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N. W. Rutter

Energy, Mines and Resources Canada

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PREFACE

During construction of the W.A.C. Bennett Dam in northeastern British Columbia, the surficial geology was studied in those parts of the Rocky Mountain Trench and Peace River Valley that were to be flooded. Many sections critical to understanding the geology of this interesting and important area have now disappeared below the waters of Williston Lake.

This report presents the results of these studies. The region is of particular interest because it is one of the few areas where glaciers from deep within British Columbia flowed eastward into the Rocky Mountains and out onto the Alberta Plateau. In addition to the description of the Quaternary history of the region the report describes the surficial geology in detail and comments on problems of engineering geology.

Systematic studies such as these add to our knowledge of the physical basis of man's environment, so necessary for present and future planning in environmental management for resource utilization and conservation.

D.J. McLaren,
Director General,
Geological Survey of Canada

Ottawa, May 6, 1976

CONTENTS

Page

Illustrations

Maps

Three maps portraying the surficial geology and landforms of the Williston Lake area were released in December 1974. Additional copies of these maps, 1381A, 1382A and 1383A are available from the Publication Distribution Offices of the Geological Survey in Ottawa, Calgary and Vancouver.

MULTIPLE GLACIATION IN THE AREA OF WILLISTON LAKE, BRITISH COLUMBIA

Abstract

The completion of the W.A.C. Bennett Dam in 1968 resulted in the formation of Williston Lake in parts of Peace, Finlay, and Parsnip River valleys of northeastern British Columbia. Prior to flooding, extensive, well preserved glacial deposits revealed evidence for four glacial advances. Since flooding, many key sections along river banks have been lost to the record.

The oldest unconsolidated sediments are oxidized gravel and sand that underlie the oldest major till unit. These are interpreted as interglacial fluvial deposits. With the onslaught of the Early glacial advance, outwash was deposited in the major river valley systems. Early till is recognized in Finlay and Parsnip River valleys (Rocky Mountain Trench), so the advance was relatively extensive with most ice originating west of the Rocky Mountain Trench. During deglaciation glaciofluvial and glacio-lacustrine sediments were laid down. The next glacial advance, Early Portage Mountain, extended from west of the Rocky Mountain Trench, across the Trench into the Rockies, and onto the plateau area to the east. During deglaciation a lake formed to the east, probably dammed by Laurentide ice; glaciofluvial and glaciolacustrine sediments again were deposited. When retreat was complete to at least the upper parts of Parsnip and Finlay River valleys, the Late Portage Mountain advance occurred. This time glaciation was less extensive, and the ice was topographically controlled. It flowed down Parsnip and Finlay River valleys, through Peace River valley, and terminated at about Portage Mountain where an end moraine was constructed. The end moraine consists of deltaic gravel and sand and was formed in a lake that was dammed by Laurentide ice farther east. During deglaciation glaciolacustrine and glaciofluvial sediments were deposited in the valley systems to beyond the boundaries of the study area. In the Portage Mountain area lake level variations are indicated by eroded surfaces and beaches. Some time after deglaciation, Deserters Canyon advance occurred. This was a minor event whose till is observed with certainty only northwest of the mapped area.

Radiocarbon dates indicate that the Early and Late Portage Mountain advances and the Deserters Canyon advance are of late Wisconsin age. Early advance till and underlying interglacial deposits are likely early Wisconsin or older.

The area is underlain by material suitable for a wide variety of construction activities. Hazards, such as slumping and erosion, are critical only along the newly formed shoreline of Williston Lake. These will diminish in magnitude once the shoreline has stabilized and a permanent groundwater table is established.

Résumé

L'achèvement du barrage de W.A.C. Bennett en 1968 a entrainé la formation du lac Williston dans certaines parties des vallées des rivières Finlay, Parsnip et de la Paix au nord-est de la Colombie-Britannique. Avant l'inondation, de vastes dépôts glaciaires bien conservés ont révélé l'existence de quatre avancées glaciaires. Depuis l'inondation, il n'est plus possible d'accéder a plusieurs sections clé situées le long de la rivière pour les étudier.

Les sédiments non consolidés les plus anciens sont constitués de gravier oxydé et de sable sur lesquels repose le dépôt principal de till le plus ancien. Ces sédiments sont considérés comme des dépôts fluviatiles interglaciaires. Sous l'action de l'avancée glaciaire ancienne, des matériaux stratifiés fluvio-glaciaires se sont déposés dans les principaux réseaux hydrographiques des vallées. On trouve de l'épandage fluvio-glaciaires dans les vallées des rivières Finlay et Parsnip (sillon des Rocheuses), ce qui indique que l'avancée était relativement étendue et que la majeure partie de la glace provenait de l'ouest du sillon des Rocheuses. Pendant la déglaciation, des sédiments fluvio-glaciaires et glacio-lacustres se sont déposés. L'avancée glaciaire qui suivit, à savoir l'avancée ancienne de Portage Mountain, s'étendit de l'ouest du sillon des Rocheuses, traversa cette dépression et se rendit jusqu'au plateau situé à l'est. Durant la déglaciation, un lac s'est formé à l'est, probablement contenu par de la glace laurentidienne; des sédiments fluvio-glaciaires et glacio-lacustres se sont de nouveau déposés. Lorsque le retrait fut terminé, au moins jusqu'aux parties les plus élevées des vallées des rivières Finlay et Parsnip, l'avancée récente de Mountain Portage s'est

produite. Cette fois, la glaciation fut moins étendue et la glace fut soumise à des contraintes topographiques. Elle descendit les vallées des rivières Parsnip et Finlay, traversa la vallée de la rivière de la Paix et s'arrêta près de Portage Mountain où se forma la moraine terminale. La moraine terminale est constituée de gravier et de sable deltaiques et elle fut formée dans un lac que retenait la glace laurentidienne, plus à l'est. Pendant la déglaciation, des sédiments fluvio-glaciaires et glacio-lacustres se sont déposés dans les réseaux de vallées et ont dépassé les limites de la région étudiée. Dans la région de Portage Mountain, les surfaces et les plages érodées indiquent les variations du niveau du lac. Quelque temps après la déglaciation, l'avancée de Deserters Canyon se produisit. Ce fut un événement mineur dont le till n'est observable avec certitude qu'au nord-ouest de la région étudiée.

Le procédé de datation par le radiocarbone indique que les avancées de Portage Mountain, anciennes et récentes, et de l'avancée de Deserters Canyon datent de la fin de la période du Wisconsin. Le till de l'avancée ancienne et les dépôts inter-glaciaires sous-jacents datent probablement du début du Wisconsin ou d'un peu plus tard au cours de cette période.

Cette région repose sur des matériaux qui conviennent à des travaux de construction de toutes sortes. Les dangers, notamment d'effondrement d'érosion, ne sont importants que le long de la nouvelle rive du lac Williston. Par aileurs, ces dangers s'amoindritont lorsque la rive se sera stabilisée et qu'une nappe phréatique permanente se sera formée.

INTRODUCTION

GENERAL

The report describes the surficial geology, the geomorphology of the desposits, and the sequence of Quaternary events in the Williston Lake area. The primary objective was to gather Quaternary information that would be lost once Williston Lake was formed; all outcrops below 2200 feet (665 m) above sea level, the present lake level, are now lost to the record. A secondary objective was to aid agencies in locating construction materials, to identify geological hazards, and to advise on land capability for various activities during the development of this area which was initiated by the flooding of Williston Lake and subsequent power development.

The Williston Lake area encompasses parts of the Rocky Mountain Trench and a portion of the former valley of Peace River. From a Quaternary historical point of view, this is important because the Peace is the only valley that allowed glaciers, which formed deep within British Columbia, to pass eastwards onto the Alberta Plateau. The area covers about 3500 square miles (9000 km^2) and is bounded by 55°00'N to 57°00'N and 122°00'W to 125°20'W, including parts of NTS map-areas 93 N, O, and 94 B, C (Fig. 1). Most of the area is isolated; the only towns within or near the area investigated are Mackenzie, located in the southern part of the area, and Hudson Hope, located 9 miles east of the W.A.C. Bennett Dam. Trappers' cabins, sawmills, and B.C. Forest Service and Indian camps are located sporadically along the lakeshore. Logging is the principal activity in the area. Mining is restricted to small-scale coal operations in the area of the W.A.C. Bennett Dam. Gold was discovered in 1861 in the upper Peace River country, culminating in a gold rush in 1871 in the Omineca River area, but today only the rare prospector is seen panning for gold in streams entering the lake.

Transportation is principally by boat and float plane. The main road in the area extends for about 90 miles (145 km) along the east side of the lake, formerly occupied by Parsnip River, from the John Hart Highway through the town of Mackenzie to Finlay Bay. Another road connects Hudson Hope with the W.A.C. Bennett Dam then continues along the north side of the lake to the mouth of Dunlevy Creek.

ACKNOWLEDGMENTS

Personnel of the British Columbia Forest Service co-operated fully with the author in many ways. R.D. Thomas and H. Waelti arranged transportation and storage of equipment at various camps in the area. S. Clark supplied pertinent maps and mosaics. K.W. Rieche always had an open door at Camp Mile 73, near Finlay Forks, when the author was in the area.

Discussions with J. Ottesen, British Columbia Hydro and Power Authority, on aspects of the power development and with Dr. D.D. Campbell, consulting geologist, on the geology of the area were most beneficial.

Special thanks go to J. Longstreet for providing his talents as an outstanding boatman and navigator for two summers. D. Walker, University of Toronto, and L. Barrie, Queen's University, gave able assistance during 1966 and 1967, respectively.

CLIMATE

The lower part of the Williston Lake Basin lies in the subarctic climatic belt and has cool, short summers and only one to three months with mean temperatures between 32°F and 50°F (Atlas of Canada, 1957). The climate, therefore, is modified continental, controlled for the most part by the Coast Ranges to the west, which form an effective barrier against Pacific influences, and the eastern slopes of the Rocky Mountains, which form a rampart against winter thrusts of cold polar air from Northwest Territories. This barrier, however, is not impassable, resulting in occasional cold spells.

The weather station, formerly at Finlay Forks (now at Finlay Bay) at an elevation of 1900 feet (580 m), recorded mean January and July temperatures of 2°F and 57°F respectively over a six-year period. The mean annual precipitation (about half as snow) was 16.7 inches (42 cm) with most falling in July and least in March. Wind directions are variable, but northeast winds predominate.

PREVIOUS WORK

The earliest geological investigation in this area was by Selwyn (1877), who in 1875 investigated parts of Parsnip and Peace River valleys. He largely ignored the surficial deposits, although he did mention high bluffs composed of sand, clay, and gravel. McConnell (1896) in the summer of 1893 carried out explorations on Omineca and Finlay rivers. He recognized striated material in the banks of Finlay River south of Fort Grahame which he believed to be of glacial origin. Above Deserters Canyon, beyond the mapped area, he noted high cutbanks of boulder clay, silt, and gravel near the mouth of Akie River and gravel and boulder clay banks along Finlay River.

From his exploration of parts of British Columbia, Dawson (1888a, 1888b, 1890, 1891) concluded that a great Cordilleran glacier formed in the area between 55°N and 59°N and flowed principally northwestward and southeastward. Tyrrell (1919), however, concluded that the ice was much less extensive and that there was no northwestward and southeastward moving ice sheet. On the other hand, Johnson (1926), working in central British Columbia, supported Dawson but did not think that at its maximum stage the ice was more than 3000 feet (910 m) thick and thought that it should be called a "Cordilleran system of intermontane,

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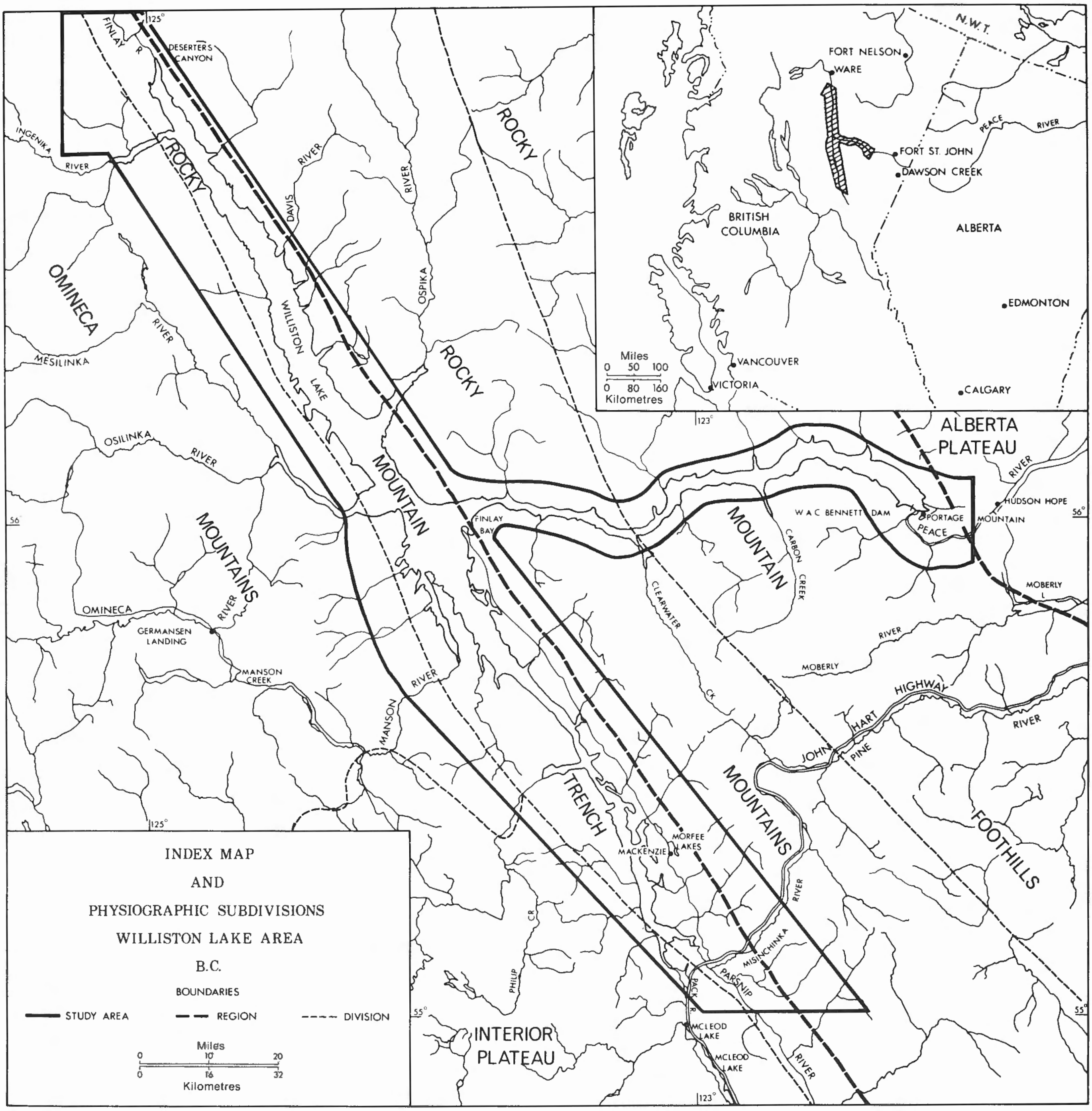


Figure 1. Index map and physiographic subdivisions of the Williston Lake area.

piedmont, and valley glaciers," rather than a "Cordilleran Glacier" as proposed by Dawson (1888). Kerr (1934) evaluated the glaciation in northern British Columbia and concluded that four types of glaciation were active: alpine, intense alpine, mountain ice sheet, and continental ice sheet. In the continental ice sheet stage all of northern British Columbia was covered with ice which spread out from a centre in the north-central area, commonly crossing mountain systems.

Beach and Spivak (1943) investigated the origin of Peace River Canyon, the site of the W.A.C. Bennett Dam. They concluded that in late-glacial times the terminal moraine, which extends between Portage and Bullhead mountains, dammed the preglacial route of the Peace. This raised the water level sufficiently to cause flow over a saddle on the west side of Portage Mountain and to excavate the canyon.

The most comprehensive report on the glaciation of north-central British Columbia that includes parts of the area under investigation is by Armstrong and Tipper (1948). They recognized at least two major advances of Cordilleran ice with the major accumulation area in the Coast Mountains. Drumlins and glacial striae indicate that the later advance moved easterly and northeasterly across the Nechako Plateau to the Rocky Mountain Trench. Here the Rocky Mountains deflected the ice to the northwest along the Trench and down Parsnip River valley. The ice apparently did not cross the Rocky Mountains.

Mathews (1954, 1955, 1962, 1963) has described the Quaternary geology of part of the Fort St. John region that borders the Williston Lake area on the east. He cites two till sheets, separated and overlain by lacustrine deposits, as evidence for two Laurentide ice advances accompanied by glacial damming. Sand and till in the western part of the area were attributed to a late Cordilleran advance.

Elaborating on his earlier work, Tipper (1971a, b), discussed ice-flow patterns in central British Columbia and stated that two, and possibly three, glaciations affected the area. The last glacier advanced into the southern part of the area, whereas an earlier one crossed the Rocky Mountains.

In addition, most bedrock geology reports covering parts of the area contain notes on the Quaternary geology. Mathews (1947) discussed the presence of two terraced drift levels at 2400 and 2050 feet (730 and 620 m) near the eastern limits of the area, which probably mark former lake levels associated with final deglaciation of the area. Irish (1970) gives a general discussion on the effects of glaciation on the Peace River valley area. In the descriptive notes for his geological map of the Pine Pass area (93 O), Muller (1961) stated that Cordilleran ice covered all peaks except some above 6000 feet (1820 m) elevation and moved generally northeasterly. Root's (1954) report on the western half of Aitken Lake map-area (84 C) covers a small portion of the northeast part of Williston Lake area. He stated there is ample evidence that the last major movement of the Cordilleran ice sheet was towards the northeast. Following the ice sheet phase, valley and mountain glaciation took over.

Dolmage and Campbell (1963) published a report on the geology of potential dam sites along Peace River. They presented the thicknesses and lithology of surficial deposits, derived from drilling information, and a detailed description of the moraine between Portage and Bullhead mountains. Much material from the moraine was used for construction of the W. A. C. Bennett Dam.

FIELD METHOD

Field work took place during the summers of 1966, 1967, and 1968. During 1966 and 1967 a 36-foot river boat was used to study the surficial geology along Peace, Parsnip, and Finlay rivers and their major tributaries. River cuts provided the best sections and formed the basis for the stratigraphic interpretations that are presented below. The boat work was supplemented by study along roads, and in 1968 a helicopter was used to facilitate mapping of the broad Rocky Mountain Trench, Peace River valley, and bordering mountains which lie beyond the banks of navigable rivers.

PHYSICAL CHARACTER OF THE AREA

INTRODUCTION

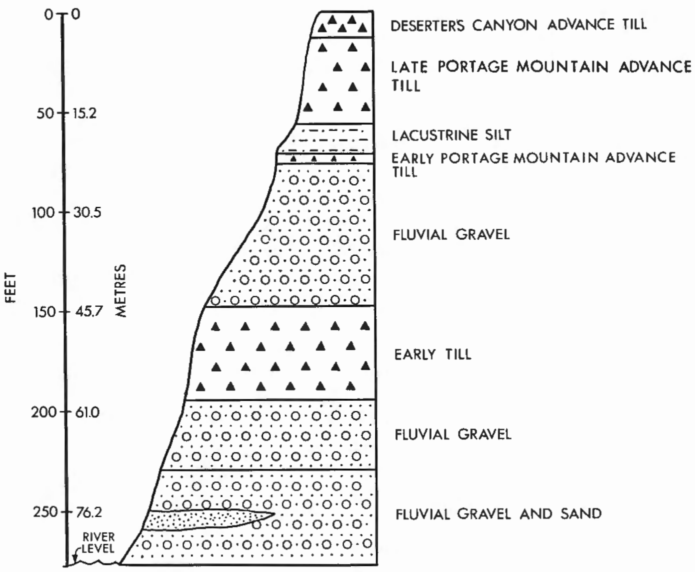
The topography of the area is controlled principally by bedrock, modified by glacial and subaerial erosion and deposition. The area can be divided into two physiographic units: the Rocky Mountain Trench and Peace River valley (Figs. 1 and 2). These units include the valley bottoms, which are generally areas of aggradation and consist of undisturbed surficial deposits, and the bordering mountains, which consist of the products of mass wasting and glacial scouring. Most of the study area lies within the Rocky Mountain Trench which is bordered on the west and southwest by the Omineca Mountains; both are subdivisions of the Central Plateau and Mountain Area physiographic region (Bostock, 1969). The Interior Plateau of the Southern Plateau and Mountain Area physiographic region borders the southwest part of the area, and the Rocky Mountains and Foothills of the Rocky Mountain Area physiographic region (Bostock, 1969) are found on the east side of the Trench and bordering Peace River valley.

ROCKY MOUNTAIN TRENCH

The Rocky Mountain Trench forms a broad lineation. Near Finlay Forks the Trench is 15 miles (24 km) wide, whereas in its narrowest part south of Ingenika River it is about 5 miles (8 km) wide. The average width is about 7 miles (11 km).

The broad Trench is generally void of major relief, although there are some bedrock-controlled uplands and ridges. The elevation near Finlay Forks in the central part of the Trench is approximately 2100 feet (640 m) and rises up Finlay and Parsnip River valleys to about 2300 feet (700 m) near the boundaries of the area, a distance of about 80 miles (130 km). In the northwestern part of the area north of Ingenika River, prominent knobs and ridges outcrop on a generally irregular surface, and local relief reaches 1000 feet (300 m). The only other prominent bedrock outcrop in the Finlay Valley portion of the Rocky Mountain Trench, which actually may be regarded as part of the eastern margin of the Trench, is Mount Moodie north of Ospika River. This mountain, an oval-shaped mound rising to more than 2600 feet (790 m), is separated from the main mountain ranges by a narrow depression.

The Parsnip River area has more bedrock relief than the Finlay portion. Broad uplands with relief of more than 1000 feet (300 m) are present between the Nation River-Cut Thumb Creek and Blackwater-Weston Creek areas. South of Nation River, bedrock, commonly with overlying surficial landforms, outcrops along the western and eastern margins of the Trench. Generally, these are broad, eroded uplands with local relief of about 700 to 800 feet (210 to 240 m).



DEL CREEK SECTION

Figure 3. Del Creek section near Del Creek on Finlay River northwest of the mapped area. Four distinct till units, separated by glacio-lacustrine silt or glaciofluvial gravel, overlie glaciofluvial gravel and interglacial fluvial gravel and sand (47°08'45"N, 125°14'15"W).

The southeastward flowing Finlay River and the northwestward flowing Parsnip River meander widely on flood plains averaging about one and one-half miles (2.4 km) wide; their gradients are low, generally about 2 feet per mile. Major tributaries from the mountains to the east include Ingenika and Omineca rivers, which flow from the Omineca Mountains into Finlay River, and Nation River which enters the Parsnip. The Ospika is the major tributary flowing east from the Rocky Mountains.

PEACE RIVER VALLEY

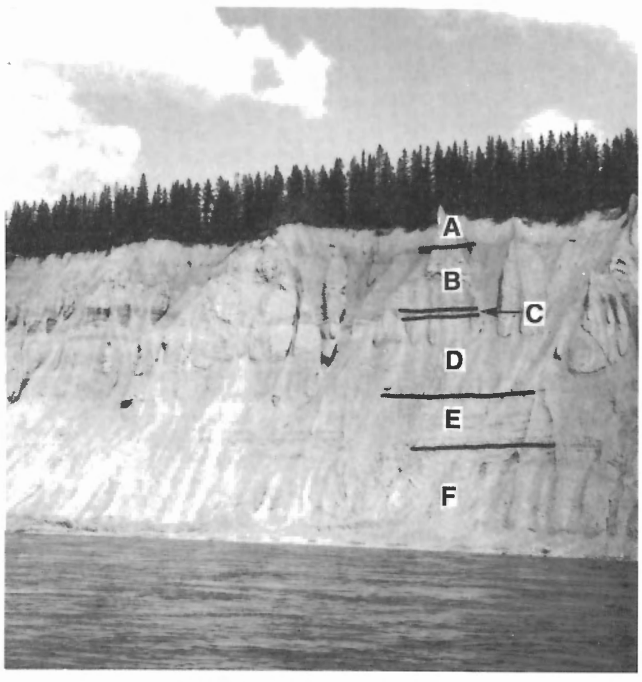
Peace River flows eastwards from the confluence of Parsnip and Finlay rivers, across the strike of the Rocky Mountains and Rocky Mountain Foothills, and onto the Alberta Plateau. Its major tributaries from the north are Wicked River, Bernard Creek, Nabesche River, and Dunlevy Creek, and from the south are Clearwater Creek and Carbon Creek. Initially the Peace cuts through surficial deposits and bedrock in a steep, narrow valley, forming a discontinuous flood plain less than one-half mile (0.8 km) wide. Downstream the valley becomes progressively wider, the stream is more sinuous, and the flood plain is about 3 miles (4.8 km) wide near Portage Mountain. The elevation of the river is approximately 2100 feet (640 m) near Finlay Forks and 1700 feet (515 m) near the eastern border of the area. The gradient averages 4 feet (1.2 m) per mile. Rapids formed by differential erosion of bedrock are common; probably the best known are those of the Peace River Canyon, which formed where late-glacial activity diverted the river from its normal course to the south side of Portage Mountain.

The origin of Peace River valley is not certain. It was formed either during tectonism or by glacial activity. Glacial origin is favoured by the author because the lack of Tertiary sediments within the valley indicates that the valley was not established by Tertiary time and because ice thickness in the Rocky Mountain Trench and Rocky Mountains during the Pleistocene reached at least 4500 feet (1365 m), thick enough to have diverted meltwater eastwards across the mountains.

BEDROCK GEOLOGY

In the Rocky Mountains and Foothills all parts of the Paleozoic, Mesozoic, and Cenozoic eras are represented with the exception of the Pennsylvanian. Paleozoic rocks are dominated by limestone, dolomite, and quartzite, with smaller volumes of chert, argillite, shale, slate, and sandstone. Conglomerate, sandstone, siltstone, and shale are volumetrically the most important Mesozoic rocks, with some coal present. Cenozoic sandstone, sand, shale, clay and conglomerate beds constitute a small part of the total volume.

In the western part of the Rockies, Cambrian and Precambrian metamorphics are present. These include phyllitic slate, chloritic phyllitic slate, chloritic schist, schistoze grit, and medium grained granitic gneiss (Muller, 1961; Gabrielse, 1971).



View shows incomplete section consisting of:

A - Deserters Canyon till
B - Late Portage Mountain advance till
C - glaciofluvial gravel
D - Early advance till
E - glaciofluvial gravel
F - interglacial gravel and sand

Figure 4. Del Creek section located near Del Creek on Finlay River northwest of the mapped area (47°08'45"N, 125°14'15"W). GSC-203036

In the Rocky Mountain Trench most bedrock is obscured by Pleistocene sediments. Along the major rivers and in a few isolated areas of relatively high relief, however, bedrock does outcrop. Metamorphics, as described above, as well as Paleozoic and older carbonates and clastics, and Cretaceous, and younger clastics are present (Rutter and Taylor, 1968).

Passing west across the Rocky Mountain Trench to the Omineca Mountains, the rocks range in age from Precambrian to Cenozoic. Metamorphics (mostly Proterozoic), like those mentioned above, and greenstone and quartz-mica schist probably are most abundant. Igneous rocks include feldspar-quartz-muscovite-pegmatite, granite, granodiorite, pseudodiorite, basic tuffs, breccias, agglomerates, and flows. Carbonates and clastics are present in smaller volumes (Muller, 1961; Gabrielse, 1971).

The structure and geomorphology of the bedrock had a profound effect on the glacial history of the area. During maximum glacier extent, or where relief was high, the younger glaciers were controlled largely by topography, whereas during earlier advances, or where relief was low, ice sheets formed. The contrast of bedrock lithologies on either side of the Rocky Mountain Trench has aided in the determination of provenance of tills and the nature of ice movement.

Figure 5. Typical Cordilleran till of the area. GSC-140851.

GLACIATION

Evidence for at least four glacial advances is present in the area investigated; the four are named: Early advance, Early Portage Mountain advance, Late Portage Mountain advance, and Deserters Canyon advance. The most complete sections are located along Finlay River between Deserters Canyon and Fort Ware, northwest of the area mapped (Fig. 2). The Del Creek section, about one-half mile (0.8 km) southeast of Del Creek, has the principal evidence for the four advances (Figs. 3 and 4; Appendix Del Creek section). In the mapped area the best exposures are along Finlay, Peace, and Parsnip rivers, but no single section contains evidence for more than three advances. The glacial stratigraphy, therefore, has been determined by methods such as lithologic similarities of deposits, stratigraphic relationships, geomorphic features, and ^{14}C dating.

Detailed analyses of undisturbed till were carried out on 49 samples collected at random sites from the till units (Table 1). The purpose was to describe more fully the lithology and texture of the till units and to aid in their correlation. Unfortunately, in any given geographical area all the tills are similar, because each glacier flowed across the same general bedrock in a similar direction, and each incorporated similar pre-existing surficial material. Also, all the tills are young, and none are greatly altered either physically or chemically (Table 1; Fig. 5). Till that is known to have been deposited by either the Early or Late Portage Mountain advances, but which cannot be assigned definitely to either, is called Portage Mountain till.

Generally the till is relatively hard and grey or oxidized buff in colour. Stones compose 3 to 50% of the volume, but mostly range between 15 and 20%. Most are pebbles, with the mode being between 0.5 and 1.5 cm and commonly with less than 1% boulder-sized material present. The stones are angular to well rounded, but most are subangular to subrounded. They are commonly striated, imbricated, and oriented in the direction of glacier flow. The lithology varies widely with rock types derived from both west and east of the Rocky Mountain Trench. The most common rock varieties are carbonate, igneous and metamorphic types, sandstone, siltstone, quartzite, and quartz, with lesser amounts of chert and conglomerate. Samples with much carbonate (limestone and dolomite) commonly contain more igneous and metamorphic types than siliceous types such as sandstone, siltstone, quartzite, quartz, chert, and conglomerate (Fig. 6).

Most samples have a loam matrix, and a few have silt loam, clay loam, sandy loam, sandy clay loam, and clay matrices (Fig. 7). Clay content typically ranges between 5 and 40%, silt between 20 and 60%, and sand between 20 and 60% (Fig. 8). Illite and chlorite content is under 30% in the less than 2 mm-size range and is in roughly equal amounts (Fig. 9). In the less than 2 mm-size range most samples have less than 8% calcite and 5% dolomite, although some have as much as 18% dolomite and 28% calcite (Fig. 10). A large variety of heavy minerals is present, the most common being hornblende, chloritoid, garnet, clinopyroxene, staurolite, epidote, clinozoisite, carbonate, olivine, and zircon (Table 1).

OLDEST SURFICIAL DEPOSITS

Stratigraphic Evidence

The oldest surficial sediments recognized are fluvial gravel and sand occurring below the oldest recorded till, northwest of the mapped area along Finlay River between Deserters Canyon and Fort Ware (Figs. 3 and 4). Deposits that may be of equivalent age are found in places along Peace River and the lower part of Parsnip River.

The deposits are strongly oxidized and have variable dips. These characteristics and the stratigraphic position enable the oldest gravel and sand between Deserters Canyon and Fort Ware to be correlated from section to section with some assurance. The correlation is strengthened by the presence of similar overlying deposits, radiocarbon dating control, closeness of sections, and similar character of the deposits. In the mapped area correlation and identification are more difficult; however, oxidized gravel and sand with variable dip directions, forming the lowest unit of a section, may correlate with the oldest sediments, although their age is uncertain.

The units between Fort Ware and Deserters Canyon are commonly more than 50 feet (15 m) thick. The sand is buff coloured, and much of the gravel is orange coloured. Although the beds are flat lying with an overall dip downstream, many dip in a variety of directions at angles up to 20 degrees and commonly truncate beds within the same unit. In addition, contorted and slumped beds are present. Sand beds within the oxidized gravel commonly contain wood fragments, and in places the gravel contains blocks of peat and marl. Till blocks have been identified in the oxidized gravel, but only where it cannot be definitely correlated with the oldest sediments. This gravel is classed as interglacial because of its degree of oxidation, wood, peat, and marl content, and age beyond the range of radiocarbon dating (*see* section on Chronology and Glacial History). In a few sections a unit of fairly flat-lying unoxidized gravel separates the oxidized gravel and sand from the Early till. It is interpreted as outwash of the Early advance.

In upper Parsnip River valley a single outcrop of steeply dipping dark grey, lacustrine, silty clay extends about 20 feet (6 m) above river level and resembles a slump deposit. It contains abundant, partly decomposed and silicified wood, coated with vivianite. This indicates an old deposit different from other lacustrine deposits observed in the area. Pollen from this deposit contains: 64% *Pinus*, 21% *Picea*, 9% *Abies*, 1% *Alnus*, 0.5% *Betula*, 3% *Polypodiaceae*, 15% *Lycopodium*, 0.5% *Cyperaceae*, 0.5% *Gramineae* — an assemblage similar to that in postglacial peat deposits found in the area. This deposit, therefore, is interpreted as interglacial, and it may be equivalent to the oxidized gravel and sand discussed above. The deposit contained the only diagnostic pollen from any Pleistocene lacustrine deposits in the area.

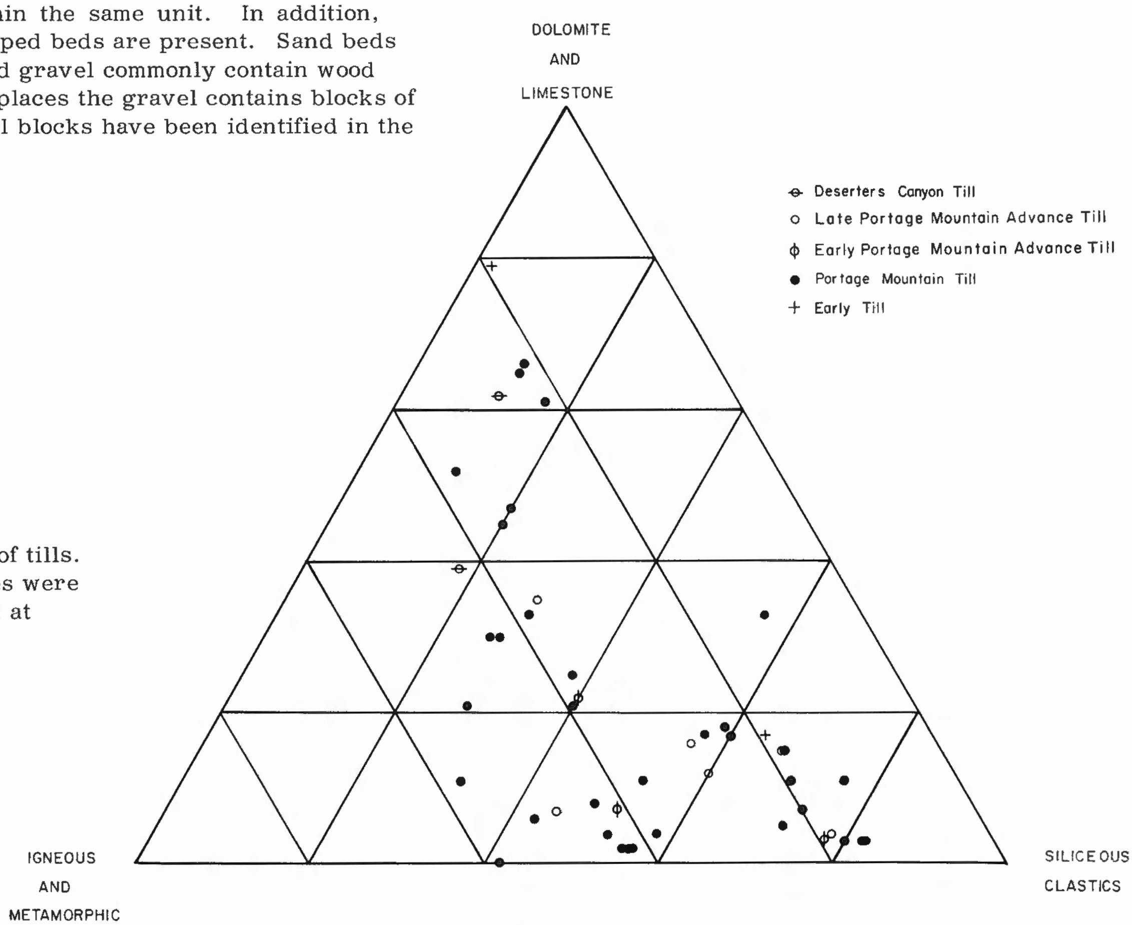


Figure 6.

Stone composition of tills. One hundred stones were randomly collected at each site.

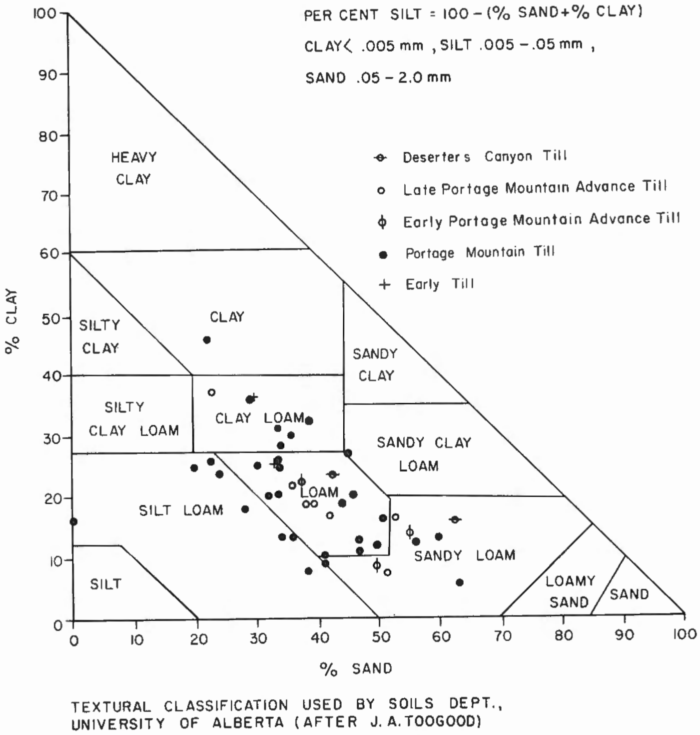


Figure 7. Size analyses of the less than 2 mm-size fraction of tills.

Description of Deposits

About 75% of the beds consist of gravel and sandy gravel (Appendix, Del Creek section, units 1 and 2). The beds are mostly soft, massive, thickly bedded, and poorly sorted, although they vary in thickness, and some are moderately to well sorted. The gravel is mostly pebble sized, subrounded to well rounded, and imbricated. Pebble lithology reflects the bedrock and varies directly with the local bedrock. Metamorphic types and quartzite are most abundant, with acid to basic igneous rock types, limestone, dolomite, sandstone, siltstone, and quartz less abundant; chert, coal, and conglomerates are minor constituents.

The gravel is interbedded with sand lenses and thick sand beds that form about 25% of the unit volume. The sand is well sorted and well bedded, commonly with small-scale cross-bedding. Silt and clay are minor constituents.

EARLY ADVANCE

Stratigraphic Evidence

Evidence for glacial activity prior to the Early Portage Mountain advance includes till and lacustrine and fluvial sediments found underlying deposits correlated with the Early Portage Mountain advance. Glacial striae and erratics located high in the Rocky Mountains and erratics found east of the Rocky Mountains may date, in part, from the Early glaciation.

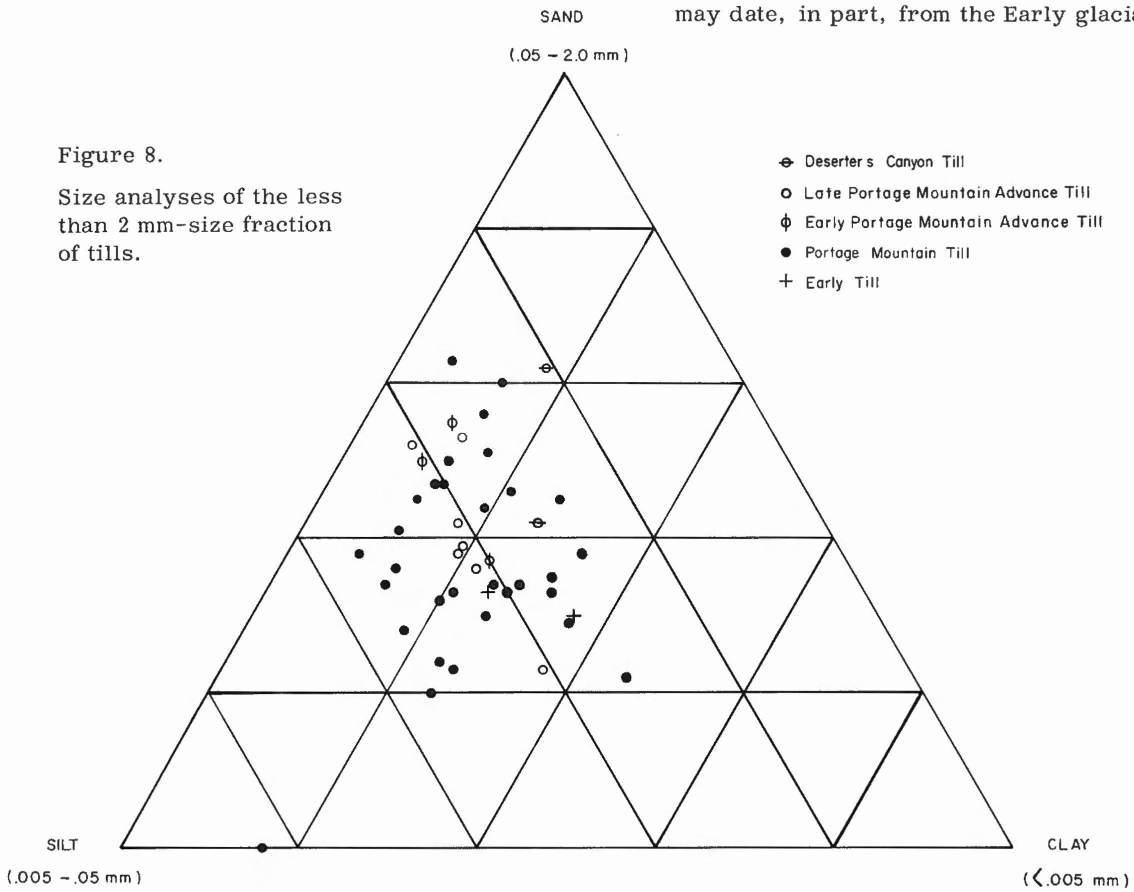


Figure 8.

Size analyses of the less than 2 mm-size fraction of tills.

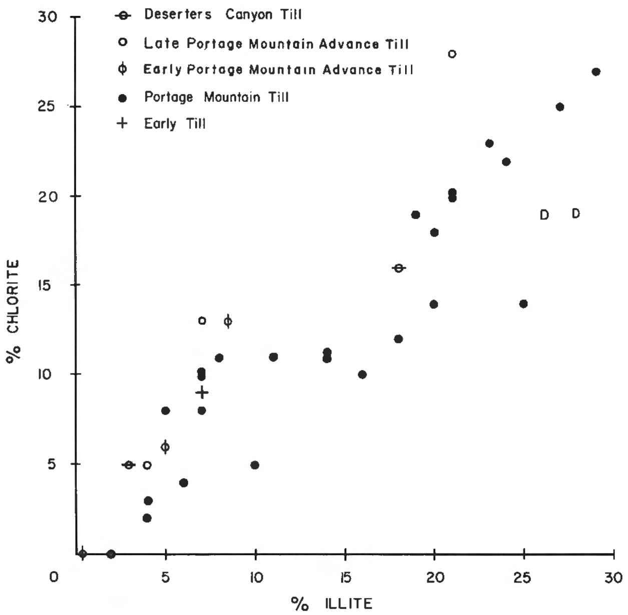


Figure 9. Chlorite and illite percentages of the less than 2 mm-size fraction of the tills (X-ray method used).

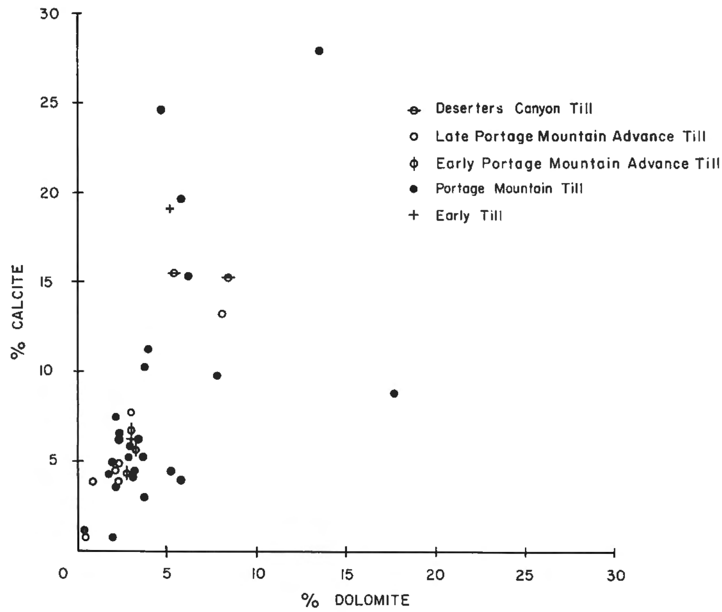


Figure 10. Calcite and dolomite percentages of tills determined for the less than 2 mm-size fraction (Chittick method employed).

The best evidence for Early glacial activity is found in the Del Creek section, located between Fort Ware and Deserters Canyon (Figs. 3 and 4) where about 50 feet (15 m) of till underlies tills of the Early and Late Portage Mountain advances, and Deserters Canyon advance.

The Scovil Flats section (Appendix), located along Parsnip River about 5 miles (8 km) west of Morfee Lakes, also contains till assigned to Early glacial activity. The till is interbedded with gravel and clay that dips about S10°E and forms an erosional surface with overlying till of either the Early or Late Portage Mountain advances. This till is not assigned to the Portage Mountain advances because of its disturbed nature and because it has fewer inclusions than normally found in younger tills.

A section along Manson River contains a lower till that is overlain by lacustrine and fluvial deposits, and by tills of the Early and Late Portage Mountain advances. Although the tills are similar in most respects, the fact that two distinct till units overlie it indicates that the lower till is of the Early advance.

The Early till is overlain by lacustrine silt and clay, fluvial sand and gravel, or till of later advances. Fluvial and lacustrine sediments, found below Portage Mountain till in sections where no Early till is present, probably can be assigned to Early glacial activity. During deglaciation a lake formed, most likely dammed by Laurentide ice east of the mountain front, although damming may have been a result of landslides or moraine construction. Some, or all, of the fluvial and lacustrine deposits could date from the advance of the Portage Mountain glacier, but probably they are from a recessional phase.

The unoxidized gravel and sand and Early till located in upper Finlay Valley (*see* section on Stratigraphic Evidence) are interpreted as outwash deposited during the onslaught of Early ice. The thick till deposits in upper Finlay and Parsnip valleys suggest that the ice originated, for the most part, west of the Rocky Mountain Trench in the Coast, Skeena, Omineca, and Cassiar mountains. Fabric analysis of Early till in the Del Creek section indicates that the ice flowed southeastwards and southwestwards within the Trench and therefore was controlled by topography (Fig. 11). It is impossible to determine how far down the Trench the ice flowed. If striae and erratics from high in the Rockies, or the erratics found east of the mountains, are equated to this event, then the ice was extremely extensive and crossed the mountains to the plateau region to the east. The fabric orientations also can be explained by topographic control of the waning ice.

During deglaciation fluvial and lacustrine deposits were laid down within the Rocky Mountain Trench.

Early Advance Deposits

Early Till

Scarcity of definite Early till exposures has allowed only two till analyses, one from the Del Creek section and the other from the Scovil Flats section. The till is relatively fresh looking and is not oxidized much. Stones compose 10 to 40% of the volume. They are commonly striated, oriented in the direction of glacier flow, subangular to subrounded, and consist mainly of carbonate or quartzite with minor amounts of metamorphic and igneous types, sandstone, and siltstone. The matrix is calcareous and consists roughly of equal amounts of sand, silt, and clay and, therefore, is classified as loam to clay loam. Roughly equal amounts of illite and chlorite were detected. A wide variety of heavy minerals is present, but clinopyroxene, hornblende, chloritoid, and carbonate predominate (Figs. 6 to 10; Table 1; Appendix: Del Creek section, unit 3; Scovil Flats section, unit 1).

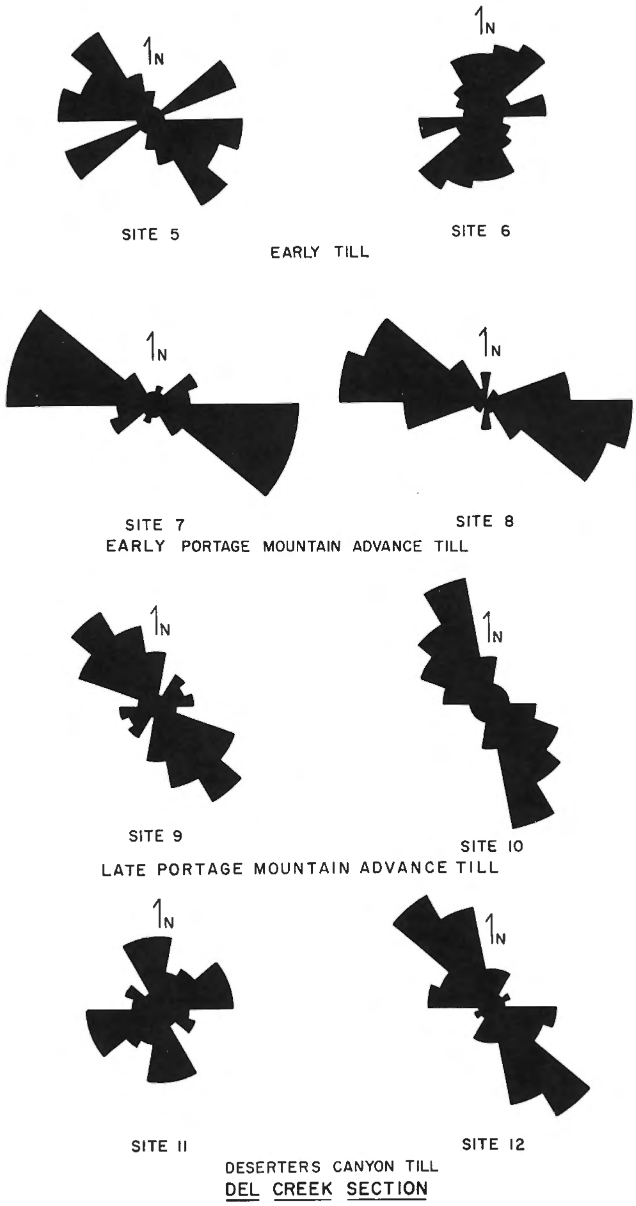


Figure 11. Rose diagrams (20° divisions) of the orientation of the long axes of 50 stones measured from each till of the Del Creek section. Section located near Del Creek on Finlay River northwest of the mapped area (47°08'45"N, 125°14'15"W).

Stratified Sediments

The three sections with the oldest tills are the only ones where stratified sediments definitely can be assigned to the Early advance. These are the Del Creek section, the Scovil Flats section, and the section on Manson River.

The Del Creek section has more than 70 feet (21 m) of gravel with sand and silt lenses over Early advance till (Appendix, Del Creek section, unit 4). The gravel beds are mostly flat lying but do have variable dip directions and steepness. The gravel is poorly sorted and consists mainly of pebble-sized material of the local rock. Its matrix is silty and sandy and is commonly oxidized buff to orange coloured. Their characteristics suggest that the deposits are glaciofluvial outwash.

The Scovil Flats section contains Early Portage Mountain advance till unconformably overlying Early till interbedded with gravel and clay (Appendix, Scovil Flats section, unit 1). The stratigraphic relationships are obscure, but 2 to 5 feet (0.6 to 1.5 m) of clay appears to overlie a few feet of gravel, which in turn overlies Early till. The gravel is mostly poorly sorted pebbles; the clay is grey with some silt.

The section on Manson River in the lower Parsnip River area has lacustrine silt underlying two till units correlated tentatively with Early and Late Portage Mountain advances. The silt is flat lying and is over 5 feet (1.5 m) thick.

EARLY PORTAGE MOUNTAIN ADVANCE

Stratigraphic and Geomorphic Evidence

The Early Portage Mountain advance strongly affected the area. The major evidence for this advance is the stratigraphic position of till deposits, northeast-oriented striae, flutings and drumlins, erratics found east of the Rocky Mountains, and till located on slopes above about 3500 feet (1060 m). Other drift outcrops may correlate either partly or wholly with deposits of the Early Portage Mountain advance. Stratigraphic position, however, indicates that most of these are equivalent to the subsequent Late Portage Mountain advance. Some erratics and till above 3500 feet (1060 m) may be from older advances.

The stratigraphic position of till is the best evidence for the Early Portage Mountain advance. Its till overlies Early drift and/or underlies drift of the Late Portage Mountain advance. When two similar tills are in succession in close proximity and it can be established by field relationships that the succession is in a relatively high stratigraphic position, it is assumed that the lower till is Early Portage Mountain. These relationships are observed in the upper part of Parsnip Valley in the Alexander, Big Bend, and Mackenzie Road sections where Early Portage Mountain advance till underlies unoxidized sand and gravel and Late Portage Mountain advance till; in upper Finlay River valley in the Del Creek section where Early Portage Mountain advance till overlies Early till and underlies

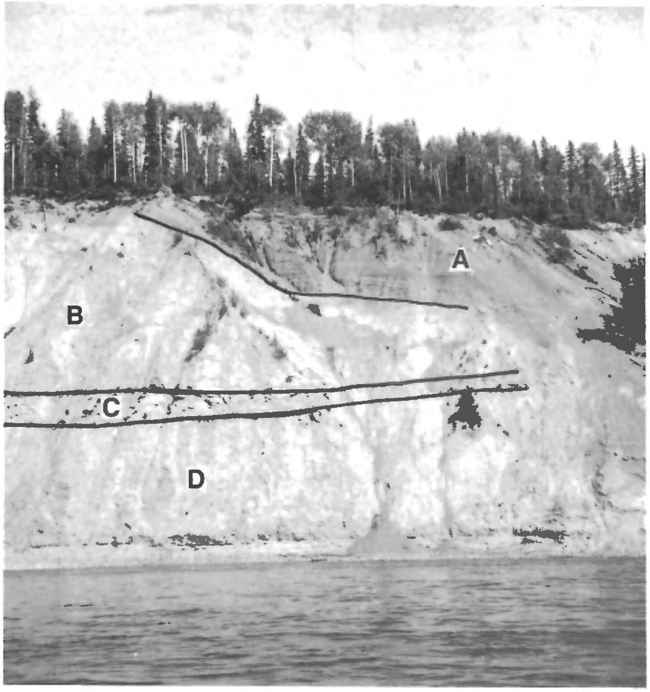


Figure 12. Big Bend section on Parsnip River about 7 miles (6.4 km) northwest of John Hart Highway: A, glaciofluvial gravel and sand; B, Late Portage Mountain advance till; C, glaciofluvial gravel and sand; D, Early Portage Mountain advance till (55°10'00"N, 123°00'15"W). GSC-118494.

two tills of later advances; and along Manson River where silt separates two similar till units (Figs. 2 [cross-section A-A'] and 12). The many sections with one till could have been deposited by Early Portage Mountain ice but probably were deposited by Late Portage Mountain ice.

Further support for the Early Portage Mountain advance comes from fresh striae occurring to elevations of about 6500 feet (1970 m) in the upper reaches of the Rocky Mountains south of Peace River and in mountains west of the Rocky Mountain Trench. They indicate that ice flowed northeast across the mountains (Fig. 13). The orientation of the striae is parallel to that of drumlinoid features in Peace River valley east of the mountain front. The striae are also parallel to drumlins near Groundbirch, about 55 miles (90 km) east of Portage Mountain. The parallelism of the striae and drumlinoid features indicates that they were formed by the same advance and that Cordilleran ice reached far onto the Alberta Plateau. Fabrics of Early Portage Mountain advance till in the Del Creek section also suggest that Early Portage Mountain ice flowed southeastwards across the Rocky Mountain Trench, although this is different from the regional trend (Fig. 11). The directional features are assigned to the Portage Mountain advance because they are relatively fresh and because all succeeding advances were topographically controlled and confined to valleys.

Metamorphic, volcanic, and plutonic erratics derived from west of the Rocky Mountains are found throughout the area. Most of those in the valley bottoms and in the plateau east of the Rocky Mountains were brought by valley glaciers. Some, however, could only have been brought in by a massive ice sheet that originated west of the Rocky Mountain Trench and flowed across the Rockies onto the plateau. One example from outside the mapped area, about 20 miles (32 km) northeast of Finlay Forks near Mount Burden, is western-derived pegmatite erratics found at elevations of over 6000 feet (1820 m) which indicates that ice crossed regional and local drainage systems. Another occurrence is a concentration of large boulders of volcanic agglomerate, containing alkaline syenite and trachyte, near Stony Lake on the east flank of the Rocky Mountain Foothills south of the mapped area. These likely came from outcrops located between the John Hart Highway and the McGregor River area on the southwest flank of the Rockies adjacent to the Trench. This is tenuous support for an Early Portage Mountain advance, but certainly some of these unweathered and slightly weathered erratics were deposited by Early Portage Mountain ice, whereas others were deposited earlier.

Ice of the Late Portage Mountain advance only reached about 3500 feet (1060 m) in Parsnip and Finlay River valleys. Therefore, unweathered or slightly weathered till located above about 3500 feet (1060 m) elevation was deposited, at least in part by Early Portage Mountain ice.

As the ice thinned during deglaciation, the flow of glaciers was controlled by local topography. This is indicated by stone orientations in the Mackenzie Road section which show that ice generally flowed parallel with the valleys (Fig. 14). The ice retreated at least as far as the upper reaches of Parsnip River in the mapped area and to Fort Ware on Finlay River outside the mapped area, as indicated by composite sections consisting of Early Portage Mountain advance till under younger till of the Late Portage Mountain advance. Peace Valley and much of the Rocky Mountain Trench, therefore, became ice free before the onslaught of later ice. It is uncertain whether valley glaciers survived within the Rocky Mountains during this period.

Stratified sediments that overlie Early Portage Mountain till or underlie younger drift are assumed to be products of deglaciation following the Early Portage Mountain advance. An example is lacustrine silt found above Early Portage Mountain till and below younger till in upper Finlay and Manson River valleys (Fig. 3). Sand and gravel are found in the same position in sections in upper Parsnip River valley (Figs. 2 [cross-section A-A'] and 12). In addition, beneath the end moraine of the Late Portage Mountain advance, near Portage Mountain, thick deposits of silt, sand, and gravel extend more than 1200 feet (365 m) below the present Peace river level (Fig. 15). It is assumed that at least the upper part of this thick silt, sand, and gravel sequence was laid down during the retreat of the Early Portage Mountain advance. Silt found at 3100 feet (940 m) on Bull Mountain north of

Portage Mountain also may be from this event (Table 2). Therefore, an extensive lake formed within the Rocky Mountain Trench and Peace River valley during deglaciation and likely was dammed by Laurentide ice on the plateau area to the east.

Early Portage Mountain Advance Deposits

Morainal Deposits (Mr)*

The only surface exposures of Early Portage Mountain advance till is above 3500 feet (1060 m) elevation, where it outcrops as discontinuous patches to several feet thick. The till is commonly washed, eroded, or masked by colluvium, and slightly to strongly weathered. Older till may be present, but no doubt most has been incorporated into till of the Early Portage Mountain advance.

The thickness of Early Portage Mountain advance till ranges from 5 feet (1.5 m) in the Del Creek section to an average of 45 feet (14 m) in the upper Parsnip River area (Appendix: Alexander section, unit 1; Big Bend section, unit 1; Del Creek section, unit 5; Mackenzie Road section, unit 2).

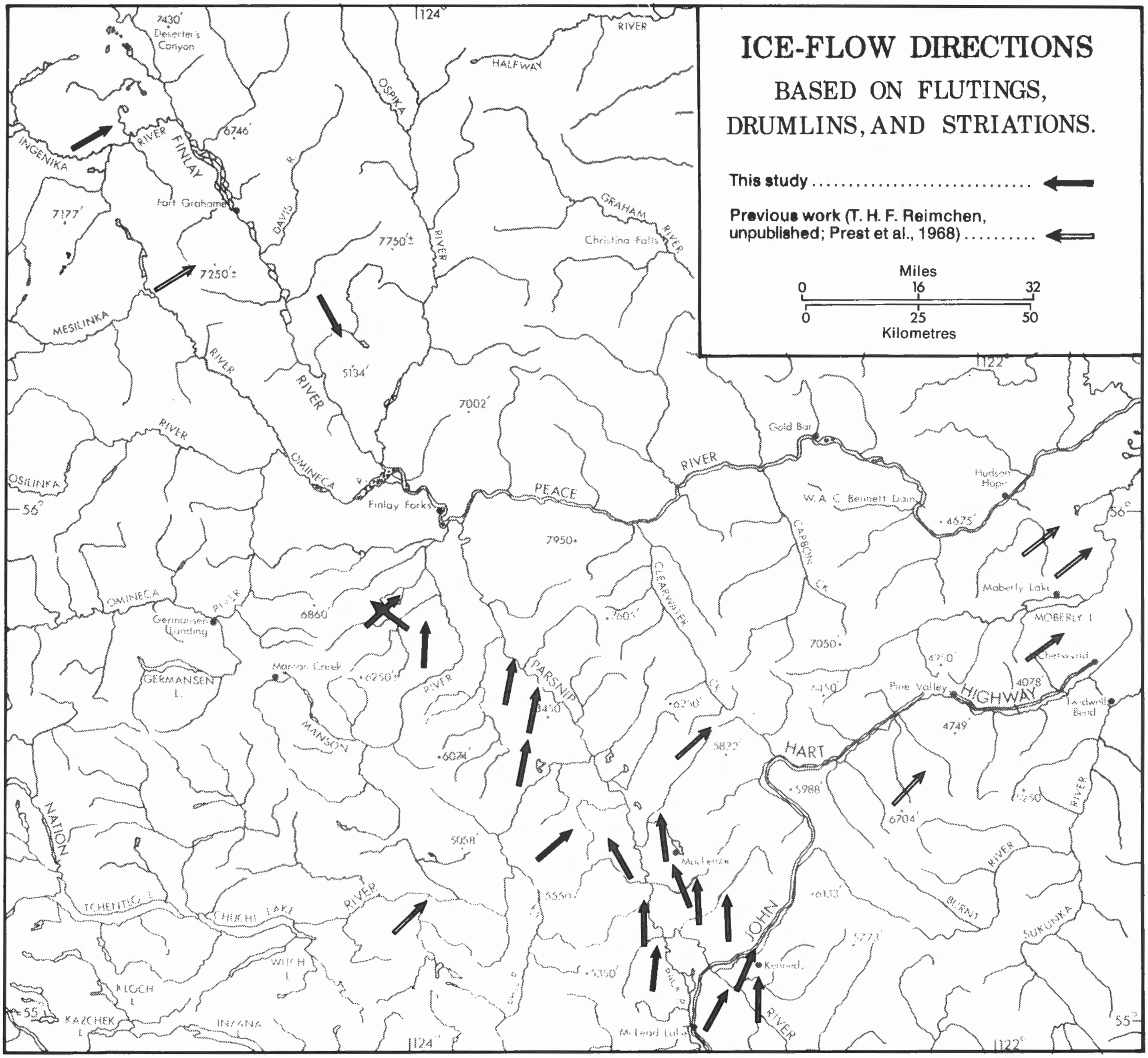


Figure 13. Ice-flow directions determined from the orientation of flutings, drumlins, and striations.

* Symbols refer to map-units on Maps 1381A, 1382A, and 1383A; these maps were released in December 1974. Additional copies are available, price $1.00 each from the Publication Distribution Offices of the Geological Survey, in Ottawa, Calgary and Vancouver.

Table 2

LATE-GLACIAL STRANDLINES (Glacioisostatic adjustment-rise of 1 to 6 feet/mile westward)			
Rocky Mountain Trench	Rocky Mountain Foothills	Alberta Plateau (Mathews, 1963, 1972, 1973)	
Approx. 124° W	Approx. 122° W	Approx. 122° W	Approx. 121° W
	+3100 ft. (+940 m) Silt on Bull Mountain	+3000 ft. (+910 m)	
	2820 ft. (855 m) Flat top of moraine		2750 ft. (835 m) (Cluster of 2 to 4 shorelines)
	±2700 ft. (±818 m) Beaches on north moraine		2650 ft. (803 m)
±2500 ft. (±760 m) Upper limit of lacustrine sediments	+2350 ft. (+710 m) Break-in-slope east of Bull Mountain	2350 - 2400 ft. (710 - 725 m)	2250 ft. (680 m)

The few samples analyzed from the Parsnip River area reveal that the till there is similar no matter where it is located. It is hard, and grey or oxidized buff where weathered. Stones compose up to 30% of the volume, and most are subrounded pebbles. Striae are present, and flat stones commonly are oriented in the direction of glacier flow. Rock types include metamorphic, quartz, igneous, sandstone, siltstone, carbonate, and chert (Fig. 6).

The matrix is a sandy loam or loam consisting of 40 to 60% sand with less silt and even less clay (Fig. 7). Clay ranges from 1 to 21%, with more chlorite than illite (Fig. 9). Carbonate content of the less than 2 mm-size fraction is about 10%, with calcite about twice as abundant as dolomite (Fig. 10). A wide variety of heavy minerals is present. In order of abundance, the most common are clinopyroxene, chloritoid, hornblende, garnet, epidote, carbonate, and clinozoisite (Table 1).

The till of the Del Creek section is somewhat different than that from the Parsnip River area. Stones compose 40 per cent of the till and are mostly sandstone siltstone, quartzite, igneous types, and chert. The matrix is a loam, containing more clay than sand. There is a small amount of carbonate, only a trace of illite, and no chlorite. The most common heavy minerals in order of abundance are chloritoid, hornblende, clinopyroxene, garnet, epidote, and olivine (Table 1).

Stratified Sediments

The only stratified sediments that can confidently be assigned to retreat of the Early Portage Mountain ice are those interbedded between Late Portage Mountain advance and Early Portage Mountain advance tills. In the Parsnip River area the thickest intertill sediments are in the Big Bend section (Appendix, unit 2) where more than 20 feet (6 m) of interbedded, roughly flat-lying, fluvial sand and gravel is present. The gravel is poorly sorted, whereas the sand is well sorted, mostly medium to coarse, with some silty, clayey, and pebbly facies. Other related sediments in the upper Parsnip region are similar but are only about 5 feet

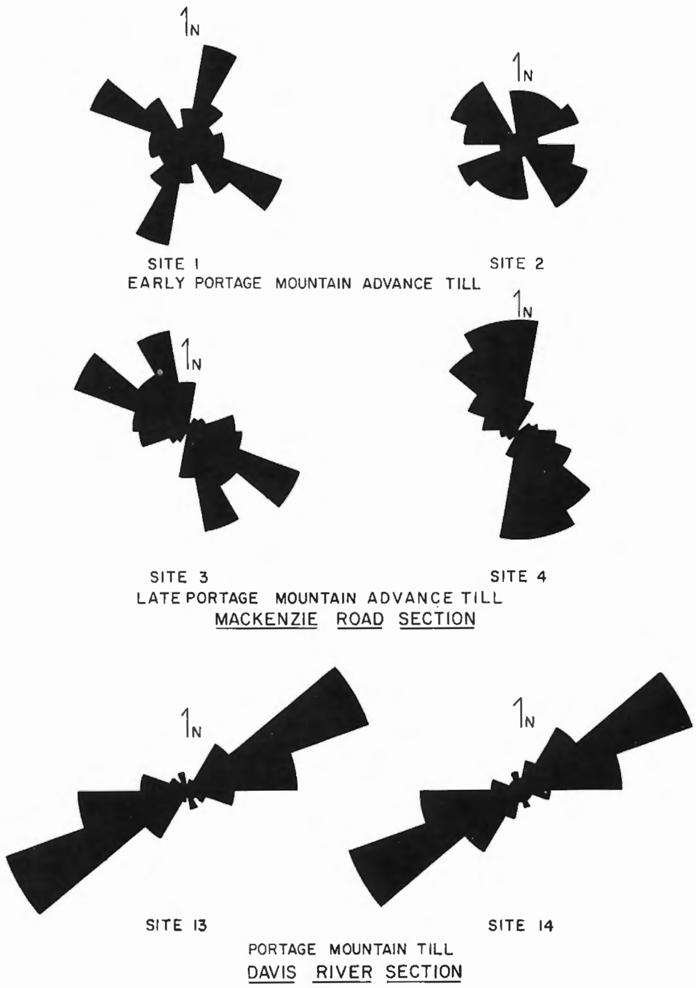


Figure 14. Rose diagrams (20° divisions) of the orientation of the long axes of 50 stones from tills of the Mackenzie Road section (55°13'00"N, 123°00'00"W) and Davis River section (56°30'00"N, 124°31'00"W).

(1.5 m) thick (Appendix: Alexander section, unit 2; Mackenzie Road section, unit 3). The Del Creek section has more than 10 feet (3 m) of thinly laminated clayey silt separating the Early and Late Portage Mountain advance tills (Appendix, Del Creek section, unit 6).

Gravel and sand commonly underlie Portage Mountain till along the upper part of Parsnip River and in places along Finlay and Peace rivers (Appendix: Blackwater Creek section, unit 1; Carbon Creek section, unit 1; McGraw Creek section, unit 1). If the till is of the Late Portage Mountain advance, then the gravel and sand are likely from the Early Portage Mountain advance deglaciation. At any rate, the gravel and sand resemble that described above.

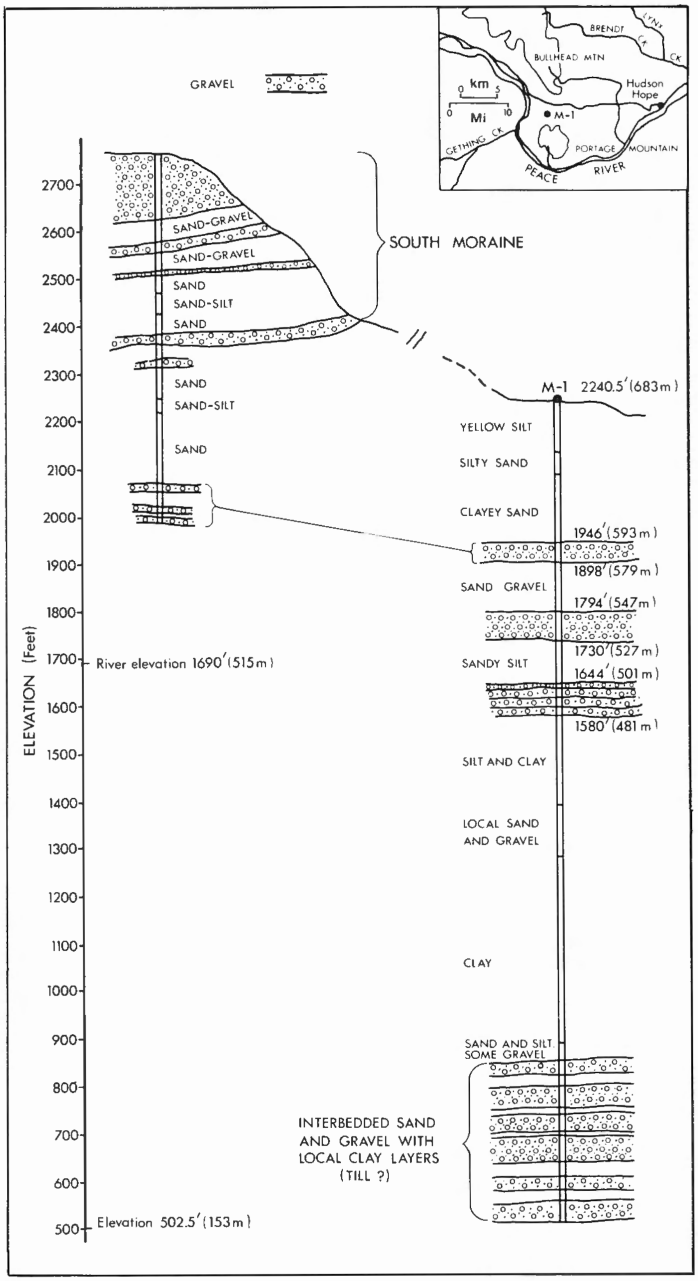


Figure 15. Sections from boreholes located near the Late Portage Mountain end moraine.

LATE PORTAGE MOUNTAIN ADVANCE

Stratigraphic and Geomorphic Evidence

The Late Portage Mountain advance was the last major glaciation to affect the area, and most surface deposits in the major valleys are from it. Evidence for the advance consists of widespread till, lacustrine and fluvial deposits located along Finlay, Parsnip, and Peace valleys, washed till and abandoned ice-marginal channels below 3500 feet (1060 m), drumlins within Parsnip Valley, and an end moraine complex near Portage Mountain.

Till of this advance is shallow or is exposed in sections containing Early Portage Mountain advance till such as those located in upper Parsnip Valley (Alexander, Big Bend, and Mackenzie Road sections), Manson River, and Del Creek section on Finlay River (Figs. 2 [cross-section A-A'], 3, 12). It is also probably the till present in incomplete sections along lower Parsnip, lower Peace, and Finlay valleys (Figs. 2 [cross-sections B-B' to F-F'], 16, 17). This till also is present in shallow drift deposits, located in extensive areas along the lower parts of upper Parsnip Valley, and as patches of undisturbed surface till throughout the area.

Where not exposed, Late Portage Mountain advance till is overlain mostly by glaciolacustrine sediments and to a lesser extent by glaciofluvial sediments deposited during subsequent deglaciation. Where erosion has removed some till, postglacial gravel and sand have been deposited. What underlies the till varies, but it generally is outwash gravel and sand and lacustrine silt and clay deposited beyond the ice front during the retreat of a glacier.

The upper limit of the advance is marked by relatively fresh, abandoned, ice-marginal channels located up to about 3500 feet (1060 m) along Parsnip and Finlay River valleys and to 5000 feet (1515 m) in the Omineca Mountains to the west. Washed till, commonly masked by colluvium, found below the abandoned ice-marginal channels is assigned to this advance.

Fabric and drumlin orientations suggest that the Late Portage Mountain glacier generally was topographically controlled. Drumlin orientation in the upper part of Parsnip River valley shows that ice flowed from the Interior Plateau and Fraser Basin towards the northeast (Fig. 13). As the glacier flowed into Parsnip Valley, it was deflected to the north and northwest by the western flank of the Rocky Mountains. Fabric analysis of till from north of Mischinsinlika Creek on the Mackenzie Road in upper Parsnip Valley supports the flow direction indicated by the drumlins there (Fig. 14). In the Del Creek section pebbles of Late Portage Mountain advance till trend parallel to the valley (Fig. 11).

The prominent, arcuate end moraine crossing Peace River valley between Bull and Portage mountains probably marks the limit of the Late Portage Mountain advance down that valley. The moraine reaches an elevation of over 2800 feet (840 m) at its north and south ends and gradually decreases to about 2300 feet (700 m) at the centre of the valley. It is about 4 miles (6.4 km) long and up to 1 mile (1.6 km) wide. The moraine consists almost entirely of deltaic sand and gravel, some incorporated with silt, indicating that the ice front terminated in water. Foreset beds dip 7 to 15 degrees southeast, east, and northeast, following the same shape as the ice front. In a few locations on the west side of the moraine the sand and gravel dip upstream, probably the result of subaqueous slumping as the ice melted. Kames and thin deposits of lacustrine silt overlie the deltaic deposits in places. The silt was deposited as the glacier retreated to the west of the moraine and as the lake encroached from the east. Silt incorporated into the otherwise well sorted gravel and sand of the deltaic deposits indicates slight fluctuations of the ice front before the major withdrawal. The ice-contact deposits indicate stagnant ice above water level.

The top of the moraine at 2820 feet (855 m) is flat and is believed to have been eroded by waves and to be near the upper limit of a high-level lake (Table 2). Another lake level is evidenced by two well developed beaches present between 2700 feet (820 m) and 2800 feet (850 m) in the upper part of the north end of the moraine. The well sorted beach gravel and the prominent nature of the beaches suggest the lake was stable for a long time. Immediately east of the moraine and associated with former strandlines are hummocky, pitted, lacustrine sand and gravel, representing either former beaches or deltaic deposits that grade eastwards into fine grained material that is equivalent, in part, to the late glaciolacustrine deposits described by Mathews (1963). These extend to the Alberta border, more than 80 miles (128 km) away (Table 2). Two to four closely spaced strandlines at the 2750-foot (835 m) level in the Fort St. John area are probably equivalent in age to the strandline marked by the flat-top moraine (Bessborough Stage of Lake Peace; W.H. Mathews, pers. comm., 1973), whereas the shore gravel near Charlie Lake, at an elevation of about 2650 feet (805 m), likely equates to the beaches on the north end of the moraine (Hudson Hope Stage of Lake Peace; W.H. Mathews, pers. comm., 1973). Equivalent strandlines show a rise to the west of one to six feet per mile. This value is close to what Mathews (1972, 1973) estimated from his surveys of postglacial tilting caused by isostatic rebound following retreat of Cordilleran ice. During the formation of the Portage Mountain end moraine, therefore, a lake 500 to 600 feet (150 to 180 m) deep covered large areas of the plateau to the east. The lake must have been dammed by Laurentide ice. It is difficult to define the exact position of the Laurentide ice front, but it was east of Charlie Lake in Alberta.

As ice withdrew up Peace River valley, the lake margin coincided with the ice front and deposited lake silt to about 2500 feet (760 m) on valley sides. Laurentide ice must have been retreating at the same time, or the deposits would extend higher. From west of Carbon Creek to Finlay Forks the valley narrows

Figure 17. Chowika Creek section along Finlay River consisting of: A, glaciolacustrine sediments overlying B, Portage Mountain till (56°41'00"N, 124°41'45"W). GSC-140853.

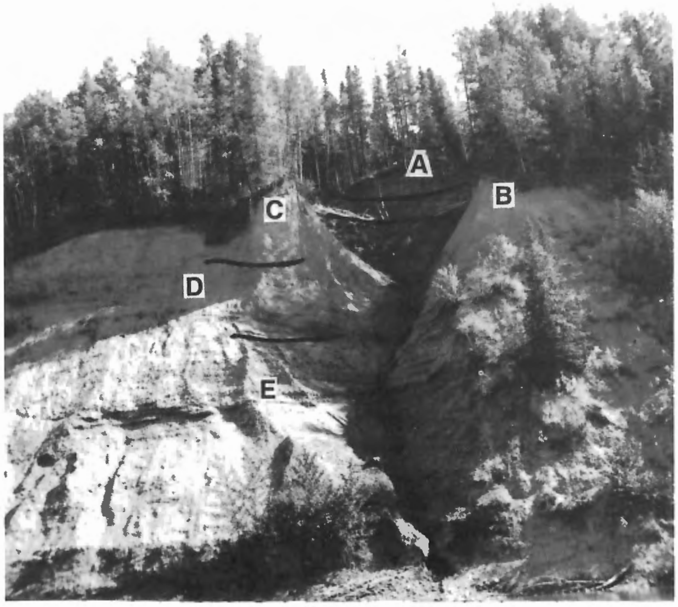


Figure 16. Blackwater Creek section, located across from the mouth of Blackwater Creek on Parsnip River: A, glaciolacustrine sand and silt; B, glaciolacustrine clay; C, Portage Mountain till and gravel; D, glaciofluvial gravel and sand; E, glaciofluvial gravel. GSC-140864.

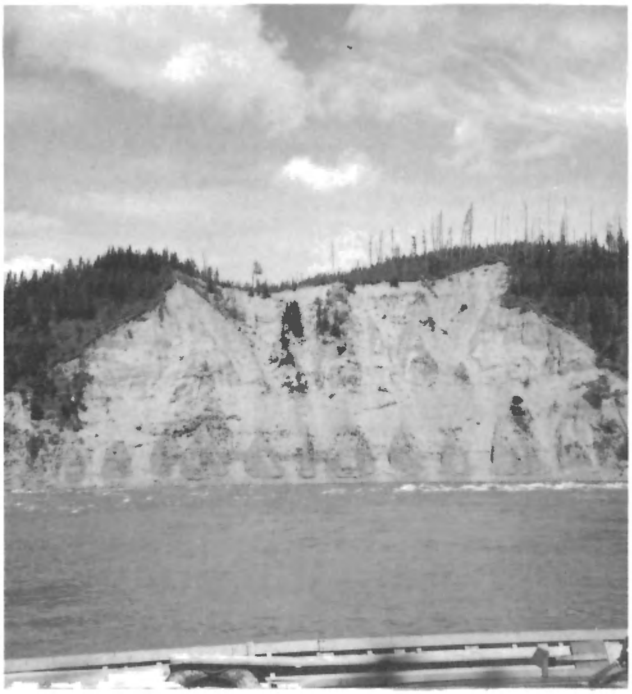


Figure 18. Ne-parle-pas Rapids section along Peace River consisting of glaciolacustrine and glaciofluvial sand and gravel (50°02' 00"N, 123°05' 00"W). GSC-118479.

and the fine lacustrine sediments are replaced by glaciofluvial gravel and sand (Fig. 18). These sediments, which are found up to an elevation of about 3000 feet (910 m), include some ice-contact deposits. Pitted surfaces are common, indicating that during deposition the ice front was nearby. When ice retreat reached the upper part of Peace River valley, morphological changes took place downstream. At least four prominent high-level terraces, located between Carbon Creek and Portage Mountain, are associated with deglaciation. Below the high silt deposits, pits are present at about 2100 feet (635 m) both in lacustrine sediments and in the coarser outwash, indicating a lower lake level still controlled by the ice front. This is the lowest terrace associated with deglaciation of the immediate area. Near Portage Mountain meltwater flowing out between Bull and Portage mountains eventually breached and eroded the end moraine to about the 2300-foot (700 m) elevation before being diverted south and east around Portage Mountain to form Peace River Canyon.

As the glacier retreated from Peace River valley into the broad Rocky Mountain Trench, it divided and retreated up Finlay and Parsnip River valleys. Both ice-contact and non-ice-contact gravel and sand up to 100 feet (30 m) thick were deposited along the sides and bottoms of the major valleys (Fig. 19). Glaciolacustrine sand, silt, and clay lap onto these deposits and cover much of the valley bottoms which narrow from Finlay Forks northwards and southwards (Figs. 20 and 21). These fine deposits are up to 100 feet (30 m) thick and reach elevations of 2500 feet (760 m). The previously mentioned isostatic rise of one to six feet per mile from Portage Mountain to the Rocky Mountain Trench would mean that the lake sediments at 2500 feet (760 m) at Finlay Forks correspond to those at about 2350 feet (710 m) near Portage Mountain. Pitted sediments at 2100 feet (635 m) west of Portage Mountain within Peace River valley indicate the presence of ice well below the level of the lake that later developed in the Rocky Mountain Trench. Further, a break-in-slope east of Bull Mountain in the Rocky Mountain Foothills at about 2350 feet (710 m) is interpreted as a strandline of a late-lake phase, probably the Clayhurst Stage of Lake Peace (W.H. Mathews, pers. comm., 1973) (Table 2). As this indicates two separate lakes, damming took place somewhere in the upper part of Peace River valley after ice withdrew into the Rocky Mountain Trench. Peace River valley may have been choked by morainic or landslide materials in the narrow stretch between Clearwater River and Finlay Forks.

Figure 19. Typical glaciofluvial ice-contact sediments, deposited during retreat of the Late Portage Mountain advance, near Dina Lake in central Parsnip River valley. GSC-140915.

Late Portage Mountain Advance Deposits

Morainal Deposits (Mh, Md, Mr, D)

Morainal deposits, are included in several map-units of maps 1381A, 1382A and 1383A but in each case till is present. Late Portage Mountain advance till overlies Early Portage Mountain till in three sections along upper Parsnip River, one on Manson River, and in the Del Creek section on the Finlay (Appendix: Alexander, Big Bend, Mackenzie Road, and Del Creek sections). Till thickness ranges from a few feet to more than 130 feet (40 m) in undisturbed sections along the lower parts of the valleys; the average thickness is 10 to 20 feet (3 to 6 m).

The till is hard, and greyish or buff coloured where oxidized. Stones compose up to 30% of the volume but generally make up about 10%; most are subangular to subrounded pebbles. Striae are present as well as many flat stones oriented in the direction of glacier flow. In the Parsnip River area the most abundant types of stones are metamorphic, quartzite, carbonate, sandstone, siltstone, igneous, chert, and conglomerate. Siliceous clastics such as quartzite, quartz, sandstone, siltstone, chert, and conglomerate are more common than igneous and metamorphic types, which in turn are more abundant than carbonate (dolomite and limestone) (Fig. 6).

The matrix of the till in the Parsnip River area is a loam or sandy loam (Figs. 7 and 8). In the less than 2 mm-size fraction, clay content ranges from 9 to 49%, with slightly more chlorite than illite (Fig. 9); carbonate content varies between 1 and 11% with twice as much calcite as dolomite (Fig. 10). The most common heavy minerals in order of abundance are chloritoid, hornblende, garnet, clinopyroxene, carbonate, and epidote (Table 1).

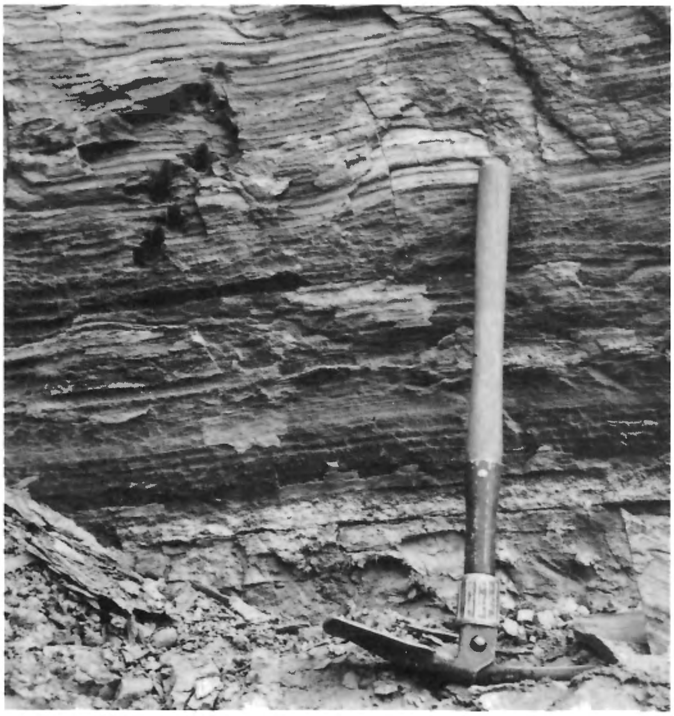


Figure 20. Typical varved glaciolacustrine clay and silt deposited during retreat of the Late Portage Mountain advance, lower Parsnip River valley. GSC-140861.

Figure 21. Contorted glaciolacustrine clay, silt and sand deposited during retreat of the Late Portage Mountain advance, lower part of Finlay River valley (56°06'30"N, 124°10'00"W). GSC-140844.

Late Portage Mountain advance till in the Del Creek section differs from till near Parsnip River in that the former has mostly limestone, dolomite, metamorphic, sandstone, siltstone, quartzite, igneous, and chert inclusions; a clay loam matrix; about twice as much carbonate in the less than 2 mm-size fraction; and a suite of heavy minerals where garnet makes up over half the total, with much less hornblende, carbonate, chloritoid, epidote, and staurolite.

Fluvial Deposits, Non Ice Contact (Ftm, Ftk, Fu)

Most exposed glaciofluvial deposits likely were deposited during the retreat of the Late Portage Mountain advance. Occurrences beneath lacustrine sediments are common along Parsnip River (Fig. 2, cross-sections D-D', F-F'; Appendix: Big Bend section, unit 4; Carbon Creek section, unit 3; Ingenika section, units 2, 3; Ne-parle-pas Rapids section, unit 2; Scovil Flats section, unit 3). Thicknesses vary considerably due to both original deposition and later erosion. A few deposits are of the order of 150 feet (46 m) thick, but most are much thinner.

Fluvial sediments consist of poorly sorted to well sorted sand that typically is deposited by braided rivers formed during deglaciation. Interbedded sand and gravel, and in places silt, beds are common. Flat-lying, moderately well sorted gravel, interbedded with well sorted medium to coarse sand, is typical of the Parsnip River area. The gravel consists mostly of rounded pebbles of quartz, quartzite, carbonate, igneous rocks, metamorphic rocks, sandstone, and siltstone.

Fluvial Deposits, Ice Contact (Fh)

Ice contact fluvial deposits from the retreat of the Late Portage Mountain advance form hummocks, kames, pits, and eskers (Fig. 2, cross-section E-E'; Appendix, Ne-parle-pas Rapids section, unit 3). The deposits consist mostly of gravel with a pebble-sized mode, although a wide variety of fragment sizes is present. They are mostly poorly to well sorted with some bedding present. Beds range in thickness from a few inches to several feet and dip in many directions at varying angles. Rock types include quartzite, carbonate, igneous, metamorphic, sandstone, and siltstone.

Lacustrine Deposits (Lp, Lv)

Glaciolacustrine deposits cover much of the Rocky Mountain Trench and the lower part of Peace River valley. Near the shores where tributaries entered the lakes the deposits are largely deltaic and coarse, ranging up to pebble-sized gravel, and form lateral facies changes with the finer fractions.

Outcrops along Finlay and Parsnip rivers consist mostly of laminated and thinly bedded, flat-lying, clayey silt, silty clay, and clay (Fig. 2, cross-sections A-A', C-C'; Appendix: Alexander section, unit 4; Blackwater Creek section, unit 3). Thicknesses vary; some sections are more than 50 feet (15 m) thick, but most are less than 20 feet (6 m). A borehole near Finlay Forks, however, penetrated more than 300 feet (90 m) of sand, silt, and clay. The upper part of the unit commonly consists of fine sand, but beds of silt and of medium to coarse sand, some with pebbles, are present. Cross-stratified and contorted sediments are present in places (Fig. 21). The cross-stratification is small scale, displaying the planar and trough varieties that indicate a low energy flow regime. It could represent stream deposits laid down during the final phases of the lake. The lower part of the unit, where clay and silt are dominant, displays varves, but they are of minor importance considering the large volume of material exposed along great lengths of Parsnip and Finlay rivers.

From Carbon Creek to Portage Mountain most lacustrine sediments along the lower parts of Peace River valley are silt. Near the surface, east of Portage Mountain end moraine, coarser sediments, up to gravel size, represent nearshore deposits of a lake that extended eastward.

The deposits of the Portage Mountain end moraine consist mainly of about 300 feet (90 m) of interbedded, deltaic gravel and sand, with gravel grading into sand eastwards and downdip and sand increasing in abundance with depth. Silt is common in the sand and gravel beds. The gravel consists mostly of thick beds of well sorted, well rounded pebbles and cobbles, and local boulders up to 6 inches (15 cm) long. Most of it is made up of fragments of quartzite, carbonate, igneous, metamorphic, sandstone, and siltstone, derived from both sides of the Rocky Mountain Trench. The foreset beds dip in directions normal to the arcuate shape of the moraine, that is, northeast, east, and southeast. The dips vary in steepness, but decrease eastwards towards the former lake basin. The deltaic deposits are overlain by patches of lacustrine silt, by poorly sorted, steeply dipping, ice-contact deposits, and by well sorted beach gravels.

DESERTERS CANYON ADVANCE

Stratigraphic and Geomorphic Evidence

The chief evidence for a minor advance following the Late Portage Mountain advance consists of a distinct till sheet found over much of the surface between Fort Ware and Deserters Canyon. This till sheet, the Deserters Canyon till, is about 10 feet (3 m) thick and is the uppermost glacial unit in many of the more complete sections found in the area (Fig. 3). It drapes over and truncates older units, indicating that the ice moulded and eroded pre-existing landforms of surficial materials. Commonly, it contains a paleosol overlain by windblown deposits. The till is underlain directly by the lithologically similar till of the Late Portage Mountain advance, is separated from it by a few feet of discontinuous beds of sand and gravel, or else is underlain by thick units of stratified sediments (Fig. 22). Where Deserters Canyon till is underlain by Late Portage Mountain advance till, they are difficult to separate. The buff colour of Deserters Canyon till, as contrasted with the greyish tint of Late Portage Mountain till, aids in distinguishing the two, but stratified sediment found at approximately the same depth in several sections is the real indicator of a separate unit.

Deserters Canyon ice probably originated in the Cassiar and Omineca mountains. The advance may have extended south beyond the Deserters Canyon area as far as the Ingenika River area, but no sections exist to verify this and the till there has not been definitely identified. Faint drumlinoid ridges indicate that ice flowed down Finlay Valley in this area, but there are also indications that ice flowed northeast out of Ingenika Valley far into Finlay Valley. This suggests that the glacier was restricted in the major valley, a situation commonly encountered near the termini of mountain glaciers.

Along Barrier Pass in the northwest part of the mapped area, fresh lateral moraines up to 3000 feet (910 m) in elevation and rugged kame deposits forming part of an end moraine extend along the west side of Finlay Valley. The freshness of the deposits suggests that these are from the Deserters Canyon advance.

Deserters Canyon Advance Deposits

Morainal Deposits (Mh, Md)

The only till that may have been laid down during the Deserters Canyon advance is found in the northwest part of the area (Map 1381A, units Mh, Md). The following till description is of two samples taken from the Del Creek and McGraw Creek sections located along Finlay River northwest of the mapped area (Appendix).

The till is hard, commonly buff coloured where oxidized, and grey where not oxidized. Stones make up nearly 40% of the volume; they have a pebble-sized mode and are commonly subangular to surbounded. Striae and flat stones oriented in the direction of glacial flow are common (Fig. 11). The most abundant rock types are limestone and dolomite, with lesser amounts of metamorphic, igneous, quartzite, sandstone, siltstone, chert, and quartz (Fig. 6).

The matrix is a loam to sandy loam, indicating more sand and silt than clay (Figs. 7 and 8). Clay mineral content ranges from 8 to 34%, with about equal proportions of illite and chlorite (Fig. 9). Carbonate content in the less than 2 mm-size fraction is about 27%, with more calcite than dolomite (Fig. 10). The most common heavy minerals are hornblende, garnet, epidote, clinopyroxene, zircon, chloritoid, carbonate, and apatite (Table 1).

POSTGLACIAL DEPOSITS

FLUVIAL DEPOSITS (Fti)

Terraces, intermediate in height between the terraces formed immediately following deglaciation and those associated with the modern flood plain, are found along Peace, Finlay, and Parsnip rivers (Fig. 23). Generally they are less than 50 feet (15 m) above the modern flood plain and are found as remnants that have escaped modern river erosion. It is difficult to state when or how these formed, but they probably were deposited during limited glacial expansion elsewhere, perhaps during the Deserters Canyon advance. Subsequent downcutting occurred during glacial retreat or during later isostatic adjustment of the Cordilleran region.

Figure 23. Typical example of postglacial fluvial gravel and sand exposed in terraces of intermediate height along the banks of Finlay and Parsnip rivers. GSC-140857.

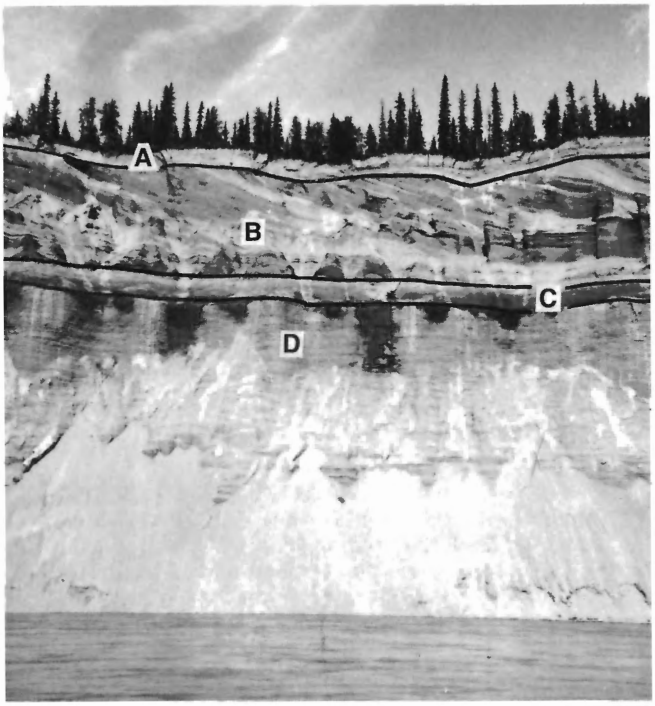


Figure 22. McGraw Creek section on Finlay River northwest of the mapped area: A, Deserters Canyon till; B, deltaic gravel; C, Portage Mountain till; D, glaciofluvial gravel (57°11'00"N, 125°17'30"W). GSC-140860.

The terraces consist mostly of locally oxidized gravel interbedded with minor amounts of sand and silt. Bedding and sorting vary greatly, but most of the material is moderately well sorted and bedded and consists of rounded siliceous clastics and carbonate, igneous, and metamorphic pebbles derived principally from older glacial deposits. The interbedded sand and silt commonly are exposed as lenses.

The terrace deposits are mostly flat lying with some large-scale cross-stratification, or have steep dips resulting from slumping. Units within the deposits commonly were eroded during short intervals of nondeposition.

MODERN ALLUVIUM (Ap)

Modern alluvium is found where major rivers have cut through glacial and postglacial deposits to form flood plains up to 3 miles (5 km) wide with associated terraces up to about 20 feet (6 m) high. The most extensive flood plain deposits are near Finlay Forks along the central and northern parts of Finlay River, along most of the Parsnip, and along the lower part of the Peace. In addition major tributaries such as Ingenika, Manson, and Nation rivers have flood plains of the order of 1 mile (1.6 km) wide.

Modern alluvium consists mostly of interbedded gravel and sand with minor amounts of silt, commonly overlain by 3 or 4 feet (0.9 to 1.2 m) of silt and fine sand. The silt and sand are well bedded and sorted and consist mostly of rounded pebbles. In places the gravel is oxidized, and fine grained material forms a hard cement.

FAN DEPOSITS (Af)

Alluvial fans are best developed adjacent to the upper part of Peace River, where the valley is narrow and is joined by high-gradient streams from some of the highest mountains of the Rockies. Some fans form sand and gravel deposits over 100 feet (30 m) thick. The fans are commonly less than a mile (1.6 km) wide but in some places are nearly two miles (3.2 km) wide. In the broad Parsnip and Finlay valleys and the lower part of Peace Valley alluvial fans are found principally on glacial or river terraces and flood plain deposits. Other sand and gravel deposits that have the characteristics of fan deposits form irregular deposits overlying older surficial material along high-gradient streams within the mountains or within broad valley bottoms.

Fan deposits are typically poorly sorted and bedded and are composed mainly of angular and subangular material derived from the local bedrock and rounded material of varying lithologies derived from older surficial deposits.

EOLIAN DEPOSITS (E)

Mappable eolian deposits are found only on fine lacustrine sediments west of Finlay Forks and at a few locations along Parsnip Valley. The deposits form dunes which are now stabilized by vegetation. They are less than 20 feet (6 m) thick and consist mostly of medium sand.

ORGANIC DEPOSITS (O)

Mappable areas of organic deposits are located in broad depressions on fine lacustrine deposits along the lower part of Finlay and Parsnip valleys. They are less than 10 feet (3 m) thick and consist of partly decomposed plant remains, along with clay, silt, and sand derived from the underlying lacustrine sediments.

Table 3

LABORATORY DATING NO.	DATE (YEARS B.P.)	LOCATION		COLLECTOR	MATERIAL	COMMENTS
		LATITUDE	LONGITUDE			
GSC-944	840 $\pm$ 140	57°11'	125°18'	N.W. Rutter	Charcoal	From soil underlying 5 to 20 feet windblown sand. Maximum age for sand.
GSC-1069	7470 $\pm$ 140	56°10'	124°07'	N.W. Rutter	Wood	From postglacial terrace deposits overlying late-glacial lacustrine deposits. Minimum age for lacustrine deposits.
GSC-1161	7470 $\pm$ 150	56°10'	124°07'	N.W. Rutter	Peat	As above
GSC-1497	9280 $\pm$ 200	55°48'	123°38'	K. Sumanik	Horn	Bighorn sheep skull from ice-contact gravel. Approx. age for final deglaciation of area.
GSC-1548*	9960 $\pm$ 170	55°58'	120°15'	T.H.F. Reimchen	Shells	From near surface of lacustrine sediments. Approx. age for final deglaciation of area.
GSC-1654	10 400 $\pm$ 170	55°59'	120°16'	T.H.F. Reimchen	Shells	As above
I-2244A	11 600 $\pm$ 1000	56°01'	122°09'	L.T. Jory	Organic Residue	Mammoth tusk from end moraine gravel and sand. Approx. age for final deglaciation of area.
GSC-573	25 940 $\pm$ 380	56°18'	124°21'	J.G. Fyles	Plant	Plant remains in sand underlying till-like lenses (Portage Mountain?) and lacustrine deposits. Maximum age for Early Portage Mountain advance.
GSC-1057	>28 000	57°18'	125°27'	N.W. Rutter	Wood	From oldest surficial stratified unit identified in the area. Minimum age for deposit.
GSC-841	>41 000	57°18'	125°27'	N.W. Rutter	Peat	As above
GSC-837	>44 000	57°11'	125°20'	N.W. Rutter	Wood	As above

*GSC-1548 originally was erroneously calculated at 16 300 $\pm$ 800 years B.P. and reported as such in Reimchen and Rutter (1972).

SLUMP DEPOSITS (Ce)

Slump deposits are common where Finlay and Parsnip rivers and major tributaries flow through fine lacustrine sediments. They are a result of rotational slumping and commonly form a series of slump blocks up to one-quarter mile (0.4 km) wide.

COLLUVIAL DEPOSITS (Cs)

Colluvial deposits are found at the base of steep slopes. They are not widespread and consist mostly of bedrock rubble, landslide material, and talus.

CHRONOLOGY AND GLACIAL HISTORY

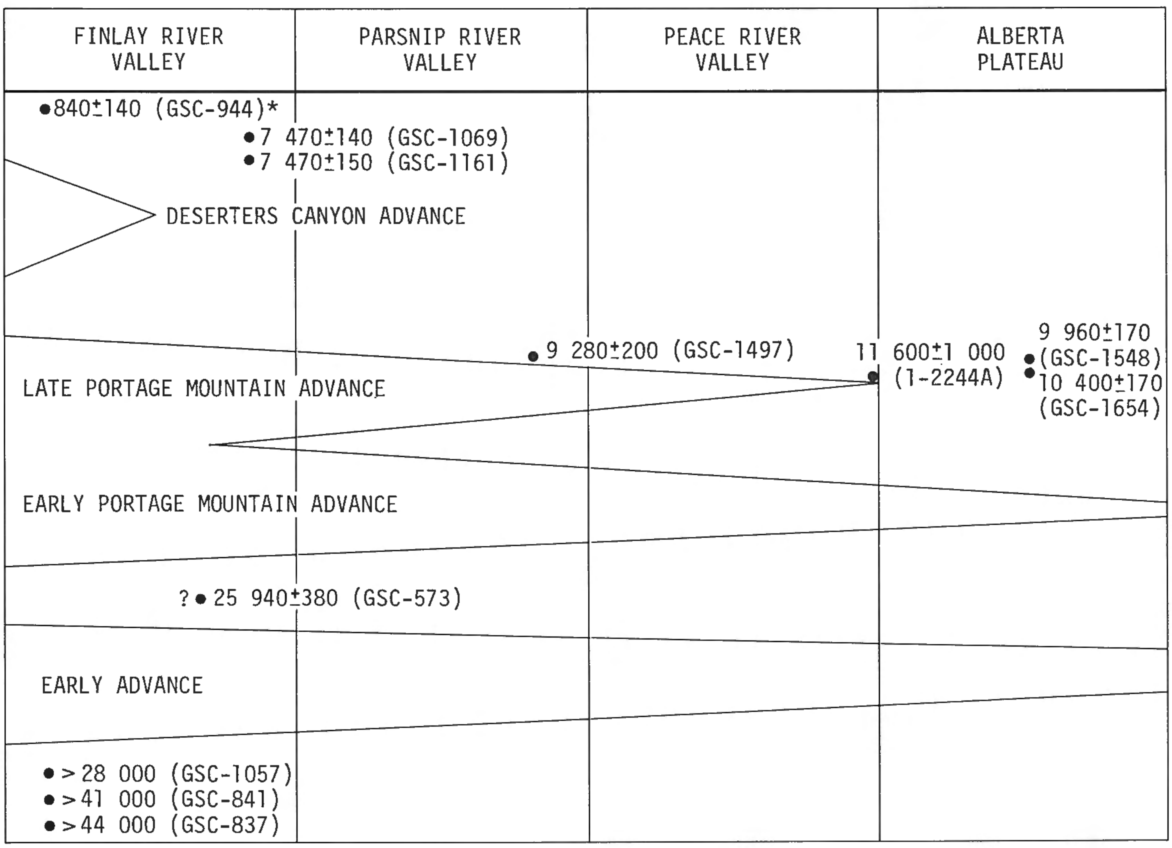
The oldest unconsolidated sediments recognized are the oxidized fluvial gravel and sand underlying the tills exposed in the Del Creek section northwest of Deserters Canyon (Fig. 3), along other parts of Finlay River, and along Parsnip and Peace rivers. Till blocks included in deposits thought to be equivalent to these, however, indicate earlier glacial activity. Radiocarbon dates from wood and detrital peat within these sediments were > 28 000, > 41 000, and > 44 000 years B.P. (Tables 3 and 4). The sediments are interpreted as interglacial.

Unoxidized fluvial gravel, overlying the oldest deposits, is interpreted as advance outwash from the following Early advance.

Distribution of Early advance till suggests widespread glacial activity, extending at least down Finlay and Parsnip valleys. Most of the ice came from west of the Rocky Mountain Trench. During subsequent deglaciation glaciofluvial gravel and sand and glaciolacustrine silt and clay were deposited throughout the valleys of the mapped area. Plant material, dated at 25 940 ± 380 years B.P. (Tables 3 and 4), was collected along Finlay River from silt and sand lying below till-like lenses and lacustrine silt. The silt and sand probably was laid down during this interval, whereas the till-like lenses belong to the next advance, the Early Portage Mountain.

The Early Portage Mountain advance was the most widespread glacial event to affect the area. Most of the ice originated west of the Rocky Mountain Trench in the Coast, Skeena, Omineca, and Cassiar mountains. It flowed eastwards and northeastwards, with local variations, across the Rocky Mountain Trench into the Rockies, incorporating valley glaciers, and thence onto the Plateau east of the Rocky Mountains. During deglaciation a lake formed east of the ice front, likely dammed by Laurentide ice. If silt on Bull Mountain dates from this time, the lake extended above 3100 feet (940 m). As the ice, which was now controlled by local topography, receded up the valleys, till and glaciofluvial and glaciolacustrine sediments were laid down. The ice retreated at least to the upper reaches of Parsnip Valley and to near Fort Ware, outside the mapped area, as indicated by composite sections consisting of Early and Late Portage Mountain advance tills.

Table 4



*Years B.P.

The Late Portage Mountain advance is the best documented and the last major glacial event to affect the area. The ice generally was controlled by local topography and flowed down Finlay and Parsnip valleys and then through Peace River valley to Portage Mountain where it built an end moraine. In the mapped area, ice did not reach much above 3500 feet (1060 m) and was up to 1500 feet (455 m) thick. This agrees with Armstrong and Tipper (1948) and Tipper (1971a, b), who showed that, farther southwest, northeasterly flowing ice reached about the same elevation. Although an ice sheet was present in the southwest part of the area, the Omineca Mountains probably supported a reticulated network of valley glaciers, some of which flowed into the Trench. Any glaciers in the Rocky Mountains at this time likely were restricted to large valleys at high elevations.

The Portage Mountain end moraine, consisting of deltaic deposits, was formed in a lake which extended to the east and which probably was dammed by Laurentide ice. A date of 11 600 ± 1000 years B.P. from a mammoth tusk indicates the time of delta formation. As deglaciation took place the lake followed the ice front up Peace River valley and during periods of stable level cut strandlines at 2820 feet (855 m), 2700 feet (820 m), and 2350 feet (710 m). Dates of 9960 ± 170 and 10 400 ± 170 years B.P. (Tables 3 and 4) from mollusc shells found in the upper lake deposits east of the mountain front indicate that the lake and local ponding had ended by 9960 years ago. When the glacier receded into the Rocky Mountain Trench, it divided to retreat up Finlay and Parsnip valleys. Glaciofluvial gravel and sand were deposited, as well as lake sediments, probably the result of damming by landslides or morainal material in upper Peace River valley. The lake followed the receding ice up Parsnip and Finlay valleys to an elevation of about 2500 feet (760 m) and extended to the upper reaches of both valley systems. A date of 9280 ± 200 years B.P. (Tables 3 and 4) from a Bighorn sheep skull found in ice-contact deposits just south of Finlay Forks suggests that it took approximately 2000 years for ice to retreat from Portage Mountain into the Rocky Mountain Trench. Ice then continued to recede up Finlay and Parsnip valleys, disappearing from the mapped area after 9280 years B.P.

The next advance, Deserters Canyon, was a minor advance of ice from the Omineca and Cassiar mountains after 9280 years B.P. During its retreat the intermediate terraces probably were constructed along the major river systems. The age of these terraces is indicated by radiocarbon dates of 7470 ± 140 and 7470 ± 150 years B.P. (Tables 3 and 4) on peat and wood, respectively, from the upper part of an intermediate level terrace along Ospika River.

Following retreat of the Deserters Canyon ice, the rivers adjusted to their present base levels, having formed and eroded a series of terraces in the process. Concurrently, alluvial fan, flood plain, eolian, organic, slump, and colluvial deposits were laid down. Charcoal dated at 840 ± 140 years B.P. (Tables 3 and 4) was taken from a soil below stabilized, windblown sand.

The dates, therefore, suggest that the Early and Late Portage Mountain advances and Deserters Canyon advance are all of late Wisconsinan age. The Early advance and the underlying interglacial gravel and sand are most likely early Wisconsin or older.

ENGINEERING GEOLOGY

Prior to flooding of Williston Lake Basin, the area under investigation was relatively stable. Slumping of lacustrine sediments along major river banks was observed in places, as well as subaerial erosion and river erosion of banks during flooding and lateral migration. Since the flooding of the basin, deposits along the shore have become unstable, and widespread failure occurs mostly in the form of high velocity debris slides. It will take years to stabilize the shoreline and to establish a permanent groundwater table. These factors should be evaluated when engineering work is planned near shore.

Table 5 rates geological units (vertical column) for capability for selected engineering activities, potential hazards, and for construction resources (horizontal column). The resulting units have been subdivided, where applicable, into coarse and fine sediments. Each category is qualified by the following explanations:

(1) Liquid waste disposal

The principal controls of liquid waste disposal sites are texture and permeability of the material and gradient of the groundwater table. The object is to select a site with minimum seepage potential so as not to contaminate the groundwater. Fine material forming closed basins away from rivers and lakes is best. Bedrock may be utilized, but fracture, joint, and fault systems, as well as soluble rock, should be avoided.

(2) Solid waste disposal

This waste, consisting of any solid waste ranging from garbage to auto bodies, may contaminate groundwater as it decays. The same conditions are necessary as for liquid waste disposal; the chief difference is that contamination from solid waste is slower.

(3) Highway, railroad, and airfield construction

The rating for highway, railroad, and airfield construction is for base material. Desirable material has low compressiblity and high shear strength when compacted and saturated, and low shrink-swell potential.

(4) Heavy foundations

Desirable material for heavy foundations has high load-bearing strength, low shrink-swell potential, and good drainage.

(5) Light foundations

The major consideration for light foundations is material with low shrink-swell potential.

(6) Underground installations

Underground installations include such items as concrete tunnels, electrical cables, and gas and oil pipelines. They require low shrink-swell potential, high load-bearing strength, good drainage, and low corrosivity.

(7) Excavations

This considers the ease of excavation with conventional machinery. It includes hardness of the deposit and hazards such as large boulders commonly found in till.

(8) Water storage (above ground)

Consideration for water storage is for unlined reservoirs above the water table in material with low permeability.

Table 5

		*LAND CAPABILITY								**HAZARDS			***RESOURCES		
		1.Liquid waste disposal	2.Solid waste disposal	3.Highway, railroad and airfield construction	4.Heavy foundations	5.Light foundations	6.Underground installations	7.Excavations	8.Water storage (above ground)	9.Gully erosion (devegetation)	10.Shoreline erosion	11.Slumping	12.Coarse aggregate (gravel)	13.Fine aggregate (sand)	14.Fill
Modern Alluvium (Ap)	Coarse	○	○	●	●	●	●	●	○	●	●	●	●	◒	●
	Fine	○	○	◒	◒	◒	◒	●	◒	◒	◒	◒	○	●	◒
Fan deposits (Af)		○	○	●	●	●	●	●	○	●	●	●	●	○	●
Organic deposits (O)		◒	◒	○	○	○	○	○	○	◒	○	○	○	◒	○
Slump deposits (Ce)	Coarse	○	○	●	○	○	○	●	○	●	●	○	◒-●	○	●
	Fine	◒	◒	○	○	○	○	●	○	○	○	○	○	◒	○
Colluvial deposits (Cs)	Coarse	○	○	●	◒	●	◒	◒	○	●	●	●	◒	○	●
	Fine	◒	◒	○	○	◒	○	●	◒	○	○	◒	○	◒	○
Fluvial deposits (Fti, Ftm, Ftk, Fh, Fu)	Coarse	○	○	●	●	●	●	●	○	●	●	●	●	◒	●
	Fine	○	○	◒	○	◒	○	●	◒	◒	◒	◒	○	●	◒
Eolian deposits (E)		○	○	◒	◒-●	●	◒-●	●	○	◒-●	◒	●	○	●	●
Lacustrine deposits (Lp, Lv)	Coarse	○	○	●	●	●	●	●	○	●	●	●	◒	◒	●
	Fine	◒-●	◒-●	◒	○	◒	○	●	●	○	○	○	○	◒	◒
Morainal deposits (Mh, Md, Mr, D)	Till	●	●	●	●	●	●	◒	●	◒-●	◒	◒	●	○	●
	Coarse	○	○	●	●	●	●	●	○	●	●	●	●	◒	●
	Fine	◒	◒	○	○	◒	○	●	◒	○	○	◒	○	◒	○
Rock and Near-Surface Rock (R)		○-◒	○-◒	●	●	●	●	○	○-◒	●	●	●	●	○	●

*Land Capability
- ● Desirable
- ◒ Possible problems
- ○ Undesirable

**Hazards
- ● Low
- ◒ Moderate
- ○ High

***Resources
- ● Excellent
- ◒ Fair
- ○ Poor

(9) Gully erosion (devegetation)

The amount of gully erosion is based on the texture of the material and the maximum angle of slope obtained after the organic mat has been removed or when a vertical exposure or slope has been cut during construction.

(10) Shoreline erosion

Since filling of Williston Lake, shoreline erosion by wave action and currents has been rapid; with time the shoreline will reach a more stable condition. Erosion under "normal" conditions is considered here.

(11) Slumping

Since filling of Williston Lake, slumping has been active along its shore; with time the shoreline will become more stable. Considerations are for those deposits that under "normal" conditions are subject to failure.

(12) Coarse aggregate (gravel)

In most deposits gravel will occur with sand beds or to a lesser extent with silt and clay. The rating, therefore, is based on the relative amount of gravel likely to be present in the deposit.

(13) Fine aggregate (sand)

In most deposits sand occurs with gravel, silt, and clay. The rating is based on the relative amount of sand present in a certain deposit type.

(14) Fill

Fill is rated according to its desirability in general engineering practices, such as for earthen structures and road fill. Desirable fill has low shrink-swell potential, compressibility, plasticity, and frost susceptibility.

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APPENDIX

BIG BEND SECTION (55°10'00"N, 123°00'15"W)

Unit No.	Description	Thickness feet	(metres)	Depth of Base feet	(metres)
4 Gravel and Sand:	Interbedded; well sorted gravel and coarse sand; flat lying; thickens southwards and northwards.	18.7	(5.7)	18.7	(5.7)
3 Till: (Late Portage Mountain advance)	Dark olive-grey; 5-10% stones, mode pebble sized; inclusions subangular to rounded, mode subrounded, striated; rock types mainly quartz, quartzite, carbonate, igneous, and metamorphic; loam matrix calcareous.	129.5	(39.5)	148.2	(45.2)
2 Gravel and Sand:	Interbedded; gravel poorly sorted, sand mostly medium to coarse; some pebbly, silty, clayey sand; flat lying.	23.7	(7.2)	171.9	(52.4)
1 Till: (Early Portage Mountain advance)	Dark olive-grey; less than 5% stones, mode pebble sized, subrounded to rounded, mode rounded, striated; rock types mainly quartz, quartzite, carbonate, igneous, and metamorphic; loam matrix, calcareous.	48.0+	(14.6+)	219.9+	(67.0+)
River Level					

BLACKWATER CREEK SECTION (55°45'30"N), 123°40'15"W)

Unit No.	Description	Thickness feet	(metres)	Depth of Base feet	(metres)
3 Sand and Silt:	Interbedded; sand, fine to medium, in beds up to 3 cm thick; silt clayey, in beds to 1.3 cm thick.	12.5	(3.8)	12.5	(3.8)
Silt:	Olive-brown; clayey; some fine grained sand; beds generally flat lying but locally contorted and cross-bedded.	11.0	(3.3)	23.5	(7.1)
Sand:	Grey; coarse; large-scale cross-bedding dip ±25 degrees N65°W; some coal fragments; slightly oxidized.	9.0	(2.7)	32.5	(9.8)
Clay:	Silty; flat lying.	10.0	(3.0)	42.5	(12.8)
2 Gravel: (Portage Mountain Till)	Extremely poorly sorted, massive; grades laterally into olive-brown till; 30 to 40% stones, well rounded to angular, mode subangular to subrounded; weak fabric; rock types mainly sandstone, siltstone, quartzite, igneous, metamorphic, some carbonate, quartz, and chert; sandy matrix, illitic, some chlorite, calcareous.	46.0	(14.0)	88.5	(26.8)
1 Gravel and Sand:	Interbedded; sand, coarse; cross-bedded; flat lying; oxidized buff.	15.0	(4.6)	103.5	(31.4)
Gravel:	Poorly sorted, massive; mode pebble sized; flat lying.	49.0	(14.9)	152.5	(46.3)
Tertiary Rocks					

CARBON CREEK SECTION (56°05'45"N, 122°45'00"W)

Unit No.	Description	Thickness feet	(metres)	Depth of Base feet	(metres)
4 Sand:	Mostly medium, well sorted and bedded; flat lying.	±20.0	(±6.1)	±20.0	(±6.1)
Gravel:	Moderately well sorted and bedded; flat lying; rock types mainly carbonate, quartzite, igneous, and metamorphic.	±15.0	(±4.6)	±35.0	(±10.7)
3 Gravel and Sand:	Interbedded; gravel beds mainly carbonate, quartzite, igneous, and metamorphic rock types; flat lying; thickens westwards.	±10.0 to ±40.0	(±3.0 to ±12.2)	±45.0	(±13.7)
2 Till: (Portage Mountain)	Brown; 30% stones, mode pebble sized, subangular to rounded, mode subrounded; fabric weak; rock types mainly carbonate, quartzite, and igneous; sandy loam matrix, illitic, highly calcareous; hard; thickens westwards.	±1.0 to ±20.0	(±0.3 to ±6.1)	±46.0	(±14.0)
1 Gravel:	Poorly sorted and bedded; flat lying; cemented; rock types carbonate, quartzite, igneous and metamorphic.	±40.0	(±12.2)	±86.0	(±26.2)
Gravel:	Moderately sorted and bedded; flat lying; rock types mainly carbonate, quartzite, igneous, and metamorphic.	20.0+	(6.1+)	106.0+	(32.3+)
River Level					

CHOWIKA CREEK SECTION (56°41'00"N, 124°41'45"W)

Unit No.	Description	Thickness feet	(metres)	Depth of Base feet	(metres)
3 Sand and Gravel:	Interbedded; moderately well sorted and bedded; some cross-bedding.	39.0	(11.9)	39.0	(11.9)
2 Sand:	Mainly fine; well sorted and bedded; cross-bedded; nearly flat lying.	29.0	(8.8)	68.0	(20.7)
Clay:	Well sorted and bedded; some silt and fine sand.	23.0	(7.0)	91.0	(27.7)
1 Till: (Portage Mountain)	Grey-brown; 20 to 25% stones, mode pebble sized, subangular to well rounded, mode subangular to subrounded, some striated; fabric weak; rock types mainly carbonate, igneous, metamorphic, and quartzite; silty sand matrix; hard.	45.0+	(13.7+)	136.0+	(41.4+)
River Level					

DEL CREEK SECTION (47°08'45"N, 125°14'15"W)

Unit No.	Description	Thickness feet	(metres)	Depth of Base feet	(metres)
8 Till: (Deserters Canyon)	Buff; up to 40% stones, mode pebble sized, angular to well rounded, mode subangular to subrounded, some striated; rock types mainly carbonate, metamorphic, igneous, quartzite, chert, sandstone, and siltstone; matrix loam to sandy loam, illitic and chloritic, very calcareous.	13.5	(4.1)	13.5	(4.1)
7 Till: (Late Portage Mountain advance)	Grey; 5% stones, mode pebble sized, subangular to subrounded; rock types mainly carbonate, metamorphic, igneous, sandstone, siltstone, quartzite, and chert; clay loam matrix, very calcareous; hard.	44.0	(13.4)	57.5	(17.5)
6 Silt:	Grey, some buff; thinly laminated; clayey.	13.5	(4.1)	71.0	(21.6)
5 Till: (Early Portage Mountain advance)	Olive; 30 to 40% stones, mode pebble sized, angular to well rounded, mode subangular to subrounded; weak fabric; rock types mainly carbonate, igneous, metamorphic, quartzite, sandstone, and siltstone; clay loam matrix, mainly illitic, some chlorite, very calcareous; hard; till grades laterally into gravel.	4.8	(1.5)	75.8	(23.1)
4 Gravel:	Some sand lenses and silt beds; buff; poorly sorted, mode small pebbles; silty sand matrix; generally flat lying, but variable dip directions.	72.6	(22.1)	148.4	(45.2)
3 Till: (Early)	Grey; 30 to 40% stones, mode pebble sized, angular to well rounded, mode subangular to subrounded; slight fabric; rock types mainly carbonate, some metamorphic, igneous, sandstone, siltstone, and quartzite; clay loam matrix, very calcareous; hard.	47.1	(14.3)	195.5	(59.5)
2 Gravel:	Poorly sorted and bedded; mode pebble sized, some large boulders; flat lying.	35.3	(10.7)	230.8	(70.2)
1 Gravel and Sand:	70% gravel, 30% sand lenses; poorly sorted; mode pebble sized, some large boulders; generally flat lying, elsewhere variable dip directions, contortions; oxidized.	48.0+	(14.6+)	278.8+	(84.8+)

River Level

INGENIKA RIVER SECTION (56°47'00"N, 124°56'30"W)

Unit No.	Description	Thickness feet	(metres)	Depth of Base feet	(metres)
4 Sand:	Brown; mainly coarse; well sorted and bedded.	16.0	(4.9)	16.0	(4.9)
Silt:	Brown; clayey; well sorted and bedded.	6.5	(2.0)	22.5	(6.9)
3 Gravel:	Poorly sorted and bedded; mainly subrounded to well rounded pebbles; some lenses of coarse sand oxidized near base.	20.0	(6.1)	42.5	(13.0)
2 Sand:	Well sorted and bedded; mainly fine; flat lying.	47.0	(14.3)	89.5	(27.3)
1 Till: (Portage Mountain)	Buff; 3-5% stones, mode pebble sized, angular to well rounded, mode subangular; weak fabric; rock types mainly carbonate, igneous, metamorphic, and quartzite, sandy matrix, soft.	24.0+	(7.3+)	113.5+	(34.6+)
River Level					

MACKENZIE ROAD SECTION (55°13'00"N, 123°00'00"W)

Unit No.	Description	Thickness feet	(metres)	Depth of Base feet	(metres)
4 Till: (Late Portage Mountain advance)	Grey-buff; less than 10% stones, mode pebble sized, angular to well rounded, mode subrounded to subangular, most stones oriented northwestwards; rock types mainly metamorphic, sandstone, siltstone, quartzite, quartz, carbonate, chert, and igneous; loam matrix, mainly chloritic, some illite, calcareous; hard.	19.4	(5.9)	19.4	(5.9)
3 Gravel and Sand:	Interbedded; gravel poorly bedded, stones mainly pebble sized; flat lying.	5.2	(1.6)	24.6	(7.5)
2 Till: (Early Portage Mountain advance)	Grey-buff; less than 10% stones, mode pebble sized, subangular to rounded, mode subrounded, some striated, most stones oriented northwestwards; rock types mainly metamorphic, quartzite, carbonate, sandstone, siltstone, quartz, and igneous; loam to sandy loam matrix, mainly chloritic, some illite, calcareous.	44.8	(13.6)	69.4	(21.1)
1 Gravel and Sand:	Interbedded; gravel, poorly to moderately well sorted, mostly pebble sized; flat lying.	34.2+	(10.4+)	103.6+	(31.5+)
Road					

MCGRAW CREEK SECTION (57°11'00"N, 125°17'30"W)

Unit No.	Description	Thickness feet	(metres)	Depth of Base feet	(metres)
6 Sand:	Well sorted; variable thickness.	4.3	(1.3)	4.3	(1.3)
5 Soil:		2.0	(.6)	6.3	(1.9)
4 Till: (Deserters Canyon)	Buff; 30 to 45% stones, mode pebble sized, angular to well rounded, mode subangular to subrounded; strong fabric; rock types mainly carbonate, igneous, metamorphic, sandstone, siltstone, quartzite, and quartz; sandy loam matrix, illitic and chloritic, very calcareous; thickens southwards.	2.0	(.6)	8.3	(2.3)
3 Gravel:	Grey; poorly to well sorted, mostly moderately well bedded; mode pebble sized; sand beds 1 inch (2.5 cm) to 2 feet (0.6 m) thick; beds dip 25 to 40 degrees S55°E, normal faults with <2 feet (0.6 m) displacement; beds flatten towards base.	134.7	(41.0)	142.0	(43.5)
2 Till: (Portage Mountain)	Grey; less than 5% stones, mode pebble sized, angular to well rounded, mode subangular to subrounded; rock types include mainly carbonate, metamorphic sandstone, siltstone, igneous, quartzite, and chert; clay loam matrix, very calcareous; soft.	12.3	(3.7)	154.3	(47.2)
Silt:	Grey; clayey silt to fine sand.	15.0	(4.6)	169.3	(51.8)
1 Gravel:	Poorly to moderately well sorted; beds 1.5 to 10 inches (4 to 25 cm) thick, appear massive; mainly pebble sized, some moderately well sorted sand beds, some contorted; normal faulting with 6 inch (15.2 cm) displacement mostly flat lying; cemented.	184.4+	(56.2+)	353.7+	(108.0+)
River Level					

NE-PARLE-PAS RAPIDS SECTION (56°02'00"N, 123°05'00"W)

Unit No.	Description	Thickness feet	(metres)	Depth of Base feet	(metres)
3 Sand:	Well sorted and bedded; mostly medium; surface pitted.	5.5	(1.7)	5.5	(1.7)
2 Gravel:	Poorly sorted and bedded; flat lying; mostly subangular to subrounded pebbles; rock types mainly carbonate, quartzite, igneous, and metamorphic.	34.5	(10.5)	40.0	(12.2)
Sand:	Mostly medium; well sorted and bedded; massive; flat lying.	13.1	(4.0)	53.1	(16.2)

Unit No.	Description	Thickness feet	(metres)	Depth of Base feet	(metres)
Gravel:	Poorly sorted and bedded; pebble to boulder sized, mostly subangular to subrounded; rock types mainly carbonate, quartzite, igneous, and metamorphic; beds dip ±20 degrees N85°W.	43.4	(13.2)	96.5	(29.4)
Sand:	Mostly medium; well sorted and bedded; flat lying.	7.1	(2.2)	103.6	(31.6)
Gravel and Sand:	Interbedded; coarser towards base; gravel beds up to 6 feet (2 m) thick; flat lying; rock types include mainly carbonate, quartzite, igneous, and metamorphic.	36.9	(11.2)	140.5	(42.8)
Sand:	Mostly medium; well bedded and sorted; flat lying.	13.3	(4.0)	153.8	(46.8)
Gravel:	Poorly sorted and bedded; flat lying; pebble to boulder sized, stones mainly subangular to subrounded; rock types mainly carbonate, quartzite, igneous, and metamorphic.	42.8	(13.0)	196.6	(59.8)
1 Gravel:	Poorly sorted and bedded; flat lying; coarse with large boulders; rock types mainly carbonate, quartzite, igneous, and metamorphic; hard; oxidized.	100.0+	(30.5+)	296.6+	(90.3+)
River Level					

SCOVIL FLATS SECTION (55°19'30"N, 123°12'45"W)

3 Sand:	Grey-brown, oxidizes yellow; well sorted; coarse beds 0.5 to 6.0 inches (1.3 to 1.5 cm) thick; cross-bedded.	6.4	(1.9)	6.4	(1.9)
Gravel and Sand:	Interbedded; gravel moderately well sorted and bedded with beds 0.5 to 0.6 inches (1.3 to 1.5 cm) thick; small pebbles, mode 0.6 to 1.2 cm; rock types carbonate, quartzite, igneous, metamorphic, quartz, sandstone, and siltstone; some cross-bedding; sand coarse, thinly bedded.	6.9	(2.1)	13.3	(4.0)
Sand:	Well to moderately sorted, mostly coarse, some medium grained; some scattered small pebbles and clay balls; oxidized.	8.7	(2.6)	22.0	(6.6)
Silt:	Clayey; some oxidized layers.	1.2	(0.4)	23.2	(7.0)
Sand:	Grey; massive; fine; some clayey beds.	4.9	(1.5)	28.1	(8.5)
Sand:	Grey; coarse.	0.2	(0.06)	28.3	(8.6)
Gravel:	Mainly medium-sized pebbles.	0.1	(0.03)	28.4	(8.6)
Clay:	Grey.	0.2	(0.06)	28.6	(8.7)

SCOVIL FLATS SECTION (cont.)

Unit No.	Description	Thickness feet	(metres)	Depth of Base feet	(metres)
2 Till: (Portage Mountain)	Grey; 20 to 40% stones, mode pebble sized, some boulders greater than 1 foot (0.3 m) in diameter, stones subrounded to well rounded, some striated; rock types mainly quartzite, some quartz, igneous, metamorphic, carbonate, sandstone, and siltstone; loam matrix, mainly chloritic, some illite, calcareous.	22.7	(6.9)	51.3	(15.6)
1 Clay, Gravel, and Till (Early):	Interbedded (upper subunit clay, lower subunit till); dips S10°E; clay well bedded, contorted; gravel poorly sorted; till grey, 10% stones, mode pebble sized; rock types mainly quartzite, some carbonate, sandstone, siltstone, metamorphic, and igneous; loam matrix, mainly chloritic, some illite, calcareous; hard.	8.0+	(2.4+)	59.3+	(18.0+)
River Level					

ALEXANDER SECTION (55°17'30"N, 123°10'30"W)

Unit No.	Description	Thickness feet	(metres)	Depth of Base feet	(metres)
4 Sand:	Well bedded; medium to coarse; some pebbles.	2.0	(0.6)	2.0	(0.6)
Clay:	Silty; grey.	4.0	(1.2)	6.0	(1.8)
3 Till: (Late Portage Mountain advance)	Grey; 20 to 30% stones, mode pebble sized, mainly rounded to well rounded; rock types mainly quartzite, some igneous, quartz, sandstone, siltstone, and carbonate; sandy loam matrix, chloritic, illitic, calcareous.	10.0	(3.0)	16.0	(4.8)
2 Gravel:	Poorly sorted, sandy matrix; pebbles mainly subrounded; some till inclusions; thickens southwards to 16 feet (5 m).	5.0	(1.5)	21.0	(6.3)
	Covered.	1.0	(0.3)	22.0	(6.6)
1 Till: (Early Portage Mountain advance)	Grey; 20 to 30% stones, mode pebble sized; rock types mainly quartzite, igneous metamorphic, quartz, sandstone, siltstone, carbonate, and chert; sand loam matrix, chloritic, illitic, calcareous.	44.2+	(13.4+)	66.2+	(20.0+)
River Level					