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AIRPHOTO PATTERN RECONNAISSANCE OF NORTHWESTERN CANADA. VOLUME I

Purdue University
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CORPS OF ENGINEERS, U. S. ARMY

AIRPHOTO PATTERN RECONNAISSANCE OF NORTHWESTERN CANADA

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ARMY-MRC VICKSBURG, MISS

Preface

The problems encountered in areas where permafrost is present have received considerable attention during the last few years. The Arctic Construction and Frost Effects Laboratory (ACFEL)*, of the U. S. Army Engineer Division, New England, Corps of Engineers, has been active in such work in the arctic and subarctic, i.e. Alaska, Canada, and Greenland. As a part of this program, staff members of Purdue University spent five summers in Alaska obtaining data to develop a technique of identifying soil and permafrost conditions in cold-weather regions. The results of Purdue's work in Alaska, and descriptions of many of the surface conditions and features that were found there have been reported by Robert E. Frost in ACFEL Technical Report 34, Evaluation of Soils and Permafrost Conditions in the Territory of Alaska by Means of Aerial Photographs (2 vols), dated September 1950. In that report, Frost discusses the airphoto technique used in Alaska, and, since the present program in Canada was carried out along the same lines, his evaluation of general soils and permafrost, including airphoto information, is required reading for a better understanding of this report.

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* ACFEL and the former U. S. Army Snow Ice and Permafrost Research Establishment were combined and redesignated U. S. Army Cold Regions Research and Engineering Laboratory as of 1 February 1961.

The investigation reported herein was conducted by Purdue under the supervision of the former Permafrost Division of the St. Paul District, Corps of Engineers, as authorized by Work Order No. 4, dated 27 June 1949, of Contract No. W-21-018-ENG-683, dated 23 May 1949, between the university and the Airfields Branch, Engineering Division, Military Construction, Office of the Chief of Engineers. The Arctic Construction and Frost Effects Laboratory was the successor to the former Permafrost Division. The interim report of the investigation was prepared in 1953 and revised in 1956.

Work Order No. 4 specifically directed Purdue "to continue review of aerial photographs of arctic and subarctic regions and continue preparation of manual on the technique of using aerial photographs for the purpose of determining the terrain and soil characteristics of permanently frozen ground in arctic and subarctic regions." The scope of the contract, as amended 14 July 1949, was as follows: "The work to be performed shall consist of research investigations on snow, ice and permafrost, and the use of aerial reconnaissance and similar means for the determination and portrayal of terrain and soil characteristics."

A study of soils and terrain features is particularly difficult in large, undeveloped areas, such as Alaska, Canada, and Greenland, for a number of reasons, some of which are as follows: few transportation facilities are available, working season is very short, sites are usually virtually inaccessible, expenses are many, and supplying a field party is most difficult.

This present report is an attempt to classify the general soils, landforms, and permafrost conditions that may be expected in the Northwest Territories of Canada. The classification is based on the pattern as exhibited on vertical and oblique aerial photographs and also ground photographs. Other airphotos which were taken and not used herein are in the reference files of the Arctic Construction and Frost Effects Laboratory. It is believed that the material contained in this report will be valuable to those engineers responsible for planning construction work on frozen ground in northern Canada.

Acknowledgment is made to the following, who were the members of the Purdue Canadian Arctic Permafrost Expedition of 1951, for their individual and collective contribution to the success of the expedition from 24 May to 21 August 1951:

Professor Kenneth B. Woods, Civil Engineer, Purdue,

Professor Olin W. Mintzer, Civil Engineer, Purdue,

Dr. Alton A. Lindsey, Botanist, Purdue,

Mr. James R. Shepard, Civil Engineer, Purdue,

Mr. Robert D. Miles, Civil Engineer, Purdue,

Mr. Ernest G. Stoeckeler, Forester, St. Paul District, Corps of Engineers, and

Mr. John A. Pihlainen, Civil Engineer, National Research Council, Canada.

Although Professor Woods supervised the work and was largely responsible for the preparation of this report, it should be noted that Professor Mintzer was directly in charge of the expedition, and all the members wrote whole parts and sections herein. Prof. Mintzer, Dr. Lindsey, and Messrs. Miles, Stoeckeler, and Pihlainen spent the summer in the Northwest Territories in the general region of the Mackenzie River Basin; Prof. Woods and Mr. Shepard worked along the Alaska Highway, then joined the rest of the staff for the last part of the study along the Mackenzie and the reconnaissance flight over the Arctic Ocean Coast.

AIRPHOTO PATTERN RECONNAISSANCE OF NORTHWESTERN CANADA

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Synopsis

This report presents the results of a reconnaissance survey of selected sites in northern Canada during the summer of 1951 conducted by the Purdue Canadian Arctic Permafrost Expedition and sponsored by the U. S. Army Corps of Engineers. Field data were obtained on soils and permafrost, and airphoto patterns of those sites where aerial photographs were taken for study are described.

The field work was limited geographically to areas along the southern portion of the Alaska Highway in British Columbia and the Yukon Territory, and the following regions in the Mackenzie District of the Northwest Territories: the entire basin of the Mackenzie River, the vicinity of Great Slave Lake, and the vicinity of the Great Bear Lake. Additional observations were made on flights between these areas.

I. INTRODUCTION

Background

1. Purpose

The threefold purpose of the Purdue investigation of soils and permafrost in Canada was as follows:

- a. To extend the range of arctic and subarctic airphoto-soil patterns to include terrain conditions found in Northwestern Canada.
- b. To obtain field data on some of the soils and permafrost in Northwestern Canada.
- c. To further develop methods of using airphotos to identify and evaluate significant characteristics of terrain conditions that influence engineering operations in the arctic and subarctic.

2. Brief description of itinerary

On 24 May 1951, Stoeckeler and Pihlainen (see Preface) arrived at Edmonton, Alberta, Canada, where they were joined by Mintzer. From Edmonton, they all departed for Hay River, Northwest Territories, with Mintzer and Stoeckeler going on to Yellowknife (see plate 1). On 13 June, Pihlainen from Hay River, and Lindsey and Miles from Edmonton arrived in Yellowknife. The party worked in this area until 20 June.

Pihlainen returned to Hay River, and from 21 to 28 June the others explored the Fort Reliance area and Et-Then Island in the east arm of Great Slave Lake. They then joined Pihlainen in Hay River, and two days were spent working along the highway to the north and in a reconnaissance flight to Fort Simpson.

The second party, Woods and Shepard, arrived in Edmonton on 4 July. After several days of preparation, they left from Hay River on 9 July going south along the Mackenzie (or Grimshaw) Highway to Dawson Creek. From 10 July to 5 August, they worked in the Whitehorse area and along the Alaska Highway between

Whitehorse and Dawson Creek, before joining the first party in Fort Good Hope on 8 August.

In the meanwhile, from 4 to 25 July, the first party traveled down the Mackenzie River from Hay River to Norman Wells, except for Lindsey who detoured through the St. Charles portage, Fort Franklin, Port Radium, and the MacTavish Arm of Great Bear Lake before he rejoined the party at Norman Wells. Along the way, they made detailed studies in the areas near Fort Simpson, Wrigley and Fort Norman.

A week was spent in the vicinity of Norman Wells. During this week, several reconnaissance flights were made, including one to Port Radium and Great Bear Lake. Afterward, the party traveled to Fort Good Hope where both parties were together for the only time during the summer.

Simultaneously, with the arrival of the second party -- Woods and Shepard -- Lindsey left for Aklavik and Kittigazuit where he spent 10 days. The remainder of the expedition's members continued to Arctic Red River, from where Woods, Mintzer, Stoeckeler, and Pihlainen made an extended eastward flight along the Arctic Ocean Coast and south to Yellowknife, and then returned to Edmonton. Miles and Shepard went to Aklavik where they were rejoined by Lindsey. From there, they returned south to Norman Wells, and to Edmonton. By 21 August, all the members of the expedition had returned to Edmonton, and the summertime itinerary had been completed.

Definitions

Alluvium - soil, sand, or gravel deposited by running water.

Annual frost zone (active layer, active zone) - the top layer of ground subject to annual freezing and thawing. In arctic and subarctic regions where annual freezing penetrates to the permafrost table, suprapermafrost and the annual frost zone are identical.

Archipelago - a group of islands interspersed in a sea.

Arctic - the northern region in which the mean temperature for the warmest month is less than 50 F and the mean annual temperature is below 32 F. In general arctic land areas coincide with the tundra region north of the limit of trees.

Barren Lands - the treeless plains or tundras of northern Canada, especially near Hudson Bay.

Cordillera - a mountain system; the main mountain axis of a continent.

Coteau - a hilly upland including the divide between two valleys.

Drumlins - an elongated or oval hill of drift.

Escarpment - a high steep cliff of considerable length.

Esker - snakelike ridge of gravelly and sandy drift deposited by a stream flowing beneath a glacier.

Frost action - a general term for freezing and thawing of moisture in materials and the resultant effects on these materials and on structures of which they are a part or with which they are in contact.

Frost mound - a localized upwarp of land surface caused by frost action and/or hydrostatic pressure.

Graywacke - a slatelike rock intensely metamorphosed.

Ground moraine (till plain) - material deposited by an ice sheet; it forms a gently rolling plain.

Ground polygon (fissure polygon, soil polygon) - the geometric configuration of surface markings caused by vertical ice wedges enclosing fine-textured soils.

Humus - the black organic matter of soil in which decomposition is well advanced.

Ice segregation - the growth of ice as distinct lenses, layers, veins, and masses in soils, commonly oriented normal to the direction of heat loss.

Ice vein - a tabular mass of ice found in an approximately vertical position in frozen soil.

Kame - a short ridge or hill of stratified drift.

Knob - an isolated, rounded hill.

Kettle - a steep-sided depression without any surface outlet for drainage.

Lacustrine - formed in or pertaining to lakes (i.e. lacustrine soils are deposited in lakes).

Moraine - an accumulation of earth and rock fragments that has been deposited as the result of glaciation.

Orogeny - mountain building activity, especially folding of the earth's crust.

Outcrop - rock which appears at the earth's surface.

Patterned ground - a general term describing ground patterns resulting from frost action such as soil polygons, stone polygons, stone circles, stone stripes, and solifluction stripes. The most common type of soil polygon is known as a fissure polygon.

Permafrost - perennially frozen ground.

Physiography - in its broad sense, physiography is the scientific study of physical geography and includes the sculpture of the land surface by running water, wind, and atmospheric weathering.

Solifluction - the slow downslope flow of saturated nonfrozen soil over a base of frozen soil.

Subarctic - the region adjacent to the arctic in which the mean temperature for the coldest month is below 32 F, the mean temperature for the warmest month is above 50 F, and where less than four months have a mean temperature above 50 F. In general, subarctic land areas coincide with the circumpolar belt of dominant coniferous forest.

Suprapermafrost - the entire layer of ground above the permafrost table.

Terminal moraine - a moraine that was deposited at the foot of a glacier at its position of farthest advance.

Terrace - a flat-topped bench situated between the floodplain of a stream and the upland.

Till - unwashed and unstratified drift, which may vary in size from silt and clay up to boulders.

Physiography of Northwestern Canada

The purpose of this section is to present general information concerning each of the physiographic divisions of northern and part of western Canada. See plates 2 and 3. The discussion that follows includes a literature survey of the region. The physiographic provinces surveyed are considered in terms of their geographic boundaries, geology, topography, climate, vegetation, geography and, where data were available, their soils and permafrost.

1. Canadian Shield

General features. The Canadian Shield is a single triangular-shaped region of pre-Cambrian rocks making up approximately one half of Canada; the Shield has an area of about 1,790,000 square miles.[18*]

It is bounded on the north by the Arctic Ocean, to the east by the Atlantic Ocean, to the southeast by the St. Lawrence Valley, and in the south it extends south of Lake Superior in the United States. The Central Lowland region, an area of flat-lying Paleozoic formations overlying the pre-Cambrian rock basement, is west of the Shield (plate 3). The islands of the Arctic Archipelago and Greenland are subunits of the physiographic division of the Canadian Shield.[37]

The Canadian Shield has been called the "Basement of the Continent" because of the predominence of pre-Cambrian rock (plate 4). These ancient formations have been subjected to many cycles of mountain building. The Shield is an old peneplain which was uplifted to approximately its present position in middle or late Pleistocene time. The Shield has been warped and faulted so that some places are now higher than others. It has been dissected by several partial river-erosion cycles and then has been modified by glaciation.[18:11] The Great Lakes and the lakes of the northwest are a result of this glacial action. It is a region of low relief with rarely a difference of more than 200 ft in elevation. Taken as a whole the surface of the Shield is almost level with gentle slopes toward the west and south with the Shield rocks underlying the younger strata to the west and south. On the east and north, low mountains of 4,000 to 5,000 ft occur in eastern Labrador and Baffin and Ellesmere Islands.

During the Pleistocene "Ice-Age," continental ice sheets scoured off the soil of most of the Shield area and disorganized

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* Raised numerals refer to items in the references listed at the end of volume 1.

the preglacial drainage. Consequently, some very large glacial lakes were formed. Some of the lacustrine silts and clays thus deposited are now drained, and make up the only good agricultural land on the Shield.

The southern part of the Canadian Shield is a timbered region; northward the stands are thinner until they finally merge into the barren lands of Ungava Peninsula and of the Northwest Territories.

The Shield is considered in three physiographic provinces - the Laurentian Upland province, the Arctic Archipelago, and Greenland (plate 2); the last two are beyond the scope of this report.

Laurentian Upland province. The Laurentian Upland province constitutes all of the Canadian Shield in continental Canada (plate 2). This province has been subdivided into several sections. The Ungava section is east of Hudson Bay while the Keewatin section is west of the bay. North of Keewatin is the Barren Lands section bordering the Arctic Ocean. The Ontario-Quebec section lies between Hudson Bay and the Great Lakes; the Clay Belt is found south of James Bay (plate 2).

The pre-Cambrian rocks of the uplands fall into two age groups, the Archaen (older) and the Proterozoic (younger), which are separated geologically by a long interval of mountain building and erosion. The Archaen rocks are subdivided into the Keewatin and the Laurentian. The Proterozoic rocks are divided into four subgroups, the Lower, Middle, and Upper Huronian and the Keeweenawan (plate 4).[19:10] In addition to those rocks of sedimentary and volcanic origin, there is a great amount of intrusive igneous rock, so that 80 percent or more of the Shield consists of granitic rocks.[18] There are lesser amounts of various basic intrusives, gabbros, norites, and peridotites, but these are economically important because of the metalliferous deposits they contain. The uplands are a "storehouse" of minerals. The area north of the Great Lakes has been called the "Treasure Chest" of Canada.[60]

The Laurentian Upland region is a peneplain with gentle slopes south, north, and west. The height of the land is reached in the eastern part in Labrador where the Torngat Mountains reach elevations of 6,000 ft. There are many lakes in the region. Most of these are a result of glacial debris forming ridges which disrupt old drainage patterns. In some parts of the northwest, lakes make up 25 to 35 percent of the area. Glaciation is responsible for the multitude of lakes, for the kames, eskers, and outwash plains of sand and gravel deposits, and for the scoured rock. Soils vary from scattered gravels of the Barren Lands to the rich lacustrine silts and clays of the Winnipeg region.

This area of almost two million square miles has a variety of climatic regions, from the severe Arctic region to the north temperate of the Ontario-Quebec section. The mean July isotherm of 55°* roughly passes along the southwestern border of the Barren Lands section. In these northern regions there are days when the temperature rises above 65 F; an 80 F reading has been recorded at Coppermine. Polar air drifting across the climatic division of the "Northern Lands Region" (plate 6) tends to maintain temperatures lower than those normal to temperate regions; fogs or low clouds collect with little or no condensation of water. The total annual precipitation is not well defined because of the light fluffy nature of the snowfall, but rainfall averages 2 to 3 in. The water content of snow has been recorded as great as 4 in. The rainfall increases to 10 to 12 in. as the Arctic Circle is approached.[8] No long-range records of this region of frostfree periods were available for the compilation of data for this report.

1) Keewatin section. The Keewatin section of the Laurentian Upland province is bounded on the south by the Churchill River, on the north by Chesterfield Inlet, on the west by the Mackenzie Lowland, and on the east by the Hudson Bay (plate 2). It was from this area that the Keewatin ice sheet spread out into the surrounding lower regions. The Keewatin area is

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* All isotherms are given in degrees Fahrenheit.

primarily underlain by pre-Cambrian granites, gneisses, schists, sedimentary rocks, and volcanic eruptives (plate 4). It has been relatively well endowed both as to mineralization and accessibility. The large area of sedimentary and volcanic rocks around Lake Athabasca extends southeast to Wollaston Lake and to Cree Lake on the south. Along the western side of Hudson Bay the coast is generally flat and low-lying. It is dotted with numerous lakes which "spill" into one another. The eastern parts of the Athabasca and Great Slave Lakes lie in the pre-Cambrian formations of the Keewatin section.

The area east of the Great Slave Lake is one of innumerable lakes separated by stretches of scrub timber or exposed bedrock. Most unconsolidated materials such as glacial drift, muskeg, and undeveloped soils are limited to local depressions in the bedrock surface.

The treeline ends on the Hudson Bay Coast close to Churchill and extends northwest towards the Mackenzie Lowland. The terrain is quite low; the hills are no more than 300 to 400 ft in height.

Great Slave Lake is 325 miles long and from 15 to 20 miles wide; its shores are rugged and barren in the Keewatin section. The western shores which are in the Central Lowland are less rugged and are timber-covered. Around the eastern end of the lake are Keewatin greenstone schist and gneiss. There are also diabase sills. In the schist slight copper mineralization has been noted.[36] Near the northeast rim of Great Slave Lake, granitic quartz veins have been found. Some of them are over 100 ft wide, most do not outcrop more than a mile, although one is thought to extend for 25 miles.[24,27,33,35,44]

Yellowknife is a gold-mining town of 4,000 people on the northwest shore of Great Slave Lake at the mouth of the Yellowknife River. An airfield is located there. Fort Reliance, at the eastern end of Great Slave Lake, is a trading post and has a police detachment and a Royal Canadian Signal Corps Station.

The north shore of Lake Athabasca is mostly rock and muskeg. However, grass does grow along the Slave River. Large sulphur deposits are found on the east side of the Athabasca River between McMurray and the lake. They are inland about two miles and beyond the lake on the east shore as well as on the west shore of Great Slave Lake. Along the Athabasca River the country consists of rolling hills with little soil development.

In areas mapped as containing continuous permafrost (plate 7) there are places where sporadic permafrost was encountered, particularly in the Yellowknife area. It is to be noted that in those areas where sand and gravel were found, permafrost was notably absent. However, where clay with an insulating blanket of moss was present, permafrost was found. In the Yellowknife area permafrost was not found in exposed bedrock. Permafrost was found to a depth of 265 ft in bedrock that is overlain by 60 ft or more of overburden. However, on Outpost Island, in Great Slave Lake, permafrost was reported in exposed bedrock to a depth of 175 ft.[2]

According to Bateman, widespread observations have been made but not much has been published concerning permafrost conditions in Canada. He reports that permafrost has been observed at Yellowknife, Northwest Territories, in varying localities.[2] The 23° yearly mean isotherm passes through Yellowknife (plate 5). Jenness indicated that continuous permafrost underlies the Yellowknife area.[32]

2) Barren Lands section. The Barren Lands lie north of the Keewatin section and adjoin the Arctic Archipelago. The Mackenzie Lowland lies to the west. The name derives from the general absence of trees and soil; however, the area is not completely barren. Tundra vegetation such as small shrubs, grasses, and flowers grow.

Rocks of the region are pre-Cambrian in age, the greater part of the region being intrusive rock. Granites, gneisses, and metamorphosed sedimentaries and volcanics predominate (plate 4). In the Coppermine River and Bathurst Inlet districts, thick series of basic lava flows occur near the top of flat-lying sedimentary rocks. Diabase dikes consisting of quartz diabase and olivine diabase commonly occur.

East of a line joining Slave and Coppermine Rivers thousands of square miles have sparse soil covering. Where there is soil, it is permanently frozen a foot or two beneath the surface. The barest areas lie between and skirt the eastern ends of Great Bear and Great Slave Lakes.[61]

The topography of the region between Great Slave Lake and Great Bear Lake is rolling country with domelike elevations rising 1,000 ft or more above sea level.[35] The area is underlain by pre-Cambrian rocks of the early Yellowknife groups of lavas and sediments and the late Snare groups consisting mainly of sedimentary and igneous intrusives of all ages.[10]

Great Bear Lake lies mainly on Paleozoic rocks but its eastern end crosses into the pre-Cambrian rock areas.[34] There is a striking difference in the topography of the two areas. The Paleozoic area is a gently undulating country of low relief; the pre-Cambrian area is a plateau of locally rugged relief. The lake has an area of about 11,660 square miles. Port Radium, on the east shore of the lake, is a mining village at the site of pitchblend deposits.[25:73]

Between Great Bear Lake, Coronation Gulf and the Mackenzie Lowland proper is a gravel-covered region with underlying Cretaceous rocks -- resembling in many respects glaciated sections of the Great Plains. Along the Arctic Coast of this region is Port Brabant, near the mouth of the east channel of the Mackenzie Delta, Stanton, and Paulatuk on the southern coast of Darnley Bay. Mission stations are located at Stanton and Paulatuk.

The Anderson and Horton Rivers empty into the Beaufort Sea. They flow between Stanton and Paulatuk. The country between the rivers is a rolling tundra plain well covered with small lakes.[56:5] The coast between Pearce Point (east of Paulatuk) and Coppermine (on Coronation Gulf) consists, in part, of low steep walls of rock rising 200 ft from the water and in other sections of sloping lowlands, marked with parallel ridges of former beach lines. Inland elevations increase to about 1,000 to 2,000 ft in the Melville Mountains, which parallel the coast.

Coppermine is a village at the mouth of the Coppermine River. The Coppermine River is 525 miles long, rising in the central part of the Mackenzie District, Northwest Territories, and flowing northwest and north to Coronation Gulf. Nuggets of native copper have been found in glacial deposits on the lower Coppermine River.[4]

Repulse Bay, on the southern coast of Melville Peninsula, and Perry River, on Queen Maud Gulf, are two of the trading posts found along the Arctic Coast of the Barren Lands section.

2. Interior Plains

General features. The plains region adjoining the western edge of the Canadian Shield includes most of the Great Lakes, the Great Plains, and the Mackenzie Lowland of northern Canada. The Plains region in Canada lies between the Arctic Ocean on the north and the United States on the south, and between the Canadian Cordillera and the western face of the Canadian Shield (plate 2).

The Plains lie on a base of pre-Cambrian rocks, which were downwarped into a large geosynclinal trough. The area was several times inundated by the sea during the various geological ages (plate 4) A great thickness of sediments was deposited; the upper strata are of Tertiary and Cretaceous age, consisting of deep beds of sandstones and shales with some coal strata. The shales predominate.

The Plains region surrounding the Shield is level or rolling land less than 1,500 ft in elevation. To the west, however, the prairie level gradually rises to about 4,000 ft and merges with the foothills of the Rockies. Large areas of the Plains are characterized by the absence of drainage. This causes water in the lakes and ponds to be generally saline and numerous alkali flats occur. These alkali flats are characterized by sparse vegetation.

The Interior Plains in Canada have been divided into the physiographic provinces of the Great Plains and the Central Lowland (plate 3).

In Canada, the climate of the southern portions of the physiographic provinces of the Canadian Rockies, the Interior Plateaus, and the Great Plains is frequently considered under the climatic region of "Southern Prairies"[8] (plate 6). The mean July temperature isotherm of 60° passes through this region. It is reported that the prairies have some of the coldest summers and some of the warmest winters of any of the regions of Canada. The character of the prairie winter is variable from year to year. The path and direction of air flowing through the polar regions and the amount of precooling which it has undergone before reaching the prairies determine the climate.

The prairies experience a rainy season from late May to early September, and the dry season occurs during the late autumn, winter, and early spring months. The records indicate that rainfall data are quite variable from year to year. The highest annual precipitation occurs in the eastern section of the prairies and in the foothills of the Rockies. It ranges from 20 to 25 in.

Only a limited portion of the Southern Prairies has an average frostfree period of 100 days or more. Less than 70 frostfree days occur north of the North Saskatchewan River.[8]

The northern extension of the Central Lowland in Canada coincides approximately with the "Northwestern Lands" climatic region (plate 6). Here the mean July isotherm of 57° passes along the Arctic Ocean near the mouth of the Mackenzie River and along the crest of the Rocky Mountains in Alberta (plate 5). At the 60° parallel it is reported that to the west of the divide between the rivers flowing eastward to Hudson Bay and those flowing north to the Arctic Ocean, the temperatures range higher than to the east of this line.[7] Temperatures averaging 16 to 25 F below zero in January indicate that the winters are bitterly cold along the Mackenzie River (plate 5).

The annual precipitation is 10 or 11 in. at the delta of the Mackenzie and at Fort Norman, and as high as 13 in. at Fort Smith, whereas it exceeds 17 in. at Fort McMurray. Generally there is more than an inch of precipitation per month only during the period May to November. In August the precipitation peak occurs at those stations above the Arctic Circle.

The data available concerning frostfree days do not reflect an overall average for the entire region. However, at Aklavik there are 65 frostfree days, at Fort Norman a period of 45 days, Hay River 87 days, and at Fort Smith 56 days. These periods are representative of the average interval between the last frost of the spring and the first frost of the fall.

Great Plains province. The Great Plains province in Canada has its southern boundary at the International Boundary. The Central Lowland forms its northern and eastern boundary. The western boundary is the Canadian Cordillera (plate 2). It is a shallow trough with Paleozoic and Mesozoic beds underlying the whole area (plate 4). The region was folded and faulted when the Rockies were formed. Extensive oil and coal deposits have been found in this province. A characteristic of the Great Plains province is that almost all the streams flow east from the mountains across the plains. In Canada the Great Plains province has been divided into the Arctic Plains, the Peace River Plains, and the Saskatchewan Plateau sections, of which only the last two mentioned are covered by this report (plate 3). One of the differences between the two sections is drainage; the Peace River flows into the Mackenzie, which drains into the Arctic Ocean, while the Saskatchewan River empties into Hudson Bay. The presence of local folding in the Saskatchewan Plateau and its absence in the Peace River Plains is another criterion by which the sections are distinguished. The Great Plains region is an area of scant rainfall with a yearly average of 10 to 12 in.

1) Peace River Plains. The Peace River Plains are bounded on the west by the Rockies and on the north by the Mackenzie River; to the east the Peace River Plains end in a scarp that overlooks the Mackenzie Lowland. The Athabasca River is the approximate location of the southern boundary. The section includes the northernmost part of Alberta and adjacent British Columbia (plate 3).

The rocks of the Peace River Plains are of Lower Cretaceous age (plate 4). They were much glaciated, and the surface deposits are largely a clayey till with a covering of black humus. Much shale and sandstone are found, with isolated cappings of Tertiary gravels present in the foothills. Coal, natural gas, gypsum, gold, and oil traces have been found. There are railroad, highway, and airport facilities in the southern portion of the Peace River Plains section. The greater portion of the area is wooded.

2) Saskatchewan Plateau. The northern boundary of the Saskatchewan Plateau is approximately the Atchabasca River; to the east the plateau overlooks the lowlands; to the south it merges with the Missouri Coteau near the Cypress Hills; to the west is the Cordillera (plate 3).

The Saskatchewan Plateau is drained by the Saskatchewan River drainage system. The section includes the southern half of the Province of Alberta and extends across the southeast corner of the Province of Saskatchewan. The highest elevations of the Interior Plains of Canada are found in this section. The plateau has an elevation of 5,000 ft at the base of the Rockies which decreases about 6 ft per mile in the eastward slope of the plateau. Near the mountains, streams have cut valleys with precipitous sides. Where Tertiary gravels still cap the area the resultant topography is mesalike. Some gravel deposits may be found in the lacustrine-soil areas. Other gravels occur in the form of kames and eskers.

The bedrock underlying the drift of the Saskatchewan

Plateau section are of Upper Cretaceous age, as compared to the Peace River Plains rocks of Lower Cretaceous age (plate 4). Several oil and gas fields lie in ridges produced by folds along the foothills of the Rockies. Important lignite deposits are found in both Cretaceous and Tertiary strata.

Edmonton and Calgary are two of the largest cities in the region. Edmonton, the capital of Alberta, is the center of an important mixed farming area. It is also the center of an important coal mining district, although in the city itself natural gas is used from the Viking, Kinsella, and Fabyan fields to the east. Tar sand deposits containing the largest known reserve of oil in Canada, are located north of Edmonton on the Athabasca River near Fort McMurray. Calgary, south of Edmonton, is the center of wheat growing and stock raising in Northwestern Canada.

Central Lowland province. This is one of the largest physiographic provinces in North America. In Canada it includes the Mackenzie Lowland and the Western Lake section and extends between the Laurential Upland on the east and the Great Plains and Arctic Rocky Mountains on the west (plate 3).

Ordovician, Silurian, and Devonian limestones and shales form most of the bedrock of the province (plate 4). There is Cretaceous material at the boundary with the Great Plains. There are some pre-Cambrian materials in the uplifted areas. Iron and coal are found on the fringes of the area.

1) Mackenzie Lowland. The Mackenzie Lowland is a region underlain by predominantly Paleozoic rocks covered with glacial deposits and contemporary alluvium (plate 4). The rock strata are continuous with the plains formation. The lowland lies between the Canadian Cordillera on the west and the pre-Cambrian Shield on the east (plate 3). Many feet of glacier-deposited boulders, gravel and sand have been covered by a finer mantle deposited by postglacial rivers. The Mackenzie River has cut a channel through the unconsolidated material, and flows between generally high banks of gravel and clay.[54:31]

The climate of the Mackenzie district is determined in part by the warm "chinook" winds.[43] The southern coast of Hudson Bay (55°N) has lower average temperatures than Aklavik and other settlements on the Mackenzie Delta (68° to 70°N).

The lowlands section is drained by the Mackenzie River and its tributaries. A succession of lakes and rivers occupies the Mackenzie Lowland belt. The largest of these are Great Bear Lake and Great Slave Lake and the Peace, the Slave, the Liard, and the Mackenzie Rivers. The Mackenzie River has an average width of one mile (in places 2 to 4 miles), an average fall of 6 in. to the mile and a total length, including the Peace and Slave Rivers from Lake Athabasca, of 2,514 miles; it drains 699,400 square miles. The Mackenzie River system flows through a generally broad, flat valley varying in width from a few miles to about 40 miles.[54:31] Much of the lowland is covered with lakes, muskegs and poorly-drained soils. The shallows of the Mackenzie are very tricky as the channels shift every season as a result of floods.

The Athabasca River flows north from Lesser Slave Lake through Lake Athabasca and Lake Clair, merging with the Peace River to become the Slave River. The Slave is a placid river for 70 miles, then there are 16 miles of rapids between Fort Fitzgerald and Fort Smith. There is a highway over the portage to bypass the only unnavigable stretch in 1,300 airline miles.[53] The Slave River follows a meandering course through an alluvial lowland. West of the river is a semiopen wooded plain. At Fort Smith the soil is quite sandy, but along the lower courses of the Slave River there are areas of deep clay with sandy beach ridges. The Slave River empties into Great Slave Lake at Fort Resolution.

Great Slave Lake is 518 ft above sea level. It is 325 miles long and from 15 to 50 miles wide, and has an area of 10,719 square miles. Its water is clear and deep, and its coastline is irregular. The northern and eastern shores lie in the pre-Cambrian rocks of the Canadian Shield, the southern and western shores lie in the Paleozoic formation of the Great Plains province (plate 4). Its western shores are wooded; the northern and eastern shores are barren. West of the Slave River Delta, the south shore of Great Slave Lake is low and rises gradually to the limestone Niagara (Silurian) Escarpment marking the northern edge of the Peace River Plains.[37:7] The lowland is wooded and is quite level with occasional swamps and areas of grasses. The settlement of Hay River, the terminus of the Mackenzie Highway, is on the south shore of Great Slave Lake. The Mackenzie Highway extends from the mouth of the Hay River to Grimshaw, Alberta, where it connects with the railroad.

Fort Providence is at the western end of Great Slave Lake, where the Mackenzie River begins its long journey to the Arctic Ocean. The Mackenzie River merges with the Liard River at Fort Simpson. The trading post of Wrigley, with a landing field 5 miles southeast on the east side of the river, is between Fort Simpson to the south and Fort Norman to the north. Two hundred and fifty miles north of the confluence of the Liard and Mackenzie Rivers, the Mackenzie is joined at Fort Norman by the waters of the Great Bear River which flow west from Great Bear Lake. The Mackenzie flows on north past Fort Norman .

Great Bear Lake, a treacherous body of water, is of very irregular shape with an area of about 11,660 square miles. It has a depth of 270 ft and is about 400 ft above sea level.

Norman Wells, about 50 miles north of Fort Norman, is 700 miles from the mouth of the river. The Mackenzie is nearly 4 miles wide at Norman Wells, the site of the Canol Project. The Canol Road and Pipeline went from Norman Wells across the Mackenzie Range to near Whitehorse, Yukon Territory.[13:67] At Fort Good Hope the Mackenzie flows between white ramparts 125 to 200 ft high through a gorge about 300 ft in width.[54:34] Soil on the plateau at Fort Good Hope consists of a covering of humus over clay subsoil.

The settlement of Arctic Red River is near the junction of the Mackenzie and Arctic Red River. Fort McPherson is on the Peel River near its junction with the Mackenzie. More than 100 miles before emptying into the Beaufort Sea, the Mackenzie River begins to divide into a series of channels that flow through the delta. Reindeer Depot is on the East Channel of the delta, and the reindeer industry is supervised from there. The town of Aklavik, the "metropolis" of the north, is on the West Channel of the delta.

Permafrost has been described as 100 ft deep at Norman Wells, 175 ft at Yellowknife, and 345 ft at Port Radium. Summer thawing extends about 3 to 10 ft under filled soil, and only 2 to 3 ft in wooded soil, and somewhat less under muskeg.[54:34] Frost danger is less along the riverbanks where air drainage is more active and the warmer waters of the north-flowing rivers have a temperate effect. In the Fort Providence area along the Mackenzie River in deposits of lacustrine clays no frozen ground was encountered.[2]

3. Canadian Cordillera

The Canadian Cordillera is a mountainous belt that lies between the Pacific Ocean and the Great Plains and embraces British Columbia, parts of Alberta, the Yukon, and the Northwest Territories. It is about 500 miles wide by 2,400 miles long, and includes three physiographic systems: The Rocky Mountain system on the east, the Intermontane (Interior) Plateau system in the middle, and the Pacific Mountain system on the west. The Rocky Mountain system in Canada breaks down into two provinces: the Northern Rockies in the south, and the Arctic Rockies in the north. The Intermontane Plateau system is composed of a series of low mountain ranges and plateaus, of which only the Stikine and Yukon Plateaus are covered in this report. The Pacific Mountain system, which includes the Pacific Coast Range and the low mountains of the coastal islands, is beyond the scope of this report and will not be discussed further.

The rocks of the Canadian Cordillera range from pre-Cambrian to Cenozoic in age. The youngest rocks and the most recent mountain building is found in the Pacific Mountain system. Metamorphosed sedimentary rocks and igneous intrusives characterize much of the Interior Plateaus; these are thought to be Paleozoic and Mesozoic in age. Relatively undeformed limestones of Proterozoic age constitute the thick Beltian series of the southern part of the Rocky Mountain system.

Rocky Mountain system. The Rocky Mountain system in Canada is characterized by parallel ridges of sedimentary strata which have been either thrust eastward over the younger rocks of the Great Plains or simply domed upwards in curvilinear arches. Erosion has followed the outcrop of the weaker beds, thus emphasizing the parallel grain. The rocks of this mountain system are almost entirely unaltered sedimentaries; igneous rocks are notably absent.

The most striking feature of the Rocky Mountain system in Canada is the Rocky Mountain Trench, a straight narrow trough which parallels the northwest-southeast trend of the Rockies from Montana to the northern boundary of British Columbia. It is occupied from south to north by the headwaters and tributaries of the Columbia, the Fraser, the Finlay, the Peace, and the Liard Rivers. Parts of the Pelly and Yukon River drainages lie within its less-distinct continuation into the Yukon Territory.

1) Northern Rockies. The Northern Rockies in Canada comprise the Canadian Rockies east of the Rocky Mountain Trench, and the Purcells, Selkirks, and the Columbia Range to the west. The Laird River on the north, the Intermontane Plateaus on the west, the International Boundary on the south, and the Great Plains on the east delimit this physiographic province.

The steel-gray limestone ramparts of the Canadian Rockies, rising abruptly to 13,000 ft from the plains on the east, are a familiar sight to any traveler in this part of Canada. Extending 1,000 miles to the northwest and averaging 70 miles in width, they form a series of parallel ridges with precipitous eastern faces and gently inclined western slopes carved from essentially flat-lying pre-Cambrian strata. This reflects their structure -- a series of fault blocks thrust eastward over the younger rocks of the plains. This overthrusting has caused intricate folding and faulting in the foothills, where coal, oil, and gas deposits are found. The Continental Divide follows the crest of the highest ranges and also marks the Alberta-British Columbia boundary throughout much of its length. The high peaks are notched in the north where the Peace River cuts through them, and to the south many troughlike depressions transect the mountains forming passes, of which the Yellowhead Pass on the headwaters of the Athabasca River at 3,700 ft is best known. In the Canadian Rockies there are many glaciers, the Columbia Icefield being the most famous.

The Purcell Range is bounded on the east and north by the Rocky Mountain Trench, to the west by the Purcell Trench, in which lies Kootenay Lake, and dies out to the south at the Canada-United States border. The range is composed of massive quartzite, which holds the fault-block Purcells up to a fairly uniform and unspectacular elevation of 7,000 to 8,000 ft. Glaciers are few and small.

The Selkirks, bounded by the Purcells on the east and on the west by Selkirk Trench, in which the Columbia River lies, are cut off by the Rocky Mountain Trench to the north and by the Kootenay River to the south. These are also fault-block mountains and rise to elevations of 10,000 to 11,000 ft, supporting many glaciers. They compare in ruggedness and scenic grandeur to the Canadian Rockies to the east.

The Columbia Range lies to the west of the Selkirks, with the Rocky Mountain Trench to the north, the Interior Plateaus to the west, and the International Boundary to the south as its other borders. Elevations are about 7,000 to 9,000 ft, and the higher peaks support some glaciers. Geologically the area is complex and bears a close affinity to the Interior Plateaus on the west with its folding, metamorphism, and igneous intrusions.

2) Arctic Rockies. The Arctic Rockies are confined to the Yukon and western Northwest Territories north of the Liard River. They consist of the Mackenzie Mountains west of the Mackenzie River, the Franklins to the east, and the Richardsons west of the Mackenzie River Delta along the Arctic Coast. In contrast to the thrust-block Northern Rockies, the Arctic Rockies are linear, domed structures with the sedimentary rocks arched across them.

The arcuate Mackenzie Mountains are the largest of the three ranges, attaining elevations of 7,000 to 9,000 ft and extending for 450 miles north-south. The abandoned Canol Pipeline between Norman Wells and Whitehorse crosses the 100-mile breadth of the Mackenzies near their highest point, 9,800-ft Keele Peak. The eastern ranges are made up of parallel ridges deeply incised by streams draining to the Mackenzie River and hence are called the Canyon Ranges. To the west of these lie the higher, rugged Backbone Ranges in largely unmapped country. The rock seems to be chiefly limestone.

The Franklins form a low, narrow, disconnected belt of parallel limestone ridges about 4,000 ft high east of the Mackenzie River. They are eastern outliers of the Mackenzie Mountains and in their southern part swing west to join the main ranges. At Camsell Bend, where the Mackenzie River cuts through the southern end of the Franklins, it makes a pronounced change in course from the westerly direction of its upper reaches to the generally northwest trend which this river maintains from Camsell Bend to the Arctic Ocean.

The Richardson Mountains are the continuation of the Mackenzie Mountains north of the Peel River and west of the Mackenzie River. They are a low, treeless range 4,000 to 5,000 ft high, paralleling the west bank of the Peel River north to the Mackenzie River Delta. Here they swing westward following the Arctic Coast, and gradually rising in elevation, merge with the Brooks

Range of Alaska. The geology of these mountains is poorly known.

Interior (Intermontane) Plateau system. The Interior (or Intermontane) Plateaus form a belt of plateaus and low mountains 200 miles wide and 2,200 miles long between the Rocky Mountain system on the east and the Pacific Mountain system on the west. To the north, this system is continuous with the Central Alaska Plateaus and Plains, and to the south is terminated at the junction of the Cascade and Columbia Ranges near the International Boundary.

Geologically, the Interior Plateaus consist of relatively undisturbed, younger sedimentary rocks on the west and a narrow mountainous belt on the east with folded, much intruded and metamorphosed older rocks. The plateau surfaces have been deeply incised by streams which flow 1,000 ft or more below the general plateau elevations.[37] Valleys are filled with gray, glacially derived, rock-flour silt; there is little clay.

Since only the Stikine and Yukon Plateaus were investigated in this reconnaissance, the other sections of the Interior Plateaus (Fraser Plateau, Porcupine Plains) will be omitted from this discussion.

1) Stikine Plateau. The Stikine Plateau is north of the Fraser and south of the Yukon Plateaus (plate 3). It is rugged on the east adjacent to the Rocky Mountain Trench and levels off towards the west. Average elevation is 5,000 ft, but in the east the Cassiar and Omineca Mountains attain elevations of 8,000 ft. The plateau was glaciated, leaving the valleys U-shaped and flat-bottomed with alluvial deposits. The Stikine and the Taku Rivers, which flow west, drain the plateau.

2) Yukon Plateau. The Yukon Plateau is the largest of the Interior Plateaus. It extends from northern British Columbia across the southwestern part of the Yukon Territory into Alaska. It is an area of many plateaus and mountains. Typical rocks are igneous and metamorphic. The 500-mile-long Tintina Valley runs longitudinally throughout the central part of the Yukon Plateau and

appears to be a continuation of the Rocky Mountain Trench. The trench is occupied by parts of the Pelly and Yukon Rivers.

The northern half of the Yukon Plateau -- the Klondike Plateau -- was never glaciated.[37:11] The southwestern part of the plateau was glaciated, and as a result of glaciation some of the longest and most attractive finger lakes in the world were formed. These include Atlin Lake, Tagish Lake, Teslin Lake, Lake Laberge, and Kluane Lake, each having a length of 50 to 100 miles or more. The Yukon Plateau is an area of low rainfall, and generally sands and gravels overlie silt deposits in the valley bottoms. Major cities on the Yukon Plateau are Dawson in the north, and Whitehorse in the center.

The Selwyn and Ogilvie Mountains lie within the Yukon Plateau section and represent the transition from the tablelands on the west to the Mackenzie Mountains on the east. The Selwyn Mountains, the more southerly of the two, attain elevations of 6,000 to 7,000 ft. The Ogilvie Mountains, north and east of Dawson in the Klondike, rise 5,000 to 7,000 ft. Though these two ranges lie adjacent to the Arctic Rockies province, they differ from the latter in having complex structure and igneous intrusions, which are notably absent in the Rocky Mountain system.

II. INFLUENCE OF SOIL-ROCK MATERIALS

Remarks on Airphoto Interpretation

The form and composition of the earth's surface materials are the result of erosion, which has been acting since the beginning of geological time. Each rock or soil type has a characteristic landform which reflects both the inherent physical properties of that material and the climatic conditions by which the landform is produced. For example, sandstone is relatively resistant to erosion and will stand as a ridge, while softer surrounding shales are eroded from around it. Limestone, being soluble in water containing carbon dioxide, generally develops a subdued sinkhole-pitted topography in moist climates; it is a ridge-former under arid conditions. Granular soils, because they are well-drained internally, develop only a few steep, V-shaped gullies; clay soils are impermeable, and rainfall drains across the surface, resulting in many U-shaped gullies in humid climates and in "badlands" topography under semiarid conditions.

A basic principle of airphoto interpretation is that like materials, under like topographic and climatic conditions for equal lengths of time, will produce identical airphoto patterns. An excellent example of this principle is the remarkable uniformity in the airphoto pattern of the Wisconsin glacial drift throughout Ohio, Indiana, and Illinois.[14] Any difference in conditions will affect the type and degree of soil development. Material in a humid climate weathers much more rapidly than does the same material in a dry climate. Material which has been exposed to weathering processes for a long time develops deeper soils than material which has been exposed for a shorter length of time.

Aerial photographs present a record of the earth's features in a form that enables one to study the area thoroughly. From a detailed analysis of the airphotos an experienced interpreter can determine many characteristics of earth materials. The interpreter must be able to evaluate such features as landforms, drainage patterns, gully shapes, color tones, and vegetation. The information that he can glean depends to a large extent upon his background and experience. His work will be accelerated if he has some knowledge of geology, pedology, forestry, climatology, and geography.

Papers and reports have already been written on the use of airphotos for engineering soil studies. Some of these go into considerable detail on the methods of using airphotos and the descriptions of some of the typical features of the most common soil patterns. Because this information has been adequately presented elsewhere, the basic principles of airphoto interpretation are not covered in this report. A number of papers are listed in the references.[15,16,31]

Although the primary purpose of the program was the identification and evaluation of permafrost conditions, the party encountered no permafrost along the Alaska Highway. Conversations with officials of the Northwest Highway System revealed that permafrost has not been much of a problem along the Canadian portion of the highway. Permafrost is found in some spots in the vicinity of Whitehorse, but only about half a dozen sites were named as "permafrost problems" along the highway: Mile 558, Mile 828, Mile 1048, Mile 1084, Mile 1121 to 1156, and Mile 1221 to the Alaskan border.

According to Raup and Denny,[52] the highway was built over permafrost for about 19 of the 275 miles between Whitehorse and the Liard River, or 6.9 percent of the distance. South of that point practically no permafrost was encountered. This serves to emphasize the point that permafrost is not a great problem along the southern part of the Alaska Highway.

In the following sections, airphotos are discussed under these physiographic headings: the Great Plains, the Rocky Mountains, the Interior Plateaus, the Mackenzie Lowland, and the Keewatin and Barren Lands sections of the Laurentian Upland. Each physiographic section in turn is subdivided into glacial, water-deposited, wind-deposited (where applicable), and bedrock materials.

Great Plains

The Great Plains extend from the Mexican border for 2,300 miles north into west-central Canada. With an average width of 300 miles, the region lies east of the Rocky Mountains in a semiarid rainfall belt. Wheat growing and grazing are the chief economic activities.[37]

The areas that were studied are located in the Peace River Plains section, which is the northernmost part of the Great Plains. The section is underlain by Lower Cretaceous sediments and is traversed by three main streams: the Athabasca River along the southern margin, the Peace River through the middle, and the Liard River across the northern edge.[37] The foothills of the Rockies are included in this section, although its topography has the general appearance of mountains.

In contrast to the plains to the south, this region is covered with forests. This is due to the fact that evaporation is less than it is farther south, and although rainfall is light, there is sufficient moisture in the earth to support tree growth.[1]

To the north and west the section is well dissected, and sandstone ridges are prominent; sandstone is used for road materials through much of the area.

The entire region has been glaciated.[52] Glacial boulders were found near the top of Trutch Mountain, over 4,000 ft above sea level. Gravels are scarce except near the mountains. There are large terraces along the main rivers. At some sites, however, residual materials were found at the surface.

The Alaska Highway with several short side roads is the only all-year transportation route across the Peace River Plains. Several trails are usable only in winter.

1. <u>Glacial materials (Peace River area)</u>

At Mile 35 the Alaska Highway crosses the Peace River over a 2,300-ft suspension bridge. The swift-flowing Peace River has cut a deep channel across the plains. From examination of the area it appears that a large preglacial drainage channel was filled in by drift. The glacial river carved out a wide channel that was partially filled with gravel. The smaller river of present time has cut through the gravel and into the underlying shale, leaving a hundred feet of the terrace gravel exposed. In a gravel pit (indicated by E on fig. 1) are found all sizes of granular material from boulders to sand. Some layers are rather firmly cemented. This terrace is about 1,000 ft wide, capped by a second terrace which stands about 15 ft higher, and extends for about 2 miles. The first half of the second terrace is level, then it slopes gently to the upland.

The upland soil is black and waxy and has a nutlike structure which indicates that it is probably a residual soil developed from shale. This soil is found at the surface at point A as shown in figure 1. Geologically, the area is mapped as Lower Cretaceous.

Between point A and the terrace at C there are evidences of glacial materials. It is probable that the postglacial river has not removed all the drift that was deposited in the large preglacial channel. At point C, which is at the escarpment of the upland, the road ascends through a long, deep gully. Examination of material near the road at point B revealed drift characteristics. A hundred feet above the road near the top of the gully at this point, some fine, cemented silt is exposed.

Along the escarpment and the edge of the major gullies are "scallop" gullies (fig. 2). Bushy vegetation makes these appear dark on the airphotos, while the high, drier slopes have sparse grassy vegetation and appear lighter on the airphotos. This escarpment has two slopes. The underlying shale has a dip of about 30 degrees along the scarp, while the slope of the drift is much steeper, about 45 to 50 degrees. At the scarp at C (fig. 1) the drift is 60 to 80 ft deep, then less than a mile north at site A, shaley soil is found at the surface.

The surface of the drift is fairly level to undulating. Top of drift is over 100 ft above the terrace. Deep gullies of fairly shallow gradient extend back from the escarpment. Gully sides have shallow slopes for the top 30 ft and are steeper (50 to 60 degrees) below that.

Color tone is light to dark and somewhat mottled. Most of the area in the locality has been cleared and is used for farming or pasture. There are a few small undrained depressions. Some data were obtained at several locations, which are shown on the mosaic in figure 1. Drift on shale was found at site B. Along the Alaska Highway at the edge of the escarpment at site C, drift on shale was found. Some silt was exposed at the top of the gully. At site D "scallop" gullies were examined. The dark streaks are due to bushy vegetation in shallow gullies. Light streaks are on higher dry slopes which have only sparse grassy vegetation. Face of the escarpment has two slopes on it, which indicates two different materials. In this case, it is drift on shale. The drift has a steeper slope than shale.

2. Water-deposited materials (Peace River area)

The surface of the terrace is flat, but it slopes gently upward near the upland. Moderate gray color tone is not mottled. The land is highly cultivated. The terrace face has a steeper slope than is ordinarily found on terraces. A strip about 1,000 ft wide, adjacent to the face, is 15 ft lower than the rest of the terrace. Gullies are generally deep but short, and extend back from the face of the terraces. Usually the large gullies in the upland do not extend across the terrace, but the upland runoff drains internally through the terrace. Gullies are V-shaped with smooth sides. The gravel pit at site E (fig. 1) is shown in figure 3. Size ranges from sand to large boulders. Some of the layers of stratified gravel are cementatious.

3. Bedrock materials

Sikanni Chief Airstrip (Mile 148). This area is in the Peace River Plains. Although the area has been subjected to glaciation, the soils are predominantly residual. The strong sandstone ridges have an important effect on the topography.

At Mile 145 is a high, flat, sandstone ridge that is underlain by shale. The top of the ridge has a shallow slope, but its escarpment is relatively steep. The shale has a shallower slope on its surface and breaks off gently at the edge of a major gully system. The vertical airphoto in figure 4 shows some of these features.

The airstrip is located on shaley soil. The Beatton River flows along here, although it is a small stream about 15 or 20 ft wide. At Mile 149 some soil was found that appeared to be lacustrine clay. Adjacent to the west end of the airstrip is a small muskeg with 2 ft of peat on a shale soil.

Peace River. Although this area has been glaciated, residual shale soil is found at the surface near the Peace River (see fig. 1, site A). Along the escarpment the shale has a slope of about 30 degrees, and the shale and the soil which developed from it are black. The soil color is modified by vegetation. The black color of the shale, where it is exposed beneath the terrace along the river, is clearly discernible on the airphotos. At site A the profile is 6 in. of peat on 12 in. of dry B-horizon with nutty-structure, which grades into the shaley material. Pebbles were found in the profile, indicating probable glaciation. Residual shale clay was found at the bottom of an adjacent gully.

Rocky Mountains

The Canadian Rockies are a long narrow strip of overlapping parallel ranges, predominatly of limestone, that were formed by an eastward thrust of massive pre-Cambrian and early Paleozoic strata.[37] The Alaska Highway crosses the northern tip of the Rockies; this is the area of the province that was studied as a part of this project.

The "foothills of the Rockies" are a piedmont area about 50 miles wide adjacent to the eastern face of the Rockies. Although they are generally classified as a part of the Great Plains, they present a rough topographic appearance. The limestone mountains rise abruptly above the foothills. The elevation of the pass at Summit Lake is 4,256 ft. There is an abundant supply of construction materials and water in the Rockies, but location is a serious problem. Generally the highway follows along the narrow channel of one of the swift-flowing rivers. Glacial deposits are common in the valleys with terraces of drift or gravel over a hundred feet high. Huge boulders are found in the riverbeds.

Most unusual of the landforms in this area are the "hoodoos," pinnacles of cemented glacial material which are left standing as the surrounding materials are eroded away. These were observed at two locations, although they are known to exist at one or two other places in this area and at other distant locations: Banff and Drumheller in Alberta. At Mile 394 several hoodoos were observed from a distance and appeared to be a driftlike material of boulder-clay (fig. 5). Hoodoos at Mile 471 were examined closely and found to be composed of cemented rock-flour silt.

1. Water-deposited materials (Muncho Lake)

At the mouths of several of the deep gullies at Muncho Lake, large alluvial fans have been deposited by the seasonal movement of water from the mountains. Some of these fans have extended out into the lake in a delta form. The fans are composed of granular materials that were derived from the rock in the mountains. They vary in size from sand particles to large boulders. Granular composition is indicated on the airphotos by the disappearance of the stream channels near the lake. Evidently much of the runoff infiltrates beneath the surface.

At the southern end of the lake, bedrock is limestone; to the north, the rocks have been metamorphosed. Fans at the north end of the lake seem to have more vegetation than those to the south. This may be due to the difference in the ages of the deposits or differences of the parent materials. Figure 6 shows a fan to the north of the Toad River at Mile 436.

2. Bedrock materials (Muncho Lake)

The mountains in the vicinity of Muncho Lake are mapped as Paleozoic rocks, mainly sedimentaries. Some of these rocks have been metamorphosed. In figure 7 both sedimentary and metamorphic rocks are shown.

The sedimentary rocks, which are a light gray limestone, have a light appearance on the airphoto. Although the mountains were originally formed by overthrusting, they have been deeply dissected. Slopes are steep and the gullies are hundreds of feet deep. Important identification features on the airphotos are evidences of stratification, the sharp, angular intersections of slopes, and little vegetation.

The metamorphic rocks have more rounded features, there is less evidence of stratification, and vegetation is heavier than on the limestone.

Interior Plateaus

This province is a long belt of rugged country that is bordered on the east by the Rocky Mountains and on the west by the ranges of the Pacific Coast system. The province is divided into a number of sections: Porcupine Plains, Ogilvie Mountains, Selwyn Mountains, Yukon Plateau, Stikine Plateau, and Fraser Plateau.[37] The Alaska Highway crosses the southern end of the Yukon Plateau and the northern tip of the Stikine Plateau. Considerable study was made of the Whitehorse area in the southwestern part of the Yukon Plateau.

Whitehorse is located on the banks of the Yukon River (formerly known as the Lewes). Canyon Mountain, a long, symmetrical limestone ridge, lies east of the river. To the west, the valley is bordered by several peaks and ridges that are separated by drift-filled depressions. The preglacial valley is floored with silts and boulder-clays, and the Yukon has cut its present channel through these deposits.[38]

Carboniferous limestones are the oldest known rocks in the area. These have been largely destroyed by several igneous intrusions. Later basalt flows from the valley of Hoodoo Creek extended as far down as the Whitehorse Rapids. Boulder-clays and silts were deposited during the glacial period.[38]

From an examination of a number of airphotos taken in the vicinity of Whitehorse, it has been observed that slopes facing to the south are steeper and have less vegetation than those facing to the north. This feature is particularly pronounced in the granular deposits. It is common to find many of the granular south-facing slopes devoid of vegetation (figs. 13 and 16). Although it is not as noticeable on the airphotos of the silt and rock areas, these same conditions seem to prevail generally. Analysis of this phenomenon on Canyon Mountain is complicated by the fact that the sedimentary strata are tilted. However, it should be remembered that these observations were made from the examination of only a small number of prints in the vicinity of Whitehorse.

1. Glacial materials

Whitehorse silts. The Yukon River has cut down through 200 ft of rock-flour silts at some places in the vicinity of Whitehorse. These rock-flour silts are a very light gray and are firmly cemented in stratified layers (fig. 8).

The silts represent accumulations of the fine materials brought down by glacial streams and deposited in slack current or still water. They were not deposited in one large continuous sheet of water, but in separate basins and at different elevations. In some cases these basins in which silt was being deposited were subsequently covered with boulder-clays by the advancing glacier. Silts with similar characteristics to these in the Yukon Valley are being laid down at the present time at the upper end of Kluane Lake by the Slims River, which drains from the Kaskawulsh Glacier.[38]

The Whitehorse Airport is located at the top of a 200-ft silt bluff overlooking Whitehorse. This bluff is very steep, from 60 or 70 degrees to almost vertical in some places. In wet weather the saturated silts tend to flow. During the summer of 1951 a road was closed by landslides caused by the "flowing silt" (fig. 9).

Figure 10, a stereopair, shows the silts at a site several miles north of Whitehorse. The slope is steep and almost white in color. The surface is undulating. Vegetation is sparse, but timber may have been cleared or burned. In the southwest corner of the photo is a high terrace remnant where glacial boulders were found. Views of riverbank exposures of the silts are shown in figures 11 and 12.

Miles Canyon. Deep deposits of granular materials are found in the valley in the vicinity of Miles Canyon (figs. 13 and 15). The underlying rock is basalt which extends downstream as far as the Whitehorse Rapids. The Yukon has cut a narrow gorge through the columnar basalt at Miles Canyon.

Adjacent to the river the granular deposits are rough with a kettle-kame type of topography (fig. 14). There are a number of depressions with no surface drainage (kettles). Several of these contain water, but it can be seen that the level is receding. The granular material takes a fairly steep slope of 45 or 50 degrees, but it is not as steep as the silt bluffs.

Yukon Dam. In the vicinity of the Yukon Dam are some deep granular deposits. At several places sands over 200 ft deep are exposed. Some of the deposits are unsorted granular materials. Several places where the materials were observed are marked on the stereopair in figure 16.

The topography is rough in this locality. Several terrace elevations can be seen on the airphotos; in addition, there are kames and eskers. At several places the slopes have been undercut by streams which caused the sands to slide. These bare slopes are too steep for vegetation, 40 to 50 degrees, and appear almost white on the airphotos. Except for these steep exposures, the surface is generally covered with some scrubby timber (figs. 17 and 18).

2. Bedrock materials (Canyon Mountain)

Canyon Mountain is a long limestone ridge on the opposite (east) side of the Yukon River from Whitehorse. The limestones in this area are generally a pure carbonate of very light color.[12] The mountain is high and very steep in some places, which can be seen on the stereopair in figure 19. The surface features are generally rounded (figs. 20 and 21). Much bare rock is exposed; but there is vegetation where soil cover exists, which is usually in the gullies.

Mackenzie Lowland

The Mackenzie Lowland section is a physiographic subdivision of the Central Lowland province of North America as outlined by Lobeck.[37] It is a region underlain by rocks similar to those of midwestern United States. It is a lowland drained by the northward flowing Athabasca, Peace, Slave, and Mackenzie Rivers, and contains the western portions of Great Slave Lake and Great Bear Lake. North of Camsel Bend the underlying bedrock is an important feature of the topography and forms several anticlinal ridges, low mountains, and uplifted scarp faces. The Horn Mountains, Franklin Mountains, Caribou Hills, Grooved Plains, Mackenzie Delta, and Arctic Coastal Plain are divisions of the Mackenzie Lowland.

The Mackenzie Lowland section is underlain for the most part by nearly flat-lying beds of limestone, sandstone, or shale of Silurian and Devonian age, and sandstones and shales of Cretaceous and Tertiary age.[6:55] Cretaceous (?) materials of sandstones or shales were observed along the banks of the Mackenzie River in the vicinity of several prominent landmarks, such as the mouth of the Dahadinni River; for about 50 miles south of the Ramparts; and from around Fort Good Hope north to the Mackenzie River Delta. Tertiary (?) sands, clays, and/or gravels were observed at the mouth of the Great Bear River near Fort Norman. All of these deposits have been overridden by glacial ice from either the continental ice sheet from the Canadian Shield or by mountain glaciers from the Cordilleran Mountains to the west.[6:77] The results of glaciation are revealed by erosional surfaces in the plains, hills, and mountains of the Mackenzie Lowland. Generally, glaciation has affected the lowland by filling in preglacial channels and leaving in its wake ground moraines and outwash plains of large areal extent.

Depositional forms, such as eskers and kames, are found in the lowlands, and there are several areas where granular outwash mantles the boulder drift of the ground moraines. (Due to the large areal extent of the lowland and the many variations observed in preliminary study of airphoto mosaics and on reconnaissance flights, it is impossible at this time to give intricate details of soils and permafrost in the various regions of the Mackenzie Lowland. A few of the airphoto patterns will be discussed and those particular sites investigated will be reported.)

The eastern border of the Mackenzie Lowland is the contact between the Paleozoic materials of the lowland and the pre-Cambrian materials of the Laurentian Upland of the Canadian Shield. This contact zone extends from the western end of Lake Athabasca, across the east arms of both the Great Slave and Great Bear Lakes, and up the Horton River to Darnley Bay on the Arctic Ocean. The southern border is well defined by the escarpment of the Peace River Plain. The western border is marked by a line along the foot of the Mackenzie Mountains, the escarpment of the Peel River Plateau, and the Richardson Mountains and extends to the Arctic Ocean. The northern border is the Arctic Ocean from the Richardson Mountains east to Darnley Bay.

The southern section to the base of the Horn Mountains has been covered by lake-bed sediments of Great Slave Lake. From the Horn Mountains to the delta, the lowland is a plain with essentially flat-lying bedrock mantled with glacial drift, and in some places lake-bed sediments of Great Bear Lake. North of this region is the large delta plain of the Mackenzie River and the large coastal plain which extends from the delta east to Liverpool Bay. A portion of this northern region supports low tundra vegetation. The banks of the Mackenzie River and its tributaries are rarely over 50 ft high in the southern and delta portions, but range from 50 to about 250 ft in the central portions. Figures 22 through 24 show variations in cutbanks and terrain along the Mackenzie River and its tributaries.

1. Glacial-deposited materials

During or after the continental glacial period the large water bodies of Winnipeg, Athabasca, Great Slave, and Great Bear Lakes occupied a much greater area than at the present time. Evidence of much higher beach ridges indicating, in part, a higher lake elevation are found on the Canadian Shield portions of both Great Slave and Great Bear Lakes. Also, on the western ends of these lakes, a great number of beach ridges are evident on the lowland. Figures 25 and 26 are stereopairs of concentric beach ridges of the old lake beds.

The beach ridges in figure 25 are low, but they do stand out from the lake bed by the contrast in vegetation. Due to the narrow distance between ridges, it is believed that these ridges indicate periodic changes in lake level; therefore, the material of which the ridge is composed would be sandy. This is also revealed by the vegetative cover of aspen and jack pine which grow in rather dry soil, as shown in figure 27.

A few of the concentric ridges in the lake-bed area are fairly large and may indicate earlier periods of constant lake level. These ridges would be expected to contain more gravel. Such a ridge is illustrated in upper portion of figure 26.

Inland from the lakeshore and between the beach ridges, there are depressed center polygons in the muskegs and poorly drained portion of the lake-bed sediments, as shown by figures 28 and 29. Some of the narrow troughs do not contain typical polygons, but on the airphotos a definite pattern due in part to frost action can be distinguished, as shown in figure 25. Figures 30 and 31 show the vegetation changes from muskeg to beach ridge. Tests revealed frost at 30 to 40 in. in the depressed troughs, and the profile consisted of about 2 ft of peat on frozen silty clay. Except for the sand-beach ridges, which would be expected to have a deep permafrost table, the lake-bed material is permanently frozen at depths of approximately 3 ft, because the insulating peat mat is relatively thick. It was observed that where the peat had been burned out, the frost line was much deeper.

The old Great Slave Lake bed is dissected by a few rivers. In the area adjacent to the rivers, the beach ridges have been eroded away in some places and the surface materials are stratified alluvial materials. In the Hay River area the alluvial material is predominantly sand, as shown by the steep banks (fig. 32). In other places -- e.g. along Trout River -- coarse granular material which may have been deposited by water overlies the lake-bed clays, as shown by figure 33. Farther inland along the banks of Hay River are vertical scarps developed in stratified limestone. Rapids and waterfalls can be observed on the airphotos. A thin mantle of lake-bed material overlies the limestone and is revealed by concentric beach ridges as shown in figure 34.

A few eskers and kames were observed on aerial mosaics, especially in the western portion of the Mackenzie River basin between Norman Wells and Fort Good Hope. Figure 35 illustrates an airphoto pattern of eskers with outliers of a few kame mounds. The esker has a characteristic serpentine form with narrow crest and steep side slopes, while the kames are somewhat rounded mounds. Since the esker seen in the illustration follows the shore of several lakes, it is believed that the lakes are water-filled kettles of a ground moraine. A few of the lakes in the area may be thermokarst lakes, which are the result of the upset of thermal balance. In many areas this upset may be caused by forest fires.

The region surrounding the esker in the illustration appears to be a "till" ground moraine. The gullies are broad but saucer-shaped, and the topography is gently rolling. Evidence of soil flow due to frost action resulting in solifluction appears as a streaky pattern in the center of figure 35. (More detailed ground investigation is necessary to establish the amount and type of permafrost.)

In the Ontaratue River area between Norman Wells and Fort Good Hope observations made from the airphoto mosaics and during a reconnaissance flight indicate that there are sections of terrain some 10 to 20 miles wide and 50 to 80 miles long with a northwest trend containing hundreds of very irregularly shaped, shallow lakes. The regions on either side of this type of terrain had considerably fewer lakes and appeared to be better drained internally. Examination of the airphotos indicates that some of the lakes with steep banks and leaning trees may be thermokarst lakes. It is believed that there is a tendency for large masses of ground ice to exist. Figure 36 shows such lakes along Ramparts River. Notice that the recent alluvium, indicated by abandoned channels, does not show evidence of thermokarst thaw and subsidence. The recent alluvium lying within the meander belt (indicated by arrows in fig. 36) is probably not frozen.

Upset of thermal balance, probably due in part to "burns," is shown in figure 37, where several landslides along the Hume River have occurred. Thermokarst lakes also occur in the upland, and many have smaller lakes within a larger lake. These smaller lakes were rimmed with vegetation. At another location along Hume River a small landslide was investigated on the ground. Figure 39 shows ground views of the slide and exposure of ice within the slide area. A large amount of ground ice was found under the thick moss and peat overhang. Underlying the peat were stratified layers of frozen sand and silt with some layers of gravel. All exposed banks along the Hume River showed stratified materials with sand predominating. The absence of abandoned channels on the airphotos, combined with stratification, would tend to indicate materials that may have been deposited and sorted by glacial outwash action. (Further ground investigation and subsequent study of the airphoto patterns are necessary before the materials can be classified as to origin.)

Another type of landslide (slumping) was noted along Mountain River and is illustrated in the stereopair of figure 38. The V-shaped gullies and steep bank indicate that the material is coarse-textured sands and gravels of an outwash terrace formation. Thermokarst lakes are absent, although in the upland there are some obliterated lakes in shallow depressions. The aspen growth on the well-drained soils is evident by the white specks visible on the illustration. Ground study indicated that the sand was previously frozen, and that the landslides were caused more by undercutting action of swiftly flowing streams than by the thawing of permafrost.

Boulder clay was observed in several upland areas and along cutbanks of the Mackenzie River. The topography was gently rolling. Details of airphoto patterns of these materials that form "till" ground moraines are not available at this writing. As mentioned previously, much of the drift deposits of boulder clay are overlain with sands and gravels of outwash origin, and on any one airphoto mosaic it is difficult to differentiate these changes at this time without more pertinent field investigation by deep drilling methods. The methods used in the field for securing profile information were inadequate, as frost and gravel prevented deep penetration with the hand tools used.

Throughout the Mackenzie Lowland section are numerous ridges of glacial origin that contain granular materials. On airphotos they are low topographic ridges somewhat drumlinoid in form. They do not look like eskers as they are much wider and not so prominent. They may be kames, but such a landform could not be definitely identified on the photos because of dense vegetation. They occur in clusters that give parallelism to the airphoto pattern. Some of these ridges were observed on the Canol Road and an exposure was examined on the St. Charles Rapids portage road on Great Bear River. Figure 40 shows an oblique view from the air, and figure 41 shows a ground view of the ridge near

Great Bear River. The ridge was predominantly coarse sand with numerous angular gravel particles, and some stratification with coarser beds was evident. This gravel deposit was high topographically, and was well drained. No evidence of permafrost was found.

At another location near the north end of the portage road there were gravel deposits overlying thinly bedded shales that were permanently frozen. These gravels appeared to be glacial outwash deposits. Figure 42 is a closeup of these deposits at the north end of portage landing. The gravel was estimated to be about 25 ft deep overlying at least 50 ft of exposed shales above Great Bear River.

A boring made farther inland from the river showed very bouldery material with silts and sand around the large boulders. No frost was encountered in the shallow hole. The surface material was an organic silt and the underbrush was quite dense, as shown in figure 4[illegible] The local topography was somewhat hummocky and the forest cover was predominantly white spruce.

2. <u>Water-deposited materials</u>

One of the greatest difficulties in the interpretation of airphotos of the Mackenzie Lowland is differentiating the origin of the stratified sands and gravels found so extensively in the area. Dense vegetation also limits application because it obscures the abandoned channels and other evidences of water action. In this section and the previous subsection, some of the glacial deposits may have been classified as glacial-deposited when they should have been classified as water-deposited. Both agents have influenced to a greater or lesser degree the airphoto patterns of the Mackenzie Lowland. Only more detailed data will reveal errors if they have occurred.

Many terraces or benches occur along the major valleys of the Mackenzie Lowland section, and these landforms may be identified on airphotos by their small areal extent, flat topography, steep faces, and contrasting vegetation of well and poorly drained materials. Also, the gullies that have developed are V-shaped in character and have very steep, short gradients.

At Wrigley the airfield is constructed on an outwash terrace remnant that has been left in its elevated position by change in the channel and by downcutting of the Mackenzie River. Figure 44 shows a view of the airfield looking east across a valley to the Franklin Mountains. Figure 45 is a closeup of the exposed gravel underlying the terrace. No evidence of permafrost was found in the upper portion of this terrace. North of the terrace, in the trough, frost conditions varied with topography, vegetation, and soils. Some of the areas have been burned, as shown by figures 46 and 47. A trek was made inland along the survey trail for about 5 miles, and depth to frost was found to vary from 10 to over 40 in. depending on moss and peat cover. In the low slack-water areas, the survey trail had settled as much as 2 ft because of removal of vegetation. Trees along the trail were leaning towards the survey trail as shown in figures 47 and 48. Very little settlement of soils was observed in higher topographic positions. The depth of the active layer was not determined. A test pit dug in the lowest portion of the survey trail showed frost at about 10 in. underlying a thick peat horizon. The low topograpic positions had been eroded by running water while the high topographic positions were deposits of drift as morainic ridges, or outwash terrace remnants.

Two terrace levels are indicated in figure 49. These terraces were observed along Mountain River, and the lower terrace was covered by muskeg with an approximate 4-ft peat mat, underlain by frozen stratified silts and sands. The low terrace is about 30 ft high, while the upper terrace is approximately 100 ft or more. The upper terrace showed a profile of about 8 in. of moss and humus overlying stratified beds of silt, sand, and gravel. Figure 50 shows the vegetation on the high terrace. The underbrush is quite thick, and frost was encountered at about 24 in.

The streams coming from the Cordilleran region are very swift, and many braided stream channels occur in the central section of the Mackenzie Lowland. A good example of this is the

Keele River, a portion of which is shown in the stereopair of figure 51. Willow and alder growth is dense on a few of the islands, but the channel markings of flood stage are visible. The pointed ends of the island show that current is swift and will move a considerable amount of gravel.

In the vicinity of Ontaratue River an investigation was conducted on a terrace to determine frost conditions. The terrain was very hummocky with about a 2-ft difference in elevation between channel and hummock, as shown in figure 52a. These hummocks were too small to be seen on airphotos of a scale of 1/20,000 (fig. 52b). Frost was encountered at about 24 in. in the hummocks, and around 8 in. in the channels. On digging out the hummock a 2- to 3-in. layer of ice and soil was found, below which frozen soil was found as seen in figure 53a. Figure 53b shows a general view of a site with alluvial material overlying shales near the hummock site shown in figure 52a.

At Norman Wells the airfield is constructed on a granular terrace believed to be a terrace remnant. In the immediate vicinity but farther inland, glacial scour of bedrock, eskers, and drift ridges are evident on the aerial mosaic. Figure 54 is a stereopair of the airfield as constructed on the terrace. There is a linear arrangement on the airphoto which parallels the direction of flow of the Mackenzie River; the lakes are confined to a narrow trench parallel with the river. Inland from these lakes is a topographic rise, and from this point the terrain slopes upward to the Franklin Mountains as shown in figure 55. All drainage inland from the topographic rise flows perpendicular to the river in contrast to the parallel flow in the vicinity of the airfield.

The flat granular terrace on which the airfield is built, as well as the matching terrace on the opposite side of the river indicated by the stratified well-rounded sands and gravels in the cutbank in figure 56, were probably deposited by floodwaters from the continental glacier. It is believed that this material is glacial outwash, through which the Mackenzie has now entrenched itself, leaving the elevated terraces. The lake-filled drainage channels paralleling the present-day river are probably old preglacial channels.

The unconsolidated surface material is relatively thin, as the Mackenzie River and Bosworth Creek cutbanks exhibited thin alluvial deposits overlying shales. Along Bosworth Creek 6 to 10 ft of sandy-silt overburden was found overlying shales. Test holes showed that peat extended from a depth of 10 to over 24 in. in the area, and frost was encountered at about 24 in. This may be permafrost, but local residents say that at from 8 to 12 ft there is a zone of no frost. The latter was not confirmed by test holes.

Considerable settlement was observed in some of the buildings at Norman Wells. Figure 57 shows settlement of the boiler plant and figure 58 is an interior view showing the sagging floor. This building was constructed on piles set into permafrost, and boiler water was allowed to pond on the surface. A new plant is being constructed, as seen in the background of figure 57, and here the piles are being carried to shale at about 30 to 40 ft.

In house construction, a building contractor at Norman Wells is using two insulated floors separated by a 2-ft airspace to prevent thaw and subsequent settlement. The arrangement is shown in figure 59.

The Mackenzie Delta on airphotos is an area of low, flat topography interlaced with numerous meandering streams. A large percentage of the delta consists of lakes, many of which are obliterated by vegetation. These latter depressions show a definite depressed-center type polygon; these polygons are found in the old abandoned channels. Figure 60 is a stereopair of the Mackenzie Delta at Aklavik, Northwest Territories.

Deep peat deposits are found in parts of the delta. Some peat or buried root mat is found to depths of 5 ft, overlain by stratified silts and sands which in turn are overlain by a peat horizon. This indicates periods of flood aggrading the delta alternating with periods of low water. The water-laid deposits in the delta support a dense growth of stunted willow, alder, and spruce.

At a site near Aklavik, borings were made in polygons of an obliterated channel. The profile in the ridges around the depressed-center polygons showed none to 2 in. of moss, 2 to 8 in. of unfrozen woody peat, 8 to 13 in. of frozen peat with thin ice lenses and ice crystals, 13 to 15 in. of frozen silt with ice crystals, 15 to 17 in. of large ice crystals with lenses of silt, and 17 to 24 in. of frozen silt with ice lenses up to 1/4 in. The core of the 8- to 13-in. level broke in layers 1/4 to 1/2 in. thick, and showed some silt. The depressed center profile revealed none to 4 in. of saturated moss, 4 to 18 in. of saturated peat, 18 to 28 in. of frozen peat with large ice crystals and 1/4-in. lenses, and 28 to 40 in. of silt with ice crystals and lenses. The depressed center of the polygon showed a hummocky surface with water standing on the surface.

East of the Mackenzie River Delta and the Caribou Hills is a large coastal plain region that is devoid of tree cover except dwarf species in depressed and more sheltered regions. (Details of airphoto patterns are lacking because of insufficient airphoto coverage.) A reconnaissance flight covered a portion of the area and a few landings were made where feasible. Evidence of glaciation was lacking and the airphotos that are on hand show no indications of glacial activity.

Figure 61 shows an oblique view of what appear to be sand ridges surrounded by raised-center polygons in the intervening low areas, and figure 62 shows larger raised-center polygons on a terrace. It is believed that this latter area is a region of flat-lying sedimentary rocks.

A very interesting feature of the Arctic Coast is the development of pingos in the center of many of the lakes. Figure 63 is a stereopair showing numerous pingos in different stages of development. Notice that almost all pingos are surrounded by a lake or an obliterated lake. Figure 64 is a low oblique view showing the gullies that dissect many pingos.

Porsild[46] has reported on these pingos and also those of the Alaska Coastal Plain. He believes that many of the pingos of the Mackenzie area are of a different type than those of Alaska. The Mackenzie pingos are "always found in level country, in or near the border of a lake or in the basin of a former lake."[46:49] The conditions of hydraulic pressure formation are not evident, and Porsild believes that these pingos differ from some of those in Alaska in that they were formed by local upheaval. A few pingos, believed formed by hydraulic pressure, were found by Porsild on the slopes of the Caribou Hills.[ibid.]

3. <u>Wind-deposited materials</u>

N extensive wind-deposited materials have been observed in the study of airphoto mosaics of the Mackenzie Lowland. At a few scattered locations on the survey, uniform brown to yellow silt deposits were found as surface mantle on hills and ridges adjacent to streams. Many of the streams were choked with large boulders of diverse lithological characteristics, and they must have been deposited by glacial meltwaters. A valley glacier would serve as a source of the windblown material that mantles the surrounding ridges. Figure 65 shows views of the boulder-bed rivers and the silt-mantled hills. No definite identifying airphoto elements have been observed except that there is a vegetation change. The silt deposits supported dense aspen growth and no evidence of "burns" was found. Figure 66 shows the thick aspen growth on the silt along Ochre Creek north of Wrigley. The test sites revealed none to 3 in. of forest litter, 4 to 18 in. of brown powdery silt, and 18 to 36 in. of fine sandy silt. No frost was encountered in this well-drained soil, located on a high topographic position.

4. <u>Bedrock materials</u>

As evidenced by figures 22 through 24, bedrock is present and forms many valley walls from Camsell Bend north to Point Separation at the beginning of the delta. Most of the rocks are flat-lying sedimentary rocks, limestones and shales predominating.

The largest areal exposure of flat-lying limestone that was studied in the field is at the Ramparts on the Mackenzie River. Here the river narrows from a width of about 3 miles to 300 ft. The narrow Ramparts are about 6 miles long,[30] and the vertical cliffs decrease in height from 250 to about 150 ft at the northern end just below Fort Good Hope.

Figure 67 is a stereopair of a portion of the Ramparts, and the rock bench of limestone is evident. A few remnants of overlying sandstones and shales mantled with trees can be seen. There is the possibility of a thin drift mantle overlying the higher regions, but this was not revealed in the field at the areas visited, although igneous erratics were found. Figure 68 shows several views of the scarps along the Ramparts.

In the upper portion of figure 67, peculiar erosional forms on the tributary valley wall may be seen. The steep vertical cutbanks indicate flat-lying sedimentary rocks. Bedding planes are visible. The steep banks would not be characteristic of shales, and in this climatic region the sandstones and shales would support denser tree growth than limestone. The gullies also appear as U-shaped solution valleys characteristic of limestone. For these reasons, and with some prior knowledge of the area, the airphoto pattern indicates a limestone rock bench. The overlying rocks have different erosional and vegetation characteristics; ground study showed shales with some sandstone. Figure 69 shows mixed vegetation on the shales that overlie the limestone. Frost was encountered at depths of 16 to 36 in. in silty material, and shale was visible at 3 to 5 ft below the top surface on the riverbank. Figure 70 shows the changes in slope between the shales and the underlying limestone at the south entrance to the Ramparts. Here the limestone is just beginning to show its effect on the cutbank of the river.

At the north end of the Ramparts, just north of Fort Good Hope, is a high granular ridge containing igneous boulders deposited by glacial meltwaters. This ridge was approximately 300 ft above the Mackenzie River, and therefore would indicate the presence of drift deposits overlying the topmost shales in the Ramparts area. Boulders in the drift were 3 to 4 ft in diameter. Figure 71 shows a general view of the ridge which supports birch, aspen, some spruce, and a thin growth of underbrush. Seasonal frost conditions were encountered at 12 to 14 in., and it was impossible to dig deeper holes because of large boulders.

On the west bank of the river, downstream from Fort Good Hope, high limestone cliffs continue, and surface deposits are thin. Several obliterated lakes occur in this upland and show on the airphotos a simulated polygonal pattern (fig. 72). In the bogs frost was encountered at about 28 to 42 in., while in the surrounding ridge frost was met at about 20 in. Peat was present to at least 18 in. in both ridges and bogs, but the bog was saturated, and water was standing on the surface. No drillings were made to determine the depth of the active layer. In some test holes near the valley wall, hard rock was encountered at 3 to 4 ft. The ridges in the bog supported scattered spruce 10 to 20 ft high while the bogs contained clumps of niggerheads (cotton-grass tussocks) about 1 ft high.

Evidence of rock underlying water-deposited and glacial-deposited materials has been found throughout the central portion of the Mackenzie River basin from Fort Simpson to Point Separation at the delta. At the mouth of Great Bear River the well-drained features of the topography, the V-shaped gullies with short gradient, and the vertical cutbanks below old terraces indicate, on airphotos, underlying rock. Figure 73 shows the mouth of the Great Bear River with these features illustrated.

Ground study showed that the topmost formation in the ridge on the illustration consisted of stratified semiconsolidated sands, clays, and gravels overlying shales and limestone. The sands, clays, and gravels are Tertiary in age.[6:76]

Ice layers were found along the survey trail shown in figure 73.

It is believed that this is seasonal frost as the material in and around the ice was wet and the ice appeared to be melting. Figure 74 shows an exposure of ice on a slope a few feet away from the tractor trail. Evidence of permafrost is not revealed on the airphotos, but conversation with local people disclosed that in wildcat oil wells drillers encountered permafrost at depths of 150 to 200 ft in the Fort Norman and Norman Wells area.

On a reconnaissance flight over the Great Bear River area, rolling plains dotted with lakes and muskeg were observed, and they are probably in ground moraines composed of till (boulder-clay). Figure 75 shows a general terrain view of the area.

An interesting feature in the Fort Norman area was the burning banks of lignite beds along the Mackenzie River south of the town of Fort Norman. Many smoldering fires in the lignite beds were visited. Figures 76 and 77 show views of these lignite beds.

Besides the Ramparts, the major bedrock exposures in the Mackenzie Lowland are the Horn Mountains, Carcajou Ridge, Franklin Mountains, Caribou Hills, and Smoking Hills of the Arctic Coast. The Carcajou Ridge was accessible from the river and portions of it were visited. The beds were predominantly limestone with softer rocks forming valleys. The high, parallel scarp faces visible on the stereopair of figure 78 indicate tilted bedrock. On the dip slope are rounded ridges with adjacent parallel grooves scoured by glacial action. These ridges are rock with spruce growing in cracks and in grooves where soil has accumulated, as shown in figure 79.

Figure 80 shows topographic views looking from the north to the scarp face, and looking north from the river towards East Mountain. In the flat terrain surrounding the ridge, locations along cutbanks of the river showed thinly bedded shales, flat-lying limestones, stratified sands, and some deposits of boulder clay. A shale exposure near East Mountain is shown in figure 81. Upstream from this exposure there are stratified layers of silt and sand that may be a local delta deposit of a postglacial stream. This deposit is visible on the stereopair of figure 78, where the V-shaped gullies and evidence of solifluction show in the upper portion of the illustration. A ground view may be seen in figure 22. Seasonal frost was encountered in the upland in both sands and peat at depths of 10 to 16 in. Exposures of permafrost could be found in the face of the stratified sands where numerous tree stumps could be pulled out of the face. These stumps may have been driftwood buried by delta deposits. Some were found embedded at least 60 ft below the top of the formation.

On the opposite shore of the Mackenzie River from the Carcajou Ridge, a 30-ft bank contained over 2 ft of peat and woody material in a frozen state. This was underlain by stratified silt and sand, which was also frozen wherever a natural condition could be reached. Figure 82 shows the deep peat overhang with leaning trees where thaw and/or stream undercutting has caused underlying material to slump. Farther inland at this point there were low ridges that had only about 1 ft of peat underlain by water-worked silt and sand. This condition was found at numerous points along inland streams of the Mackenzie Lowland. On airphotos where leaning trees are visible on stream banks with no evidence of bedrock in the banks, unconsolidated frozen materials may be expected. These materials have a deep peat layer, and it is believed that the active layer is rather shallow.

Figure 83 is a stereopair of high terraces along the Canol Pipeline Road. The gullies are saucer-shaped in the high, flat portions and change to V-shaped at the terrace face. The Canol Road crosses these several terraces and then enters Dodo Canyon of the Mackenzie Mountains. The terrace levels and a view of the road in the canyon are shown in figure 84.

The erosional characteristics of figure 83 indicate impervious materials. The absence of numerous lakes on the terraces would indicate that till surface material is improbable. If granular drift or outwash gravels were present, the airphoto pattern would indicate a better drained appearance, and there would probably be some parallelism of ridges. On the lower terrace near the oblong lake there is a small ridge that may be an esker. This ridge is mantled with dense birch or aspen. The region has been glaciated, but most glacial features have been removed, in all probability by the action of running water. On the aerial mosaic the numerous terrace levels also indicate that erosion by running water has been pronounced. It is believed that the material is underlain by bedrock.

There is no evidence of angularity or blockiness on the airphoto mosaic which would be characteristic of the harder limestones and sandstones. Since this is a region of flat-lying sedimentary rocks, it is probable that shale forms the high terrace. Field investigation did reveal that shale was the formation, and in one of the bare areas along the road an excavation showed thinly bedded and broken shales as shown in figure 85. Numerous exposures of black shale were found along the road underlying a thin mantle of alluvial silts and sands. Also, there were several low ridges that were minor topographic features which contained sands, gravels, and boulders. Some of the boulders were of igneous origin, indicating that all drift has not been removed. Figure 86 shows an exposure of a rounded slope of one of these ridges. A few of these ridges could be outlined on the airphoto mosaic, but more study is needed to interpret and develop elements to differentiate the drift from the shales.

The depth to frost along the road varied from 8 in. to at least several feet in the cleared granular areas. Details of type and extent of permafrost were not obtained on the reconnaissance survey.

Keewatin Section (Laurentian Upland Province)

The Keewatin section is a physiographic subdivision of the Laurentian Upland province of the Canadian Shield division of

North America as outlined by Lobeck.[37] This physiographic section must not be confused with the political subdivision of the District of Keewatin. Part of the political district lies within the physiographic section but most of the district lies to the north of the physiographic section. The eastern border of the Keewatin physiographic section is Hudson Bay; the southern border is the Nelson River in Manitoba; the western border is the contact between pre-Cambrian bedrocks on the east and the younger geologic formations of the Mackenzie Lowland section; the northern border, as used here, is the northern limit of tree growth from Hudson Bay to Great Bear Lake.

The overall topography is that of a plateau dotted with numerous lakes surrounded by rock knobs or glacial drift ridges. The materials as observed in a flight from Yellowknife to Artillery Lake were about equally distributed between bare rock and glacial drift deposits. This is also the distribution observed on airphoto mosaics, although the Yellowknife area is as much as 80 percent rock. Figure 87 shows typical topographic views of the Keewatin section.

1. Glacial-deposited materials

South of McLeod Bay at the eastern end of Great Slave Lake, extensive glacial drift deposits with scattered rock knobs were observed. Most of the deposits consisted of outwash deposits or valley fill, but some eskers and kames were visible on aerial mosaics.

Figure 88 shows a stereopair of McLeod Bay region with many complex glacial features. The flat benches beside the stream in the upper portion of the illustration are small outwash terraces with some surface markings as the result of current action. Small kettles are visible, and the light tones and open vegetation indicate the material is well drained. The steep side slopes are characteristic of granular outwash materials. The material is predominantly sand with some gravel.

In the lower portion of figure 88 an esker ridge with narrow crest and steep side slopes can be identified. Above this ridge and adjacent to it is another outwash plain pitted with kettle holes. The kettles are irregular in shape and do not contain much water. It is estimated that this material is not frozen for at least the upper 15 to 25 ft or these kettles would contain more water than they do. The upland area is composed of bedrock with very little if any drift on top as the knobs appear somewhat jagged and broken.

Figure 89 is a few miles distant from the site discussed above, and thus it can be seen that the granular outwash plains are extensive. In the center portion of the figure is a ridge perpendicular to a valley; this ridge is probably an esker. Faint sinuous connecting ridges running between the lake at the left-hand margin of the stereopair and the ridge crossing the valley indicate that the transverse ridge is part of an esker "chain"; the steep sides and the uniform color tone are also identifying features of an esker.

The white mottling of the knobs is indicative of outcropping bedrock. On the aerial mosaic the presence of bedrock is also indicated by numerous faults and joints. Many of the lakes in the area have one side formed by a straight fault scarp. The glacial deposits are confined to the valleys, and are sand outwash plains that give a very blotchy or a white streaked pattern to the mosaic. Some outwash plains are as long as 1 mile in length but are restricted by valleys to only a few hundred yards in width. The outwash plains are the only areas that are flat enough for airfield sites, and their use is limited by the high rock knobs surrounding them.

A large outwash plain a few miles from Yellowknife was used as the site for the Yellowknife airfield. Figure 90 is a stereopair showing the outwash plain before the airfield was constructed. The outwash plain is about 2 miles long and 1 to 1-1/2 miles wide. It is surrounded by fractured granitic rock knobs; a fault scarp can be seen along the north shore of Long Lake in the upper portion of the illustration.

The overall topography of the outwash area is that of a flat plain, and the absence of surface drainage markings indicates that the material is well drained internally. There are changes in photo gray tones from light to medium dark. Some of the darker tones are due to vegetative changes. The white-toned areas support little vegetation and are irregularly shaped blowouts of sand. Slight rises occur where masses of reindeer lichen abound. The medium-dark tones are the well-drained granular soils with surface deposits of thin peat. The vegetative cover is mainly jack pine and white spruce-types that like well-drained soils. The darker portion on the left side of the illustration is a slightly depressed area with a deeper accumulation of peat and the more hydrophytic black spruce vegetative type.

The lighter toned strip that crosses this darker area is a slight topographic rise. It is believed that this is a burned-over area and most of the peat in the light area was burned, while in the darker area higher moisture content prevented complete burning. The effect of burning on the gray scale tone of photographs is pronounced.

Figure 91 shows a small outwash plain that is one of the many local deposits suitable for granular borrow material for road construction in the bedrock region around Yellowknife. Figure 92 is a ground view of stratified sands, silts, and gravels in the outwash. The dip of the beds away from a central point indicates that the form may be a kame. The landform is academic, but the absence of jointing, banding, and knobs, indicative of bedrock in the mosaic study, leads to the conclusion that this is unconsolidated material suitable for borrow. Under the stereoscope kames are moundlike, have no gullies, and support dense stands of trees unless burned. Steep side slopes, light tones, and absence of polygonal forms also help to distinguish the form as a source of granular materials.

The depressions in the bare rock area were once filled with water; fine sands and silts with surface deposit of peat were encountered in test pits in these depressions. The light tones within some of these depressions are slight mounds with lichen vegetation.

and are indicative of frost hummocks caused by growing ice lenses, dikes, and interstitial ice which are seldom over 1/2 in. in width.

In the Yellowknife region and east to the treeline, the contrasting gray tones between bare rock and drift deposits are very pronounced. The bare rock is covered by lichens which photograph light, while the drift deposits are mantled with spruce, aspen, and jack pine which photograph dark. The texture of the vegetative cover is to some degree indicative of moisture content, soils, and permafrost. Details of vegetation and significance of typical patterns are discussed thoroughly in Part III of this report.

2. Water-deposited materials

Extensive water-deposited materials were not found in preliminary examination of airphoto mosaics or on reconnaissance flights to areas where the party had no photographic coverage. Minor water-deposited terraces were found along major streams such as the Lockhart River, and there were numerous beach ridges on Et-Then Island and along the MacDonald Fault on the south shore of Great Slave Lake. Beach ridges similar to those of Great Slave Lake were also found in valleys, on rock islands, and at the foot of scarp faces in the eastern part of the Great Bear Lake region. The beach ridges around the Hay River area on the west shore of Great Slave Lake are discussed in the Mackenzie Lowland section of this report.

Figure 93 is a stereopair of a sandy terrace along the Lockhart River between Great Slave Lake and Artillery Lake. The terrace is a flat-topped bench with scars left by current action. The terrace face is eroded into V-shaped gullies with very steep gradients that are characteristic elements for identification of granular materials from airphotos. Figure 94 shows an oblique view of the large gully of figure 93. The terrace is predominantly sand, and is a dissected outwash plain deposited by g[illegible]cial meltwaters. Similar forms are discussed later in this report.

Ground information on permafrost conditons is not available, but it would be expected that, due to topographic position and lack of a dense insulating mat of vegetation, the sand would be frozen at a greater depth than areas where the mat is thick. The material may be in the so-called "dry frozen" state.

The beach ridges of Great Slave Lake were studied in detail on Et-Then Island; they were found to extend almost to the highest point on the island, some 600 ft above the present lake level. The beach ridges observed here and at other locations in the east arm of Great Slave Lake and Great Bear Lake were concentric rings along gullies and scarp faces, and represent former levels of the lake (fig. 95). The distance between crests varied from about 30 to 60 ft and the elevation change was seldom over 5 ft. The beach ridges on Et-Then Island were composed of very blocky, angular pieces of broken rock. Some sands with finer material were observed in these ancient ridges at other localities around the two lakes.

These beach ridges indicate either that the level of the lakes has dropped since glacial time or that local uplift has raised the beaches to their present level. Of course, some uplift has taken place on a regional scale, but the lake has also dropped, leaving varved clays and silts in depressions at other localities in the Keewatin section. Bateman[2] reports stratified lacustrine clays overlying outwash gravels in the present and former valley of Baker Creek just north of the town of Yellowknife.

3. Bedrock materials

The airphoto patterns of rock materials in the Keewatin section are many and in most cases very complex because of metamorphism and igneous activity. A few of the patterns described below will also be characteristic of many parts of the Barren Lands section except for the absence of normal tree growth.

The rock materials of this section and of the entire Canadian Shield province consist of granitic rocks overlain in some localities by sedimentary rocks or basalt flows. The area has been much faulted, and usually metamorphics are present in the fault regions. Glacial activity has scoured away the residual soil of the area leaving in its wake bare rock hills and valleys filled with glacial drift.

Figure 96 is a stereopair showing the typical airphoto pattern of granitic rocks. The topography is very irregular due to faulting and weathering. The many joints that crisscross the area are the result of contraction of the cooling of the once-molten granite. Wide troughs visible on the airphoto sometimes indicate a weathered-out igneous dike. The upper portion of the illustration is a large fault that separates the granite from a complex area of metamorphic, igneous, and sedimentary rocks.

The overall tone of the granite is light to almost white due to lichen vegetation. The crevices will have some soil and, therefore some tree growth, which produces a darker tone.

The drainage pattern has been completely destroyed by glaciation. Some surface water follows joints to small lakes while major streams follow fault zones. Many of the lakes in the region are fault lakes as shown in the upper portion of the illustration and in figures 108 and 109.

Many of the larger troughs and depressed fault zones are filled with granular outwash of glacial origin. Overlying the outwash, lacustrine sediments that hinder surface drainage may be found. Overlying these deposits are moss and peat of varying thicknesses.

In the Baker Creek area north of Yellowknife, Bateman reports that the Pleistocene and Recent deposits extend to depth of at least 110 ft. He further reports that depth of permafrost varies with depth of overburden, and where the overburden was in excess of 60 ft, permafrost was found at 280 ft below surface in a deep gold mine shaft [2:10] He states that permafrost is not present where rock outcrops at surface.[ibid.:9] Even after a two-year interval it was possible to reenter and deepen a hole drilled in rock outcrop without encountering signs of frost. Bateman also reports that "shallow deposits of clay, sand and gravel on uplands or ridges, if not covered by moss, are not permanently frozen." ibid. The above observations were made from more than 200 surface diamond drill holes, 67 holes drilled to determine the depth of permafrost in overburden, and numerous horizontal underground diamond drill holes at 115-ft level in Giant Gold Mine shaft No. 2. The latter observations were taken after an interval of 24 hours or more. Figure 97 is a photograph of frost crystals observed in an unventilated shaft at approximately the 115-ft level in Giant Gold Mine shaft No. 2. The crystals are formed on gold-bearing igneous flows in the faulted zone of figure 96.

Figure 98 shows the general topographic expression of igneous intrusives in the Yellowknife area and the more regular rounded knobs of metamorphic slates. Tree vegetation is confined to glacial-filled valleys and crevices in the rock surface. Several species of lichen mantle the rock and help to give it a light tone on aerial photographs.

Many glacial erratics of various sizes were found scattered over the surface of the rock knobs in the Keewatin section. Figure 99 shows granitic boulders left by glacier on graywacke sediments.

In the much-faulted rock regions in the Canadian Shield, of which Keewatin is a subsection, dikes form prominent topographic ridges or long, narrow valleys depending on the resistance of the dike material to weathering. Dikes may be only a few feet in width to over 100 ft. They cross an area irrespective of the type of rock material or its structural trend. Figure 100 is a stereopair of a very large, resistant dike in a granite bedrock area. On aerial photographs the dikes usually appear as ridges with parallel sides, and they may extend across the topography for several miles, offering natural barriers to cross-country movement. They may also form valleys as shown by the dike in the valley that empties into the lake in figure 100. Figure 101 shows a very narrow dike that would be difficult to distinguish from a fracture on aerial photographs of 1/20,000 or smaller scale.

The intrusive bedrock forms mentioned above may have considerably more valleys filled with glacial debris than is evident in figure 96, and the topography may be more rugged. Figure 102 shows exposed granite on northwest shore of Artillery Lake with more rugged features than those shown in figure 96. Fracturing is in evidence and also faults, but the valleys are filled with glacial outwash which supports a denser tree vegetation. In the rock regions there is no residual soil development. The unconsolidated material that is in evidence is probably of glacial origin and reworked in part by the action of running water. Compare this illustration with figure 116, which is on opposite shore of lake.

In the area under discussion large intrusive sills form scarp faces or other major breaks in the topography. Where they are interbedded with sedimentary deposits and later exposed by uplift, the sills show in plan a serrated edge on the scarp face and show evidence of columnar jointing. Where intruded between sedimentary deposits the sill on airphotos appears similar to sedimentary beds in outcrop pattern, but study of airphotos reveals that there is no horizontal bedding in the sill while bedding will be present in the sedimentary materials. If the sill is exposed at the surface by removal of overlying sedimentary beds, it will have general characteristics of sedimentary beds on airphotos. Figure 103 shows airphoto pattern of sedimentary beds intruded with igneous sills. Figure 104 shows the vertical jointing in the sill with horizontal bedding in sedimentary deposits, and figure 105 is a closeup of columnar jointing.

Details of patterns of all sedimentary rocks are not available at this time because of insufficient airphoto coverage and the small areal extent of sedimentary rocks. Limestone and shale were observed underlying diabase sills on Et-Then Island and at other points in the eastern area of Great Slave Lake (figs. 103 and 104). Large conglomerate ridges and sandstone ridges were also seen in this section of the lake. Most of these materials were rather local in extent, exposed in fault zones and scarp faces.

Metamorphic rocks were recognized in some localities by their characteristic banded and contorted pattern in aerial photographs, but details of their airphoto pattern have not been investigated. The metamorphic rocks are mainly schist, gneiss, and slates, but they may also have beds of basalt and other igneous rocks that complicate the airphoto pattern. Figure 106 shows a striking change in tone between the light granitic rocks and a complex system of darker metamorphic rocks. There is no soil development except for glacial debris in depressions and valleys; therefore engineering problems will be those associated with bedrock. Where igneous intrusive or extrusive flows are interbedded with the metamorphic rocks, columnar structure in a weathered face may reveal these different materials as shown in figure 107.

Barren Lands Section (Laurentian Upland Province)

The Barren Lands section is a physiographic subdivision of the Laurentian Upland province of the Canadian Shield division of North America as outlined by Lobeck.[37] The northern border of the section is the Arctic Ocean; the eastern border is Hudson Bay; and the southern and western borders are formed by an irregular line from Churchill on Hudson Bay across Artillery Lake and Great Bear Lake up the Horton River to Darnley Bay on the Arctic Ocean. This line is designated as the northern limit of tree growth. The western border near the ocean, as well as being the limit of tree growth, almost corresponds to the contact between pre-Cambrian and Paleozoic bedrocks. This contact zone is difficult to determine because of thick glacial deposits; therefore, the treeline is used instead of change in bedrock. Where the treeline crosses to the west of Horton River, the river is used as a border.[2]

The entire Barren Lands section has been glaciated, and there are many drumlins and striations which indicate the direction of glacier movement. The reconnaissance survey of the area indicated that, in addition to glacial deposits, there are also exposed bedrock landforms of igneous, metamorphic, and sedimentary origin. Many of these bedrock forms are exposed as the drift mantle is relatively thin. At the present time detailed information on the airphoto patterns exhibited by these materials is lacking because of insufficient airphoto coverage of the Barren Lands section. Some bedrock areas of the Keewatin section were observed to be similar to the Barren Lands section except that the latter area is devoid of trees.

The entire section is believed to be within the limit of permanently frozen ground. Many polygonal areas were found. Most polygons are found in the valleys filled by glacial drift. The type varies with moisture content, soil, and vegetative cover. Several ridges of glacial origin had polygons on slopes and even on crests of the ridges.

The overall topography of the section is that of a plain dotted with lakes of all sizes and shapes. Locally the topography may vary from 200 to as much as 800 ft. Large faults and dikes cross the area and in many instances indicate major changes in materials. Many scarps are also found. In some areas there is a definite parallelism to the ridges caused by drumlinoid forms or crevasse fillings of the continental ice sheets. Ground moraines, eskers, and other glacial-deposited landforms are also found.

1. Glacial-deposited materials

At the present time no deep accumulations of morainic forms have been analyzed on the ground. The eskers, drumlins, ice-crevasse fillings, outwash plains, and surficial drift mantle have been studied from airphotos taken in the vicinity of Artillery Lake and north of the east arm of Great Slave Lake.

Figure 108 shows the border between the drift-mantled bedrock below the fault zone; above this zone are granitic rocks with a relatively thin mantle of drift in hollows and valleys. The rugged and fractured pattern of the granitic area is in contrast with the smoother slopes associated with deeper glacial filling. In this area there are also rock outcrops as indicated by the ragged crests. Some fracturing is also evident, and it is surmised that the rock underlying the drift mantle is granitic or allied rock.

The character of the drainage pattern of the area is one of glacial scoured lakes with only a few scattered kettle lakes. This area is near the border between the Barren Lands and Keewatin sections; as in the fault zone and in a few depressions, the vegetative cover can be distinguished. Figure 109 shows that the vegetation is confined to the depressed areas and along the fault. The background is the portion shown in figure 108.

The topography of the drift-mantled region varies from irregularly shaped ridges and depressions to parallel ridges of drumlinoid form with intervening elongated lakes. The parallel ridging is characteristic of an area where drift deposits are of greater depth. The ridges may appear singly or in clusters of a hundred or more drumlinoid forms. Observations indicate that the drift deposits are predominantly sands with gravel and boulders and few fines. Where the drift is thin, boulder fields are extensive.

The depth to permafrost varies in the drift-filled valleys according to the amount and type of vegetative cover. In the depressions, where peat and moss were thick, ice lenses and ice dikes were found at depths of 8 to 12 in. below the ground surface.

In the Barren Lands section there are numerous esker forms varying in length from a few hundred feet to over a hundred miles. These are well-defined on airphotos as long serpentine ridges, usually with narrow crests and steep side slopes. There is a sharp change in gray tone on the airphotos; since the eskers are granular and support scrub vegetation, they photograph light gray to almost white, while the surrounding areas are dark because of denser vegetative cover and poorer drainage. Figure 110 shows the airphoto pattern of esker ridges. Under the stereoscope, the narrow crest and steep side slopes are visible with a narrow parallel esker trough at the foot of the slopes. Kames and kettles are found adjacent to the esker or a slight distance away. Also, at the end of many eskers the granular outwash forms an apron or fan. This is not illustrated in figure 110.

The esker forms observed on airflights and on the ground were composed of sands and gravels, and no evidence of permafrost was observed in the shallow borings made. They offer one possibility for location of overland routes and are suitable for use in construction in the Canadian Shield region. Many esker ridges cross bedrock ridges and lakes; they sometimes appear to be broken where they are submerged below lake level.

Kames, in contrast to eskers, are roughly circular mound forms rarely exceeding 100 ft in height. They are granular in texture and exhibit bedding. They are well-drained internally, and seldom is a drainage pattern visible. If a pattern is present, it will be radial in plan, implying a mound formation, and gullies will be V-shaped.

Another type of ridge was observed in the Artillery Lake area. These ridges have a drumlinoid form, but with both ends somewhat pointed. For that reason the writer believes they are ice-crevasse fillings and that the deposits were water-worked and therefore are somewhat stratified. Figure 111 shows the airphoto pattern of these ridges. Notice the polygonal surface markings. Figure 112 is an oblique view of a similar ridge showing raised center polygons and surrounding terrain features. These ridges are very dry, and there is no peat development (fig. 113). The polygons are believed to be the result of contraction and expansion due to thawing and freezing. It is believed the ridges are oriented with their long axes in the direction of ice movement, and therefore are parallel with drumlin ridges that are found in the glacial drift area. The ridges are similar in form to drumlins but a stoss or steep, broad ice-pushed end is not present. Both ends are somewhat pointed and uniformly sloped. These ridges are not as wide as the drumlin forms, but there is a possibility that they may be drumlins with surface deposits of granular material underlain by unsorted till. The ridges are also lighter in color than the drumlin forms and do not support extensive tundra vegetation. Like drumlins they do not have a characteristic drainage pattern.

In the depressions between the parallel ridges of drumlins and crevasse fillings there is a deep accumulation of peat, and raised-center polygons are formed in the lowest portion of the valleys. Since the peat decreases in thickness upslope, the polygons become smaller or disappear. The crest of the hill is cracked as a result of contraction caused by changes in temperature. The peat has high capillary action, and the high water content in these depressed areas is conducive to thick ice-lens formation which produces expansion and heave. Figures 114 and 115 show the very dark tones of polygons indicative of saturated peat deposits in depressed valleys.

The outwash-plain deposits associated with glaciation were not extensive in the area of the Barren Lands section observed during this reconnaissance survey. Minor deposits were found along Wolf Creek south of Artillery Lake, in Benjamin Lake area, Coppermine region, and south of Warburton Bay. Small local outwash aprons were found at the end of eskers and near some lakes. These deposits were flat-topped fans or sand plains with no drainage pattern.

2. <u>Water-deposited materials</u>

The water-deposited materials within the Barren Lands section are not extensive because they have been removed by glaciation. Local terraces are found in the valleys of major streams, but they are believed to be former outwash plains dissected by subsequent stream erosion. These deposits are flat-topped terraces with very steep faces between the streambed and the upland area. Gullies developed on the terraces are V-shaped with short steep gradients, and the material is usually of coarse-granular texture.

3. <u>Wind-deposited materials</u>

Like water-deposited materials, wind deposits are local features. A few sand dunes were observed, but they were not of such extent as to warrant discussion.

4. <u>Bedrock materials</u>

Rock materials in the Barren Lands section are very extensive. They vary from much fractured massive granite and intrusive sills and dikes to contorted metamorphic rocks and sandstones, limestones, and shales. Even where parallel ridging due to glacial activity is evident on an airphoto mosaic, stereoscopic examination will reveal outcrops of bedrock in many places.

The airphoto patterns of rock materials in the Barren Lands section are very complex, just as they are in the Keewatin section. At one locality, characteristic fracturing and fissuring of granite rocks may change at a fault zone or major topographic break to contorted bands of metamorphics intruded by sills and other igneous forms. The metamorphics may vary from slates to gneiss and schist. Sandstone, conglomerate, limestone, and shale may also be found. The materials that are large enough in extent to develop a characteristic airphoto pattern will have similar airphoto patterns to the corresponding rocks discussed in the Keewatin section, except that the pattern is devoid of trees.

There is little or no soil development on the bedrocks of the Barren Lands section; therefore, it is not very important to identify specific rock types. The important feature in photo interpretation is to recognize that below the drift mantle there may be bedrock to serve as excellent support for pile foundations in permafrost regions. Another factor is that where bedrock is exposed over a large area, the terrain is very difficult to cross by wheeled or track vehicles because of loose rock, jagged gullies, and steep scarp faces. Also, concealment is difficult or impossible except in the valleys filled by unconsolidated drift deposits.

Figure 116 shows a glacial-mantled, igneous-bedrock region on the east shore of Artillery Lake with crests showing a jagged, blocky appearance. Because of lichen vegetation, the bare rock areas photograph rather light in color. The overall topography is a system of irregular rock knobs with side slopes mantled by talus and in some places by glacial ridges. Fissures and cracks in the bare rock areas are visible. Figure 117 shows enormous boulders deposited by the glacier on bedrock. In effect the glacier gave a rounded appearance to rock knobs. The lower slopes of the bedrock ridges in figure 116 show ridges similar to that of figure 111 but not as long. An esker is also visible in the lake at the bottom of the stereopair; a ground view is shown in figure 118.

On the lower slopes where raising and lowering of the lake level has developed a thick peat deposit polygons are found; these can be seen in figure 116 on the peninsulas extending into Artillery Lake. Figure 119 shows a low oblique of these same polygons, and they compare to those of figure 115. Peat hummocks 2 to 4 ft in height give the airphoto a stippled appearance. Some peat hummocks may appear as low ridges where they are in clusters.

The trees in the valleys of the border region are stunted, and aid in determining the overall climate of the locality. Figure 120 shows the stunted spruce growth.

The metamorphic and sedimentary rocks studied on the airphotos that were available for the Barren Lands section looked like those discussed in the Keewatin section of this report. Preliminary examination of the Coppermine River and Bathurst Inlet aerial mosaics show definite banding and contorted beds which indicate metamorphosed rocks. There also may be some igneous intrusions. Stratified layers of sedimentary rocks appear in some of the larger fault zones. More data are required to report on these patterns in detail. It is anticipated that future work on the aerial mosaics of the Coppermine River and Bathurst Inlet regions will reveal additional patterns in the Barren Lands section.

Discussion of Results

With data at hand there is an indication that the influence of surface materials, whether they be rock, thin soil mantle on rock, or deep soil, can be analyzed, and that an evaluation of the expected engineering problems can be made from airphoto patterns.

The reconnaissance survey conducted during the summer of

1951 furnished additional data on the distribution of permafrost and contributed many additional regional airphoto patterns. The shortness of time allotted for detailed study of airphoto mosaics has limited the reporting of all regional airphoto patterns.

Although the Great Plains, or more specifically the Peace River Plains, have been glaciated, the bedrock materials are important in determining the topography of the section. Residual shale soil was found near the Peace River where evidences of glaciation were also found. Granular materials are scarce except in the high gravel terraces. Many of these are cemented and maintain a steeper slope than is usually found in granular materials. No permafrost has been reported in the area.

The terraces present patterns similar to those that have been observed elsewhere, except that slopes seem to be steeper. Insufficient study has been made of the patterns of residual soils in areas which have been subjected to glaciation.

Since the Rocky Mountains are topographically rough, the province was studied to a lesser extent than the others. However, some differences were noted in the patterns presented by sedimentary and metamorphic rocks. Large alluvial and colluvial fans composed of granular materials have been deposited at the mouths of many of the deep gullies that separate the mountains. These are a source of materials for construction and are easily identified on the airphotos.

A variety of soil materials and hence airphoto patterns is found in the Interior Plateaus. The sites discussed in this province are in the vicinity of Whitehorse, but there are additional airphoto patterns representing soils in other localities. Deposits resulting from glaciation are important in the Whitehorse area. The patterns of granular deposits seem to be similar to those in other glaciated areas. The small amount of vegetation on south-facing slopes deserves further investigation. Insufficient work has been done on the airphoto identification of silts, although several significant features have been noted. The slopes of the silt bluffs seem to be steeper than those of granular materials. The pattern of the limestone of Canyon Mountain is unusual.

There is some permafrost in the Whitehorse area, but it is not continuous. Engineers report that it does not present a major problem. There is an abundant supply of materials for construction, and many well-drained granular sites are available for construction projects.

Of major importance are the bedrock airphoto patterns in the Canadian Shield region. These patterns contrast strikingly with those reported in other regions. The patterns which represent the fractured granitic rocks are distinctive, and usually definite contrast exists between the glacial drift deposits and the surrounding bedrock. Glacial activity in the Shield has scoured the bedrock and left depositional forms such as eskers, kames, outwash plains, and ground moraines that may be identified, for the most part, by the application of the principles of airphoto interpretation.

Permafrost problems associated with the arctic and subarctic regions in the Shield will be confined to the drift deposits for most engineering operations. From the data that have been collected it is possible to select from detailed study of aerial photographs the good soil areas that are least affected by permafrost, and the inferior soil areas where polygonal, hummocky, or pitted surface indicates adverse permafrost conditions. Preliminary analysis indicates that the unfavorable conditions are confined to the low-lying, poorly-drained areas in the glacial-filled valleys. Here, the thick peat development serves as an insulating blanket to keep the permafrost table very near the surface. Most of the higher topographic positions do not show surface expression of permafrost on airphotos, and the construction practices of disturbing the thermal balance as little as possible should prevent excessive thawing and associated subsidence.

The Mackenzie Lowland section, being a region of glacial and alluvial deposition, has characteristic patterns of terraces, eskers, outwash plains, and ground moraines similar to those of other areas of continental glaciation, except that the climate is more severe here. Because of glaciation the lowland has some areas of granular materials, particularly in the upper reaches of the Mackenzie River, and most of these can be identified from airphotos by the absence of a developed drainage pattern, of hydrophytic vegetation, or of numerous lakes, and by the topographic form such as a plain, terrace, or ridge. The fine-textured materials, in contrast, present an airphoto pattern broken by many kettle lakes and/or thermokarst lakes. Where these lakes have been obliterated by vegetation, the airphotos will show in most cases polygonal surface markings and muskeg vegetation.

Again, airphotos are a valuable aid in differentiating the fine-textured materials with poor drainage from the better drained and coarser materials. The upset of thermal balance in the fine-textured areas will cause thaw detrimental to construction operations.

Within the Mackenzie Lowland, especially the central part, bedrock influence is pronounced. Cutbanks of streams and control of major streams reveal on the airphotos the presence of underlying bedrock. With a few exceptions, the data that are available from field and laboratory work of one summer's expedition are insufficient to establish the elements of identification from airphotos of bedrock materials occurring in the areas studied.

III. VEGETATION

Overall Considerations

1. Classification of types

Investigators have subdivided the northern Polar Regions to suit their particular objectives. Thornthwaite,[59] Nordenskjold,[42] and others based their classifications on climatic considerations. Porsild,[47] Raup,[50] and Polunin[45] were concerned principally with the botanical aspect. For the purpose of this report the Arctic Regions are defined as those areas having both a mean July temperature of less than 50 F and a mean annual temperature of less than 30 F. The northern limit of trees corresponds generally to the 50° July isotherm. Therefore, the Arctic is characterized by the complete absence of forests. In Northwestern Canada, the southern limit of the Arctic varies from the 69th parallel at the Mackenzie Delta to the 59th parallel on the west side of Hudson Bay.

The area bounded by the treeless arctic plains to the north and the mixedwood section in northern Alberta and Saskatchewan is known as the subarctic forested region. Halliday, in his Forest Classification for Canada[21] divides the forested regions in the Northwest Territories into several forest sections, the most extensive of which are the Mackenzie Lowland section and the northern transition section. The Mackenzie Lowland extends from the southern boundary of the Permafrost Zone at Lake Athabasca in a northwesterly direction nearly to the Arctic Coast, comprising the relatively flat lowlands of glacial, lacustrine, and alluvial origins between the Mackenzie Mountains on the west and the northern transition section on the east. The northern transition section includes the area immediately surrounding Great Bear Lake, and the eastern portion of Great Slave Lake, which is physiographically classified as the Canadian Shield.

The main tree species found in the subarctic forests of North

America, or the northern portion of the boreal forest, are white and black spruce, aspen, white birch, tamarack, jack pine, and balsam poplar. The composition and zonal position of the boreal forests in Northwestern Canada are quite similar to those found in Alaska, Northeastern Canada, the Russian Urals,[23] and in the Lena Valley in Siberia.[5] A study of vegetation as an indicator of soil and permafrost conditions in North America might possibly have worldwide application.

The cover-type classifications, as well as the general presentation, are based primarily on military and engineering considerations, with special reference to permafrost distribution. The following major vegetation types are discussed in detail below:

- a. Southern Mackenzie mixed forest,
- b. Northern Mackenzie white spruce-birch forest,
- c. Transition forest, and
- d. Tundra.

2. Environmental factors influencing natural vegetative cover

The cover type established on a particular site reflects the total effect of various climatic and substrate factors on plant growth. Often the distribution of a plant is influenced by a single limiting factor, especially at locations near the limits of the natural range of the particular species. In the transition zone between the tundra and the forested regions, or at specific sites between the lowlands and the uplands, for instance, an individual factor such as soil moisture, cold winds, or soil temperature might govern plant distribution. Hare[23] states that in eastern Canada temperature is the determining factor in classifying sites and local climate, and that moisture is adequate for growth throughout the region; Sanderson[57] is of the opinion that moisture is of considerable importance in portions of western Canada. Although most workers agree that the 10 C July isotherm roughly forms the northern limit of trees, numerous discrepancies have been observed. Marr[39] concluded that the paucity of tree growth on the east side of Hudson Bay near Richmond Gulf is due to lack of soil and inadequate water supply rather than unfavorable atmospheric conditions. Air drainage, temperature inversion, frost and fog pockets materially affect microclimate in a local area.[28] Violent frost action also alters the general character of vegetation established in poorly drained areas containing fine-grained mineral and organic soils.[29] It is quite evident that the effects of climatic and subsurface conditions on plant distribution are rather complex. The interpreter must evaluate the environmental conditions at each individual site to appreciate the significance of the vegetation cover.

The physiological requirements, preferences, growth habits, and descriptions of the various species occurring in Northwestern Canada are given in the detailed discussions of the major cover types. A knowledge of the ecological habits of a tree species with reference to topography and landform will greatly assist the interpreter in identifying individual species and cover types.

3. Criteria for airphoto interpretation

The novice interpreter will attempt to recognize species by tone and texture, tree heights, crown diameters, and tree spacing. Moessner[40] notes that experienced interpreters usually first identify the site quality (relief, slope aspect, and landform), then by inference identify the vegetation cover. simply by knowing which species are capable of growing on the particular site. After the interpreter has identified the cover type and by knowing the ecological requirements of the individual trees in the stand, he can predict moisture conditions, and often soil and permafrost characteristics. Spurr[58] emphasizes that the airphoto pattern description of a particular cover type is applicable to only one set of conditions. The general appearance of a deciduous forest is much different in summer when leaves are green than in fall when leaves are changing color, or in winter when the branches are bare. The type of film and filters used also greatly affect the tonal characteristics. Scale of the photography has a great influence on photo texture. For instance, a dense 15-ft willow stand has a smooth or solid texture on small-scale photography, while the same cover type has a pebble grain texture on photos having a scale of 1:5,000.

The aerial photography used to illustrate the various cover types herein is printed from panchromatic film having an average scale of 1:30,000. For detailed vegetation and permafrost studies small-scale photography of this type is not adequate. Airphotos with a scale of 1:12,000 (1 in. equals 1,000 ft) or larger are necessary to resolve small components, such as low-lying heaths, hummocks, boulders, and the like.

4. Definitions

Ecology - the science of plants and animals in relation to their environment. The latter includes soil, permafrost, and climatic factors in general. Describing vegetation and explaining causes of the distribution of different vegetation types come in the field of plant ecology.

Heath - a dense cover of low-growing vegetation, generally underlain by organic terrain deposited by the plant cover. Two[5] common types of heath vegetation are formed by heath-shrubs, and lichens and mosses.[9]

Heath-shrub - a low woodv shrub belonging to the heath family of plants. Heath-shrubs include heathers, bearberries, blueberries, ledum, and many others.

Lichens - small plants growing on trees or on the ground, the latter type sometimes dominating the vegetation and forming a closed (continuous) cover. Lichens are almost never bright green, many are light grayish to black in tone, some are yellow or orange. Three body forms are recognized: crustose, foliose, and fruticose. Crustose lichens lie flat on the substrate (usually rock), being attached to it over most of their lower surface. Foliose lichens are attached to the substrate by one point on their lower surface, their edges usually curving upward. The term foliose means "leafy" but the resemblance to a leaf is not always very apparent. Fruticose lichens are erect, usually branched, lichens which often form domeshaped mats or a closed cover on rocks and soil. Individual plants resemble miniature trees, and are dyed green for use as trees in model train layouts, etc.

Organic terrain - a land surface covered by a peat derived from the remains of dead plants partially decayed and compressed. Organic terrain occurs largely in bogs, moist and wet tundra, and mature forests.

Subarctic Forests

1. Southern Mackenzie mixed forest

This vegetation type of the upper Mackenzie and region south of the main body of Great Slave Lake corresponds to the southern half of Halliday's Mackenzie Lowland section; Raup[51] has written on this vegetational region. As delimited for the present purpose, the mixed forest occurs on the relatively flat drift and water-worked soils mantling sedimentary rocks in the Mackenzie Lowland. On the east, it is bounded by the transition forest of the Canadian Shield, to the west by the Mackenzie Mountains, and on the north it gradually merges into the spruce-birch forest of the lower Mackenzie Valley, with Wrigley serving as an approximate separation point. Figures 121 through 124 are typical views of mixed forest vegetation.

While the white spruce represents the final developmental stage, fires have been so very widespread that most of the air-photos used on this survey showed evidence of "burns" (fig. 125). As a result, the species composition is decidedly mixed. It appears that at least 85 percent of the vegetation cover shows fire effects. White spruce, aspen, jack pine, paper birch, balsam poplar, black spruce, and tamarack are the important species. The first three are the most generally distributed. Figure 126 illustrates an aspen stand on a fairly dry, sandy silt. The others are less abundant, or tend to be restricted to special site conditions. Balsam poplar is typical only of alluvium (fig. 127) and black spruce and tamarack occur largely in peat bogs (figs. 128 and 129). Aspen, jack pine, and paper birch are most significant as fire types.

Of the three major species, white spruce alone is characteristic of very moist sites. Aspen is too widespread in habitat range to serve as an indicator of specific site conditions, as it does in other forest types. It occurs in moister sites in the mixed forest than in the spruce-birch or transition forests. Jack pine runs more true to type in that it is entirely restricted to well-drained sites. Thus it occurs chiefly on rock with little or no soil mantle, or on granular glacial or waterborne deposits (figs. 130 and 131).

The great latitudinal extent of the mixed forest brings about a considerable climatic difference between its extremes. This is reflected by a marked difference in the occurrence of permafrost, tentatively described as follows. The portion south of Great Slave Lake, although north of the limit of permafrost, has only sporadic permafrost which occurs chiefly in bogs. The middle portion has discontinuous or intermittent permafrost, while the extreme northern portion near Wrigley probably is underlain by continuous permafrost.

The thickness of the active layer can be correlated with Raup's subdivision,[49] which applies to white spruce forests within this area. Of the three kinds of white spruce cover, that on silty floodplains displays a dense undergrowth, but the moss layer on the ground is poorly developed. The active layer is relatively thick compared to the upland spruce stands where the insulating moss layer is 4 to 5 in. thick and the undergrowth sparse. The third type, open parklike spruce stands with little undergrowth and ground cover of lichens and heath-shrubs, has the thickest active layer.

Frequently a distinctly zoned arrangement of vegetation parallels lakes and watercourses (figs. 127 and 133). Water and marsh plants at water's edge are replaced by bands of low sedge-grass and low willow cover which withstand submergence and the mechanical attrition of spring floods. Farther back are the taller clumped willows (figs. 132 and 133) and alders, 15 or 20 ft high, then a band of balsam poplar on moist alluvium. These zones form a steplike series up to the white spruce farthest back from the water's edge. On the inner bends of meanders, the various zones are especially broad.

Marshes and bogs are common in this re 'on of numerous shallow glacial lakes and ponds (fig. 134). Their vegetation contributes toward ultimate obliteration of the open water areas by depositing peat. In overflow areas this process is accelerated by silting. Horsetails and sedges are prominent in marshy habitats.

Principal bog plants are black spruce, tamarack, ledum, mosses, sedges, and heath-shrubs (figs. 135 and 136). Another very common type of bog is termed birch muskeg because of the prevalence of dense ground birch up to 6 ft in height. The active layer is thicker in the birch bog than in black spruce-tamarack bog. Marshes show a much thicker active layer than bogs. The southern limit of permafrost occurs in black spruce-tamarack bogs along the Grimshaw Highway at approximately the 60th parallel, where the active layer is about 3 to 4 ft thick.

2. Northern Mackenzie white spruce-birch forest

The forest near the Mackenzie River changes very gradually from the mixed forest of the southern Mackenzie to the spruce-birch type of the northern Mackenzie. The southern limit of the latter is here somewhat arbitrarily considered to fall at Fort Wrigley, although stands transitional between the two types are found in the 200-mile section between Camsell Bend and Fort Norman. In this transitional area the important temporary tree, aspen, is gradually replaced by paper birch towards the north. Jack pine becomes much less prominent, finally reaching its northern limit near Fort Norman.[9:152] The white spruce reaches lower heights in this transition area than in the mixed forest; 85 ft is the upper limit on the most favorable alluvial sites in the southern white spruce-birch (figs. 137 through 139), while on the upland few trees exceed 50 ft.

Balsam poplar stands are very typical of alluvium bordering streams, forming bands intermediate in height between the willow clumps paralleling the streambank and the spruce forest on better-drained sites away from the river.

Recent or old burns, although prominent in the white spruce-birch type (figs. 140 and 141), are not nearly as widespread as in the mixed forest.

White spruce, the final species in forest development, maintains a thinner active layer than stands of birch or aspen. The dense shade of the closed spruce stand encourages the growth of a dense thick mat of live moss, whereas the more open aspen and birch stands fail to provide the protection necessary for a luxuriant moss mat. Also, aspen is here indicative of well-drained sites, too dry for a thick moss cover. Of all the factors directly affecting permafrost in the white spruce-birch type, the thickness of the moss mat is the most important. The thicker the moss cover, the thinner the active layer. The types of moss common in white spruce forests form a light, loose dry mat in contrast to the dense wet mat of bog mosses. The loose upper layers of peat dry out and their dead air spaces enhance the insulating effect.

On level upland sites supporting white spruce-birch forests, permafrost is found at depths ranging from 15 to 30 in. Under aspen, on the dry granular sites which this tree favors, the frost line is at least 36 in. deep and may be much deeper (fig. 142). In bogs, frozen ground occurs at depths from 10 to 18 in. during the latter part of August.

Bogs in the white spruce-birch type show no consistent differences from bogs in the mixed forest, except that sphagnum moss is a less important plant in the former type. The only true floating mat bogs encountered during the survey are within the white spruce birch area (fig. 143); but they are uncommon. Most bogs along the rivers are marshlike with considerable silt, from river flooding, mixed intimately with the peat instead of forming distinct layers. In the upland bogs the peat is interlaminated with distinct mineral horizons marking long periods of deposition, usually from erosion following a forest fire on the watershed. Charcoal layers often substantiate this.

Bog plants in both the mixed forests and white spruce-birch types (fig. 144) include black spruce, tamarack, mosses, watersedge, heath-shrubs, willows, horsetails, and buckbean. Marshy lakeshores support horsetails, sedges, grasses, willows and, higher up, balsam poplar (fig. 145).

3. <u>Transition forest</u>

The northernmost forest type of the continent, bordering the treeless tundra, presents a gradation of climatic rigor from the two Mackenzie forest types to the arctic timberline. It forms a broad northwest-southeast band from the Mackenzie Delta to southern Hudson Bay, surrounding Great Bear Lake and the large eastern arm of Great Slave Lake. The transition spruce forest includes the Mackenzie Delta forest and Halliday's[21] "Northern Transition Section" of the boreal forest.

Despite the frequent statement that the forest-tundra border follows in general the 50° isotherm for the mean July temperature, a comparison of timberline on Halliday's forest map[22] with the July temperature map in <u>Meteorology of the Canadian Arctic</u>[11] shows a much closer correspondence to the 55° mean July isotherm. However, inland meteorological stations are extremely few in the transition forest. Wind is undoubtedly an important climatic factor in this belt, but the scarcity of wind-trained tree crowns indicates that the important effect of summer wind is through drying the trees and soil rather than through its mechanical force. The winds during the growing season are too weak in force or too inconstant in direction to modify crown form.

Since each of the major types of vegetation in the District of Mackenzie forms a band which trends northwest-southeast, paralleling the trend of the arctic timberline, it is apparent that the climate becomes more severe toward the northeast, rather than toward the north.

<u>Pre-Cambrian Shield transition forest.</u> The transition forest on the Canadian Shield is rather open and often very scattered on the upland of the pre-Cambrian Shield, due to the combination of thinness or absence of soil and severe climate. The effect of cold is obvious, but lack of adequate moisture also seems important. Unfavorable water relation is correlated with the presence of bedrock and coarse glacial mantle at the surface over much of the pre-Cambrian upland, as well as with the limited precipitation. These factors promote an open parklike type of forest cover. Where dense continuous forests occur on the upland, a continuous

mantle of glacial drift is indicated; scattered tree cover indicates that there is little or no drift. Figures 146 through 150 illustrate the vegetation of this region.

On lakeshores, riverbanks, and other lowlands in the Canadian Shield area, the forest shows a denser or closed character, so that vegetation itself assumes much more direct engineering and military importance.

White spruce is by far the predominant tree over the entire transition forest, except in muskegs where it is largely replaced by black spruce. This relation applies even at the very timberline; no black spruce were seen bordering the tundra on upland sites.

The effect of exposure is pronounced in the transition forest. Vegetation is better developed and of a more southerly type on south slopes where plants and soil are more exposed to the sun. North slopes tend to have dwarfed trees and a more northerly type of ground cover; the tundra vegetation first appears towards the northeast on steep north slopes. The permafrost table is less than 2 ft deep under moss-heath cover throughout most of the transition forest area.

As the forest-tundra boundary is approached northeast of Great Slave Lake, the size and numbers of trees decrease. A lichen heath made up chiefly of large reindeer lichens (fig. 151) appears first on the ridgetops, becoming progressively more extensive towards the northeast. Over great areas of this glacial drift and exposed bedrock country, the vegetation forms a "mosaic" of white spruce forest and lichen heath, the latter on topographically higher sites (fig. 152). Tree stands become discontinuous, and the trees within the stand are widely spaced. White spruce develops a characteristic snow-mat of low, dense, basal branches. With increasing climatic severity the upright tree decreases in height while the diameter of the basal mat increases, so that the latter may be more noticeable on airphotos than the erect tree. At the last outposts of spruce growth on the Canadian Shield, the erect portions are often absent and the entire plant is the prostrate mat which is sheltered by an insulating snow mantle. Far beyond the general timberline, small clumps occur in moist spots and narrow lines of trees border lakes and streams.

At the forest-tundra border on the uplands east of the Mackenzie Delta, moist tundra plants penetrate far into the transition forest and blanket the sandy substrate with organic terrain. The deep organic soil and the more moist climate produce a very different airphoto pattern than that in the white spruce forest south of the dry tundra of the inland Shield area. Lichens are not prominent in the ground cover between trees. Ground birch, alder, heath-shrubs, sedge, and grass produce a darker tone which contrasts less with the forest. Also, the change from forest to tundra is much more abrupt and white spruce snow mats are small and relatively unimportant, with erect trees rather than prostrate mats at the forest edge.

Black spruce is reported as much more important in eastern Canada than it was found to be in the Mackenzie District. Hare[23] states "In Labrador-Ungava, black spruce is overwhelmingly the most common." In Northwestern Canada, visited in the 1951 survey, white spruce was far more abundant than black everywhere except in bogs.

Scattered through the mature white spruce stands and dominating burns, paper birch ranks next to the spruces in importance. After disturbance, it forms a temporary cover which precedes the reestablishment of spruce forest, playing the same role in the transition belt that trembling aspen fills in the southern Mackenzie mixed forest. On bare bedrock exposures, both white spruce and paper birch are limited to crevices, faults, and protected niches where a little soil has accumulated. Figures 153 through 160 illustrate this vegetation.

The portion of the transition forest near the southern Mackenzie mixed forest border has a climate favorable to a closed forest cover. On silt or clay soils, undergrowth is especially prominent. Where airphotos show wide spacing of trees in this milder climate, it is indicative of bedrock, coarse glacial drift, or dry granular glacial outwash materials. On the contrary, under the more severe climate near the tundra-forest border, the open parklike aspect of the stands is primarily an expression of climate.

Mackenzie Delta transition forest. Most of the extensive Mackenzie Delta contains more water-surface area than land (figs. 161 and 162). The flat tops of the fine-textured alluvial islands are less than 10 ft above the stream in late summer, a period of low water. Bank erosion is severe so that undermined trees are frequent along channels. The forest is remarkably well developed considering that it is located well above the Arctic Circle.

Aklavik, nearly halfway down the delta, has a mean annual temperature of 15 F, and July mean of 56 F.[11] Winds are generally from the north or south, the former being more prevalent. In July and August, the growing months, north winds are about twice as frequent as south winds. The mean annual rainfall is 4 in., and snowfall is approximately 60 in.

In spite of a gradual diminution in the size of spruce trees from south to north, the timberline, which averages about 68°45' N. Lat., is remarkably abrupt. The height of trees in the northernmost clumps averages about 25 ft, and they appear unusually vigorous. Giddings[17] reported some delta spruce as being 500 years old.

Due to the frequent overflow of the channels into the bodies of standing water, marsh vegetation is much more important in the delta than bog vegetation.

Balsam poplar frequently borders the waterways except in the places where erosion has carried the bank into mature spruce stands (fig. 163). The poplars in this climate are considerably more stunted than the spruce. Other important plants are horsetails, sedges, low willows, high willows, and alders; these form definite zonation on the inner banks of channel meanders which on air-photos reflect increasing elevation above the water. Ground birch is unimportant, and paper birch is practically absent in the delta alluvium, although it occurs as far north as Reindeer Station in the East Channel on the adjacent upland. The temporary role played by aspen and birch in the mixed forest and white spruce-birch forest is performed in the delta by willows, alders, and balsam poplar.

Permafrost is widespread throughout the delta region. The moist silty alluvium is frozen at an average depth of 18 in. beneath forested areas. The active layer at brush-covered sites seldom exceeds 24 in. In the vicinity of Aklavik, the fine-grained alluvial soils are at least 25 ft thick. Granular materials for construction purposes are completely absent in the delta transition forest.

Arctic Tundra

The arctic lands, defined as those north of the northern timberline, have had scant investigation by students of vegetation. The results to date have been complex and inconsistent. Confusion is encountered at the start in the usage of the term "tundra" itself, which is given a variety of meanings by different writers. Griggs[20] pointed out its ambiguity and proposed its abandonment as a category of vegetation, retaining it in the geographic sense to include all the vegetation types of the treeless arctic. Since the present purpose would not be served by a detailed discussion of the many subdivisions of arctic vegetation described by botanical writers, the term "tundra" is here used broadly in accordance with Griggs' suggestion, and its subdivisions named on the basis of substrate characteristics and topography. These considerations are important not only in determining the vegetation cover, but are primary for the discussion of airphoto patterns and permafrost. The various types of patterned ground -- polygons, rock stripes -- are more important as identification elements than vegetation cover. The reader interested in a brief nontechnical account of arctic plant life and its basic ecology is referred to Porsild.[47]

Generally speaking, the arctic tundra has a climate characterized by less than 10 in. of precipitation, and short cool summers. In this report the tundra regions are subdivided into dry, moist, and wet. The dry and moist tundra vegetation types are geographically extensive as continuous types, while the wet tundra comprises relatively small local areas within the other two types where drainage conditions favor bog or marsh vegetation. In addition, dry and moist tundra areas are not mutually exclusive; each also occurs locally as an expression of suitable physiography within the general area of the other. For example, ridgetops, dunes, and eskers might show dry tundra plant cover, in contrast to the surrounding moist tundra on lower ground.

1. Dry tundra

The vegetation of dry tundra is an open cover type; a generally continuous heath or mat of plants does not occur. Vegetation ranges from scattered isolated plants to large mats in sheltered sites. Beneath the latter a very thin layer of peat may be deposited, but exposed mineral rather than organic terrain is typical of dry tundra habitats. The mineral surface promotes rapid runoff and infiltration of the meager water supply beyond reach of the upland plants. This results in sparse vegetation and limited peat deposition; the water-absorbing and -conserving capacity of organic terrain is lacking. The presence of low-growing crustose and foliose lichens on the more exposed surfaces scarcely ameliorates this difficulty. Porsild[48] states "In central Keewatin large parts of the 'barren grounds' are treeless not because of insufficient summer temperatures but more likely because of insufficient precipitation during the summer coupled with high frequency of winds and extreme dryness of the air during the winter." It should be added that winter precipitation is likewise low so that on most of the terrain plants are not afforded the protection of snow cover against the desiccating winds.

Bedrock. The subdivision of the dry tundra most significant in permafrost studies is based on whether the substrate is bedrock or unconsolidated surficial deposits (fig. 164). Where the glacial drift was thinly deposited on irregular topography, a "mosaic" of the two substrate types often results (fig. 165). Much of the pre-Cambrian Shield regions beyond timberline northeast of Artillery Lake was so heavily glaciated that it was scraped free of unconsolidated material; consequently, permafrost is not an important engineering problem in this area.

The general airphoto tone is very light (fig. 165), somewhat relieved in depressions and drainageways by the darker wet tundra vegetation. Elsewhere the vegetation, except for the varicolored submerged pond plants and their deposits, is practically invisible on airphotos. When abundant, crustose and foliose lichens may modify the airphoto tone of bedrock (fig. 166), but their effect is less marked than that of the dense light reindeer lichens in the colder parts of the transition forest.

Loose rocky or granular plains. This category of dry tundra includes all unconsolidated materials occurring under arctic climate too dry for widespread moist tundra cover. Most of this in the tundra region is glacial drift, but it also consists of glacial outwash, stream and lake terraces, dunes, fell fields derived by frost action, coastal marine deposits, and elevated ancient beach deposits, which range from sand to coarse boulders. In depressions within dry tundra, where drainage and permafrost conditions bring about a high water table, wet tundra occurs. In contrast to the low crustose and foliose lichen cover on bedrock tundra (fig. 167), the taller and denser reindeer lichens characterize granular plains.

In dry tundra that grades toward moist tundra, the same shrubby plants as in moist tundra occur but do not form a continuous heath or mat (fig. 168), and consequently the peat deposit is thin or absent. Other than lichens the most important plants are dryas, sedges, grasses, dwarf willows, crowberry, blueberry, ledum, ground birch, and loco-weed. The form of many of the species is a low mat or cushion. Dryas is especially characteristic of dry tundra (fig. 169), forming very low mats on ·cky and granular terrain, and occupying small crevices and depressions in bedrock areas.

The root systems of plants in unconsolidated dry tundra terrain are extremely shallow when the permafrost table is high. Comparing regions of equal air temperatures, loose rocky or granular tundra has a thicker active layer than moist or wet tundra where thick organic deposits insulate frozen ground against thawing in summer. Whereas in wet or moist tundra the active layer is less than 2 ft thick, in unconsolidated material it is usually over 5 ft thick. Polygons of the fissure type occur in such dry tundra (figs. 170 and 174). Because of good internal drainage and granular soils, these sites are favorable for construction purposes.

Dry tundra of this type was encountered north of Hornby Bay of Great Bear Lake and in many areas along the Beaufort Sea between Franklin Bay and Coronation Gulf.

2. Moist tundra

The vegetation of moist tundra forms a closed cover or continuous heath overlying a shallow layer of peat. This type corresponds to Porsild s use of the term "tundra" in general.[47] The moist tundra climate provides sufficient precipitation for the plants of average height to have a protective snow blanket in winter.

Just north of treeline, the moist tundra may support local stands of shrubs up to 6 ft tall. Such stands occur in ravines, depressions, and . uth slopes. The tall shrubs are alders, willows, and ground birch that lack the single erect main trunk characterizing trees. In the typical moist tundra, however, the taller species on the upland reach only 1 or 2 ft in height.

A number of low mat-forming heath-shrubs, such as ledum, bearberry, mountain cranberry, and white heather, are abundant, often set in a matrix of mosses. Their interlacing roots bind the underlying peat into a tough vegetation mantle. The peat layer retards thawing of the frozen ground in summer so that the active layer extends only approximately 18 in. down. Typical vegetation is shown in figures 171 through 173.

The slightly drier portions of moist tundra support a lower growth of plants, made up principally of fruticose lichens and mosses. This type also characterizes raised polygon centers where the local drainage is fair (fig. 174). Another type of moist tundra is composed chiefly of sedges and grasses.

Fissure polygons are frequent in moist tundra, especially in lower topographic situations. The centers generally display the vegetation type of the surrounding region, while the polygon channels often grade toward wet tundra vegetation, with occasional small hummocks.

3. Wet tundra

As the name implies, wet tundra occupies locations where the water table is at or very near the surface throughout the year. Shallow gullies, drainageways, obliterated lakes, basins, and other poorly drained areas nearly always support a dense vegetation mat. These areas are covered with a deep insulating snow mantle which protects the plants from cold, desiccating winter winds. Such local protected sites offer the most favorable conditions for plant growth in the windswept areas abutting the Beaufort Sea. Geographically, wet tundra is much less extensive than the dry or moist types in Northwestern Canada. Wet tundra usually occupies depressions having an area of a few square miles or less, and is surrounded by drier tundra (fig. 175). Occasionally large basins up to 20 miles in diameter are covered predominantly with a wet tundra mat.

One of the significant characteristics of this cover type is the presence of a surficial peat deposit at least 2 ft thick. With the exception of brush thickets in ravines, the vegetation in wet tundra is the most luxuriant found in the Arctic. Principal plants are various sedges and grasses, blueberries, ledum, ground birch, small willows, and mosses. The vegetal cover is continuous except where violent frost action churns the ground, usually peat, to such a degree that even hardy lichens do not have a chance to establish themselves (fig. 176).

Fissure polygons (fig. 177) are most common in saucer-shaped drainageways, while depressed-center polygons are prevalent in obliterated lakes and basins. Peat hummocks and ridges are widespread (fig. 178). Relatively few sedge tussocks, or "niggerheads," which are very common in Alaska, were observed in Northwestern Canada. The active layer varies from 1 to 2 ft in very wet sedge marshy areas to 3 to 4 ft in relatively drier heath-shrub sites.

Vegetation Summary

Vegetation, together with climate and soils, has an important effect in determining occurrence and depth of permafrost. The climatic and soil factors which influence permafrost also determine the vegetation type. Therefore, the general cover types depicted on airphotos serve as indicators of permafrost conditions.

Dwarf black spruce with heath-shrub or lichen-moss mat in a bog indicates a thin active layer. On drier forested sites, wide spacing of trees is evidence of a thick active layer; parklands in the less rigorous climatic regions of the transition forest are good indicators of dry granular or bedrock sites, but towards the fringes of the timberline, parklands are common in all situations reflecting climatic rather than soil conditions. Jack pine in Northwestern Canada is a good indication of a thick active layer in well-drained granular sites. Aspen in this region is not restricted to granular soils; however, this species is usually indicative of a rather dry subsurface condition. Beneath spruce forests, a thick ground cover of live moss is a very effective insulation against thawing; where underbrush is dense and moss thin, the active zone penetrates deeper. Birch, aspen, and jack pine are fire species, or temporary types occupying a site following a forest fire.

Wet tundra regions, characterized by a deep surficial peat mantle, are found only in local drainageways and basins surrounded by extensive areas of relatively better-drained sites mantled with moist or dry tundra vegetation. Patterned ground is absent or very faint on dry tundra, but is widespread on moist or wet types. Pitting, soil flows and stripes, vegetation rings (figs. 179 and 180), and fissure polygons are characteristic surface features found in moist tundra regions. Well-developed fissure and depressed-center polygons, hummocky ground, and peat ridges are common in wet tundra. The active layer in moist and wet tundra is very thin, a matter of 1 to 2 ft, while in dry tundra the active layer may exceed 5 ft in thickness.

IV. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

One of the most outstanding results of the 1951 Purdue Canadian Expedition was the discovery of many important and varied areas in the Arctic and subarctic which produce airphoto patterns unlike those previously studied.

A reconnaissance survey, such as this one was, serves a useful purpose in locating areas where detailed studies would be worthwhile.

Detailed study is needed of several localities in Northwestern Canada, which are mentioned in the recommendations.

Many of the areas that were checked in the field still require further study on airphotos for proper evaluation.

Permafrost is not a major problem along the Alaska Highway in Canada.

Recommendations

The following points are recommended for consideration for any future studies of this region:

1. A more detailed laboratory analysis of regional airphoto patterns and field data of the past summer's work should be undertaken.
2. Further field work should be preceded by extensive preliminary planning and study of the aerial photographs.
3. A more detailed field program should be made concerning the airphoto patterns at the locations listed below:

Airphoto Pattern	Base of Operations
Glacial-deposited materials	Whitehorse area Norman Wells to Fort Good Hope McLeod Bay area Artillery Lake area
Water-deposited materials	Aklavik area Hay River Port Brabant area

Airphoto Pattern	Base of Operations
Wind-deposited materials	Ochre Creek area
Bedrock materials	Yellowknife area Coppermine area Mayo area Port Brabant area Franklin Bay area
Combination of above materials	Norman Wells area Wrigley area

4. A field survey party should be stationed at each of the above-listed locations for a sufficient period of time to field-check airphoto analysis and to collect data on permafrost conditions.

5. From observations that the expedition made in Northwestern Canada, indications are that intensive studies should be made in other parts of the Canadian Arctic and Subarctic: Arctic Islands, Barren Lands, Hudson Bay Lowland, and Ungava.

6. Adequate provisions should be set up for making the support of field survey parties more flexible, with the following considerations:

  a. Adequate air support should be furnished, preferably by the Air Force.

  b. Field personnel should be hired locally for unskilled assistance.

  c. Portable boring equipment, easily transported to work areas, should be furnished.

7. An aerial camera for obtaining aerial photography should be added to the equipment needs.

8. The occurrence of hummocks, peat ridges, types of polygons, and pitting in relation to depth of peat should be studied; also an attempt should be made to determine if such surface features are related to the subpeat subtrates at depth, or are strictly determined by the surface material; and finally an attempt should be made to correlate such patterns with slope and moisture conditions.

9. A study of stone stripes and vegetation rings should be made as these configurations relate to airphoto identification of permafrost.

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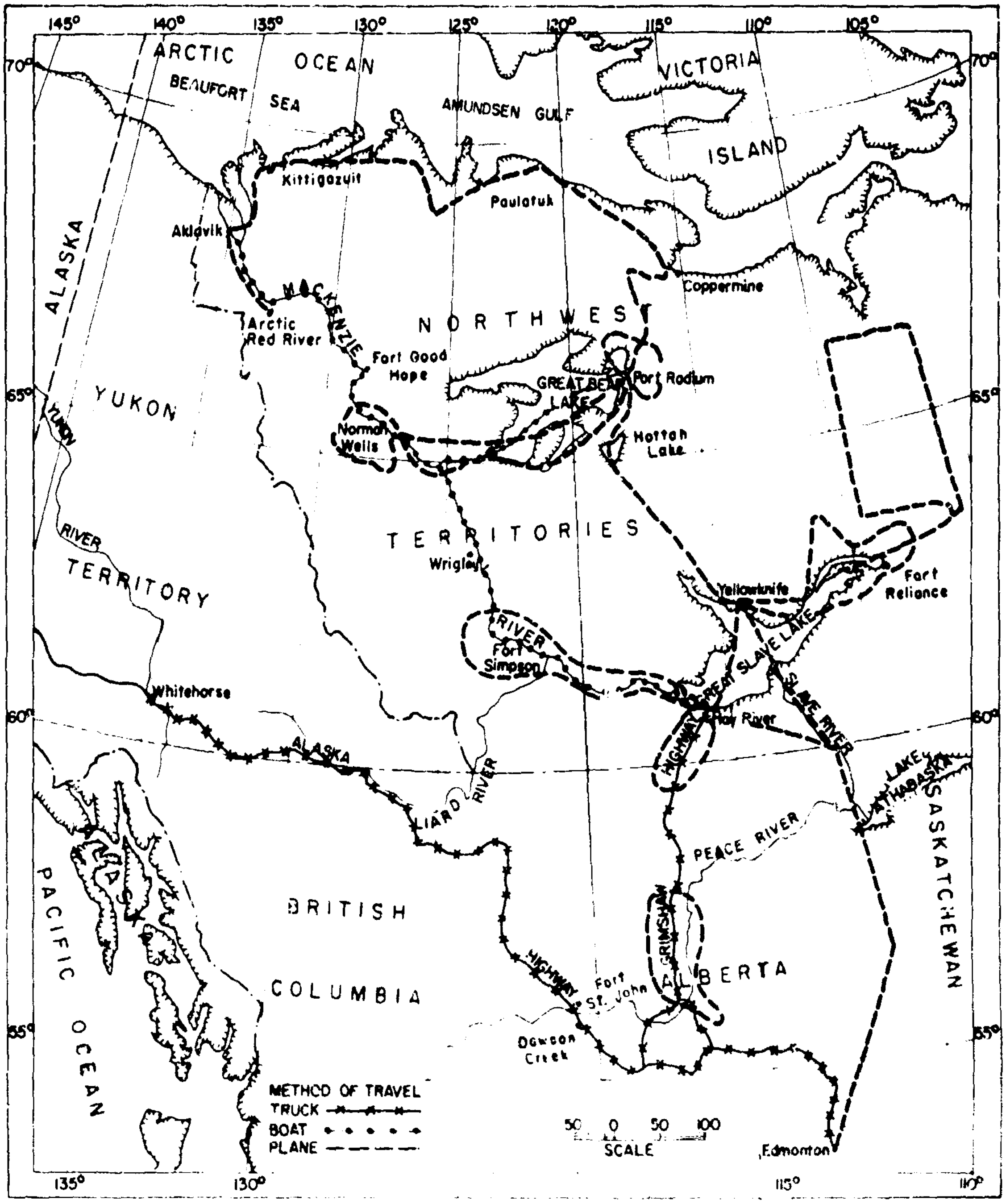
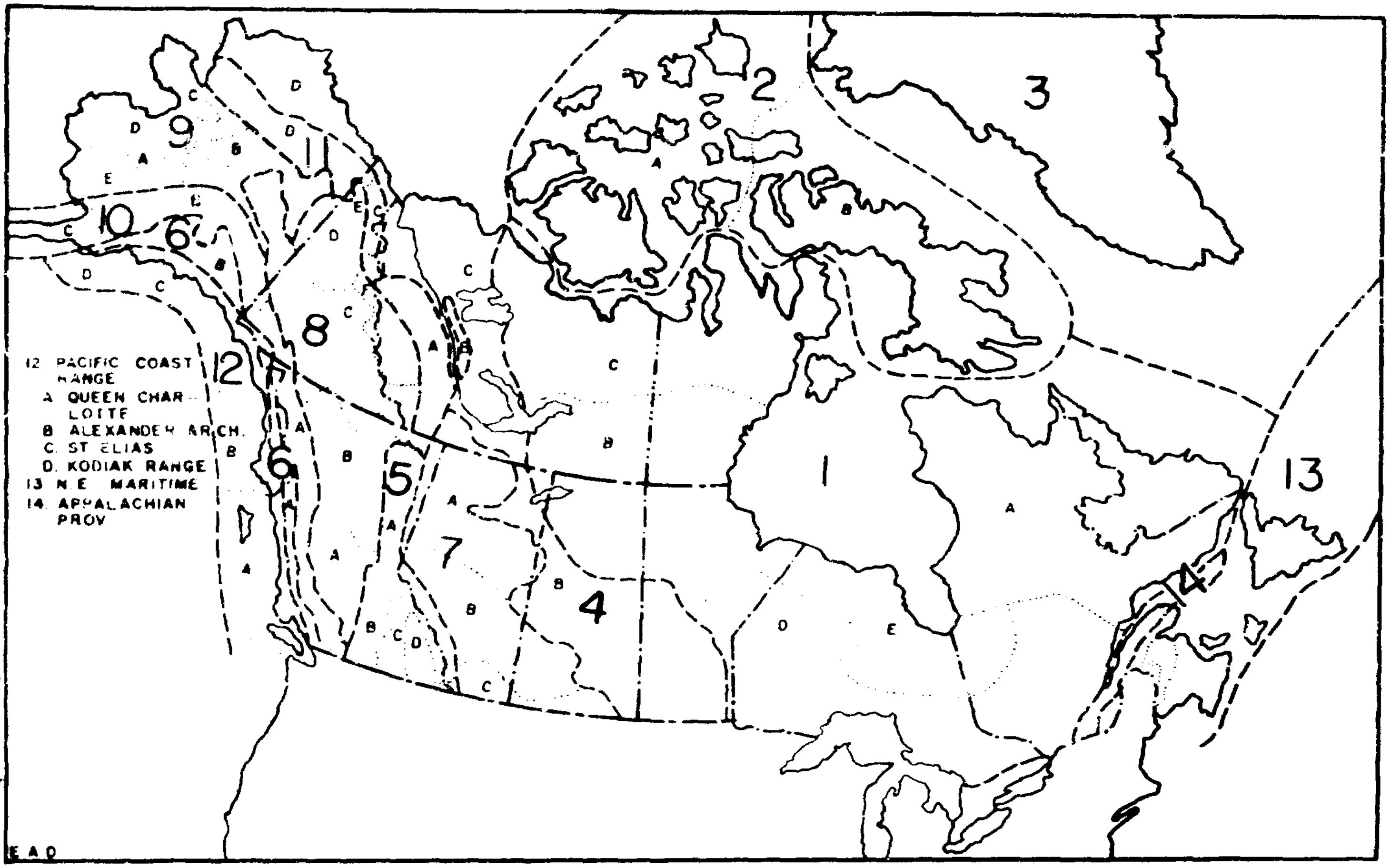


ITINERARY OF THE 1951 PURDUE
CANADIAN ARCTIC PERMAFROST EXPEDITION

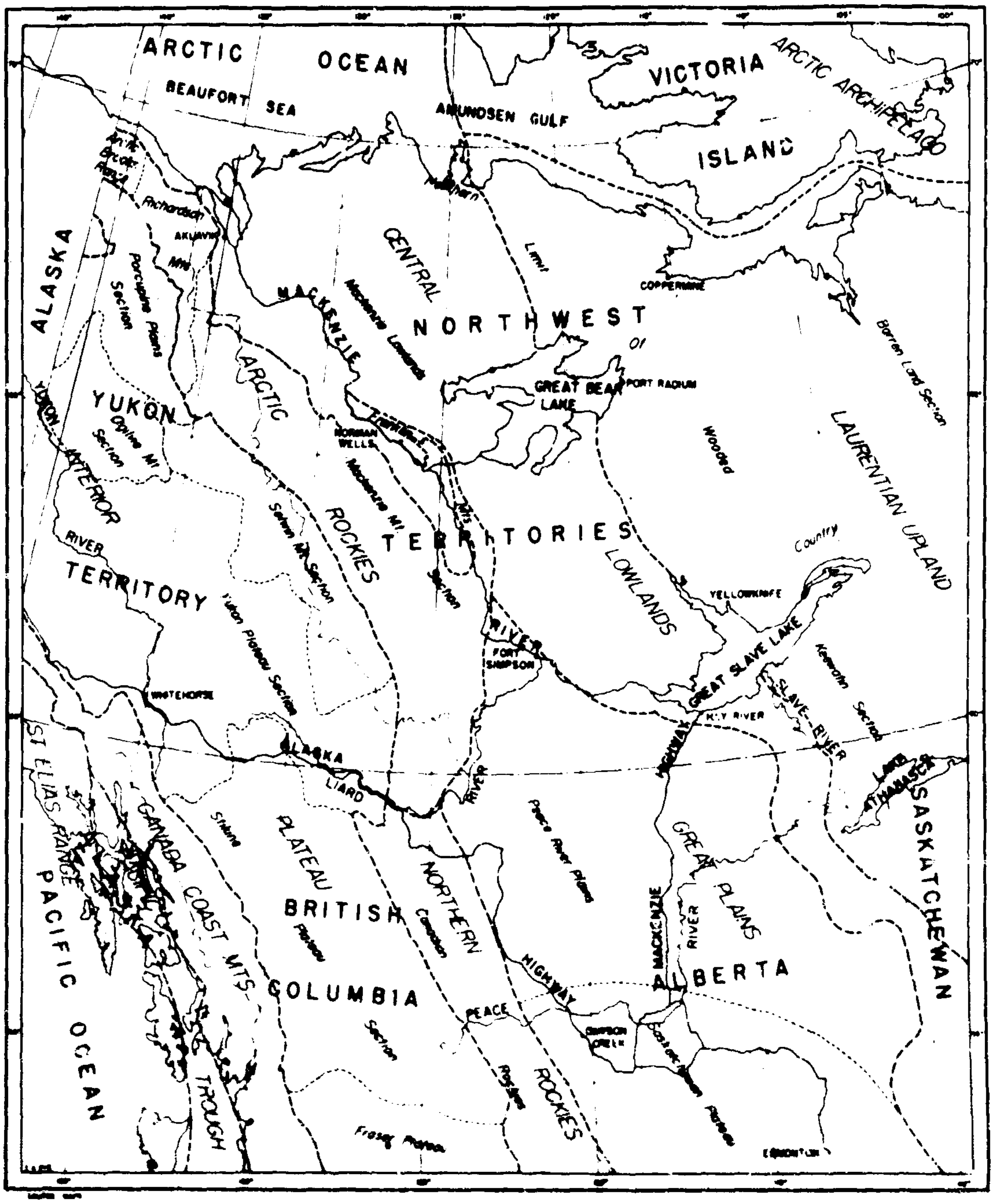
PLATE I

LEGEND

1 LAURENTIAN UPLAND
A LABRADOR SECT
B KEEWATIN SECT
C BARREN LANDS
D ONTARIO-QUEBEC SECT
E CLAY BELT
2 ARCTIC ARCHIPELAGO
A LOW WESTERN SECT
B HIGH EASTERN SECT
3 GREENLAND PROV
4 CENTRAL LOWLAND
B WESTERN LAKE SECT
C MACKENZIE LOWLAND
D ARCTIC PLAINS
5 NORTHERN ROCKIES
A CANADIAN ROCKIES
B COLUMBIA RANGE
C SELKIRK MTS
D PURCELL RANGE
6 PACIFIC TROUGHS
A INLAND PASSAGE
B ALASKA BASIN
7 GREAT PLAINS
A PEACE RIVER PLAIN
B SASKATCHEWAN PLATEAU
C MISSOURI PLATEAU
8 INTERIOR PLATEAU
A FRASER PLATEAU
B STIKINE PLATEAU
C YUKON PLATEAU
D OGILVIE MTS
E PORCUPINE PLAINS
F SELWYN MTS
9 CENTRAL ALASKA UPLANDS
A KUSKOKWIM UPLAND
B KOYUKUK UPLAND
C SEWARD PENINSULA
D YUKON PLAINS
E KUSKOKWIM PLAIN
10 SIERRA CASCADE MT.
A CANADIAN COAST MT
B ALASKA RANGE
C ALEUTIAN RANGE
11 ARCTIC ROCKIES
A MACKENZIE MTS
B FRANKLIN MTS
C RICHARDSON MTS
D BROOKS RANGE



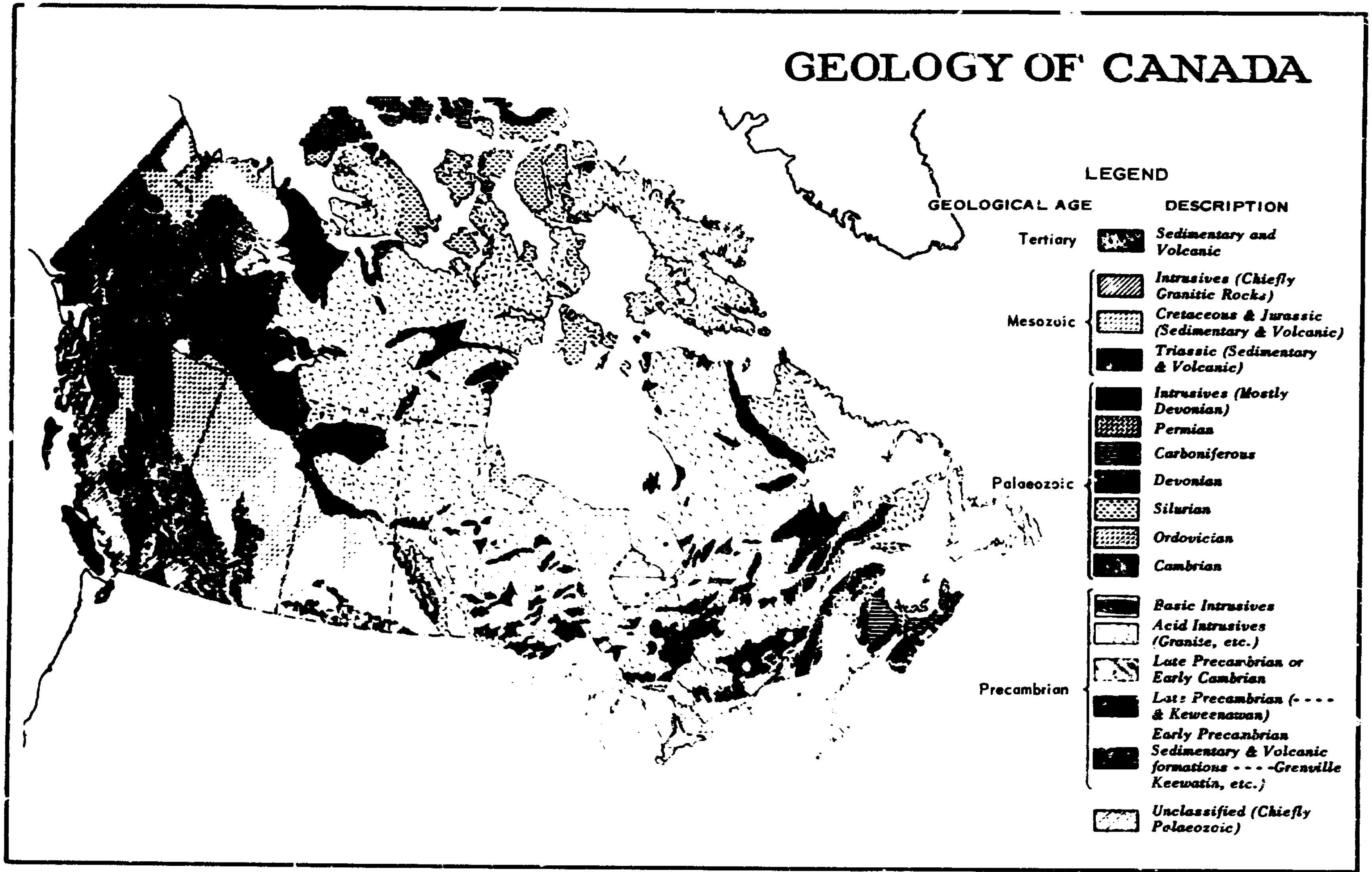
PHYSIOGRAPHIC PROVINCES OF CANADA AND ALASKA



PHYSIOGRAPHIC DIAGRAM OF NORTHWESTERN CANADA

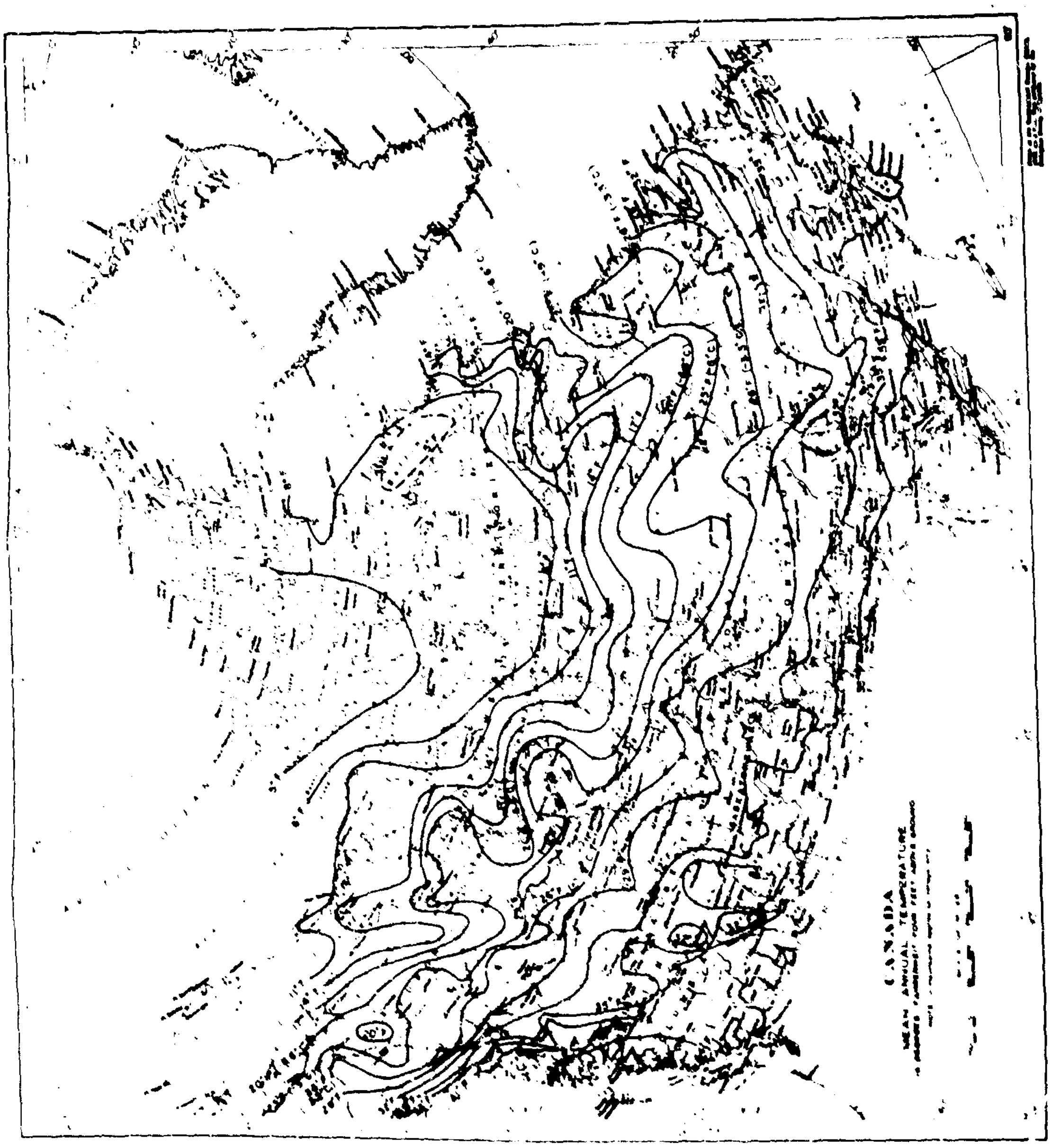
SCALE

PLATE 3



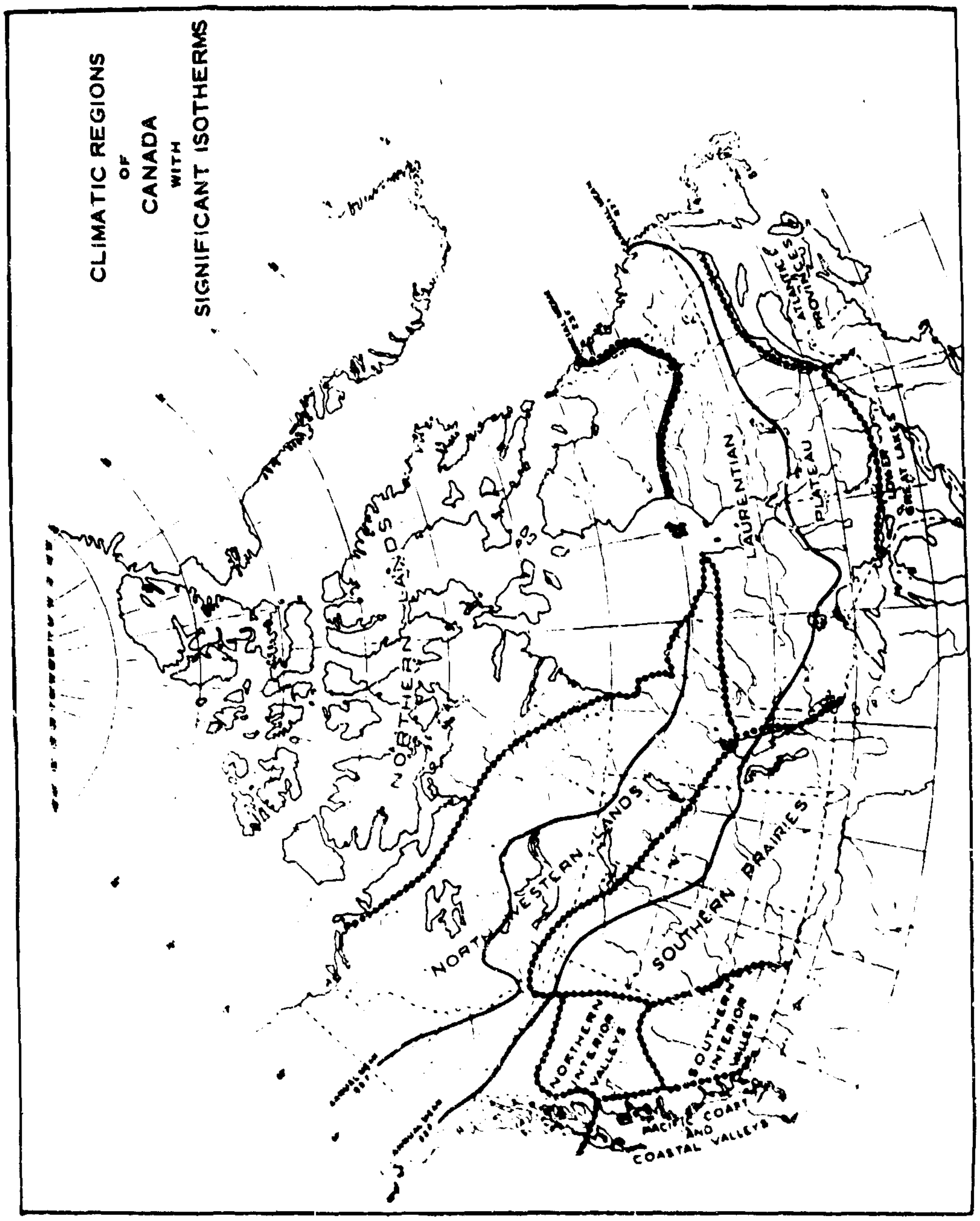
FROM CANADA YEAR BOOK, 1947

PLATE 4



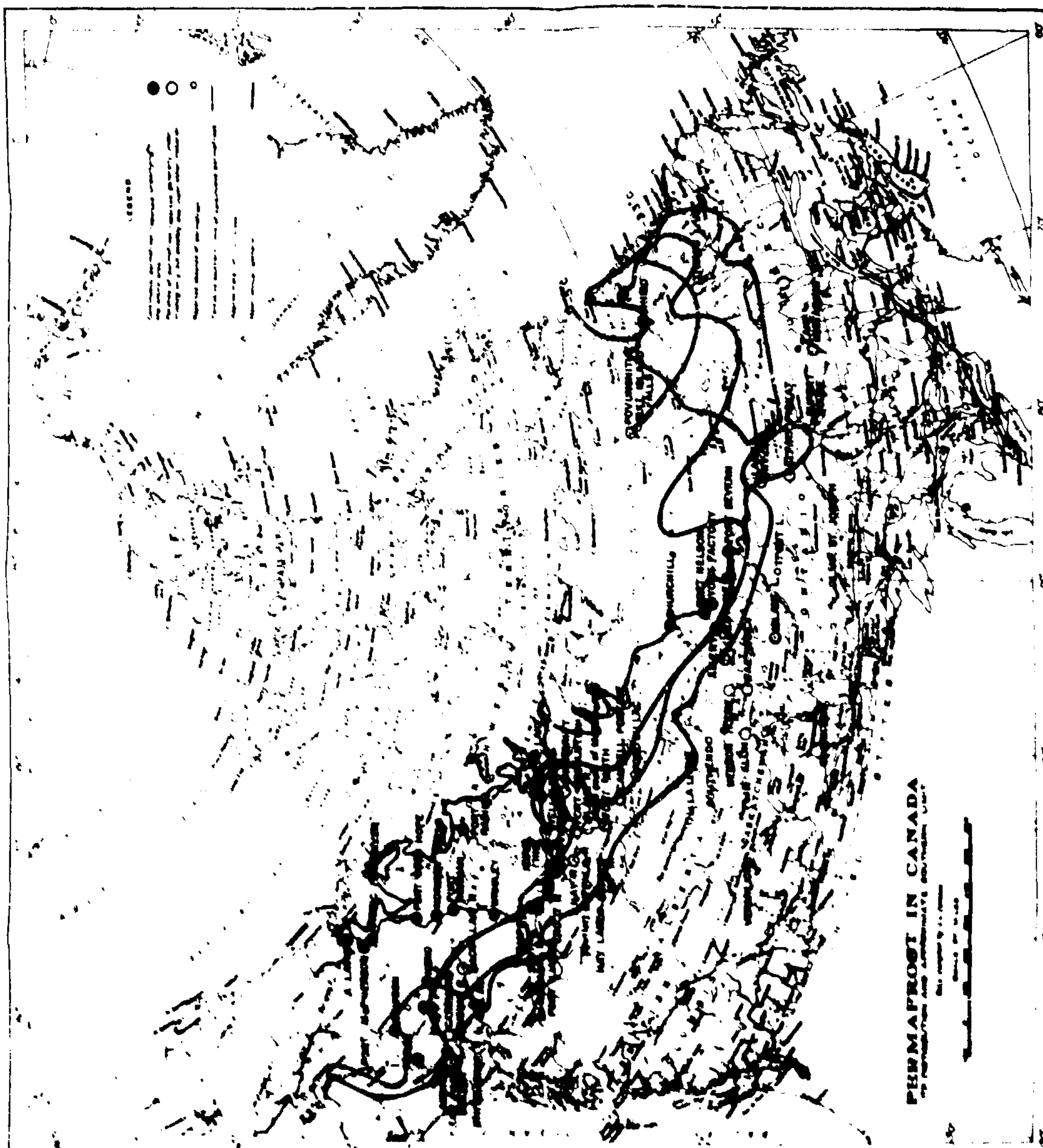
FROM JENNESS[32]

PLATE 5



FROM JENNESS[32]

PLATE 6



FROM JENNESS[32]

PLATE 7