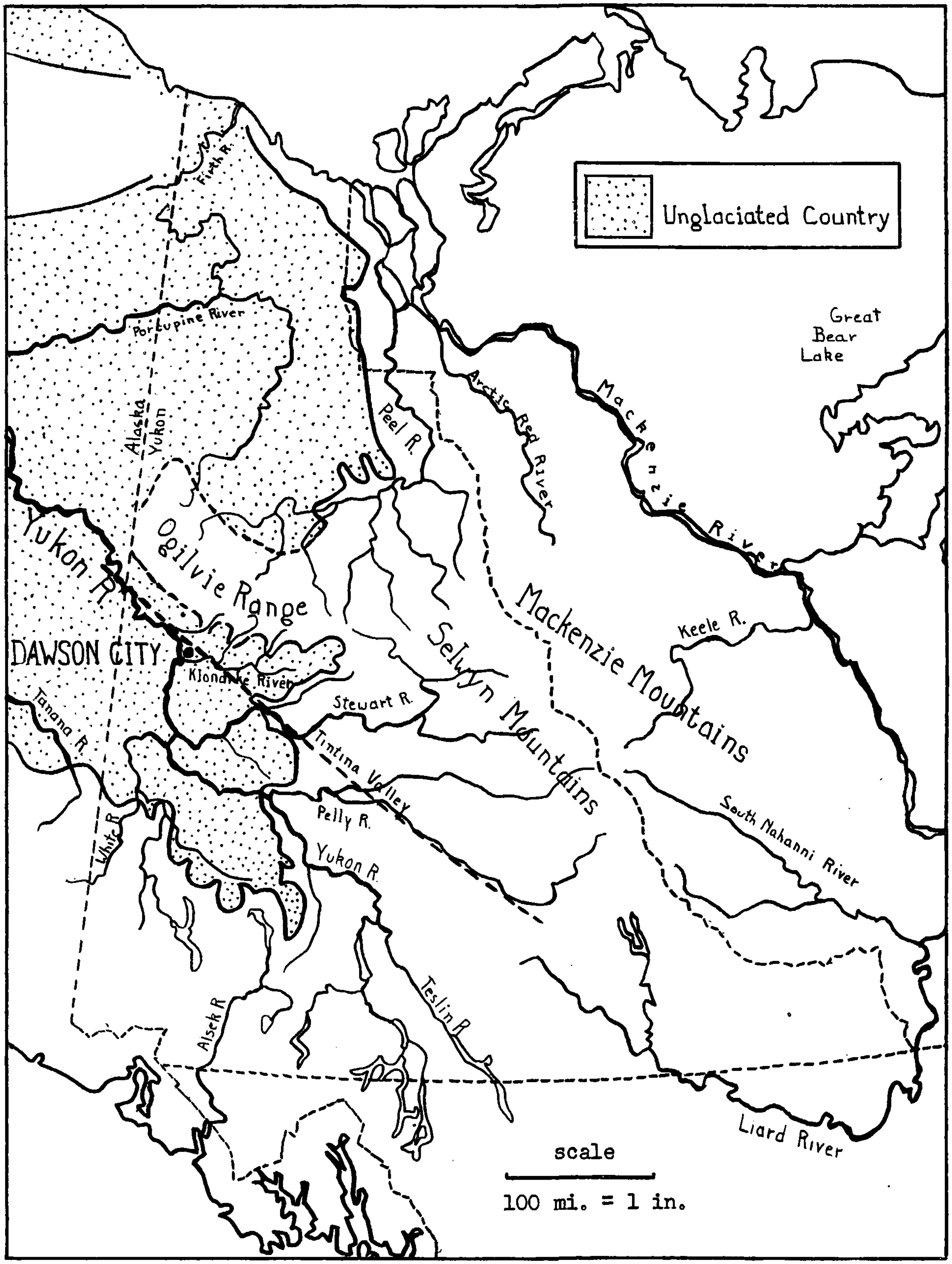
The western limit of glaciation in the Yukon is imperfectly known. Capps (1931-32) drew a map showing the limit for Alaska and Yukon and has since brought it up to date, but his details in the Yukon are vague. Flint et al (1945) published a "Glacial map of North America" showing some details in the central Yukon. Bostock (1948) in his map of the Physiography of the Canadian Cordillera, drew in the glacial limits known to him, giving us probably the most accurate picture available at the present time.

In general, there was extensive mountain and piedmont glaciation in the high ranges of Alaska and Yukon which surround the basin of the Yukon River: in the St Elias, Alaska and Aleutian Ranges in the south; in the Brooks Range on the north; and in the Mackenzie and Selwyn Mountains on the east. The ice in the Yukon, whose limit is outlined in Figure 7, pushed north in the valley of the White River from the St. Elias glaciers and westward in the valleys of the Teslin, Pelly, Stewart and Peel Rivers from the Mackenzie and Selwyn Mountains; a tongue of alpine glaciation extended westward in the Ogilvie Range north of the Klondike district.

The region west of the glacier limit and south of the Ogilvie Range corresponds to Porsild's fourth phytogeographical province (Porsild 1951).

Two different systems of ice approached the Klondike district in the last advance of the ice: alpine glaciers in the valleys of the Ogilvie Range on the north side of the Tintina Valley above Coal Creek; and a lobe of the Mackenzie-Selwyn ice-mass which pushed down the valleys of the Stewart and McQuesten Rivers and up the Tintina Valley towards Flat Creek (Bostock 1947, 1948). Little is known about the extent of the Ogilvie glaciers. Cockfield (1920) found that the North Fork Klondike River, in its course southward through the mountains, flows in a deep ice-carved valley; Bostock (1948) states that no ice extended beyond the outer boundaries of the range. But every time the glaciers melted back, great quantities of melt-water and glacial detritus must have poured out of the mountains into the lowlands of the Tintina Valley to build up the enormous irregular gravel deposits which now lie at elevations of 3000 feet or more at the head of Rock Creek.

How far the Stewart River ice lobe pushed up the Tintina Valley is unknown, but it must have radically disrupted drainage there. Between the Stewart River and the Klondike River lie the "Flat Creek beds", first described by McConnell (1905). They are over 10 miles wide and 45 miles long, and they are best exposed as an enormous bluff at the junction of Flat Creek and the Klondike River, and up both these streams for some distance. They



GLACIAL MAP of YUKON TERRITORY

(Modified from Bostock, 1948)

FIG. 7

consist of interbedded sands and gravels of which many of the pebbles come from the Ogilvie Mountains. The streams that cross them, Flat Creek, the Klondike River, and the streams from the Ogilvies, have cut deep channels into them, leaving large areas of the original flat surface as mesa tops about 600 feet above stream level, or only a little higher than the surface of the high-level "Klondike River gravels." Bostock (personal communication) feels that they, too, may be outwash from glaciers, both those in the Ogilvies and the lobe in the Stewart Valley.

The ice front from the east may possibly have been related to another large feature of the topography of the Yukon Plateau to the south of the Klondike district, the large-scale displacement of the major streams. It is possible that these diversions may have been caused by interference with the old drainage system by ice, although this seems unlikely since the deep gorges cut into hard rock by the Yukon River in its new course west of Selkirk must have required more time than the Pleistocene epoch for excavation.

In the area surrounding the Klondike district we can see many definitely glacial features; but it is by no means certain that they are all of the same age. In all glaciated regions that have been intensively studied, several major periods of ice advance have, as we have seen, been detected, with interglacial periods of sufficient length to destroy most of the ice sheets. And in the Alaska-Yukon region there is evidence that the ice advanced more than once. Capps (1931-32) described an older till overlain by a newer till at the edge of a glaciated region in the Alaska Range. Taber (1943) as we have seen deduced two glacial periods separated by an interglacial which he was bold enough to call Yarmouth in age. In the Yukon, Bostock (1936, 1947, 1948) has discovered evidences of more than one glaciation at several places. North of the McArthur Range in the Mayo area and at Dublin Gulch north of Mayo, he found deeply weathered glacial gravels as much as several miles beyond the limit of well-marked unweathered glacial deposits (Bostock, 1947, 1948). In the Carmacks area, on Victoria Creek, he found a blue tillite, with weathered cobblestones in it, underneath a placer gold deposit some distance beyond the limit of the last glaciation. At Selkirk he found volcanic rocks carried westward and uphill in an area where stream action is out of the question. Bostock adds that these are probably not contemporaneous; he believes that probably the age of the blue tillite is greater (Bostock, 1936, 1948). If this is so, he has evidence of three glaciations.

2. Methods of Investigation.

a. Field Work.

Journeys.

The writer has made three trips to the central Yukon, each of which has added its contribution to this study. The first of these trips was made in 1948 in the employ of the National Herbarium of the National Museum of Canada accompanying the Geological Survey of Canada party under Dr. H.S. Bostock on a survey of the McQuesten Map-area which lies between 63° and 64° north latitude, and between 136° and 138° west longitude. The object of the trip was to collect vascular plants and mosses for the taxonomic collection of the National Herbarium; 911 sheets were collected of which 772 were vascular plants, and all of them are now in the National Herbarium. The party of nine members outfitted at Fort Selkirk, at the junction of the Pelly and Yukon Rivers, and set out on June 15 to travel by pack train overland northward, circling the McQuesten Map-area and returning to Fort Selkirk on September 8. In the 86 days in the field, the party made 37 different camps and covered about 400 miles moving camp, not counting traverses into the mountains for survey purposes. In this time there was every opportunity to study the ecology and geomorphology of the area, across which runs the limit of the last glaciation. The farthest northwest point reached on our trip was about 50 miles east of Dawson City.

In 1950 the writer returned to the Yukon, this time going alone directly to Dawson to collect samples in the Klondike district for this study. For financial reasons a job as laborer was obtained in a gold dredge camp. The officers of the Yukon Consolidated Gold Corporation, owners of all the Klondike dredges, kindly arranged a job on the stripping gang at Hunker Creek camp where the most satisfactory exposures of muck are to be expected. Eighty-three samples of muck of various types were collected representing four vertical series; and a small collection, of 97 sheets of vascular plants, was collected to represent the modern flora. The writer remained from May 5 until September 22 at Hunker Camp except for occasional visits to Dawson, 17 miles away.

In 1951, a grant-in-aid from the Arctic Institute of North America made it possible to return again to Dawson for a further summer of collecting, again alone. This time only 6 weeks, from May 23 to July 4, were spent working at Hunker Camp, and the remaining two months, until August 28, were spent in and around the town of Dawson itself. A cabin was obtained for living and a bicycle for transportation, and trips were made to Hunker and Bonanza Creeks to study the stripping and dredging operations and also the high level bench placer cuts. A four-day excursion, July 27 to July 30, was made to an alpine mountain-top 40 miles west of Dawson on the ridge-road that leads to the mining camps on the Sixty-Mile River near the Alaska boundary for the purpose of collecting alpine plants.

The week from August 2 to August 9 was spent at Fairbanks, Alaska, meeting workers at the University of Alaska and visiting dredge camps at Gold Hill and Fairbanks Creek where the famous deep muck is exposed. This visit was made especially valuable because of the help of Dr. Ivar Skarland and Mr. Otto Geist and of others at the University of Alaska.

In late August several excursions were made to creeks of the Indian River drainage, and one to the Klondike River above Hunker Creek. During the summer, 167 samples of muck or gravel were taken representing 12 separate vertical series of which two were from Fairbanks, two from the Indian River drainage, and the rest from Hunker and Bonanza Creeks. Beside this, 158 sheets of vascular plants were collected of which approximately 67 were from timberline or above, on the Sixty-Mile road.

Vascular Collections.

The collection made in 1948 in the McQuesten Area, now in the National Herbarium at Ottawa, has been determined by Mr. A.E. Porsild, Chief Botanist of the National Museum. At this point only two tree species need be mentioned: Pinus contorta Loud. var. latifolia Engelm., the lodgepole pine, and Abies lasiocarpa (Hook.) Nutt., the alpine fir. They were noted and collected from several extremely isolated patches which undoubtedly have phytogeographic significance.

The collection made in 1950 has now been identified, except for a few specimens, by Mr. M. Raymond of the Montreal Botanical Garden. It contains no important additions to the flora, only several introduced species. The list follows.

List I

1.	Salix sp.	May 25
2.	Salix sp.	May 25
3.	Salix sp.	May 25
4.	Salix sp.	May 25
5.	Salix sp.	May 25
6.	Petasites frigidus (L.) Fries	June 6
7.	Equisetum sylvaticum L.	June 6
8.	Lupinus arcticus S. Watson	June 6
9.	Picea mariana (Mill.) B.S.P.	June 6
10.	Lycopodium complanatum L.	June 6
11.	Arctostaphylos Uva-ursi (L.) Spreng. var. coactilis Fern. & Macbr.	June 6
13.	Vaccinium uliginosum L. var. alpinum Bigel.	June 6
14.	Rubus Chamaemorus L.	June 6
15.	Vaccinium uliginosum L. var. alpinum Bigel.	June 6
17.	Vaccinium Vitis-Idaea L.	June 6
18.	Ledum palustre L.	June 6
19.	Ledum groenlandicum Oeder	June 6
20.	Arenaria lateriflora L.	June 6
21.	Mertensia sp.	June 6
22.	Arnica alpina (L.) Olin & Ladou. ssp. attenuata (Greene) Maguire	June 6
23.	Alnus crispa (Ait.) Pursh	June 6
24.	Polemonium boreale Adams	June 6
25.	Carex capillaris L var. elongata Olney	July 8

26.	Trisetum spicatum (L.) Richt. var. molle (Michx.) Beal	July 8
27.	Erigeron elatus Greene	July 8
28.	Taraxacum lacerum Greene	July 8
29.	Potentilla fructicosa L. var. grandiflora Lehm.	July 8
30.	Galium boreale	July 8
31.	Polygonum alaskanum (Small) Wight.	July 8
32.	Rumex sibiricus Hultén	July 8
33.	Descurainia sophioides (Fisch.) O.E. Schultz.	July 8
34.	Agropyron sericeum Hitchc.	July 8
35.	Hordeum jubatum L.	July 8
36.	Bromus Pumpellianus Scribn. var. arcticus (Shear) Porsild.	July 8
37.	Achillea lanulosa Nutt.	July 8
38.	Carex canescens L.	July 8
39.	Eriophorum Scheuchzeri Hoppe	July 8
40.	Juncus castaneus Smith	July 8
41.	Carex brunnescens (Pers.) Poir	July 8
42.	Hippuris vulgaris L.	July 8
43.	Arctostaphylos rubra (Rehd. & Wils.) Fern.	July 8
44.	Parnassia palustris L.	July 8
45.	Equisetum scirpoides Michx.	July 8
46.	Spiranthes Romanzoffiana Cham. & Schlecht.	July 8
47.	Andromeda polifolia L.	July 8
48.	Rubus Chamaemorus L.	July 8
49.	Epilobium angustifolium L.	July 8
51.	Epilobium adenocaulon Hausskn.	July 8
52.	Epilobium lactiflorum Hausskn.	July 8

53.	Stellaria graminea	July 8
54.	Epilobium angustifolium L. f. albiflorum	July 14
55.	Arenaria lateriflora L.	July 14
56.	Rorippa barbareaefolia (DC.) Kitagawa	July 14
57.	Carex rhynchophysa C.A. Meyer	July 14
58.	Rosa rugosa Thunb.	Aug. 18
59.	Trifolium repens	Aug. 18
60.	Solidago decumbens Greene var. oreophila (Rydb.) Fern.	Aug. 18
61.	Arnica sp.	Aug. 18
63.	Populus balsamifera	Aug. 18
64.	Rorippa barbaraeaefolia	Aug. 18
65.	Chenopodium capitatum	Aug. 18
66.	Ranunculus Cymbalaria	Aug. 18
67.	Potentilla	Aug. 18
68.	Dracocephalum parviflorum Nutt.	Aug. 18
70.	Lepidium densiflorum Schrad.	Aug. 18
71.	Saxifraga tricuspidata Rottb.	Aug. 18
72.	Stellaria sp.	Aug. 18
75.	Bromus Pumpellianus Scribn.	Aug. 18
76.	Chenopodium gigantospermum Aellen.	Aug. 18
77.	Saxifraga sp.	Aug. 18
78.	Potentilla nivea L.	Aug. 18
79.	Delphinium glaucum Watson (?)	Aug. 18
80.	Eriophorum angustifolium Honckn. var. majus Schultes	Aug. 18
81.	Ribes hudsonianum Richardson	Aug. 18

84.	Potentilla norvegica L.	Aug. 18
85.	Androsace septentrionalis L.	Aug. 18
86.	Populus tremuloides Michx.	Aug. 18
87.	Shepherdia canadensis (L.) Nutt.	Aug. 18
88.	Conioselinum chidiifolium (Turcz.) Porsild.	Aug. 18
89.	Solidago decumbens Greene var. oreophila (Rydb.) Fern.	Aug. 18
90.	Hedysarum Mackenzii Richards	Aug. 18
91.	Aster sibiricus L.	Aug. 18
92.	Rosa rugosa Thunb.	Aug. 18
93.	Boschniakia rossica (Cham. & Schecht.) Fedtsch.	Aug. 5
94.	Delphinum glaucum Watson	Sept. 6
95.	Plantago major L. var. pachyphylla Pilger	Sept. 6
96.	Polygonum buxiforme Small	Sept. 6
97.	Matricaria suaveolens (Pursh.) Buchen.	Sept. 6

The collection made in 1951 is at present in the hands of Mr. M. Raymond for identification. As yet only Gramineae, Cyperaceae and some other monocotyledons have been determined. The list of these follows.

Scheuchzeriaceae

Triglochin palustris L.

Gramineae

Agrostis scabra Willd.

Calamagrostis canadensis (Michx.) Nutt.
ssp. Langsdorffii (Link.) Hultén

C. purpurascens R. Br.

Festuca altaica Trin.

Hierochloe alpina (Sw.) R. & S.

Poa arctica R. Br. ssp. longiculmis Hulten

Cyperaceae

Carex aquatilis Wahl.

C. canescens L.

C. concinna R. Br.

C. Cyclocrapa Holm.

C. lagopina Wahl.

C. lapponica O.F. Lang

C. lugens Holm.

C. microchaeta Holm.

C. podocarpa R. Br.

Eleocharis palustris (L.) R. & S.

Eriophorum brachyantherum Trautv. & Meyer.

E. Scheuchzeri Hoppe

E. vaginatum L.

Juncaceae

Juncus arcticus Willd. ssp. alaskanus Hultén

J. castaneus J. Sm.

Luzula confusa Lindeb.

L. parviflora (Ehrh.) Desv.

Muck Collection.

The frozen condition of the superficial deposits of the Klondike and their stony nature as well make it impossible to collect samples for microfossil work by conventional methods of boring; but on the other hand the many monitor cuts, old and new, in the district largely overcome this difficulty and add the advantage of occasionally exposing large sections of the deposits for stratigraphic study. Of course, the placer cuts expose only those deposits interesting to the miners; and often the monitors in the haste necessary to keep up production, destroy stratigraphic relationships or contaminate various layers with fossils from others. The White Channel deposits which are dry gravel with a compact matrix, stand in vertical cliffs and preserve their stratigraphy long after the mining operation has ceased. The Jackson's Gulch cut at the mouth of Bananza Creek has vertical cliffs about 250 feet high with surprisingly little talus at the foot although there has been no mining there for over 20 years. On the other hand, the valley bottom mucks, which have a high water content, slump and cave badly as soon as the cut-face thaws out. One must collect these as soon as the stripping monitor has stopped working over the particular face; and one must make sure to collect only frozen muck to avoid contamination since the great force of the monitor stream, which can lift a car off the road at a distance of 50 feet, frequently implants bits of wood and muck high above their correct level.

At present the only way to collect material from below the grade level is to take it from the dredge buckets as they bring it up. The dredge swings from one side to the other, digging a sweep about 200 feet long at one depth, then lowering the bucket-line to dig back again at the next depth. It repeats this swinging and lowering until it has dug 2 or 3 sweeps in bedrock when it raises the bucket-line to the top of the pond, moves forward, and begins again. Thus the depth from which material is coming at any time should be known; but the caving of ground above the bucket-line and the churning of the buckets most surely contaminates all the samples. Two vertical series were collected from the Hunker dredge bucket-line one in 1950, the other in 1951, but except for general information on the character of the lower muck and of the "rotten" bedrock, they are not to be relied on.

Following is a description of the series of muck samples collected.

Hunker Stripping Operations -- 4 series: A and D, 1950; F and M, 1951.

-- A, D and F are from cut-faces on the north east side of the creek about ½ mile above the mouth of Last Chance Creek, where the muck is 20 to 45 feet deep above grade level.

-- The surface of the muck slopes to the south west side of the creek where it is little if at all above grade level. M. collection came from this side 2 miles upstream.

-- On the north east side, 9 layers were distinguished and traced along the stream for about ½ mile. They appear to persist across the valley as well, though the stripping operations make tracing in that direction quite difficult.

-- Opposite the little side streams ("pups") the lower levels consist mostly of sharp gravel ("slide rock") with much cut-and-fill cross-bedding. The deposits here are thickest and most frequently contain the bones of extinct mammals.

-- Between the "pups" or opposite the steep south-facing hillsides, all the deposits are fine-grained, with much evidence of solifluction and a large number of ice veins.

-- The age of the uppermost layers is, of course, unknown, since the present surface was probably formed by erosion.

-- I have numbered the layers at Hunker as follows:

1. Uppermost, 3-5 feet thick, very fine-grained with considerable organic content, deeply weathered and humified, solifluction

absent, caved over top of the large ice-veins which never penetrate up to this layer, frozen to within 1-2 feet of surface, but contains only thin little lenses of ice.

2. Organic layer, 6 in.-1 ft. thick, contains much humified wood and sedge peat, tree stumps up to 8 inches diameter. In the section studied, this forms the upper limit of the ice veins presumably because of its insulating effect.

3. silt, 3-5 feet thick, never contains gravel, often contains rootlets and occasional lenses of organic material, shows a little evidence of solifluction.

4. Organic layer, 6 in.- 2 ft. thick, in some places composed of stream-laid wood chips, in others of tree stumps in position of growth with moss and sedges as forest floor. Most of tree stumps about 6 inches diameter, though many up to 14 inches diameter. Material, little humified, in excellent state of preservation.

5. Mineral layer, 3-4 feet thick, in some places fine, in others containing coarse lenses, occasional organic material especially rootlets, quite a bit of evidence of solifluction.

6. Organic layer, 6 in.-2 ft. thick, very much like layer 4, in one place contained a thick pond deposit of calcareous silt containing well preserved aquatic moss remains.

7. Mineral layer, 4-6 feet thick, fine or coarse; very much solifluction if fine; very much cross-bedding if coarse; very little organic material.

8. Organic layer, 1-6 inches thick, very thin and sometimes interrupted by cut-and-fill of no. 7 layer, no tree wood, only shrubs often in place of growth.

9. Mineral layer, depth unknown, no organic material, almost entirely coarse sharp gravel showing cut-and-fill cross bedding and quite a bit of solifluction.

M series is from a cut-bank on the south west side of the valley, about 8 feet high. Its layers are mostly highly weathered peat poorly defined; probably they don't correlate with those just described.

Hunker Dredge -- 2 series: B, 1950; L, 1951.

B -- consists of 21 samples taken at 6 inch - 2 foot intervals between grade and bedrock which here was 21 feet deep. All are sandy or gravelly; many contain wood fragments which may come from old underground mines of the gold rush days.

L -- consists of 20 samples, 10 pairs, taken at 6 inch - 2 foot intervals between grade and bedrock which here was 15 feet deep. Very similar to B; much wood, also probably contaminant.

Independence Peat Bed -- one series: C, 1950 -- added 3 duplicate samples 1951.

On the south west side of Hunker Creek about 3 miles upstream from the place of collection of A, D and F, at the mouth of Independence Creek, is a bed of Sphagnum peat about 16 feet thick and ¼ mile long. The area was stripped in 1938 and dredged soon after so that the bed is represented by a vertical bank of solid frozen unhumified peat against the side of the valley; how far it extended out into the valley is unknown. Mr. Harry Pogson, stripping Foreman at Hunker Camp, who first drew the writer's attention to the bed, said that there was ordinary muck under about 15 feet of peat. At one place the writer was able to get down to a depth of 17 feet, through the "talus" of peat chunks slumped against the base of the bank, and discover coarse sharp gravel and a thin layer of moderately humified non-sphagnum peat under 16 feet of the unhumified sphagnum peat. The bed is faintly stratified and quite flat-lying, but there is no variation in the peat and therefore apparently no real subdivision. This proved to be the best series collected for pollen analysis; it is the only series that is continuous to the present time for its top was apparently still actively growing up to the time stripping dried it up in 1938. It was a bed of sphagnum growing above water-level using the moisture draining off the hillside.

-- 17 samples were taken at intervals of 1 foot from top to bottom. All were fresh unhumified brown sphagnum peat with very occasional roots of trees or ericaceous shrubs, except the 17th or bottom sample which consisted of coarse sharp gravel and some moderately humified and compressed black peat very much like organic layers in the stripping cut bank. There appears to be a sharp change here.

High Benches -- 2 series: E and K, 1951.

-- from monitor cuts in the benches above the streams .

E series -- from Jackson's Gulch cut which is on the north side of Lovett Hill facing the Klondike River valley. At the time of White Channel deposition, Bonanza Creek flowed straight north west into the Klondike stream, but when the new valleys were dug, Bonanza veered about ½ mile to the west before flowing northward to join the river, thus leaving a tongue at high bench level bearing White Channel and Klondike River gravels. This tongue is called Lovett Hill; here the high level gravels reach their maximum development.

-- Bedrock floor about 300 feet above river level, weathered 15-20 feet deep.

-- White Channel gravel approximately 120 feet deep, quite white, completely inorganic except for a few very small lenses of carbonized wood fragments, one of which was found to contain good pollen grains!

-- Klondike River gravels overlie the White Channel to a depth of 125 feet making the cut about 250 feet above bed rock level. Klondike gravels completely inorganic.

-- Collected 11 samples in the White Channel and 6 in the Klondike; at intervals of 5-20 feet.

K series -- from the placer cut operated by Mr. J. Bremner on Preido Hill which is a tongue of bench land at the confluence of Hunker Creek and its tributary Last Chance Creek about 2 miles above the mouth of Hunker Creek.

-- Bedrock floor about 250 feet above stream level, weathered 10-15 feet deep.

-- White Channel gravels approximately 60 feet thick, white or reddish, completely inorganic as far as could be seen.

-- Klondike River gravels absent.

-- Collected 11 samples at about 5 foot intervals.

Low Bench — 1 series: P, 1951.

— from bulldozer cut on low bench on north east side of Hunker Creek 1 mile above its mouth.

— Claim owned now by Mr. J. Bratsberg (formerly by Murdock).

— Bench at least 400 feet long parallel to the creek and at least 200 feet wide.

— Bedrock floor is flat, about 5 feet above stream level where stream is on top of muck estimated at 20 feet thick.

— Bedrock weathered at least 2 feet deep, probably a little more.

— Gravel on top of bedrock is rounded and slightly weathered to a reddish color, and contains many thin stringers and lenses of very highly humified reddish peat. The present surface of the gravel is an erosion surface, bevelled to a 30° slope; the gravel is at least 35 feet thick, and must be thicker back in the hill.

— Collected 15 samples, mostly from the peat lenses and stringers, at intervals of 6 inches - 5 feet.

Indian River — 2 series: J, lower Sulphur Creek stripping, 1951.
N, Dominion Creek stripping, 1951.

— The muck beds seem to be 30-50 feet thick on Sulphur Creek but very thin on Dominion Creek. They consist mostly of fine silt which shows evidence of solifluction. Three prominent persistent organic layers showing signs of stream deposition were seen at Sulphur Creek, but at Dominion Creek there were several thin, discontinuous organic layers, mostly contorted by solifluction. The collections made in these creeks are not considered reliable as their stratigraphic positions are unknown.

J -- lower Sulphur Creek stripping operation; north east side of valley.

-- collected 7 samples at about 3 foot intervals, 3 of the samples from the prominent organic layers.

N -- Dominion Creek stripping operation, south west side of valley.

-- collected 10 samples at intervals of 10 inches - 3 feet. Most of the samples were of highly humified peat

Fairbanks, Alaska -- 2 series: G, Gold Hill on Ester Creek, stripping operation.

H, Fairbanks Creek, stripping operation.

-- In the creeks of the Fairbanks district, the "muck" is exceptionally thick.

H -- at Fairbanks Creek, where the muck is 50-60 feet deep above grade, there is some gravel in the lower layers, but most of the exposed muck is very fine mineral material with many beds of organic material whose state of preservation varies from poor to excellent; some leaves of sedge were seen that appeared to retain their green color (see item below on "State of Preservation"). The whole is exceptionally contorted by solifluction scrolls so that stratigraphic correlation is pretty much impossible.

-- Here 23 samples were taken.

G -- at Gold Hill on Ester Creek, the "muck" is about 120 feet deep above grade and consists entirely of very fine mineral material. Here can be seen a fine example of Tuck's (1940) distinction between "muck" and "silt." The silt is brownish, unstratified, unfrozen and almost completely devoid of organic remains; it could easily be a massive loess deposit as Tuck claims. It is bevelled at an angle of about 20 degrees and against the lower side of this slope lies the "muck", obviously the product of large-scale solifluction, probably from the silt itself. The muck is black and evil-smelling (as is also the muck of the Klondike) and has a high organic content, both plant and animal; its organic layers are highly contorted and it contains many very large ice veins. -- Here 12 samples were taken.

The samples taken from these 14 series were mostly about 25 to 200 cc. in volume. All were satisfactorily preserved by wrapping in paper and drying near a stove.

b. Laboratory Work.

The samples were all shipped from Dawson to the Department of Botany at McGill University where examination was carried out.

Macrofossils were sifted from some samples using a graduated series of screens. Thus were obtained scraps of birch bark (species unidentified), seeds and leaves of Carex (species unidentified), and joints of Equisetum stem (also species unidentified).

Fragments of wood picked from the samples were identified from sections cut on a sliding microtome. Sturdy pieces were boiled in 50% glycerine and sectioned immediately, and the sections were mounted in balsam without staining as the wood was invariably a good brown color from the "humates" present. Fragile pieces of wood were placed dry into a 50% mixture of alcohol and ether and pumped for 15 minutes, then embedded quickly in celloidin; to cut sections of these, the surface of the last cut was painted evenly before each cut with 10% celloidin which was hardened with chloroform. In this way sections were obtained even from very poor material.

Most wood identification was done using keys and descriptions by Brown and Panshin (1940); occasionally keys by Record (1934) or Penhallow (1907) were used. Wood of shrubs was identified entirely by comparison with type slides made from living material collected in the Yukon.

Mosses in all the samples from Independence Peat bed and in the sample from the pond deposit in number 6 layer of the Hunker stripping cut were identified by Mr. J. Kucyniak of the Montreal Botanical Garden, reference being made to standard works by A.leR. Andrews (1913), Fry (1937) and Wynne (1944).

c. Pollen Analysis.

Several methods were tried for preparing material for pollen analysis. The method of von Post, of simply boiling a pinch of peat in a drop of NaOH solution, was inadequate in all samples tried because of the very low number of pollen grains present. The mechanical dispersion method of McCulloch (1939) also proved inadequate partly for the same reason, partly because it did not sufficiently separate pollen grains from moss leaves and other debris, for examination. The chlorination-acetolysis method of Erdtman (1936, 1943), however, gave success even in difficult samples. One final sample was also treated according to the KOH-acetolysis method of Faegri and Iverson (1950) with success. The writer feels he will in future experiment with this method as it appears to be less harsh on the pollen grains.

The Erdtman method appears a little complicated in the directions, but when reduced to a routine, is found to be quite easy to carry out. As many samples may be treated simultaneously as the available centrifuge has tube-holders. The writer carried out all operations, except the initial sifting with a 200-mesh screen, in ordinary scft glass round-bottom test tubes which can be used in a centrifuge with safety if water is placed in the tube-holder of the machine to support the tube evenly. The schedule outlined by Erdtman (1943) was followed exactly.

To study a sample with a high mineral content, the method of Assarson and Granlund (1924) could not be used as the ventilation system in the building is not meant to handle the corrosive vapours produced. But the method used by Radforth's laboratory at McMaster University (personal communication), of soaking the sample overnight in cold 30% hydrcfluoric acid in waxed bottles, proved quite satisfactory.

Mounting at first was done with uncolored glycerine-gelatine and a cover-glass ringed with Canada balsam, but slides made this way are difficult to store, impermanent and much too small. Therefore another technique from Radforth's McMaster laboratory (unpublished) was adopted, with only slight modification. A mounting medium was made up approximately of:

50 cc.	commercial Corn Syrup	
50 cc.	water	
10 cc.	glycerine	(to prevent cracking)
2 gm.	phenol crystals	(to prevent spoilage)
2 gm.	commercial detergent, "Dreft"	(to allow even spreading)

The residue produced by the Erdtman method was re-suspended in its own volume of water and thoroughly mixed. A drop of this re-suspension was placed on a clean glass slide with 2-4 drops of the mounting medium; the whole was then stirred thoroughly with a glass needle and spread out evenly over an area of 6-8 sq. cm. This film was allowed to dry for 2-4 hours in a flat position away from possible contamination. The resulting film is quite hard and glassy and the slide may be stored an an ordinary vertical-type slide box. There is little distortion from surface irregularities except immediately beside a large particle which, of course, should have been removed anyway; oil immersion may be used provided the oil is immiscible in water. And pollen grains may be rolled over for closer examination by placing a tiny drop of water on top of them with a steel pen and then stirring the dissolved patch of medium with a needle; the medium dries again in a few minutes into a ruffled area which may be smoothed out quickly by breathing vigorously on the slide.

Examination was made with a binocular microscope using a mechanical stage and high power (660X); occasionally oil immersion was used for critical examination. The slide was traversed from one side to the other and all the grains that came into the field of vision were tabulated until the total of all the grains of the tree-genera, spruce, pine, balsam, willow, birch and alder, (i.e. the A.P. count) was 50; then a duplicate slide was examined in the same manner until an A.P. count of 50 was recorded. In critical samples, a total of 150 tree-genus grains were recorded. Since the N.A.P. count seldom exceeded 10% of the A.P. count, and since the number of tree-genera is very small, this method seems adequate. (Erdtman in Wodehouse, 1935).

In identifying grains the keys and illustrations of Sears (1930), Wodehouse (1935), and Erdtman (1943) were used to a certain extent. Separation of species of Betula and Picea by size differences using the method of Cain (1940), though attempted, was discontinued because of insufficient data on the species involved.

Mostly, identification was based on a series of pollen "type slides" made from specimens in the herbarium of McGill University. Most of these were made by the method of Wodehouse (1935) mounting the grains in glycerine-gelatine that had a weak concentration of basic fuchsin to stain the exine. But one slide was made by staining the grains in a weak aqueous solution of basic fuchsin and mounting in Radforth's medium, with more permanent results.

Using the type slides, the illustrations, Figures 8 and 9, were drawn, and the following key to the characters of pollen grains found in the Klondike deposits was constructed. The identification of grains as reported in this study followed this key very closely.

The key is entirely dichotomous; the numbers in brackets are back-references.

Key to Pollen of some Important Genera of the Yukon

1 a - Spores -- Monolete or trilete — Bryophyta and Pteridophyta

b - Pollen Grains -- colpate, pored or psilate — 2

2(1) a - Grains united in tetrads, usually tetrahedral Ericaceae and Empetraceae (reported as "Tetrads")

b - Grains single — 3

3(2) a - Air bladders present — 4

b - Air bladders absent — 6

4(3) a - Bladders usually less than hemispherical, definitely wider (parallel to the furrow) than long, and almost crescentic in dorsal view, as wide as the body and appearing to clasp it. Cap poorly defined; boundaries between cap and bladders seldom marked by a re-entrant angle. — Picea

b - Bladders hemispherical or more, little wider than long, always round or oval in dorsal view. Cap well defined;

boundaries between cap and bladder marked by a re-entrant angle. 5

5(4) a - Length less than 85 mu.; cap thin <u>Pinus</u>

b - Length greater than 85 mu.; cap noticeably thick and sculptured <u>Abies</u>

6(3) a - No apparent perforate pores or furrows 7

b - Pores or furrows distinctly present 9

7(6) a - Exine scurfy, very thin; grain spherical, about 30 mu. diameter (report only if intact). <u>Populus</u>

b - Exine psilate or extremely finely reticulate; grain crumpled, obscuring pore 8

8(7) a - Exine psilate, seldom torn; grain crumpled from a spheroidal shape <u>Gramineae</u>

b - Exine finely reticulate, often torn; grain crumpled from a sub-prismatic shape <u>Cyperaceae</u>

9(6) a - Pore single and distinct; furrows absent 10

b - Pores or furrows more than one, distinct or indistinct 11

10(9) a - Exine psilate; pore small and circular with distinct margin <u>Gramineae</u>

b - Exine granular; pore very small and rounded with distinct, crenate margin <u>Sparganium</u>

11(9) a - Pores scattered, indefinite in number, mostly more than 5; furrows absent 12

b - Pores equatorial 3 or 5; furrows absent or present 14

12(11) a - Pores circular, with distinct margins; exine heavy and granular <u>Caryophyllaceae</u>

b - Pores irregular in shape, margins often ragged; exine very finely reticulate 13

13(12) a - Grains roughly tetrahedral, sub-prismatic to sub-globular; pores extremely indistinct, one always apical, about 3 others lateral <u>Cyperaceae</u>

b - Grains globular or sub-globular; pores 4-10 (often 5) in number, distinct but with irregular margins <u>Plantago</u>

14(11) a - Furrows absent; pores 3, 4 or 5; pore margins very definitely thickened ("aspidate"). 15

b - Furrows present, 3 in number; if pores present, their margins not thickened 17

15(14) a - Pores 4 or 5; "<u>Arci</u>" noticeably present <u>Alnus</u>

b - Pores 3; "<u>Arci</u>" not noticeably present 16

16(15) a - Grains 20-35 mu. diameter <u>Betula</u>

b - Grains 60-80 mu. diameter <u>Epilobium</u>

17(14) a - Exine reticulate, reticulations finer at poles than at equator; edges of furrows appearing indistinct or roughened; furrows extending nearly to poles; pores absent; grain sub-orbicular to ellipsoidal. <u>Salix</u>

b - Exine spiny or granular; edges of furrows distinct; pores present inside furrows 18

18(17) a - Exine spiny 19

b - Exine granular 20

19(18) a - Spines large, regularly placed, triangular, often obscuring the furrows <u>Entomophilous Compositae</u>

b - Spines small, irregular in number, rod-like, blunt; furrows distinct; grain 35 mu. diameter, orbicular <u>Rubus Chamaemorus</u>

20(18) a - Grain deltoid in polar view; exine thin; furrows at apices of delta <u>Cornus</u>

b - Grain quite orbicular; about 20 mu. diameter; exine thick, curving into furrows <u>Artemisia</u>

d. Carbon-14

In 1951, two samples were collected from Hunker Creek and sent to the Yale University Geochronology Laboratory, New Haven, Connecticut, for age determination by the Carbon-14 method. One is about 100 gm. dry weight, of <u>Sphagnum</u> peat from the 16-foot layer of the Independence Peat bed; its age would, of course, tell at what time the bed began to grow, and, as will be discussed below, possibly at what time the muck deposits were bevelled. The other consists of two chunks of trunk-wood, totalling about 100 gr. dry weight, from a stump, identified as <u>Populus</u> standing in position of growth in the number 6 layer of the Hunker stripping cut near the place where series <u>A</u>, <u>D</u> and <u>F</u> were collected; since it was below the level of truncation of the ice veins, its age might tell whether

POLLEN GRAINS 1

Pteridophyta

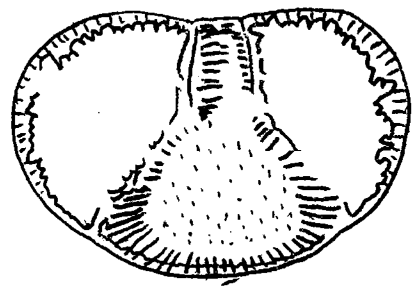
Lycopodium dendroideum — a.

Gymnosperms

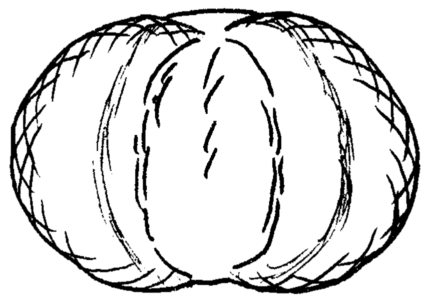
Picea mariana

length = 102 mu.

lateral b.



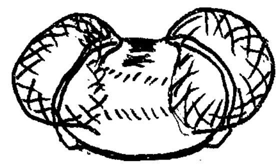
dorsal c.



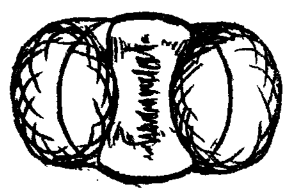
Pinus contorta

length = 66 mu.

lateral d.



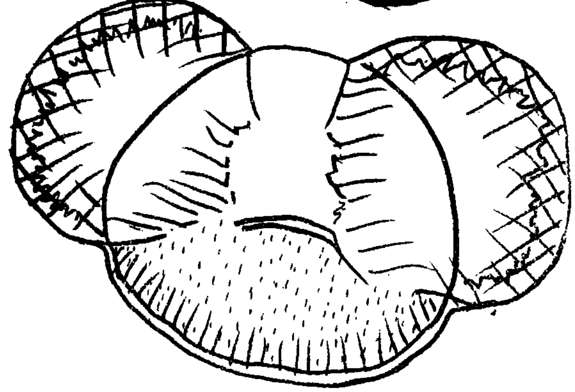
dorsal e.



Abies balsamea

length = 148 mu.

f.



Scale

1 in. = 50 mu.

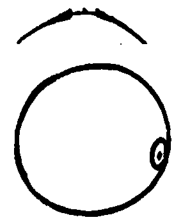
Figure 8.

POLLEN GRAINS 2

Angiosperms

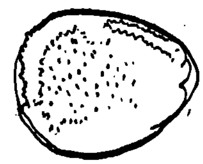
Festuca rubra — a.

diameter 40 mu.



Carex plantaginea — b.

length 50 mu.

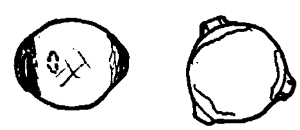


Salix lucida — c.

23 x 21 mu.

Betula papyrifera — d.

diameter 28 mu.



Alnus incana — e.

diameter 25 mu.

Plantago major — f.

diameter 23 mu.

Artemisia dracunculoides — g.

diameter 18 mu.

Scale

1 in. = 50 mu.

Figure 9.

or not Taber (1943) is correct in concluding that the truncation occurred in the Yarmouth Interglacial. **The samples are not yet determined.**

3. Discussion — The Results of Investigations

a. Geological and Geomorphological Observations

Klondike Valley.

The most prominent feature of the Klondike district is the great valley of the lower reaches of the Klondike River itself. Yet this valley is only about 12 miles long from the narrow gorge where the river breaks out of the Tintina Valley to the equally narrow gap in the bench at Dawson at the river's mouth. In that 12 miles, however, the valley is a magnificent trench a mile or more wide with walls that rise clearly to the hilltops 2000 feet above it. Where Hunker, Bear and Bonanza Creeks join the valley on the south side there are benches bearing White Channel gravels and the "Klondike River" gravels; but on the north side, except where the river in its turn joins the Yukon, there are practically no benches at all. The present form of the valley is almost entirely the work of a single cycle of erosion. This is not to say that the valley has been dug in a single stage, but that the most recent stage has so worked over all the exposed surfaces, especially its floor and its north wall, that most of the evidences of previous cycles have been obliterated. Clearly a stream much larger than the present Klondike River must have done it.

The Klondike Valley is, at the present time, floored with a deposit of gravel essentially similar to the "Klondike River" gravels of the bench tops: it consists of rounded unweathered cobblestones derived mostly from the Ogilvie Range (McConnell 1905). It is not overlain by muck so far as the writer was able to ascertain except such thin deposits as could be explained by the natural growth of recent local peat-bogs. The gravel varies in thickness but apparently the 3 large dredges which were constructed to dig there (one still remains; it has been going steadily since 1912) have never had to dig deeper than 50 or 60 feet, and usually only dig about 25 feet for the gold.

Such a depth of gravel in such a stream does not require aggradation as an explanation. The Yukon River at Dawson, which flows in a valley no larger than that of the Klondike, is known to be cutting its bottom to a depth of 50 feet or more below water-level, and filling it in afterward, and Bostock (personal communication) thinks it may be cutting to a depth exceeding 100 feet in the canyon region below Fort Selkirk. The flood pools of a small creek can be observed to be as much as one-third as deep as wide, and they are constantly migrating downstream by cutting at their lower limit and filling at their upper. Thus it is not inconceivable that a stream probably not much less than half the size of the Yukon could have cut the present broad valley without a lower base-level of erosion than exists at the present time.

High Benches

The White Channel gravels, as pointed out, consist of the residue from long ages of chemical weathering; they consist mostly of milky white vein-quartz such as can be seen intruded into any of the older rocks of the district. As they stand, they vary considerably in depth: on Nugget and Paradise Hills on Hunker Creek about four miles up from its mouth, the gravels are 30-40 feet thick, while on Lovett Hill at the mouth of Bonanza Creek they are about 120 feet thick. However, where the White Channel gravels are not capped by "Klondike River" gravels, erosion has very likely reduced the depth considerably.

If we assume a 100 foot depth for the Hunker Creek bench at Preido Hill, we find that the volume of the White Channel gravels would have been, before erosion, 1% - 2% of the volume of the broad valley. Not much of the vein quartz in the rocks eroded away to make the broad valley can have escaped down the river; it is almost all lying in the White Channel beds. This suggests that the broad valley was eroded completely by chemical weathering, and the products of erosion were removed entirely in solution for if any of them had been removed mechanically, far more of the vein quartz would have been lost.

On the other hand, the bedrock under the White Channel beds is weathered very deeply — on Lovett Hill to depths of 15-20 feet. In the walls of the placer drains cut into this bedrock, quartz veins can be seen as a loose chain of cobbles and pebbles standing in place in a matrix of soft, powdery reddish or yellowish earth almost like a laterite soil. It seems highly improbable that such deep oxidative weathering could have occurred while the bedrock was covered with 100 or 120 feet of very compact White Channel gravel. The present bedrock floor must have lain exposed to the atmosphere for a long period of time before the gravels were deposited in their present position.

Thus erosion down to the present valley floor must have been of such a nature that it never covered the bedrock and that it removed the surplus entirely in solution. This could happen only in a watershed with a very low grade and in a warm, humid climate; the bedrock over the whole valley surface would be converted to a laterite soil, such as occurs now in the south-eastern United States, with the quartz veins still standing in it; gradual seepage of water would serve to slowly remove the laterites leaving the quartz as a residual surface deposit which the grade would be insufficient to move to the creek in the centre of the valley.

Deposition of the White Channel beds as we see them would come not with a raised base-level and interrupted transportation, but with a very slightly lowered base-level -- enough to remove the laterites mechanically from the valley slopes and take them down the rivers and so free the quartz cobbles, but not enough to move the quartz beyond the stream bed where it would be slowly deposited as McConnell (1907) described.

The "Klondike River" gravels, which are as much as 100 feet thick on top of the White Channel gravels, represent a sort of catastrophe that burst over the sluggish valley of White Channel times. McConnell (1907) supposed that these gravels represent a depression of the land when the Klondike River broke into its present valley. Certainly they are composed of well-rounded, unweathered boulders of rock types foreign to the district. And they were laid down by a violent, aggrading stream.

Out in the Tintina Valley from which the Klondike River broke at the time of the "River" gravels, are those remarkable series of gravel deposits, the Flat Creek beds, described earlier, which are quite flat-topped and rise to roughly the height of the barrier which the Klondike River had to breach in order to enter its new course; and they are very little higher than the "Klondike River" gravels of the benches.

It seems likely that the Flat Creek beds are related to the "Klondike River" gravels and to the breaking out of the Klondike from the Tintina Valley. And it also seems likely that all these facts are related to the beginnings of the Pleistocene ice age; for all the gravels and sands involved show no evidence of chemical weathering, but only of violent abrasion and transportation such as they would get in a pro-glacial stream. Such a stream would, in the waning phase of a glaciation, be far larger than the normal precipitation of an area would warrant. A later glacial stage than the one that presumably deposited the "River" gravels can account for the increased size of the Klondike River necessary to carve the great valley of the present.

Low Benches.

The writer has had opportunity to examine four low benches: the bench from which was collected series "P", one mile above the mouth of Hunker Creek; two benches one mile farther upstream on the south west side of Hunker Creek at the mouth of "Eighty Pup"; and a bench three miles farther still upstream on the south west side of Hunker Creek at the mouth of Independence Creek. The first bench, Bratsberg's claim, stands five feet above the present creek level, or about 25 feet above the bedrock floor of the creek; the second bench stands at creek level perhaps 15 feet above the bedrock floor and was covered with valley bottom muck until exposed by stripping operations; the third bench stands directly above the second about 50 feet above creek level; while the fourth bench, which has been worked over completely by an individual miner, stands about 25 feet above the "grade" level.

Three characteristics of these low benches stand out, beside their invariably small size: their bedrock floor is weathered to a black sticky mass much like the "rotten" bedrock of the valley bottom; they are covered with gravel deposits much eroded away and moderately weathered, but essentially similar to the gravelly lower levels of the valley bottom deposits (McConnell reported they occasionally had a "muck" layer on top of their gravel); and their levels cannot be correlated.

That they are former levels of the Creek bottom was early recognized (McConnell 1903, 1905, 1906); but they have always been presumed to be meander terraces or slip-off terraces formed in the course of a constant downward cutting of the valley. The fact that no level-series of benches, marking pauses in downcutting, have ever been recognized argues against such pauses having ever occurred.

But here as in the high benches we find deep gravel deposits, far deeper than Hunker Creek could lay down unless aggrading, themselves only lightly weathered, overlying strongly weathered bedrock. The bedrock must have been exposed at some time and the creek must have aggraded afterwards.

The absence of correlation of these benches into recognizable level-series can be explained partly as a result of the quite small number of them available for study. But the absence of correlation is even more understandable when we realize that the creek would undoubtedly form many meander or slip-off terraces and that these, if low enough could easily be covered over with muck and gravel the next time the stream aggraded; for we have seen that the present muck in Hunker Creek reaches 65 feet in depth in many places. When the next cycle of downcutting occurred, it would destroy most of the valley bottom but would leave many of the existing low benches so that today we probably see an over-representation of meander terraces.

The process in its simplest form can be represented by the following series of diagrams.

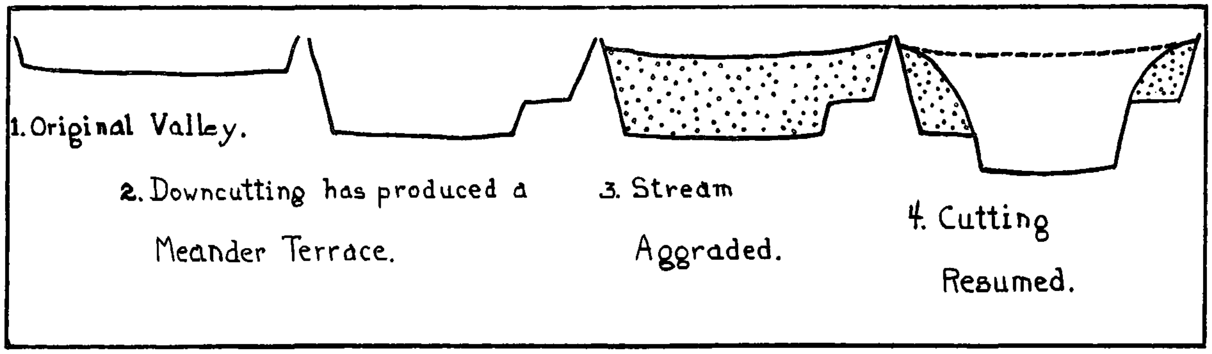


Figure 10.

And by the combination of several cycles and several processes, a truly bewildering maze of terraces could be produced.

Valley Bottom Muck.

The mucks of the valley bottoms of Hunker and Bonanza Creeks are (or were before the miners got at them) the most nearly complete of the deposits of those watersheds. Unlike the valley bottom deposits of the present Klondike River, they consist entirely of native material, unweathered and sharp. Like the other gravels they rest on quite deeply weathered bedrock, although they themselves, except for a thin layer of their present surface, are completely unweathered. As with the other deposits, this fact must mean that the valley bottom bedrock was exposed to atmospheric oxidation for a considerable period of time. The great depth of the mucks lend weight to this evidence; they could not have gotten there while the creek was excavating the valley, they must have been deposited during a period of aggradation afterwards.

As McConnell (1905), Tyrell (1912) and the miners have noticed, the mucks change character from bottom to top. On bedrock they are coarse and sharp, and, at "grade" level at least, they are cross-bedded as if deposited by rapid stream flow. However there is always a matrix of silty material which should be removed by rapid water. The writer has never studied deposits known to be laid down by the solifluction movement of coarse particles called "rock streams" and "rock stripes" described by Washburn (1950) but it is possible that such movements can produce patterns similar to stream cross-bedding. At any rate, the time of deposition of the lower levels must have been one of violent mechanical action to chip the bedrock and dump it in large quantities. Possibly it was a time of frequent freezing and thawing such as Taber (1943) visualized for maximum rock waste movement in northern countries.

Later the processes of deposition appear to have become milder, for the average size of particle decreases considerably at about the "grade" level. Still there is no clay in the deposits, only the silt fraction becomes more prominent, and in the beds of pure silt, typical solifluction scrolls appear.

Above this there is no coarse material at all, only fine silt, horizontally bedded or somewhat contorted by mild solifluction, and containing a large amount of organic material. In these upper levels there are several prominent organic layers which contain good-sized stumps of trees in positions of growth. Judging by their development and their continuity, they appear to represent times when the climate was suitable for a good forest growth, when deposition was temporarily suspended. They must have lasted for considerable periods of time, for in one place the writer found two spruce stumps, each about 18 inches in diameter, one growing on top of the other's roots so that it must have grown after the other had died. Still these forests probably grew in a climate as dry as that of today, for they show very frequent, definite evidence of forest fires.

The silt that is found in the lowermost layers, and makes up the bulk of the upper layers, is of quite uniform size. There is little size-intergradation with the chips and blocks that make up the gravelly beds. It is never as small as clay particles and never as coarse as sand. It consists of tiny, sharp unweathered fragments; in every way it answers to the description of a loess. Apparently it was deposited at a roughly constant rate through all the muck accumulation period, but with the slowing of the violent mechanical deposition of the early stages, it came to make up more and more of the inorganic part of the deposits. In this connection Black (1951) has shown that Aeolian deposits, mostly Pleistocene, are far more widespread in Alaska than was hitherto believed.

The muck, then, is a record of a period probably beginning with a time of violent frost action and continuing into a time of climate sufficiently milder for forest dominance and cessation of rock-chipping. Yet all this time the loess kept blowing in from some fairly close source of supply which would probably be a glacial outwash fan. It need not be blown directly to the creek-bottom; it could be washed off the hillsides in springtime by the multitude of little melt-water rills that percolate over the moss; therefore the loess need not be very plentiful.

It seems likely that the valley bottom deposits record a single glacial period from its onset to its waning stages. The loess would be derived from outwash fans in the Ogilvie Range or the Stewart River Valley not more than 60 miles away; the coarse "gravel" on the bedrock records the cold onset stages, and the silty and organic upper layers record the waning with warmer intervals of forest growth interrupted by cooler intervals of resumed solifluction.

The present surface of the valley, however, probably does not represent the present time. The large ice veins which penetrate up through the silt and forest layers have been distinctly melted back by a warm interval exactly as described by Taber (1943) for the Fairbanks district. The surface bevelling described by Taber is, however, a little harder to demonstrate at Dawson than at Fairbanks because of the methods used in the stripping operations.

The surface of the muck at Hunker Creek slopes strongly everywhere from the north east side of the valley down to the south west side with a drop of 10-25 feet. The bedrock floor of the valley slopes everywhere from the sides down to the centre with a drop of possibly 10 feet. The forest layers in the muck on the north east side where they are known also slope downwards away from that side, though whether or not they slope (or sloped) up to the other side again with the bedrock floor, is not known. But at any rate, the forest layers do not slope down enough to parallel the surface, and therefore they must come out to the surface. This indicates that the present surface is the product of erosion.

Independence Peat Bed.

The stratigraphic position of the Independence Peat bed is important as it is the only deposit whose surface represents the present time. If the bottom of the bed is continuous in deposition and therefore in time with the deposits underneath, then the record is complete from the mucks to the present. But since the bed stands on the south west side of Hunker Creek valley which everywhere else is the low side, and since there is a very strong difference of appearance between the peat and the muck underneath, it seems likely that the bed is built on top of the erosion surface discussed above; that is, it dates only from the time of erosion or later.

b. The Fossil Record.

Animal Fossils

The frozen sub-arctic deposits of Alaska and Siberia are famous for the spectacular animal fossils which they have yielded. The famous Beresovska Mammoth (Herz, 1904) was well enough preserved to provide meat of a sort for a formal dinner in St. Petersburg. The writer saw a giant bison which Mr. Otto Geist, Fairbanks representative of the American Museum of Natural History, had just excavated from one of the Fairbanks creeks; it had the skin of head, forefeet and most of the body preserved like tanned leather, and about half a bushel of loose hair was found around it. Skinner and Kaisen (1947) have subdivided the genus Bison into 6 subgenera and 24 species largely on the basis of collections made at Fairbanks. It is interesting that 87% of the Alaska and Yukon collection consists of specimens of the species Bison (Superbison) crassicornis, an extinct Eurasian form that apparently never spread farther into America.

No remains of flesh and hide are reported from the Klondike district, but bones are plentiful in the muck of the valley bottoms especially in the coarse lower deposits up to and a little above "grade" level on Hunker Creek. The writer has found, or been present at the finding of, remains of Grizzly Bear, Horse, Wapiti, Moose, various extinct Moose-like Cervids, Bison of several kinds, various Musk-ox-like Bovids, and Mammoth, in Hunker Creek. But all these are extinct or wide-ranging so that their ecological significance is negligible.

Plant Fossils -- State of Preservation

Plant remains occur in all degrees of preservation. Some remains are simply charcoal, others are the original substance of the plant. The peat lenses from the Low Bench gravel on Bratsberg's claim and the peaty layers from the muck at Dominion Creek stripping operation were all very highly humified and granulated so that identification of fossils was difficult.

But much of the vegetable material is in an excellent state of preservation. Mosses from the Independence Peat bed were almost perfectly undecomposed, and quite satisfactory for identification, as were the samples of water moss from the pond deposit in the number 6 layer of the Hunker Creek stripping cut. Tree stumps in the forest layers of the Hunker stripping cut are usually so well preserved and so abundant that they present a major obstacle to mining. They must be piled up and burned. A sample of Larix wood and a sample of Salix wood, both from the number 6 layer, were analysed by Mr. G. H. N. Towers, formerly a graduate student in the Department of Botany, McGill University, for the quality of their lignins.

Following the method of Stone and Blundell, Towers subjected the ground samples to alkaline oxidation with nitrobenzene at 130° C. followed by paper partition chromatography to separate the lignins into their component aromatic aldehydes. By this method it has been found that angiosperm lignins regularly broke up into units of two different aldehydes, Vanillin and Syringaldehyde, while gymnsoperm lignins broke up into units of only Vanillin (Creighton, Gibbs and Hibbert, 1944; Towers, 1951, unpublished thesis.) Towers found that the fossil wood lignins reacted precisely as should modern wood lignins of the same species: Larix, the conifer, yielded only Vanillin; Salix, the angiosperm, yielded both Vanillin and Syringaldehyde. A color reaction, the Maüle test, found by Creighton, Gibbs and Hibbert (1944) to correlate with the presence of syringaldehyde, was tried by the writer on these same samples; as expected, Larix lignins were negative, while Salix lignins were positive.

Miners have often reported green leaves in the mucks of Fairbanks and Nome, Alaska. The writer was fortunate enough to find a fresh exposure of green leaves of some Cyperaceous plant buried about 25 feet deep in a solifluction scroll in the muck of Fairbanks Creek, Fairbanks district. In the laboratory these leaves were extracted several times with acetone, with petroleum ether and with water, but no green extract was ever obtained -- only a clear bright yellow extract. The best extract, obtained using acetone, was transferred to petroleum ether and analysed for its absorption spectrum using the Coleman diffraction -- grating spectrophotometer. An absorption spectrum identical with that for the carotenes of living plants (see Gortner, 1949, Rabinowitch, Vol.II, 1949) was obtained. Subjecting this same extract to filter-paper chromatography, using petroleum ether containing .05% 1N butanol as the developing solvent, gave only a large spot of yellow pigment which moved ahead of the solvent just as the carotenes do, and a trace of a yellowish substance which failed to move at all. From the results of these two tests it appears that the leaves contain carotenes and no other pigments. Microspectroscopic examination of leaves mounted in glycerine failed to show any trace of absorption in the red bands at all; chlorophyll must be absent. However it was pointed out by an artist friend that a yellow pigment plus a fine black substance such as powdered charcoal appears to the eye as a green;

experiment proved this to be true. It is therefore suggested that the green coloration seen occasionally in fossil leaves in frozen mucks is due to a combination of preserved carotenes in the leaf and fine particles of silt in the muck.

Part of the residue of the leaves used for extraction was treated with Millon's reagent (1 ml. mercury dissolved in 9 ml. concentrated nitric acid to give a mixture of mercurous and mercuric nitrates and nitrites), and another part with concentrated nitric acid ("Xanthoproteic reaction"). In both cases, distinctly positive tests for proteins were observed; this probably indicates the presence either of actual proteins, or at least of large degradation products of protein.

Thanks are due to Dr. E.R. Waygood and to Dr. N. Hansl of the Department of Botany, McGill University, for technical advice on the tests performed on these green leaves.

Plant Fossils -- The Independence Peat Bed.

All of the 17 samples from the "C" series collected at the Independence Peat bed were examined by Mr. J. Kucyniak of the Montreal Botanical Garden. The great mass of the peat is made up by a single species of *Sphagnum* with only traces of *Polytrichum* in some samples and a few vascular plant remains. Of the *Sphagnum* species, Kucyniak reports:

"Probably *Sphagnum robustum* (Russ.) Röll. In analysing the species by making use of Andrews key (North American Flora) the choice of species...narrows down to *Sphagnum robustum* and *Sphagnum fuscum*. In dealing with live material, the typical brown pigment sets *Sphagnum fuscum* apart from robustum... Since this material is fossilized...we cannot use this character. However in examining leaf sections, the relation of the chlorophyllose cells with the hyaline cells is almost identical with Sphagnum Girgensohnii and Sphagnum robustum. Reference — A.LeRoy Andrews, "Sphagnaceae" in North American Flora 15: 24-26."

Kucyniak reported Sphagnum robustum definitely present in every sample except C14 and C17. In C17, no recognizable moss was found at all, thereby adding another point to the already great difference between C17 and the other samples of the series. In C14, the moss was somewhat decomposed and identification consequently difficult, but the sample consisted almost entirely of Sphagnum, believed to be Sphagnum robustum.

In sample C5 there was a small fragment of a Polytrichum believed to be P.juniperinum var. alpestre (ref. Fry, 1937) and in sample C8, there was a fragment identified as Polytrichum commune var. Yukonense (Card.&Ther.) Fry.

Thus we find a single species of Sphagnum overwhelmingly dominating this peat bed from beginning to end.

A pollen diagram, as far as the writer is aware the first from the central Yukon, was worked out as completely as possible from this bed. The results are expressed as percentages of the total arboreal-species pollen count, that is, the total number of grains of spruce plus pine plus fir plus poplar plus willow plus alder plus birch. They are presented in graphic form in figure 11. Estimated trends have been superimposed on the three most important graphs, Picea, Alnus and Betula.

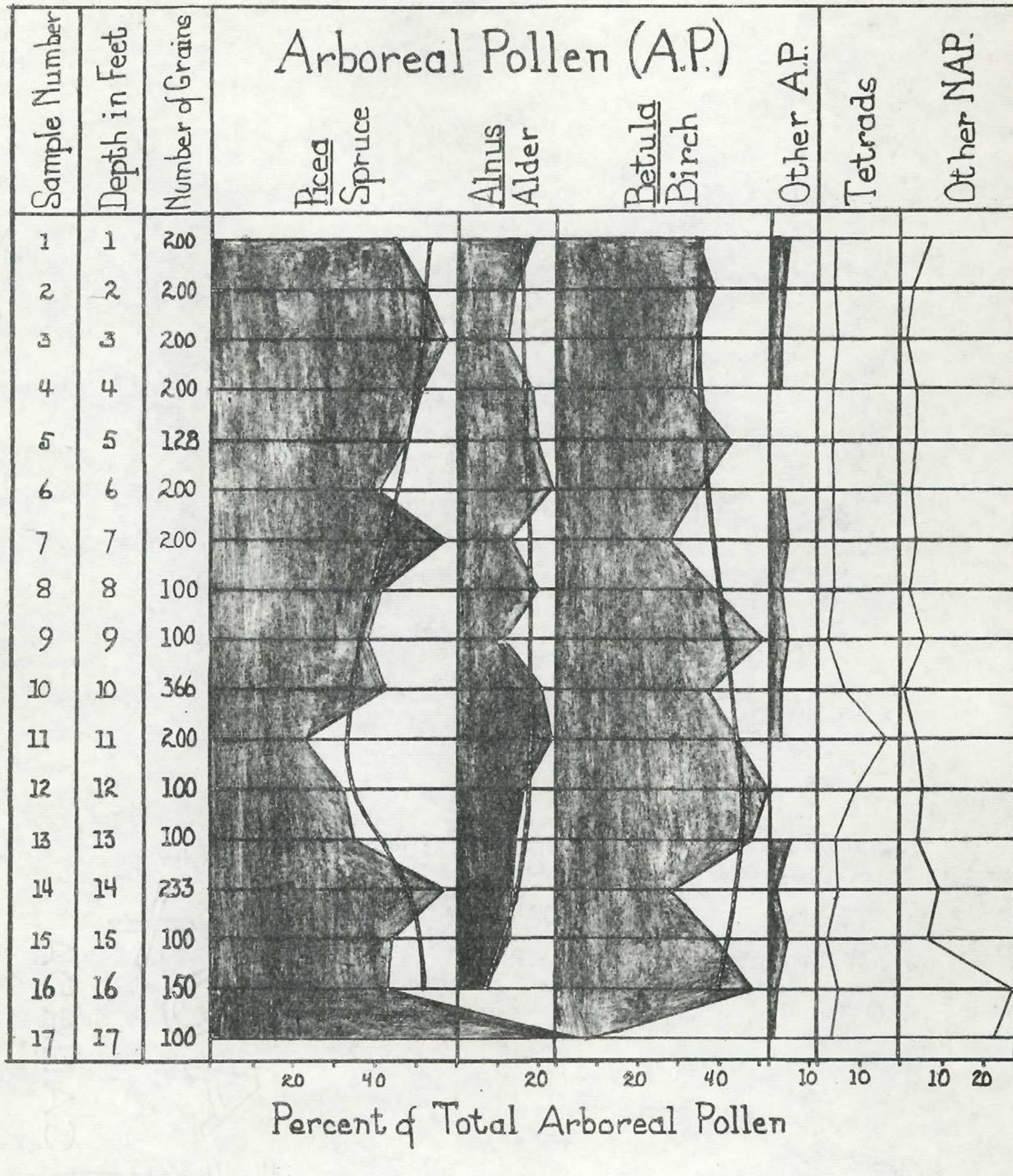


Figure 11.

From the diagram it appears that this peat bed records a slow cooling of climate from about sample 12 or sample 13 up to the present, marked by a slight increase in spruce percentage. There may be some evidence in the alder and birch graphs for a halt to this trend. Between samples 13 and 14, however, there appears to be a mild break marked by a decrease in the spruce percentage. Sample 14 was the only one in which the *Sphagnum* was decomposed enough to make species identification difficult, and it contained more roots than usual (identified as *Picea*). Therefore there may be at this point a "recurrence surface" or slowing of peat deposition until the climate became cooler again.

It should be mentioned that the *Betula* graph contains both the tree-birch species and the dwarf-birch species percentages. The graph should therefore show maxima at both extremes of climate. The slight maximum around samples 12 and 13, being associated with a definite decrease in spruce, may be taken to indicate an increase in the percentage of tree-birches, while the suggestion of a trend towards an increased percentage at the present, coupled with a continuing increase trend in spruce may be taken to mean a slight increase in the number of dwarf birches.

There is a very distinct and large break between sample 16 and sample 17. The latter contains no alder, very little birch, in fact very little except spruce. And the peat of sample 17 is of a very different character. Undoubtedly sample 17 was deposited in a much cooler climate. Apparently the peat bed rests on top of the erosion surface which bevelled the valley bottom mucks; sample 17 is a bit of an organic layer in the muck.

The fact that the peat bed above sample 17 is essentially homogeneous in nature with only a single species of *Sphagnum* making up its mass and a pollen spectrum that records only minor fluctuations in climate, suggests that it is entirely post-glacial. Thus the interval of erosion was followed by a completely post-glacial period of quite steady and slightly cooling climate; and had, as we have seen, itself followed upon the period of waning of the most recent glaciation recorded in the district. It seems likely, then, that the interval of erosion can be correlated with the "Post-Glacial Climatic Optimum" of the Eruopean writers. It is impossible that the slight warm period shown by samples 12 and 13 was the Optimum, for its climate was not warm enough to thaw the peat to the level of samples 14, 15 and 16 and so decompose them, while the interval of erosion was certainly warm enough to thaw the valley bottom mucks and their ice veins to a depth of three or four feet.

Plant Fossils -- Other Series.

No pollen diagram has been worked out for any other series collected because of their fragmentary nature. However, "pollen floras" have been worked out for eight organic layers in order to get some idea of the conditions under which some of the beds were laid down.

A very luckily found and, in fact, almost unique little lens of organic material in the middle of the White Channel deposit at Jackson's Gulch cut ("E" series) yielded a very good pollen flora which showed the warmest climate recorded by any deposit studied. Three pieces of wood were also identified. The flora is given in the following list.

Pinus	38%
Picea	10%
Abies	4%

Alnus	23%
Betula	25%
Tetrads	2%
Unidentified	5%

Wood

Abies

Abies

Larix (possibly Picea)

This is a picture of a warm climate, one suitable for the dominant growth of Pinus and Abies. At the present time the northernmost species of Pinus, P. contorta, is dominant in south and south-eastern Yukon where the only weather stations recorded in the "Climate Summaries" (Canada, Dept. of Transport, Meteorological Division) are Carcross and Watson Lake both of which have a yearly average daily mean temperature of 29°F. That of Dawson is 23°F. If, therefore, we assume that the annual average daily mean temperature of Bonanza valley in White Channel times was roughly similar to that of Carcross and Watson Lake today, we find a climate deterioration of 6 degrees or more since the Pliocene.

The only species of Abies found in the Yukon, A. lasiocarpa, is dominant in the hills near only one recorded weather station in the Yukon, Watson Lake. Since Abies requires, besides a little more warmth than the Klondike now provides, a little more moisture too, we may for purposes of estimation assume that the precipitations of the Bonanza Creek area in White Channel times was at least like that of Watson Lake at the present time, about 16 inches per year. This is an increase of almost 4 inches per year over the present Dawson precipitation. Chaney (1938.b) estimated that in eastern Oregon, there had been a decrease of average precipitation of almost

5 inches since lower or middle Pliocene times.

Thus assuming that the species of Pinus and of Abies found in the sample are the northernmost representatives of their genera, we can deduce a climate just warm enough to prevent permanent freezing of the ground. Of course, if the species represented are more southern species, then the climate was warmer still. Chaney (1938a) surveying the Pacific Coast regions of Asia and America from Tertiary time onward, finds evidences of a gradual southward shifting of climatic zones all through the Cenozoic and continuing down to the present. Just how far south they have shifted in northern regions since the Pliocene remains to be seen.

From the low bench of Bratsberg's claim, one mile above the mouth of Hunker Creek ("P" series) the sample of peat studied yielded only 3 grains of Betula and 5 unidentified grains or spores in two large slides exhaustively examined. A twig apparently came from a shrub of Arctostaphylos and a fragment of wood from a conifer. The peat was badly humified consisting only of a brownish sticky granular mass. Apparently it records a cool-climate flora but has passed through a period of strong weathering.

Three fragments of twigs brought up by Hunker dredge ("B" series) all proved to be Larix. This tree does not now grow in the Klondike district so far as the writer is aware, but probably does grow on the north slopes of the Ogilvie Range in the Peel River country (Porsild 1951). It is improbable that twigs would be introduced into the deposits by miners, although a piece of Douglas fir timber obviously got there that way. Thus we have here a possible record of local extinction.

From the lowermost of the undoubted organic layers in the Hunker

Creek stripping cut, the number 8 layer, were obtained several well-preserved shrub fragments, an indifferently preserved pollen flora and a mass of tiny calcareous concretions which on solution in acid, were seen to contain organic remains. The shrub wood fragments were of Salix and Potentilla fruticosa; conifer wood was absent. However the pollen flora showed quite a high spruce percentage in spite of the fact that the spruce grains did not show up nearly as well as they usually do. It is a distinctly cold-climate flora.

Picea	58%
Salix	6%
Alnus	4%
Betula	32%
Gramineae	4%
Unidentified	12%

The organic remains in the concretions were of a coarse fungus bearing large bladder-like structures about 60-100 mu. in diameter. The only organism which the writer has found to resemble it, is an extinct Pleistocene fungus genus found in peat from a deep well in Minnesota (Rosendahl, 1948). It is therefore tentatively identified as "Rhizophagus sp." There is said to be a living representative, Rhizophagus of the Mucorales.

The number 6 layer yielded a poor pollen flora indicating a cool dry climate:

Picea	3 grains
Salix	1 grain
Betula	8 grains

Gramineae	1 grain
Cyperaceae	8 grains
Artemisia	1 grain
Cornus	1 "

The pond deposit found in the number 6 layer was a marl bed in which was embedded a great amount of a water-moss which Mr. Kucyniak of the Montreal Botanical Garden identified as Drepanocladus aduncus (Hedwig) Warnst. var Kneiffii (Bry. Eur.) Warnst., a submerged inhabitant of cool calcareous water.

From this same layer came the chunks of wood for Carbon-14 analysis (Populus sp.), the two chips of wood tested for lignins (Salix sp and Larix sp) and an extra chip of Populus wood. This still was a cool period, and Larix was not yet extinct in the Klondike district.

The number 4 layer of the Hunker stripping cut still recorded a cool climate. The rather well preserved pollen flora consisted of:

Picea	79%
Alnus	4%
Betula	17%
Gramineae	5%
Cyperaceae	4%
Caryophyllaceae	3%
Unidentified	18%

It resembled sample 17 under the Independence Peat bed except that it contained a little less spruce, a little more birch, and a trace of alder. Possibly it is later than sample 17 and represents a slightly warmer climate, though not as warm as any time recorded in the Sphagnum peat. Two pieces of wood were probably Picea although one of them, a twig containing much compression wood, may have been Larix.

A careful examination of several slides made from the middle organic layer from the lower Sulphur Creek stripping cut revealed only one fragment of a Picea pollen grain and a single doubtful Betula grain. This examination therefore must be considered inconclusive.

From Fairbanks Creek in the Fairbanks district of Alaska, a sample of blackish muck collected from beside the tusk of a small mammoth yielded no pollen grains at all. However, the sample of "green" sedge leaves contained a few badly corroded grains probably indicating a cooler climate than now. The list is:

Picea	6 grains
Betula	3 grains
Gramineae	1 grain
Epilobium	1 grain
Caryophyllaceae	1 grain
Tetrad	1
Unidentified	6 grains

In this connection it might be noticed that Chaney and Mason (1936) obtained macrofossils from similar samples from mostly unrecorded stratigraphic positions in the mucks of the Fairbanks district. They listed a flora consisting of 27 species all except two of which are present-day inhabitants of the Fairbanks district, and those two are both alpine species of Salix recorded from Alaskan mountain-tops. Here again is a record of a slightly cooler climate than that of the present.

4. Discussion -- the Sequence of Pleistocene Events.

The basic stratigraphic sequence of Pleistocene time in the central Yukon is derived from the geomorphology of the terraced valleys of the Klondike district. We can say with assurance that the White Channel gravels are the oldest superficial deposits known in the district, and that they were preceded by a long period of erosion. Younger than the White Channel gravels are the "Klondike River" gravels; younger still are the new valleys and the low benches on their sides; and youngest of all are the valley bottom mucks.

This series, broad valley erosion -- White Channel deposition -- "Klondike River" gravel deposition -- valley cutting -- valley bottom muck deposition, is a record of rough alternation between erosion and deposition. To this we can add the evidence of the bedrock. Everywhere there is deeply weathered bedrock lying under deep deposits of unweathered or slightly weathered gravel or muck. This must mean that the bedrock lay fairly well exposed to the atmosphere for considerable periods of time before being covered over. The weathering could occur under a shallow covering of shifting stream-bottom material in which the gold was laid down, but it could never occur under the gravel deposits we see now. In other words there must have been an alternation of erosion and aggradation to account for the visible bedrock and gravel relationships.

In the living flora of the district we have evidence, on the other hand, of alternation, or at least of variation, in climate. The mountain peaks are covered with a moderately rich alpine vegetation which must have immigrated at a time, or times, when it could freely cross the valleys between the mountain-peak "islands" where it is now isolated; that is, at a time when the climate was cooler than now. (compare Raup, 1947)

On the other hand Pinus contorta is found in the Klondike district today as completely isolated groves on 2 dry warm hills, and Abies lasiocarpa is found in the Ogilvie Range north of the Klondike (Porsild, 1951) and in the McQuesten Map Area eastward, on a few moist warm hillsides. These groves are all so isolated that the species must have immigrated at some time when the climate was warmer than now. But from this evidence alone, we cannot tell when they came. In glaciated countries we may normally be sure that a warmth-loving plant must have immigrated at a time of some post-glacial "Optimum", but here, where plants lived somehow all through the ice ages, we can only assume that the climate would be too extreme for these species to survive.

Valley Bottom Muck

The only part of the valley bottom deposits seen by the writer which continue the record up to the present is the Independence Peat bed. It has been shown above that, although this deposit gives evidence of a slight warm period in the course of its growth, it is essentially a record of uniform climate and therefore entirely post-glacial. It dates from some time after a period of erosion and sufficient warmth to thaw the underlying deposits rather deeply. If this period is also post-glacial, as it must be since there is no deposit younger than it indicating a colder climate, it would probably be synchronous with the "Post-Glacial Climatic Optimum" described by writers in Europe and the United States, and estimated by varve analysis and Carbon-14 determination to have occurred roughly 4000 years ago.

An age of 4000 years or less for a 16-foot bed of peat makes necessary a rather rapid rate of growth, over one and one-half feet per century. But the extremely homogeneous nature of the deposit and the relative scarcity of pollen grains in the unprepared peat make this rate seem quite possible.

All the other valley bottom mucks seen by the writer must be older than the period of erosion, for they all seem to have been truncated by it. Their fossil flora records a climate distinctly cooler than that of the present. The deposits themselves record a gradual change from a violently cold climate to a less violent climate with no interlude when it became as warm as the present. It seems reasonable to assume that these deposits record the time of the Wisconsin Glaciation.

The New Valleys

Under the present muck there is the deeply weathered bedrock floor which, as we have seen, must have been fairly well exposed to a mild climate for a considerable period of time. There also lies the placer gold which, being the product of stream concentration, must have been laid down at a time when almost everything else was being washed down to the river. The time of valley cutting must have been a long period of warm climate; it seems reasonable to correlate it with an interglacial period.

The low benches are fragments of valley bottom to which the same sort of reasoning may be applied. The weathered bedrock bench itself is the product of a long warm period, and the thick deposits on top the products of a very cold period. As mentioned above, they need not conform in elevation to be used as evidence of an alternation of warm erosional and cool depositional times. The flora obtained from the bench studied, though damaged by weathering in the subsequent erosional period, could indicate a cool period.

Thus the "time of valley cutting" was probably not a single time, but a series of times of cutting interrupted by cold periods as intense and as long, to judge by the depth of some of the remaining low bench deposits, as that which produced the present valley bottom mucks. It seems to show the alternation of glacial age and interglacial that marks the Pleistocene epoch.

But carving of valleys always involves a lowering of base-level which usually means an uplift of the country; and the Pleistocene was, all over the world, a time of drastic crustal movement. (Flint 1947). Interglacial ages would be marked by steady uplift and climate warm enough to allow chemical weathering. Glacial ages would be marked by slight but sufficient eustatic depression from the weight of the ice 50 or 60 miles to the eastward, to interfere with drainage, and by a climate cold enough to prevent removal of rock waste by chemical means. Thus there would be an alternation of erosion and deposition corresponding with retreat and advance of the ice. The erosional surface bevelling the present valley bottom muck is a sign that post-glacial (or interglacial if you will) valley cutting is beginning again.

"Klondike River" Gravels

McConnell (1907) has shown that the "Klondike River" gravels are foreign to the district and probably represent a bursting of the Klondike

River in on a small sluggish stream valley where the Klondike Trench is now, from a former course somewhere in the Tintina Valley. The writer feels that the gravels are probably outwash from glaciers up the Klondike in or beyond the Tintina Valley. Since the gravels lie directly on the White Channel gravels, they must represent the first or Nebraskan Glacial age (if we are right in assuming there were only four major glaciations). At that time a lobe of ice pushing down the Stewart River in the same path as the latest ice followed, whould have blocked the Tintina Valley and damned up the Klondike which very likely flowed to the Stewart up till then. The Klondike waters, rising to the height of the low divide east of Hunker Creek that separated them from the Yukon drainage would then flood the little valley that ran there, dumping their load of gravel over its bed. With the waning of the ice sheet the excessively great amount of melt-water would enable the Klondike to deepen its new exit so that it would not return to the old. As each ice sheet waned, it would again enlarge the Klondike flood and enable it to cut the tremendous valley it occupies now, below Hunker Creek.

That is, the Klondike valley as we see it is the product of two different types of erosion: first, normal interglacial downcutting and deepening; and second, late-glacial widening. The second might not cut as deeply as the first and would possibly leave some deep holes in the bedrock floor of the valley, but it would spread widely and eat at the side-walls of the trench, destroying most evidences of previous erosional cycles.

White Channel Times.

The White Channel gravels are undoubtedly the oldest in the district. They were laid down, as McConnell pointed out, by small meandering streams of very low gradient over a very long period of time. But they too rest on deeply weathered bedrock, the most deeply weathered in the district. As indicated above, the White Channel times must have been preceded by a very long period of erosion during which the quartz gravel stayed in its original place, being moved to its present site and deposited there not by a raising of the base-level, but by a very gentle lowering of it. Presumably we have here an evidence of the very first signs of the approaching crustal instability of the Pleistocene. Yet the presence of the moisture-loving Abies suggests that the barrier of Pacific Coastal mountains had not yet risen high enough to completely block off the moist winds from the ocean.

The length of time covered by "broad valley time" must have been very great. The cross-sectional area of the broad valleys is approximately 50 times that of the new valleys. If the new valleys were carved during the million years of the Pleistocene by the violent climate and uplift of the age, then the broad valleys in a period of gentler climate and conditions may have taken 25 to 50 times as long to carve — that is 25 to 50 million years. According to the time-scale worked out by the Uranium-degradation-product method (Zeuner, 1950) this would place the beginnings of broad valley times far back in the Tertiary age, to the Miocene epoch at least or possibly as far back as the Eocene. However, the errors and unknown quantities involved in estimating times from rates of erosion are so great as to render this merely an interesting but quite idle guess.

It should be noticed here that this sequence of geomorphological history applies only to those Klondike creeks that flow into the Klondike River itself and have well-marked high benches, that is to Hunker Creek and

Bonanza Creek. The streams of the Indian River drainage that have no benches, Dominion, Gold Run and Sulphur, were not affected by the uplift which caused the new valley cutting, or at least they were not affected enough to make a valley that could not be filled over completely by the next period of cold climate muck deposition. The climate that affected the terraced creeks must have equally affected the others, for they are only 20 miles away; and no doubt the muck in the unterraced creeks was deposited entirely in periods of cold climate. But the relationship of deposits is not the same. It must await further investigation.

IV CONCLUSIONS AND SUMMARY

In this paper the writer has attempted to show from the evidences of Fossil Botany, Phytogeography, Geomorphology and Stratigraphy that during the Pleistocene epoch the climate of the Klondike district, central Yukon Territory, alternated from relatively colder than now to relatively warmer than now, and that these alternations of climate were associated with alternations in the erosional cycle of the country, from a time of cutting in warm periods to a time of deposition in cold periods. Of course, the fossil record of any period of erosion is likely to be absent. We have only fossils, here, from periods of deposition, that is, from periods of cold climate.

The writer has also attempted to trace the history of the district a little time before the onset of the Pleistocene epoch. Here has been found fossil evidence in support of McConnell's opinion that the oldest superficial deposits of the district, the White Channel gravels, were laid down in a period that was both warmer and moister than today .

The following table presents the geological sequence postulated here, and its possible correlation with world events during the Pleistocene.

1.	Broad Valley erosion - long continued period of erosion with a warm humid climate and practically no grade to the streams.	- Tertiary
2.	White Channel deposition - slow deposition of residual gravels in the centre of the valley formed in the previous period, as a result of a very slight increase in grade. The climate was still somewhat warmer and moister than it is at present.	- Pliocene
3.	"Klondike River" gravels - sudden rush of glacial melt-water into the present Klondike Valley. Climate cold.	- Nebraskan Glacial
4.	Digging of Klondike Valley spillway.	- End of Nebraskan
5.	Beginning of New Valley cutting on the creeks - uplift progressing - climate warm - some upper small bedrock terraces formed.	- Aftonian Interglacial
6.	Muck and Gravel on upper small bedrock terraces - climate cold.	- Kansan Glacial
7.	Broadening of Klondike Valley spillway.	- End of Kansan
8.	Continued New Valley cutting on the creeks. Uplift progressing - lower small bedrock terraces - e.g. Bratsberg's claim - climate warm.	- Yarmouth Interglacial

9.	Muck and Gravel on lower small bedrock terraces - e.g. Bratsberg's claim - climate cold.	- Illinoian Glacial
10.	Re-Broadening of the Klondike Valley Spillway.	- End of Illinoian
11.	New Valley of the creeks cut to its present bedrock floor - bedrock "rotted" - possibly a few of the lowest bedrock terraces date from this time - climate warm.	- Sangamon Interglacial
12.	Present Valley Bottom coarse muck deposited on bedrock - very cold.	- Early Wisconsin Glacial
13.	Upper finer Valley Bottom Muck deposited - climate moderating.	- Later Wisconsin Glacial
14.	Klondike Valley spillway broadened to present shape.	- Waning Wisconsin Glacial
15.	Truncation of Valley Bottom mucks.	- Post-Glacial Climatic Optimum
16.	Independence Peat bed.	- Recent Climatic Deterioration

The evidence presented in this paper strongly suggests that alternation of climate and alternation of erosion with deposition did in fact take place; it indicates the climatic conditions at the time of deposition of specific beds; and it establishes the general sequence of formation of the deposits and geomorphological forms examined. On the other hand it must be admitted that the evidence does not so clearly support certain details of the sequence postulated above, such as the "post-glacial interval of erosion" and the origin of the White Channel deposits; and it leaves unproved the correlation of the sequence here presented with sequences of glacial and interglacial ages derived in other parts of the world.

Nevertheless, the writer believes that both the sequence and the correlation are essentially correct. The evidence all fits the hypothesis, although the evidence by no means fills it out.

In order to verify the theory there are several possible lines of approach. In the first place, the evidence in the terraced valleys, particularly that of Hunker Creek, very definitely ought to be re-examined. The idea of a "post-glacial interval of erosion" must be tested by observation on the present sloping muck surface; all the low benches should be carefully scrutinized for evidences of earlier glaciations and of earlier stationary valley floors; and in particular, a careful search should be made for some kind of interglacial fossiliferous deposit.

In the second place, the very different valleys of the Indian River drainage could be studied. The mucks of Sulphur Creek are very deep; no doubt they are confusing, but it may be possible to find in them traces from each of the four glaciations superimposed on one another. And nearby, the buried stream courses of Domonion Creek above the mouth of Gold Run Creek may contain evidence of one kind or another to clarify the problem of glacial and interglacial period.

In the third place, the hypothesis might be tested by an examination of the gigantic "Flat Creek Beds" of the Tintina Valley south east of the Klondike River. At their south east end they touch on moraines, tills and other deposits of glacial origin, and everywhere they have lakes and ponds on their surface. These lakes should be, according to the views of Faegri and Iverson, the best places to take samples for pollen analysis if methods of sampling their bottom sediments can be found. And if the hypothesis presented here of the formation of the upper "Klondike River" gravels and the present Klondike Valley be correct, then the surface of at least the north west end of the Flat Creek Beds should date from Nebraskan times. It may be possible to find on that surface a pollen record going back to the end of the Nebraskan Glaciation.

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