502

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

EXISTING ENVIRONMENT OF NATURAL CORRIDORS FROM PRUDHOE BAY, ALASKA TO EDMONTON, CANADA

by

D. B. Krinsley, W. E. Davies, J. Rachlin
and E. G. Newton

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards or nomenclature.

Washington, D. C.

1971

CONTENTS

ILLUSTRATIONS

INTRODUCTION

The purpose of this report is to describe and evaluate the existing environment in natural corridors from Prudhoe Bay, Alaska, to Edmonton, Canada, and from Big Delta, Alaska, to Edmonton (fig. 1), for potential transportation system construction and operation purposes. The elements of the environment discussed are topography, drainage, vegetation, surficial deposits, permafrost, bedrock, seismicity, and climate. Brief evaluations of the general impact of the environment on the nature of alignments, stability of foundations, and availability of construction materials are given.

This report was prepared at the request of the Environmental Impact Statement Task Force of the Federal Task Force on Alaskan Oil Development. The instructions given specifically requested that the analysis not include consideration of any factors other than those related to the natural environment. In other words, all socioeconomic factors, including existing national and land management boundaries, were purposefully excluded.

OVERVIEW OF THE EXISTING ENVIRONMENT

Topography - The North American Cordillera is the most prominent and important topographic feature of the Alaska-Canada region. In Alaska, the Cordillera consists of two mountain systems which lie parallel and adjacent to the northern and southern coasts respectively (fig. 1). These mountain chains are separated by intermontane plateaus and lowlands. As these mountain systems bend southeastward in Canada, they approach each other with the result that the plateaus become less extensive and the lowlands more constricted. Further southeastward, the two mountain systems are separated only by the Rocky Mountain Trench. Aside from low passes, the mountain chains are major obstacles to movement and construction. Less severe, but nevertheless important are the topographic hindrances imposed by the hills, plateaus, and uplands which separate the high mountains. If only topography were considered, the most favorable corridor from Prudhoe Bay to Edmonton would follow the coastal plain lowlands and interior plains around the outer (northern and eastern) margin of the northern mountain chain (fig. 1).

Drainage - As a result of the orientation of the mountain chains, numerous streams flow down the mountain sides in northerly or southerly directions through most of the study area. Large rivers then gather up these tributaries, and flow parallel to the mountain chains. Thus the Yukon River drains the vast interior of northwestern North America and the Mackenzie River drains an extensive lowland which receives the eastern runoff of the Northern Rockies.

Many streams head in ice fields or in glaciers; consequently their flow varies seasonally, and during the thawed period, diurnally. The glacier-fed Tanana River, for instance, has low discharge in February or March. Discharge gradually increases until May at breakup time, after which discharge increases rapidly, reaching a peak in July or August, a time of maximum melt and rainfall (Holmes and Foster, 1968, p. 8). Maximum discharge at this time is commonly about 10 times the minimum flow in late winter. During the spring breakup (May) large quantities of ice born on swollen rivers have a great potential for destroying fixed structures in or adjacent to the rivers. Streamflow decreases rapidly in September because of freezeup, and gradually decreases through the winter.

Vegetation - The vast area between the two mountain chains has been referred to as the interior spruce and birch forest region (Sigafoos, 1958, p. 171), and contains many forest types. The timberline lies at 1,000 to 1,500 feet on the south slopes of the Brooks Range; 2,000 to 3,000 feet in interior Alaska; and 4,000 to 5,000 feet in the Yukon and interior British Columbia. White spruce with white birch forest are common in the lowlands and well-drained uplands. Many trees are 70 feet high and 20 inches in diameter in lowland sites, and the largest trees in the interior of British Columbia are more than

100 feet high with diameters of 24 inches (Raup and Denny, 1950, p. 7). Black spruce in pure stands grow in poorly drained sites underlain by thick peat layers and fine-grained soils. The mountain chains have either an alpine flora or are barren at higher elevations and the northern coastal plain has a tundra vegetation. Moderate clearing problems can be anticipated along all lowland corridors.

Surficial deposits - The principal lowland corridors along the mountain chains are generally underlain by glacial drift and associated fluvial deposits, modern flood-plain sands and gravels, lacustrine and aeolian silt, and locally thick deposits of peat. Inter-stratified alluvial and marine sediments extend along the Arctic coast in a zone at least 10 miles wide. Where permafrost occurs, the finer grained sediments and organic deposits are characterized by bogs, muskegs, and during the summer, water-logged soils.

The mountains have a thin regolith of rubble of which the shape and character are determined by the parent material. Almost all rock types are represented along the mountain chain, ranging from granites throughout the Cordillera to incompetent siltstones and mudstones along the eastern flanks of the Richardson Mountains. The lower mountain slopes and hilly plateau surfaces are mantled with colluvium derived in large part from solifluction. Depressions and narrow valleys within the extensive plateau region may be underlain with frozen deposits of silt, sand, gravel, and peat 100 or more feet thick.

If only surficial deposits were considered, the coarse outwash and higher terrace gravels along the lowland corridors would provide suitable bearing strength, adequate drainage and plentiful construction materials.

Permafrost - Zones of continuous and discontinuous permafrost are delineated in Figure 1. In the continuous zone, permafrost occurs everywhere beneath the ground surface except possibly in newly deposited sediments or adjacent to large water bodies. Permafrost thickness ranges from 1,330 feet near Point Barrow (Ferrians, 1965) to approximately 200 feet near the southern limit of this zone (Brown, 1967). The active layer, where not stripped of vegetation, varies in thickness from 1½ to 3 feet and usually extends to the permafrost table. The temperature of the permafrost just below the zone of seasonal variation generally ranges from 5°F in the extreme north to 23°F in the southern part of this zone. Mean annual air temperature generally ranges from about 10° to 20°F.

In the discontinuous zone (fig. 1), there are areas and layers of unfrozen ground. Toward the southern limit of this zone, the permafrost

becomes less extensive and it occurs in scattered islands a few square feet to several acres in area (Brown, 1967). In its reduced state it is mainly confined to peat bogs or poorly drained organic soils. Permafrost may also be found in north facing slopes or in forested stream banks where summer shade inhibits thawing and reduced snow cover enhances permafrost expansion.

Where permafrost is extensively developed in unconsolidated materials, it provides a firm foundation if left undisturbed. This necessitates the construction of an insulated buffer, generally a thick gravel pad, between any structure and the permafrost. Permafrost in clean, coarse materials is less subject to volume changes upon thawing, and permafrost in bedrock poses no special foundation problems.

Bedrock - The Rocky Mountain System of the North American Cordillera, including the Brooks Range, is composed mainly of Paleozoic rocks consisting of limestone, sandstone, and shale, or their metamorphic equivalents (Wahrhaftig, 1965, p. 5). These rocks were thrust northward during Late Cretaceous and early Tertiary time and folded into great flat folds overturned to the north. Southward in the Rocky Mountain Thrust Belt, the dominant structures resulting from the Laramide Orogeny are subparallel, west-dipping thrusts that produced a series of narrow, linear mountain ranges formed of resistant Paleozoic carbonates (Douglas and others, 1970, p. 367).

The Pacific Mountain System of the Cordillera contains an almost continuous belt of granitic batholiths which have intruded great thicknesses of tightly folded graywacke, argillite, conglomerate, and basalt and andesite flows and tuffs. The greatest intrusive and volcanic activity has occurred in the Pacific Mountain System with its chain of active or recently active volcanoes. The evidence of igneous activity decreases across the Cordillera away from the Pacific, and there was relatively little igneous activity along the north front of the Rocky Mountain System (Wahrhaftig, 1965, p. 7).

The connecting intermontane plateaus are composed of Precambrian-Paleozoic (?) Birch Creek Schist, and Paleozoic limestone, sandstone and shale, chert, volcanic rock, and graywacke as old as Ordovician. The extensive Canadian interior plains are underlain predominantly by flat-lying Cretaceous shale and sandstone, and Devonian shale and sandstone, Bedrock outcrops become scarcer in the lowland corridors and southeastward in the vicinity of Edmonton where thick glacio-lacustrine deposits or glacial drift mantles the bedrock. Where rock is not available for crushing, fluvial or glacio-fluvial gravels are usually present.

Seismicity - Epicenters for all earthquakes of magnitude M_s6* or greater for the period 1899-1971 in Alaska and northwestern Canada are shown on Figure 1. Earthquakes of smaller magnitudes are much more numerous, and for the most part have occurred in the same general areas as the large shocks. In some places, however, such as east of Prudhoe Bay, there have been shocks of low magnitude in areas that have not experienced magnitude 6 or larger earthquakes.

On the basis of recorded earthquakes, and strain release maps with corollary maximum expected shocks (Milne, 1967), it appears that

each of the corridors proposed here traverses areas of much lower seismic activity and risk than the previously proposed Trans-Alaska pipeline. In particular, all the new corridors avoid the very high seismic zone in the Prince William Sound area, and those in Northern Canada also avoid the high risk area around Fairbanks.

The only area crossed by the northern corridors with recorded earthquakes of magnitude greater than 6 is in the Richardson Mountains, near Fort McPherson. Additionally there have been a few shocks with magnitude about 6.5, within 75 to 100 miles south of the corridor in the Mackenzie Mountains. The magnitude of the largest earthquake recorded in that general area was 6.7. According to Milne (1967) the maximum expectable magnitude is less than 7. Elsewhere along the corridors there have been a few scattered shocks with magnitude less than 5.

The proposed corridor E is within areas of very low seismicity east of Whitehorse. West of Whitehorse there has been one recorded earthquake of magnitude between 6 and 7 and several of magnitude less than 5 have occurred within about 25 miles of the corridor, mostly in the vicinity of the Shakwak Fault. Northwestward from Big Delta towards Fairbanks, where this corridor joins the proposed Aleyeska route, much higher seismicity is encountered. Frequency of earthquake is greater, and maximum magnitudes exceed 7.

---

*M_s is based on the ground amplitude, in microns, of the maximum amplitude surface wave possessing an approximate 20-second period, recorded by a horizontal seismometer. The body-wave magnitudes

reported by the Coast and Geodetic Survey since June 1963 have been converted to surface-wave magnitudes using the Richter formula $M_s = (m - 2.5/0.63)$ where m and M_s are magnitudes derived from body waves and surface waves respectively (Wood, F. J., 1966). For the magnitude range of 6 to 9, M_s is 0.2 to 0.1 lower than the original Richter (1935) magnitude scale for surface waves of shallow focus earthquakes in southern California.

Climate - The climate is characterized by short, cool, relatively dry summers of long daylight hours, and by long cold winters with little to moderate amounts of snow and with little daylight.

Lowest recorded winter temperatures range from -60°F along the Arctic Coastal Plain and in the Edmonton area to -81°F at Snag, Yukon Territory. Generally, winter minimum temperatures in the areas traversed by the corridors range from -65° to -70°F. The highest recorded summer temperatures range from 80°F along the Arctic Coastal Plain to 100°F in the Edmonton area. Maximum expected temperatures in the areas traversed by the corridors range from 85° to 95°F.

The mean annual total precipitation ranges from 10 inches along the Arctic Coastal Plain to 16 inches in the vicinity of Edmonton. Mean annual total snowfall ranges from 40 inches along the Arctic Coastal Plain to 50 inches near Edmonton and in the Snag to Whitehorse section of Corridor E. Measurable precipitation can be expected, on the average, during 80 days of the year along the Arctic Coastal Plain

and during 140 days in the Cordilleran section. In most of the area it can be expected from 100 to 120 days.

Wind chill during the winter is a critical element in this environment. Arctic winds can deposit huge snow drifts in valleys, blocking roads, or force snow through normal door and window closures and into clothing.

Of particular significance to arctic construction is the number of times the water content of a foundation material freezes and thaws, with resultant expansion and then release. There are 20 freeze-thaw cycles per year in the vicinity of the Arctic Coast, but in the Rocky Mountain Section of the Cordillera there are 80 per year, a reflection of the greater diurnal temperature changes at higher elevations.

DESCRIPTION OF THE NATURAL CORRIDORS

CORRIDOR A

Prudhoe Bay to Kay Point (Off-shore Route)

This corridor lies mostly off-shore along the continental shelf from Prudhoe Bay to Mackenzie Bay in the vicinity of Kay Point, where it joins Corridor B (fig. 1). The corridor is 200 miles long. Foundations are firm and generally free of ground ice along all of this corridor except the on-shore section from Kay Point to Corridor B where it crosses wet tundra soils. Special engineering would be required to protect against on-shore ice flows and possible ground ice in the vicinity of Barter Island. Ice scour between the shore and depths of 60 feet and also at depths of 200 to more than 400 feet limit the usable portion of the corridor. The deep water (100 to 500 feet) along the northwest side of Mackenzie Bay prevents the extension of the corridor into the lower part of the Mackenzie Delta. Low seismicity characterizes the corridor.

Topography - The continental shelf off the north coast of Alaska is from 20 to 30 miles in width. The shelf slopes gently to the north and shoal water with numerous islands extends 5 to 12 miles off the coast (USC&GS, 1968-70). The 50-foot depth line is up to 20 miles off the coast in the Prudhoe Bay area but to the east it is progressively closer to the shore and at the Alaska-Yukon boundary it is only 2 miles offshore.

The front of the continental shelf is a steep slope generally dropping from a depth of about 200 feet to 600 feet or more in a distance of 2 miles.

Water 100 to 500 feet deep in the Mackenzie Sea valley extends close to shore in the area between Herschel Island and the central part of Mackenzie Bay.

The large deltas along the Alaskan coast do not alter the symmetry of the shelf and the smoothness of the 30-foot depth line is uninterrupted along the coast. No canyons or valleys cut across the shelf in the area of the corridor.

At Kay Point the shore is a 30-foot bluff behind which is a terrace rising to 250 feet. The west side of the point is protected from wave action but the east side is exposed and is being cut back. From Kay Point to the junction of Corridors A and B, the corridor crossed 22 miles of low, wet tundra with extensive ground ice and 10 miles of rolling benchland on Cretaceous shale and sandstone with a thin cover of silt.

Ice scour - Scour from rafted and pressure pack ice commonly extends out to a depth of 60 feet. From 60 to 200 feet scour is generally absent. From 200 to 400 feet scour occurs from icebergs and ice islands moving through the pack ice. Icebergs in the area of the corridor are rare but ice islands or fragments from them are common. Thus, ice scour could most likely be avoided by placement of the corridor where the depth is 60 to 100 feet.

For 9 to 11 months a year the sea along the corridor is ice covered and in some years, parts of it are covered all year. The ice cover in summer varies with the wind. During offshore winds the coastal area is clear but onshore winds force the ice onto the shore and may cause pile-ups that extend to a depth of 60 feet.

Tidal range is from 1/2 to 2 feet and is greatest in the vicinity of Mackenzie Bay. Wind generated surges rise to 3½ feet or fall to 1 foot below normal water level. Currents are weak and unpredictable (Carsola, 1954).

Bottom deposits - The deposits along the continental shelf average 4.5 percent clay, 18.2 percent fine silt, 31.8 percent coarse silt, 36.4 percent sand, and 9.1 percent gravel. Along the corridor the median grain diameter is 8.62 microns and the sediments are dominantly coarse silt (Carsola, 1954). Sorting is poor and the Trask sorting coefficient is in the order of greater than 4.5 reflecting the indiscriminate mixing of cobbles, pebbles, and sand in the silts. Organic carbon, representative of the amount of decomposable organic material in the sediments, is low, ranging from less than 0.5 to 1.5 percent by weight.

The thickness of the bottom sediments is probably in the order of 10 to 100 feet. Underlying them are bedded, poorly consolidated silt, sand, gravel, and some lignitic coal up to 1,500 feet thick.

Permafrost - Recent observations indicate that ground ice probably exists locally offshore, and in the vicinity of Barter Island bottom features occur that resemble pingos.

Seismicity - Low seismicity characterizes this corridor. A few earthquakes of magnitudes up to 4 M_s have been reported near the edge of the continental shelf northwest of Barter Island, and along the 138th meridian north of Herschel Island.

CORRIDOR B

Prudhoe Bay to Fort McPherson (Coastal Route)

This corridor lies along the inner edge of the coastal plain from Prudhoe Bay east to the mouth of the Mackenzie River at the Yukon-Mackenzie territorial boundary and then south along the narrow benchland on the west side of the Mackenzie delta (fig. 1). The land is rolling and cut by numerous narrow, shallow, steep-sided valleys; upland elevations are from 100 to 1,500 feet above sea level. Mountains that flank the corridor rise to over 4,000 feet. Vegetation is grass-moss tundra and low brush with isolated stands of trees near Fort McPherson. Soils are mainly sand and gravel covered with silt and, at the surface, with organic material. Although permafrost is continuous, thick ground ice is absent from about 50 percent of the corridor. Very low to minimal seismicity characterizes most of this corridor. The southern end, however, is within 30 miles of a recorded earthquake of magnitude about 6.5 associated with strike-slip faults in the Richardson Mountains. There is no surface indication of recent movement.

Foundation conditions are good along 75 percent of the corridor. In the other parts ground ice and unstable slopes could require special engineering treatment. Sand, gravel, and stone suitable for crushing are abundant in the western and central part of the corridor; elsewhere they are scarce.

The area of unstable slopes can be avoided by an alternate corridor along the headwaters of the Bow River to the Porcupine River along the west side of the Richardson Mountains. This could involve crossing a greater area with ground ice but would avoid areas of unstable slope.

Section B-1 - Prudhoe Bay to Kongakut River (Mile 0-170)

This section is along the Arctic coastal plain and the foothills of the Romanzof Mountains. Flat coastal plain is dominant in the western part of the section, rolling plains and low hills in the central part, and dissected plains and low ridges in the eastern part. Seven major rivers cross this section of the corridor; soils are wet throughout 65 percent of the section; permafrost is continuous and ground ice is present in much of the section.

Foundation conditions are poor in 40 percent of the corridor because of extensive areas of ground ice. In the remaining areas ground ice occurs as thin layers or widely spaced masses that can be avoided or controlled by special engineering. Seven large rivers and problems involved in winter icing would involve special engineering techniques to provide safe crossings. Gravel and sand are available from stream channels and upland deposits.

Topography - The 50 miles east of Prudhoe Bay to the Canning River, comprising 30 percent of the section, is in the low, wet coastal plain. Elevations rise from 40 feet above sea level at Prudhoe Bay to 430 feet

at Canning River. The coastal plain is gently rolling and about 40 percent of its surface consists of lakes, most of which are less than 500 feet in diameter with the largest having a diameter of a mile.

East of the Canning River the corridor consists of low hills and rolling plains (38 percent of the section) and, on its inner edge, of dissected alluvial fans and pediments (32 percent of the section). The low hills and rolling plains are in areas of highly modified glacial moraine and outwash developed from Pleistocene glaciation of the Canning, Sadlerochet and other valleys draining the Romanzof Mountains. Elevations rise from 300 feet at the Canning River to 1,300 feet on the alluvial fans to the east. The terrain in the hilly area has relief up to 50 feet and long interfluve slopes of 5 percent or less are common. On the alluvial fans or pediments relief generally is up to 100 feet and steep slopes are confined to the sides of narrow, shallow valleys which are up to 300 feet deep at the inner part of the fans. The Sadlerochet and Romanzof Mountains, lying along the south flank of the corridor in this section are rugged, rising 2,300 to 3,400 feet above the inner part of the Arctic Coastal Plain.

Drainage - Seven major rivers draining the mountains to the south trend across this section of the corridor. All have braided channels and the river beds are from 3,000 to 10,000 feet wide. These rivers form major deltas along the Arctic coast which are up to 15 miles wide and extend inland up to 23 miles. The river beds are mainly sand, gravel, and boulders, except in their lower parts and in the deltas where silt is dominant (Leffingwell, 1919). In this section of the corridor the river banks are 10 to 30 feet high and are being undercut by shifting stream channels. Numerous small streams, spaced 1 to 3 miles, trend across the corridor and most are in shallow, indistinct valleys 6 to 25 feet deep. During the summer the seven major streams have swift current with primary channels over 4 feet deep. The Hulahula, Okpilak, and Jago Rivers are turbid and have large diurnal variations in flow during mid-summer. During winter they freeze to the bottom and aufeis (aggradation of ice by flow over existing ice) is common along parts of the middle and upper sections of the streams (Leffingwell, 1919). Ice mounds resulting from lateral hydrostatic pressure during freeze up have been reported to occur adjacent to the lower part of the rivers (Lewis, 1962). In the area of the corridor major rivers freeze up in late September and early October; breakup occurs in late May and early June.

Vegetation - Grass, sedges, and moss with isolated clumps of low brush cover most of the area. Stands of brush up to 10 feet high occur along some of the stream valleys near the mountains (Spetzman, 1959).

Surficial deposits - The soils in the coastal plain are dominantly fine sand and silt overlain by organic silt and muck up to 10 feet thick. Coarse gravel deposits and glacial till up to 40 feet thick are in isolated bodies on the coastal plain. All of the soils on the coastal plain are saturated with water (Lewis, 1959).

The hills on old glacial moraine are formed of boulder and cobbles in a matrix of clay and sand. Moisture content is high but the soils are not saturated. The alluvial fans or pediments are mainly fine sand and silt with extensive gravel beds and lenses. In general, these are well drained. However, the gravel is overlain by silt beds 10 feet or more thick which have a high water content (Leffingwell, 1919).

Permafrost - This section of the corridor is in an area of continuous permafrost over 500 feet deep. Ground ice is prevalent in the coastal plain soils. Slump, subsidence, and solifluction are extensive, especially along rivers and in disturbed areas. The glacial moraines contain isolated ice lenses and wedges. The alluvial fan and pediments are probably free of extensive ground ice in the gravel beds but ground ice is present within 10 feet of the surface in the overlying silt. Annual thaw extends to a depth of 2 feet or less throughout the section.

Bedrock - Most of the area in the Arctic Coastal Plain along this section of the corridor is covered by surficial deposits over 50 feet thick. Weakly cemented shale and sandstone of Tertiary age lie beneath this cover and crop out in scattered areas along the lower part of the Katakturuk River and Marsh Creek and along the upper part of Okpilak and Jago Rivers (Leffingwell, 1919, Lewis, 1959). The mountains on the south flank of the corridor are Precambrian schist and quartzite, Mississippian black shale and limestone, and Triassic-Jurassic black shale, coal, and sandstone. All are folded and faulted. Cretaceous shale, siltstone and sandstone are at the surface at numerous points along the inner edge of the alluvial fan north of the Sadlerochet Mountains (Reiser and Tailleur, 1969).

Seismicity - Seismicity does not pose significant engineering problems.

Alternate corridor - The area of wet coastal plain soils to be crossed can be reduced from 50 to 18 miles by utilizing a corridor south from Prudhoe Bay. The first 18 miles is across wet coastal plain to the mesa-like upland formed of Pliocene sand and silt on the east side of the Sagavaniktok River (Keller, Morris, and Detterman, 1961). The upland corridor would trend southeast to near the Kadleroshilik River and then eastward across the higher portions of the loess benches to the Canning River. East of the Canning River the alternate corridor would traverse low hills of glacial moraine and outwash to the Katakturuk River where it would follow to the east the section previously described. The alternate corridor is 10 miles longer than the first one described but avoids 32 miles of wet coastal plain.

Section B-2 - Kongakut River to Mackenzie Delta (Mile 170-347)

This 177-mile section of the corridor lies along the north flank of the British and Richardson Mountains. Low foothills and adjacent alluvial fans are dominant; no large rivers cross this part of the corridor; permafrost is continuous; and, soils are wet in the low areas and prone to slump in the foothills.

Foundation conditions are good along 80 percent of the corridor and massive ground ice is not extensive. Slumping along valley walls would require special engineering to maintain good foundations. Gravel and sand are available from stream channels and upland deposits. Large quantities of stone suitable for crushing are available in the mountains along the south flank of the corridor.

Topography - The foothills within the corridor rise to 1,000 to 1,500 feet above sea level with relief from 200 to 600 feet. Slopes are gentle and are generally less than 10 percent in interfluve areas except in the vicinity of the Alaska-Yukon border where the hills and ridges are steep sided with slopes up to 60 percent. Foothills and ridges cover about 75 percent of this part of the corridor. Another 7 percent of this section is on alluvial fans within or flanking the foothills. The fans are 400 to 1,000 feet in elevation with relief less than 100 feet. The middle portion of the section, comprising 18 percent of this portion of the corridor is on the inner portion of the coastal plain with elevations of 300 to 500 feet and relief up to 100 feet.

Drainage - All of the streams within this section are small except the Clarence, Malcolm, Babbage, and Blow Rivers. These four rivers are up to 1,000 feet wide and flow across the corridor in braided channels. The channels are less than 4 feet deep and the current is not swift. Banks along the four large streams are less than 30 feet high in the area of the corridor. The stream channels are formed of sand, gravel, and boulders. During winter these rivers freeze to the bottom.

Minor streams are spaced 1 to 8 miles along the corridor. They are in narrow valleys, 20 to over 150 feet deep, with steeply sloping valley walls. The volume of water is small and many of the streams flow only during the melt period. The channel materials are mainly cobbles and boulders.

Vegetation - Throughout the section vegetation in the coastal plain and on the lower part of alluvial fans consists of a mat of grass, moss, and lichens with some stunted brush growing over peat and organic silt. In the foothills and upper parts of alluvial fans vegetation is sparse and consists of isolated patches of grass and stunted brush.

Surficial deposits - Thick, wet silty sand soils with a cover of organic silt and peat up to 4 feet thick are on the coastal plain. The alluvial fan soils are thick and consist primarily of poorly sorted gravel, sand, and silt with a cover of organic silt and muck, which are up to 10 feet thick in the lower parts of the fans. The soils are wet in the lower part of the fan but in the upper part are drained and are low in moisture. Soils in the foothills are shallow, extending to depths of 6 feet or less. They are primarily sandy silt and sandy clay overlying shale, siltstone, and sandstone. Moisture content in the soils on the upper part of the foothills is low but on the lower flanks and in valleys the soils are saturated. In areas where siltstone and mudstone are present, the soil and bedrock are prone to slump during the

melt season. Colluvial deposits accentuated by solifluction are extensive on the lower flanks of the foothills. In the area of rugged hills at the Alaska-Yukon boundary talus occurs on the lower flanks of ridges.

Permafrost - Permafrost is continuous throughout this section. The depth of summer thaw is on the order of 2 to 4 feet. Frost action is greatest in the wet soils of the coastal plain and on the lower part of alluvial fans, giving rise to slump and collapse during thaw periods and extreme heave during freeze-up. Frost action is slight in the shallow soils of the foothills except during the thaw period when slumps, primarily earthflows, are common on valley walls and other steep slopes.

Bedrock - The western part of this section is underlain by quartzite and quartzitic schist of the Neruokpuk Formation along with Mississippian limestone, shale, and sandstone. The latter are folded and faulted. Similar rocks form the British Mountains along the south flank of the corridor. East of the Alaska-Yukon boundary the rocks are Mesozoic (Triassic through Cretaceous) shale, siltstone, and sandstone. These rocks are folded and faulted. Similar rocks are on the flanks of the Richardson Mountains to the south of the corridor (Douglas and MacLean, 1963).

Seismicity - Seismicity does not pose significant engineering problems.

Section B-3 - Mackenzie Delta to Fort McPherson (Mile 347-415)

On the west side of the Mackenzie delta the corridor is along a terrace-like bench for 68 miles. The bench is 1 to 4 miles wide and on the east it drops abruptly to the wet flats of the Mackenzie delta; on the west it is bordered by the Richardson Mountains. The central part of the section is narrow and foundation conditions are poor. In addition unstable slopes on the flanks of the Richardson Mountains cause mudflows and earthslides which further disrupt the stability of the soils on the bench. Elsewhere in the section foundation conditions are good and ground ice is of small extent. Construction material is limited to pockets of sand and gravel on the bench and small quantities of rock suitable for crushed stone in the Richardson Mountains.

Topography - The bench is 100 to 400 feet above the Mackenzie Delta flats. For 10 miles in the northern and 35 miles in the southern part of the section it is as much as 4 miles wide; in the central part, however, it is 4,500 to 6,000 feet wide. The surface of the bench is gently rolling and the front facing the Mackenzie Delta is a steep slope or scarp generally 10 to 40 feet high but in some areas rising to 150 feet. In areas of alluvial fans, the upland of the bench grades imperceptibly into the delta. The bench ends abruptly at the steep slopes of the Richardson Mountains which rise 1,500 to 2,000 feet above

the bench (Legget, Brown, Johnston, 1966). In the south quarter of the section the west side of the bench is bordered by a low plateau 300 to 1,000 feet above the bench.

Drainage - No large streams cross the bench. At the north end the streams are up to 100 feet wide and are spaced 3/4 to 2 miles. They are in steep-walled, narrow valleys that are 40 to 150 feet deep. Elsewhere the streams, spaced 2,000 to 5,000 feet, cut across the bench in V-shaped gulleys up to 50 feet deep.

Vegetation - Grass, moss and knee-high brush are prevalent on the bench. Along half its length, in areas of bogs, swamps, and wet soil, the cover is continuous; on rolling, dry surfaces the low brush is in clumps and patches separated by grassy areas. Willow and alder thickets are present in gullies. On alluvial fans there are small stands of spruce up to 25 feet high (Pihlainen, Brown, and Johnston, 1956; Legget, Brown, and Johnston, 1966).

Surficial deposits - The bench is covered by silty sand, and silty clay with minor amounts of gravel and sand. Most of the soil is from old, highly modified glacial moraine covered in part by Pleistocene and later alluvial fans. At a depth of 7 to 20 feet beneath the surface there is a thick zone of brownish gray silty clay. Soil moisture is on the order of 80 percent in the upper 20 feet of the bench (Pihlainen, Brown, and Johnston, 1956). The Mackenzie delta flats are dominantly wet fine sand, sandy silt, and clay. The Richardson Mountains along the flank of the bench are formed of folded sedimentary rock with only a thin soil cover on the summits (Jeletzky, 1961).

Permafrost - This section is in an area of continuous permafrost. Along the northern quarter of the section isolated masses of ground ice are within a few feet of the surface and locally the soil is subject to subsidence, slumping, and heave. In the central and southern part of the section the soils are better drained and only very thin, discontinuous ice laminae are present to a depth of 10 to 15 feet. Polygons and frost mounds are up to 2 feet in diameter. Earth slides arising from frost action are common along the flanks of the Richardson Mountains. The severe frost action in the silty and clayey deposits of the alluvial fans causes a rapid disintegration of the soil when exposed (Legget, Brown, and Johnston, 1966).

Bedrock - The northern quarter of the bench is underlain at depths of 50 feet or less by Lower Cretaceous shale and sandstone. The flanking Richardson Mountains are dominantly folded Jurassic and Lower Cretaceous shale and sandstone with some Mississippian limestone, shale and sandstone. A major strike-slip fault system and several overthrust faults cut the bedrock in the southern half of the section (Jeletzky, 1961; Norris and others, 1963).

Seismicity - The south end of the section lies about 30 miles from an area where several earthquakes with magnitudes up to 6.5 M_s have occurred in the past 70 years. The strike-slip fault system along

the east side of the Richardson Mountain is apparently associated with the earthquakes, there are no surface indications of recent movement along the faults.

Alternate corridor - To avoid the unstable ground on the east side of the Richardson Mountains an alternate corridor 100 miles long in the Blow River Basin between the British and Richardson Mountains can be used. The corridor leaves section B2 of Corridor B at Mile 270 south of Kay Point and heads SSE along low ridges and spurs in the foothills of the Barn Mountains to the headwaters of the Blow River. Continuing south it follows along low spurs on the foothills of Richardson Mountains on the east side of the Driftwood River Basin. This corridor joins Corridor C along the upper Porcupine River near Mile 380 of the latter corridor. The distance from Prudhoe Bay via Corridor B, the Alternate Corridor, and Corridor C is 455 miles.

Elevations along the alternate corridor are from 1,000 to 2,500 feet; relief is from 50 to 250 feet. Surface deposits are in the order of 10 to 40 feet thick and consist of silt and fine sand with some gravel. Bedrock is dominantly gently dipping Lower Cretaceous shale and sandstone.

The alternate corridor is in the zone of continuous permafrost and it is probable that 50 percent of the area is underlain by ground ice. In the southern part there are large areas of muskeg and bogs along the valleys of the Bell River.

Vegetation is primarily wet grass-moss tundra. Small clumps of pine and spruce trees occur at the extreme southern end of the alternate corridor.

Gravel and sand for construction purposes are scarce along the corridor. Crushed stone is available from quartzite and limestone formations in the middle and southern parts of the corridor.

The alternate corridor does not cross seismically active areas.

CORRIDOR C

Prudhoe Bay - Fort McPherson (Inland Route)

This 465 mile-long corridor is an inland route from Prudhoe Bay southeast through the eastern part of the Brooks Range (Philip Smith Mountains), along the south flank of the Old Crow Flats, and across the Richardson Mountains into the Mackenzie lowland south of Fort McPherson (fig. 1). The first 70 miles south of Prudhoe Bay is across the Arctic Coastal Plain, the northern half of which is very wet. The corridor through the Brooks Range is along narrow valleys. South and east of the Brooks Range the country is open with broad valleys and a few low ridges to the Richardson Mountains. The corridor crosses these mountains where they are low with broad, open summits. Foundations along the corridor are on firm bedrock for two-thirds of the distance; in the remainder the soils are wet. The entire corridor is in the zone of continuous permafrost but ground ice is present only in the areas of wet soils. Rock suitable for crushed stone is available in most of the corridor. Sand and gravel are available along the rivers in the Brooks Range. The eastern end of the corridor crosses a zone of seismic activity previously described in Corridor B.

Section C1 - Prudhoe Bay to Canning River (Mile 0-65)

This section of the corridor crosses the gently rising Arctic Coastal Plain. The surface is gently rolling with low hilly areas at the southeast end of the section. Three major rivers with braided channels up to 4 miles wide cross the corridor. Vegetation is limited to a cover of grass, moss, and some stunted brush. Soil is mainly silt, most of which is wet and contains considerable ground ice. Mixed soils of gravel, sand, and silt are in the hilly areas. Foundation conditions in most of this section are poor because of weak, wet soils, and the presence of ground ice. Gravel and sand for construction purposes are available from the braided channels of large streams that are crossed by the corridor.

Topography - This section is along the coastal plain. The land surface is flat to undulating for 40 miles to the Kavik River. The soils in this low area are saturated. Lakes and ponds up to a mile in diameter cover 50 percent of the surface. Elevations range from 40 feet at Prudhoe Bay to 250 feet at the Kavik River. Relief is less than 20 feet along this part of the section. Southeast of the Kavik River the corridor is on low rolling hills in an area of loess and glacial deposits. Elevations are 250 to 1,300 feet. Relief is from 30 to 100 feet.

Drainage - Three major rivers are crossed in this section. They flow in braided channels up to 4 miles wide. The channels are over 4 feet deep and the current is swift. Sand and gravel along with numerous boulders form the stream bed. The banks are 40 feet or less in height

and are very steep to vertical. Channels shift continually and most banks are undercut at different times. Along the west side of the Shaviovik River and on both sides of the Kavik River in the area of the corridor there are long bluffs up to 40 feet in height.

Vegetation - The surface has a continuous cover of grass and moss with some stunted brush.

Surficial deposits - In the area of the low, wet coastal plain the soils are dominantly silt and silty sand overlain by organic silt and muck up to 10 feet thick. The loess cover east of the Kavik River is up to 40 feet thick. The glacial deposits lying southeast of the loess at the southern end of this section are up to 100 feet thick and consist of reworked gravel and sand mixed with clay (Leffingwell, 1919).

Permafrost - Ground ice is present throughout the low, wet part of the coastal plain. Slump, subsidence and heave from frost action are widespread. In the loess and reworked glacial deposits ground ice is in the form of thin beds and wedges. Frost action in these soils causes local slumping and heaving (Leffingwell, 1919).

Bedrock - The Arctic Coastal Plain along this part of the corridor is underlain by Cretaceous shale and Tertiary sandstone and shale (Reiser and Tailleur, 1969). Outcrops are rare and are confined mainly to river banks.

Seismicity - Seismicity does not pose significant engineering problems.

Alternate Corridor - The distance across low, wet coastal plain soils could be reduced by about 50 percent by selecting a route south from Prudhoe Bay to the mesa-like upland along the east side of the Sagavanirktok River. The corridor along the east side of the upland would rise to 500 feet on a gradual slope with relief of 20 feet or less. The descent at the southeast end of the upland is 100 feet on a grade of 20 to 40 percent. Soils on the upland are thin, silty sand over weakly cemented shale and sandstone (Keller, Morris, and Detterman, 1961). After descending from the upland the corridor turns east across the Kadleroshilik, Shaviovik and Kavik Rivers on a rolling lowland of loess and joins the southern end of the section described above. Ground ice is scattered in the soils of the upland and is extensive but discontinuous in the loess. This corridor is 8 miles longer than the one previously described but it crosses only 18 miles of wet coastal plain soils as compared to 40 miles in the former.

Section C-2 - Canning River to Chandalar River (Mile 65-165)

This section of the corridor cuts through the Franklin Mountains along the valley of the Marsh Fork of Canning River to near its headwaters in the Philip Smith Mountains. From the headwaters of the Marsh Fork it extends east along narrow headwater valleys of the Junjik River to the Chandalar River. The Marsh Fork flows in braided channels along a broad, flat-floored valley. The headwater valleys are narrow and steep sided. Gravel and sand are extensive along the braided

channels with morainal benches on the flanks of the valley. Headwater valleys are mainly in bedrock with a cover of frost rubble. Permafrost is continuous but ground ice is probably extensive only in the morainal benches.

Sand and gravel are available from the beds of streams and rock suitable for crushed stone is available along most of the corridor. Most of the valleys are free of ground ice and foundation conditions are good.

The main engineering problems along this section would involve avoidance of isolated ground ice, avoidance of scour by ice and water and protection against hydrostatic head developed in aufeis. The flanks of valleys in this section are poor for foundations because of unstable talus slopes and ground ice in the morainal benches. Aufeis would preclude construction during 9 to 10 months of the year in areas of braided streams.

Topography - The first 20 miles of this section is on the east flank of a high bench that borders the Canning River on its west side. The bench rises to elevations of 2,000 to 2,400 feet with relief of 1,000 to 1,400 feet. The slopes on the flanks of the ridge are uniformly about 15 percent.

Most of the section lies in the Franklin Mountains where the elevations of peaks and ridges are from 4,000 to 7,070 feet. Relief is on the order of 2,500 feet with a maximum of 5,000 feet. The mountain ridges trend east-west and are dissected into numerous spurs.

The ridge lines are serate with peaks rising a thousand feet above the adjacent ridge. Slopes are steep, ranging from 50 percent to vertical. The Marsh Fork of the Canning River is in a flat-floored valley from 1 to 2 miles wide and mostly occupied by braided channels. The valley walls are steep and their slope is 90 percent or more. Gradient along the Marsh Fork is about 40 feet per mile. About 65 percent of the corridor in this section is along this valley.

The headwater valleys connecting the Canning and Chandalar Rivers are 100 to 1,000 feet wide and are at elevations of 4,000 to 5,200 feet. Valley walls slope over 100 percent and the valley gradients are 10 to 30 percent. The headwater valleys form the remaining 35 percent of this section.

Drainage - The Marsh Fork of the Canning River normally flows in only a few of its many braided channels except during the melt period in early summer when all channels are filled (Leffingwell, 1919). Current is less than 5 miles per hour and water is up to 4 feet deep in individual channels. Most of the tributaries to the Marsh Fork are 2 to 6 miles long with a few up to 10 miles long. They are spaced 1 to 4 miles apart and trend at right angles to Marsh Fork. All flow in narrow, deep, steep-sided valleys. The streams are up to 10 feet in width and are generally less than a foot deep.

Aufeis is extensive on the upper half of Marsh Fork, reaches a thickness of 12 to 15 feet, and single fields may be up to 3 or 4 miles long. Aufeis remains in the valley until as late as July. In autumn

the river begins to freeze in mid-September but flow beneath the ice and overflow on the ice continues until late November. During this period considerable hydrostatic head exists in the water confined beneath the ice; domes and ridges up to 15 feet high are formed where the water escapes (Leffingwell, 1919).

Vegetation - Most of the section is barren except for small patches of grass and stunted willow on the sides of the Marsh Fork. On old gravel bars willows and cottonwoods to the height of 15 or 20 feet are present in small patches.

Surficial deposits - The bench at the northern end of the section is a moraine composed of cobbly, sandy silt and clay up to 100 feet thick. The moraine lies over Jurassic-Cretaceous shale and sandstone (Reiser and Tailleur, 1969). The flanks of the Marsh Fork Valley contain interrupted deposits of glacial moraine in benches and terraces up to 50 feet above the valley floor. The soils in the moraine are cobbly sandy clay and silt with a large quantity of boulders. The braided channel of the Marsh Fork is formed of cobbly, silty sand with some boulders (Leffingwell, 1919). Upland soils are patchy and thin, consisting of boulder and cobble frost rubble and small areas of upland moraines. Talus slopes occur along the middle and upper Marsh Fork.

Permafrost - The section is in a zone of continuous permafrost. Ground ice in the form of beds and lenses up to a foot or two thick is probably present in the moraines. Isolated masses of ground ice also probably occur along the braided channel of Marsh Fork. Bedrock is free of ground ice, although its temperature is always below freezing.

Bedrock - The northern and southern parts of the Franklin Mountains and most of the Philip Smith Mountains are formed of intensely folded Mississippian rocks. Limestone is dominant along with some sandstone. Dips are 30° to 80° and some folds are overturned. The central part of the Franklin Mountains is mainly massive schistose quartzite and quartz-mica schist (Reiser and Tailleur, 1969). On the southern edge of the Franklin Mountains is a belt of folded limestone, shale, and sandstone of Permian and Triassic age. A few overthrust faults trending east-west occur in the Franklin Mountains (Mertie, 1930).

Seismicity - Seismicity does not pose significant engineering problems.

Section C3 - Chandalar River to Richardson Mountains (Mile 165-380)

From the Chandalar River to the west base of the Richardson Mountains the corridor crosses a variety of terrain. The western 140 miles of the section is across low mountains and hills alternating with broad glaciated valleys. In the vicinity of the Alaska-Yukon border the corridor traverses low mountains east of which it crosses the southern edge of the Old Crow Plain, a rolling lowland. Soils are wet along most of the route and ground ice is extensive in the valley flats and glaciated valleys. Foundation conditions are good along

50 percent of this section but any construction would require detailed field investigations to avoid areas of extensive ground ice. In the remaining half of the section ground ice is extensive and foundation conditions are poor. Sand, gravel, and rock for crushed stone are available along the corridor.

Topography - The corridor crosses the Chandalar River at the west end of the section. The Chandalar Valley is 4 to 5 miles wide and flat-floored with the river flowing in a braided channel over 2 miles in width. In this part of the corridor the valley floor is 2,800 feet in elevation and the spurs and ridges rise to about 6,500 feet. The valley walls are highly dissected and slope from 20 to 80 percent. East of the Chandalar River the corridor is across a hilly area that has been extensively glaciated. Elevations on the open valleys in this area are from 3,000 to 3,800 feet. The tops of hills and low ridges are 3,600 to 4,510 feet; isolated peaks rise to 5,400 feet. Slopes are gentle with interfluve areas rising at the rate of 5 percent or less. The Chandalar Valley and the hill area cover about 50 percent of the section.

East of the Coleen River the corridor is in an area of low mountains for about 50 miles (23 percent of the section). The mountain ridges are irregular in plan but trend in a general direction to the north. The ridges are rounded and widely spaced, and the upland rises and falls along gentle crest lines at elevations of 2,400 to 4,000 feet. Valleys are at 1,600 to 2,000 feet in elevation. East of the mountains, the remaining 27 percent of the section is on the southern edge of the

Old Crow Plain bordering the upper Porcupine River. The plain is flat and to the north of the corridor it is dotted with lakes. Along the corridor, between the lakes on the north and the entrenched Porcupine River on the south, the plain is undulating and well drained. Elevations are 1,000 to 1,890 feet; relief is 100 feet or less, exceeding 50 feet only at the east and where two major streams are crossed.

Drainage - Three major rivers, the Chandalar, Sheenjek, and Coleen, cross this section of the corridor. They flow in braided channels along flat-floored valleys 2 to 5 miles in width. Along the Chandalar the valley walls slope 20 to 90 percent; along the other two major rivers the walls are indistinct and rise gently away from the bottom lands. The braided channels occupy from 10 to 50 percent of the bottom lands and the remainder of the valley floors are low, wet flats with numerous potholes and lakes. Along the Chandalar River discontinuous morainal benches lie along the flanks of the valley and rise from 10 to 100 feet above the valley floor. The channels in the braided parts of the rivers are up to 200 feet wide and in midsummer the water is up to 4 feet deep. Scour and shifting channels are extensive along the Chandalar; on the Sheenjek and Coleen little such action occurs. Spring breakup occurs in late May and early June. The major rivers flow with full channels and very swift current from early June to early July during which times large quantities of driftwood are carried along (Mertie, 1930). Aufeis is present on the Chandalar in

the vicinity of the corridor. It is up to 10-feet thick and generally persists to late summer; in some years it does not melt completely.

Vegetation - Along the Chandalar, Sheenjek and Coleen Rivers as well as along the south side of the Old Crow Flats there are extensive patches of spruce, poplar, and birch forest. Separating the forests are wide expanses of wet tundra and muskeg. Tree line is about 2,500 feet in the tributary valleys. Above the tree line there are thick stands of willow and alder brush in the valleys and on the lower slopes of mountains. On the high ridges and spurs grass and moss occur in patches.

Surficial deposits - Sand and gravel form the beds of the large braided streams and the adjacent flats. A veneer of fine sand and silt covers the flats to a depth of several feet over which is a cover of organic silt and muck several feet thick. Silt covers the lower flanks of the hills and uplands. Between the Chandalar and Sheenjek Rivers moraine extends as high as 300 feet above the major valleys and the floor of the low valleys between the rivers is filled with moraine 5 or more feet deep (Mertie, 1930). The moraine consists of unsorted boulders and gravel mixed with sandy clay. On other uplands frost rubble is extensive and covers many of the summits and valley floors. Talus is extensive along the valley walls.

Permafrost - This section lies near the southern edge of continuous permafrost. Ground ice is extensive along the major river flats and large blocks and wedges of ground ice are present in the morainal areas. Along the southern edge of Old Crow Flats ground ice is present in large wedges and beds. Ground ice is generally present in talus slopes but is absent in the bedrock areas of the Philip Smith Mountains. Small lenses of ground ice are probably present in the weathered rocks of the mountains southwest of Old Crow Flats. Ice mounds are common in the broad, flat valleys of the Sheenjek, Coleen, and Chandalar Rivers. The active zone over permafrost is probably up to 4 feet thick in this section.

Bedrock - West of the Coleen River the rocks are dominantly Permian shale and chert with some Mississippian limestone. Thick sills of gabbro, diabase and quartz-diorite are intruded into the sedimentary rocks. The rocks are folded with gentle dips west of the Sheenjek River and steep dips between the Sheenjek and Coleen Rivers (Mertie, 1930; Brosge, and Reiser, 1969).

East of the Coleen granite and metamorphic rocks, mainly quartzite and schist, occur as far east as the Old Crow River. East of this limestone area, shale and chert of Carboniferous and Permian age are dominant (Norris, Price, and Mountjoy, 1963).

Seismicity - Seismicity does not pose significant engineering problems. A large but inactive fault has been postulated along the Coleen River (Brosge and Reiser, 1969).

Section C-4 - Mackenzie Mountains to Fort McPherson (Mile 380-465)

This section of the corridor crosses a rolling to hilly plain and low foothills on the west side of the Mackenzie Mountains. The central part of the corridor across the mountains reaches an elevation of 2,630 feet in an area of steep, narrow valleys and highly dissected ridges and spurs. The eastern third of the section is along the Peel Plateau which is highly dissected and is bound on the east by a long steep face rising 1,200 feet in 3 miles. The eastern 5 miles of the corridor is across a broad dissected terrace ending in a steep slope at the Peel River. Deposits of sand, gravel are in a very small quantity along this section. Limestone and sandstone suitable for crushed rock are available in the Richardson Mountains. Foundation conditions are good and ground ice is not extensive in this section.

Topography - The western foothills, comprising 47 percent of this section, are low and rolling with north and northeast trends. Elevations are from 1,000 to 2,680 feet and relief is generally less than 500 feet with a maximum of about 1,500 feet. Slopes are gentle, generally less than 10 percent except in two areas where low ridges trend northeast across the corridor. Slopes on the flanks of the ridges are up to 50 percent.

Twenty-three percent of this section lies in the Richardson Mountains. The mountains trend north and reach an elevation of 3,000 to 5,000 feet in the vicinity of the corridor, where relief is up to 2,000 feet. The corridor itself, however, is along a broad open valley with a summit elevation of 2,630 feet and along which relief of 500 feet or less. Slopes reflect dips of strata and joint faces and are from 30 percent to vertical along the corridor. The east side of the Richardson Mountains rises abruptly from the Peel Plateau. Relief is from 500 to 1,700 feet and slopes are from 50 to 100 percent with some nearly vertical. Locally vertical scarps are present.

The Peel Plateau is an upland with concordant summits between 1,300 and 1,500 feet. It is highly dissected and slopes on valley walls are steep, ranging from 30 to 50 percent. The terrace along the Peel River grades into the plateau. It is at an elevation of 200 to 400 feet and the front along the Peel River is a bluff 150 to 200 feet high.

Drainage - The foothills part of the section is drained by small tributaries flowing into the Porcupine and Bell Rivers. These tributaries are swift flowing streams, up to 100 feet wide and 2 to 6 feet deep. They are in shallow valleys with stream banks 4 to 20 feet high. The tributaries on the west side of the Richardson Mountains are in broad open valleys. The streams are up to 100 feet wide and 1 to 4 feet deep with swift current. The river beds are coarse gravel and river banks are 2 to 20 feet high. Several small lakes are along the headwater streams in the mountains.

The streams in the Peel Plateau are entrenched in narrow valleys up to 300 feet deep. The major streams are from 1 to 5 feet deep, up to 200 feet wide, and swift.

Vegetation - Open spruce forests grow along the hills and low ridges in the foothill areas. The mountains are barren but the headwater valleys have stands of spruce along with alder and willow thickets among extensive areas of grass. The Peel Plateau is primarily an area of wet soils with extensive grass, moss and brush tundra. Patches of spruce occur on the upland and are extensive along the valleys, valley walls, and parts of the adjacent upland. Along Stony Creek white spruce attains a height of 40 feet and is 10 inches in diameter at the butt (Gabrielse, 1957).

Surficial deposits - The foothills contain a thin soil cover of silt and organic silt up to several feet thick. The headwater valleys in the Richardson Mountains are dominantly sand and gravel with some silt. Talus deposits are along the valley walls. The upland of the mountains has a thin cover of frost-rived rubble lying over bedrock. The Peel plateau has been glaciated but in this section the drift is thin and spotty, consisting of patches of silt and gravel. Bedrock is close to the surface. The terrace on the east side of the plateau is a bedrock bench with a thin veneer of silt and gravel (Gabrielse, 1957; Bostock, 1948).

Permafrost - The corridor in this section is at the southern limit of continuous permafrost. Ground ice in the form of thin discontinuous beds and lenses is extensive in the foothill area. Large masses of ground ice are present in the valley of the Bell River and the lake-strewn headwaters leading into the Richardson Mountains.

The Peel Plateau is primarily bedrock; ground ice is probably confined to thin beds and lenses along major stream valley and in patches of glacial till. Temperature observations in a test well on the Peel Plateau at an elevation of 1,300 feet indicate that the bottom of permafrost is 400 feet below the surface (MacKay, 1967).

Bedrock - Most of this section of the corridor lies along a broad zone of folded and faulted limestone, much of which is cherty. In the western 10 miles the corridor crosses quartzite, sandstone, and black shale of Upper Jurassic and Lower Cretaceous age. Between the Porcupine and Bell Rivers these beds are covered by Tertiary sand and clay (Gabrielse, 1951).

The Peel Plateau is dominantly flat-lying to gently dipping shale and sandstone of Cretaceous age. The benchland on the east side of the plateau is cut into folded shale and sandstone of Devonian (?) age.

Seismicity - The section cuts across the seismically active zone on the east side of the Richardson Mountains described in Section B3. The largest recorded earthquake, magnitude about 6.5 M_s, occurred just north of the section.

CORRIDOR D

Fort McPherson to Edmonton

This corridor is 1,240 miles long and traverses the Mackenzie lowland and Interior plains to Fort Simpson and the Alberta High Plains south to Edmonton (fig. 1). No mountain ranges are crossed; elevations are from near sea level to 1,900 feet north of Fort Simpson and up to 3,300 feet between Fort Simpson and Edmonton. Relief is less than 500 feet along the corridor. Nine major rivers are crossed by the corridor. Soils are dominantly silt-clay, stony tills with subordinate areas of gravel and sand. Ground ice is extensive south to the Hay River, about 160 miles south of Fort Simpson. Vegetation is primarily spruce-pine, aspen forest intermixed with moss-grass bogs. Bedrock is dominantly shale with some sandstone, primarily of Cretaceous age. Foundation conditions are poor along about 40 percent of the corridor because of ground ice and weak bedrock. Construction materials are not plentiful along the corridor. Gravel and sand are available in the northern and southern parts of the corridor from eskers. Stone suitable for crushing is available from the mountains adjacent to the central and southern part of the corridor. Corridor D is characterized by minimal seismicity except in the vicinity of the Richardson Mountains. In this area a few earthquakes of magnitude about 6.5 have been recorded 75 to 100 miles south of the corridor. Barge transportation along much of the corridor is maintained on the Mackenzie River during the summer.

Placement of the corridor on the east bank of the Mackenzie was considered from Fort Good Hope to Fort Norman but was dropped because of unstable slopes resulting in mudflows and earthslides in that area.

Section D1 - Fort McPherson to Fort Norman (Mile 0 to 330)

This northwestern part of this section is on the upland between the Peel and Mackenzie Rivers for about 200 miles. Southeast of this it is along the western part of the Mackenzie lowland. The upland is rolling, from 500 to 1,500 feet in elevation, and relief of 50 to 500 feet; the lowland is at an elevation of about 500 feet with relief of 50 to 100 feet. The upland has a thick cover of silt-clay and sand with some extensive areas of gravel ridges (eskers). Bedrock is Cretaceous shale, siltstone and sandstone dipping gently south. Permafrost is discontinuous but ground ice is extensive, underlying most of the upland bogs. Foundation conditions are good in 25 percent of the area along gravel ridges; elsewhere they are poor to fair in areas of bogs with ground ice and on shale banks. Construction materials are scarce and the only suitable deposits are the gravel ridges (eskers).

There are no road systems or major towns along this section. Barge transportation is operated on the Mackenzie River in summer and the Peel River can be used for barges to the point where the corridor crosses it.

Topography - Ten miles south of Fort McPherson the Peel River flows in a terraced valley about one and a half miles wide. On the west

side a terrace rises 250 feet above the river with a slope of 25 to 30 percent along its front. The terraces on the east are at an elevation of 100 to 150 feet and stand 90 to 140 feet above the river. To the east and southeast the terraces grade with the eastern portion of the Peel-Mackenzie upland. The upland rises gradually to the southeast attaining an elevation of 500 to 550 feet midway along the section. Farther to the southeast, on the flanks of the Carcajou Range, Mackenzie Mountains, it reaches about 1,200 feet elevation and then abruptly ends where cut by the Carcajou River. The upland is smooth to rolling. Low, broad, rounded ridges trending northwest are common on the upland between the Arctic Red and Peel Rivers. Relief is less than 100 feet except along the Arctic Red, Rampart, and Carcajou Rivers where it is up to 300 feet.

The lowland east of the Carcajou River to the Mackenzie River at Fort Norman is 250 to 500 feet in elevation with relief of 100 feet or less. It has a flat to undulating surface and near Fort Norman it is in the form of a river terrace 250 feet above the Mackenzie River.

Drainage - The corridor between the Peel River and the Mackenzie River at Fort Norman crosses six major streams. In the northwest the Peel River is crossed 10 miles south of Fort McPherson where it is about 3,000 feet wide. During low flow the Peel discharges about 20,000 cubic feet per second with a current of 2 miles per hour. At low flow the river is about 15 feet deep but in flood it rises up to

30 feet above low flow and discharge increases to about 80,000 cubic feet per second. The stretch of the Peel in the vicinity of the corridor is subject to impoundment and reversal of flow when the Mackenzie is at flood stage. The Peel is entrenched 13 to 75 feet in the area of the corridor and its banks are of similar height (Henoch, 1961).

The Arctic Red River and Ramparts River have characteristics similar to, but of much less magnitude than the Peel.

The Mountain and Carcajou Rivers are crossed at the southeastern end of the upland. The former is a braided stream up to a mile wide and with numerous sand bars. It is sluggish and subject to flow reversal from floods on the Mackenzie. The north bank of the river is 10 feet or less in height and grades with the upland. The south bank is a bluff up to 100 feet high. The Carcajou is a meandering stream about 1,000 feet wide with steep banks up to 100 feet high on the north and 10-foot banks on the south. The Little Bear River which is crossed near Fort Norman is similar to the Carajou. Freezeup on the Mackenzie River is in late November in the Fort Simpson area and is progressively earlier downstream to the delta where freezeup occurs in early to mid-October. Breakup is in early May at Fort Simpson and in mid- to late May in the reaches below Fort Good Hope (MacKay, 1963).

Other streams along the section are irregular in pattern, spaced 1 to 5 miles, and are generally less than 10 feet wide with little current. Their valleys are shallow and slopes are less than 5 percent.

Numerous lakes lie along these streams as well as on other parts of the upland and lowland section of the corridor. Some are up to 4 miles long and a mile wide and many are up to a mile in length and a quarter mile wide. Most of the lakes are oriented towards the northwest.

Vegetation - About 80 percent of the Peel-Mackenzie upland is covered by open stands of spruce-pine, aspen and birch up to 50 feet high. The forested areas are in roughly parallel bands trending northwest along the higher portions of the upland. The remainder of the area is in moss and hummocky grassy bogs. Forest fires throughout this part of the Mackenzie Basin are a very serious hazard. The lowland along the Mackenzie River southeast of Mountain River is about half bogs and muskeg with moss-grass vegetation with the remainder in small stands of spruce-pine, aspen, alder, and birch (McConnell, 1890).

Surficial deposits - The upland is covered by a thick deposit of sand and clay boulder till up to about 150 feet thick (Stewart, 1945; Tassonyi, 1969). In the Fort McPherson area, which is probably typical of much of the upland, the till is in the order of 80 to 95 percent silt-clay and 5 to 20 percent fine sand (Henoch, 1953). Beneath the boulder till is a discontinuous strata of indurated gravel from 10 to over 100 feet thick.

Midway along this section there is an area of eskers about 20 miles in length and 10 miles in width which contain a large quantity of sand and gravel.

Permafrost - Although most of this section lies outside of the zone commonly designated as continuous permafrost it contains ground ice and ice wedges throughout the entire section. At Fort McPherson permanently frozen ground extends to a depth of about 350 feet (Mackay, 1967). At the southern end of the section ground ice is sporadic in occurrence but underlies all areas of moss-grass muskeg. In this area permanently frozen ground extends to depths of 140 to 240 feet. The active zone throughout the section is from 1 to 2 feet in areas of undisturbed cover and $3\frac{1}{2}$ to 6 feet beneath areas that have been stripped (Hemstock, 1953; Harding, 1963).

Bedrock This section of the corridor is underlain by shales of Lower Cretaceous age (Hume, 1954). From the Peel River to the Arctic Red River Devonian shales are on the north flank of the corridor and in the vicinity of the Peel River Carboniferous shale and sandstone are present (Douglas and MacLean, 1963; Hume and Link, 1945). The boulder till covers practically all of the shales except for isolated outcrops along the Peel River. Permafrost extends into the shales and where the shales are exposed in excavations they disintegrate rapidly (Harding, 1963).

Seismicity - The northwestern part of this section enters the seismically active zone of the Richardson Mountains described in Section B3. A few earthquakes of magnitude about 6.5 have occurred in the southern part of this zone within about 75 to 100 miles of the corridor.

Section D2 - Fort Norman to Fort Simpson (Mile 330 to 597)

This section lies along the Interior High Plains on the east side of the McConnell Range (Franklin Mountains) and along the west flank of the Horn Plateau. The high plains consist of large, dome-shaped hills, 10 to 30 miles across, which rise to 1,900 feet in elevation and have local relief of 100 to 500 feet. Slopes on the sides of the hills are 100 feet per mile or less.

The only major stream is the Mackenzie River which is crossed at the north and south end of the section. At both crossings it is about a mile wide and has low banks with gentle slopes inland.

Most of the area is covered with silty clay, stony till in the form of drumlinoid ridges; eskers composed of gravel and sand cover 1,500 square miles in the middle part of the section. At the north end of the section, adjacent to the Mackenzie River is an area of Eocene weakly cemented sandstone and shale with beds of lignite that have been burning for centuries. Bedrock is flat-lying shale of Cretaceous age and some Devonian sandstone, shale, and limestone. There is no road system in the area of this section. Barge service is operated on the Mackenzie River during the summer.

Permafrost is discontinuous but ground ice is present in 60 percent of the northern and 20 percent of the southern part of the corridor.

Weak foundation conditions occur in about 50 percent of the section in areas of bogs underlain by permafrost and in the zone of burning lignite beds. Elsewhere foundation conditions are good on gravel ridges.

Placement of the corridor along the east bank of the Mackenzie was considered but unstable slopes reflected in mudflows and earth-slides along much of the valley on the flanks of the Franklin Mountains would have entailed extremely difficult engineering to obtain satisfactory foundations.

Topography - The Mackenzie River is crossed in this part of the corridor between Police and Seagull Islands, about 20 miles above Fort Norman. The section trends east through a wide gap in the Franklin Mountains on a rolling plain that rises to the east on a gentle slope of 100 feet to the mile. East of the Franklin Mountains the section trends southeast on a rolling upland at elevations of 800 to 1,900 feet. Relief is 100 to 500 feet with long slopes at 100 feet to the mile on the flanks of large, round, dome-like hills. The southern end of the section, 15 miles east of Fort Simpson, slopes gently towards the Mackenzie River at the rate of 50 feet per mile.

The McConnell Range (Franklin Mountains) lies on the west flank of the corridor, rising to elevations between 2,500 and 5,000 feet. The east side of the range is a broken scarp with relief of 500 to 1,500 feet above the rolling uplands to the east. The Horn Mountains on the east flank of the corridor near the southern end of the section is a rounded plateau with elevations about 2,600 feet. On the north and west sides the plateau grades gently with the level of the corridor and relief is less than 50 feet. On the south side of the plateau the slope is steeper with a rise of 1,200 feet in 3 miles.

Drainage - The Mackenzie between Police and Seagull Islands flows in a single channel about a mile wide with a current of 2 to 3 miles per hour and a depth of about 20 feet. The banks are 10 to 20 feet high and slump occasionally. At the south end of the section the Mackenzie is crossed again. Here the river is about a mile wide but depth is probably about 10 to 15 feet with current of 2 to 4 miles per hour. Except for the Mackenzie River the section does not cross any major streams. Four large streams trend west across the McConnell Range with numerous small subparallel tributaries at right angles to the main streams. The main streams are 30 to 40 miles apart and tributaries are 1 to 5 miles apart. Valleys are shallow, seldom more than 50 feet deep and valley walls have slopes of less than 20 percent. Lakes and bogs are strung out along all of the valleys.

Vegetation - The area has extensive pine-spruce, aspen, birch forests broken by large moss-grass bogs. The trees in the forest are up to 80 feet tall and 12 inches in diameter at the bole. The tree line is at 1,500 and above this the hills are covered with moss-grass tundra (Douglas and Norris, 1963).

Surficial deposits - The entire section is covered by thick glacial deposits. East of the McConnell Range the area is covered by silty clayey, stony till with large areas in drumlinoid form. Some of the drumlinoid forms contain deposits of sand and gravel. In the central part of the section there are numerous gravel-sand eskers in an area 50 miles long and 30 miles wide. The esker ridges are short, sinuous and are grouped in series of multiple ridges (Craig, 1965).

At the north end of the section, on the east side of the Mackenzie River is an extensive area of Eocene rocks made up of weakly cemented sandstone, shale, and lignite. Much of the lignite is now burning or has undergone combustion for long periods of time. The ground in this area has been baked and has slumped (Camsell and Malcolm, 1919).

Permafrost - Permanently frozen ground occurs in large but discontinuous areas along this section. Ground ice is prevalent throughout 50 percent or more of the section and lies beneath muskegs and bogs at a depth of not more than 2 feet. In the northern part of the section the bottom of permafrost is from 140 to 150 feet beneath the surface (Hemstock, 1953); in the southern end the base of permafrost is probably in the order of 40 feet below the surface (Brown, 1967).

Bedrock - Except for the northern end of the section where the Eocene formations occur, most of the section is underlain by flat-lying Cretaceous gypsiferous shale. In the southern third of the area Devonian shales, mudstone, siltstone, and some limestone are exposed beneath the Cretaceous and the boundary between the two is at about 1,000 feet elevation (Douglas and Norris, 1961, 1963; Stott, 1960).

Seismicity - Seismicity does not pose any engineering problems.

Section D3 - Fort Simpson to Edmonton (Mile 597 to 1,240)

This section lies mainly on a glacial till plain with occasional, widely spaced hills and low ridges. Bogs are extensive, covering

50 percent of the section, and spruce forest and high brush cover most of the other half. Permafrost in the form of shallow ground-ice lenses occurs sporatically in the bog areas south to about 58°N. Sand and clay soils cover the till plain and are about equally distributed. Bedrock is sandstone snd shales with a high content of bentonite making them subject to slump on steep slopes. Except for areas of slump and ground ice foundation conditions are good. Construction materials are not plentiful and are confined to isolated pockets of gravel and sand in the till plain and along the major streams. In general, the bedrock is not suited for use as crushed stone. The extreme southern part of the section is farmland. Railways extend north parallel to the section as far as Lesser Slave Lake. The Mackenzie Highway and Hay River railroad are crossed midway along the section.

Topography - The northern Alberta plains are 950 to 2,300 feet in elevation with occasional low hills and ridges rising to about 3,300 feet. The plains are flat to undulating and relief is from a few feet to 100 feet; slopes are less than 10 percent except for a few isolated rolling areas where slopes are 10 to 15 percent. The low hills and ridges are rounded and slopes on their sides are from 10 to 30 percent; relief on the hills and ridges is in the order of 500 to 1,200 feet.

Drainage - The drainage is disarranged because of glaciation and bogs and lakes are numerous. The major rivers trend northeast across this section of the corridor. They flow in shallow valleys, seldom more than 50 feet below the level of the plain and the slope of the valley walls is 15 percent or less. Streams are from a half to 6 miles apart. Except for the Hay, Peace, and Athabasca Rivers, the streams are 5 to 100 feet wide and up to 2 feet deep. The Hay and Athabasca Rivers are in open valleys with banks 10 to 100 feet high alongside their meandering channels. The valley walls along the Peace River are rounded with gentle slopes rising 50 to 150 feet above the river and the river meanders on bottom lands up to 2 miles wide.

Vegetation - Most of the plains are covered by pine-spruce, aspen, and some birch forests with trees up to 80 feet high and 12 inches in diameter at bole height (Moss, 1953a). Between the Mackenzie River and the Peace River the section crosses extensive areas of moss bogs (muskeg) enclosed by the forests. The bogs are from 100 feet to over 1 mile in diameter and have a cover of moss, lichen, grass, and stunted shrubs (Moss, 1953b). Where the corridor crosses Hay River and the Keg River (mile 820 and 900) grass meadows are extensive (Moss, 1952).

Surficial deposits - On the south side of the Mackenzie for a distance of 25 miles the section crosses an area of sand dunes. The dunes form low ridges from 20 to 40 feet high and are stable, being covered with a thin mat of grass and small groves and isolated stands of spruce (Craig, 1965).

South of the dune area and continuing to Edmonton the plains are covered by glacial deposits to a depth of 100 feet. Glacial till consisting of clay silt and inorganic silt are dominant south to the Peace River. In the Peace River Valley the deposits are lacustrine fine sand and sandy silt. South of this are alternating areas of lacustrine clay and silt and glacial moraines of gravelly sand and clay silt (Lindsay, Heringa, Pawluk, and Odynsky, 1958; Lindsay, Pawluk, and Odynsky, 1959, 1960, 1961).

Throughout this section of the corridor the percent of clay in the soils is up to 40 percent south to Lesser Slave Lake and up to 30 percent between Lesser Slave Lake and Edmonton. Silt is on the order of 30 to 40 percent along the entire section; sand is 20 to 40 percent south to Lesser Slave Lake and up to 50 percent from there to Edmonton. Plastic limits are 15 to 20 percent along most of this section except between Hay River and Peace River where they are 20 to 25 percent; plasticity numbers are on the order of 15 to 20 in the section. Montmorillonite content of the clay is 20 to 35 percent south to Lesser Slave Lake and 45 to 55 percent south to Edmonton. Hydrous mica is 25 to 35 percent of the clay south to Lesser Slave Lake and 20 to 25 percent from there to Edmonton. Along most of the section corrosive potential is low; electrical conductivity of soluble salts is in the range of 0 to 1 mmhos/cm except in the vicinity of Peace River where it is from 1 to 2 (Pawluk and Bayrock, 1969). Gravel is scarce along the entire section.

Permafrost - Large areas of ground ice are present between the Mackenzie River and Hay River. The ice is in 80 percent of this area in organic soils beneath bogs and in large frost mounds (pals). In the former case the ice is 19 to 26 inches below the surface and its thickness depends to a great extent on the thickness of peat ranging from 8 feet in the south to 40 feet in the north. Generally the glacial till beneath the peat is not frozen (Lindsay, Pawluk, and Odynsky, 1961). The frost mounds average about 3 feet in height with the largest up to 12 feet high and ground ice extends to a depth 5 to 8 feet. The mineral soils derived from glacial till in this area probably have minor areas of frozen clay at depths of 30 inches or more. South of the Hay River there are no significant areas of ground ice.

Bedrock - The section is underlain by weakly cemented Upper Cretaceous marine sandstone, shale, and siltstone south to Lesser Slave Lake (Stott, 1960). Bentonite and volcanic ash are present in subordinate amounts. The presence of bentonite causes slumping on steep slopes. The sandstones are poorly suited from crushed stones (Lindsay, Pawluk and Odynsky, 1959, 1960, 1961; Lindsay, Heringa, Pawluk, and Odynsky, 1958).

South of Lesser Slave Lake the bedrock is Upper Cretaceous non-marine sandstone and shale. The rocks are moderately well cemented and contain interbedded bentonitic shale and thin coal seams (Allan and Rutherford, 1934).

The Cretaceous rocks in the section are not folded and dip gently to the south from 10 to 50 feet per mile. Minor changes of

local dip are common. Outcrops are short, discontinuous and are primarily along major valleys.

Seismicity - Seismicity does not pose engineering problems.

CORRIDORS A THROUGH D

Climate

There are about 20 to 30 freeze-thaw cycles per year within the Alaskan area and from the Canadian border to Fort Good Hope; 30 to 40 cycles per year from Fort Good Hope to Fort Simpson; 40 to 50 from Fort Simpson to the Hay River area; 50 to 60 from Hay River to Watt Mountain; southeastward toward Edmonton, the cycles increase to more than 60 but less than 80 per year.

Rainfall is light but falls over a long period of time along the Alaskan coastal area. Maximum precipitation for a 24-hour period is 0.73 inches in July; minimum is 0.06 inches in April. The mean annual precipitation is 7 inches, falling over a period of 80 or more days. In the eastern part of the Brooks Range rainfall is also light. In the northern Canadian area the rainfall is light, occurring mainly during the summer months. Total rainfall is about 10 inches falling over a period of about 80 days. In the Mackenzie Valley, south of the delta barrens, the rainfall varies from 10 inches in the northern part of the valley to 13 inches in the southern part. Maximum amounts of rain fall on a few days during the summer months. There are about 80 rain days within the valley, somewhat less west of the valley, and somewhat more east of the valley. In the Alberta High Plains rainfall is about 13 to 16 inches per year, decreasing northward; the heaviest rainfall occurs during the summer months, usually as light daily rain. Droughts, not unknown within this region, can occur from April to September.

In the Alaskan coastal area the annual mean snowfall is 35 inches with the heaviest fall during October. There are about 46 snow days per year and records indicate some snowfall has occurred during every month of the year. The eastern part of the Brooks Range has moderate to heavy snowfall, accumulating as much as 37 inches; December, March, and early April are the months of heaviest fall. Annual mean snowfall in the northern Canadian area is about 50 to 60 inches. The annual mean snow days are 44 to 60. Snow occurs during every month except August (rarely in August) with maximum fall in October and November. Farther south in the Mackenzie Valley, the annual mean snowfall is about 50 inches, beginning as early as October or November and lasting through February. There are about 45 to 60 annual snow days, the heaviest fall occurring in November and December. Annual snowfall in the Alberta High Plains area is about 50 to 60 inches. Continuous snow cover persists for about 4 months and snowfall is common for all months except July and August. The mean annual snow days are 30 to 40; December and January have the heaviest snowfall.

In the Alaskan coastal area January and February are the coldest months, with a mean monthly temperature of -16°F; July and August are the warmest months, with 37° to 38°F the mean monthly temperature. Summer temperatures in the eastern part of the Brooks Range range from 50° to 70°F; maximum temperature is 70°F and minimum is 40°F. Winter temperatures are commonly below -45°F. The northern Canadian area is characterized by its cool summers, with mean temperature for July and August of 50°F and below, and cold harsh winters with mean monthly temperatures for October through May of below 32°F; temperatures of -45°F are not unusual. Farther south the Mackenzie Valley is also characterized by a long cold winter, the mean monthly temperatures, October through April, are below 32°F and January, the coldest month, has a mean monthly temperature of -20°F. The Alberta High Plains region has a winter mean monthly temperature of below 32°F; January, the coldest month, has a maximum of -10°F and extreme temperatures of -70°F have been recorded in the Peace River valley. The summer monthly mean maximum is above 50°F and July, the warmest month, has a maximum of about 60°F.

Daylight is used here to mean adequate light in which to work, recorded as of the 15th of each month. During the winter months, there are no daylight hours above 70° latitude with exception of about 3 hours in November; at latitude 65°, there are about 5 hours of daylight; at latitude 60°, there are about 6 to 7 hours of daylight; at 55° latitude there are about 8 hours of daylight. In the summer months, at latitude 70°, there are 24 hours of daylight; at latitude 65°, there are 21 hours of daylight; at latitude 60°, about 18 hours of daylight; and at latitude 55°, about 16 hours of daylight.

In the Alaskan coastal area the prevailing winds are from the northeast except during July when they are from a southwest direction. The average wind velocity is 10 to 15 mph, highest during October and lowest during February. In the eastern part of the Brooks Range, winter winds are quite common, with prevailing north winds; summer winds are from the south. The northern Canadian area has north and northwest prevailing winds, between 3 and 10 mph. Extreme winds of 30 to 39 mph

have been recorded. Farther south, in the Mackenzie Valley the prevailing winds are also north and northwest. The winds are light, about 1-12 mph, with spring and autumn having the highest wind velocities. Prevailing winds in the Alberta High Plains are westerly and easterly; the east wind being frequent in late winter and early summer. Wind velocities range from 3 to 15 mph.

In the Alaskan coastal area, gales are not uncommon, occurring most frequently in October. The rare thunderstorms usually occur in June. There are about 5 thunderstorms per year in the northern half of the Canadian area and about 10 per year in the southern part, usually occurring during the warmer months. Blizzards are frequent during winter months.

CORRIDOR E

Big Delta to Edmonton

This corridor extends southeastward for 1,535 miles from Big Delta, Alaska, to Edmonton, Canada (fig. 1), and generally parallels the Alaska Highway. The first five sections of the corridor occupy five separate physiographic regions, and the sixth section crosses three physiographic regions. Sections seven and eight are part of an additional generalized physiographic unit, but are separated for convenience because of their lengths.

The entire corridor lies within a region of low seismicity. The only earthquake recorded in this region with a magnitude greater than 6 had its epicenter 15 miles south of the corridor in the vicinity of Haines (fig. 1). The only major fault within the corridor, along which there has been movement during the Holocene Epoch, is the Shakwak Fault, an extension of the Denali Fault in Alaska (fig. 1). The Shakwak Fault lies along the southwestern margin of the Shakwak Valley section of the corridor. Except as noted below, the axis of the corridor lies northeast of the fault-line scarp.

The western end of the corridor lies well within the zone of discontinuous permafrost and 65 percent of the corridor is north of the southern boundary of that zone (fig. 1). However, in the Tanana Valley the permafrost is generally more than 25 feet below the surface of coarse-grained deposits, which are very extensive, and 1 to 3 feet below the surface in the fine-grained deposits, which can usually be

avoided. Permafrost from 1 to 2 feet below the surface occurs in the fine-grained deposits within the Shakwak Valley, but is more degraded within the Takhini Valley. Southeast of Whitehorse, permafrost is no longer a serious problem, and south of Fort Nelson it is rarely encountered, except in bogs.

The first section, through the Tanana Valley, provides relatively easy access to the Canadian Border. Ten large stream crossings, moderate clearing, and local foundation improvement would require arctic construction methods. Section 2, through the Shakwak-Takhini Valley, poses no major topographic problems, but six large rivers, numerous small streams, and poor drainage in the central Shakwak Valley would require careful design of structures. Special consideration is required at the broad mouth of the Slims River which is intersected by the Shakwak Fault. Section 3 through the Yukon Plateau, is somewhat constricted topographically in the narrow valley between Marsh and Teslin Lakes and along the steep narrow shores of Teslin Lake. There are three major water crossings, and moderate clearing problems. The fourth section traverses the Cassiar Mountains and is moderately limited by the narrow through valley with its axial streams. Section 5, which crosses the Liard Plain, is limited only locally by scarps, the constrictions of terraces at river meanders, and moderate clearing problems.

The sixth section, which crosses the Liard Uplands, is 70 miles shorter than the adjacent route of the Alaska Highway. The principal construction difficulties are the steeper grades across the Rocky

Mountain foothills, four major river crossings, and the increased distances away from the existing road. However, at its most extended position, new construction would not be more than 25 miles from the Alaska Highway.

Sections seven and eight occupy part of the Alberta Lowlands and Plateaus. Section seven, from Mile Post 250 of the Alaska Highway to Dawson Creek, would involve construction difficulties locally, in the plateau area where numerous curves would be required by the considerable dissection and heavy clay soils rich in bentonite. A major crossing is required at the Peace River where its width is one-third of a mile, and the adjacent bluffs are up to 700 feet high. Section eight, from Dawson Creek to Edmonton, includes steep grades at two major river crossings. Northwest of Edmonton this section crosses glaciated terrain characterized by lakes, bogs, and numerous small streams. This area is underlain by thick clay beds many of which contain bentonite.

Section El - Big Delta to Canadian Border

The 200-mile section from Big Delta to the Canadian Border follows the Alaska Highway through the Tanana Valley. There are important road connections at Delta, Tok, and Tetlin Junctions. The valley provides relatively easy access to the Canadian Border with no important topographic obstacles. Ten large stream crossings, moderate amounts of clearing, and local foundation improvement would necessitate careful engineering with methods designed for arctic construction.

Topography - The Tanana Valley decreases in width from 25 miles near Delta Junction to 1 mile at Cathedral Bluffs, and then increases to a maximum width of 30 miles near the confluence of the Nebesna River. Average width is about 10 miles. The floor of the valley is a flat to rolling lowland with steep scarps separating terrace levels adjacent to the Tanana River and its major tributaries. The floor slopes upward to the southeast from an elevation of 1,200 feet at Delta Junction to slightly over 2,000 feet at the Canadian Border. Foothills of the Alaska Range lie along the southern margin of the valley, where they reach altitudes of 8,000 feet. They are characterized by rugged, sharp, steep ridges and narrow glaciated valleys which drain into the Tanana River. The Yukon-Tanana Upland lies along the northern margin of the valley. Its unglaciated rolling hills are generally less than 2,000 feet above the valley floor, but higher, locally glaciated mountains range in elevation from 5,000 to 6,000 feet, attaining heights of 3,000 to 4,000 feet above the valley floor.

Drainage - Pleistocene glaciers pushing northward from the Alaska Range forced the longitudinal drainage of the ancient Tanana River against the southern slopes of the Yukon-Tanana Upland. Subsequently, the outwash fans of the major tributaries which flow northward have maintained the course of the river, and have even forced it to cut against the bedrock walls of the Yukon-Tanana Upland. Consequently, the land area of the valley lies almost entirely south of the Tanana River except where valley reentrants extend into the Yukon-Tanana

Upland. There are six large streams that cross the valley between Delta Junction and the Tanana River at Tetlin Junction. At this part of the valley, the Tanana River extends diagonally across the valley, necessitating a river crossing. Four large streams cross the valley between Tetlin Junction and the Canadian Border. Numerous other smaller streams are tributaries of the Tanana. There is a significant difference in the character of the drainage of the valley northwest and southeast of Tetlin Junction. The northwestern sector is characterized by generally well-drained sloping outwash fans, and small lakes or ponds are usually restricted to the immediate flood plains of the Tanana. The southeastern valley sector is a vast lowland with numerous lakes and muskegs. Here the better-drained land is more restricted, being confined to a narrow swath between the Tanana River together with its headwater streams and the Yukon-Tanana Upland. Highest terraces are utilized by the Alaska Highway. Better-drained valley land ranges in width from 1 to 5 miles along the south slope of the Yukon-Tanana Upland, near the Canadian Border.

Vegetation - The tree line ranges from an elevation of 2,500 feet on the north-facing slopes of the Tanana Valley to 3,500 feet on the south-facing slopes. The low forests of white spruce and aspen on the better-drained sediments have trees as much as 50 feet in height and 6 inches in diameter; locally along the major streams the cottonwood trees are larger. High brush occurs primarily on recent forest-burn areas, and a zone of dense low brush rises to just above tree line and up to

4,000 feet elevation. Alpine tundra occurs from 4,000 to 5,000 feet, above which the mountains are barren of vegetation. Muskegs with black spruce occupy the poorly-drained lowlands. The areas of major clearing problems coincide with those underlain by the coarser, better-drained sediments.

Surficial deposits - The Tanana Valley is underlain primarily by unconsolidated sediments probably several hundred feet in thickness; the maximum recorded thickness is 200 feet adjacent to the Canadian Border. The most extensive unconsolidated materials occupy broad alluvial fans and consist of sand and gravel. Overlying parts of these fans are moraines composed of coarse-to-fine-grained soils. Finer grained deposits, primarily poorly drained silt high in organic material and peat, occur in parts of the Tanana Valley, especially adjacent to the floodplain, and in the lowlands southeast of Tetlin Junction. These materials are generally soft and wet during the summer, and they are firmly frozen during the winter. Large but discontinuous deposits of sand and gravel are available from the river bars, which are inundated during the spring. Most of the surficial materials are covered by loess; and sand, in the form of dunes, has locally accumulated to form low hills, many of which are stabilized by vegetation. Gravel and sand are difficult to excavate during the winter because of the deep frost. Granular material is then more readily available from the sand dunes and from the drier parts of the large alluvial fans.

Permafrost - The predominantly coarse-grained deposits, which are most extensive, are generally underlain by numerous isolated masses of permafrost more than 25 feet below the surface. Its base has been recorded at depths of from 90 to 209 feet. Scattered lenses of permafrost in the hills composed of loess and sand are $2\frac{1}{2}$ to $3\frac{1}{2}$ feet below the surface. In the finer grained deposits containing silt, organic soils and peat, the permafrost is usually 1 to 3 feet below the surface except in the immediate vicinity of streams or ponds.

Bedrock - Granitic rocks, quartz-mica-schists, and gneiss are the major rocks in the foothills of the Alaska Range. Similar rocks form much of the Yukon-Tanana Upland. Northeast of Tok Junction there are extensive areas of dark basalt and light gray rhyolite that apparently overlie the older granitic and metamorphic rocks. Permafrost is present below a depth of 3 feet.

Seismicity - A major regional lineament, the Denali Fault, lies in a sweeping arc 30 miles south of and parallel to the lower part of the Tanana Valley section. The eastward continuation of this fault coincides with the southeast margin of the Tanana Valley from the Nebesna River to the Canadian Border. Although there are no recorded earthquakes of magnitude 6 or above in the Tanana Valley section of the southern corridor, there have been several smaller magnitude shocks in the vicinity of the junction of this section and the proposed Trans Alaska Pipeline.

Section E2 - Canadian Border to Whitehorse

The Shakwak-Takhini Valley section extends from the U. S.-Canadian Border southeastward and eastward for 260 miles to Whitehorse. The Shakwak Valley is 180 miles long to Haines Junction where the Takhini Valley is joined. The Alaska Highway extends through the entire valley section with a major road connection from Haines, at Haines Junction.

There are no major topographic obstacles through this section, nor is seismicity considered a significant problem. However, several large rivers and numerous other smaller streams together with poor drainage conditions in the central Shakwak Valley would necessitate careful engineering design of structures. The narrow southern shores of Kluane Lake are crossed by the Shakwak Fault; this zone requires special consideration.

Topography - The Shakwak-Takhini Valley is at its maximum width of 30 miles at the U.S.-Canadian Border where the Tanana Valley and the Wellesley Basin abut to the northwest and northeast respectively. The valley width averages 10 miles but widens to 15 miles locally in the vicinity of Haines Junction. The Shakwak Valley floor has generally flat to rolling morainic topography broken locally by the incised valleys of major streams. From Haines Junction to Whitehorse there is little relief as the Takhini Valley is floored by late Pleistocene lacustrine deposits. At the U.S.-Canadian Border, the elevation is approximately 2,000 feet. The valley floor rises southeastward, reaching about 3,100 feet at Haines Junction, but subsequently decreases to the range of 2,300 to 2,400 feet through the Takhini Valley to Whitehorse.

The Shakwak-Takhini Valley is bordered on the north by the Yukon Plateau, the Canadian extension of the Yukon-Tanana Upland. This plateau area consists of uplands with smoothly rounded ridges between elevations of 5,000 and 6,000 feet, above which a few isolated peaks rise to 7,000 feet. Most of the terrain in this part of the Yukon Plateau consists of slopes of moderate gradient although the summits of the higher peaks are considerably more rugged. The Kluane Ranges lie along the southwest margin of the Shakwak Valley. They rise along a fault-line scarp, the continuation of the Denali Fault, and form a steep wall along the valley. Their ridges are serrated and narrow, with generally accordant summits. Elevations are generally 7,000 feet with the highest peaks approaching 8,000 feet. Alpine glaciers are present in some of the mountains. The Yukon Plateau also extends along most of the southern margin of the Takhini Valley. A short length of that margin is bordered by a continuation of the Coast Mountains which are higher and considerably more rugged than the adjacent Yukon Plateau.

Drainage - There are six large rivers and numerous smaller streams that cross the Shakwak-Takhini Valley. Throughout most of the Shakwak Valley, large central areas of the valley floor contain numerous small lakes, ponds, and bogs. Numerous streams course down the steep scree slopes of the southwest side of the valley. The northeast side of the

valley is drier, as well as more stable. The southeast end of Kluane Lake occupies most of the Valley, and the valley side is further restricted by the wide outlet of the Slims River. Drainage conditions are considerably better east of Kluane Lake where fewer large streams cross the valley. The Takhini Valley is drained by two large rivers which are generally in axial position through the valley; thus the Dezadeash River is not crossed at all by the Alaska Highway, and the Takhini River is crossed only once.

Vegetation - Tree line in the Shakwak-Takhini Valley ranges from 4,100 to 4,400 feet on all slopes except those of the north-facing quadrant (Rampton, 1971, p. 963), where the trees grow below 4,000 feet. In the Shakwak Valley, black spruce forest is the dominant type on the flat and gently rolling valley bottoms. Trees are generally 20 to 30 feet in height and less than 6 inches in diameter. White spruce/aspen forest or pure white spruce forest grows on permeable outwash plains that are not underlain by permafrost. White spruce are 50 feet high with diameters of at least 6 inches. These trees become the dominant forest type in the Takhini Valley reaching diameters of 2 feet in well drained localities (Kindle, 1953, p. 4). Black spruce muskeg is present where drainage is impeded and permafrost is present.

Surficial deposits - The Shakwak Valley has been glaciated several times as evidenced by morainal loops of different ages within the valley (Krinsley, 1965, p. 387). Consequently, the surficial materials consist of poorly sorted till with lenses of coarse sand or gravel and locally pockets of fine sand or silt. These sediments are covered locally with talus along steep slopes or recent fluvial deposits adjacent to streams. Depressions are occupied by organic soils or thick layers of frozen peat. Gravel, generally requiring washing, is available from pits exploited by the road maintenance crews and from the large rivers. The Takhini Valley was also glaciated several times during the Pleistocene. During the late-Wisconsin recession with ice dams remaining at the southeast end of Kluane Lake and in the Whitehorse area, a huge proglacial lake, Glacial Lake Champagne, filled the Takhini Valley to an elevation of at least 2,800 feet (Kindle, 1953, p. 16) or approximately 500 feet above the present valley floor at Champagne. As a result of its post-glacial history, the Takhini Valley is underlain with glacio-lacustrine sediments. Beds are generally stratified silts that settled from the glacial meltwaters. A 200-foot thick exposure of these silts occurs near the junction of Aishihik and Dezadeash Rivers (Kindle, 1953, p. 16). Beach deposits of sand and gravel are best developed between elevations of 2,300 to 2,800 feet on steep, exposed slopes where wave action was most pronounced. Sand and gravel deposits occur near the mouths of incoming streams, and the finer sands have been formed by the prevailing wind into northeasterly migrating sand dunes.

Permafrost - Permafrost of undetermined thickness is encountered 1 to 2 feet below the ground surface in many unconsolidated materials except in recent fluvial deposits and in the coarser, better drained Pleistocene sediments (Krinsley, 1965, p. 391-392) within the Shakwak

Valley. Permafrost is more degraded within the Takhini Valley and thermokarst topography is in evidence locally (Wheeler, 1961, p. 20). The proglacial lake beaches are not frozen.

Bedrock - The Kluane Ranges are composed of metasedimentary rocks locally intruded by granites. The Yukon Plateau adjacent to the Valley system is mainly granite except in the vicinity of Haines Junction where peridotite and serpentine are predominant. Bedrock outcrops are scarce and of small extent along the valley floor.

Seismicity - The Shakwak Valley fault, a continuation of the Denali Fault in Alaska, is a prominent topographic lineament where offset features suggest significant lateral slip. However, although there has been displacement along this fault in the Holocene Epoch (Grantz, 1966, table 10), there is no record of movement within historical time. The land area of the Shakwak Valley pinches out at the place where the fault-line scarp of the Kluane Ranges is intersected by the wide outlet of the Slims River, at the southeast end of Kluane Lake. This point, currently crossed by the Slims River Bridge, would require special design considerations in addition to those associated with a major crossing. The only earthquake recorded in this region with a magnitude greater than 6 occurred on February 3, 1944. The epicenter was 15 miles south of the corridor in the vicinity of Haines (fig. 1), and its magnitude was between 6 and 7. Several earthquakes of less than 5 magnitude have occurred within 25 miles of the corridor in the vicinity of the Shakwak Fault.

Section E3 - Whitehorse to Cassiar Mountains

This section extends from Whitehorse generally southeasterly for 150 miles to the Cassiar Mountains east of Teslin Lake. The Alaska Highway extends through the entire section, and the White Pass and Yukon Railroad connects Whitehorse with Skagway at the head of Lynn Canal. Minor roads form a net between small communities along the shores of Marsh and Atlin Lakes, south of the Alaska Highway.

There are no major topographic obstacles through this section. The principal limitations to construction are the narrow valley between Marsh and Teslin Lakes and the steep narrow shores of Teslin Lake. There are three major water crossings, moderate clearing problems, and only minimal permafrost.

Topography - The axis of this section passes through narrow valleys within the Plateau or along the narrow lower slopes of wider valleys that are partly occupied by lakes. In the vicinity of Whitehorse, the valley is 3½ miles wide but along most of this section, valley width or valley side averages less than 1 mile, and locally along Teslin Lake, side cuts may be required. Elevations of the valleys range from 2,200 feet at Whitehorse to less than 3,000 feet in the pass between Marsh and Teslin Lakes. Relief along the section is extremely low.

The Yukon Plateau uplands, adjacent to the axis of the corridor, have an undulating surface between 4,500 and 5,000 feet in elevation. The summit areas of the higher peaks, which extend upward to 6,000 feet, are more rugged and retain vestiges of alpine glaciation.

Serrated ridges and cirques, some of which are occupied by moraine dammed lakes, are common.

Drainage - Narrow valleys in this section are restrictive elements of the natural environment and the presence of lakes and transverse streams further limits the available land surface. An extensive marsh at the outlet of Marsh Lake, the source of the Lewes River, limits the area of valley bottom land. Although the Alaska Highway uses the narrow northeast shore of Marsh Lake, the southwest shore has more flat land and would require only one major water crossing rather than the two now used by the Highway. Both sides of Teslin Lake are steep, with little flat land. At least two major water crossings are required from the outlet of Teslin Lake to the Cassiar Mountains.

Vegetation - Forest growth is restricted generally to the valley floors, but extends up the hillsides in sparse stands to approximately 4,000 feet on all but north-facing slopes. On these latter exposures, the treeline is a few hundred feet lower. White spruce, aspen and lodgepole pine forest is widespread in this section, growing on soils ranging from silty clay loam to gravel (Raup and Denny, 1950, p. 109). The largest trees are white spruce which may be 100 feet high with diameters of 2 feet at breast height. Black spruce muskegs occupy the poorly drained or impounded areas.

Surficial deposits - The valley bottoms within the section are underlain with glacial drift, glacio-fluvial sediments, lacustrine sediments and recent fluvial sands and gravels. Proglacial beach deposits are widespread around the margins of the large lakes. Eskers composed of sand and gravel are present along the section, particularly from Whitehorse to Marsh Lake (Wheeler, 1961, fig. 1).

Permafrost - From Whitehorse to the mouth of the Nisutlin River at Teslin Lake, a distance of 113 miles, only 11 miles of permafrost were encountered during construction of the Alaska Highway (Eager and Pryor, 1945).

Bedrock - Bedrock in the section contains coarse clastics, basalt flows, limestone, and metamorphosed volcanic rocks. These are intruded by granitic rocks.

Seismicity - This section passes through a region of low seismicity.

Section E4 - Cassiar Mountains to Liard Plain

The Cassiar Mountains section extends from the valley of Teslin Lake generally northeastward for 65 miles to the Liard Plain. The Alaska Highway extends through the entire section, and minor roads reach into the adjacent backcountry.

The principal limitations to construction through this section are the narrow valley and its axial streams. There are no major water crossings, moderate clearing problems, and only minimal permafrost.

Topography - The axis of this section passes through a narrow valley that crosses the Cassiar Mountains. The valley floor averages 1 mile in width, with few wider locations and numerous narrower constrictions. The floor of the valley lies at elevations of from 3,000 to 3,500 feet with very low local relief. The adjacent mountains are extremely dissected, and have been considerably glaciated. Cirques, tarn lakes, serrated ridges, and moraine dammed lakes are widespread. There is a conspicuous level surface at from 5,000 to 5,500 feet above which the higher summits reach to almost 7,000 feet. Many of the connecting tributary valleys are wider than the section valley, but their orientation precludes consideration as routes.

Drainage - The section valley is drained by two principal streams which enter the midsection of the valley from the north and then turn in opposite direction. The Swift River flows westward toward Teslin Lake; the Rancheria, the larger of the two, flows eastward to the

Liard Plain. The meander belts of these rivers occupy almost the entire valley bottom at numerous locations, seriously restricting the area of land available for construction projects. Numerous smaller streams intersect the valley, and small ponds and muskegs locally border the rivers and streams.

Vegetation - Forest growth is restricted generally to the valley floors and lower slopes, extending upward to 4,000 feet in sparse stands. Spruce, aspen, and lodgepole pine forest extend throughout the section except near its midpoint where a combination of poor drainage and exposure to northern winds have restricted forest growth. White spruce 100 feet high and with diameters of 2 feet are the largest trees.

Surficial deposits - The section is underlain by glacial drift, glacial-fluvial deposits, and recent fluvial sand and gravel.

Permafrost - It is estimated that approximately 6 to 8 percent of the section contains permafrost, and this would be generally limited to the fine-grained soil and muskeg areas.

Bedrock - Metasedimentary rocks form the adjacent mountains.

Seismicity - The section crosses a region of low seismicity.

Section E5 - Liard Plain

The Liard Plain section extends from the Cassiar Mountains generally southeastward for 130 miles to the Liard Plateau. The Alaska Highway extends through the entire section. Watson Lake in the north-central part of the plain is the center for a moderately well-developed local road net.

The principal hindrances to construction are local scarps, constrictions of terraces at river meanders, and the two major river crossings. Clearing problems are moderate and permafrost is negligible.

Topography - The Liard Plain is a large elongate basin whose long dimension is oriented northwest-southeast, and whose axis is occupied by the upper course of the Liard River. The elevation along the corridor as well as that for the basin as a whole decreases from 3,000 feet along the west margin to 2,000 feet at the Liard Plateau. The plain is rimmed on all sides by plateaus and mountains, and from them the tributaries of the Liard River flow onto the plain from all directions except the east (Bostock, 1948, p. 51). Glacial and post-glacial stream sources, marked by eskers, abandoned canyons, and broad flats extend across it southward toward the Liard River and eastward on both sides of the river, but most conspicuously on the north side. The Liard River and its main tributaries have entrenched their courses in narrow valleys several hundred feet below the general level of the Liard Plain to a degree that in less mountainous regions would raise this unit to the status of a plateau, but with the relief of the surrounding plateaus measured in thousands of feet, this area is classified as a plain (Bostock, 1948, p. 51). The corridor generally avoids the more dissected parts of the plain by following interfluves eastward to the terraces of the Liard River and then paralleling the river to the Liard Plateau. Scarps at the edges of the terraces are often vertical and frequently over 100-feet high.

Drainage - As a consequence of the course of the Liard River and the location of its main tributaries, the corridor would follow the Alaska Highway to Watson Lake and then parallel the north side of the Liard River to the Liard Plateau. This would necessitate crossing the Liard River southwest of Watson Lake and the Hyland River north of its junction with the Liard River. Several smaller streams would also require crossings. Locally, as in the triangle described by the Cassiar Mountain front, the Alaska Highway and the Liard River, the surface is dotted with lakes, ponds, and muskegs.

Vegetation - The flood plain of the Liard River southeast of Watson Lake contains white spruce; the adjacent terraces and uplands support mixtures of white spruce, aspen, and lodgepole pine (Raup and Denny, 1950, p. 126). The abundance of pine on the terraces indicates fairly well-drained sandy and gravelly subsoils. The almost total absence of black spruce, even in depressions, is indicative of light, well-drained soils, probably derived from sandy and gravelly substrata (Raup and Denny, 1950, p. 127).

Surficial deposits - The Liard Plain is underlain by glacial drift which is more than 200-feet thick in many places (Bostock, 1948, p. 51). The glacial drift is generally covered by glacio-fluvial gravels and sand, and recent fluvial sediments (Brandon, 1965, p. 87).

Permafrost - From the lower crossing to the upper crossing of the Liard River by the Alaska Highway, which is almost entirely within the Liard Plain, only a total of half-a-mile of permafrost in a distance of 146 miles was encountered.

Bedrock - The glacial deposits are underlain by sedimentary rocks, lavas, and coal-bearing strata.

Seismicity - The section passes through a region of low seismicity.

Section E6 - Liard Uplands

This section extends from the Liard Plain generally southeastward for 160 miles to the Prophet River at Mile Post 250 of the Alaska Highway. The initial 22 miles of this section parallels the Alaska Highway as far as the south side of the Liard River Crossing. Along this stretch of the Liard River, the southern limit of the Liard Plateau lies against the northern boundary of the Rocky Mountains. The section then continues across low divides within the Rocky Mountain foothills to the Fort Nelson Lowland. Because this section crosses several physiographic uplands which are all drained by the Liard River system, the term Liard Uplands is applied for convenience in this study.

In diverging from the route of the Alaska Highway in this section, approximately 70 miles of construction can be eliminated, although increased logistical effort would be required by construction at a distance from the existing road. However, at its most extended position, new construction will not be more than 25 miles from the Alaska Highway. The principal difficulties in construction are the steeper grades across the Rocky Mountain foothills, and the several river crossings. Clearing problems are moderate, and permafrost is rarely encountered.

Topography - The initial 22 miles of this section would utilize low terraces of the Liard River. These decrease in elevation from 1,800 feet at the Liard Plain to 1,500 feet at the Liard River Crossing. The section leaves the route of the Alaska Highway at Mile Post 490, on the south side of the Liard River, and follows the extensively developed 1,500 feet terrace southeastward to the rapids section of the Grand Canyon of the Liard. The section continues across the Rocky Mountain foothills from 1,500 feet to the lowest divide at 4,000 feet. This rise of 2,500 feet is attained in a distance of 6 miles, with an average gradient of 400 feet per mile. Continuing through narrow valleys and then broad flats, the section once more descends to an elevation of 1,500 feet which is maintained in the Fort Nelson Lowland to Mile Post 250 of the Alaska Highway.

The uplands adjacent to the axis of the corridor consist of even-topped hills rising in their higher parts to about 5,000 feet. These hills are separated locally by wide, rolling valley areas, which drain eastward, and lie at elevations of 2,000 to 1,500 feet. The Rocky

Mountains, south of the corridor, are considerably more rugged with elevations approaching 10,000 feet. The Fort Nelson Lowland along this part of the section has less than 500 feet relief. Locally, the only abrupt interruptions in the extensive terrace levels occur at the channels of the larger streams.

Drainage - Major crossings are required at the Liard, Toad, Muskwa, and Prophet Rivers. Numerous smaller streams and some wet areas adjacent to the Muskwa and Prophet Rivers are probably subject to spring flooding from the adjacent mountains.

Vegetation - White spruce and balsam poplar occur on lowland river floodplains. Balsam poplar generally occupies the higher, drier sand bars. Forests of white spruce, aspen, and lodgepole pine are widespread on the upper terraces and uplands to elevations of approximately 4,000 feet.

Surficial deposits - permafrost and bedrock - Most of the uplands were covered by Pleistocene ice, except perhaps for the higher summits; the lower slopes and narrow valleys were well scoured by the ice (Bostock, 1948, p. 14). Thick drift is present locally in the valley bottoms, and glaciofluvial and recent alluvial deposits cover the mantle of drift. Coarse, well-drained terrace deposits line the larger stream valleys, and these sediments are almost entirely free of permafrost. The glacial deposits are underlain by sedimentary rocks which extend beneath the physiographic boundaries adjacent to the corridor section.

Seismicity - The region is one of low seismicity.

Section E7 - Mile Post 250, Alaska Highway to Dawson Creek

This Alberta Lowlands and Plateaus section extends from Mile Post 250 of the Alaska Highway southeastward for 220 miles to Dawson Creek. The Alaska Highway passes through the entire section, and there are major road and rail junctions at Fort St. John, 40 miles north of Dawson Creek. The initial 40 miles of the section utilizes the terraces of the Prophet River as it crosses the Fort Nelson Lowland, a subdivision within the larger physiographic unit that is used in this study (fig. 1). The section continues southeastward for 140 miles across a plateau area which terminates in a lowland drained by the Peace River. This lowland part of the section continues southeastward 40 miles to Dawson Creek.

Construction difficulties would occur in the plateau area where numerous curves would be required by the considerable dissection. This area is mantled with heavy clay soils rich in bentonite, and covered by dense stands of black spruce. The Peace River requires a major crossing because of its width and the adjacent high, unstable bluffs.

Topography - The axis of the corridor follows an extensive terrace east of the Prophet River which is less dissected than that on the west bank. This terrace level rises from approximately 1,500 feet at Mile Post 250 to 2,500 feet at Mile Post 200; a gradient of only 25 feet per mile.

Local relief along most of this terrace section is probably less than 100 feet. Across the northern half of the plateau, the axis of the corridor utilizes the rounded remnants of interfluves which are subparallel to the corridor, but which are cut by streams normal to the corridor. As a result of this rectangular drainage pattern, there is considerably more relief than in the previous terrace section. Local relief in the plateau ranges from 100 to 500 feet, and there are few areas of flat land above the stream valley. The southern half of the plateau area follows the narrow and considerably dissected interfluve between the Blueberry and Cameron Rivers. Numerous bends would be required in order to avoid cut and fill. Local changes in relief are more frequent over short distances than in the northern part of the plateau. The lowland of the Peace River is characterized by broad flats deeply dissected by the Peace River and its tributaries. River bluffs are frequently 600 to 800 feet high, but on the flats, local relief is generally less than 100 feet.

Drainage - The corridor crosses the divide between the Liard and Peace River systems, in the plateau area. Crossing would be required for numerous small streams within the plateau and for the longer Sikanni Chief River. Southeast of Fort St. John, a major crossing would be required for the Peace River. In this area the river is one-third of a mile wide, with bluffs that are 700 feet high. No extensive areas of swampy ground or bogs should be encountered along the axis of the corridor; locally, the immediate floodplains of the larger streams contain filled-in sloughs or small bogs.

Vegetation - In the lowland white spruce and balsam poplar grow on the river floodplains along the Prophet River. Balsam poplar grows in pure stands on the better drained terraces. Within the valleys of the plateau area, there are mixed forests of black spruce, lodgepole pine, white spruce, and aspen. Repeated burning has produced extensive areas of dwarf-birch and willow scrub and a few grassy areas. The plateau remnants and adjacent steep slopes have the same mixed forests, but with the addition of some alpine fir. Plateau summits have abundant stands of pure black spruce (Raup and Denny, 1950, p. 130).

Surficial deposits and bedrock - The Alberta Lowlands and Plateaus section has been repeatedly glaciated with the result that glacial drift mantles most of the upland surface. Locally, in valleys and depressions within the uplands, the pockets of drift may be more than 100 feet thick. Extensive areas were subsequently covered with proglacial lakes that led to widespread lacustrine deposits and beach gravels. As the ice sheet withdrew eastward, the proglacial lakes were lowered by a succession of outlets at about 1,800, 1,500, and 1,200 feet in the Peace River drainage (Prest, 1970, p. 741). Consequently, the valleys are underlain with glacio-fluvial sands and gravels and recent fluvial sediments. Sand and gravel are generally available along the major streams, and many pits established during the construction of the Alaska Highway are still productive. The higher slopes and dissected flat-topped interfluves of the plateau area are mantled with heavy clay soils containing up to 60 percent

clay, much of which is rich in bentonite (Pawluk and Bayrock, 1969, fig. 21; Douglas and others, 1970, p. 463). The clay is developed on Upper Cretaceous marine shales of the Colorado Group which are widespread throughout this part of the corridor. These materials were easily incorporated into the glacial drift, and significantly affect its engineering properties. The heavy clay soils are usually covered by dense stands of pure black spruce. Sites that are topographically similar but have lighter, better drained soils can be identified by forests of white spruce, aspen, and lodgepole pine (Raup and Denny, 1950, p. 130).

Permafrost - Permafrost is rarely encountered in this section.

Seismicity - The entire region is one of low seismicity.

Section E8 - Dawson Creek to Edmonton

The section extends through the Alberta Lowlands and Plateaus from Dawson Creek southeastward for 350 miles to Edmonton. Roads pass through the entire section and there is a well developed road and rail net. The initial 130 miles of the section utilizes connected valleys and former glacial meltwater channels within the dissected lowland between Dawson Creek and Sturgeon Lake. From Sturgeon Lake southeastward to Whitecourt on the Athabasca River, the section crosses 120 miles of rolling topography which is a broad saddle within a plateau area. The 100 miles from Whitecourt southeastward to Edmonton follow rolling to flat plains.

The principal difficulties in construction would occur at the crossings of the Smoky and Athabasca Rivers, and in the Whitecourt to Edmonton leg of the section. This stretch is characterized by poorly drained glaciated terrain, and thick clay beds in which there are widespread deposits of bentonite. There are minimal clearings problems because of the sparse stands of small trees.

Topography - The axis of the corridor extends southeastward from Dawson Creek, following a narrow valley which lies 200 feet below the general surface of the plain. The section rises southeastward through connecting valleys to the surface of the plain north of Grande Prairie, and continues eastward to Sturgeon Lake. The elevation increases from 2,200 feet at Dawson Creek to 2,500 feet in the vicinity of Grande Prairie. Gradients are generally low over the flat to rolling plains, but the valley of the Smoky River, halfway between Grande Prairie and Sturgeon Lake, lies 400 to 500 feet below the surface of the plain and has slopes ranging from 18 to 127 percent. The section passes south of Sturgeon Lake and turns southeastward toward Whitecourt to cross rolling topography with small hills rising 400 to 600 feet above the general surface. There are moderately steep slopes locally in the vicinity of narrow stream valleys, but over long stretches the gradient is less than 20 feet per mile. Elevations along this part of the section range from 2,200 to 3,000 feet at a few flat-topped hills. The bluffs of the Athabasca River at Whitecourt are less than 100 feet high, but bluff height increases east and west of the town, on the south bank of the river. Continuing

southeastward from Whitecourt, the section crosses an area characterized by impounded drainage with numerous lakes, bogs, and small streams. This rolling glaciated terrain generally ranges in elevation from 2,200 to 2,500 feet with isolated hill reaching 2,700 feet. The better drained higher ground is usually less than 100 feet above adjacent lakes or bogs, but a continuous route can be aligned by connecting elements of the higher ground. This method has been followed in constructing the parallel routes of the adjacent road and railroad. The flat, smooth plain in the vicinity of Edmonton is interrupted only by a few small draws along streams.

Drainage - The two major rivers crossing this section are the Smoky and Athabasca. Both rivers are at least 1,000 feet wide in the places at which they would be crossed. Smaller crossings would be required by the tributaries of the Little Smoky River, and by the Paddle and Pembina Rivers. Numerous small streams and bogs would necessitate drainage accommodation or diversion.

Vegetation - The small areas along the deeper valleys are wooded with white spruce and balsam poplar. The south bank of the Peace River is forested in this manner, and this growth extends above the adjacent plain southwards for several miles (Rutherford, 1930, p. 12). The plains are in part open with grasses, willow scrub, and dwarf birch, or covered with white spruce, balsam poplar, and aspen. Periodic forest fires have gradually reduced the size of these forest stands. Black spruce, scrub birch, sedges, reeds, grasses, and mosses occur in the low-lying, poorly drained parts of the area. The larger trees are generally less than 30 inches in diameter throughout the plains (Wyatt, 1935, p. 3).

Surficial deposits and bedrock - During late Pleistocene time a Continental ice sheet overran most of Alberta. A Cordilleran ice sheet advancing eastward from the Rocky Mountains met the Continental ice in the foothills area of the Rocky Mountains (Pawluk and Bayrock, 1969, p. 4). As a result of this glaciation, practically all Alberta is now covered by a mantle of glacial drift which in the Prairie ranges in thickness from a few inches to more than 1,000 feet (Prest, 1970, p. 738), but averages 200 feet. Sandy till with a smaller percentage of clay and silt can be found near lake borders, especially northwest of Edmonton. Poorly washed gravel may be found locally, and along the major streams. The drift contains up to 40 percent clay, and locally this clay may be composed of as much as 55 percent montmorillonite, the clay mineral which gives bentonite its swelling properties in the presence of water. The area between Sturgeon Lake and Edmonton contains extensive proglacial lake clay deposits derived from the drift. Bentonite occurs in numerous deposits immediately northwest of Edmonton (Babet, 1966, fig. 1). The glacial drift in this section is underlain by Upper Cretaceous nonmarine sandstone and shale which were incorporated into the drift. The shale in particular has provided the parent material for the thick clayey drift sheets, and the subsequently reworked and sorted lacustrine clay.

Permafrost - Permafrost is rarely encountered in this section.

Seismicity - The entire region is one of low seismicity.

CORRIDOR E

Climate

In the vicinity of Big Delta, there are about 40 freeze-thaw cycles per year; at Snag, approximately 50; at Whitehorse, as many as 60; southeastward to Edmonton there are probably more than 60 cycles.

The mean annual rainfall in the Alaskan area is about 12 inches; July and August are the months of heaviest rainfall; February and April, months of least rainfall. In western Yukon the rainfall is about 14 inches per year, falling mostly during the summer months. Annual rainfall is about 12 to 14 inches in south-central Yukon, including Whitehorse; July and August are the wettest months here. Mean annual rainfall for the area from Watson Lake to Edmonton is about 14 to 16 inches; the summer months having heaviest rainfall.

In the Alaskan area the mean annual snowfall is about 54 inches. There are about 80 snow days annually; December, January, and March are the months of heaviest snowfall. The mean annual snowfall in western Yukon (Snag) is about 60 inches. Snowfall is exceptionally heavy along the Bates and Alsek River valleys in southwestern Yukon Territory. Snowfall in south-central Yukon is about 45 inches per year, with November, December, and January, the months of heaviest fall. From just east of Whitehorse to the vicinity of Watson Lake, the mean annual snowfall increases to 75 inches. In the area from the Crow River to Fort Nelson and southward to Grand Prairie it is about 60 inches per year, and from Grand Prairie southeastward to Edmonton, the fall is about 50 to 60 inches. The months of greatest snowfall are December and January.

Ranges in temperature in the Alaskan area vary from -11°F, the January mean temperature, to 60°F, the July mean temperature. December, January, and February are the coldest months in this area with average monthly temperatures below 0°F; the warmest months are June, July, and August with temperatures in the 50° to 60°F range. There are about 230 days of freezing temperature within this area. Mean monthly temperatures in western Yukon range from -14°F (Snag) in January, to 57°F in July. In the vicinity of Whitehorse, the mean monthly temperature varies from 3°F in December to 56°F in July. The mean January daily temperature from east of Whitehorse southward to Edmonton is -20°F to +10°F and the mean July daily range in temperature for the same area is 45° to 75°F; these are the coldest and warmest months respectively.

During the winter months, there are about 5 hours of daylight (adequate for working as of the 15th of the month) at latitude 65°; about 6 to 7 hours at 60°; and about 8 hours at 55°. During the summer months there are about 21 hours of daylight at 65° latitude; about 18 hours at 60°; and 16 hours at 55°

The prevailing wind direction in the Alaskan area is north and the average velocity is 5 mph; May and June are windiest months. From Snag to Watson Lake the prevailing winds are from the west; winds in the vicinity of Fort Nelson are southerly or northerly; east winds

prevail at Dawson Creek and south winds prevail at Edmonton. The mean winter and summer wind velocity in all the Canadian areas is approximately 10 mph.

Thunderstorm activity is restricted to about 7 to 8 storms per year within the Alaskan area. Five to ten thunderstorms per year are usual for the Canadian area; frequency is greater in the vicinity of Edmonton.

Blizzards are frequent during winter months, particularly in the vicinity of Whitehorse, where storms are generated by winds sweeping down from coastal mountains to the Yukon Plateau.

SUMMARY OF THE CORRIDORS

Corridor A - Submarine construction and maintenance is extremely difficult in this area because of the presence of pack ice. No accurate estimate can be given about a safe yet feasible depth for emplacement of a structure that will avoid ice scour. The shore-water interface has the compounded problem of both permafrost and ice shove from pack ice driven ashore.

Corridor B - This corridor has the advantage of traversing flat plains and subdued hills, as it skirts the mountainous areas. Coarse-grained materials are plentiful for construction needs in most of the area, but permafrost with ground ice is present. Numerous stream crossings and the absence of any transportation facilities except at Prudhoe Bay and at the Mackenzie Delta are disadvantages. A critical location for construction lies at the eastern end of this corridor where unstable slopes adjoin the corridor axis in a particularly narrow area. The corridor terminates in an area of reported seismicity.

Corridor C - Firm foundations on bedrock for approximately half of the length of this corridor are its one advantage. Disadvantages are the crossing of two major topographic obstacles, the Brooks Range and the Richardson Mountains, and numerous rivers; crossing extensive areas of fine-grained soils 50 percent of which contain ground ice; and remoteness from transportation facilities. This corridor also terminates in an area of reported seismicity.

Corridor D - Terraces, flat lowlands, and some gently rolling uplands are found along this corridor which represents the most direct natural route from Fort McPherson to Edmonton. Advantages of this corridor include low relief, few major streams, and favorable stream crossing sites. During the summer river transportation is available.

Moderately well drained materials in the terraces of the Mackenzie River along 60 percent of the corridor would provide fair foundations with only scattered ground ice. Less favorable foundations would be encountered along most of the remaining 40 percent where finer grained materials containing more ground ice occupy the flat lowlands. Bogs and muskegs dot the surface, and the southern half of the corridor is covered by a moderately dense, low forest. Gravel deposits are generally scarce except along some of the river bars. Except for the initial part of the corridor, the region traversed is one of low seismicity.

Corridor E - Along most of this corridor, valleys are broad, and include both wide lowlands and areas of low rolling hills. Locally, valleys are narrow or are constricted by streams or lakes. Particularly on the Liard Uplands there are short stretches of moderate grade. Coarse outwash and higher terrace gravels along more than half of the corridor would provide suitable foundations, adequate drainage and plentiful construction materials.

Fine-grained soils containing permafrost at shallow depth are most prevalent in the Tanana and Shakwak Valleys. Elsewhere, permafrost is not a serious problem, and can generally be avoided. There are 26 large river crossings, but poor drainage conditions are significant only locally. A large river crossing along the trace of a major fault makes the southeast end of Kluane Lake a location for careful engineering consideration. Seismicity is not a serious concern in the corridor except at its point of origin which lies adjacent to a region of moderate to high seismicity (fig. 1), and near the junction of the Shakwak and Takhini Valleys.

CONCLUSIONS

The conclusions presented here are based solely upon consideration of those elements of the natural environment described in this report.

If a hot-oil pipeline is considered, Corridor C, the inland route from Prudhoe Bay to Fort McPherson, has naturally occurring physical advantages over the northern coastal Corridors A and B as the environment most favorable for construction. For road or railroad transport, however, the onshore coastal Corridor B has advantages over Corridor C, and the offshore Corridor A is obviously unsuitable.

In Corridor A, a submarine pipeline would be subject to ice scour and probably to foundation problems related to permafrost. The mountains of Corridor C would be a severe hindrance to construction of a road or railroad but the rugged terrain would be less of a detriment to emplacement of a pipeline than the foundation problems, associated with permafrost, in Corridor B.

Corridor B together with Corridor D, which extends on from Fort McPherson to Edmonton, does not encounter any major topographic obstacle nor pass through an area of significant seismic risk. This combined Corridor B-D has drainage and foundation problems related to unstable slopes in Corridor B in the vicinity of the Mackenzie delta, troublesome clayey soil in Corridor D to the south, and extensive permafrost.

Siting of the final alinement within Corridor D would be constrained by the transportation mode. To avoid ground ice, a hot-oil pipeline should occupy the higher, better drained, but discontinuous terraces. Abrupt changes in slope would not be critical for this mode. A road or railroad, however, would more likely be aligned along continuous low grades without abrupt slope changes, in spite of more ground ice.

Choice of mode is less critical within Corridor E, from Big Delta to Edmonton, because of the absence of serious topographic obstacles or extensive areas of ground ice.

Corridor B-D for a road or railroad and C-D for a pipeline have natural advantages over Corridor E. Although Corridor E has considerably less ground ice and less severe drainage and foundation problems than either Corridor B-D or C-D, major problems would be encountered along any corridor between Prudhoe Bay and Big Delta. These include the topographic obstacle of the Brooks Range, extensive permafrost, a major crossing at the Yukon River, and relatively high seismic risk in the Fairbanks area.

REFERENCES

Allan, J. A., and Rutherford, R. L., 1934, Geology of central Alberta: Geological Survey Division, Research Council of Alberta, Report no. 30, 41 p

Atlas of Canada, 1957: Canada, Dept. of Mines and Technical Surveys, Geographical Branch, Ottawa, 110 pls

Babet, P. H., 1966, Some characteristics of bentonite in Alberta: Research Council of Alberta, Rept. 66-2, 25 p

Bostock, H. S., 1948, Physiography of the Canadian Cordillera, with special reference to the area north of the fifty-fifth parallel: Geol. Survey Canada, Mem. 247, 106 p

______ 1967, Physiographic regions of Canada, scale 1:5,000,000: Geol. Survey Canada, Map 1254 A

Brandon, L. V., 1965, Groundwater hydrology and water supply in the District of Mackenzie, Yukon Territory and adjoining parts of British Columbia: Geol. Survey Canada, Paper 64-39, 102 p

Brosge, W. P., and Reiser, H. N., 1969, Preliminary geology map of the Coleen quadrangle, Alaska, 1:250,000: U.S. Geol. Survey, open-file map

Brown, R. J. E., 1967, Permafrost in Canada, scale 1:7,603,200: Geol. Survey Canada, Map 1246 A

Camsell, Charles and Malcolm, Wyatt, 1919, The Mackenzie River Basin: Geol. Survey Canada, Mem. 108, 159 p

Canada, Army Survey Establishment, scale 1:50,000

Canada, Dept. of Energy, Mines and Resources, Seismological series of the Dominion Observatory, data 1899-1965

Canada, National Topographic System, Series A733, scale 1:50,000

Canada, National Topographic System, Series A502, First Edition, scale 1:250,000

Carsola, A. J., 1954, Recent marine sediments from Alaska and northwest Canadian Arctic: Am. Assoc. Petroleum Geologists, v. 38, no. 7, p 1552-1586

Craig, B. G., 1965, Glacial Lake McConnell and the surficial geology of parts of Slave River and Redstone River map-areas, District of Mackenzie: Geol. Survey Canada, Bull. 122, 33 p

Douglas, R. J. W., and MacLean, B., 1963, Geology, Yukon Territory and Northwest Territories, 1:3,000,000: Geol. Survey Canada, Map 30-1963

Douglas, R. J. W., and Norris, D. K., 1961, Camsell Bend and Root River map-areas, District of Mackenzie, Northwest Territories, 95-J and K: Geol. Survey Canada, Paper 61-13, 36 p

______ 1963, Dahadinni and Wrigley map-areas, District of Mackenzie, Northwest Territories, 95-N, and 95-O; Geol. Survey Canada, Paper 62-33, 34 p

Douglas, R. J. W., and others, 1970, Geology of Western Canada in Geology and Economic Minerals of Canada: Geol. Survey Canada, Econ. Geol. Rept. 1, p. 365-488

Eager, W. L., and Pryor, W. T., 1945, Ice formation along the Alaska Highway: Public Roads, v. 24, p. 55-82

Ferrians, O. J., 1965, Permafrost map of Alaska: U.S. Geol. Survey Misc. Geol. Invest. Map 1-445, 1:2,500,000

Fraser, J. K., 1959, Freeze-thaw frequencies and mechanical weathering in Canada: Arctic, v. 12, no. 1, p. 40-53

Gabrielse, H., 1957, Geological reconnaissance in the northern Richardson Mountains, Yukon and Northwest Territories: Geol. Survey Canada, Paper 56-6, 11 p

Grantz, A., 1966, Strike-slip faults in Alaska: U.S. Geol. Survey open-file report, 82 p

Harding, R., 1963, Foundation problems at Fort McPherson, NWT.: Proceedings, 1st. Canadian Conference on Permafrost, National Research Council of Canada, Technical Memorandum 76, p. 159-166

Hemstock, R. A., 1953, Permafrost at Norman Wells, NWT.: Imperial Oil Ltd., Calgary. 100 p

Henoch, W. E. S., 1961, Fluvio-morphological features of the Peel and lower Mackenzie Rivers: Canada, Dept. Mines and Technical Surveys, Geographic Bull. 15, p. 31-45

Holmes, G. W., and Foster, H. L., 1968, Geology of the Johnson River Area Alaska: U.S. Geol. Survey Bull. 1249, 49 p

Hume, G. S., 1954, The lower Mackenzie River area: Geol. Survey Canada, Mem. 273, 118 p

Hume, G. S., and Link, T. A., 1945, Canol geological investigations in the Mackenzie River area, Northwest Territories and Yukon: Geol. Survey Canada, Paper 45-16, 87 p

Jeletzky, J. A., 1961, Eastern slope, Richardson Mountains: Cretaceous and Tertiary structural history and regional significance, in Geology of the Arctic: University of Toronto Press, v. 1, p. 532-583

Keller, A. S., Morris, R. H., and Detterman, R. L., 1961, Geology of the Shaviovik and Sagavanirktok Rivers region, Alaska: U.S. Geol. Survey, Prof. Paper 303-D, p. 169-222

Kendrew, W. G., and Currie, B. W., 1955, The climate of central Canada: Ottawa, Queens Printer, 194 p

Kindle, E. D., 1953, Dezadeash Map-Area, Yukon Territory, Geol. Survey Canada, Mem. 268, 68 p

King, P. B., 1969, Tectonic Map of North America, scale 1:5,000,000: U.S. Geol. Survey

Krinsley, D. B., 1965, Pleistocene geology of the South-West Yukon Territory, Canada: Jour. Glaciology, v. 5, no. 40, p. 385-397

Leffingwell, E. de K., 1919, The Canning River region, northern Alaska: U.S. Geol. Survey, Prof. Paper 109, 251 p

Legget, R. F., Brown, R. J. E., and Johnston, G. H., 1966, Alluvial fan formation near Aklavik, Northwest Territories, Canada: Geol. Soc. America Bull., v. 77, no. 1, p. 15-30

Lewis, C. R., 1959, Geology of Barter Island and the Alaska Arctic coast, in Preliminary Report of the Mt. Chamberlin-Barter Island Project, Alaska, 1958: Military Geology Branch, U.S. Geol. Survey, p. 61-83

______ 1962, Icing mound on Sadlerochet River, Alaska: Arctic, v. 15, no. 2, p. 145-150

Lindsay, J. D., Heringa, P. K., Pawluk, S., and Odynsky, W., 1958, Exploratory soil survey of Alberta map sheets 84-C (east half), 84-B, 84-A, and 74-D: Research Council of Alberta, Preliminary Soil Survey Report 58-1, 32 p

Lindsay, J. D., Pawluk, S., and Odynsky, W., 1959, Exploratory soil survey of Alberta map sheets 84-D (north half), 84-E, 84-F, and 84-G: Research Council of Alberta, Preliminary Soil Survey Report 59-1, 48 p

_____ 1960, Exploratory soil survey of Alberta map sheets 84-J, 84-K, and 84-L: Research Council of Alberta, Preliminary Soil Survey Report 60-1, 49 p

_____ 1961, Exploratory soil survey of Alberta map sheets 84-M, 84-N, and 84-O: Research Council of Alberta, Preliminary Soil Survey Report 61-1, 43 p

MacKay, J. R., 1963, Progress of break-up and freeze-up along the Mackenzie River: Geographical Bull. no. 19, p. 103-116

_____ 1967, Permafrost depths, lower Mackenzie Valley, Northwest Territories: Arctic, v. 20, no. 1, p. 21-26

McConnell, R. G., 1890, Report on an exploration in the Yukon and Mackenzie Basins, NWT.: Geol. Survey Canada, Ann. Report, n.s., v. 4, pt. D, 1888-1889 (1890), 163 p

Mertie, J. B., Jr., 1930, The Chandalar-Sheenjek district: U.S. Geol. Survey Bull. 810, p. 87-139

Milne, W. G., 1967, Earthquake Epicenters and Strain Release in Canada: Canadian Jour. Earth Sci., v. 4, no. 5, p. 797-814

Moss, E. H., 1952, Grasslands of the Peace River region, western Canada: Canadian Jour. Botany, v. 30, no. 1, p. 98-124

_____ 1953a, Forest communities in northwestern Alberta: Canadian Jour. Botany, v. 31, no. 2, p. 212-252

_____ 1953b, Marsh and bog vegetation in northwestern Alberta: Canadian Jour. Botany, v. 31, no. 4, p. 448-470

Norris, D. K., and others, 1963, Geology, Northern Yukon Territory and northwestern District of Mackenzie 1:1,000,000: Geol. Survey Canada, Map 10-1963

Pawluk, S., and Bayrock, L. A., 1969, Some characteristics and physical properties of Alberta tills: Research Council of Alberta, Bull. 26, 72 p

Pewe, T. L., 1963, Ice-wedges in Alaska-classification, distribution, and climatic significance, in International Conference on Permafrost, Lafayette, Ind., 1963, Proc., p. 76-87

Pihlainen, J. A., Brown, R. J. E., and Johnston, G. H., 1956, Soils in some areas of the Mackenzie River Delta region: National Research Council (Canada), Div. Building Research Tech. Paper 43, 26 p.

Plafker, George, 1969, Tectonics of the March 27, 1964 Alaska Earthquake: U.S. Geol. Survey Prof. Paper 543-I, 74 p

Prest, V. K., 1970, Quaternary geology of Canada in Geology and economic minerals of Canada: Geol. Survey Canada, Econ. Geol. Rept. 1, p. 676-764

Rampton, Vern, 1971, Late Quaternary vegetational and climatic history of the Snag-Klutan Area, Southwestern Yukon Territory, Canada: Geol. Soc. America Bull., v. 82, no. 4, p. 959-978

Raup, H. M., and Denny, C. S., 1950, Photo interpretation of the terrain along the southern part of the Alaska Highway: U.S. Geol. Survey Bull. 963-D, 135 p

Reiser, H. N., and Tailleur, I. L., 1969, Preliminary geologic map of Mt. Michelson Quadrangle 1:250,000: U.S. Geol. Survey, open-file map

Rutherford, R. L., 1930, Geology and water resources in parts of the Peace River and Grande Prairie Districts, Alberta: Research Council of Alberta, Rept. 21, 68 p

Sigafoos, R. S., 1958, Vegetation of Northwestern North America, as an aid in interpretation of geologic data: U.S. Geol. Survey Bull. 1061-E, p. 165-185

Slaughter, C. W., and Samide, H. R., 1971, Spring breakup of the Delta River, Alaska: U.S. Army, Cold Regions Research and Engineering Laboratory, Spec. Rept. 155, 32 p

Spetzman, L. A., 1959, Vegetation of the Arctic slope of Alaska: U.S. Geol. Survey Prof. Paper 302-B, 58 p

Stewart, J. S., 1945, Recent exploratory deep drilling in Mackenzie River Valley, Northwest Territories: Geol. Survey Canada, Paper 45-29, 24 p

Stott, D. F., 1960, Cretaceous rocks in the region of Liard and Mackenzie Rivers, Northwest Territories: Geol. Survey Canada, Bull. 63, 36 p

Tassonyi, E. J., 1969, Subsurface geology, lower Mackenzie River and Anderson River area, District of Mackenzie: Geol. Survey Canada, Paper 68-25, 207 p

Thomas, M. K., 1953, Climatological atlas of Canada: National Research Council (Canada), Div. of Building Research, 256 p

Thompson, H. A., 1963a, Freezing and thawing indices in Northern Canada: National Research Council (Canada), Associate Comm. on Soil and Snow Mechanics, Tech. Memo. no. 76, p. 18-36

______ 1963b, Air temperatures in northern Canada with emphasis on freezing and thawing indexes, in International Conference on Permafrost, Lafayette, Ind., 1963, Proc., p. 272-280

U.S.A.F., Operational Navigation Charts, scale 1:1,000,000 (n.d.)

U.S. Army air forces. Weather division, 1943, Climatic atlas for Alaska, Rept. 444 and suppl., v.p.

U.S. Coast and Geodetic Survey, 1968-70, Alaska, Arctic Coast 1:50,000, chart nos. 9472-9478 inclusive

U.S. Dept. of Agriculture, Weather Bureau, 1921, Summary of the climatological data of Alaska, by sections, sections 1, 2, 3, v.p.

U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, 1971, Hypocenter Data File, 1965-Feb. 1971, computer print out

U.S. Geol. Survey, Alaska Topographic Series, scale 1:63,360

U.S. Geol. Survey, 1955-1956, Alaska Topographic Series, scale 1:250,000

U.S. Geol. Survey, 1965, Geologic map of North America, scale 1:5,000,000

Wahrhaftig, C., 1965, Physiographic divisions of Alaska: U.S. Geol. Survey Prof. Paper 482, 52 p

Weyer, E. M., 1956, Daylight and darkness in high latitudes in The Dynamic North, Book I: Technical Assistant to the Chief of Naval Operations for Polar Projects (Op-03A3), 22 p

Wheeler, J. O., 1961, Whitehorse Map-Area, Yukon Territory 105D, Geol. Survey Canada Mem. 312, 156 p

Wood, F. J. ed., 1966, The Prince William Sound, Alaska, Earthquake of 1964 and aftershocks, v. 1: U.S. Coast and Geodetic Survey, 263 p

Wyatt, F. A., 1935, Preliminary soil survey of the Peace River-High Prairie-Sturgeon Lake Area: Research Council of Alberta, Rept. 31, 28 p